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Opera Assessment Report
Revision 2

Matimba power plant, source: Eskom

Independent Assessment of Eskom's Operational Situation

August 2023

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AC	Activity Class (Transmission assessment)
ADF	Ash Dump Facility
APH	Air Preheater
BFP	Boiler Feed Pump
BTF	Boiler Tube Failures
BTL	Boiler Tube Leaks
CAPEX	Capital Expenditure
CBM	Condition Monitoring System
CFD	Computational Fluid Dynamics
CHP	Coal Handling Plant
C&I	Control and Instrumentation
CSC	Compliance with Standards Classification
CSIR	Council of Scientific and Industrial Research
CV	Calorific Value
CW	Cooling Water
DCS	Digital Control System
DFFE	Department of Forestry, Fishery and Environment
DHP	Dust Handling Plant
DMRE	Department of Mineral Resources and Energy
DOEL	Department of Employment and Labour
DPE	Department of Public Enterprises
DSO	Distribution System Operator
EAF	Energy Availability Factor
EAL	Eskom Academy of Learning
ELV	Emission Limit Value
ERA	Execution Release Approval
ESP	Electro-Static Precipitator
FD	Forced Draft Fan
FFP	Fabric Filter Plant
FFFR	Fossil Fuel Firing Regulations
FGD	Flue Gas Desulphurization
FLL	Full Load Losses
FTE	Full-time Equivalent
FY	Financial Year

GAH	Gas Air Heater
GCCA	Generation Connection Capacity (Assessment)
GCV	Gross Calorific Value
GIS	Gas Insulated Switchgear
GO	General Overhaul
HFO	Heavy Fuel Oil
HMI	Human Machine Interface
HP	High Pressure
HR	Hot Reheat
HSE	Health, Safety and Environment
HV	High Voltage
ID fan	Induced Draft Fan
IN	Inspection Outage
IPP	Independent Power Producer
IR	Interim Repairs
IRP	Integrated Resource Plan
KISSY	KraftwerksInformationSSYstem
KPI	Key Performance Indicator
LOPP	Life of Plant Plan
LP	Low Pressure
LV	Low Voltage
MCR	Maximum Continuous Rating
MDBFP	Motor Driven Boiler Feed Pump
MO	Major Overhaul
MS	Main Steam
MV	Medium Voltage
NECOM	National Energy Crisis Committee
NQF	South African National Qualification Framework
NT	National Treasury
OAC	Operation Age Classification
OEM	Original Equipment Manufacturer
O&M	Operation and Maintenance
OHL	Overhead line
OPEX	Operational Expenditure
PAH	Primary Air Heater

PCLF	Planned Capacity Loss Factor
PJFF	Pulse Jet Fabric Filter
PLF	Plant Load Factor
PLL	Partial Load Losses
PTW	Permit to Work
PV	Photovoltaic
QCP	Quality Control Plan
RES	Renewable Energy Sources
RH	Reheat
RTS	Return to Service
SA	Secondary Air
SAH	Secondary Air Heater
SCAPH	Steam Coil Air Preheater
SEC	Safety and Environment Classification
SH	Superheater
SHEQ	Safety, Health, Environment and Quality
TDBFP	Turbo Driven Boiler Feed Pump
TDP	Transmission Development Plan
TRFR	Transformer
TSO	Transmission System Operator
UAGS	Unplanned Automatic Grip Separation
UCLF	Unplanned Capacity Load Factor
UPS	Uninterruptible Power Supply
VSD	Variable Speed Drive
WTC	Wear and Tear Classification
YTD	Year to Date

Abbreviations referring to companies, institutions and common measurement units (e.g. MW, min) are not included in this list.

1 Executive Summary

Against the background of electricity shortages and load shedding, the National Treasury of the Republic of South Africa assigned the vgbe consortium to conduct an independent assessment of Eskom's operational situation.

The scope of work comprised a review of the operational situation of the coal fleet, an assessment of the power plant maintenance budgets, a skill-level assessment of power plant personnel, as well as a transmission grid assessment. The consortium was led by vgbe and included teams from the other partners: Dornier, KWS, RWE and STEAG. These partners have decades of experience in the operation and maintenance (O&M) of coal fired power plants.

The project started on 27 February 2023 and was completed within a period of 4.5 months. Documentation, interviews, and site visits at Eskom's Megawatt Park, at all coal-fired power plants, as well as at grid facilities, formed the information basis for the investigation. The Eskom teams at the sites and at Megawatt Park supported this assessment in every way they could – in a very responsive and co-operative manner.

1.1 Eskom Generation – Coal Fleet

The main objective of the coal fleet investigation was to find out reasons for the low Energy Availability Factor (EAF) of the coal fleet – 50.83% as of April 2023 – and to develop measures to improve the situation. Most of the issues relating to the low EAF can be attributed to a single root cause, namely:

The management system with its governance, structure and processes is dysfunctional and too complex.

- Too many organisational layers and opaque decision-making processes generate a tremendous amount of red tape, with lengthy procedures and a lack of accountability. In many cases the decision-making is delegated to committees, of which there are too many at all levels of the hierarchy.
- The coal fleet is managed centrally, and very limited authority is given to the plant management. The plant management has to follow complex procedures and is therefore unable to manage day-to-day operations and maintenance challenges in a timely and effective manner.
- Eskom generation has been trapped within this complex management system for so long that it is no longer able to maintain or improve the technical performance of the coal-fired power plants.
- Although the problems and their solutions are known, the Eskom management has not been able to implement appropriate measures in a sustainable and successful manner. The solutions can be summarised in one sentence:

Operation and Maintenance (O&M) must be improved and conducted according to industry standards.

- The plant management, with its limited authority and high level of interference from headquarters, is unable to focus its attention on its primary responsibility: reliable plant O&M. Currently, even a mediocre level of performance (e.g. EAF) is accepted as sufficient.
- Since O&M procedures have not been carried out correctly for years, the overall condition of plant health is in many cases mediocre to poor.
- In O&M management, many deficits were identified. The quality of operations has suffered from a lack of ownership and leadership, as well as a lack of training and high staff turnover. The planning and execution of maintenance work need to be more stringent, more goal-oriented and more carefully executed.
- Furthermore, the complete outsourcing of maintenance has contributed to low plant reliability – the personnel is unfamiliar with plant requirements, reaction time and administrative interface efforts.
- The extent of the deficits in O&M competence is also reflected in the amount of severe plant damage that has occurred over the past years, leading to the long-term unavailability of entire plant units, e.g. Duvha Unit 3, Medupi Unit 4, Kusile Units 1 to 3. All of these incidents were related to deviations from prudent plant O&M practices.
- In particular, the complicated procurement policy and processes proved to be a bottleneck in supporting the plants with timely provision of spare parts and qualified services by third parties. In addition to its impact on plant performance, the procurement process is also a significant contributor to high service and supply costs.

Moreover, it is important to note that the assessment of the maintenance budget figures for the last ten years, and the current mid-term planning resulted in the following statement:

Compared to international benchmarks, the maintenance budgets of Eskom's coal fleet are higher – although the EAF is much lower.

- Maintenance budget figures from coal-fired power plants operated in Europe, America and Asia were used to define an international benchmark.
- For the period 2013 to 2027, Eskom's budgets for plant maintenance are well above the international benchmark. Hence, the money spent by Eskom should have been sufficient to execute proper maintenance and to keep the power plants in good condition.
- The EAF of Eskom's coal fleet is currently at about 51% whereas international benchmarks are in the range of 78%[1]. The only way to improve the EAF is to ensure the execution of thorough operation and maintenance practices and procedures.

[1] This figure refers to an average derived from the vgbe database KISSY of European power plants with unit outputs from 150 MW to above 600 MW.

The fixation on the EAF is a dead end and leads to poorer plant performance.

- Outage and maintenance activities have been deferred over the last months and years to lift – or at least to maintain – the EAF.
- The priority of the Eskom coal fleet operation has been to quickly fix the actual bottle-necks in generation capacities rather than to restore the plants to “as new conditions” after an outage.
- The plants have been forced to continue operating at the expense of their technical condition. The consequences are reflected in the high number of incidents, trips and partial load losses (PLL).
- This cycle has now gained so much momentum that it could lead to the collapse of plants or to further capacity losses. It must be stopped immediately by executing proper maintenance and outage work – even if this means a higher level of load shedding for a limited period of time.
- Moreover, up to 6 000 MW in partial load losses (PLL) could be reactivated by fixing the plants’ defects and applying prudent operation and maintenance practice.

The capacity constraint risks – especially for newer plants – need to be addressed immediately.

- The Kusile power plant is soon expected to become an important contributor to generation capacity, with Unit 5 starting within the next few months and Units 1 to 3 starting once construction of the temporary chimney has been completed. However, it should be noted that the achievable capacity is limited, due to the incomplete coal handling system, restrictions in water supply and the ash discharge situation. These restrictions result in a very high risk that the Kusile site cannot be operated with more than three units at any one time – hence, only 2 400 MW instead of 4 800 MW would be available.
- The Medupi and Matimba sites share the raw water treatment plant. This plant urgently requires at least maintenance and upgrading. If the existing plant fails, 12 units – 9 800 MW – would go off grid. Moreover, the current raw water supply is not sufficient to install the wet flue gas desulfurization plant that needs to be built for the Medupi and Matimba sites by 2025, in order to meet legislative requirements.
- The water treatment plant at Kendal is in a very poor condition and needs urgent maintenance and refurbishment. If the existing plant fails, six units – 3 840 MW – would be off the grid.

People can make the difference – good performance should be rewarded.

- As a result of the continuous crisis mode, many employees are frustrated and demotivated. In many areas, a working atmosphere characterised by indifference, ignorance and blame-shifting has been fostered. Salaries have not been increased for several years and there is no system in which good performance is rewarded.

- To lift spirits, the Eskom performance culture needs to change. The vgbe team recommends implementing an incentive scheme for good performance on both an individual and institutional level. For example, power plants should receive a bonus if they are able to reduce their losses by a defined percentage rate. Another incentive could be to provide accommodation for Eskom staff – e.g. free of charge – near the power plant.

The way forward: Empower the power plants

- The current electricity crisis can only be overcome in the power plants, which is why it is imperative that they are empowered right away to manage the technical turn-around, without being hampered by lengthy company procedures. This empowerment includes full budget responsibility and accountability of the Power Station General Manager (PSGM). Moreover, and at least for a limited period of time – e.g. 1.5 to 2 years, the power plants should be allowed to apply fast-track procurement processes under the supervision of the National Treasury.
- This change in governance requires changes in the management structure of the Generation Division. The vgbe team proposes decoupling the coal fleet from the rest of the generation business. The sole objective of this coal division should be the revitalization of the existing power plants.
- For the newer plants, Kusile and Medupi, the focus should be on improving operational management and risk mitigation related to capacity constraints. For the other plants, the primary aim is to eliminate the existing load losses through carefully executed maintenance and outages.

Immediate intervention is required.

- Unless there is immediate intervention, the situation will continue to escalate. Besides empowering the power plant management, the vgbe team recommends engaging an interim external expert team which reports directly to the National Treasury. Member(s) of the expert team should be permanently situated at each site to follow up key risk areas and intervene if required. The assignment should be limited to a defined period, e.g. 1.5 to 2 years.
- If these measures are taken and appropriate budgets are provided, it can be assumed that plant performance and reliability will improve significantly. When it comes to budgets, it should be considered that the current unavailable capacity of about 17 419.5 MW corresponds to financial losses of about R 152 billion per year[2] – not taking the cost of diesel into account. Against this background, even significant investments, e.g. for a life-time extension, will pay off within the short term.

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[2] As of today: Eskom has an installed capacity for the coal fleet of 35 550 MW. 1 MWh accounts for R 1 000, 17 419.5 MW (Eskom's capacity * (1 – EAF)) multiplied by 8 760 hours per year result in R 152 billion.

- In parallel to the turnaround activities, a concept for the long-term business model of the coal division should be developed. There are several options to be considered – they range from expert support through to concessions for individual power plants and privatization.
- In order to ensure a best-practice transfer for O&M of power plants and to support a continuous improvement process the experience exchange at expert as well as at management level – especially with international peers – should be intensified.

1.2 Skills at the Power Plants

Our assessment of the skills at the power plants focused on evaluating the competencies of the technical managers – plant manager, operating manager, maintenance manager, engineering and outage manager, as well as the training manager. Training progress and implemented training, as well as staff development and factors affecting staff performance were also reviewed. In addition to the management interviews, the assessment also included input from written online tests.

Throughout the assessment, the impact of the current situation on the workforce was clear to see low morale, lack of motivation, heavy workload with long working hours in a demanding working atmosphere, as well as the deferral or interruption of training programmes.

The competencies of the technical managers seem to be at a reasonable level, but there is greater potential for improvement.

- Within the scope of the evaluations, we repeatedly noticed that there is a high degree of theoretical knowledge. However, its application is made very difficult by the complex management system, as mentioned in the previous chapter.
- In general, leadership competencies are not at the required level. In the past, suitable leadership development programmes existed and these need to be re-established. Training should focus on turning skills and knowledge into competencies.
- In order to ensure continuous improvement, a sound plan for the further development of technical and non-technical competencies should be developed and implemented.

In addition to this, the vgbe team recommends the following measures:

- Eskom needs to develop a work ethic model that details the expected work ethic and aims at integrity and clear accountability.
- Recognition of personal performance should play a decisive role in human resource management. Regular performance reviews and feedback need to be of a high standard. To this end, managers should conduct regular employee appraisals and set common goals that can then be verified and serve as a basis for further feedback. Money or other rewards are needed as performance bonuses.
- Particularly in the area of training, there should be regular contact and exchange of information between central training and on-site training facilities. Their objectives and

programmes should be coordinated and aligned with each other. Communication is going to play a key role in this regard.

- Unit 4 at the Kusile plant achieves an EAF of > 90%. This unit is currently operated by the boiler OEM. This team has successfully demonstrated that it is possible to achieve a high EAF in the newer plant units. It is a perfect opportunity for knowledge and best practice transfer to the future O&M team of Eskom. This learning opportunity should be seized immediately.

1.3 Transmission Grid Assessment

The multiple load shedding that occurs every day is not the result of the transmission system being in poor condition.

- The load disconnections result from insufficient available power plant capacity, even though sufficient power plant capacity has been installed. The lack of required power plant capacity is not the responsibility of the transmission system operator (TSO).
- The power shortage is managed by the TSO, with the planned load shedding in an excellent way and thus ensures the secure and available grid operation within the scope of the possibilities.
- The danger of a blackout is largely excluded by this network operation method.

Compared to European transmission systems, a high proportion of the transmission system's facilities are relatively old, and an above-average proportion have reached the end of their operating life.

- Despite the high proportion of old equipment, the overall condition is excellent due to intensive maintenance measures. Nevertheless, it is essential to continue the modernisation process of these outdated plant components, which has been underway for several years.
- If this modernisation is neglected, an accumulation of equipment failures can be expected within a short space of time in the near future. This could lead to a critical situation in the operation of the transmission system. Sufficient financial resources must be made available for these modernisation measures, to ensure the safe and reliable operation of the transmission system in the future.
- The urgent need for these measures has already been recognised by management and has led to an increase in approved investment budgets in recent years. It has also been included in the Transmission System Development Plan (TDP).

The good overall condition of all parts of the transmission system is mainly due to excellent maintenance.

- This maintenance status is based on well-trained and highly motivated personnel.
- The management of the transmission system is very well organised and the cooperation between top and middle management down to the working staff is very good.
- All relevant processes are laid down in work instructions and are stringently applied. This efficient work environment should be secured through sufficient qualification measures, competitive wages, recruitment of young staff and knowledge-transfer to newly hired employees.

The transmission system development plan is a very good tool for planning the transmission system.

- The plan will be updated annually for the next ten years, thus ensuring continuous revision and adaptation to changing conditions.
- The current TDP is based on the status of the Integrated Resource Plan (IRP) as of 2019. It is recommended to use more up-to-date sources of information for the update of the TDP in addition to the IRP in order to be able to react more quickly to new requirements for network expansion.
- It will include modernisation measures that take the condition and age of the plants into consideration. The development of the grid will include grid expansions that reflect additional demand and new power plant connections in the area of renewables and independent power producers (IPP).
- Transmission System Operator (TSO) stakeholders should use the measures described in the transmission system development plan as a guide for their decisions on how to manage the company.

In order to connect additional renewable generation capacities, a significant grid expansion is required.

- The grid expansion projects are included in the budget planning. By FY2028, R 74.2 billion of financial resources are planned for upgrading and expanding the network. The network expansion budget will increase from R 2 billion in FY2024 to R 10.1 billion in FY2026.
- The budget for the grid expansion, as well as for sustaining the grid, seems to roughly reflect the requirements of the renewable capacity increase.
- Implementing the associated expansion measures is a major challenge for Eskom Transmission and requires sufficient internal human resources.

2 Introduction

The South African government continues to support Eskom in its efforts to remain financially sustainable during its transition. Eskom is faced with a large amount of debt that remains a challenge to service without assistance and this debt situation remains a concern for its creditors and South Africa's investors alike. The National Treasury has been leading a project team to develop a debt solution for Eskom that is equitable and fair for all stakeholders.

The National Treasury is undertaking this work while being fully aware that addressing the debt alone will not solve Eskom's financial challenges and return it to financial sustainability. Hence, a multi-pronged approach is required to return Eskom to financial sustainability. For this reason, the National Treasury wanted to commission an international service provider with experience in the energy sector to provide an independent assessment of Eskom's operational situation before any debt solution is implemented.

The vgbe consortium was assigned to conduct this assessment. The scope of work comprised a review of the operational situation of the coal fleet, an assessment of the power plant maintenance budgets, an assessment of the skill levels of power plant personnel and an assessment of the transmission grid. As Eskom's operational situation was the overarching focus of the assessment, **Opera** was chosen as the project's acronym.

The consortium was led by vgbe and included teams from the other partners; Dornier, KWS, RWE and STEAG. The project started on 27 February 2023 and was completed within a timeframe of 4.5 months.

The report represents the results of all workstreams – that means the Generation's asset management, the technical power plant assessment, the transmission grid Assessment and the skill assessment.

Note of Thanks

On behalf of the whole consortium, vgbe expresses its deep gratitude to the National Treasury team – and in particular to Jeffrey Quvane and Ravesh Rajlal – who were the driving force behind the project and supported it from the very beginning until the very end. They were constantly involved in all activities and facilitated all required discussions, interactions and site visits at Eskom's Megawatt Park, at Eskom's power plants and at Eskom's grid facilities. This support was key to the success of the project. The active involvement is a clear sign of the National Treasury's commitment and dedication to overcoming the challenges in the supply of electricity. The willingness to provide solutions has been evident at all times.

The vgbe team would like to thank Eskom for the excellent cooperation and great support throughout the project. Special thanks go to Norman Mkhize and his team. As a single point of contact they managed all activities – especially the coordination with all power plants – in a very professional and efficient manner. The organisation of the parallel site visits was a particularly big challenge which was managed admirably.

Furthermore, we would also like to extend our gratitude to the Eskom teams at the sites and at Megawatt Park. They supported this assessment to their very best – in a very responsive and co-operative manner. The vgbe consortium received all information it asked for – every meeting request was fulfilled. During the site visits, everything was well organised and prepared. The vgbe teams felt very welcome and appreciated the hospitality during the stays. Hence, we would like to thank the very many people not named here, who contributed their time, knowledge and contacts and made the assessment possible.

3 Opera Concept and Project Organisation

This assessment aims to provide support in overcoming the current electricity supply crisis. The Opera project was an assessment and not an audit. Benchmarking served the purpose of identifying bottlenecks and potential areas for improvement. The ultimate target was to provide recommendations that increase the availability, reliability and performance of Eskom's coal fleet, as well as of Eskom's transmission grid expansion planning.

3.1 Scope of Work

The assessment comprised the following activities:

- Review of the operational effectiveness of Eskom's coal-fired power plants and advice on the status of the plants, in terms of performance and maintenance required to keep them in continuous operation.
- Review of and advice on the appropriateness of existing skills at power plants.
- Advice on whether sufficient and appropriate maintenance investment is being made in power plants.
- Review of capital expenditure requirements in terms of generation, transmission and distribution, including upgrading the existing network to accommodate any additional generation, including IPP programmes inclusive of the Just Energy Transition (JET) programme.
- Advice on any other operational considerations (including risks) that the government needs to consider with respect to improving Eskom's operational challenges.
- Visits to the following coal-fired power plants in the Eskom network: Arnot, Camden, Duvha, Grootvlei, Hendrina, Kendal, Komati, Kriel, Kusile, Lethabo, Majuba, Matimba, Matla, Medupi, and Tutuka (refer to the figure below).
- Engage with various divisions within Eskom and other stakeholders (including the Department of Public Enterprises and Department of Mineral Resources and Energy).
- Preparation of a comprehensive report and provision of recommendations addressing the areas outlined in the scope of the assessment.
- Provision of further follow-up advice, as may be requested by the National Treasury.

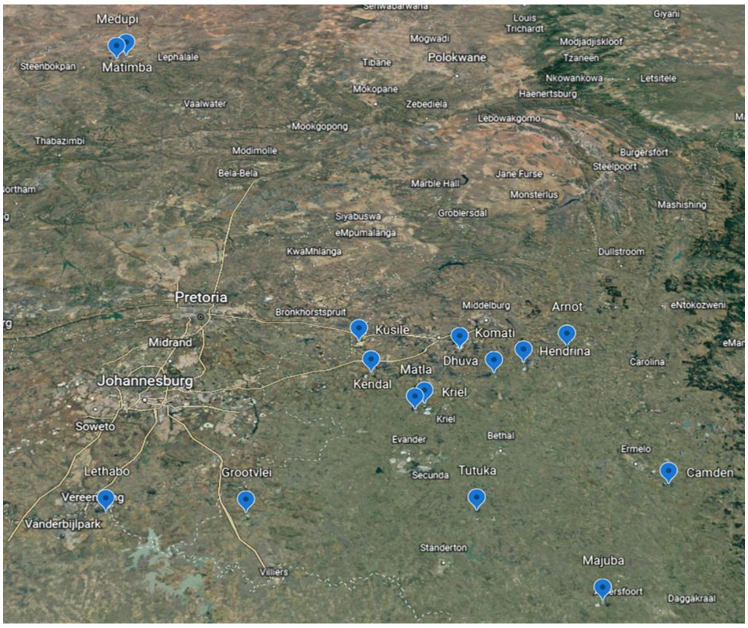


Figure 1: Overview of the geographical location of Eskom's coal-fired power plants
Source: Map data ©2022 Google

The scope of the assessment was categorised in four work streams shown in Figure 2.

1. Technical assessment at the power plants
2. Skills assessment at the power plants
3. Review of Generation's asset management activities with a focus on assessment of the maintenance budget
4. Transmission grid assessment

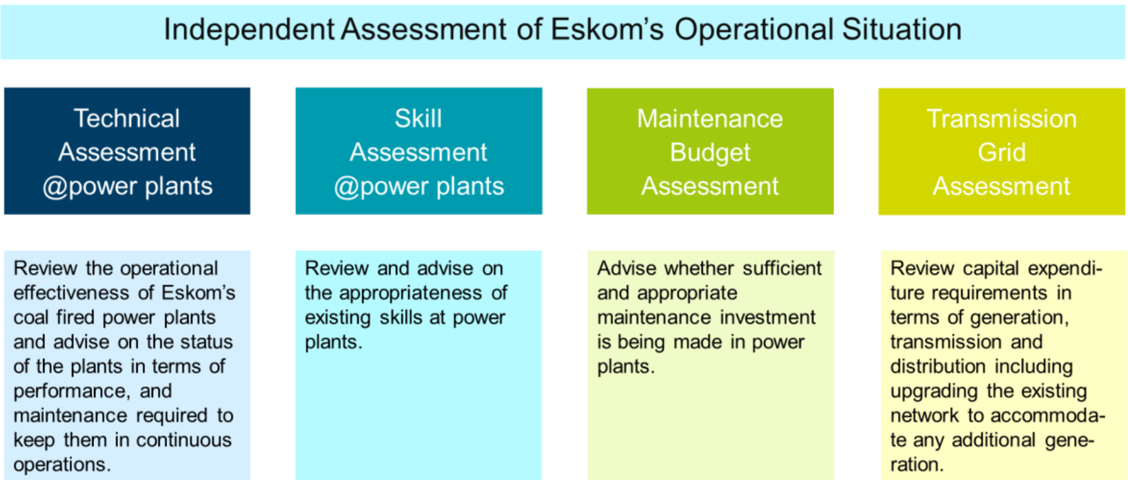


Figure 2: Overview of the Opera workstreams

3.2 Project Partners

In order to conduct this assessment, vgbe energy e.V. and its fully owned subsidiary vgbe energy Service GmbH (vgbe), Dornier Power and Heat GmbH (Dornier), KWS Energy Knowledge eG (KWS), RWE Technology International GmbH (RWETI) and STEAG teamed up under the leadership of vgbe.

About vgbe

vgbe energy e. V. – vgbe – is the international technical association of energy plant operators. vgbe energy Service GmbH is its fully owned subsidiary, responsible for the provision of technical and engineering services. As an independent technical competence centre and network, the association supports its members in their respective business activities, as well as in the implementation of innovations and strategic tasks. The vgbe currently has 437 members in 32 countries worldwide, 90 percent of them in Europe. The members represent an installed capacity of around 300 GW. This includes a wide range of systems – from thermal power plants and wind energy and hydropower plants to energy storage systems.
www.vgbe.energy

About Dornier

Dornier Power and Heat GmbH (formerly known as "VPC" or "Vattenfall Europe PowerConsult") is an engineering consultancy focused on the energy sector. Dornier has about 230 employees in Germany and can rely on additional energy sector resources in Serbia and India with a total of 1800 staff. For five decades, Dornier was part of different German power utilities operating about 16 GW of thermal, mainly coal-based generation. The company is familiar with technical and procedural plant operation improvements including maintenance and inspection planning and implementation. www.dornier-group.com

About KWS

KWS Energy Knowledge eG is more than a mere vocational training school – it is an institution whose origins date back to the late 1950s. In the 1950s, Germany's power industry, represented by the VGB, the Association of Large Boiler Owners, decided to act on the recognition that disturbances, malfunctions, and serious accidents in power plants were often mismanaged or even caused by insufficiently trained operating crews. With the rapid expansion of Germany's power plant capacities and the ever-increasing complexity of power plant technology, the need for standardised high-quality personnel training throughout the industry was evident. Therefore, KWS Energy Knowledge eG, a school dedicated exclusively to comprehensive basic and advanced training of power plant personnel, was set up in Essen, Germany in the year 1957. Initially, training focused on power plant shift supervisors from German fossil-fuelled power plants only, and all courses were conducted on the school's premises in Essen, with emphasis on theoretical classroom instruction. www.kws-eg.com

About RWETI
RWETI is a wholly owned member of the RWE Group, which has successfully operated and maintained its own fleet of power stations in Europe for more than 120 years and is Germany's biggest power producer. RWETI's success is driven by our world-class experts in the fields of operations, engineering and maintenance and across the whole range of engineering disciplines. RWETI combines global reach with local understanding to provide a range of innovative solutions and techniques for operating power plants in a variety of commercial environments. The company's extensive expertise in mining technology, operations and environmental protection is recognised worldwide. In the report RWETI is referred to as RWE.
www.rweti.com

About STEAG
STEAG has 80 years of experience in the operation of its own coal-fired power plants and as a provider of engineering and O&M services to third party companies. With its approximately 2,000 staff members the company has served in 80 countries. Over 100,000 MW of electrical power plant capacity of all technologies respectively with various types of fuel have been designed and implemented by STEAG. The company currently provides a total of about 15,000 MW of operation management as well as 2,000 IT systems for plant planning and performance optimization support for third parties worldwide. An example of successful power plant O&M service support is the coal-fired power plant Morupule B, Botswana of the state-owned Botswana Power Corporation. Since 2014 the contracted services comprise the operation of the four units 24/7 including daily maintenance, repair and overhaul management which has lifted the EAF from 30% to > 70%. A structured competency building program of the client's local staff made it possible to reduce the initial STEAG workforce to a skeleton support group. https://www.steag.com/en/

More than 30 experts worked on the Opera project – most of them were part of the site teams that visited the coal power plants and grid facilities. The team included experts from Germany, India, Poland, Serbia and South Africa.

Figure 3: Team members of the vgbe consortium

3.3 Project Execution and Schedule

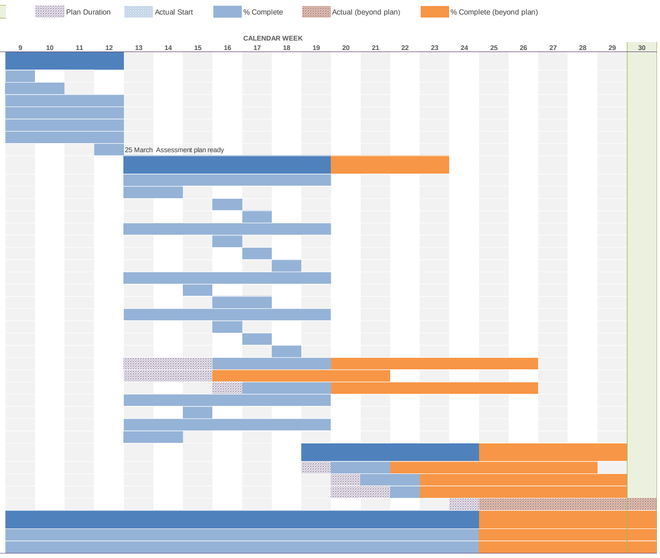
The project execution was structured into three phases: preparation (1), site investigation (2) and assessment (3). In order to manage the assessment in a short period of time, the investigation on-site was planned with several teams working in parallel. On-site either refers to different power plant sites or to Eskom's Megawatt Park and ministerial institutions. In order to meet the requirements as shown in scope of work, the following activities were conducted:

Work Package (1): Preparation	
1.0	Project set-up and signing of NDAs
1.1	Review of documentation
1.2	Development of a site visit procedure
1.3	Assessment matrix for technical + organisational aspects
1.4	Preparation of skill assessment
1.5	Development of checklists
1.6	Kick-off with Eskom (held on 23 March 2023)
Work Package (2): Site Evaluation, Surveys and Interviews	
2.1	Site investigation vgbe
2.1.1	Site visit: Duvha
2.1.2	Site visit: Duvha, Arnot
2.1.3	Site visit: Kriel, Grootvlei
2.2	Site investigation Dornier
2.2.1	Site visit: Hendrina, Matla

2.2.2	Site visit: Matla, Kendal, Lethabo
2.2.3	Site visit: Lethabo
2.3	Site investigation RWE
2.3.1	Site visit: Camden
2.3.2	Site visit: Tutuka, Majuba
2.4	Site investigation STEAG
2.4.1	Site visit: Medupi
2.4.2	Site visit: Matimba
2.4.3	Site visit: Kusile
2.5	Skill Assessment KWS
2.5.1	Written
2.5.2	Interviews
2.6	Transmission assessment Dornier
2.6.1	Site visit: Megawatt Park
2.7	Headquarter assessment vgbe
2.7.1	Site visit: Eskom Megawatt Park, Stakeholder
Work Package (3): Assessment Report	
3.1	Analysis of all site visit reports, interviews and reports
3.2	Synthesis of findings
3.3	Assessment report
3.4	Presentation of assessment
Work Package (4): Project Management	
4.1	Coordination of activities
4.2	Client communication

Table 1: Overview of Opera work packages

The project started on 27 February 2023 and was completed within a period of 4.5 months. Originally, the plan was to complete the assessment within a four-month period. However, due to some delays with regards to skills assessment, an extension of the project timeline was necessary. The final project schedule is shown in the next figure.



Opera Project Schedule

Select a period to highlight at right. A legend describing the charting follows.

Current Calendar Week 30

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
1. Preparation	9	4	9	4	100%
1.0 Project set-up and signing of NDAs	9	1	9	1	100%
1.1 Review of documentation	9	2	9	2	100%
1.2 Site visit procedure	9	4	9	4	100%
1.3 Assessment matrix for technical + organisational aspects	9	4	9	4	100%
1.4 Preparation of skill assessment	9	4	9	4	100%
1.5 Development of checklists	9	4	9	4	100%
1.6 Kick-off with Eskom	12	1	12	1	100%
2. Site Evaluation, Surveys and Interviews	13	7	13	11	100%
2.1 Site investigation vgbe	13	7	13	7	100%
2.1.1 Site visit: Duvha	13	2	13	2	100%
2.1.2 Site visit: Duvha, Arnot	16	1	16	1	100%
2.1.3 Site visit: Kriel, Grootvlei	17	1	17	1	100%
2.2 Site investigation Dornier	13	7	13	7	100%
2.2.1 Site visit: Hendrina, Matla	16	1	16	1	100%
2.2.2 Site visit: Matla, Kendal, Lethabo	17	1	17	1	100%
2.2.3 Site visit: Lethabo	18	1	18	1	100%
2.3 Site investigation RWE	13	7	13	7	100%
2.3.1 Site visit: Camden	15	1	15	1	100%
2.3.2 Site visit: Tutuka, Majuba	16	2	16	2	100%
2.4 Site investigation Steag	13	7	13	7	100%
2.4.1 Site visit: Medupi	16	1	16	1	100%
2.4.2 Site visit: Matimba	17	1	17	1	100%
2.4.3 Site visit: Kusile	18	1	18	1	100%
2.5 Skill Assessment KWS	13	7	16	11	100%
2.5.1 Written	13	3	16	6	100%
2.5.2 Interviews	16	4	17	10	100%
2.6 Transmission assessment Dornier	13	7	13	7	100%
2.6.1 Site visit: Megawatt Park	15	1	15	1	100%
2.7 Headquarter assessment vgbe	13	7	13	7	100%
2.7.1 Site visit: Eskom HQ, Stakeholder,	13	2	13	2	100%
3. Assessment Report	19	6	19	11	100%
3.1 Analysis of all site visit reports, interviews and reports	19	3	20	9	100%
3.2 Synthesis of findings	20	3	21	9	100%
3.3 Assessment report	20	3	22	8	100%
3.4 Presentation of assessment	24	1	25	6	0%
4. Project Management	9	16	9	22	100%
4.1 Coordination of activities	9	16	9	22	100%
4.2 Client communication	9	16	9	22	100%

Figure 4: Opera project schedule

3.4 Information Basis

The investigation was based on information drawn from documentation, interviews and site visits to Eskom's Megawatt Park, to all the coal-fired power plants and to grid facilities. Detailed feedback on the discussions and site visits is included in the relevant chapters of the report.

Below is a list of the documentation that was analysed. Eskom was requested to provide this information ahead of the project start, as it served as the basis for preparing the site investigations.

<u>Documentation from each power plant site:</u>

- Organisation chart of the site team.
- Staffing/resource and training plan.
- Schematic overview of the plant / P&ID: units and shared facilities, such as water treatment, ash handling, coal supply etc.
- Main design data and technical description.
- Operation manual.
- EAF data for the last five years.
- Full load hours for the last five years.
- List of issues that caused unforced outages, respectively unplanned unavailability (TOP10), along with the period of resulting unavailability.
- Log of incidents and measures taken for the last two years.
- Outage log for past five years with information about any deferred outages and reasons why they were deferred.

- Planned maintenance budget vs. actual budget spending for short-term, medium and large inspections over the past five years.
- Measures taken to improve the power plant availability over the past five years, together with the main maintenance measures undertaken.
- Planned maintenance budget spending for short-term, medium and large inspections for the next five years.

Documentation from Eskom's head office:

- HR organisational structure and responsibility at plant level.
- Training arrangements and responsibility structure.
- Organisation manual for the Generation division.
- Maintenance strategy description.
- Spares and parts procurement structure and responsibility structure.
- Organisation chart from the asset management division.

From Eskom Transmission

- Organisation manual for the transmission division
- Digital transmission system model (in DIgSILENT or PSS/E format preferably) – current status and planned status in 2028 and 2035.
- Load demand and forecast for the next ten years.
- List of generation plants currently feeding at transmission level – with name plate and actual capacity per unit.
- List of confirmed and upcoming IPP plants with
    - technology type
    - gross/net generation capacity
    - associated storage facilities (if applicable)
    - site name/coordinates
    - feeding substation and the year of starting production
- Grid map of the transmission system with the following information (current status and planned status in 2028 and 2035):
    - grid map of each voltage level and single line diagrams
    - substations, transformers and transformer power
    - transmission capacity of the lines
    - connection points of power plants and the infeed power

4 Generation Asset Management

The review of the Eskom Generation's asset management formed an integral part of the present independent assessment of Eskom's operational situation in the coal fleet. This part of the review covers only those aspects relevant to the operational effectiveness of Eskom's coal-fired power plants: the appropriateness and effectiveness of maintenance investments, as well as supplementing operational considerations in respect of improving the operational challenges. The review took into consideration both the perspective of external stakeholders and that of internal management at head office. The discussions with relevant persons from Eskom's headquarters at Megawatt Park and with representatives from various ministries were invaluable for this assessment. The following table provides an overview of the interactions:

Day	Institutions	Location
27 March	National Treasury	Pretoria
28 March	DMRE	MS Teams
	Eskom Management	Megawatt Park
	Eskom CEO (Calib Casim)	Megawatt Park
29 March	NECOM (National Energy Crisis Committee)	MS Teams
	Eskom Management	Megawatt Park
	Department of Public Enterprises	Pretoria
3 April	Eskom Management	Megawatt Park

Table 2: Overview of interactions with Eskom management and ministry representatives

Discussions with the following Eskom general managers and their teams were conducted:

Bruce Moyo – Coal Cluster 3

Danie Odendaal – Engineering

Dhiraj Bhimma – Production and Sales

Eric Shunmagum – Office of the Group Executive

Gcobisa Mashegoana – Procurement and Supply Chain Management

Mandla Dube – Human Resources

Paula Goatley – Operation, Maintenance and Outages

Thomas Conradie – Acting Group Executive Generation (at the time of the visit)

With respect to the scope of the present report, the review of Eskom Generation's asset management was limited to three areas:

1. Review of the management system, including organisational structure, management processes and governance
2. Assessment of maintenance budgets
3. Review of coal purchase

4.1 Management System

Eskom Generation Division's (Gx) management system, with its governance, structure and processes, is dysfunctional and too complex. Eskom Generation has been trapped in this situation for several years, preventing it from maintaining and eventually improving the technical performance of the coal-fired power plants. Although the problems and their solutions are known, Eskom's management has not been able to implement appropriate measures in a sustainable and successful manner. The following key problem areas have been identified:

1. Too much involvement of Generation's top management has led to ineffective implementation and an additional organisational level between headquarters and the power plant management, causing unclear responsibilities and a lack of ownership and leadership within the line organisation.
2. In addition to excessive organisational layers, opaque decision-making processes generate a tremendous amount of red tape with long-winded procedures and a lack of accountability. In many cases, the decision-making is delegated to committees, of which there are too many at all levels of the hierarchy.
3. The central management of the generation fleet, along with the very limited authority of the power plant management, has led to a situation in which the PSGM is unable to act autonomously on decisions required for daily operation and maintenance challenges. Even in the current crisis mode, the PSGM has to follow complex internal procedures and decision-making processes.
4. In particular, the complicated procurement policy and processes have turned out to be a bottleneck in supporting the coal plants with timely provision of spare parts and qualified services from third parties. This complicated procurement process not only impacts plant performance but is also a significant contributor to high service and supply costs.

The analysis of the current organisational and procedural landscape at Generation highlighted several areas that need to be addressed – organisational structure, management processes and governance – in order to achieve long-term improvements in operational performance.

4.1.1 Organisational Structure

The current organisational structure of Eskom's generation division does not properly reflect the crisis mode in which the coal fleet has been stuck. A simplified organisational chart is shown in Figure 5.

Figure 5: Simplified organisational structure of Eskom's Generation division[3]

From the vgbe team's point of view, changes within Generation's organisational structure are urgently needed in order to stabilise and improve the coal fleet's operational performance.

The current crisis can only be overcome in the power plants. Their essential role needs be reflected in the organisational structure. The power plants must immediately be empowered to manage the technical turnaround independently of long-standing company procedures. We propose making organisational changes based on the proven practices of European utilities, to establish fast and efficient decision-making processes and clear responsibilities and ownership. Key elements of this organisational proposal are:

- The implementation of a dedicated coal fleet division with a "Coal Division General Manager" reporting to the Generation Group Executive (Bheki Nxumalo) and for an interim period also to National Treasury. This division should be headed by an experienced coal plant manager and have the sole aim of improving operational performance.
- A division focused purely on fleet operation and maintenance is prerequisite to tackling the issue of underperformance and unavailability in the coal fleet. Efforts to improve coal plant performance need to be kept separate from strategic issues around

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[3] Source: Eskom file 230202_Gx Visual Organogram 2023_Rev1-23 Updated_1.pptx

the "Just Transition" in Eskom Generation (e.g. new build or repurposing, renewables and storage, etc.) and the Eskom Group. Moreover, these efforts should not be affected by any strategic initiatives for unbundling the Eskom divisions on group level.

- Grant the coal division full responsibility for the O&M budget, enabling it to take control of all necessary business decisions, including staffing and procurement. In the short-term, we recommend the implementation of emergency procurement support exempting the coal fleet division from corporate procurement constraints (see below).
- The clusters should be dissolved, enabling the PSGM to report directly to the coal division manager. The cluster level in the current setup is not effective and only slows the decision-making process.
- The PSGMs should have full responsibility for their allocated budgets and for their operational and financial results. Moreover (at least for a limited period of time – e.g. 1.5 to 2 years), the power plants should be allowed to apply fast-track procurement processes under the supervision of National Treasury.
- "All hands on deck" approach: The functions at head office should focus on direct technical, financial and operational support to the power plants. The same applies to experts allocated to specific "SWAT" teams (see below). Existing task forces, committees and initiatives looking at operational performance should be reduced to a minimum and anyone still involved needs to be assigned to specific measures and projects at the power plants.
- At the older plants, in particular, there are common problems that arise again and again, such as air leakages at the boiler, mill issues, poor vacuum, water and steam leakages in the turbine and feed water area, as well as boiler tube leakages. We recommend the creation of expert teams specialised in fixing these issues – from planning to execution. We suggest a centralised service, based at Megawatt Park, that serves all the plants.
- In order to support the turnaround process, we suggest installing an interim team of independent experts that reports directly to National Treasury. This should be with immediate effect.
- The existing structure of the Eskom executive committees should be critically reviewed – at least for the coal division – and reduced to a minimum, as described in the next sub-chapter.

One option for a potential organisational structure is shown on a basic level in Figure 6. It should be noted that a detailed organisational structure and review of the related management processes and governance functions would need to be developed in the next phase of this project.

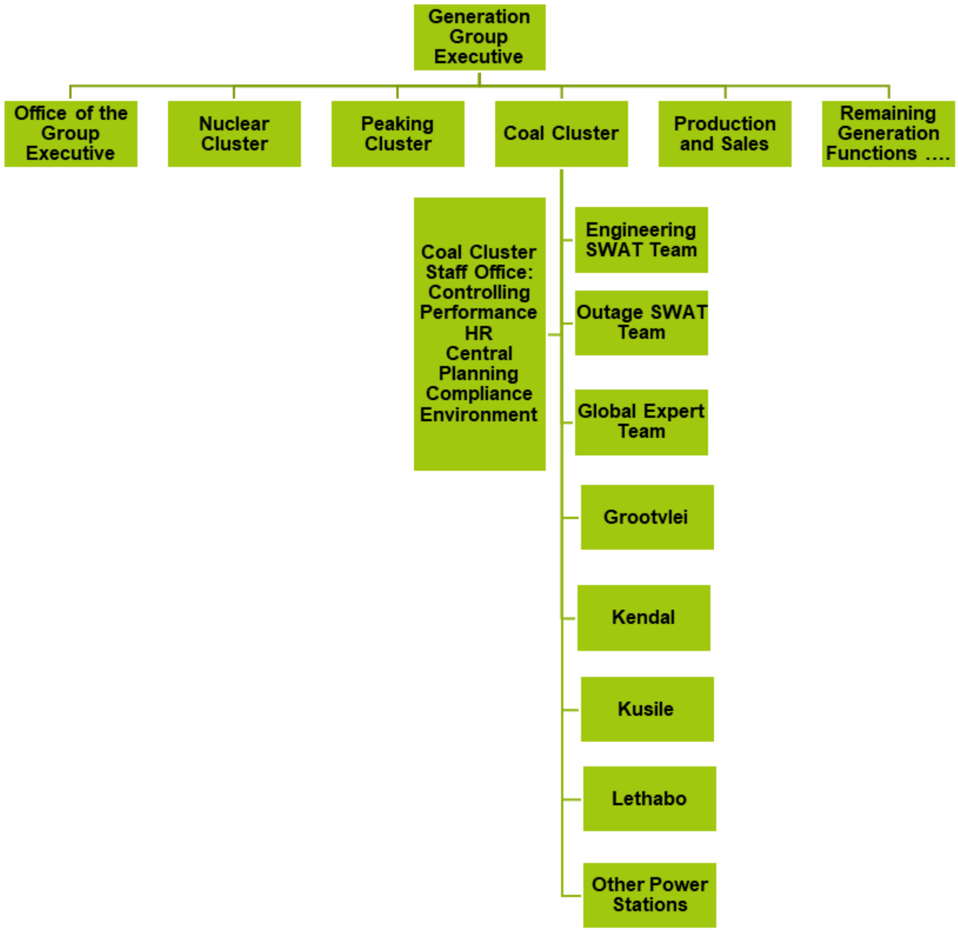


Figure 6: Proposed principal organisational structure of coal fleet division

4.1.2 Management Processes including Governance

Eskom's highly elaborate and complex management processes are not effective in dealing with crises like current one. We propose changing the following processes and governance structures:

<u>Key Performance Indicators</u>

The KPI portfolio is too complex to understand and too inconsistent to be used as a guide for power plant operation. The large number of KPI are at times contradictory, leading to unclear decision priorities. As an example, the Outage Readiness Index (ORI) and the Maintenance Performance Index (MPI) should be replaced by simple and understandable indicators which reflect the real situation and show real progress. Their determination should be based on straight-forward systematics.

The KPI portfolio should be reduced to a maximum of 10 to 15 indicators, based on best industry practice, compiled in an easy-to-understand management dashboard that can be used across all power plants. We recommend a principal dashboard as follows:

- Operation
  - EAF
  - UCLF (Unplanned Capability Loss Factor) and PLL
  - Energy supplied and electrical efficiency
  - UAGS (Unplanned Automated Grid Separation)
- Finance
  - Commercial availability
  - Budget consumed
  - Cost of electricity supplied
- Environment
  - PM (Particulate Matter)/NO_x/SO_x emissions compared to limit values (as appropriate) and/or AEL (Atmospheric Emission Licenses) compliance
  - Specific water usage
  - Ash production
- Human Resources (HR)
  - LTIFR (Lost Time Injury Frequency Rate)
  - Health rate
  - Number of improvement suggestions
  - Staffing rate

Business support to power plants

Current financial practices follow a central approach which strictly limits the PSGM's ability to make business decisions, leading to little accountability on-site. This is demotivating and does not give a feeling of ownership. The power plants should be empowered to make decisions within their attributed budget framework. In addition, the coal fleet division should be empowered to adjust budget allocation between the power stations, as long as the overall budget is met. Nevertheless, critical business decisions that exceed a set budget limit should continue to be reported to the Generation Executive and the Eskom Board and be decided on a case-by-case basis at corporate level.

Emergency procurement support

Current procurement practices are not suitable for urgent and emergency sourcing of essential spare parts. We suggest establishing an independent body outside of Eskom that reports directly to National Treasury. This body should be empowered to procure essential parts as and when required for safe and reliable plant operation. Eskom should carry out a cost/benefit analysis and the independent body should assess what is needed and should be authorised to approve the process.

Human resource support

As a result of the constant crisis mode, many employees are frustrated and demotivated. A working atmosphere characterised by indifference, ignorance and blame-shifting has been fostered in many areas. Salaries have not been increased for several years and a system in which good performance is rewarded has not been implemented. The turnover of management staff at several power stations is very high. This leads to a loss of plant know-how, demotivation and constant pressure with regards to keeping the power plant organisation functional and efficient. Measures should be implemented to:

- attract and secure skilled and high-performing staff,
- secure site-specific know-how,
- enable management continuity,
- facilitate teambuilding and build-up of trust among the power plant staff.

It is important to lift employees' spirits, and to do this Eskom must change its performance culture. The next chapter addresses this problem, proposing measures related to salaries and incentive schemes.

<u>Expert support for the power plants</u>

Experts currently employed at Megawatt Park should be allocated to the following teams, to work directly with the power stations and on-site support staff:

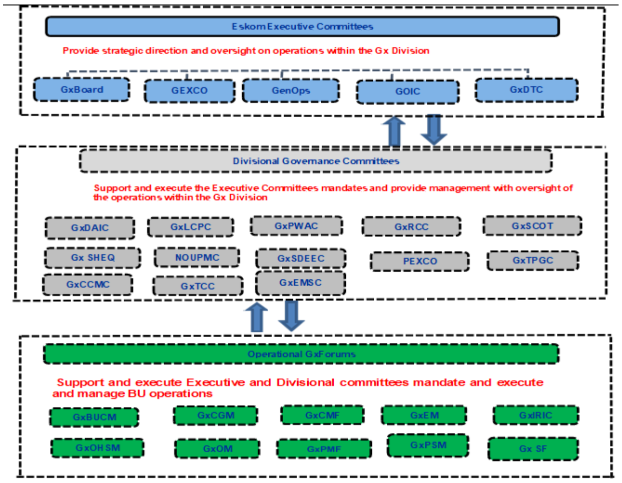
- „Global System Engineers" senior expert team for important process and main equipment issues (e.g. turbine island, boiler tube leakages, cooling system)
- „Engineering-SWAT-Team" to support on-site on a rolling basis
- „Outage-SWAT-Team" to execute urgent and repetitive maintenance issues existing at many power stations (e.g. repair/exchange of spraying valves, water and steam leaks in valves and pumps sealings, air ingress in ducts and air preheaters

<u>External expert support</u>

We believe that the necessary turnaround cannot be achieved within the framework of the current management structure at Eskom. Implementing an appropriate structure, as set out in the first chapter, will take time; we strongly recommend the immediate establishment of an interim team of independent experts (outside of Eskom) that reports directly to National Treasury. Member(s) of the expert team should be permanently situated at each site, to follow up key risk areas and intervene if required. Furthermore, the team should be authorised to procure critical spare parts, as emergency procurement support is also needed. The assignment should be limited to a defined period, e.g. 1.5 to 2 years. At minimum, there should be one financial and one technical expert on-site. Also, the procurement of critical spare parts can be supported by the team.

<u>Eskom Generation committees</u>

The existing structure at Eskom, with its 28 executive committees (in addition to the GxBoard), has not proven successful in mitigating poor operational performance of the coal fleet or supporting decision making. Figure 7, below, gives an overview of the committees.



Abbreviation	Meaning
EXCO	Executive Committee
GEXCO	Generation Executive Committee
GenOps	Generation Operations Committee
GOIC	Generation Operations Investment Committee
GxBUCM	Generation Business Units Compliance Management Forum
Gx Board	Generation Board
GxCCMC	Generation Coal Cluster Management Committee
GxCGM	Generation Clusters Managers
GxDAIC	Generation Division Assurance Integration Committee
GxDSDEEC	Generation Division Skills Development and Employment Equity Committee
GxDTC	Generation Division Tender Committee
GxEMF	Generation Engineering Managers Forum
GxLCPC	Generation Licensee Capital Portfolio Committee
GxMMF	Generation Maintenance Managers Forum
GxPWAC	Generation Private Work Adjudication Committee
GxRICF	Generation Regulatory Interface Co-ordinating Forum
GxSCOT	Generation Steering Committee Technologies
GxSF	Generation Security Forum
GxSHEQ	Generation Division Safety, Health, Environmental & Quality Executive Committee
GxTPGC	Generation Technical Process Governance Committee
GxTCC	Generation Divisional Tactical Command Centre
NOUPMC	Nuclear Operating Unit Portfolio Management Committee Client Committee

Figure 7: Overview of current Eskom executive committees[4]

As far as is possible, we recommend separating Eskom Generation's coal division from the rest of its business and from the overarching Eskom Group organisation and processes. For the existing committees we suggest this approach:

- Executive Committees
  As the coal fleet division has a clear focus and budget responsibility, the actual cross-divisional functions of the GexCo and GenOps for the coal fleet are bundled in one staff department for the coal fleet division (Office to the coal fleet Executive). The interface to the rest of the Generation division is ensured via the direct reporting to the Generation Executive and participation of coal fleet representatives in the executive Committees for information. GOIC (Generation Operations Investment Committee) and GxDTC (Generation Division Tender Committee) are handled in the same way for information only. The coal division must be separated as far as possible from the rest of the generation division.
- Divisional Governance Committees
  The divisional governance committees should be reduced and concentrated into the staff department to the coal fleet division as well which then acts as the one interface to the Generation Division.
- Operational Gx Forums
  Close collaboration and best-practice transfer is a key enabler for sustainable operational performance. To enable it to focus on the current situation, the coal fleet should – at least temporarily – setup its own forums, on a smaller scale, to specifically address its operational issues. We suggest the following forums:

[4] Source: Eskom file Gouvernance Structures (002).pptx

- Power station managers, coal management and regulatory affairs
- Production managers
- Engineering, maintenance and outage managers
- Support functions (e.g. security)

In the long-run, interdivisional forums can be re-established again.

Governmental oversight and governance

Not insignificant to developments is the fact that governance of Eskom, as a state-owned company is characterised by multiple and – to a certain extent – uncertain or contradictory political priorities and goals. The main external stakeholders, as described in related policy documents[5] and as established in meetings held with various government departments in the course of the assessment, are shown in simplified form in the figure below.

Figure 8: Key governmental stakeholders to Eskom

The Department of Public Enterprises (DPE) is the shareholder representative for the Government of South Africa and is mandated to oversee and help shape the formulation of policy, legislation and regulation. Under the Public Finance Management Act, the DPE and Eskom conclude an annual shareholder compact, which tracks the KPI for supporting Eskom's mandate and the strategic objectives that have been set up by DPE in the Strategic Intent Statement.

The Department of Mineral Resources and Energy (DMRE) regulates the mineral and energy sector and sets energy policy. Amongst other things, it develops the Integrated Resource Plan and the Integrated Energy Plan, which determine the national energy mix and the development of the national electricity generation portfolio.

The National Treasury is responsible for ensuring the necessary financial funding of Eskom. The Ministry of Electricity, which is relatively new within the Presidency, oversees all aspects of electricity crisis response, including the work of the National Energy Crisis Committee

[5] Source: Eskom document "Generation Division Business Plan FY 2023 - 2027 Rev07 (240-109132834) in the file „Generation Division Business Plan FY2023-27.pdf "

(NECOM). It also oversees the procurement of new generation capacity and security of supply – previously within the remit of the DMRE.

The National Energy Regulator of South Africa (NERSA) regulates the industry under the National Energy Regulatory Act 2004 and the Electricity Regulation Act 2006, providing licences, regulatory rules, codes and guidelines. NERSA also determines the revenue allocation in accordance with the Electricity Pricing Policy and approves new build projects and shutdown plans.

The intergovernmental body of the NECOM comprises all relevant government departments and Eskom, led by the Director-General in the Presidency. The body reports to an interministerial committee, which is chaired by the President and comprises the Minister in the Presidency, the Minister of Mineral Resources and Energy, the Minister of Public Enterprises, the Minister of Finance, the Minister of Forestry Fisheries and the Environment and the Minister of Trade Industry and Competition. Its short-term objective is to reduce the severity and frequency of load shedding through immediate measures to stabilize the energy system, with the long-term goal of ending load-shedding.

Other government departments (e.g. of Labour, of Trade Industry and Competition or of Water and Sanitation), governmental stakeholders (e.g. Competition Commission or National Nuclear Regulator) and public stakeholders are not mentioned here but are also able to influence the company's strategic decisions.

We recommend that the Eskom Board receive clear strategic guidance and political governance from a single point of responsibility, based on an aligned set of goals agreed by all the relevant governmental stakeholders mentioned above.

4.2 Maintenance Budgets Assessment

As part of the overall assessment of the operational performance of Eskom's coal fleet, the vgbe team reviewed all the maintenance, outage and Tecplan budgets from 2013 until 2027. The aim was to evaluate whether reasonable and appropriate budgets have been and will be made available, to allow proper maintenance in the power stations. As a basis, Generation Finance provided the budgets going back as far as 2013 and actual planning data from the 2022 generation business plan, for the period until 2027, for all the power stations. The provided data files have been finally aligned between Generation Finance and vgbe to find a correct base for the review with a high confidence level.[6]

[6] Source: Eskom file vgbe Maintenance Budgets Coal Fleet_2023-04-12_wo_Germany_updatedBS Rev 1.xls provided by Brian Stobbs on May 22nd, 2023.

The total maintenance costs used for this assessment consist of three parts:

1. Maintenance costs for day-to-day operation.
2. Outage costs.
3. Tecplan costs, which were combined with outage costs for the purpose of this assessment.

Large-scale projects (e.g. for refurbishing, replacement or upgrades, for example for flue gas desulphurization (FGD)) were not considered.

Despite the analysis of the quantitative development of the budgets, a qualitative benchmark of the relevant parameters, with a relevant population from the international generation market, was performed. The benchmarking parameters are normalised metrics that can be used for comparison with peer group data. Costs are typically normalised on a per MW and/or per MWh basis. vgbe has utilised operational data from internal sources, as well as from data available publicly, to develop an appropriate peer group incorporating comparable technologies and unit sizes:

- Technology: Pulverised coal plants of sub-critical to supercritical types.
- Regions: Germany, Europe, United States, South America, East-Asia.
- Unit size: 200−800 MW.
- Age: 10–50 years.
- Single and double units.
- Dust removal systems (ESP or bag-type) installed in all cases; $DeNO_x$ (removal of NO_x)/FGD included in many cases.

The benchmark analysis compares Eskom’s key metrics with the corresponding peer group metrics, adjusted for differences in currency: all costs have been converted to EUR using the yearly bank exchange rates as an annual average. Our data source is the World Bank.

For this qualitative benchmark, no further adjustments have been made for inflation, regional wage rates and productivity. Intentionally, the peer group has been setup on a very broad basis (e.g. including $DeNO_x$/FGD), to avoid theoretical cost adaptions on the raw data. Nevertheless, the trend of such potential adaptions of the data would lead to a significant reduction in the benchmark numbers and further underscore the main messages of our report.

The average values used in the following charts are shown with their standard deviation, calculated based on the deviations of the selected peer group and its bandwidth of units.

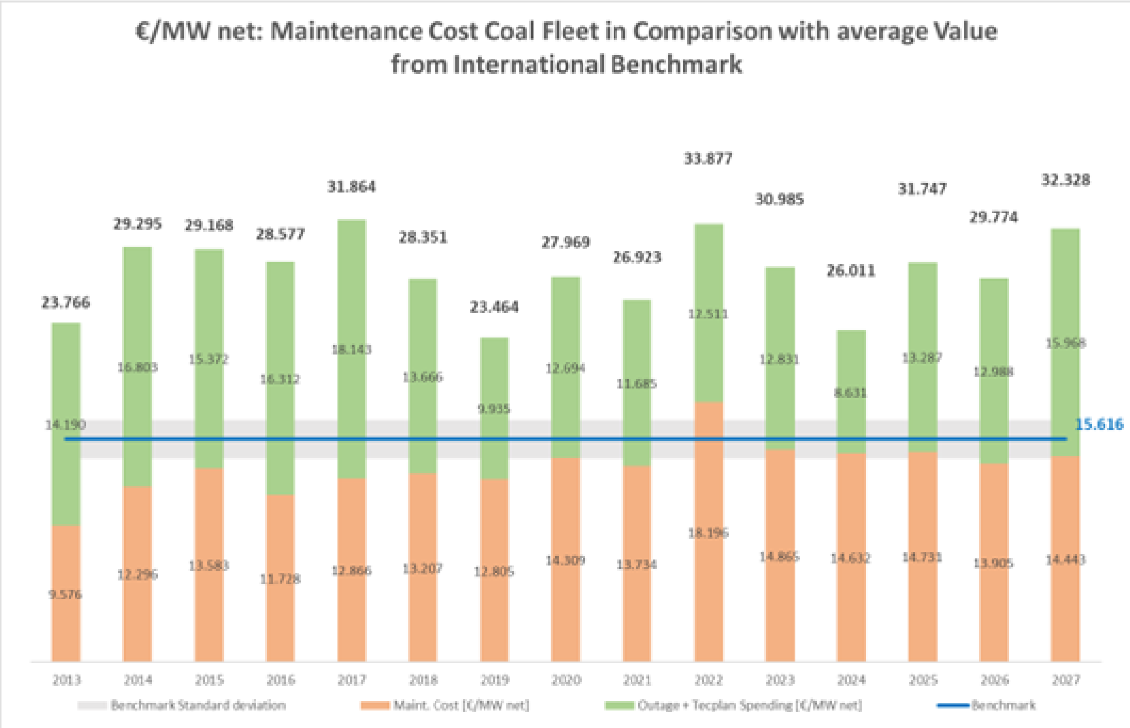


Figure 9: Specific total maintenance costs in EUR per MW net per annum

Figure 9 clearly shows that the total maintenance costs per MW net have been far above the international average in all years to date and will continue to be significantly above average in the coming years.

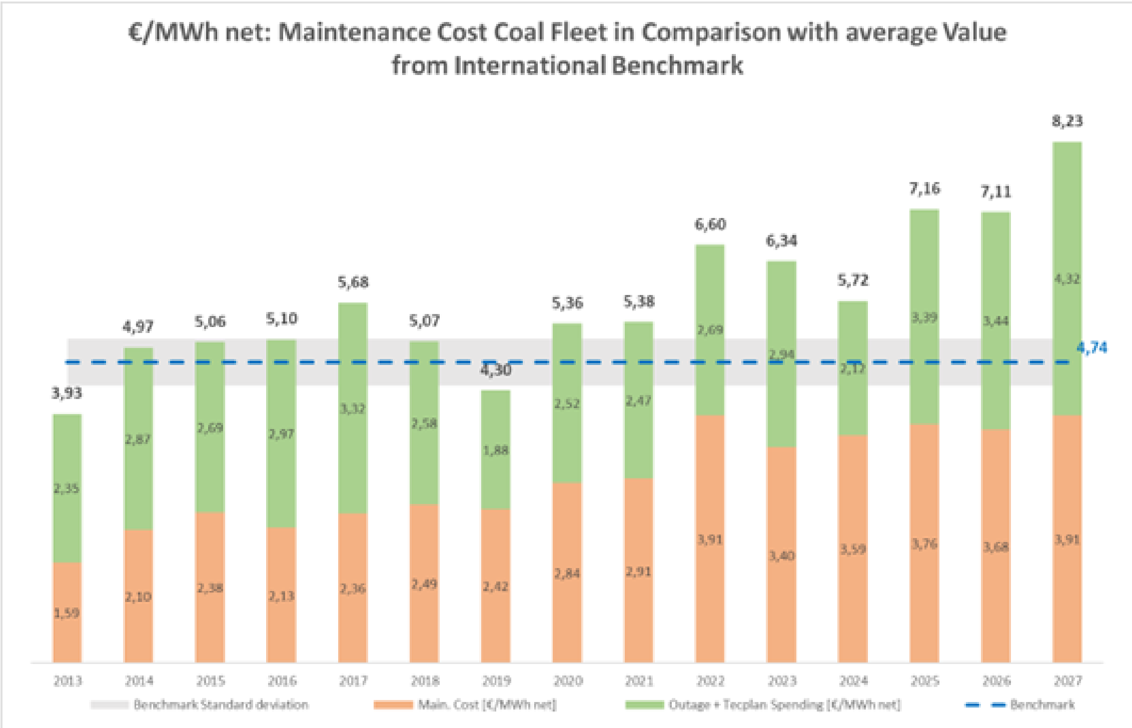


Figure 10: Specific total maintenance costs in EUR per MWh net

The specific maintenance costs per MWh net, see Figure 10, were in line with the international average in most years since 2013 but will be significantly above average in the coming years. It should be noted that an increasing EAF should reduce the specific costs.

Figure 11 shows a specific example, a comparison is made with a German coal unit (single unit, 700 MW class, supercritical, with $DeNO_x$ and FGD plant). Even compared with this unit, which has several cost-driving characteristics, Eskom's annual maintenance budgets are much higher.

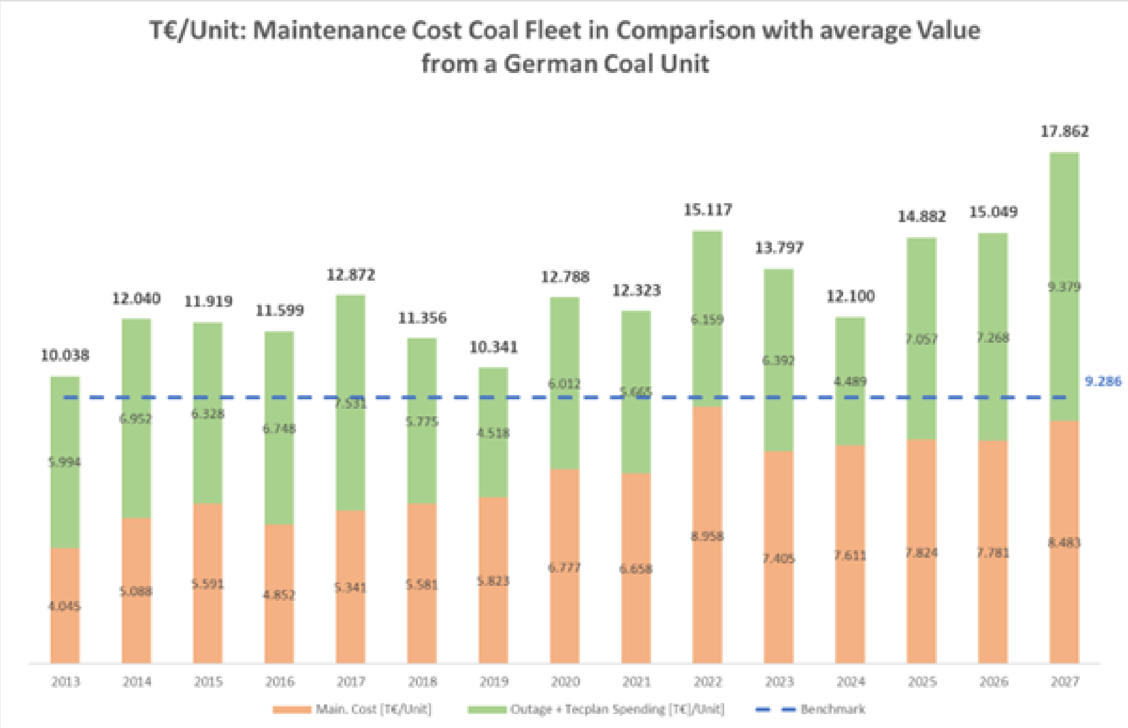


Figure 11: Total maintenance costs in EUR per unit per annum

<u>Summary</u>

The analysis shows that the specific maintenance costs budgeted by Eskom for its coal fleet between 2013 and 2027 are above or at least within the bandwidth given by international benchmark figures, taking into account the technology, size and age of the coal fleet. Compared to German figures, the Eskom budgets are significantly above the average in currency-adjusted terms, but the above-mentioned corrections on regional wage rates and productivity would need to be considered to calculate exact deviation figures. This, however, was not the purpose of the assessment. Hence, the money spent by Eskom should have been sufficient to execute proper maintenance and to keep the power plants in a good condition. Given that the maintenance budgets are above or, at the very least, within the internationally comparable range, it is necessary to understand why the status and performance of the coal fleet - especially in terms of energy availability – is significantly lower than the international benchmark. Although not within the scope of this assessment, the next step must include an evaluation of what caused the discrepancy between spending and results, in order to avoid the same development in the future:

1. Was the scope of the maintenance and outage work appropriate?
2. Was the planned maintenance and outage work executed in a proper way?
3. Were the internal costs for maintenance and outage work appropriate and did they correspond to international benchmarks?

4. Were the prices charged by third-party suppliers for the maintenance and outage measures appropriate and comparable to corresponding international benchmark prices?
5. Were proper governance, surveillance and quality assurance processes functional to enable high level spending?

Points 1 to 3 and point 5 refer to Eskom's internal organisation and processes and are largely covered by the recommendations given by the vgbe team in this report. Point 4 refers to the market situation – both in South Africa and internationally - for services in the energy sector and related industries and needs to be evaluated in a separate step.

4.3 Coal Purchase

Coal supply has a significant impact on the operational effectiveness of Eskom's coal-fired power stations and on a substantial share of the required maintenance efforts. Eskom's power plants are fired by domestic hard coal, which is abundantly available in South Africa. Some power plant sites are supplied directly from neighbouring coal mines via conveyor belts. Otherwise, deliveries are made by rail and/or truck. In the case of delivery by truck, in addition to the question of whether it makes economic and ecological sense, there is the issue that continuous quality control has not yet been optimally implemented by Eskom at all power plant locations. Information about coal delivery and the corresponding coal quality control can be found in the chapters addressing the individual power plant visits. There are two types of contracts for coal procurement:

- Cost-plus based contracts
- Price-based contracts

Cost-plus based contracts

Cost-plus contracts are contracts in which Eskom pays for all the operating costs of the mine, plus a return on the mine's capital expenditure. The initial mine capital is either paid in full by the mining company or shared between Eskom and the mining company. These mines are usually purely for Eskom's use, with all costs charged to Eskom's account. Eskom is consequently fully involved in the mine planning processes and uses its influence to optimise the operation of the mines for Eskom's benefit. The "cost plus" contract structure provides Eskom with the flexibility to search the market for cost-saving opportunities at short notice.

Eskom currently has cost-plus contracts for the Kriel, Matla, Kendal, Lethabo and Tutuka coal supply sites.

Negotiations on the cost-plus contracts focus on return on investment (ROI), which determines the mining company's profit. This ROI is determined in advance and, in the past, has been divided into two components - a fixed portion and a variable portion, based on actual production. Thus, the variable portion changes with production performance each month. An important point to note is that, due to the high fixed cost component, the unit cost of Eskom's coal is very sensitive to changes in production. If the supplier does not deliver the agreed/contracted tonnage, the ROI formula normally provides for a reduction in the variable return payable to the supplier. If the non-delivery was within management's control, Eskom would be entitled to "import" the shortfall, with the supplier responsible for the cost difference. However, it should be noted that the supplier has the right to "make up" the tonnage within the CSA at marginal cost. If agreement cannot be reached on whether the matter was "within management's control," an arbitrator is appointed, resulting in a significant delay between the direct costs Eskom must incur to rectify the shortfall and the supplier's eventual reimbursement.

The contract specifies a range for each quality component, e.g. calorific value, ash, moisture, size, attrition, volatile matter, ash fusion temperature. If the actual qualities fall outside this range, Eskom would levy a penalty or surcharge in accordance with the contract. The fact that lower quality coal can be used in the power plant, which may affect the power plant's performance and operating costs, is not a factor.

Price-based contracts

A predetermined but escalating/indexed price is paid for a predetermined quantity of coal. The mining risk lies with the mining company, so Eskom is not involved in the mine planning processes. However, Eskom reviews mining plans at a high level, to reduce the risk to the company. These mines are generally multi-product mines that sell a portion of their production to customers other than Eskom, making it very difficult to secure mining costs for coal produced for Eskom's consumption.

The supply contracts for Duvha, Matimba and Medupi are price-based contracts. The new contract for the Medupi power station will also be price-based.

There are a number of factors that influence the price charged by the mining company. The key determinants are market demand versus supply, the spot price, alternative investment opportunities and the risks that the supplier perceives the mining company to face. In the current environment, Eskom's bargaining power is limited due to very strong global and local demand and low supply. Unit costs are adjusted annually or monthly depending on the terms of the contract.

The required quantities are specified in the contract. The power plants' production requirements in excess of the quantities specified in the contract must be supplemented by coal from other sources. The supplier is given a reasonable period of time to make up the shortfall, usually between 6 and 9 months. If the supplier does not deliver the agreed shortfall within the prescribed period, Eskom may purchase the shortfall from another source and the supplier is responsible for the difference in cost to Eskom (delivery price of short-term coal versus contract price). However, Eskom must ensure that the short-term coal was purchased at a fair and reasonable price. It should be noted that the process usually results in a long delay between Eskom incurring the cost (Eskom often buys the shortfall immediately on the "spot market" due to production pressure) and the supplier being reimbursed for the cost.

The contract specifies a range for each quality component, e.g. calorific value, ash, moisture, size, abrasion, volatile matter, ash fusion temperature. If the actual qualities are outside this range, Eskom will levy a penalty or surcharge in accordance with the contract. This is not affected by the fact that lower quality coal may be used in the power plant, which may affect output and energy costs, nor does it prevent Eskom from finding an alternative source of suitable coal while the mine finds a solution to the problem.

If demand for high quality (export) coal is high, there is a risk that the mine will manage Eskom coal grades to the lower limit of the Eskom quality range, even accepting disadvantages that are more than offset by the high export price.

Recommendations

It is clear that the coal contracts are very complex and have a high monetary impact on Eskom's operating results, especially in terms of coal mine investments and penalties or mark-ups on quality requirements. Here, we propose the preparation of a report which, in summary, corresponds to a business report "Coal Procurement". This report should also be submitted annually to an independent auditor for review. Although all bookings are recorded in the SAP system, they are not yet checked coherently. In case of delivery by truck, in addition to the economic and ecological sense of such a delivery, the implementation of consistent quality control has not yet been implemented at all power plant locations at Eskom. However, the resulting monetary losses and the impact on power plant operations are known to all parties involved. There is a need for action here as quickly as possible.

5 Technical Assessment of the Power Plants

The main objective of the coal fleet investigation was to find out reasons for the low Energy Availability Factor (EAF) of the coal fleet – 50.83% as of April 2023 – and to develop measures to improve the situation. The EAF of Eskom's coal fleet is currently at about 51% whereas international benchmarks are in the range of 78%.

This international benchmark was derived from the KISSY (KraftwerksInformationSSYstem) data base of vgbe. This data base includes availability data and unavailability events of individual power plants and their components. KISSY enables the comparison of parameters of an individual plant with characteristic values of similar plants. The following figures show such a comparison in which the EAF, Energy Utilization as well as Unplanned Availability of Eskom plants as well as of European power plants are presented.

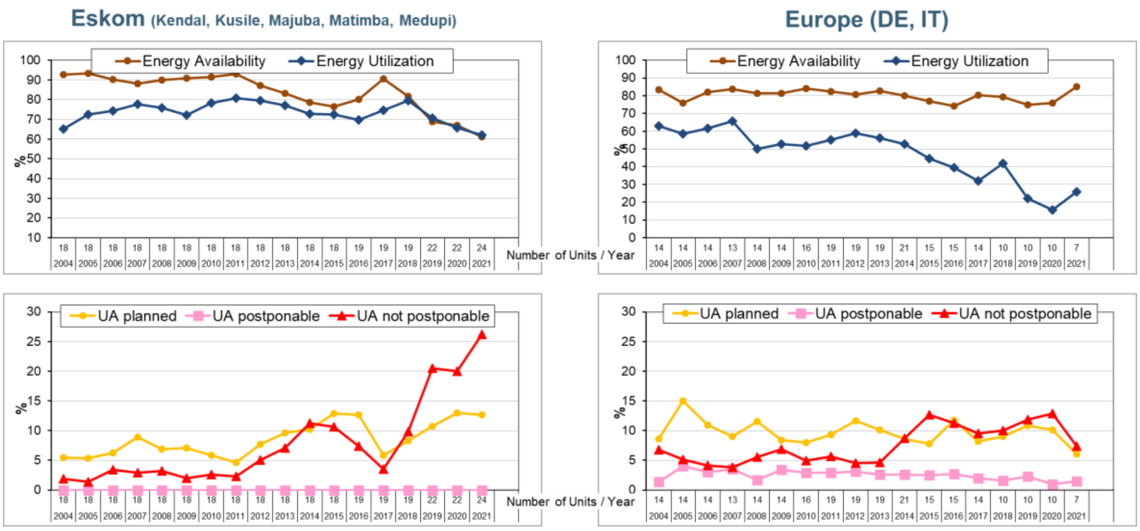


Figure 12: Comparison of EAF and UA of hard coal units (more than 600 MW)
Source: KISSY, vgbe

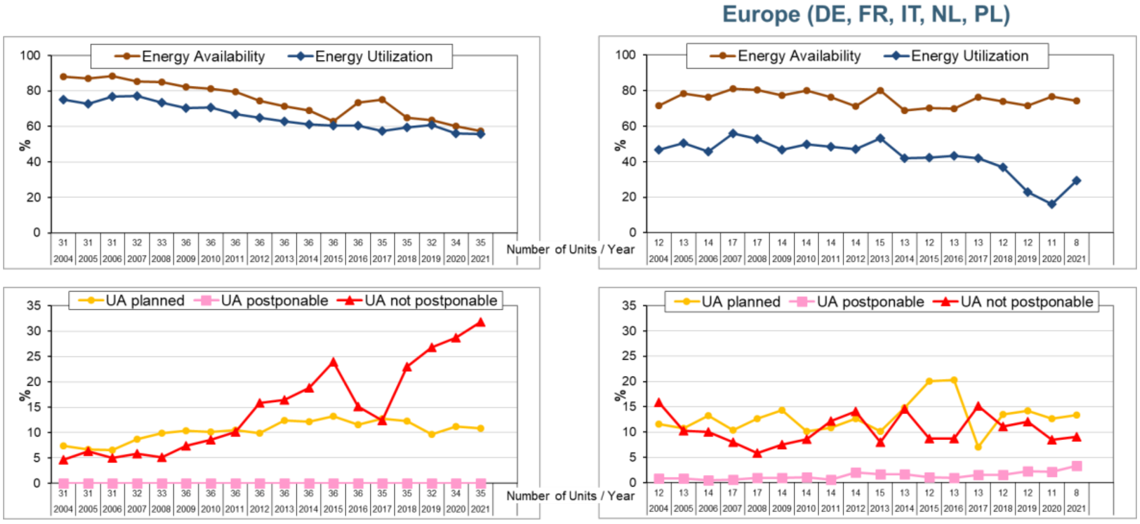


Figure 13: Comparison of EAF and UA of hard coal units (350 to 600 MW)
Source: KISSY, vgbe

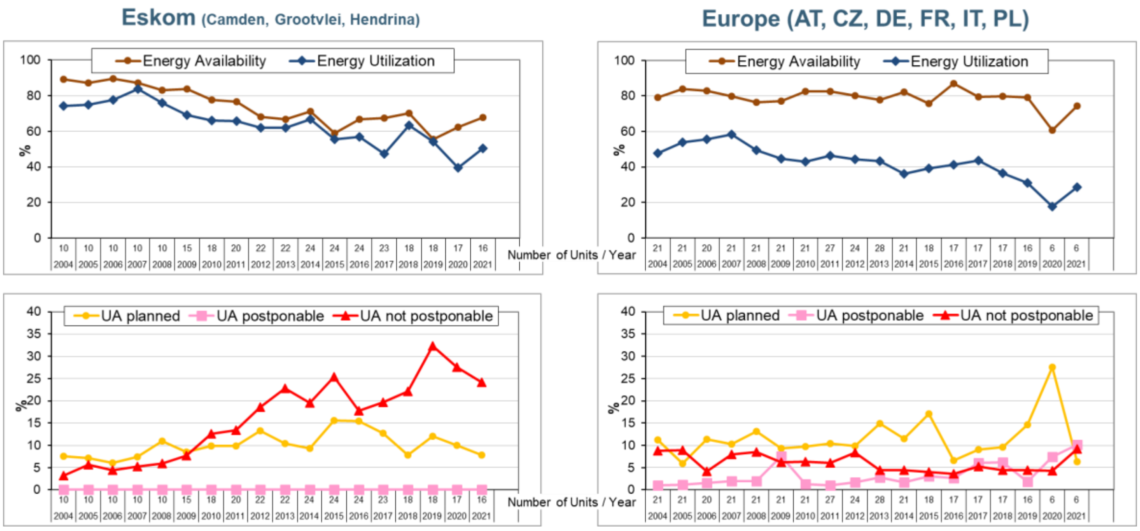


Figure 14: Comparison of EAF and UA of hard coal units (150 to 250 MW)
Source: KISSY, vgbe

The abbreviations are as follows: AT = Austria, CZ = Czech Republic, DE = Germany, FR = France, IT = Italy, NL = Netherlands, PL = Poland

5.1 Common Findings and Conclusions

Besides the analysis of the information provided by Eskom – as outlined in chapter 3.4 –, site visits formed a key input for the technical assessment of the individual power plants. The following table provides an overview of the visits conducted.

Power Plant/ Date	Partners	Persons	
Arnot 18–21 April	vgbe, KWS	Dr. Christian Ullrich (vgbe) Dr. Claudia Stockheim (vgbe) Dr. Claudia Weise (vgbe) Dr. Mark Newby (vgbe)	Sener Günes (vgbe) Bev Lawrence (KWS) Lonia Rashapuoa (KWS)
Camden 12–14 April	RWE, KWS	Axel S. Meschgbiz (RWE) Markus Burkhardt (RWE) Petros Terzis (RWE)	Tim Bettermann (RWE) Klaus Reichelt (RWE) Terence Richardson (KWS)
Duvha 30–31 March, 18 April	vgbe, KWS	Dr. Mark Newby (vgbe) Sener Günes (vgbe) Dr. Claudia Stockheim (vgbe) Dr. Oliver Then (vgbe) Dr. Christian Ullrich (vgbe)	Dr. Claudia Weise (vgbe) Jörg Schulte-Trux (KWS) Malcolm Fawkes (KWS) Pieter Janse van Rensburg (Dornier)
Grootvlei 26–27 April	vgbe, KWS	Dr. Mark Newby (vgbe) Sener Günes (vgbe) Dr. Claudia Stockheim (vgbe) Dr. Oliver Then (vgbe) Dr. Christian Ullrich (vgbe)	Dr. Claudia Weise (vgbe) Terence Richardson (KWS) Lonia Rashapuoa (KWS) Pieter Janse van Rensburg (Dornier)
Hendrina 17–19 April	Dornier, KWS	Zajda Bartosz (Dornier) Vladan Dokic (Dornier) Pieter Janse van Rensburg (Dornier)	Klaus Bransch (Dornier) Gladman Mkwai (KWS) Bev Lawrence (KWS)
Kendal 25–28 April	Dornier, KWS	Zajda Bartosz (Dornier) Vladan Dokic (Dornier) Pieter Janse van Rensburg (Dornier)	Klaus Bransch (Dornier) Bev Lawrence (KWS) Lonia Rashapuoa (KWS)
Kriel 24-25 April	vgbe, KWS	Dr. Mark Newby (vgbe) Sener Günes (vgbe) Dr. Claudia Stockheim (vgbe) Dr. Oliver Then (vgbe)	Dr. Christian Ullrich (vgbe) Dr. Claudia Weise (vgbe) Carl Haupt (KWS)
Kusile 2–5 May	STEAG, KWS	Jagdish K. Bhardwaj (STEAG) Naveen Kumar Gupta (STEAG) Lalatendu Pattanayak (STEAG)	Werner Renk (STEAG) Shivendra K. Shina (STEAG) Bev Lawrence (KWS)

Power Plant/ Date	Partners	Persons	
Lethabo 2–5 May 2023	Dornier, KWS	Zajda Bartosz (Dornier) Vladan Dokic (Dornier) Pieter Janse van Rensburg (Dornier)	Klaus Bransch (Dornier) Lonia Rahapuoa (KWS) Carl Haupt (KWS)
Majuba 20–24 April	RWE, KWS	Axel S. Meschgbiz (RWE) Markus Burkhardt (RWE) Petros Terzis (RWE) Tim Bettermann (RWE)	Klaus Reichelt (RWE) Terence Richardson (KWS) Gladman Mkwai (KWS)
Matimba 24–28 April	STEAG, KWS	Jagdish K. Bhardwaj (STEAG) Naveen Kumar Gupta (STEAG) Lalatendu Pattanayak (STEAG)	Werner Renk (STEAG) Shivendra K. Shina (STEAG) Dietmar Breuer (STEAG) Gladman Mkwai (KWS)
Matla 20–24 April	Dornier, KWS	Zajda Bartosz (Dornier) Vladan Dokic (Dornier) Pieter Janse van Rensburg (Dornier)	Klaus Bransch (Dornier) Malcolm Fawkes (KWS) Carl Haupt (KWS)
Medupi 17–21 April	STEAG, KWS	Jagdish K. Bhardwaj (STEAG) Naveen Kumar Gupta (STEAG) Lalatendu Pattanayak (STEAG) Werner Renk (STEAG)	Shivendra K. Shina (STEAG) Dietmar Breuer (STEAG) Malcolm Fawkes (KWS) Carl Haupt (KWS)
Tutuka 17–19 April	RWE, KWS	Axel S. Meschgbiz (RWE) Markus Burkhardt (RWE) Petros Terzis (RWE)	Tim Bettermann (RWE) Klaus Reichelt (RWE) Terence Richardson (KWS)

Table 3: Overview of the power plant site visits

The vgbe team has compiled specific reports for each power plant – they follow from chapter 5.3 onwards. However, there are some common findings and conclusions that are outlined in this chapter that is structured according to main fields of action.

5.1.1 Power Plant Management

The main root cause for the low EAF is the dysfunctional management system of Eskom. It is characterised by inefficient processes – especially in procurement –, a lack of authority and an opaque decision-making structure. The **plant management, with its limited authority** and high level of interference from the headquarter is unable to focus its attention on its primary responsibility: reliable plant O&M. Currently, even a mediocre level of performance (e.g. EAF) is accepted as sufficient.

In O&M management, many deficits were identified. The quality of operations has suffered from a lack of ownership and leadership, as well as a lack of training and high staff turnover. The planning and execution of maintenance work need to be more stringent, more goal-oriented and more carefully executed.

Furthermore, the complete outsourcing of maintenance – with few exceptions – has contributed to low plant reliability. The contractors' personnel are unfamiliar with plant requirements, and this results in a long reaction time and high administrative interface efforts.

In particular, the **complicated procurement policy and processes** proved to be a bottleneck in supporting the plants with timely provision of spare parts and qualified services by third parties. In addition to its impact on plant performance, the procurement process is also a significant contributor to high service and supply costs.

A typical power plant organisation chart is shown in the following figure.

Figure 15: Example for a plant organisational chart (Arnot)

The core functions of the power plant – operation, maintenance, and outages – are assigned to separate departments. These departments are on the same hierarchy as many other functions. The vgbe team believes that the exceptional role of these functions should be reflected by the **organizational structure**; other functions than O&M should be sub-ordinate. Moreover, maintenance, outages and spare parts management should be assigned to one organisational unit.

5.1.1.1 Maintenance and Outage Procedures

To track and to control the progress of maintenance and outage work Eskom has establish a comprehensive set of KPI which are accumulated in **Maintenance Performance Index (MPI)** and **Outage Readiness Index (ORI)**.

The following table shows the factors that are considered in the calculation of the MPI (KPA stands for Key Performance Area).

KPA	KPI	Short Description
Cost	Real cost rate year-on-year (OPEX)	Cost spend on maintenance comparing previous year to current year to achieve savings
	Maintenance OPEX variance (actual / plan)	Actual money spent compared to the set budget
People	Resource utilisation	Hours worked by employees based on the confirmed hours against maintenance work order on SAP
Maintenance work	Preventive maintenance template tasks implemented (Maintenance strategies and manage work progress)	Maintenance strategy implementation
	Preventive maintenance compliance	Execution on preventive maintenance according to set strategies
	Schedule compliance	Execution of the set schedule for the week
	Scope stability (how much scope changes between T-4 and T-1)	Change of scope locked four weeks prior execution week
	Emergent work (work added during the execution week)	Additional work that was not part of the locked schedule
	Notification response compliance	How soon are P1 and P2 notifications attended
	Online corrective backlog growth rate quarter-on-quarter	Growth of defect list on SAP comparing the previous quarter with the current quarter
	Online corrective backlog in number of weeks of work	How long will it take to complete existing defect list in number of weeks
	Outage slip	
	Statutory order violations	Was statutory done according to planned date
	Recurring work	Same plant that is reported to be defective repetitively, AKZ code is used to measure this
	Work sampled for completeness	Selected work orders on the schedule to be quality controlled by line manager
Support	Critical spares availability	spares of high importance to be used on the critical plant
	Strategic spares availability	spares that have a long lead time and critical
	Operational spares availability	normal stock

Table 4: Components of the MPI calculation
Source: Eskom

The next figure reflects an application of the MPI at the Duvha power plant.

Eskom	Duvha Maintenance Indices															February 2023 rev 0 p1 of 1
Duvha Maintenance Indices																
KPA Weight			Performance Indicators			KPI Weight		Performance Target					Results			
KPA	MHI	MPI				MHI	MPI	Floor	Kick-In	Norm	Stretch	Ceiling	Actual	MHI	MPI	
Cost	12%	24%	C01	Real Cost Rate Year-on-Year (OPEX)	YTD	4%	8%	-41%	-42%	-43%	-44%	-45%	-14%	1.00	1.00	
			C04	Maintenance Opex Variance (Actual / Plan)	YTD	4%	8%	110%	105%	100%	98%	95%	161%	1.00	1.00	
People	5%	10%	P01	Resource Utilisation	QTD	1%	1%	20%	40%	50%	60%	69%	16%	1.00	1.00	
			P05	LTIR (LTIFR)	YTD	3%	0%	0.34	0.32	0.3	0.2	0.00	0.24	3.60		
Maintenance Work	23%	46%	W01	PM Template Tasks Implemented (MSMW Progress)	ITD	4%	8%	90%	92%	95%	98%	100%	95%	3.13	3.13	
			W02	PM Compliance	QTD	2%	4%	90%	92%	95%	98%	100%	95%	3.05	3.05	
			W03	Schedule Compliance	QTD	2%	3%	90%	92%	95%	98%	100%	96%	3.22	3.22	
			W04	Scope Stability (how much scope changes between T-4 and T-1)	QTD	2%	3%	20%	15%	10%	5%	0%	6%	3.84	3.84	
			W05	Emergent Work (work added during the execution week)	QTD	2%	3%	30%	27%	25%	21%	17%	37%	1.00	1.00	
			W06	Notification Response Compliance	QTD	1%	2%	80%	85%	90%	95%	100%	97%	4.32	4.32	
			W07	Online Corrective Backlog Growth Rate Quarter-on-Quarter	QoQ	0%	1%	10%	5%	0%	-5%	-10%	12%	1.00	1.00	
			W08	Online Corrective Backlog in number of weeks of work	QTD	0%	1%	6	5	4	3	2	7.5	1.00	1.00	
			W09	Outage Slip	YTD	3%	6%	9%	8%	7.5%	7%	6%	39%	1.00	1.00	
			W10	Statutory Order Violations	QTD	3%	6%	1.00	0.75	0.50	0.25	0.00	0.44	3.22	3.22	
			W13	Recurring Work	QTD	1%	3%	80%	70%	60%	50%	40%	46%	4.37	4.37	
			W14	Work Sampled for Completeness	QTD	1%	3%	80%	85%	90%	95%	100%	96%	4.19	4.19	
Plant	50%	0%	T01	EAF	YTD	20%	0%	63%	64%	65%	65%	66%	40%	1.00		
			T02	UAGS	YTD	10%	0%	44	40	36	32	28	61	1.00		
Support	10%	20%	S01	Critical Spares Availability	YTD	7%	14%	80%	85%	90%	95%	100%	76%	1.00	1.00	
			S02	Strategic Spares Availability	YTD	1%	2%	90%	92%	94%	98%	100%	70%	1.00	1.00	
			S03	Operational Spares Availability	YTD	2%	4%	80%	85%	90%	95%	100%	87%	2.31	2.31	
														1.68	2.07	

Figure 16: Maintenance Performance Indices (Duvha)

As already described in chapter 4.1.2 the vgbe teams considers this MPI as too complex and inefficient. Especially in the view of the fact that in many plants the plant condition was not reflected by the MPI – the KPI implied a much better situation than it was in reality.

The plant outages follow a common philosophy that is shown in the next figure.

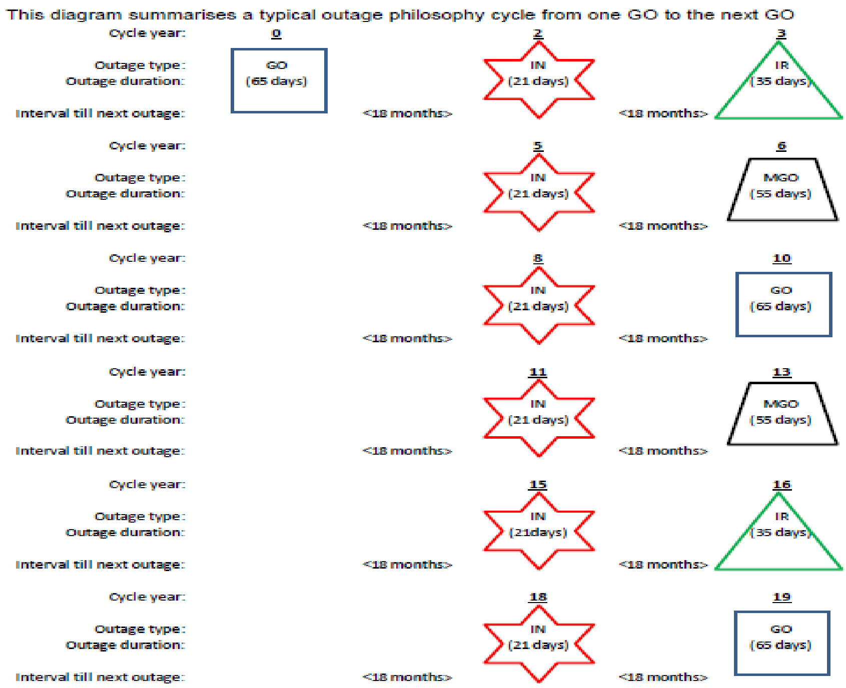


Figure 17: Eskom's outage philosophy

MGO = Major General Overhaul, GO = General Overhaul, IN = Inspection Outage, IR = Interim Repairs

With respect to the planning the following process is followed.

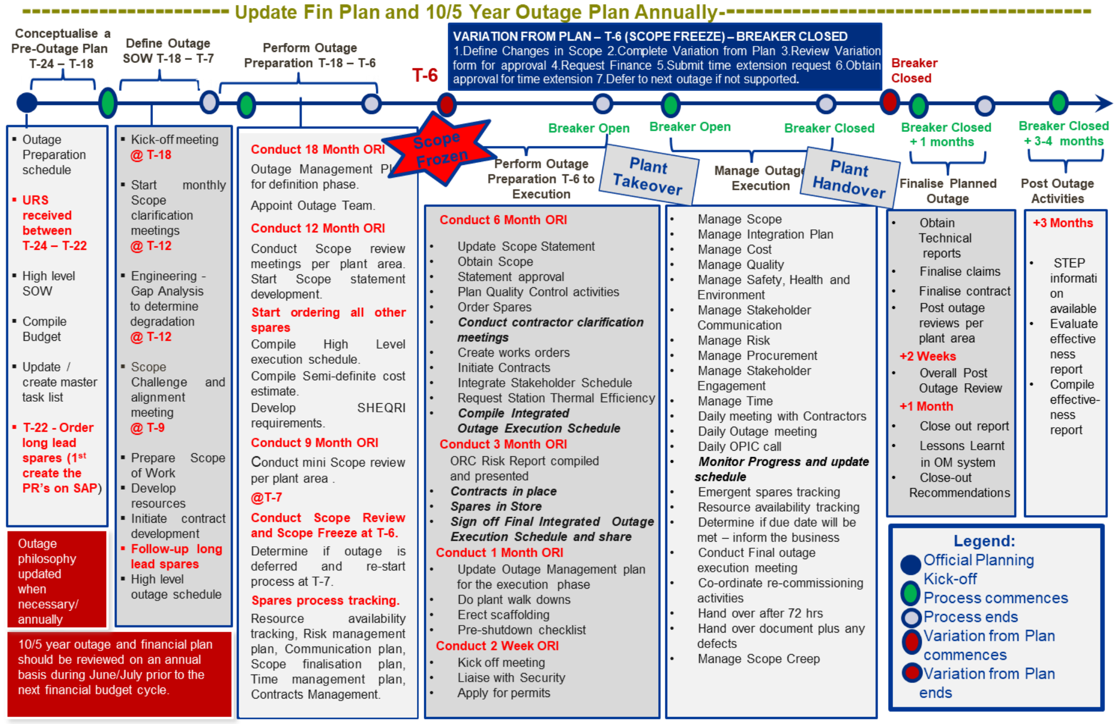


Figure 18: Eskom's outage process

The funds are allocated according to the defined philosophy scope. A request for extra funding needs to follow a Scope-of-Work-variation process. Many sites reported that this process is time-consuming and inefficient.

The ORI is a KPI that was developed to track the progress of outage planning. It uses a readiness percentage measurement that starts 24 months before the outage. The vgbe team considers this indicator also as too complicated. Instead of increasing from 0% to 100% as the readiness increases, the indicator fluctuates significantly up and down at different audit stages as the criteria for the evaluation vary – 20% fluctuation was observed during site visits. This is not logical and does not provide a clear information about the true planning status.

5.1.1.2 Incentive Schemes

Staff morale is a problem in the organisation. Observations during the site visits highlighted the variation in motivation levels amongst staff, with a number still being very committed, but a significant number lacking motivation. This does not lead to good teamwork and is evidenced by the variation in maintenance and housekeeping standards.

Incentives and recognition for committed work are key for enhancing the performance of the organisation. Observations from the site visits included:

- Staff have not been receiving any recognition for good performance, at least for the last four years.

- HR plan states that they want to achieve a high-performance culture, but this appears to be largely unsuccessful.
- There is a high turnover of staff at power stations due to the remote and difficult working conditions. Previously there were incentives in place to attract and retain site staff. This needs to be looked at urgently.
- As a result of the continuous crisis mode, many employees are frustrated and demotivated. In many areas, a working atmosphere characterised by indifference, ignorance and blame-shifting has been fostered. Salaries have not been increased for several years and there is no system in which good performance is rewarded.

To lift spirits, the Eskom performance culture needs to change. The vgbe team recommends implementing an incentive scheme for good performance on both an individual and institutional level. For example, power plants should receive a bonus if they are able to reduce their losses by a defined percentage rate. Another incentive could be to provide accommodation for Eskom staff – e.g. free of charge – near the power plant. In some cases, there are accommodation buildings close to the power stations, owned by Eskom, but staff cannot access them.

5.1.1.3 Spare Parts Management

As already mentioned, the procurement process is one of the key bottlenecks for the outage and maintenance management. This is especially relevant for the spare parts management. An example for this situation is the generator at Medupi Unit 4. It is very strange that the procurement of the generator has taken so long – even two years after the incident the process is not yet finalised. It is also completely incomprehensible why an alternative was not sought and, for example, the currently redundant generator from Kusile or a used generator from another power plant were not taken into consideration.

At some of the plants, there is a mismatch between listed and existing spare part items. This issue can be resolved by conducting regular inventories. Moreover, the quality of the spare part management needs to be improved at some sites. In many cases, spare parts are not being properly protected from dust and dirt. These conditions pose a serious threat to quality and can result in unusable equipment. Affected parts need to be cleaned or possibly even replaced immediately. This quality check should be an integral part of the spare parts inventory.

5.1.2 Partial Load Losses

The PLL are a key driver for the deterioration of the EAF. As of March 2023, the **PLL accounts for 6 057 MW**. Many of the PLL reduction measures mentioned below can be implemented during a plant outage, standstill or even during regular operation. These outages and standstills often occur randomly due to unit trips. This means that the maintenance teams in the various power plants should be prepared and flexible to perform maintenance work at any given opportunity.

5.1.2.1 Analysis of the PLL Data

Eskom was requested to supply EAF and PLL data for the coal fired fleet for the financial years 2010 to 2023. The financial year runs from 1 April to 31 March. This data was initially supplied as an average for the whole fleet. Subsequently EAF and PLL data has also been supplied for each coal fired power station for the financial years 2010 to 2023. The data supplied in May 2023[7,8] varies slightly from the data supplied by Eskom initially and quoted in the different power station reports. This was due to the conclusion of FY data at the end of March 2023.

The analysis considers the correlation between EAF and PLL, with plots shown for the whole fleet and each power station. The losses due to PLL present an opportunity for recovery of some power in the short and medium term. It was observed during the site visits that outage scopes are not completed sufficiently for a unit to return at full load. As a result, the PLL conditions have not improved after maintenance.

The correlation between reduction in EAF and increase in PLL is clearly illustrated in Figure 19 below. The increase in PLL since 2018 has been steadily getting worse.

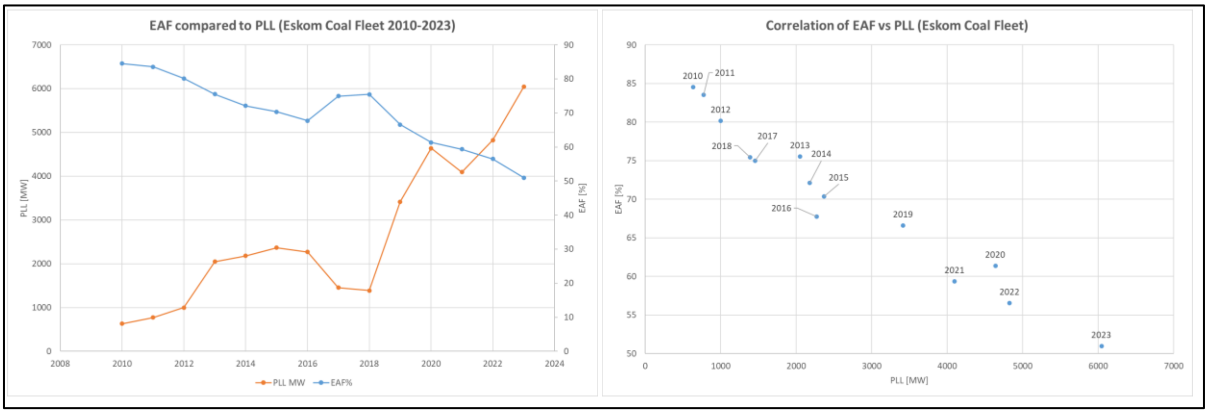


Figure 19: Plots of EAF and PLL data for the coal fleet (FY2009/2010–FY2022/2023) [7]

The data for each power station was then verified and plotted. This trend in EAF reduction is reflected at most of the power stations with a few exceptions such as Lethabo and Matimba, as shown in Figure 20. An industry average was derived from the vgbe database for European power stations as a comparison and is included in Figure 20.

The data used for the plots is shown in Table 5. There is a strong potential for improving these PLL losses if systematic maintenance is implemented.

[7] Eskom supplied data, email from Lebohang Kubayi, 15 May 2023

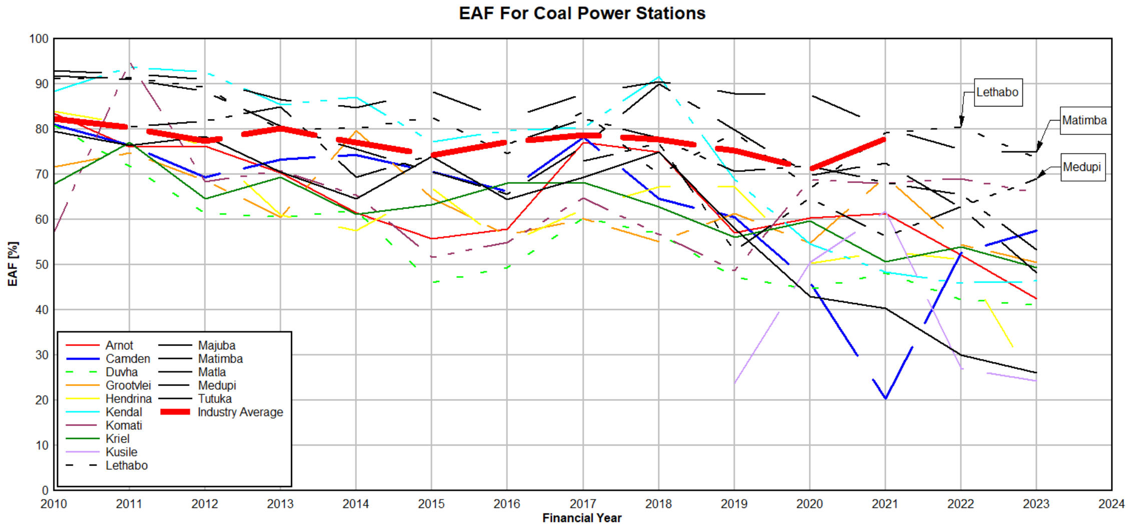


Figure 20: Plots of EAF data for each power station (FY2009/2010–FY2022/2023) [8]

	Power Station EAF [%]															
Financial Year	Arnot	Camden	Duvha	Grootvlei	Hendrina	Kendal	Komati	Kriel	Kusile	Lethabo	Majuba	Matimba	Matla	Medupi	Tutuka	Industry Average
2010	83.48	81.03	80.90	71.57	83.86	88.28	57.17	67.91		91.09	91.75	92.87	82.65		79.47	82.36
2011	76.10	76.42	71.76	74.72	81.18	93.82	94.84	77.09		91.29	91.06	92.25	80.41		76.44	80.37
2012	76.19	69.42	61.44	68.75	76.15	92.60	68.36	64.64		89.19	88.44	90.92	81.85		78.42	77.34
2013	70.37	73.22	60.48	60.52	61.04	85.35	70.87	69.28		79.88	80.61	86.57	84.97		70.57	80.14
2014	61.46	74.19	62.00	79.70	57.55	87.11	65.46	61.11		80.19	75.62	84.76	69.39		64.51	77.09
2015	55.81	70.65	46.09	64.79	66.88	77.27	51.68	63.34		82.58	70.65	88.44	74.26		74.01	74.30
2016	57.87	66.28	49.41	56.51	54.51	79.63	54.88	68.08		74.67	65.59	82.13	76.72		64.44	77.14
2017	77.06	78.17	60.28	60.17	62.33	80.39	64.83	68.24		83.92	76.31	87.89	82.24	72.95	69.28	78.67
2018	74.85	64.51	56.81	55.02	67.26	91.71	56.80	62.75		69.79	89.98	90.47	78.05	76.90	74.99	77.64
2019	57.05	60.43	47.18	61.38	67.15	68.79	48.67	56.13	23.72	79.37	79.84	87.89	70.60	53.15	57.98	75.20
2020	60.33	46.11	44.61	54.82	50.32	54.61	68.70	59.66	50.44	66.85	69.80	87.48	71.78	64.70	43.01	71.19
2021	61.23	20.36	48.26	69.45	53.02	48.30	68.00	50.60	61.86	79.10	72.41	80.25	68.24	56.21	40.40	77.88
2022	52.21	52.61	42.30	54.36	51.11	45.96	69.00	53.93	27.05	80.50	62.69	75.48	65.65	62.76	30.06	
2023	42.44	57.49	41.05	50.46	22.95	46.40	65.95	49.39	24.31	73.68	48.16	74.97	53.33	69.01	26.05	

Table 5: EAF data per power station[8]

The PLL data per power station from 2010 to 2023 was supplied by Eskom. Table 6 shows the data for each financial year.

[8] Eskom supplied data, email Lebogang Kubayi, 9 May 2023 and 25 May 2023

Power Station PLL MW]															
Financial Year	Arnot	Camden	Duvha	Grootvlei	Hendrina	Kendal	Komati	Kriel	Kusile	Lethabo	Majuba	Matimba	Matla	Medupi	Tutuka
2010	112	27	120	4	12	22	0	110		8	11	6	60		139
2011	150	36	197	13	55	19	1	166		11	19	10	46		50
2012	211	89	190	18	74	42	1	183		21	52	14	60		44
2013	297	61	356	32	186	153	3	372		148	104	45	77		215
2014	269	73	517	67	115	143	42	332		119	290	49	64		100
2015	366	78	340	151	135	128	89	219		152	379	38	116		173
2016	293	106	299	104	122	164	33	288		141	252	40	33		395
2017	224	75	174	92	102	79	37	248		55	204	27	18	4	116
2018	252	103	193	26	121	106	22	264		34	43	23	21	33	147
2019	654	208	326	37	124	537	48	268	49	50	308	26	96	262	419
2020	484	222	433	43	84	630	31	400	207	136	400	108	364	479	612
2021	433	51	439	64	96	545	3	287	87	130	355	106	318	503	671
2022	490	167	395	56	95	720	4	485	138	122	523	347	369	374	540
2023	458	236	530	78	91	1077	4	546	279	218	938	422	408	231	524

Table 6: PLL data per power station (FY2009/2010–FY2022/2023) [8]

The plot of the PLL data is shown in Figure 21. The increase in PLL since 2018 is again apparent.

The power stations with the highest potential for gaining power availability by reducing PLL, more than 400MW per station, are labelled and indicate the areas where the most power can be gained by reducing PLL. Kendal and Majuba power stations have the highest PLL data and should be targeted urgently.

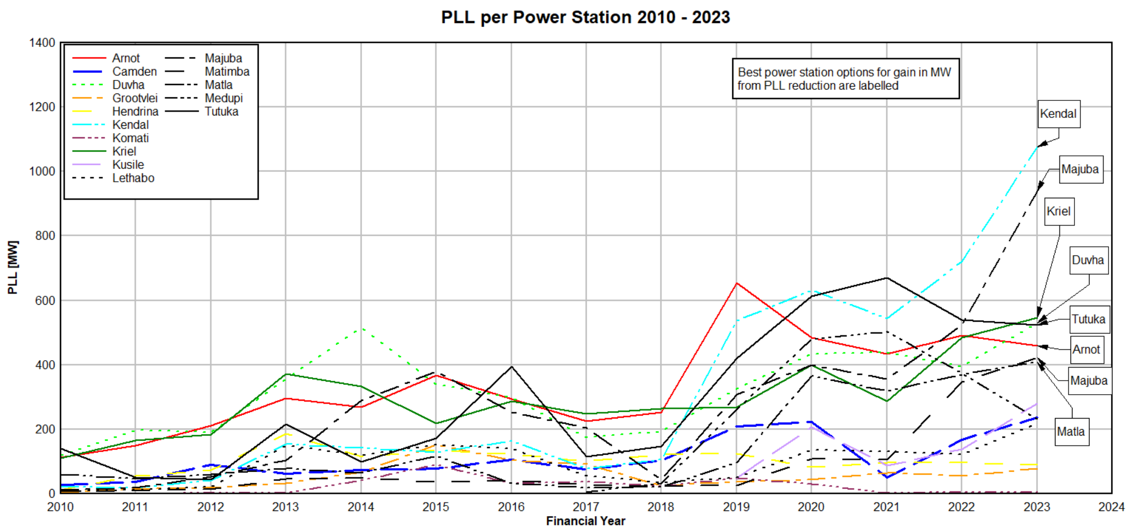


Figure 21: PLL data per power station in MW

5.1.2.2 Overview of PLL Reduction Measures

Many of the PLL reduction measures mentioned below can be implemented during a plant outage, standstill or even during regular operation. These outages and standstills often occur randomly due to unit trips. This means that the maintenance teams in the various power plants should be prepared and flexible to perform maintenance work at any given opportunity. The following power plant reports (from chapter 5.3 onwards) include more details on the specific measures.

Spray Water Valves: Leaky spray water valves contribute significantly to PLL, as these leakages result in operating conditions with reduced steam temperatures. Spray valves are used to control the steam temperature by injecting water but, if they are leaking or just completely open, this causes a tremendous decrease in the efficiency of the effected unit. If the steam temperature drops too much, this will cause a turbine trip and can also damage the turbine. Replacing the valve only takes a few days or, at most, a week. As such, it could be carried out during unplanned standstills. In some cases, an overhaul of the valves might be sufficient. We strongly recommend immediately checking the availability of the valves at Eskom and procuring a sufficient number of valves as soon as possible.

The PLL reduction potential is site-specific **– up to 20 MW per unit,** depending on the steam temperature difference between design and operation condition. The total contribution to load losses is assumed to be **300 MW**.

Significant leakages were identified at Arnot, Duvha, Medupi, Matimba and Kriel.

To fix this problem, the plants have to be on short outage, e.g. weekend.

Leakages: In most of the plants, there are many air, water or steam leakages at fans, pumps, valves, or pipes. If fixing these leakages does not require a longer shut-down of the unit, they should be fixed right away – if possible, during operation or during unplanned standstills. A very effective measure to increase the performance of the power plant is to seal the air preheaters and the air ducts on the individual units. This brings the air requirement back into the design range of the boiler and thus the FD and ID fan come back into their operational range and can be controlled. These measures will also have a positive effect on the operation of the dust separation systems. These measures can be implemented relatively quickly and with not so high effort.

We recommend creating a leakage register to help monitor the progress of repair work. The motto should be, “Every leak, no matter how small, is one leak too many”. During the site visits, we found leaks in safety valves, bypass valves, feedwater pumps and demineralised water pumps, among others.

Leakages at safety and bypass valves need special attention as there are safety concerns arising from this disfunction. Checking whether the valves are intact and fixing leakages should be a priority and can be carried out during unplanned standstills. Based on the current overall status and lifetime of the equipment, in many cases a replacement of leaking/passing valves is recommended.

The leakages significantly contribute to PLL at the boiler and feed water with a total contribution of **741 MW** capacity losses. According to Eskom's data these areas contribute most at[9]:

- Tutuka: up to 204 MW
- Duvha: up to 179 MW (however, a significant load loss is due to hp heater issues not related to leakages)
- Matimba: up to 96 MW
- Kriel: up to 120 MW
- Matla: up to 44 MW
- Majuba: up to 38 MW
- Arnot: up to 34 MW
- Kusile: up to 26 MW

The work to fix the problems can partially be done during operation of the units. For most of the repairs the units have to be on an outage; a short outage is often sufficient.

Mills: Unreliable mills cause problems, respectively PLL, in many plants. Usually, the plant is designed in such a way that there is one spare mill per unit at full load (redundant design, 5 out of 6 mills for full load). Maintenance on this spare mill could be carried out during operation, e.g. by fixing the gear box and reinforcing the foundation. We recommend the creation of a dedicated team of qualified persons to carry out this work. Furthermore, the shortage of OEM spare parts should be addressed right away.

The mills contribute significantly to the PLL at the following plants – the MW figures refer to Eskom's data and total up to **960 MW** capacity losses:

- Majuba: up to 503 MW (large portion has been already recovered)
- Kendal: up to 115 MW
- Matla: up to 91 MW
- Tutuka: up to 87 MW
- Duvha: up to 45 MW
- Kriel: up to 42 MW
- Matimba: up to 39 MW
- Arnot: up to 38 MW

[9] The Kendal team reported about a PLL of 300 MW due to a HP steam leak which could be fixed during a 90 days outage. This is not reflected by the overall Eskom PLL data.

This work can partly be done in parallel to service. However, it should be noted that the recovery of these MW needs a systematic maintenance approach – the full potential cannot be unleashed during the winter period.

5.1.2.3 Advantages of a Systematic PLL Reduction

A simulation of the existing situation of incomplete repair compared to systematic and complete repair was performed on a 6 x 500 MW power station. Load and outage data were estimated using averaged EAF data from Kriel power station for the last three years. This simulation shows the potential for improvement.

A set of data was generated for 16 months to simulate the time required to reduce the PLL losses. Random outages were assumed to total 15 months and systematic outages were initially set to 3 months per unit, followed by 1 month, totalling 21 months for the period.

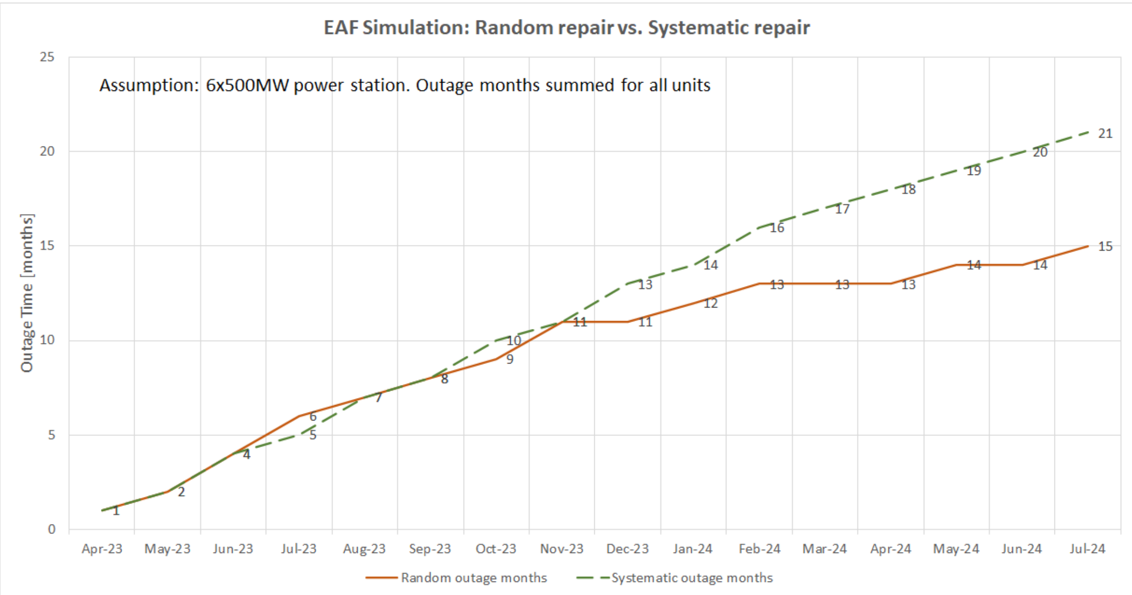


Figure 22: EAF simulation – outage time comparison

Figure 22 shows that the outage time remains the same for the two conditions until November 2023, after which more time is spent on systematic maintenance.

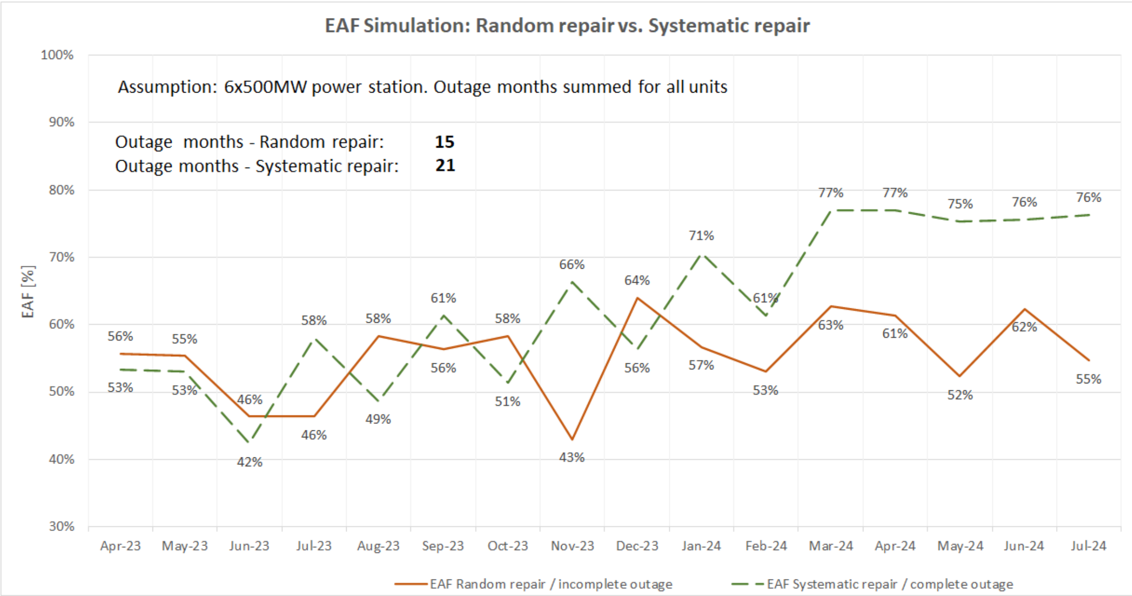


Figure 23: EAF simulation – EAF comparison

The plot shows the difference between continuing with the current scenario and the philosophy of completing outage scope to return the units to full operation. There is an improvement in EAF after ten months followed by a sustained improvement after a further three months.

5.1.3 Capacity Constraints

There is a high risk of losing additional generating capacity because individual plant components are at high risk of failure due to maintenance or operation gaps. One example is the water treatment plant in Matimba, which is a single plant serving the six units of Matimba and Medupi. The plant requires urgent maintenance and upgrading to prevent catastrophic failure.

Among other high-risk areas are the ash filter and ash handling plants in Matimba and Kusile. The required maintenance and operation care are lacking with high risk of additional load losses.

The Kusile power plant is expected to become a main contributor to power generation capacity short-term by starting Unit 5 within the next months and the units 1 to 3 after the completion of the temporary chimney construction. During our site visits we learned that the achievable capacity is limited due to the incomplete coal handling system and the ash discharge situation. These restrictions result in a very high risk that the Kusile site cannot be operated with more than three units at the same time. Hence, immediate and urgent actions are required to allow full generation capacity contribution of the plant.

The water treatment plant at Kendal is in a very poor condition and needs urgent maintenance and refurbishment. If the existing plant fails, six units – 3 840 MW – would be off the grid. A temporary unit is urgently required to enable this refurbishment work.

5.1.4 Other Overarching Topics

There are several topics that are important and relevant for either some or all power plants. These topics are outlined in this chapter.

5.1.4.1 Coal Quality

Coal quality is an issue for many power plants. Impurities (mainly rocks) cause damage to the mills. Since the quality of the delivered coal cannot be influenced, efficient coal and sorting management should be carried out in the power plant as far as possible. On the other hand, there is a lack of space at some locations.

Often, the results of the coal analysis are reported to the boiler operator after the coal is burnt. In this case, the boiler operator cannot respond to the coal change in advance. The coal quality must be checked when the coal arrives in the stockpile and, if necessary, the unusable coal must be rejected. The problem can be solved by intermediate storage and fuel management in the stockpile.

5.1.4.2 Lifetime extension

A lifetime extension is currently under discussion for various power plants such as Arnot, Camden, Grootvlei and Hendrina. A clear decision to extend their lifetime is necessary for strategic planning security and would encourage staff at the power plants to improve their maintenance activities and to execute outage work as per the defined scope. A clear decision here would enable measures to be taken to immediately implement projects to reduce PLL.

Power plants are designed for a specific lifetime. The real lifetime can massively vary from the design lifetime depending on the original quality and also on operation and maintenance conditions. However, coal fired power plants, are expected to have a service life of about 30 to 40 years both for economic and technical reasons. Components which are calculated with time dependent properties (undergoing creep processes) are calculated for a minimum of 200 000 operational hours. In reality, the components can very often be used much longer due to conservative assumptions of the design approach. Detailed supervision of these components in parallel to operation is absolutely necessary to identify creep damage prior to potential failure. Other parts of the plant are exposed to regular wear and have to be maintained or even changed to keep the plant reliably running. The condition of the critical plant components should be systematically and periodically investigated by a condition monitoring program. This program should be started latest around mid-life of the plant.

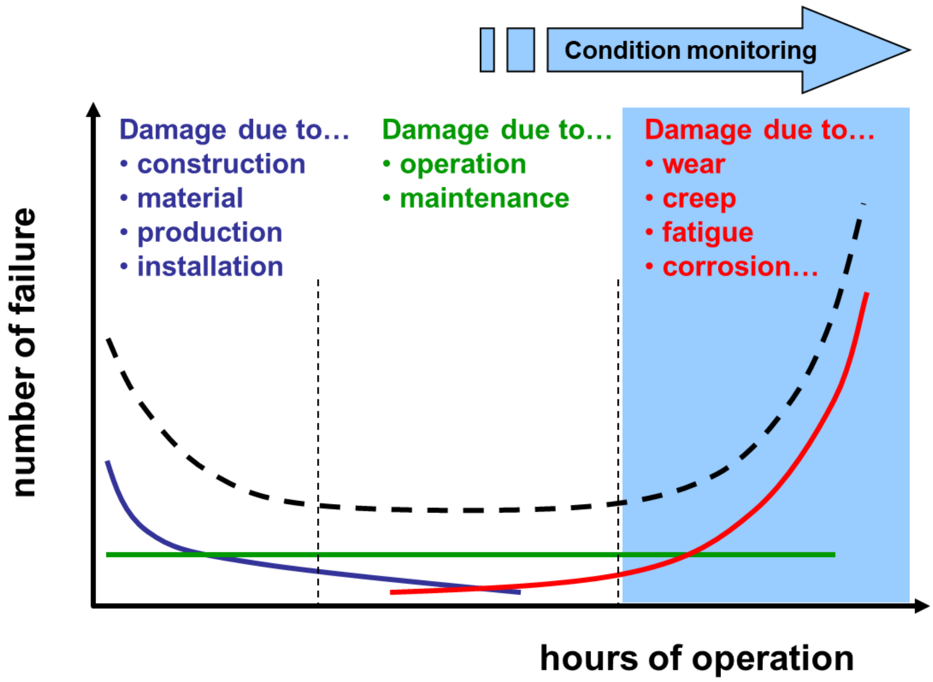


Figure 24: Failures over lifetime

For the lifespan of a plan one important influence is the quality of the operation and maintenance. By extensive renovations and upgrades which can be performed during all stages of stations life, the life of a power plant can be extended nearly indefinitely. However, economic or technological developments may cause also a well-maintained power plant to be decommissioned prematurely. Reasons can be a too low efficiency, too high fuel costs or too massive investments which must be made to fulfil external regulatory requirements.

Normally there is not a real criterion which technically defines the end of the lifetime of a power plant. In most cases it is more an economic and environmental decision to stop the operation of a plant. With proper maintenance and sufficient budget, a plant condition can be achieved which will allow reliable operation from technical point of view. For sure, the maintenance budget will increase during the life of the plants as more and more components have to be changed with increasing lifetime.

If a proper maintenance approach is not followed over the plant service life as it is the case in the Eskom fleet, a lot of the equipment and components of the power plant are to be changed in a lifetime extension program after 40 years of operation.

For extending the lifetime of an old coal-fired power plant which was not properly maintained over a longer period, several considerations and actions have to be taken to extent lifetime. Following steps could be followed:

1. **Definition of the extended lifetime period:** Eskom and its stakeholder must define by how much the lifetime of the plant should be extended. This is important to finally adjust the scope of work.

2. **Regulatory compliance: Ensure that the power plant meets all necessary environmental regulations and standards at least for a mid-term period:** Eskom and its stakeholders have to make sure that the plants can be operated after the implementation of technical measures taken. If a long extension of lifetime is foreseen, potentially emission control such as FGD have to be installed. Hence, the consideration of regulatory compliance forms an essential part of the lifetime extension planning.
3. **Conduct a detailed condition monitoring study:** A detailed technical assessment of the power plant's current condition must be made. The target of this study should be to systematically estimate the remaining lifetime of all power plant components. Doing this the remaining lifetime of critical components can partly be calculated by numerical tools. This study must take all available condition monitoring results and inspection reports into account. Besides that, operational experience of the plant (failures, hot spots etc.) must be highlighted. Finally, it must be agreed on which components have to be exchanged or repaired to keep the plant running reliably running for the desired period.
4. **Maintenance and refurbishment:** A rigorous maintenance program must be initiated to keep the plant running smoothly for the desired extended period. This program will be based on the previous study which was carried out. Regular and extraordinary inspections, repairs, and upgrades of key components like boiler, piping, turbine, electric generator, and condenser can help prevent breakdowns and improve efficiency. The investment backlog must be eliminated. Large investments may be necessary for the life extension proposal as the previous shut-down date would have precluded the execution of several maintenance measures, believed to be not economical due to the short remaining operational period.

5.1.4.3 Housekeeping

Proper housekeeping is not directly related to an EAF improvement. However, it is a prerequisite in order to execute proper maintenance and to ensure reasonable plant conditions. It is a precondition for reliable plant operation and maintenance, especially with regards to work on challenging plant sections, e.g. while refilling oil for bearings or working on open pumps/turbines. There is also a strong link between effective housekeeping and good health and safety standards. In some plants, high levels of pulverised fuel emissions were observed. This is a severe safety risk which needs to be addressed immediately.

Housekeeping does not require any standstill and can be carried out by the workforce employed by the plant (either Eskom's or contractors' personnel).

5.1.4.4 Excess Air in the Boiler

In 2014, Unit 3 at Duvha power station experienced an over pressurisation incident that caused very significant damage to the structure. This eventually resulted in the complete dismantling of the boiler and the unit was taken out of service.

An extensive investigation into the incident revealed that the event occurred because of the operators manually reducing the boiler O_2 levels as well as a massive clinker build-up in the boiler. The reduction in O_2 levels caused the formation of CO which resulted in the combustion becoming unstable and the subsequent over pressurisation. To manage this significant risk to other boiler structures an instruction was issued across the organisation to revert to OEM O_2 settings for all boilers.

During the Arnot site visit there was a discussion about reducing the O_2 limit with a view to generating more power from the boiler. Subsequent discussions with Eskom specialists were held and a summary of these discussions is listed below:

- The directive for plant to operate at OEM O_2 limits came into effect after the explosion in the Duvha U3 boiler as a risk mitigation measure.
- Due to the seriousness of the risk, any change to this directive must go through an engineering change management process and be approved by “The Fossil Fuel Firing Regulations (FFFR)” committee.
- The most relevant recommendations from the investigation were to ensure operation without generating CO and to install sensors to confirm both O_2 and CO levels.
- The generation of CO is not linear and increases exponentially as the O_2 level drops. This is illustrated in Figure 25 using test data from Kendal power station.
- Power gains from reducing O_2 limits will be most beneficial for tangentially fired boilers. There are only three power stations that fall into this category: Arnot, Matimba and Kendal.
- Tests conducted at Duvha in October 2021, where the O_2 was reduced by 0.5%, showed a negligible gain in power[10].
- Annual surveys for O_2 and CO levels are performed by Eskom’s Research, Testing and Development division. The results are sent to the power stations, this data should be used by any power stations motivating for a reduction in O_2 limits.
- The Lambda parameter is not always reliable as it is a calculated value – dependent on station air and coal measurements.

[10] Eskom Duvha process engineering report, “Unit 5 and 6_ O2 testing”, Feb 2022

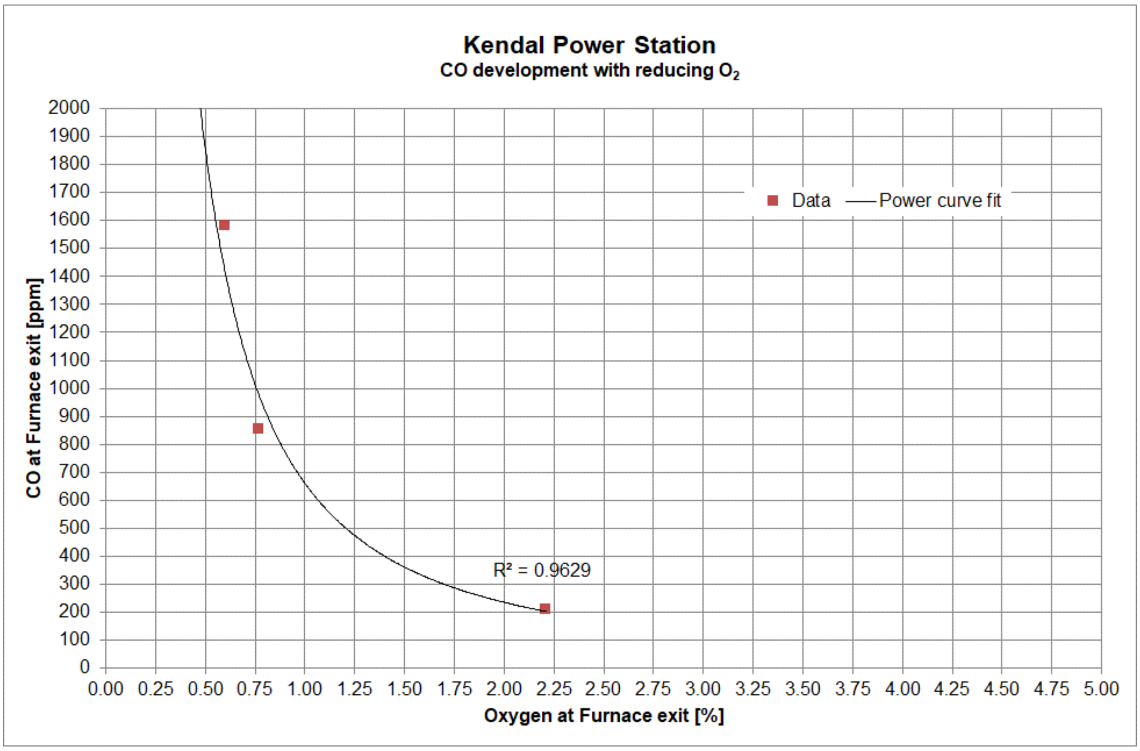


Figure 25: Development of CO as O_2 levels reduce
Source: Eskom

The vgbe team recommends that any power station wishing to reduce O_2 levels should follow the Eskom directive and motivate the application to the FFFR committee. In addition, the installation of suitable O_2 and CO sensors should be expedited at any power stations that have not already done so.

5.1.4.5 Operational and Process Know-how

Eskom has comprehensive data on the operating status of its power plants. Moreover, there are many very useful tools that provide valuable information for the optimisation of the O&M strategies. The following two tools are especially supportive in this regard. The vgbe team strongly recommends making them an inherent part of the O&M planning.

Thermal Index: Eskom uses a Thermal Index (TI) to track the thermal excursions on boiler outlet headers, main steam pipework and hot reheat pipework. The TI program is governed by the Eskom standard, "240-87099069 Implementation and Calculation of the Thermal Index for Coal Fired Power Plants Standard (Rev 4)". The TI is a long-term plant health indicator for the high temperature/high pressure components, but not a life management system. It gives an indication about the operating behaviour of the station.

Thermocouples installed on the selected systems are monitored continuously with data stored every two minutes. Excursions above the design temperature are reported as events, depending on the level of excursion and the time duration. Up to 50°C above design is treated as one condition Equation 1, more than 50°C above design has a higher damage weighting Equation 2.

$$TI_{<50} = 0.085 \times \left[\sum_{entire\ month} (\Delta\theta \times \Delta t) \times \frac{\text{Calender Hours in the Month}}{\text{Unit Operating Hours for the Month}} \right]$$

Equation 1

$$TI_{\geq 50} = \left[\sum_{entire\ month} (\Delta\theta \times \Delta t) \times \frac{\text{Calender Hours in the Month}}{\text{Unit Operating Hours for the Month}} \right]$$

Equation 2

Tolerance limits for events are listed as;

Favourable
Acceptable
Unacceptable

Tolerance Limits for Thermal Index:	
< 35	Favourable
36- 73	Acceptable
> 73	Unacceptable

The data for the TI may also be used as a check on the operational stability of the boiler, as the thermocouples are indicating time spent above normal operating conditions. This was evident in data for Duvha (poor operation) as opposed to Matimba (good operation), see Figure 26. In general, most of the power stations are exceeding thermal index limits, this is described in the individual power station chapters.

	SYSTEM	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23
DUVHA	Header Reliability	12	18	18	20	20	20	12	18	18		18	0	18
	Header TI	198	857	2088	372	998	414	1391	4357	3392		4902	0	1246
	MS and HRH reliability	0	0	0	0	0	0	0	0	0		0	0	0
	Main Steam TI	1	2	0	9	2	2	0	4	3		7	85	85
	Hot Reheat TI	5	32	25	14	35	21	15	9	60		0	0	82
MATIMBA	Header Reliability	0	0	0	0	0	0	0	0	0	0	0	0	0
	Header TI	7	1	6	10	6	8	4	8	104	65	35	20	75
	MS and HRH reliability	0	0	0	0	0	0	0	0	0	0	0	0	0
	Main Steam TI	0	0	0	1	0	2	1	0	1	0	0	1	1
	Hot Reheat TI	0	0	2	0	0	1	0	0	1	11	0	0	1

Figure 26: Thermal Index data for Duvha and Matimba

Step Etapro: Eskom has installed a very detailed program (EtaPro) to calculate and thus monitor the heat consumption of all coal-fired power plants. Among other things, it is used to calculate the so-called STEP factor. The STEP factor is a KPI that is determined from the quotient of the actual thermal efficiency and the real thermal efficiency.

Hence, the tool calculates – based on control system data and manual inputs – the efficiency of each power plant unit. Thus, it is possible to make a very detailed statement about incipient or existing efficiency losses. These details can refer to:

- Incorrect operation by the operating personnel
- Influence of the coal quality, especially the calorific value

- Malfunction or functional impairment of power plant components and power plant systems
- Fouling of power plant components and power plant systems
- External influences such as temperature and humidity.

The tool forms a very useful basis to determine concrete maintenance measures or instructions for the operating personnel to improve the PLL factor. It clearly identifies areas in which plant improvement is required.

5.1.4.6 Cold End

In many plants issues resulting in partial losses can be assigned to the “cold end” – condenser, cooling water system and cooling tower. Reasons for poor condenser vacuum or condenser tube leakages could be:

a) Insufficient performance of the cooling towers due to damaged or fouled cooling fills causing increased cooling water temperatures.

b) Clogging of condenser tubes by debris such as broken internals from cooling tower or other debris that was carried into the cooling tower by wind, pieces of concrete or other debris from the cooling system. Clogging of tubes by debris and plugging of leaking tubes reduce cooling water flow and heat transfer area of condenser.

c) Deposits in condenser tubes such as calcium carbonate scaling or fouling from suspended solids or biological matter (biofouling) due to insufficient cooling water quality, poor cooling water treatment (chemical dosing or side stream filtration) or the missing operation of a tube cleaning system.

d) Air ingress into low pressure steam at the LP turbine or condenser. This leads to air blanketing of condenser tubes and rise of condenser pressure.

e) Insufficient cooling water flow.

Often a combination of these possible reasons occurs. Reasons b), c) and d) can also lead to corrosion in condenser tubes and cause tube leakages, d) can also cause steam side corrosion in condenser.

The first step to solve poor condenser vacuum problems or condenser tube leakages is to check the possible reasons mentioned above. This can be done by analysis of different operational data to identify the reason of poor performance. Additional inspections of cooling tower, turbine condenser and cooling water chemistry help to find the root cause for unavailability or poor performance. Only a holistic approach considering all these three elements of the so called “cold end” can lead to a sustainable improvement of power plant operation. Future operation should include precautions to avoid all above mentioned problems.

<u>Condenser inspection:</u> During each outage a detailed condenser inspection should be performed before cleaning the water-boxes to check b) and c) and the status of corrosion.

Tube blockages by debris can be found mainly in the inlet water boxes, while scaling and fouling as well as corrosion of tubes is often related to temperature rise and so it appears more in the outlet water box.

To check the condition of the inner condenser tube surface the use of an endoscope or the pulling out of one or several selected tubes for laboratory examination is recommended. Eddy current testing of condenser tubes gives information about remaining wall thickness and detection of most corroded tubes before leaking occurs and allows the estimation of remaining lifetime of tube bundle. A leaking test should identify leaking condenser tubes which must be plugged to avoid pollution of condensate with cooling water, that could cause deposits in turbine and boiler.

Tube blockages must be removed from tube sheet and inside tubes as well as tube fouling or scaling must be cleaned by appropriate methods.

Condenser tube cleaning system: Operation of a tube cleaning system is state of the art to keep condenser tubes clean during operation. Sponge balls are injected into the cooling water right before the condenser and recollected at condenser outlet by a strainer. Precondition for effective operation of the tube cleaning system is:

- use of appropriate cleaning balls (diameter, hardness, type, tolerance, number and quality).
- sufficient cooling water flow. Sponge balls must not get stuck in tubes.
- faultless operation and condition of the tube cleaning system (strainers, pumps, collector).
- replacement of sponge balls when worn. If sponge balls get lost reason must be identified and solved.

Cooling tower inspection: The inspection of the cooling tower can be performed in operation. Points to be checked are:

a) Even and fine water distribution over the full area of the cooling tower? Damages of distribution pipes or spray nozzles?
b) Damages or deposits on the cooling fills
c) Debris in cooling tower basin or at basin outlet?
d) Biological growth or slimy deposits in the cooling towers?
e) Drift eliminator above water distribution clean and not damaged or is the air flow obstructed?

If by checking of these points any problems are discovered appropriate repairs or cleanings and countermeasures for future operation should be performed.

5.1.4.7 Water Treatment Chemical Discharge

The ion exchangers in the water treatment plants at Arnot, Kriel and Grootvlei sites are re-generated with diluted sulphuric acid or caustic soda. The excess chemicals and the rinse water are discharged into the sump and to the ash dams subsequently. Neutralisation of the waste water is not usually considered because of a lack of facilities for acid or caustic dosing and neutralisation basins, or ignorance of the possible consequences for pumps and concrete materials.

A consequence of this is the large sinkhole that occurred in Arnot. Due to a prolonged failure of a pump, the foundations and pipelines near the water treatment plant were exposed to the acid wastewater (due to un-neutralised sulphuric acid) and damaged severely and collapsed. To repair foundations, pipelines, and pumps, they must be excavated (more than 10 m depth).

5.2 Key Recommendations at a Glance

Based on the conclusions mentioned in chapter 5.1 the vgbe team compiled the following key recommendations for Eskom's coal fleet:

Empower the power plants and focus an O&M.

- A fundamental change in the management system is needed. It should aim at an empowerment of the power plants with full budget responsibility and accountability of the Power Station General Manager.
- Moreover and at least for a limited period of time – e.g. 1.5 to 2 years – the power plants should be allowed to apply fast-track procurement processes under the supervision of National Treasury.
- To support this turnaround process, an interim independent expert team (outside of Eskom) which reports directly to National Treasury should be engaged with immediate effect. Member(s) of the expert team should be permanently situated at each site with a small oversight / management team that the site teams report to and who is the link with NT and Eskom.
- The sole focus of the power plants should be on O&M as these are the asset's core tasks. This should be reflected by the organizational structure; other functions than O&M should be sub-ordinate. Maintenance, outages, and spare parts management should be assigned to one organisational unit.
- The Outage Readiness Index and the Maintenance Performance Index should be replaced by simple and understandable KPI which reflect the real situation and indicate real progress. Their determination should be based on a straight-forward systematic.
- Many specialised functions (e.g. in engineering) were centralised. This expertise should be made available for the sites, e.g. by enabling the use of experts at the power plants where they are really needed.

- Some experts were allocated to only one plant, resulting in a loss of these specialised skills to the other power plants. The system of specialised groups located close to the power stations should be reinstated.

Execute proper maintenance and do the full outage scope.

- The fixation on the EAF must come to an end. The focus should be rather on the PLL reduction as this would address a key technical source for the low EAF. There is a potential of gaining up to 6 000 MW which is related to partial load losses (PLL) and could be reactivated by fixing the plants' defects. As shown in the exemplary simulation which compared the current situation ("random outages") with a thorough maintenance and outage scenario, a systematic approach will pay-off within one year with sustained improvements. Even if a higher EAF has to be accepted in the meantime.
- There are many common technical issues which can be resolved by proper maintenance. Especially at the older plants there are common defect areas such as air leakages at the boiler, mill issues, poor vacuum, water and steam leakages in the turbine and feed water area as well as boiler tube leakages.
- The vgbe team recommends forming expert teams that are specialised in fixing these issues – from planning to execution. They should support the maintenance work at all plants with their expertise – this could be a service from Megawatt Park for the plants.
- Any regular outage should be properly planned and prepared and then carried out as thoroughly as possible. The outage period should be used to fix all issues contributing to PLL, e.g. fix all leakages and sources for air ingress.
- Eskom currently takes up to ten days to restart its units after outages. This needs to be challenged. It is prudent practice to restart units in parallel with the outages, thus reducing by several days the time needed to reinstate the plant.
- Housekeeping is also one aspect of maintenance work. Although not directly related to an EAF improvement, it is a prerequisite in order to execute proper maintenance and to ensure reasonable plant conditions. Hence, housekeeping can be regarded as an indicator for the quality of maintenance work.

Improve the operation of the power plants.

- Learn from Kusile Unit 4: This unit had been operated by the boiler OEM prior and during the period of the Opera assessment. It achieves an EAF of > 90%. Hence, the team has successfully demonstrated that it is possible to achieve a high EAF in the newer plant units. Therefore, the vgbe team recommends keeping the OEM team on-site for as long as possible to guarantee safe operation of the plant.
- Furthermore, future operation teams should learn as much as possible from this Unit-4-team. If this O&M competence could be transferred to similar units at Matimba and Medupi, an additional capacity of up to 1 600 MW could be activated.

- Operators' training should be a top priority for Eskom's coal fleet. In-depth understanding of the thermal power plant processes is essential to ensure proper O&M. Above all, simulators – of which Eskom has a few – should be used to make this training practice-oriented.
- The excellent existing engineering tools such as Step EtaPro and the Thermal Index should be used to control and direct O&M planning.

Mitigate the risk of capacity losses and constraints.

- The raw water treatment plant of the Medupi and Matimba power plant – both sites share of this plant – urgently requires maintenance and upgrading. A second independent water treatment plant additionally would be even a better solution. If the existing plant fails, 12 units – 9 800 MW – would go off the grid.
- Moreover, the current water supply in the Lephalale region is not sufficient to install the wet flue gas desulfurization plant at the Medupi site. Immediate actions should be taken to mitigate the risk and to develop alternative supply options.
- The water treatment plant at Kendal is in a very poor condition and needs urgent maintenance and refurbishment. If the existing plant fails, 6 units – 3 840 MW – would be off the grid. A temporary unit is urgently required to enable this refurbishment work.
- Immediate actions are required to address the capacity limitations of the Kusile power plant which are due to the incomplete coal handling system and the ash discharge situation. These restrictions mean that the site cannot be operated with more than three units at the same time – hence only 2 400 MW instead of 4 800 MW would be available after the returning four units back to operation. The four units refer to unit 5 coming back within the next months and the Units 1 to 3 after the completion of the temporary chimney construction.
- In several plants, e.g. Kendal, Kusile, Lethabo, Matla, Majuba, Matimba, Medupi and Tutuka, the current environmental permits to operate the plant are close to the limits of allowance or capacity in respect of a) environmental compliance of flue gas emissions and b) to dispose ash. It is strongly advised to clarify the permit situation for short- and long-term in order to allow operation of the plants in line with the legislation of South Africa.

Incentivize persons, departments and plants.

- Good performance should be rewarded – on individual and institutional level. The vgbe team proposes to provide bonuses for power plants if they were able to reduce their losses by a defined percentage rate.
- Further bonus models for good-performing employees and departments – e.g. for the boiler maintenance team that could close a high number of points on the punch list – are useful and should be implemented by the PSGM.
- Many power plants are located in remote industrial areas. In order to attract qualified personnel incentives such as the provision of affordable or free-of-charge accommodation, salary supplements and reimbursement of travel expenses should be considered. There are several cases in which Eskom owns land and housing nearby the power plant – these properties should be used to create an attractive living environment for the power plant staff.

5.3 Arnot Power Plant

Arnot power plant has been running for almost 50 years. Maintenance and outages have been deferred and/or not been executed according to the philosophy, which is why the overall health of the plant is not good. Moreover, the plant is reaching its end of life. During the site visit, many air, steam and water leakages were found, which are indicators of significant losses.

Of the 2 100 MW installed nominal capacity, PLL accounts for 458 MW – this corresponds to almost 22% of the total. One of the main PLL contributors is the draught plant. Even if operated at maximum load, the ID fan capacity is not high enough to guarantee appropriate pressure in the furnace. This can be largely mitigated by tightening the flue gas ducts and air heaters as well as by reducing the pressure loss over the FFP. We also strongly recommend the inspection and repair of all other potential sources of air ingress on the boiler.

Furthermore, combustion urgently needs to be optimised in order to prevent unfavourable operating conditions in the boiler. Over-firing affects the area of the headers and hot reheat pipework, in particular, and boiler tube leakages (BTL) occur. Combustion optimisation would also eliminate the root cause of the ignition losses, which eventually causes a transfer of oil to the fabric filter plant (FFP). Bringing the HP heaters back into full service to avoid low feedwater temperatures would also act as an important lever to improving combustion.

Another technical area needing improvement are the steam temperatures. The vgbe team recommends checking, repairing and eventually replacing the spray water valves. The steam temperature control should be also checked to see whether it is functioning properly. All measures are thus aimed at enabling operation at design steam temperatures. With respect to water treatment, the neutralisation of effluents is strongly recommended in order to avoid any further sink-hole accidents.

During the site visit, very poor housekeeping and serious safety issues, such as missing insulation and warning signs, were observed in the boiler area. Clearly, there is a big gap between theory and practice. The working atmosphere was also characterised by low morale and low team spirit, as well as by blame-shifting and lack of ownership. This is reflected in the high turnover of staff. However, taking into account the competencies of staff met during the site visits and assuming that a cooperative management approach will be implemented, it should be possible to significantly improve this situation at the power plant. If the strengths and knowledge of individual team members can be synergised and team spirit strengthened, then a turnaround is possible.

5.3.1 EAF and PLL

The Arnot plant consists of six units, which were erected between 1971 and 1975. The first one commissioned was Unit 3, the last one Unit 6. Between 1992 and 1998, three units (4–6) were mothballed. Between 2007 and 2010, all units were upgraded in their gross capacity – hence, Units 4 to 6 were brought back to the grid.

Unit	1	2	3	4	5	6
Commissioning date Re-commissioning date	07/1972	10/1971	09/1971	07/1973 08/1997	07/1974 04/1998	08/1975 03/1999
400 MW upgrade	01/2009	07/2008	12/2007	01/2010	01/2011	11/2008
Gross installed capacity [MW]	2 220					
Nominal installed capacity [MW]	2 100 (350 per unit)					

Table 7: Key figures for Arnot power plant[11]

The thermal efficiency is around 33.8% at full load. In the last five years, the **EAF** was in the range of 52.2% to 60.9%. For 2023, the value is currently at 42.4%.

Year	Plant	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
2019	60.9	51.6	-	-	63.4	68.0	56.8
2020	60.7	69.3	73.8	63.3	67.9	59.0	43.1
2021	56.5	53.8	38.5	54.6	51.8	67.6	69.6
2022	52.2						
2023 YTD	42.4						

Table 8: EAF (%) at Arnot power plant (FY2018/2019–FY2022/2023) [12]

[11] Data supplied by Eskom as part of the initial documentation package
[12] Data supplied by Eskom as part of the initial documentation package and KISSY data

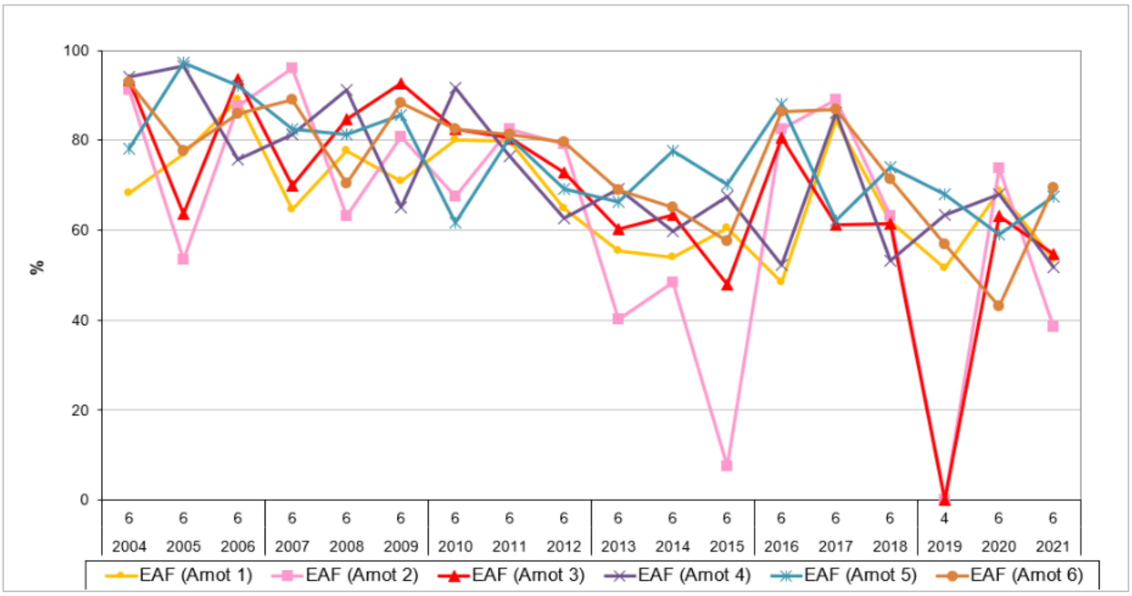
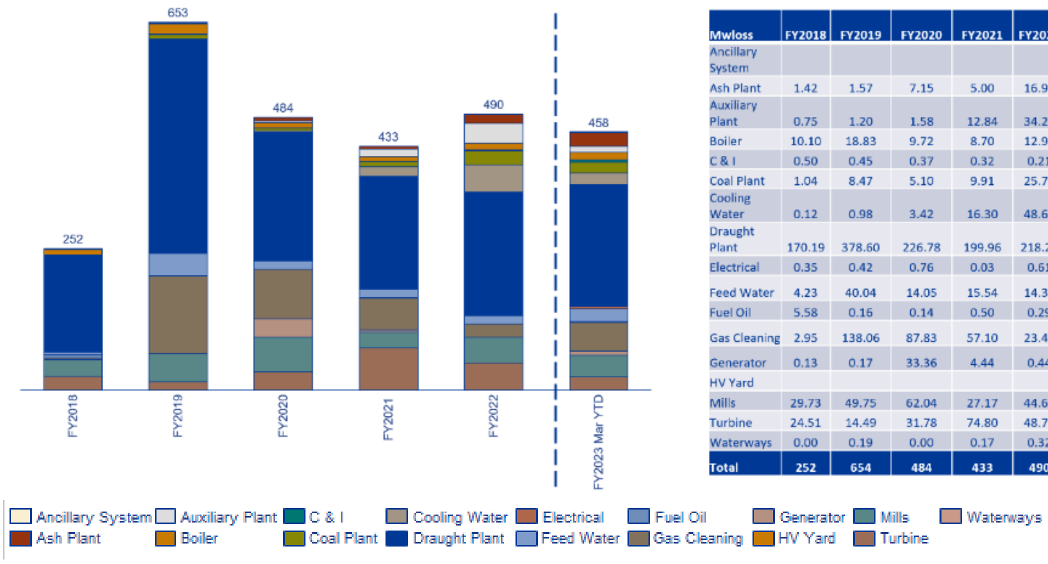


Figure 27: EAF at Arnot power plant (FY2003/2004–FY2020/2021)
Source: KISSY database, vgbe

The main PLL sources are shown in the next figure. It shows that many different components influence PLL – the main components are the draught plant, the gas cleaning (fabric filter plant), the mills, the turbine, the cooling water/condenser and the feed water.



Mwloss	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023 March YTD
Ancillary System						0.06
Ash Plant	1.42	1.57	7.15	5.00	16.90	24.28
Auxiliary Plant	0.75	1.20	1.58	12.84	34.24	11.62
Boiler	10.10	18.83	9.72	8.70	12.96	13.32
C & I	0.50	0.45	0.37	0.32	0.21	3.79
Coal Plant	1.04	8.47	5.10	9.91	25.73	19.32
Cooling Water	0.12	0.98	3.42	16.30	48.66	20.54
Draught Plant	170.19	378.60	226.78	199.96	218.20	216.78
Electrical	0.35	0.42	0.76	0.03	0.61	3.89
Feed Water	4.23	40.04	14.05	15.54	14.31	21.84
Fuel Oil	5.58	0.16	0.14	0.50	0.29	1.92
Gas Cleaning	2.95	138.06	87.83	57.10	23.43	51.14
Generator	0.13	0.17	33.36	4.44	0.44	6.52
HV Yard						0.06
Mills	29.73	49.75	62.04	27.17	44.64	38.91
Turbine	24.51	14.49	31.78	74.80	48.79	23.48
Waterways	0.00	0.19	0.00	0.17	0.32	0.06
Total	252	654	484	433	490	458

Figure 28: PLL contributors at Arnot power plant (FY2017/2018–FY2022/2023) [13]

[13] Eskom data sent by Lebohang Kubayi per e-mail on 11 May 2023

5.3.2 Technical Status

The plant has been running for 50+ years. Maintenance and outages have been deferred and/or not executed to the full extent mainly because of the tight electricity supply situation. Hence, the plant is not in good health overall.

5.3.2.1 Technical Status of the Boiler

Based on what we saw during the site visit, **housekeeping** at Arnot is very poor. Clearly, de-ashing of the plant has not been undertaken for a long time, resulting in massive amounts of ash everywhere on 0m level. During the visit, no effort was made to improve the situation by cleaning. Besides ash accumulation on the ground, many areas were covered in dust (Figure 29). The dust is apparently a mixture of steam, ash coal and oil dust.

Over the last few years, there have been some forced mill shut-downs due to the unavailability of mills. The mills should be maintained, respectively repaired, more regularly.

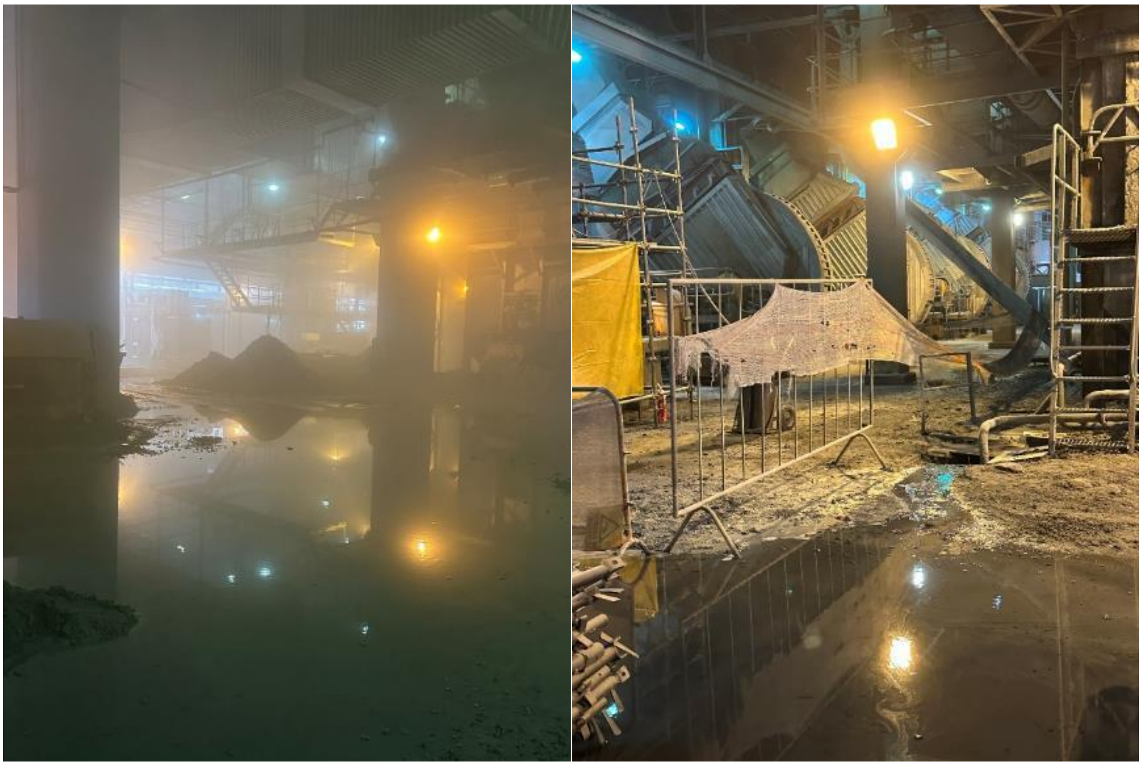


Figure 29: Example of poor housekeeping at Arnot power plant

The status of the housekeeping is unacceptable. Even if it has no direct impact on plant performance, it is important to keep it at an acceptable level so that it is possible to work safely in the boiler house at all times. During the visit, the plant team promised to immediately take steps to improve the situation. They agreed to send photos after implementing corrective actions. These photos were sent on the 7 May 2023 and showed a significant improvement in the situation.

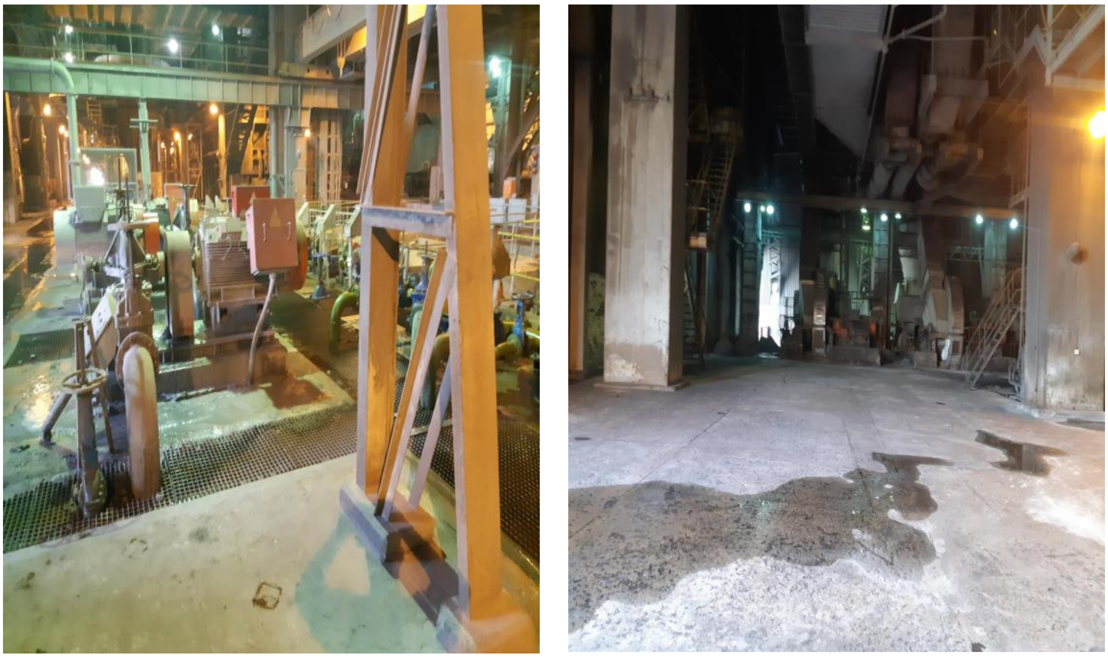


Figure 30: Arnot’s boiler house after intense cleaning

Lots of steam and water leakages were identified. Figure 31 shows examples of leaking valves, one of them located on the steam system.

Figure 31: Examples of steam and water leakages in Arnot’s boiler house

In the interview with the PSGM before the plant walk, the PLL situation was discussed. It was mentioned that the air ingress to the ducts and the boiler cause a PLL of 216 MW. The reason for this is that, with the present air ingress, the unit's load has to be reduced due to the capacity limit of the draught plant. Operating the unit at full load would lead to a situation in which the flue gas could not be sufficiently removed from the boiler. It should be noted that the higher the level of leakages the higher the air demand of the boiler – this is due to the pressure level that needs to be maintained in the boiler.

During the Arnot site visit, there was also a discussion about reducing the O_2 limit with a view to generating more power from the boiler, potentially up to 20 MW on a unit generating 400 MW. Subsequent discussions with Eskom specialists were held and a summary of these discussions is listed in section 5.1.4.

The directive for operating plants at OEM O_2 limits came into effect after the explosion in the Duvha Unit 3 boiler in 2014, as a risk mitigation measure. This event resulted in the unit being taken out of service permanently. The most relevant recommendations from the investigation were to ensure operation without generating CO and to install sensors to confirm both O_2 and CO levels. Arnot has already started this process. Arnot is one of three power stations that has tangentially fired boilers that may benefit from reduced O_2 limits. Tests at Duvha in 2021 showed a very limited benefit for wall-fired boilers. Due to the seriousness of the risk, any change to the directive must go through an engineering change management process and be approved by "The Fossil Fuel Firing Regulations (FFFR)" committee.

Figure 32: Measurement of oxygen in the flue gas at Arnot's Unit 3

During the site walk, poor insulation of components could be seen at various places. Two examples are illustrated in Figure 32. On the left side, an uninsulated opening to the combustion chamber can be seen. The glow radiating from inside the boiler, alone, demonstrates that high air ingress is taking place here. The second picture shows the drum, also with uninsulated components. Improper insulation of the components leads to:

1. Efficiency loss, as heat is lost to the atmosphere.
2. Safety risks, as staff at the plant can be hurt.

3. Higher stresses on components, as temperature gradients are present.

We strongly recommended changing and improving this situation in the short term. The site team should systematically check where uninsulated components are present and insulate these areas, so that the cover temperature does not exceed 45°C maximum.

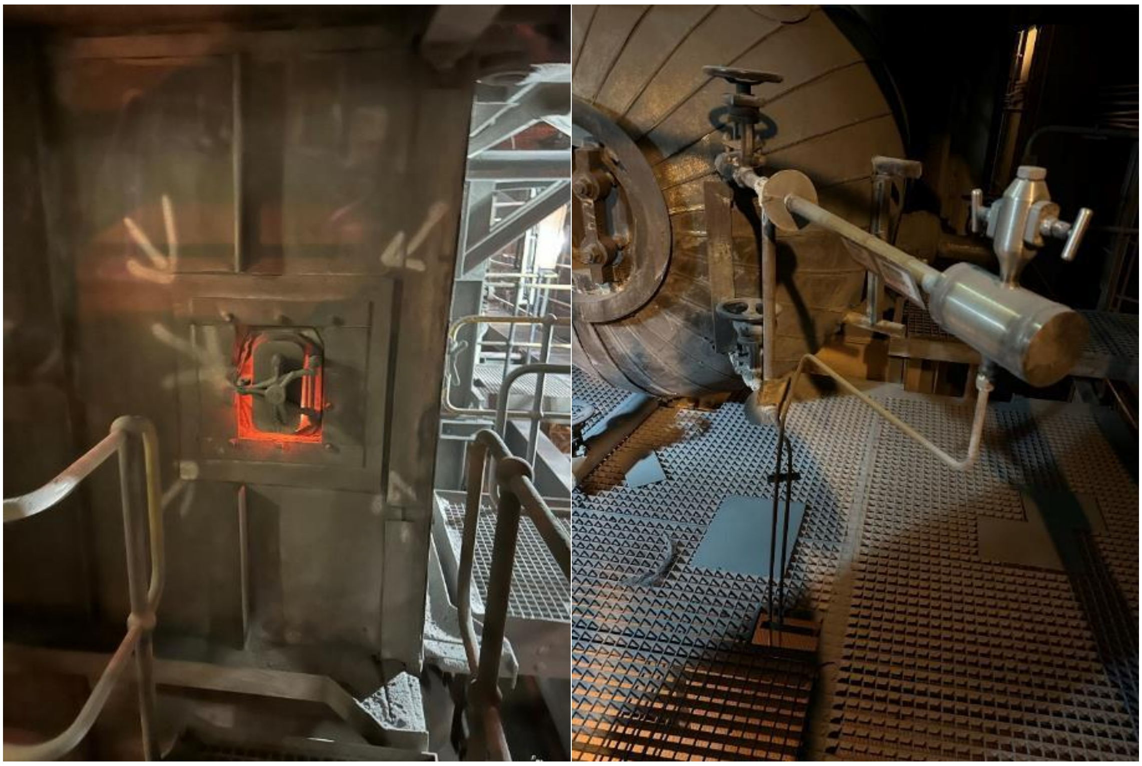


Figure 33: Examples of poor insulation at Arnot

Boiler tube leaks (BTL): BTL are a major issue at the plant. There are currently approx. 10 BTL every month, which is very high, and not all of them are investigated to find out their root causes. According to available RCA reports on investigated BTL, the root causes are mostly resulting from insufficient boiler operation. One of the contributing factors is the non-availability of the HP heaters, which leads to unwanted cold feedwater temperatures. To counteract and increase the feedwater temperature, the combustion temperatures are elevated (sometimes even higher than the design values for metal temperatures). This occasionally leads to overheating of tubes.

In order to avoid unfavourable boiler operating conditions and, at the same time, reduce PLL, the HP heaters should be brought back into service as soon as possible.

Another reported root cause of BTL is erosion caused by fly ash. As the ash content of the fuel cannot be influenced by operation, the provision of protection plates/shields for the most affected tube areas should be considered. In the past, some BTL were also found in the RH section. The source was identified as pitting corrosion, which mainly came from improper standstill conditions during outages/repairs in the RH section. As a countermeasure, the power plant introduced a procedure to dry out the RH section after shutting down the boiler. This type of BTL seems to be well managed and no longer contributes significantly to BTL.

Drum level: Apparently, the trips are due, in main, to the malfunctioning of the controls and/or to the limit values of the drum level being exceeded.

Looked at more closely, this is often a consequence of transient operating conditions, which are often associated with BTL. Therefore, it should be a priority to resolve the root causes of BTL and thus enable smooth boiler operation. However, there are also some discrepancies between the field readings and the DCS records of the drum level measurements, which will need to be addressed.

Leaky spray injection valves: In the control room, the main steam and the reheat temperatures were checked. The temperatures were approx. 15 K lower than the desired operational temperature of the units. The reason for this can be leaking spray injection valves or inadequate set points. If the valves are the root cause, the steam temperature cannot be controlled properly. In any case, operating the boiler at a significantly lower temperature leads to the following problems:

- Reduction of plant efficiency
- Potential turbine problems

We strongly recommend implementing measures that will lead to increased steam temperatures as soon as possible.

Ignition losses: Very high ignition losses are leading to unit trips and also contributing to PLL. Time delays often occur during the oil ignition, sometimes even resulting in unburned fuel oil being found in the filter bags of the FFP. This negatively impacts the functionality of the FFP itself and leads to increased differential pressure at the FFP and, subsequently, to a loss of partial load capacity. The complete combustion system (oil and coal), including the oxygen control in the combustion air, has to be refurbished and reset to either design conditions or to current fuel qualities.

Eskom uses a **Thermal Index** (TI) to track the thermal excursions on boiler outlet headers, main steam pipework and hot reheat pipework. The TI is a long-term indicator of plant health with regards to the high temperature/high pressure components. The data for the TI may also be used as a check for the operational stability of the boiler, as the thermocouples indicate time spent above normal operating conditions. More detail on the TI is listed in section 5.1.4.5.

Arnot's TI report for FY2023 shows that the header and hot reheat temperatures are above limits and unacceptable, while the HP pipework is within limits. This is due to the boiler overfiring as a result of the poor vacuum conditions, air-heater leakages as well as defective primary firing equipment (mills, SA dampers and burner tilts). This data confirms the conditions resulting in high PLL and, in addition, has significant long-term implications for the creep life of the headers and hot reheat pipework.

Tolerance Limits for Thermal Index:	
< 35	Favourable
36- 73	Acceptable
> 73	Unacceptable

	SYSTEM	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23
ARNOT	Header TI	50	17	100	100	64	116	84	21	30	47	93	134	242
	Main Steam TI	39	20	24	2	42	6	61	2	2	17	3	5	5
	Hot Reheat TI	114	199	121	121	56	78	22	149	100	173	65	57	44

Table 9: Extract from Arnot’s TI report

Boiler at a glance:

- The boilers have a lot of issues – BTL, in particular, are a major contributor to EAF degradation. The root causes of BTL need to be eliminated, e.g. replacement of HP heaters.
- The combustion system needs to be optimised in order to avoid ignition losses and oil slippage to the FFP.
- Steam temperatures are below design values and result in PLL – this can be mitigated by replacing leaky spray water valves and improving the temperature control.
- Proper insulation of hot surfaces and implementation of regular safety checks.
- Proper housekeeping should become a regular activity.

5.3.2.2 Technical Status of the Machinery

Turbine: The turbine hall was reasonably clean. Some problems were reported regarding turbine vibration levels. These problems were ascribed to a variety of causes, including bearing misalignment, proximity probes becoming loose and shaft deflection/distortion. The centreline vibration is monitored online by the condition monitoring group based in Rosherville, who provide comprehensive reporting and data analysis. Generally, these problems can be addressed through improved maintenance and care. The issue of shaft distortion is normally due to “quenching” events, which happen when the steam temperature drops too rapidly, resulting in thermal shock to the turbine. This type of event is related to poor operating skills and should be addressed through further training. The station is encouraged to consult the turbine corporate specialists in group engineering to find solutions for these problems.

Cooling Water: A partial flow (10%) of the recirculating cooling water is treated (clarifier, dosing of biocide and dispersants). A combination of poor cooling water chemistry control and unavailability of the online tube cleaning system (Taprogge system) caused scaling and fouling problems in the condenser. High pressure water jet and acid cleaning were carried out at the condensers, successfully removing the hard scale and fouling.

Due to the damaged, brittle cooling tower internals, it was decided that the lower layers be removed (Figure 34). According to Eskom's calculations, the remaining layers are sufficient for the required cooling capacity.

Figure 34: Removed filling of Arnot's cooling tower

Machinery at a glance:

- The turbine area is reasonably clean. The root cause of the turbine vibrations should be investigated.
- The cooling water chemistry control needs to be improved.

5.3.2.3 Technical Status Electrical and C&I

There were no issues reported relating to the generator and transformer. The C&I system is from ABB – most of the field system defects require manual interventions. The system, Procontrol 13 &14, is up-to-date (Unit 4–6 PR014, Unit 1–3 PR013).

No issues were reported with respect to the generators (manufacturer BBC) and the transformers (manufacturer Siemens).

5.3.2.4 Technical Status of the Water Treatment Plant

The station has a central make-up water plant, which we visited during the site walk. The capacity of the make-up water plant is sufficient to cover the consumption needs of the site and the quality of the water is also adequate, although the water requirement is higher than foreseen.

New online measurement instruments have been installed at the plant (Figure 35). Also, the pre-treatment plant (flocculation) is currently being refurbished. It should also be mentioned that the offline sampling is carried out intensively by the site team. Water samples are taken and analysed for key performance indicators.

Figure 35: Instrumentation at Arnot’s water treatment plant

Sinkhole: The ion exchangers in the water treatment plant at Arnot are regenerated with diluted sulphuric acid or caustic soda. The excess chemicals and the rinse water are discharged into the sump and subsequently dumped in the ash dams. Neutralisation of the waste water is not usually considered, both because of the lack of facilities for acid or caustic dosing and of neutralisation basins and also perhaps because of a lack of understanding about the possible consequences for pumps and concrete materials. A consequence of this disregard is the large sinkhole that occurred at Arnot. Due to a prolonged failure of a pump, the foundations and pipelines near the water treatment plant were exposed to acid wastewater (due to un-neutralised sulphuric acid) and were damaged severely and collapsed. To repair foundations, pipelines and pumps, they must be excavated (14 m depth).

Figure 36: Sinkhole at the Arnot site

Figure 37: Silica and conductivity measurement in Arnot's make-up water

Water treatment at a glance:

- Capacity of the make-up water plant is sufficient, despite high losses due to steam and water leakages at the plant.
- The plant is capable of producing water of sufficient quality.
- Neutralisation of effluents is urgently needed.

Coal and Ash: Although most of the coal is trucked-in from many different coal suppliers, the power plant has limited influence over the supplies. Between 5% and 10% of the coal is transported from the nearest mine to the power plant via a conveyor belt (started last year). A well-thought-out system has been established, encompassing the coal delivery, coal quality control (frequent samples are taken) and the distribution to the site stockpile. It was reported that 60% of the incoming coal is quality-checked (demand: CV: 22.3 MJ/kg – 169 t/h per unit at full load, CV of 19.6 MJ/kg: 192 t/h per unit at full load).

The capacity of the ash dams is sufficient for the remaining lifetime.

	Typical low volatile coal	Basis for boiler performance guarantees
Calorific value (gross) MJ/kg	23.313	22.213
Ash %	19.6	19.7
Volatile %	18.0	21.9
Fixed carbon %	53.8	48.9
Total moisture %	--	8.80
Sulphur	--	0.38 to 0.73
Hardgrove Index	75	60
Abrasiveness Index	370	370

Table 10: Coal composition at Arnot
Source: Arnot power plant (BLUE_BOOK_MENU.xls, page 36)

Emission situation: The plant suffers from an unreliability of monitors affecting the south stack. The measured emission values of the north stack show that the current emission limit values can be met but, for SO_2, retrofitting measures must be carried out in order to comply with the emission limit value which becomes effective in 2025.

The **spare-parts warehouse** and maintenance workshop were also visited. No issues were found with regards to spare parts and the warehouse was reasonably in order. The workshop is well-equipped and clean. It provides many options for carrying out repair work at the site.

Auxiliaries at a glance:

- The coal and ash plant are in order.
- Coal quality is not an issue.
- The spare-parts warehouse and maintenance workshop are well-equipped.

5.3.3 Technical Measures to Improve the Plant Condition

Boiler including FFP: The maximum potential MW gain of the following measures is 255 MW.

The boiler has several issues which, if addressed, would result in immediate improvements and a positive impact on PLL. As discussed in the previous chapters, the draught plant was identified as one major component causing high PLL. Even if operated at maximum load, the capacity of the ID fan is not adequate to guarantee an appropriate pressure in the furnace, so that the boiler load has to be reduced. This problem can be addressed by carrying out the following measures:

- Tightening the flue gas ducts
- Tightening the air heaters

We strongly recommend the inspection and repair of all other potential sources of air ingress. This can be carried out during short stops and would lead to immediate improvements. Besides the locations mentioned, we also recommend inspecting the wall penetrations of the superheater, reheater and shoot blowers. Moreover, there are many other water and steam leakages at many positions around the plant. We recommend systematically repairing leaking valves, pumps, etc., in order to improve plant efficiency and reliability. Many repairs can even be carried out step-by-step in short standstill periods.

The root cause of the ignition losses needs to be eliminated by optimising combustion. This will also prevent oil leakage to the FFP – which results in an increased differential pressure at the FFP. The complete combustion system (oil and coal), including the oxygen control in the combustion air, has to be refurbished and reset to either design conditions or to current fuel qualities. This might also include the replacement of appropriate measurement instruments. In this regard, the excess air requirements for operation (resulting from the Duvha accident) should be re-assessed jointly with the corporate engineering experts.

The HP heaters should be brought back into full service – either by repairing them or replacing them. Their insufficient operation causes low feedwater temperatures, which lead to unfavourable boiler operation conditions. These conditions are one of the main root causes of high BTL.

The vgbe team recommends checking, repairing and eventually replacing the spray water valves. The functioning of the steam temperature control should also be checked. Hence, all measures aim to achieve operation at steam temperatures as per design.

Machinery: One of the main areas needing improvement is the cooling water system. In order to investigate the root cause of PLL, activities as described in chapter 5.1.2 should be conducted.

Some problems were reported regarding turbine vibration levels. These problems were ascribed to a variety of causes, including bearing misalignment, proximity probes becoming loose and shaft deflection/distortion. The centreline vibration is monitored online by the condition monitoring group based in Rosherville, who provide comprehensive reporting and data analysis. Generally, these problems can be addressed through improved maintenance and care. The issue of shaft distortion is normally due to "quenching" events, which happen when the steam temperature drops too rapidly, resulting in thermal shock to the turbine. This type of event is related to poor operating skills and should be addressed through further training. The station is encouraged to consult the turbine corporate specialists in the engineering group, to find solutions for these problems.

Water Treatment: In order to avoid any further sinkhole accidents, the vgbe team strongly recommends the neutralisation of effluents.

More use should be made of the **maintenance workshop** – especially in view of the backlog of maintenance work relating to leakages and air ingress. The vast possibilities to repair and manufacture parts in-house should be exhausted.

5.3.4 Power Plant Management

Currently, 738 employees are working at the power plant – 85 of them managers. In addition to this, 512 contractors are active at Arnot power plant. Several staff members at management level have only been working at Arnot site for a few months. We were told that only 40% of the staff have been there long-term – the rest fluctuate. The instability in key management positions at the power plant is one factor that contributes to the low team spirit that we observed during the site visit. The working attitude is often characterised by blame-shifting and a lack of ownership. Despite the fact that there are knowledgeable and experienced people working in most areas of the plant, their potential has not been utilised to manage the technical turnaround needed at Arnot. The Arnot team seems to have lost pride in its work and given up on hope for improvement in the situation. The poor housekeeping situation at the time of the site visit was somehow a reflection of the low morale that has spread throughout the plant.

However, as a result of the site visit, the site management team committed to tackle the challenges that were brought up by the vgbe team. As stated in the previous chapter, photos of cleaned boiler areas were sent showing real progress in housekeeping.

Besides the housekeeping issue, many water, steam and air leakages were observed during the plant walk. The high number detected is an indicator of insufficient maintenance carried out at Arnot. However, the KPI do not reflect this situation. In theory, the plant looks to be in better condition than it really is.

Taking into account the competencies of staff met during the site visits, and assuming that a co-operative management approach will be implemented, the status of the plant should be able to be improved significantly. If it succeeds in synergising the individual strengths and knowledge of its staff and manages to lift spirits, then a turnaround can be managed. An according incentive scheme – as described in chapter 5.1.1.2 – would also support this process.

Last but not least; the resource shortage is a very big issue: There are more than 300 positions vacant in maintenance, operation and outages alone. Hopefully, if changes are made to the management approach, then this resource shortage can be decreased.

Maintenance

Currently, 484 employees are assigned to the maintenance department. More than half of the positions (280) are vacant. This resource shortage poses a major challenge – especially in the view of the fact that 92% of the maintenance work is conducted by Eskom personnel. The next figure provides insights into the resource situation.

Designation	Level	Complement	Actual	Vacancy
Middel Manager	M18	1	1	0
Line Manager	M16	9	7	2
Senior Advisors	G14/15	8	1	7
Senior Supervisor	T13	24	23	1
Senior Technician	T12	51	11	40
Senior Planner	T12	4	4	0
Technician/Principal Artisan	T11	81	30	51
Planner	T11	20	8	12
Senior Artisan	T10	61	35	26
Artisan	T09	181	64	117
Senior Data Capturer	T07	5	3	2
Crane Driver	T06	21	2	3
Tech Official	T05	18	15	19
Grand total		**484**	**204**	**280**

Figure 38: Resource situation in Arnot's maintenance department

Eskom procedures are used for maintenance planning and to measure performance (via MPI). The following figure provides a snapshot of the count of active maintenance plans in SAP, per plant system.

PLANT CODE	PLANT SYSTEM	Call in SAP
115	Air Heaters	713
118	Bottom Ash	5453
114	Boiler	10126
111	FD and PA Fans	1673
112	Milling Plant	11686
113	PF Burners	9702
116	Flue Gas	6192
117	ID & Smoke Stack	1476
448	Ancilliary System	9241
449	Auxiliary System	3475
445	Common C&I	685
447	Civil & Structures	1454
442	Coal Plant	26895

PLANT CODE	PLANT SYSTEM	Call in SAP
446	Common Electrical	4886
441	Fuel Oil	878
451	HV Yard	6
444	Mixed Ash	2925
443	Water Treatment Plant	4760
333	Unitised Electrical	4592
331	Generator	3775
332	Unitised C&I	807
223	Condensate System	6553
225	Cooling Water System	3538
224	Feedwater	9689
221	Steam Piping	6141
222	Turbine and Condenser	6479
		88771

Figure 39: Count of active maintenance plans in Arnot's SAP system

Currently, almost 89,000 activities are listed in the system. From the vgbe team's point of view, this number is way too high for it to be possible to ensure appropriate (quality) control and tracking. The number of activity positions should not exceed 200 per unit and 200 for common systems. These figures would also include some minor actions such as the purchase of gaskets, outstanding cleaning works and the removal of scaffolds.

Although detailed procedures for quality control are available, contractors' performance was reported to be poor. Limited influence over the contracting companies was given as the main reason for not being able to change this unfavourable situation.

The non-availability of spare parts and a mismatch between existing spare parts on-site and the inventory as shown in the SAP system were reported. These are apparently the key reasons for the high backlog in maintenance work. In this regard, the lengthy procurement process was mentioned as a main driver of the situation. The site team reported that it takes up to 120 days to place a single contract to procure a certain spare part component. This situation could be mitigated if – along with the proposed empowerment of the power plants –fast-track procurement processes were to be implemented for a limited period of time.

Operation

The operation team works in 12-hour shifts. The shift hand-over is conducted between 06:00 to 07:00 and 18:00 to 19:00. Operating manuals, plant inspection and alarm handling procedures, as well as work instructions, are available.

222 people are currently working in the operation department. It was reported that 55 positions are vacant.

In FY2023, 39 trips and twice as many ignition losses were reported for the whole plant. 12 trips were attributed to poor operation skills. The according training is organised by the HR department. According to Arnot's operation KPI, there is a significant backlog in training activities. This needs to be addressed right away. Moreover, the vgbe team recommends designing the training strictly according to the needs of the operating personnel. Hence, the operation team should be involved in the development of applicable training programmes.

The operation team reports defects, such as leakages, etc., which are then handed over to maintenance. The maintenance group is responsible for fixing the defects. These defects should be identified during inspections, which form an integral part of the operation team's activities. However, the high number of leakages shows that the work processes have not been effective.

Outage
The Arnot team developed an outage philosophy that is based on the overall Eskom procedure. The scope and frequency of the outages are planned using a combination of condition-based, time-based and running-hour activities. The major outage activities are based on the operating hours of the turbine and its associated components: For example, the inspection of the LP cylinder and turbo-driven feedwater pump within 50 000 hours (6-year-cycle), and the inspection and overhaul of HP and IP cylinders inspections and overhaul within 100 000 hours (12-year-cycle).

Other major time-based activities relate to the draught group, air preheaters, pressure parts, HP piping, generators, and transformers. Fabric-filter-bag changes coincide with the outage schedule. The sequence of outage activities is shown in the next figure.

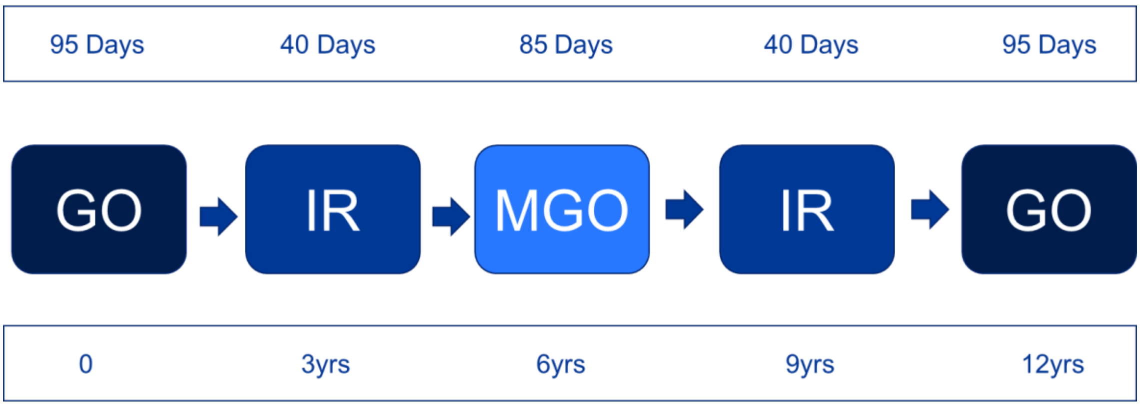


Figure 40: Outage philosophy at Arnot

The scope of the work to be carried out is reviewed for appropriateness by the site's engineering department and, if necessary, is reduced or increased, depending on the amount of work that needs to be carried out. The site team reported that the scope of repair work has not been cut due to lack of funds. However, the scope of work for the boiler section at Unit 4 was reduced due to non-availability of boiler tubing material. Several outages have been deferred in the past due to capacity planning and procurement delays. The latter mainly refers to problems with the timely availability of spares, which could be overcome with a more efficient procurement process. Moreover, the site team claimed to need more support with outage planning.

5.3.5 Technical Profile of Main Plant Areas

Boiler and related areas:

Manufacturer	ICAL /ACIP=>Alstom
Type	Drum Boiler
mass flow [t/h]	1 200
Pressure [bar, a]	161 before turbine
Temperature [°C]	510
Firing system	
Number of burners	24
Type of mills	Unit 1: Tube Unit 2–6 vertical spindle
Mill capacity [t/h] – per mill	Unit 1: original 65 t/h derated to 60 t/h Unit 2–6: 38.5 t/h
Reheat system	
Pressure [bar, a]	36 before turbine
Temperature [°C]	510
Coal supply	
Coal supply (truck, mine)	90% truck, conveyor (start 2022)
Precipitators/ Flue gas cleaning	
Manufacturer	Lurgi
Type	Electrostatic dust
Wet ash handling	

Machinery and Electrical:

Turbine	
Manufacturer	BBC CEM 1971–1975
Type	Multicylinder impulse reaction
Casings (HP-IP-LP, double/single flow)	HP-IP-LP
Main steam pressure [bar, absolute]	165.5
Main steam temperature [°C]	535
Reheat steam pressure [bar, absolute]	37.5
Reheat steam temperature [°C]	535
Cold end	
Condenser	Dual-pressure surface type
Cooling tower	Natural draught, North 3, South 3
Generator	
Manufacturer	BBC
Terminal voltage	15 kV (50 Hz)
Cooling system	Stator: Demineralised water Rotor: Hydrogen
Transformer	
Manufacturer	Siemens
Terminal voltage primary/ secondary	15 kV/420kV Unit 3-6, 15kV/300kV Unit1-2
Placement	Generator Transformer

5.4 Camden Power Plant

The Camden power plant is more than 55 years old, but has been mothballed for up to 20 years. Due to insufficient maintenance and its age the plant suffers from a high number of losses. In April 2023 approximately 17% (246 MW_e) of the installed net capacity of 1 481 MW_e was not available due to PLL. Another 24% (365 MW_e) were unavailable due to full load losses (FLL) at the time of the visit.

One of the main PLL contributors is the limitation of the draught fans. The units cannot operate at higher load due to the fact that the ID fans have reached their capacity limit. This can be mitigated mainly by tightening the flue gas ducts and air heaters. It is strongly recommended to also inspect and repair all other potential sources of air ingress at the boiler. Upgrading the ID fans also possess a possible solution.

The superheated live steam temperatures at the boiler outlet observed during the visit were lower as per design. This leads to power and efficiency losses. The reasons for this temperature difference are complex and can also occur in a concatenation, such as a limitation of coal feeders, air leakages in the preheaters and a faulty turbine and/or coal supply control. The power loss is already counteracted by increasing the boiler temperature, which causes a decreased life expectancy.

Due to poor coal quality, rocks in the coal and a missing on-line measurement a rapid degradation of coal mills have been observed and is to be expected further in the future. To avoid this a rock separation system needs to be installed and the online coal analysis system needs to be renewed in order to determine the coal quality before entering the combustion.

One of the main areas of improvement are the condenser vacuum and the cooling towers. In order to solve both problems, it is necessary to check the cooling water circuit and refurbish existing clarifiers.

In general, it can be said that the necessary work maintenance work has not been carried out sufficiently. To achieve a significant reduction of power losses the maintenances and outages need to be executed to the full extent. This requires an according investment into necessary spare parts (e.g. condensers, HP heaters). Many of the repairs can be done also during short stops and could lead to direct improvements.

The uncertainty about the future of the site, which is causing staff migration and low morale, is one of the main problems of the management team. Besides that, the management team seems to be knowledgeable and experienced. It is recommended that a decision on the continued operation of the site be made as soon as possible.

5.4.1 EAF and PLL

Camden power plant comprises eight 200 MW_e coal-fired units. Each of the eight boilers feeds its own turbine with steam. Originally, the station was commissioned in 1967. The units were mothballed between 1988 and 2008 due to excess capacity. The plant was returned to service in 2006 and received a new ash dam, which was partially constructed between 2016 and 2021 but was not fully completed until today. Another planned shutdown in line with the internal revision plan (IRP) occurred in 2019. The revised shutdown, as per 2035 strategy, is planned to take place between 2023 and 2025. A detailed overview of the commissioning dates, outage dates and capacities are shown in Table 11.

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8
Commissioning date	1967	1967	1967	1967	1967	1967	1967	1967
Mothballed	1988	1988	1988	1988	1990	1990	1990	1990
Recom.	2008	2008	2007	2007	2005	2005	2006	2006
Planned decom.	2024	2025	2024	2023	2025	2023	2024	2025
Gross installed capacity [MW_e]	200	200	200	200	200	200	200	200
Nominal inst. capacity [MW_e]	190	190	185	175	180	186	190	185

Table 11: Key figures for Camden power plant

Between FY2017 and FY2023, the EAF of the total power plant ranged between 67.98% (FY2017) and 21.59% (FY2020). The decrease of the EAF to its lowest availability in FY2020 was relatively steady (see Table 12). However, recent efforts undertaken to increase the EAF have led to improvements, and by FY2023 the plant's EAF had increased to 57.53% again. The plant EAF values for FY2022 and FY2023 were provided by Eskom during the site visit.

FY	Plant	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8
2017	67.98	25.03	83.96	60.92	67.68	83.71	77.76	71.01	73.65
2018	65.96	69.07	74.19	69.04	57.07	75.73	63.55	36.92	71.50
2019	48.45	52.49	56.17	60.92	19.89	28.00	57.78	50.17	25.01
2020	21.59	26.49	28.55	18.12	47.64	7.42	22.32	22.85	27.10
2021	45.49	44.63	46.87	52.77	67.68	48.46	15.68	51.94	55.97
2022	52.62								
2023	57.53								

Table 12: EAF of Camden power plant (FY2017–3/2023)

The units EAF values provided in Figure 41 were taken from the vgbe KISSY database. The data for this is supplied by Eskom on a yearly basis but, as of April 2023, the data for

FY2022 had still not been transferred. The EAF values provided by Eskom show a minor deviation from those given by the power plant general manager on 14 April 2023.

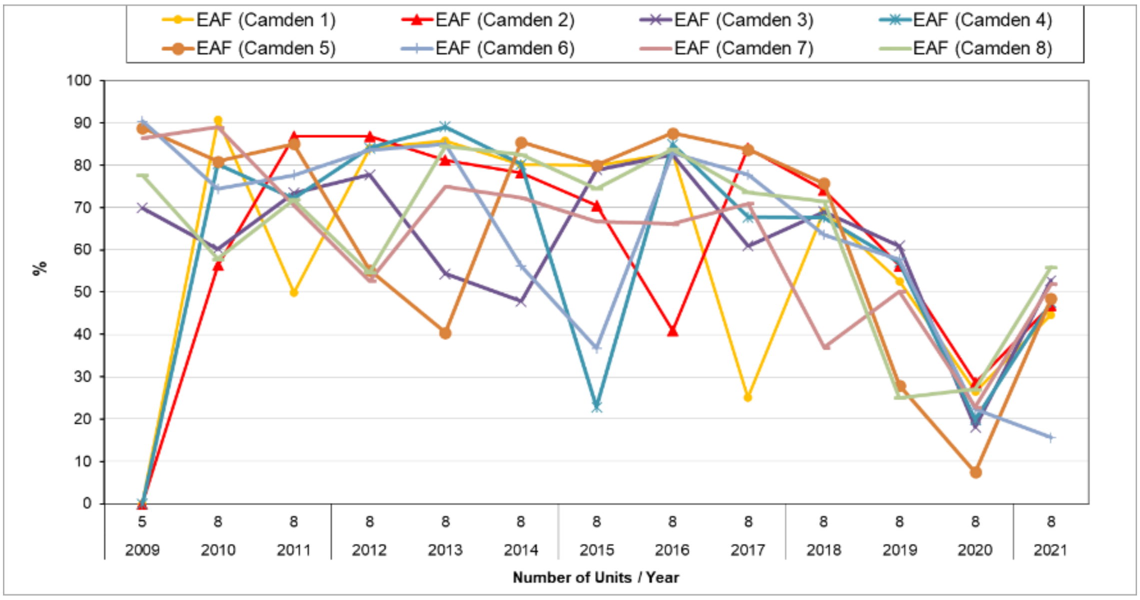


Figure 41: EAF of Camden power plant (FY2008/2009–FY2020/2021)
Source: KISSY database, vgbe

The low EAF is mainly due to significant PLL. The main PLL sources between April 2022 and March 2023 are shown in Figure 42. As can be seen, many different components affected PLL – the main components being the draught plant (39%), the mills (26%), gas cleaning (16%), the coal plant (6%), the boiler, the condenser, the feed water plant and the pipework.

The site team reported that Camden power plant was partly closed in year 2020 due to ash dam constraints (see figure above). The process of re-excavating the old ash dam was started to create ashing space. After this process the Camden units were brought back into operation. The units were operated at minimum load for 20 hours per day and four hours during the peak demand period.

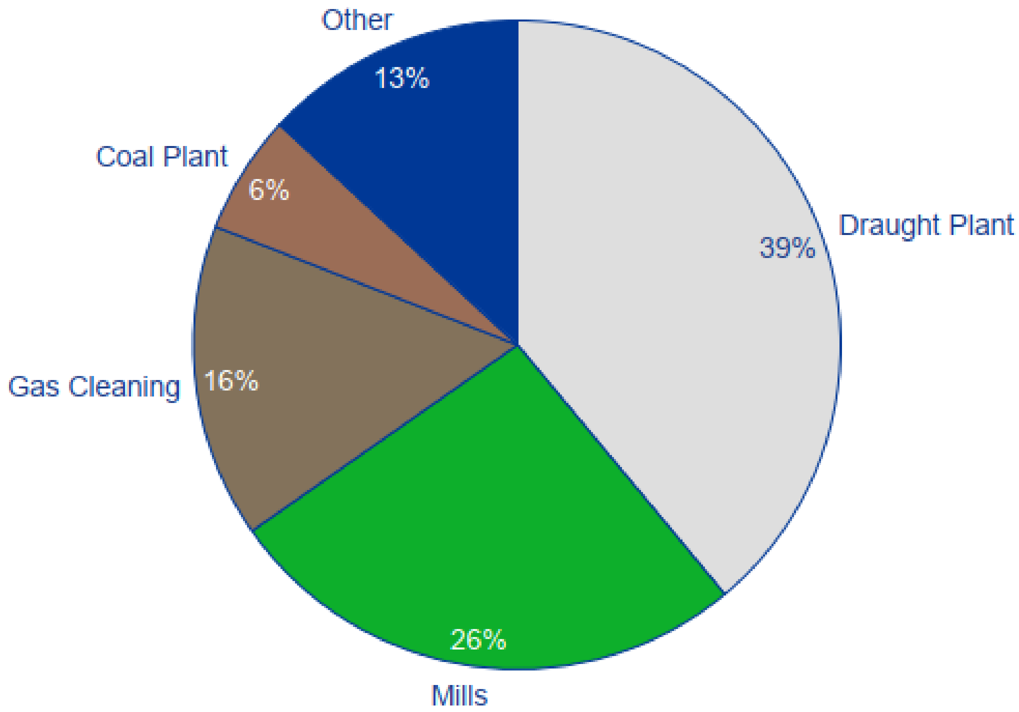


Figure 42: PLL contributors at Camden (FY200/2023 to March 2023)
Source: Eskom

The absolute numbers of PLL for the individual components and the total PLL have fluctuated over the course of the year. The values per month range from 11.89% up to 21.94%, thus marking a range of over 10%. The average PLL for FY2023 so far is 15.14% and, as such, exceeds even the full load loss (FLL) for the same period, which is 14.73% (see Figure 43).

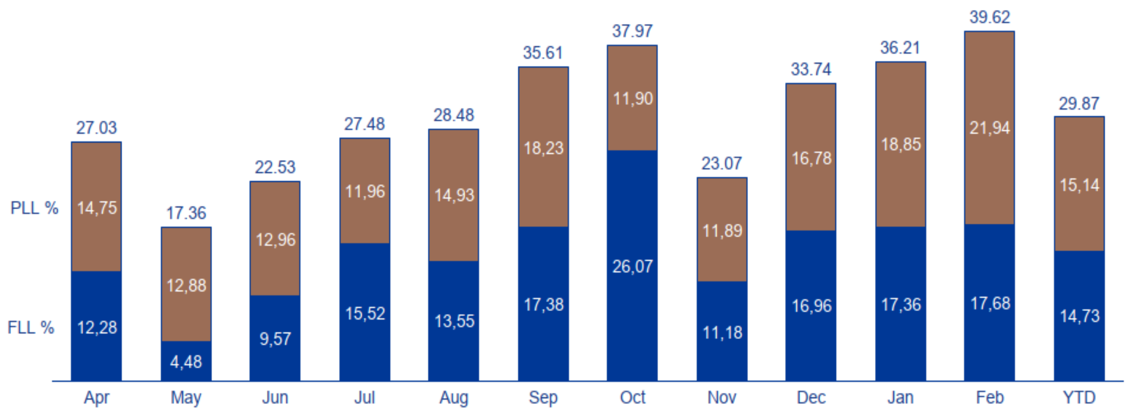


Figure 43: PLL and FLL distribution at Camden for FY2022/2023
Source: Eskom

5.4.2 Technical Status

5.4.2.1 Technical Status of the Boiler

Housekeeping: During the visit, the team walked through the boiler house. Housekeeping was deficient. High amounts of dust, ash and coal were on the floor and machinery (see Figure 44). Safety-related issues could occur due to insufficient housekeeping.

Figure 44: Camden boiler house with steam and water leakages

Steam leakages: In the boiler house, numerous steam leakages were found in various positions, both on valves and on the piping itself (see Figure 45).

Figure 45: Valve leakages in Camden's boiler house

Steam temperatures: The superheated live steam temperatures at the boiler outlet observed during the visit were lower, as per design. The desired operational temperature would be 543°C, but the temperature achieved within the boilers during the visit was approximately 526°C (see Figure 46). A downward deviation from the design parameters has an impact on efficiency and leads to power loss. The reasons for this temperature difference are complex and can also occur in a concatenation, such as a limitation of coal feeders, air leakages in the preheaters and a faulty turbine and/or coal supply control. This needs to be assessed in further detailed investigations. The power loss can be counteracted by increasing the boiler temperature and, as a result, the header temperature, but leads to a decreased life expectancy.

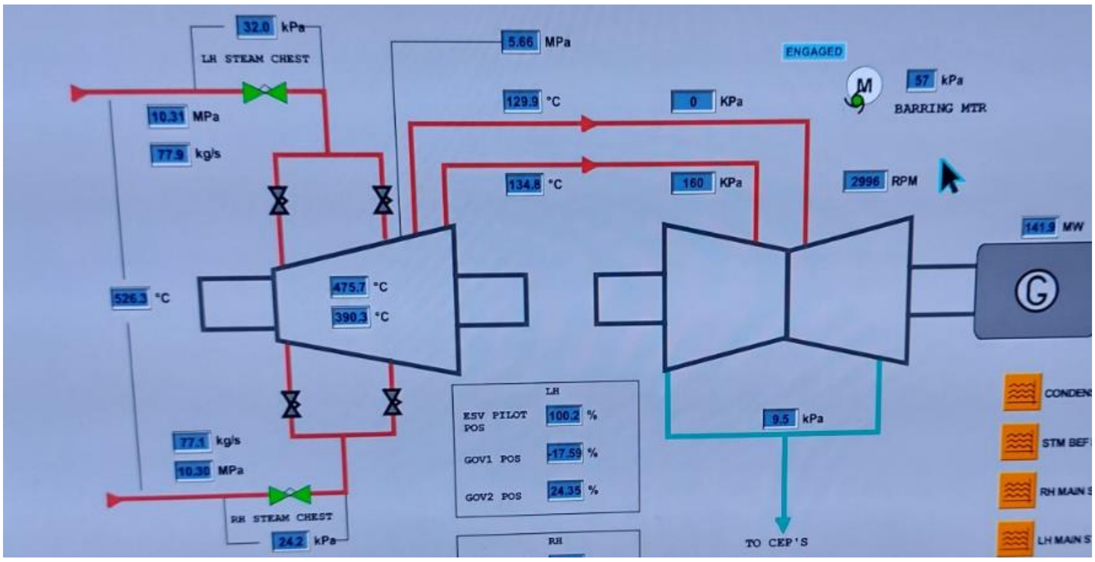


Figure 46: Screenshot of key operating parameter at Camden

Boiler tubes: There has been major boiler tubes failures in the past, which led to PLL and FLL. The failures have been recorded.

Draught plant: Per boiler, there are two induced-draft (ID) fans that draw the flue gas out of the boiler to the chimney. ID fans in the Camden power plant have reached their maximum capacity. Reaching the capacity limit is mainly caused by the air leakages within the air preheater and other air ducts.

Air leakages: A recommendation is to seal the air preheaters and the air ducts on the individual units. The cumulated air ingress into the system at Camden leads to 39% of the PLL, which Eskom says corresponds to total losses of up to 350 MW_e. The leakages lead to an increase in required air volume, which results in an increase in consumed electricity by the ID fans, as well a higher wear upon the machines. Fixing these problems could bring the fan requirements back into the design range of the boiler.

Mills: The mills were also reported as a big issue. Even though the coal mine nearby is connected via a conveyer belt, lack of capacity means that coal is trucked in from eight different mines. As a result, the coal shows quite inhomogeneous characteristics. The coal quality, which is largely based on the lower heating value (LHV), is on average 10% to 15% below the design range. The reduced quality of the coal is due to its high rock content, which leads to higher wear and abrasion of the mills and ducts. In normal circumstances, based on the quality, about 20% of the coal should be rejected. However, due to the amount of time it takes to analyse the incoming coal (about 24 hours), feedback on the quality of the coal analysed is regularly received after the coal has been burned.

It was reported that the mill casings have been cracked by the stones/rocks contained within the coal.

Figure 47: Coal stockpile management at Camden power plant

Thermal Index (TI): Eskom uses a TI to track the thermal excursions on boiler outlet headers and main steam pipework. The TI is an indicator for the long-term health of the plant with regards to the high temperature/high pressure components. The data for the TI can also be used to check the operational stability of the boiler, as the thermocouples indicate the amount of time spent exceeding normal operating conditions.

The TI report for Camden for FY2023 shows that the header temperatures are far above tolerance limits and unacceptable, while the high pressure (HP) pipework is well within limits (see Table 13). The excessive temperatures are due to the boiler over-firing as a result of the poor vacuum conditions and air-heater leakages. This has significant long-term implications for the creep life of the headers. Hence, the root causes need to be eliminated (leakages and vacuum). Since there is no reheater in the system, the hot reheat TI is supposed to be 0 in any case. As a result, the ‘57’ stated for February 2023 is probably faulty.

Tolerance Limits for Thermal Index:	
< 35	Favourable
36- 73	Acceptable
> 73	Unacceptable

SYSTEM	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23
Header TI	973	1053	1188	799	1089	1183	1124	1125	977	1030	1012	2738	815
Main Steam TI	0	0	0	0	10	0	4	30	5	3	17	5	5
Hot Reheat TI	0	0	0	0	0	0	0	0	0	0	0	57	0

Table 13: Extract from the TI report FY2023 for Camden power plant

Boiler at a glance:

- The boiler rooms are subject to poor housekeeping.
- The boilers have severe tube leaks.
- The boilers require major overhauls.
- The excess air ingress is quite high.
- The draught fans cannot provide air for full load.
- There are many steam leakages in the boiler house.
- Coal sites are well managed, ash handling is poor.
- Coal analyses take too long. The unit operator cannot react on coal quality change. The analysis result is available when the coal has been already utilised.
- Coal mills are degrading rapidly and should be overhauled.

5.4.2.2 Technical Status of the Machinery

Cold end: With respect to the cold end, the condenser vacuum is not sufficient, which has a severe impact on operations and causes PLL. One reason for the insufficient condenser vacuum could be the poor performance of the cooling towers, caused by missing and damaged end caps. Another reason could be the insufficient supply of cooling water. During our visit, only three cooling water pumps were running, due to a lack of spare parts. Furthermore, condenser tube leakages also contribute to a decrease in performance.

Cooling tower: The cooling towers themselves were in an acceptable condition, as far as we could see, but a certain degree of biofouling was visible on the steel structure within the tower. The underperformance of the towers could be caused by missing or leaking end caps within the cooling towers, which cause a massive efficiency decrease. The coarse strainers were in good condition but not adequate to guarantee a good quality of cooling water and prevent clogged nozzles. Maintenance on the cooling towers can only be performed during the winter because the full cooling capacity is needed during the summer. The procurement of spare parts is difficult and challenging, as the OEM for the cooling towers is no longer available.

Cooling water: The overall quality of the cooling water was poor. It contained a lot of floating matter and a high level of suspended solids and was brown in colour (see Figure 48). Poor quality of the cooling water can lead to clogged nozzles at the cooling towers, as described above, and to condenser tube leaks due to the increased erosive wear.

Furthermore, according to the power plant management, the pipework for the cooling water is also badly corroded. The cooling water circuit should be checked for particle entrance points and particle procedures causing this problem. Corroded pipework needs to be replaced, otherwise it will jeopardise plant operation.

Figure 48: Camden's cooling towers with bio fouling (left) and dirty cooling water (right)

Cooling water pump: The cooling water (CW) pumps and their housing were in acceptable condition. One of the pumps was dismantled at the inspection and another pump shaft was full of water, due to a sealing failure, and had to be manually emptied at regular intervals. As such, there was only a reduced capacity of cooling water available, causing a bad condenser vacuum and an undefinable amount of PLL. The valves installed on the CW-discharge side are fitted with weight-loaded flaps and have a safety function in case of CW-pump trips. Since these valves are not fitted with locking bolts, the entire power plant needs to be shut down when maintenance needs to be carried out.

Turbine: Firstly, the turbine hall was reasonably clean, as the housekeeping was conducted well (see Figure 49). The turbines were covered only with a thin layer of dust. Several leakages were detected within the turbine area. Only a few of these leakages were part of the interconnection piping and HP heaters.

Units 4, 6, 7 and 8 have already exceeded the end of their inspection interval and need a general overhaul. Their overhaul has been delayed because of the planned shutdown and decommissioning of the power plant and due to high grid demand. Due to the exceptional circumstances - unreliable and insufficient power supply - a recommendation would be to check whether it is possible to extend the lifetime of the plant. If this is an option, the above-named units should be overhauled as soon as possible.

Figure 49: Turbine hall at Camden power plant

The site staff reported increased vibration on some units due to poor alignment, which can lead to increased bearing temperatures. The increased bearing temperatures cannot be handled by the lube oil coolers, and therefore the coolers themselves also have to be cooled by water from outside (see Figure 50). The used water runs onto the measuring equipment and electrical installation below, so that a malfunction cannot be excluded.

Figure 50: Camden's turbine lube oil cooler with additional external water cooling

The insulation of some units was cracked, with a visible amount of steam rising from the cracks. One reason for this could be the steam leakages at the horizontal split joint (see Figure 51). Insulation that is no longer intact can lead to temperature differences within the casing. The temperatures differences occur most frequently between the upper and lower parts of the casing. Temperature differences can lead to buckling of the turbine casing, which can cause turbine vibrations. It is also necessary to check whether the insulation causes asbestos pollution.

Figure 51: Turbine with cracked spray insulation at Camden power plant

HP heaters: The reliability of HP heaters on-site is quite low, which results in PLL and efficiency decreases. When we visited, some of them had failures and were out of service, while others had visible steam leakages. Since these parts have little bearing on the availability of the plant as a whole, an immediate overhaul might not normally be considered necessary. However, since their malfunctioning decreases plant performance and efficiency, it is recommended that the overhaul takes place as soon as possible.

HP Piping: In general, housekeeping below the turbine floor level, down to ground level, is poor. Equipment and piping were completely covered in dust. Steam and water leakages were visible (see Figure 52). Most of the leakages are caused by flange connections that started leaking once asbestos gaskets had been replaced with non-asbestos ones. Since the leakages represent a health and safety risk, we recommend replacing the remaining asbestos gaskets during the next outage. In order to achieve a proper sealing with those new sealings it may be necessary to refurbish the flange surfaces.

Assessment of HP pipework to evaluate its lifespan is carried out in line with Eskom standards. The last assessment for Unit 4 was carried out in July 2022. HP pipework was released to return to service for another 60 000 hours.

Figure 52: Steam leakages on the lower floors of the Camden machinery house

Machinery at a glance:

- Condenser vacuum cause problems.
- Cooling towers need to be refurbished.
- The cooling water circuit should be checked.
- Many steam leakages can be found in the turbine hall.
- Turbines with exceeded intervals need an overhaul.
- Check alignment and lube oil/bearing system.
- Condenser refurbishment is needed.
- Procurement of spares for cooling water pumps is required.
- The lifetime extension of the plant should be checked.

5.4.2.3 Technical Status Electrical and C&I

Generators: In the past, the electrical generators have always run properly and as a result barely been the cause of outages or PLL.

C&I System: With respect to the C&I system, Units 1 to 8 are equipped with the Siemens SPPA T3000, following a major refurbishment. There are spares available for the system which is still supported by Siemens. The entire C&I system of the outside plant is based upon the Siemens T2000 System, which is obsolete and not supported by the OEM anymore.

MV & LV Switchgear: The MV and LV board rooms are generally in good condition (see Figure 53). They were replaced during mothballing and are cleaned well. However, the HVAC systems in those areas are not performing as they should.

Figure 53: Clean and refurbished board rooms at Camden

Electrical and C&I a glance:

- No major power loss caused by generators.
- The C&I system used for Units 1 to 8 is up to date and running properly.
- The outside plant C&I system is obsolete.
- The switchgear is refurbished.
- The boardrooms are in good condition.

5.4.2.4 Technical Status of the Water Treatment Plant

Make-up water plant: The central make-up water plant was visited during the site walk. The building of the water treatment plant was clean and, overall, in order (see Figure 54). The capacity of the make-up water plant is sufficient to cover the consumption needs of the site. The quality of the water is as it should be in most cases, with only minor increases in SO_4 amounts.

Figure 54: Water treatment plant at Camden power plant

Location	pH	Spec. Cond.	Acid Cond.	Deg. Cond.	O_2	Fe	Si	Na	Cu	Org.
Makeup water	Off	On	---	---	---	Off	Both	Both	Off	Off
Conden-sate	Off	On.	On	On	On	Off	Both	Both	Off	Off
Feed water	Off	On	On	On	On	Off	Both	Both	Off	Off
Boiler water	Off	On	On	On	On.	Off	Both	Both	Off	Off
(HP) live steam	---	---	---	---	---	---	---	---	---	---

Table 14: Types of water measurements at Camden power plant

Even though some of the sampling is done online (see Table 14), the water treatment plant as a whole has been operated manually for many years. This manual mode of operation is a risk, as it leads to a high failure potential, which also contributes to unavailability.

The raw water source is surface water coming from the Jericho dam.

Clarifiers: The clarifiers civil structures show signs of wear (see Figure 55). Refurbishment of the parts might be advisable.

Figure 55: One of the clarifiers (right) and signs of wear and tear (left) at Camden

Piping: The piping of the water make-up plant is in a moderate condition. Some of the pipes and junctions have already been exchanged. However, there are critical service waterlines that have only received a quick fix but require urgent extensive repairs in order to keep the plant running (see Figure 56).

Figure 56: Critical service water line with quick fix installed at Camden power plant

Water treatment at a glance:

- The housekeeping of the water treatment plant is in order.
- Capacity of the make-up water plant is sufficient.
- The plant is incapable of producing water with sufficient quality, due to a lack of properly functioning clarifiers.
- The manual operation is a potential risk for operation.

5.4.2.5 Technical Status of the Auxiliaries and other Systems

Coal and Ash: Even though the coal site nearby is connected via a conveyer belt, due to a lack of capacity the coal is trucked-in inconsistently from eight different sites. As a result, it shows quite inhomogeneous characteristics. The coal quality, which is mainly based on LHV, is on average 10% to 15% below the design range, which means that, ideally, about 20% of the coal should be rejected to ensure quality is maintained. The use of below-par coal results in high wear of the mills.

Pre-specification is carried out by the mines themselves, and Eskom's Primary Energy department carries out onsite verification. The installed online analyser for LHV, moisture, ash and sulphur is currently out of service and so the only way of analysing the coal is with a coal analysis report, which takes about 24 hours to arrive. This means that a timely reaction to the coal quality is not possible. The coal handling site is well managed but too small. The ash handling area has poor housekeeping. Due to a lack of funding, the ash dam has only been partially completed, so the current capacity of the ash pit is about 10 million m^3, instead of the projected 15 million m^3.

Coal handling site: All in all, the coal handling site is well managed but too small to stockpile enough coal to enable it to postpone using the coal until it has been analysed (see Figure 47).

Ash handling area: The ash handling area is subject to poor housekeeping. The lack of ash dumping capacity is one of the reasons why the plant risks being shut down in the near future.

OEM parts: Documentation of OEM parts is poor and leads to procurement of wrong or not fully compliant spare parts. There is a lack of spares in most areas of the power plant, and this is one of the major reasons for prolonged shutdown times.

Workshop: The workshop is well-equipped and clean. It provides sufficient options to conduct repair works at the site.

Auxiliaries at a glance:

- The coal quality is low and inhomogeneous.
- The coal supply is inconsistent.
- The coal handling site is small but well-managed.
- The ash handling site is neglected.
- There is a shortage of spare parts, and documentation of OEM parts is inadequate.
- The workshop is equipped sufficiently.

5.4.3 Technical Measures to Improve the Plant Condition

Boiler and draught Group: The maximum potential MW gain of the following measures is approx. 350 MWe.

There are several areas within the draught group - which includes the ID fan, FD fan, PA fan, preheater and fabric filters - in which repairs would result in immediate improvements and a positive effect on PLL. As discussed in the previous chapters, the draught plant has been identified as one of the major causes of high PLL. Even if operated at maximum load, the capacity of the ID fan is insufficient to guarantee an appropriate pressure in the furnace, which means that the boiler load has to be reduced. To address this problem, we suggest the following measures:

- Upgrading the ID fans
- Tightening or replacing the flue gas ducts
- Tightening or replacing the air heaters

Upgrading the ID fan's design capacity and, thus, increasing the airflow could in itself be enough to solve the problem. This would lead to an increase of required auxiliary energy and should be combined with the other proposed measures to reduce the negative impact.

We strongly recommend inspecting and repairing all potential sources of air ingress. This can be carried out during short stops and could lead to direct improvements. Beside the locations mentioned, it is also recommended to inspect the wall penetrations of the superheater and of shoot blowers, which would enable water and steam leakages to be identified at many positions throughout the plant. We recommend systematically repairing leaking valves, pumps etc., in order to improve the plant's efficiency and reliability. Many of these repairs can be carried out step-by-step, during short standstills.

Machinery: The maximum potential MW gain of the following measures is approx. 260 MWe.

The main areas requiring improvement are the condenser vacuum and the cooling towers. In order to solve both problems, it is necessary to check the cooling water circuit and refurbish existing clarifiers. On top of that, an overhaul of the existing condenser and cooling towers would lead to an increase in capacity. However, maintenance is only possible in winter, since high summer temperatures mean all cooling towers are needed and water consumption is also significantly higher.

Coal Handling: The online coal analysis system needs to be renewed in order to enable a reaction on the coal quality. Alternatively, the intermediate storage of coal in the stockpile for 24 hours or until the coal analysis is available would also provide an acceptable solution.

Water Treatment: In order to reduce the risk of water quality issues, the water treatment plant should be operated in automatic mode.

5.4.4 Power Plant Management

Currently, 412 employees and 1 200 contractors are working at the power plant. The rate of staff turnover is about 3%. There is a massive lack of engineering staff (4 out of 10 in C&I, and 4 out of 13 in electricals) because of uncertainty about the future of the site, which is causing staff migration and low morale. We highly recommend that a decision is reached on the future of the power plant as soon as possible.

Despite these challenges, the team is managing to keep the plant in operation. There are knowledgeable and experienced staff in the operating areas upon which this assessment focussed, and there is a comprehensive understanding of the issues at the plant. Furthermore, there is transparency regarding all key performance data for the plant (e.g. PLL). An extensive reward and incentive scheme is in place, based on yearly and monthly performance. A lack of employee training is notable.

Maintenance: The maintenance team is responsible for fixing problems reported by the operations team. The scope of the maintenance is defined by the engineering department. The maintenance group also takes care of spare-part planning.

There are seven maintenance KPIs for FY2023:

Inspections per year:	210 600 Mechanical 23 764 EMD 26 832 C&I
Annual maintenance budget specific costs:(total; per MW_e)	R901 million.; R616 700 /MW_e
Intervals between failures:	19 h
Failures per year:	3 224
Maintenance FTE/MW:	40 h
Share of outsourced maintenance:	Approx. 90%
Maintenance Contracts in place:	36 out of 37 (97.3%)

Operation: The operations team consists of 106 employees, working five shifts, 24/7, with 6 people working each shift.

There are 91 trips per year, so an average of almost eight trips per month, for the whole plant. These trips can be categorised as follows: operation caused trip (5), forced downs (62) and unsuccessful starts (24). Due to intensive monitoring of performance data, there is high transparency regarding the status of the plant.

There are six KPIs for FY2023 relating to operations:

Efficiency (design @full load):	~30%
Coal consumption:	775.2 t/h
Auxiliary Power consumption:	80 MW_e
Startup time for a cold start:	8 h
Number of damages due to bad operation:	0
Number of trips due to bad operation:	5

Outage: Camden’s outage planning is organised according to Eskom’s outage philosophy and to running hours of the low pressure (LP) turbine. As a result, a general overhaul (GO) is carried out every six years. In theory, the planning addresses the scope and timing of the outage activities. In practice, the outage philosophy cannot always be adhered to, especially in terms of timing, due to high grid demand and the resulting reduced availability of times for maintenance.

The last mini general overhaul (MGO), including outages, was conducted at Unit 7 and Unit 8 in December 2022 and included refurbishment of a superheater and replacement of a section of HP piping. The MGO at Unit 5 and the GO at Unit 2, which should have taken place in early 2022, were both postponed because of national electricity capacity constraints.

100% of the outage work is outsourced but planning is carried out exclusively by Eskom staff.

Procurement is partially organised locally and partially carried out centrally, depending on the total value of the contract.

5.4.5 Technical Profile of Main Plant Areas

Boiler and related Plant Area:

All eight boilers at Camden station have the same design. Each boiler has five coal bunkers which store up to 400 tons each. The bunkers supply the boiler at full load for up to 20 hours. This means that even a malfunction of the conveyor system or of coal production in general would not directly result in operational restriction.

Five mills are installed per boiler. Using coal of the specified quality, a maximum of four mills is needed for full load operation. One mill was designed to be spare. The pulverised coal is burned by 20 front-fired ICAL & Steinmüller PF-burners.

Firing System	
Manufacturer	ICAL & Steinmüller
Type	PF Burners
Number of burners	20
Coal mass flow [t/h]	775.2
Pressure [bar, absolute]	110
Temperature [°C]	543
Mills	
Manufacturer	Lösche
Mill capacity [t/h] – per mill	27 t/h per mill, required 90.7 t/h in total per unit
Coal supply	
Coal supply (truck, mine)	previously from open cast mine with con-veyor belt, now via truck
Coal storage capacity on-site [t]	n.a.
Boiler bunker capacity [t]	16 000 in total
Precipitators/ Flue gas cleaning	
Manufacturer	Diamond (Retrofitted 1993)
Type	Bag filters (FFP)

Machinery and Electrical:

Turbine	
Manufacturer	C.A Parsons
Type	C.A Parsons 202MW with Siemens LP Up-grade
Casings (HP-IP-LP, double/single flow)	1 HP (single flow), 2 LP (double flow)
Main steam pressure [bar, absolute]	110
Main steam temperature [°C]	543
Reheat steam pressure [bar, absolute]	none
Reheat steam temperature [°C]	none
Cold end	
Condenser	Dual-pressure surface type
Cooling tower	Hyperbolic natural draught, wet cooling
Generator	
Manufacturer	C.A Parsons
Terminal voltage	16.5 kV (50 Hz)
Rating	200 MW_e
Cooling system	Stator core: Hydrogen Stator windings: Demineralised Water
Transformer	
Manufacturer	Unit 1-6,8: Siemens Unit 7: Ferranti
Terminal voltage primary/ secondary	16.5 kV/420 kV
Placement	outside

5.5 Duvha Power Plant

The Duvha plant is more than 40 years old. Due to insufficient maintenance, the plant suffers from a high load loss. In March 2023, almost 30 percent (780 MW) of the installed capacity of 2 875 MW (net) was not available due to PLL. One of the main PLL contributors is the draught plant. Even if operated at maximum load, the ID fan capacity is not high enough to guarantee appropriate pressure in the furnace. This can be mitigated to a large extent by tightening the flue gas ducts and air heaters. We strongly recommend also inspecting and repairing all other potential sources of air ingress at the boiler.

A significant reduction in the steam temperature was noted, caused by leaky spray injection valves. We strongly recommend changing or repairing the valves immediately. Besides the PLL, these leakages can also cause potential damage due to thermal shock. There are many other water and steam leakages in many places around the plant. We recommend systematically repairing leaking valves, pumps, etc., in order to improve the plant's efficiency and reliability.

One of the main areas requiring improvement is the condenser vacuum, the root causes have been identified by the power plant and solutions must be implemented during future outages, such as the upcoming outage for unit 1 in September 2023,

We strongly recommend focusing the recovery activities on efforts to reduce the losses by at least 80%. This requires an according investment into necessary spare parts (e.g. HP heaters). This can only be done if maintenance and outage are executed to the full extent, thereby enabling all the deficits and leakages to be fixed. Many of the repairs can also be carried out during short stops and would lead to direct improvements.

The management team seems to be willing, eager and competent to drive the recovery process. Given the opportunity, we believe it is skilled and capable enough to manage the turnaround itself.

5.5.1 EAF and PLL

The Duvha power plant comprises six 600 MW coal-fired units (gross capacity). Each of the six boilers feeds its own turbine with steam. The station was originally commissioned between 1978 and 1984. The detailed commissioning dates are shown in Table 15. In the course of its operational lifespan, the plant has suffered some major damage resulting in stops lasting longer than 12 months. These are:

Unit 2: LP Turbine damage of last stage (January 2003 – February 2004)

Unit 4: Turbine damage due to over-speed (February 2011 – January 2013)

Unit 3: Boiler over pressurisation (incident in March 2014)

With regards to the damage at Units 2 and 4, the repairs were carried out and the units went back to regular operation. Unit 3 was taken completely out of operation after the accident in March 2014.

Unit	1	2	3	4	5	6
Commissioning Date	08/1980	10/1980	09/1981	07/1982	03/1983	02/ 1984
Gross installed capacity [MW]	600					
Nominal installed capacity [MW]	575					

Table 15: Key figures for Duvha power plant[14]

Over the past five financial years, the **EAF** has been in the range of 42.30% (FY2021/2022) to 48.28% (FY2020/2021). For FY2022/2023 YTD, the value is currently at 40.34%.

Year	Plant	Unit 1	Unit 2	Unit 4	Unit 5	Unit 6
2019	47.21%	19.63%	66.29%	63.71%	55.32%	24.90%
2020	44.62%	54.33%	49.88%	62.23%	28.88%	no data
2021	48.28%	50.99%	56.06%	9.59%	38.86%	54.39%
2022	42.30%					
2023 YTD	40.34%					

Table 16: EAF at Duvha power plant (FY2018/2019–FY2022/2023) [15]

The EAFs of the units were taken from the vgbe KISSY database. The data for this is supplied by Eskom on a yearly basis. The data for FY2021/2022 has not yet been transferred, as of April 2023.

The low EAF is caused, in the main, by significant PLL. The main sources of PLL are shown in the next figure. As can be seen, many different components have an influence on the PLL. The main components are the boiler, the draught plant, the feed water plant, the gas cleaning plant, the mills and the turbine.

[14] Data supplied by Eskom as part of the initial documentation package

[15] Data supplied by Eskom as part of the initial documentation package and KISSY data

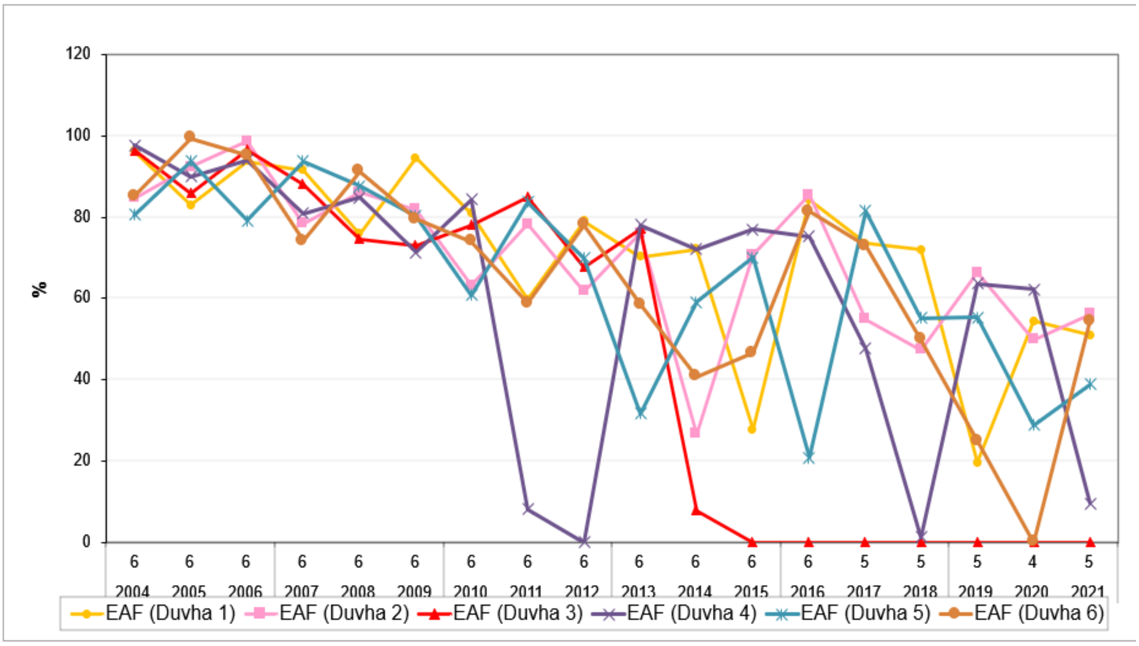
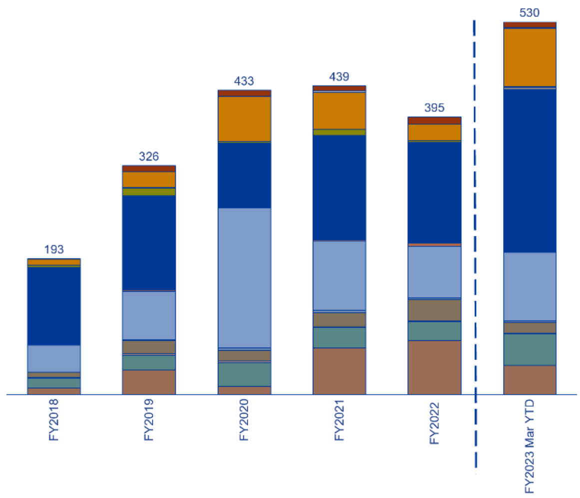


Figure 57: EAF at Duvha power plant (FY2003/2004–FY2020/2021)

The absolute numbers of the PLL for the individual components has fluctuated over the years, showing a tendency to increase from FY2017/2018 to FY2020/2021 and a slight improvement in FY2021/2022. At the beginning of FY2022/2023, a significant increase of the PLL can again be identified. The reason for this can be found in the dramatic increase of losses at the draught plant.



Mwloss	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023 March YTD
Ash Plant	0.30	8.34	8.64	7.13	9.75	8.36
Auxiliary System	0.00	0.01	0.12	1.88	0.01	0.21
Boiler	9.29	23.14	64.04	52.97	24.31	83.76
C & I	0.01	0.71	0.03	0.05	0.00	0.16
Coal Plant	2.45	10.81	2.49	8.26	1.84	0.69
Cooling Water	0.06	0.34	1.09	0.55	0.20	2.98
Draught Plant	110.37	133.72	90.67	148.38	143.05	231.23
Electrical	0.26	1.78	0.70	1.85	4.19	0.83
Feed Water	38.70	68.93	199.07	98.24	74.01	96.95
Fuel Oil	0.07	0.85	3.81	3.89	2.06	2.51
Gas Cleaning	7.88	19.18	14.33	20.32	31.11	15.53
Generator	0.25	2.03	3.14	0.40	0.79	0.22
HV Yard	0.02	0.00	0.00	0.00	0.00	0.00
Mills	14.86	20.87	33.55	28.72	26.28	45.70
Turbine	8.82	35.33	11.66	66.82	77.39	41.24
Total	**193**	**326**	**433**	**439**	**395**	**530**

Ash Plant, Boiler, Coal Plant, Draught Plant, Feed Water, Gas Cleaning, HV Yard, Turbine, Auxiliary System, C & I, Cooling Water, Electrical, Fuel Oil, Generator, Mills

Figure 58: PLL contributors at Duvha power plant (FY2017/2018–FY2022/2023)[16]

[16] Eskom data sent by Lebohang Kubayi per email on 11 May 2023

5.5.2 Technical Status

The plant has been running for more than 40 years. Maintenance and outages have been deferred and/or not fully executed due to the tight supply situation. Hence, the overall health of the plant is not good.

5.5.2.1 Technical Status of the Boiler

During the visit, the team walked through the boiler house. The **housekeeping** was acceptable (see Figure 59). Levels of dust, ash or coal were not high. Furthermore, no safety-related issues were noted.

Figure 59: Duvha boiler level 0 m

In the boiler house, numerous **steam leakages** at various positions were visible. They were both on valves and on the piping itself (see Figure 60). The team was not presented with evidence of a systematic approach to addressing leakages. It seems as if leakage has become an accepted norm over time and that it has been this way for a while. We strongly recommend that repair work is started immediately.

Figure 60: Leakages at Duvha boiler house

Steam temperatures at the boiler outlet are lower than design. We observed a significant temperature differential between the different sides of the boiler. The spray injection valves were identified as the root cause – these valves are obviously not tight. This results in the temperature of SH steam being far too low (479°C – 530°C, see Figure 61). The desired operational temperature is 535°C. Such a temperature reduction clearly leads to a significant decrease in plant efficiency and output. A reduction from 535°C down to an average of 500°C corresponds to a power loss of approximately 40 MW.

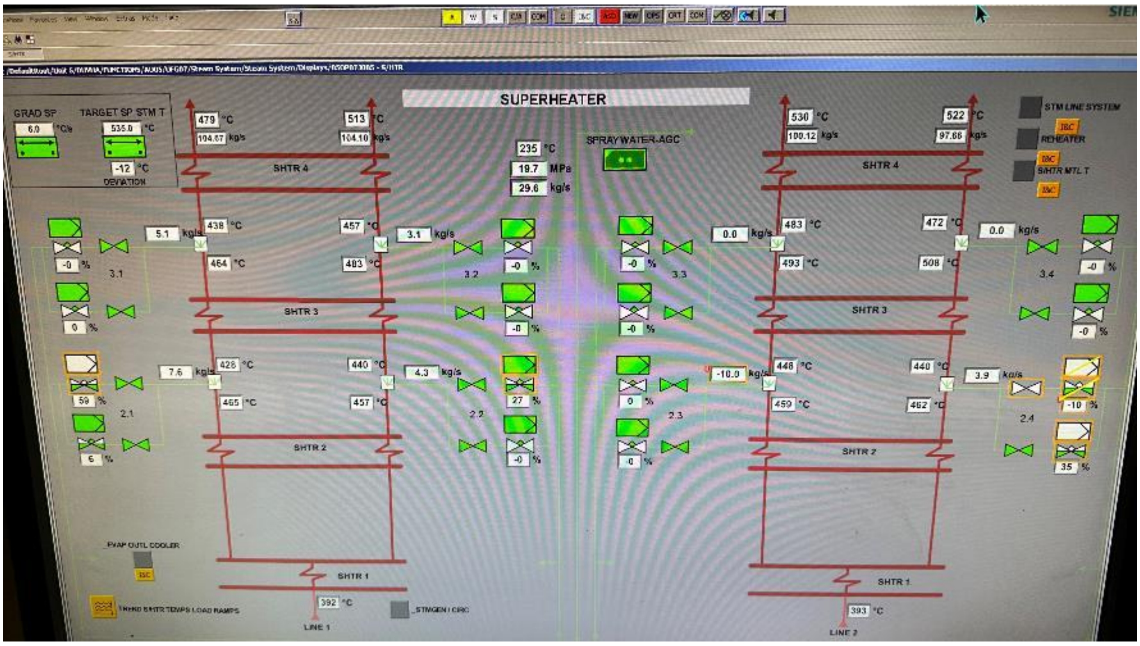


Figure 61: Temperatures of SH inlets and outlets at Duvha

The engineering manager reported that the site has a good knowledge of past boiler tube failures (BTF). According to the engineering team, this knowledge results into actions and measures. There are plans to exchange tubing in areas where several tube leakages caused by pitting were found. The power plant has developed a concept for the pitting issues. Furthermore, we were told that care of tubes has improved as a result of lessons learnt, thus helping to avoid similar damage in the future.

However, with regards to other issues identified as causing tube leakage, the Eskom team has not managed to develop methods to prevent future damage. Leaking tubes are exchanged during outages, but continuous effort is required to prevent the same type of damage appearing again in the future.

Draught plant: Two ID fans draw the flue gas out of the boiler to the chimney. At Duvha, there are problems with the ID fans because they always operate at maximum load. This is caused by air ingress to the duct and the air preheater. The site team reported that, after outage, the ingress into the ducts is quite low but, after a short period of time, it increases significantly again. Furthermore, the plant was advised by Megawatt Park to operate the boiler at O_2 levels as per original design. This specification was released as a consequence of the Duvha 3 accident, described further in paragraph 5.1.4.4. Hence, the cumulated air ingress to the system at Duvha leads to a PLL of 110 to 280 MW.

Mills were not reported as a big issue, as coal quality seems to be quite in order. As the coal is delivered by the nearby open cast mine, the quality remains consistent over time. In the past, the coal was mainly trucked in and there was a problem with high wear rates of the mills. Mass meters at the mine and at Duvha's take-up are used for accounting. The overall condition of coal and of the ash plant was acceptable. Nevertheless, on the day of the visit, Unit 5 was suffering a load restriction due to two mills being out of service.

Eskom uses a **Thermal Index** (TI) to track the thermal excursions on boiler outlet headers, main steam pipework and hot reheat pipework. The TI is a long-term indicator of plant health for the high temperature/high pressure components. The data for the TI can also be used as a check on the operational stability of the boiler, as the thermocouples indicate time spent above normal operating conditions. More detail on the TI is listed in section 5.1.4.5.

The TI report for Duvha for FY2022/2023 shows that the header temperatures exceed limits and are unacceptable, while the HP pipework is well within limits. This is due to the boiler over-firing as a result of the poor vacuum conditions and air-heater leakages and poor HP heater availability. This data confirms the conditions resulting in high PLL losses: It has significant long-term implications for the creep life of the headers.

Tolerance Limits for Thermal Index:	
< 35	Favourable
36- 73	Acceptable
> 73	Unacceptable

	SYSTEM	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23
DUVHA	Header TI	198	857	2088	372	998	414	1391	4357	3392		4902	0	1246
	Main Steam TI	1	2	0	9	2	2	0	4	3		7	85	85
	Hot Reheat TI	5	32	25	14	35	21	15	9	60		0	0	82

Table 17: Extract from Duvha's Thermal Index report

Boiler at a glance:

- The Duvha boilers – taking their age into account – are fit for purpose.
- The excess air ingress is clearly quite high. The ID fan operates at maximum load, which results in reduced load and PLL.
- There are many steam leakages in the boiler house.
- BTL caused by pitting seems to be understood and resolved – RCA-based preventive mitigation measures for other damage mechanisms need to be developed.
- Coal and ash handling are satisfactory.
- Spray injection valves are passing and need to be maintained / repaired.
- Steam temperatures are below design values.

5.5.2.2 Technical Status of the Machinery

With respect to the **cold end,** the condenser vacuum is not adequate, which has a severe impact on operation. Especially at Unit 1, the problem has become so serious that steam ejectors are permanently in full operation to keep the vacuum on a level that enables operation. This measure results in very high noise emissions all over the site – which is a serious health and safety issue – as well as high PLL. The station has identified the root causes and the solutions should be implemented during future outages.

Potential causes of insufficient condenser vacuum:

a) Insufficient performance of the cooling towers due to damaged cooling fills, causing increased cooling water temperatures. The Duvha site team reported several problems with the cooling towers in the past.

b) Clogging of condenser tubes by debris and broken internals from cooling tower that become brittle. Clogging of tubes by debris and plugging of leaking tubes reduce cooling water flow and heat transfer area of condenser.

c) Deposits in condenser tubes, such as calcium carbonate scaling or fouling from suspended solids or biological matter.

d) Air ingress into low-pressure steam at the LP turbine or condenser. This leads to air blanketing of condenser tubes and rise of condenser pressure.

e) Insufficient cooling water flow.

Often, there is a combination of possible causes: b) and c) can also lead to corrosion in condenser tubes and cause tube leakages. As a first step, all of the above potential causes need to be checked during inspections.

During the outage scheduled for September 2023, a detailed condenser inspection needs to be performed before cleaning the water-boxes, to establish the status of corrosion and check for b) and c). A leaking test should identify leaking condenser tubes, which then need to be plugged or renewed. Tube blockages must be removed and tube fouling or scaling must be removed using appropriate methods. According to the findings of the inspections, the root causes of the poor condenser vacuum must be addressed and future operation must include precautions to avoid these causes in future. For example, we recommend bringing the Taprogge system back into service, to keep condenser tubes clean.

An incident with cooling water pumps was reported. A power cable was damaged during works on-site. As a consequence of this, two of the four cooling water pumps for Duvha Units 5 and 6 and the associated control system were de-energised. Due to the lack of cooling water, the condensate pressure increased rapidly and the turbine protection system responded. According to the incident report, the root causes were improper work preparation and execution, lack of maintenance of the UPS for the control system (battery defects had been known about for a whole year) and lack of communication between departments within the plant. The only positive aspect was that the turbine protection worked properly.

Turbine: The turbine hall was reasonably clean, as the housekeeping was conducted well. However, the noise level was very high. The reason for this could not be directly identified. Leakage was visible on Unit 2's feed water booster pump. Unit 1's turbine had a leakage directly at the turbine. This leakage will increase further and represents a health and safety risk. Therefore, it needs to be repaired during the next outage.

Based on the fact that there has been no major damage to the turbines since 2018, it can be concluded that the maintenance strategy for the steam turbines is effective.

Figure 62: Leaking pump in Duvha's boiler house

HP heater: Based on plant data, the current unavailability of the HP heaters is due, in main, to their expired lifetime. Most of the HP heaters are plugged by more than 10%, which is usually a level at which the HP heaters need to be replaced. We were told that this problem will not be resolved for Unit 1 after the outage. A new HP heater is on-site but will be installed in a different unit, as the one there is in even worse condition. This is why Unit 1 cannot be operated at full load, even after the outage. This situation does not only impact PLL, it also impacts boiler operations by limiting the firing regime (cold feed water requires higher combustion temperatures which are limited by boiler design). Meanwhile, there is a purchase approval process underway to exchange six HP heaters, and the plant is reviewing the potential exchange of a further five heaters.

The site team reported that the **cooling tower** performance is currently below design. There is a project to look at repacking of the towers to get back to design values. The current mitigation approach is to clean the fills and ponds during the outage opportunity.

Machinery at a glance:

- Vacuum problems of the condenser should be fixed during the next Unit 1 outage which has been postponed from July to September 2023.
- Many steam leakages have been found in the turbine hall.
- The turbines seem to operate properly.
- The next outage opportunity should be used to enhance the cooling tower performance.
- HP heaters have reached their end of life and need to be replaced.

5.5.2.3 Technical Status Electrical and C&I

In the past, the electrical **generator** was the main source of unavailability in the turbomachinery equipment. Generator stator damage (single event on Unit 4) resulted in an outage from April to November 2018. Eskom provided an investigation report about the fault. Besides that, a generator earth fault was reported. Earth faults can appear at any time. Normal outage checks concerning resistance have to be carried out and an online earth fault detection system has to be in place. With regards to the present incident, the online monitoring system was working properly. The outage philosophy for the generators has not been changed.

The following table shows lost operating hours due to generator H_2/seal oil issues – seven events were reported between 2018 and 2022. Units 1, 2, 4 and 5 were affected. The table below shows the hours lost due to seal oil issues and H_2 leakages – the latter being the main contributor. The seal oil events were due to oil/gas differential pressure.

	Lost operating hours	**Number of incidents**
H_2 leakage	4232.1	4
Seal oil	14.28	3

Table 18: Overview of generator incidents at Duvha (2018–2022)

The incident report (4 February 2022) showed that, when starting up the unit after a trip, the motor of the AC sealing oil pump broke. The decision was made to remain connected to the grid with the (reserve) DC pump. In the course of the event, on 4 February 2022, there were various deviations from the norm, as well as oil leaks (refilling from the waste container) and, as a result, major damage. As a result of the incidents, some basic questions need to be addressed: Has the value of the generator auxiliary systems been correctly assessed? Is the concept of the sealing oil supply (but also for other areas such as cooling water and H_2 supply) state-of-the-art? Spare parts should also be available for such a sensitive area, and repair/replacement should be given preference over emergency operation, if the vulnerability of the auxiliary system is known.

With respect to the **C&I system,** Units 1 to 6 are equipped with the Siemens SPPA T3000 after a major refurbishment project was concluded in 2021. There are spares available and the system is still supported by Siemens.

The water treatment plant DCS is ABB Symphony Infi90 DCS. This system was installed between 1999 and 2000. The system is becoming obsolete, but ABB agreed on a migration path where parts of the system are replaced in smaller projects, to extend the life of the system.

Electrical and C&I a glance:

- Several generator incidents caused unit trips and, thus, decrease of EAF.
- The C&I system is in good order, whereas the water treatment C&I system needs an upgrade in order to enable automated operation.

5.5.2.4 Technical Status of the Water Treatment Plant

The central make-up water plant was visited during the site walk. The capacity of the make-up water plant is sufficient to meet the consumption needs of the site with water of adequate quality. The raw water source is surface water coming from Vygeboom and Nooitgedacht dams.

Figure 63: Measurements at the Duvha water treatment plant

However, the water make-up plant is not in good condition. Nearly all online measurement instruments installed in the plant are not working (Figure 63). These photos of the sodium / TOC measurements display implausible values.

The plant as a whole has been operated manually for more than 10 years, despite the fact that the plant was upgraded and fully automated by ABB Automation in 2000. Also, the re-generation of the resin is carried out manually. This manual mode of operation is a risk, as it leads to a high potential for errors, which also contributes to unavailability. Also, the site team carries out quite a lot of offline sampling: Water samples are taken and analysed twice a day for the key performance indicators.

Water treatment at a glance:

- Capacity of the make-up water plant is sufficient despite high losses due to steam and water leakages at the plant.
- The plant is capable of producing water of sufficient quality.
- Manual operation poses a potential risk for operation.

5.5.2.5 Technical Status of the Auxiliaries and other Systems

Coal and Ash: As the coal is delivered by the nearby open cast mine, the quality is consistent over time. The next table shows typical coal composition.

In the past, the coal was mainly trucked in, which led to problems with high wear rates of the mills. Mass meters at the mine and at Duvha's take-up are used for accounting. The overall condition of coal and of the ash plant was acceptable.

Fixed Carbon %	45.70
Volatile Matter %	20.24
Total Moisture %	7.60
Ash %	26.89
Gross Calorific Value MJ/kg	21.22

Table 19: Coal composition at Duvha, February 2023
Source: Duvha power plant

Emission situation: Duvha's Units 5 and 6 (Electrostatic Precipitator) have some problems meeting the emission limit value (ELV) for particulate matter (PM) of 50 mg/Nm³. For NO_x, all operating units meet the current ELV but will not meet the 2025 ELV without retrofitting measures. The same applies to SO_2.[17]

[17] Monthly emissions report available on internet – as of 19 April 2023. The legal emission limit values (ELV), beginning from 2025, were taken from the "Consistent Data Set for Eskom Generation Plant Revision Date September 2020 (Overview of all plants)".

The **spare parts warehouse** and maintenance workshop were also visited. No issues were established with regards to spare parts. The warehouse was in reasonable order. The workshop is well-equipped and clean. It provides many options to conduct repair work at the site.

Auxiliaries at a glance:

- The coal and ash plant are in good working order.
- Coal quality is not an issue.
- PM emissions are just below limit values for some units.
- PM, NO_x and SO_x emissions will be an issue after 2025.
- The spare-parts warehouse and maintenance workshop are well equipped.

5.5.3 Technical Measures to Improve the Plant Condition

Boiler: The maximum potential MW gain of the following measures is 300 MW**.**

There are several issues relating to the boiler, where repairs would result directly in improvements and an immediate positive effect on PLL. As discussed in previous chapters, the draught plant is one major component causing high PLL. Even if operated at maximum load, the capacity of the ID fans is not sufficient to guarantee appropriate pressure in the furnace. Therefore, to compensate this, the boiler load has to be reduced. This problem can be reduced with the help of the following measures:

- Tighten the flue gas ducts.
- Tighten the air preheaters.
- Challenge O_2 content due to Duvha incident (theoretic issue)

We strongly recommend the inspection and repair of all other potential sources of air ingress. This can also be done during short stops and would lead to direct improvements. In addition to the locations already mentioned, we recommend that the wall penetrations of superheater, reheater and soot blowers be inspected.

Furthermore, we recommended carrying out a detailed analysis of the procedure for operating the boiler with higher excess air compared to the design value. If the O_2 content can be reduced, improvement could be achieved.

As mentioned in chapter 5.5.2.1, we identified a significant reduction in steam temperature caused by leaky spray injection valves. This results in reduced efficiency and power losses. We strongly recommend urgently changing or repairing the valves. Not only do they lead to PLL but the leakages can also cause potential damage due to thermo shock.

In addition to these, there are many other water and steam leakages in many places throughout the plant. We recommend systematically repairing leaking valves, pumps, etc., in order to improve the efficiency and reliability of the plant. Many repairs can be carried out step-by-step during short standstill periods.

Machinery: The maximum potential MW gain of the following measures is 140 MW**.**

One of the main areas requiring improvement is the condenser vacuum. During the upcoming outage in July 2023, the root cause of the problem needs to be investigated and resolved (see chapter 1.1.2.2.). VGB's VGB-S-130 standard "Acceptance Test Measurements and Operational Monitoring of Water-Cooled Surface Condensers" can provide a helpful guide to locating the root cause by analysis of measurements during operation.

The cooling water flow needs to be checked, as the erosion corrosion on brass tubes can be reduced by reducing flow velocity. In case of condenser retubing, we highly recommended following VGB's standard "Tubes for Condensers and other Heat Exchangers for the Operation of Steam Turbine Plants". There are guidelines for copper alloys (VGB-R-106), stainless steel (VGB-R-113) and titanium (VGB-R-114) that provide advice on the selection of tube material, contracting, quality assurance, installation and operation.

The HP heaters have reached their end of life – their limited functionality is also a significant PLL contributor. Hence, their full replacement is recommended – even if only 10 MW could be gained, this would still correspond to R87.6 million per year[18].

Generator: To ensure proper quality control of generator components, we recommend carrying out inspections and tests according to the vgbe standard S 166 "Quality Assurance in the Manufacture of Generators".

Water Treatment: In order to reduce the risk of water quality issues, the water treatment plant should be properly equipped with online measurements and better instrumentation and automation of the plant. The latter is already in planning and needs to be implemented. Also, the new vgbe S 455 standard "Cooling Water Systems and Cooling Water Treatment" is helpful.

More use needs to be made of the **maintenance workshop**, especially in the view of the backlog of the maintenance activities regarding leakages and air ingress. The vast possibilities for repair and manufacturing parts in-house should be exhausted.

5.5.4 Power Plant Management

Currently, 788 employees are working at the power plant. Although the day-to-day operation of the power plant is challenging, the coherency and team spirit of the plant's management seem to be quite high. The team is eager and motivated to manage the turn-around of the EAF development. It has the ability to keep the plant in operation despite all the issues.

[18] 1 MWh accounts for R1 000 per 10 MW. 8 760 hours per year result in R 87.6 million.

There are knowledgeable and experienced people in the functional areas upon which this assessment focused. There is comprehensive know-how about plant issues and there is transparency with regards to the plant's status and all its key performance data (e.g. PLL).

The PSGM would like to have more authority, which is embedded in a lean governance structure. From his perspective, removing red tape should be one of the top priorities, in particular with regards to staffing and procurement processes. Moreover, the PSGM believes that incentive schemes would contribute significantly to improving the situation. Staff at the plant need to see real evidence that their work is appreciated. Resource shortages are a big issue – there are more than 100 vacant positions in the maintenance, operation and outage teams alone. There is a suggestion box in place, but there is a lack of budget to reward and implement ideas.

Moreover, the procurement process takes too long, and it is particularly difficult to access funds in order to procure spare parts in time.

Maintenance

The maintenance team is responsible for fixing the issues reported by the operation team. The scoping is defined by the engineering department. The maintenance group also takes care of spare-part planning.

Currently, 247 people are working in the maintenance department – 203 contracting staff are permanently on-site. According to the operational plan for FY2022/2023, the target for own maintenance staff is around 290, so there is a large number of vacancies.

Eskom's maintenance performance index is used to measure performance. The following figure reflects the status as of February 2023. However, the general statement regarding the MPI (in chapter Power Plant Management 5.1.1) retains its validity.

KPAs	KPIs	Apr-22	Feb-23	Improvement August vs Sept	Support Needed/ Way Forward		Due Date
Cost	Real cost rate year on year	-5	-11	9 % Improvement	Buyers to conduct Cost comparison and Line manager to manager their finances on montly basis	Line Managers	Ongoing
	Mantenance Opex Variance	143%	162%	19% Decline	Finance to reiview budget allocation	Finance	31.03.2023
People	Resouce utilisation	17%	16%	No Movement	Identify technical employess that are nologer working in the plant and remove them from the resource availability list	All Line	10.03.2023
					Perform root caurse analysis on late/ early capturing of hoour worked and impliment action planns	Langelihle	15. 04.2023
Mantenance Work	MSMW Progress	5%	95%	90% Increase	Dedicated Resources/ Additional time required in order to accelerate completion of this project	Langelihle	30.06.2023
	PM Compliance	93%	95%	2% Increase	Maintenance KPI perfomance to be part of production meeting Agenda	Morris	31.03.2023
	Schedule Compliance	90%	96%	6% Increase	Enforce timely completion of paper work from the Supervisors/ Engineering and Operating by issuing NCR for none cmpliances	All Line	31.03.2023
	Emergent Work	20%	37%	17% Decline	Fast tract the implimantation of Maintenance strateges for the station to reduce unplanned work/emergencies	all	30.06.2023
	Scope Stability	1%	6%	5% Decline	Stable perfomamnce within the terget		
	Notification Response Compliance	76%	97%	21% Increase	Stable perfomamnce within the terget	Langelihle	31.03.2023
	Online backlog	-21%	12%	15% Increase	Implementation of maintenance strategies will positively contibute in identifying deficiencies before they become breakdowns,	All	31.03.2023
	Statutory Order Violation	5.00	3.22		Within the terget		
	Outage slip	76%	39%	36% Increase	Enginering to submitt all the scope of work on time for proper planning on outage side to avoid slips	Engeneering and Outage	Ongoing
Support	Critical Spares	64%	76%	12% Increase	Increase the rate of purchase order placement by procurement and expedite delivery of dates.Material Management has taken the initiative of expediting	Procurement	Ongoing
	Strategic Spares	56%	70%	14% Increase			
	Operational Spares	85%	87%	2% Increase			
					Material Management has taken the initiative of expedite all critical spares and Strategic Stpares purchase orders	Material Management	Ongoing

Figure 64: Status of Duvha's MPI

Operation

The operation team works in four shifts, 24/7, with 60 employees working each shift. At present, there are about 60 vacancies, with a target headcount for the operation team of 300.

There are 70 trips per year, so approximately six trips per month for the whole plant. Due to intensive monitoring of performance data, there is high transparency regarding the plant's status.

Outage

Duvha's outage planning is according to the Eskom outage philosophy. This refers to the scope and timing of the outage activities. There is one change regarding the LP inspection (kindly refer to the next figure). The latest outages were conducted at Unit 2 (MO) and at Unit 4 (MO), as well as a C&I upgrade in 2021.

A total 95% of the outage work is outsourced, with just 5% conducted by Eskom personnel. From the department's point of view, there are not adequate resources for more, as the same team that is expected to carry out outage work must also do the planning. A new blueprint structure has been approved and now it is matter of starting the recruitment process. Currently, 13 people are working in the outage department but the target, according to the operational plan for FY2022/23, is 23.

Allocation of funding is based on the defined philosophy scope. A request for extra funding needs to follow the scope of work variation process. The only challenge has been that funding is released late, which normally jeopardises the unit's return to service as per plan. Procurement is mostly done locally, although some of the big contracts are handled centrally, at Megawatt Park, e.g. Howden and LHM. The unavailability of spares was reported to be a serious issue, causing outage slips and post-outage unavailability. It is apparently normal that some of the planned measures cannot be executed in time because of missing spares. Different approaches are in place for strategic, critical and operational spares. Not all necessary parts seem to be defined as spare parts, which also leads to procurement delays. Also, budget shortages prevent the procurement of non-stock items before an outage.

The limited number of qualified suppliers of spare parts poses a general problem, resulting in long lead times, which are exacerbated by the long internal procurement processes (in particular if Megawatt Park is involved in the procurement of strategic and high-value spares),

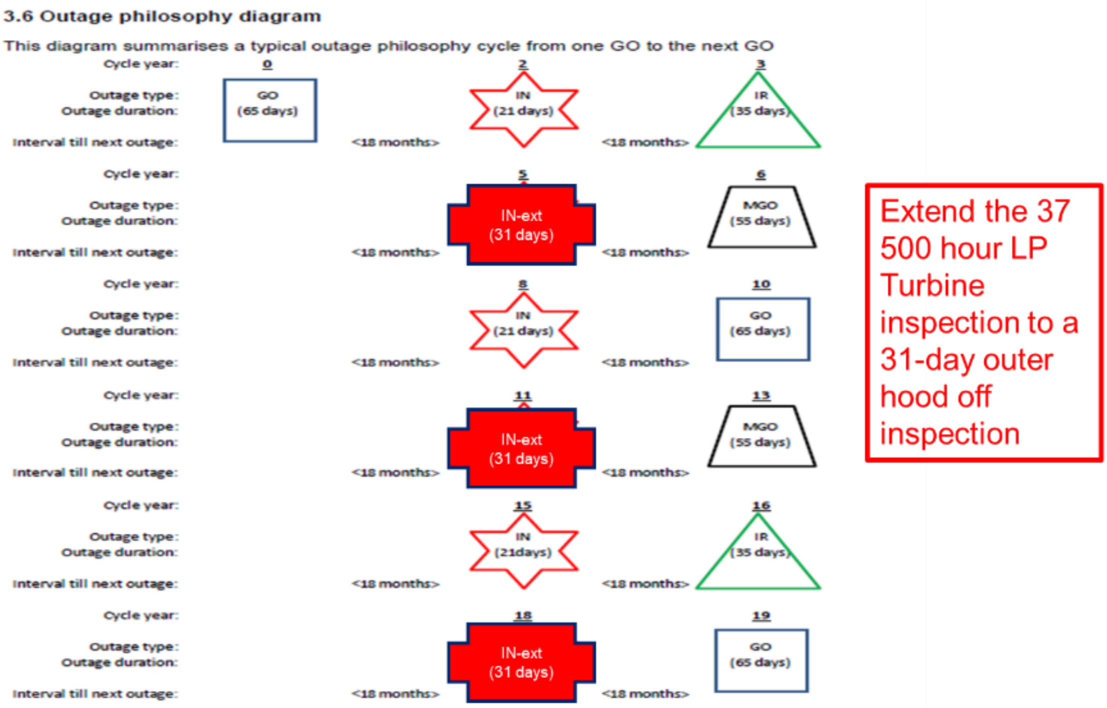


Figure 65: Outage sequence in Duvha

5.5.5 Technical Profile of Main Plant Areas

Boiler and related Plant Area:

All six boilers at Duvha station have the same design. They are designed as once-through Benson type boilers. Each boiler possesses a bunker system to store enough coal for 12 hours operation at full load. This means that even a malfunction of the conveyor system or coal production in general would not directly result in operational restriction. The coal, which is provided by the nearby open-cast mine, is fed to the coal mills. Six mills are installed per boiler. Using coal of the specified quality, a maximum of five mills are needed at full load operation. One mill was therefore designed to be spare. The pulverised coal is burned by 24 Steinmuller circular burners (boxer arrangement).

Manufacturer	Steinmüller Afrika
Type	Benson
Coal mass flow [t/h]	260
Pressure [bar, a]	165.5
Temperature [°C]	507
Firing system	
Number of burners	24
Type of mills	Units 1–4 vertical spindle (ball and ring) Units 5–6: vertical spindle (roller type)
Mill capacity [t/h] – per mill	Original 65 t/h → derated to 60 t/h
Reheat system	
Pressure [bar, a]	37.5
Temperature [°C]	507
Coal supply	
Coal supply (truck, mine)	Open cast mine with belt transport
Coal storage capacity on-site (t)	165 000
Boiler bunker capacity (t)	24 120
Precipitators/ Flue gas cleaning	
Manufacturer	Fabric filter: ABB (Retrofit 1993) Eletrostatic precipitators: Lurgi SA
Type	Units 1–3 filter bag (FFP) Units 4–6 electrostatic precipitator
Wet ash handling	

Machinery and Electrical:

Turbine	
Manufacturer	Alstom
Casings (HP-IP-LP, double/single flow)	1 HP, 1 IP, 2 LP (double flow)
Main steam pressure [bar, absolute]	165.5
Main steam temperature [°C]	535
Reheat steam pressure [bar, absolute]	37.5
Reheat steam temperature [°C]	535

Cold end	
Condenser	Dual-pressure surface type
Cooling tower	Hyperbolic natural draught, wet cooling
Generator	
Manufacturer	GEC Turbine Generators
Terminal voltage	22 kV (50 Hz)
Rating	666 MVA
Cooling system	Stator core: hydrogen at 400 kPa Stator windings: demineralised water
Transformer	
Manufacturer	AEA Electric (SA) Ltd.
Terminal voltage primary/ secondary	22 kV / 420 kV
Placement	Generator Transformer

5.6 Grootvlei Power Plant

The Grootvlei power plant is more than 50 years old. According to Eskom's planning, it is going to be shut down in the course of 2026 and 2027. The plant had been mothballed for 18 years – hence, the lifespan of the equipment is less than the plant age. Moreover, a lot of the components have been replaced or completely refurbished as part of the return-to-service programme. However, it should be noted that in 2017 the Eskom management took a strategic decision to shut-down the plant in 2019 and 2021. This has affected the planning and resulted in the reduction of maintenance, resources and spares procurement. The reduced funding has contributed to the current status of the plant. It affected the performance as the decision to ramp down was revised twice (2012 and 2021) which resulted in continued operation without maintaining the plant according to standards.

Today, three units are operated with a gross electricity generation capacity of 600 MW. Although some investigations about a further lifetime extension were conducted, no decision has yet been taken. A vote on whether or not to extend the plant's lifetime is necessary for strategic planning security. In the case of an extension, such a decision would encourage the power plant staff to intensify their maintenance activities and to execute outage work as per the defined scope. A clear decision here would encourage immediate measures to implement projects for reducing PLL.

As of March 2023, PLL accounts for 58 MW. The boiler, including the mills and the draught plant, is a key contributor to PLL. As the contractor for mill servicing was recently changed, an improvement in the technical status can be expected. With respect to the air ingress, it is necessary to inspect and repair all potential sources, e.g. by tightening the flue gas ducts and the air preheaters. This can also be done during short stops and can be expected to lead to direct improvements. Furthermore, there are a lot of water and steam leakages in many places throughout the plant. We recommend systematically repairing leaking valves, pumps, etc., in order to improve the plant's efficiency and reliability – especially in view of the limited make-up water capacity. Many repairs can be even carried out step-by-step during short standstills.

The cooling water treatment needs to be optimised. Currently, deposits in condenser tubes, such as scaling or fouling, cause insufficient condenser vacuum, which is also a significant contributor to PLL. Outages should be used as opportunities to clean the tubes and to optimise the cooling water treatment system.

The storage conditions in the spare-parts warehouse have to be improved considerably. There is a serious problem with pigeon droppings, and measures to prevent birds entering the warehouse need to be urgently implemented. In addition, there needs to be proper dirt and dust protection (e.g. protective cover) for components and equipment parts.

5.6.1 EAF and PLL

The original set-up of the Grootvlei power plant comprised six units of 200 MW each. Three of the units were mothballed in 1989, the rest in 1990. The power plant was returned to service after around 18 years of non-use in which time the plant and equipment was mothballed. The official re-opening of the Grootvlei power plant took place on 20 September 2013. As of today, the power plant has a gross capacity of 600 MW.

Unit	1	2	3	4	5	6
Commissioning Date	01/1973	03/1970	06/1969	10/1969	05/1971	11/1977
Present (2016) installed capacity [MW]	200	200	200	200	190	190
Present (2016) nominal capacity [MW]	190	190	190	190	180	180
Returned to service after mothballing	2008	2009	2010	2009	2011	2011
Planned shut down	08/2026	03/2026	09/2027	Units 4–6 removed from capacity in April 2018 – under preservation Units 5 and 6 were used as spares for the running units		

Table 20: Key figures for Grootvlei power plant

In the last five years, the **EAF** has ranged between 69.5% (FY2020/2021) and 54.4% (FY2021/2022). For the YTD, the value is currently at 50.5% (see Table 2).

Year	Plant	Unit 1	Unit 2	Unit 3
2019	61.4	47.7	74.5	63.6
2020	54.8	70.2	69.0	61.8
2021	69.5	60.3	49.1	57.1
2022	54.4			
YTD	50.5			

Table 21: EAF at Grootvlei power plant (FY2018/2019–YTD)

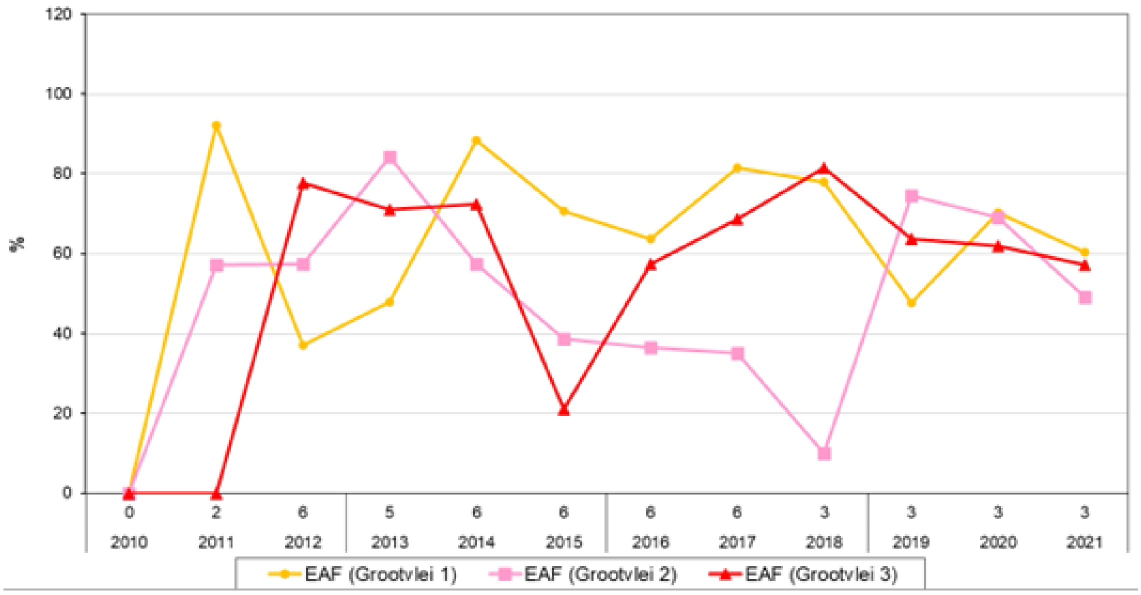


Figure 66: EAF Units 1-3 at Grootvlei power plant (FY2009/2010–FY2020/2021)
Source: KISSY database, vgbe

The main sources of PLL are shown in the next figure. As can be seen, different components impact PLL – the main components are the mills. This is shown in Figure 2. The PLL accounts for 58 MW (as of March 2023)

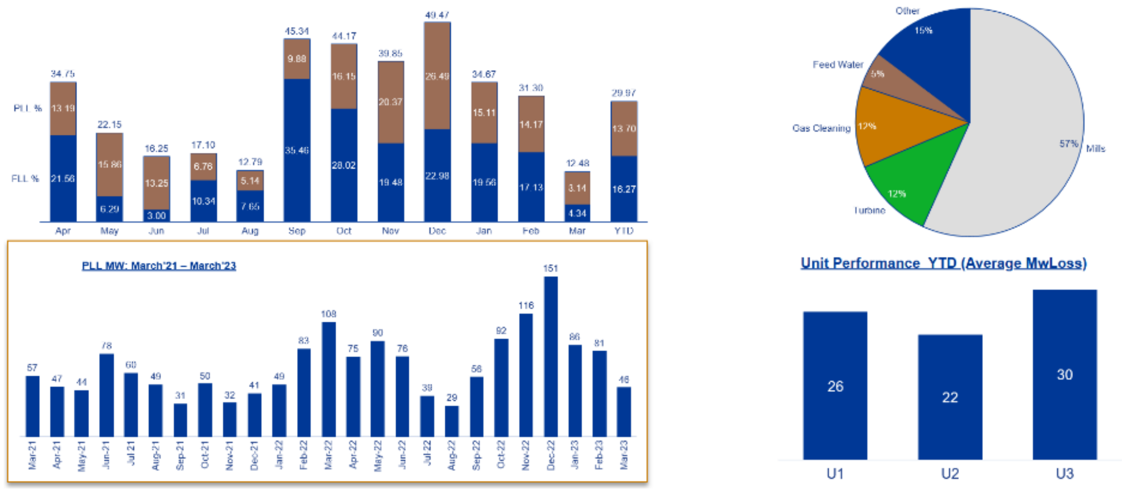


Figure 67: PLL contributors at Grootvlei power plant (FY2017/2018–FY2022/2023)
Source: Eskom

5.6.2 Technical Status

As part of the power plant's Return-to-Service programme, many components were refurbished or replaced. Therefore, the remaining three units are a combination of older parts and relatively new components. The service life of the modernised plant areas, in particular, should still be quite considerable.

5.6.2.1 Technical Status of the Boiler

The **mills** are the main contributor to PLL. They were refurbished but the maintenance has not been properly carried out due to subcontractor issues (see also the maintenance section). Besides issues with the mills themselves, their foundations also need to be strengthened/refurbished. During the site visit, an outage at Unit 3 was ongoing – one of its main purposes was to fix the mills, as well as to carry out repairs on the pulverised fuel piping, which was damaged and causing high dust contamination.

A significant number of **pulverised fuel leakages** were visible in the boiler house. This is a severe safety issue and creates a potentially explosive atmosphere. Hence, fixing these defects is of utmost importance.

In addition to this, many **water and steam leakages** were found – especially at ground zero. In some parts of the boiler house (at ground zero), the whole floor was completely flooded by water.
Apparently, water consumption at the plant is relatively high. One reason for this is the excessive number of leaks in the water steam cycle. Safety valves were visibly leaking badly. These also need to be fixed right away, to avoid any accidents. The number of leaky valves and the related water loss have reached a level that results in capacity shortages of make-up water.

Figure 68: Water leakages in Grootvlei's dusty boiler house

Figure 69: Flooded and wet floors at Grootvlei's 0 m level

There is also a high rate of air ingress in the boiler which results in **draught-plant-**related PLL, as the ID fan cannot work properly. The air ingress is due to leaks in flue gas path/ducts.

The combustion seems not to be working optimally, as a retarded combustion of the pulverised fuel was noted. As a consequence, there are BTL issues – mainly related to fly erosion. Here, we recommend inspecting the boiler carefully and checking if the dust blockers are present and installed correctly.

However, the soot blowers are mainly operated – more than 80% soot blower availability was reported – and no clinker problems occurred.

Eskom uses a **Thermal Index** (TI) to track the thermal excursions on boiler outlet headers, main steam pipework and hot reheat pipework. The TI is a long-term plant health indicator for the high temperature/high pressure components. The data for the TI can also be used to check the operational stability of the boiler, as the thermocouples indicate time spent above normal operating conditions. More detailed information about the TI can be found in section 5.1.4.5.

The TI report for Grootvlei for FY2022/2023 shows that the header temperatures generally exceed limits and are unacceptable, while the HP pipework is generally within limits, although there were some excursions in September and October 2022. The high temperatures on the headers are normally due to over-firing and this needs to be more carefully managed by the operators.

Tolerance Limits for Thermal Index:	
< 35	Favourable
36- 73	Acceptable
> 73	Unacceptable

		Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23
GROOTVLEI	Header TI	487	868	175	633	923	27	0	0	181	1908	737	2289	786
	Main Steam TI	6	18	4	3	50	6	138	255	19	10	6	5	5
	Hot Reheat TI	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 22: Extract from Grootvlei's TI report

There is no hot reheat section at Grootvlei.

Sludge in the fuel oil system/tank is causing problems by clogging the strainers, etc. This needs to be cleaned up to ensure a smooth start-up process.

During our site walks, it was noted that areas in which maintenance work was being conducted were properly fenced and signed.

Figure 70: Fenced working area at Grootvlei boiler house

Boiler at a glance:

- The mills are the main cause of PLL and need proper and urgent servicing. The pulverised fuel leakages, in particular, need to be fixed, as they present a serious safety risk.
- Many water and steam leakages were visible – including at the safety valve. The water losses lead to capacity limitations for make-up water.
- The draught plant also contributes to PLL, due to a high rate of air ingress caused by leaks in flue gas path/ducts.
- Combustion does not work optimally – issues with BTL, mainly related to fly ash erosion.

5.6.2.2 Technical Status of the Machinery

During the site walk, some **turbine** maintenance work was ongoing. The equipment and areas were not properly isolated and cleaned. This kind of environment, in which the components are not properly protected, can lead to serious damage to sensitive turbine parts. This problem arises at Grootvlei because there is no separation between boiler and turbine house. Due to this, it would make sense to create working areas which are protected from the dust by tents.

The HP heater 1 at Unit 2 was out of operation, resulting in a lower thermal efficiency. Hence, the functionality should be restored as soon as possible.

The lighting in sections of the boiler house was not working, resulting in very poor visibility on the stairwells, particularly from the 16m level to boiler basement. This is a safety issue and also impacts the quality of work.

Deposits in condenser tubes such as scaling or fouling can cause insufficient condenser vacuum. Fouling can also lead to corrosion (microbiological induced corrosion, MIC) in condenser tubes and cause tube leakages.

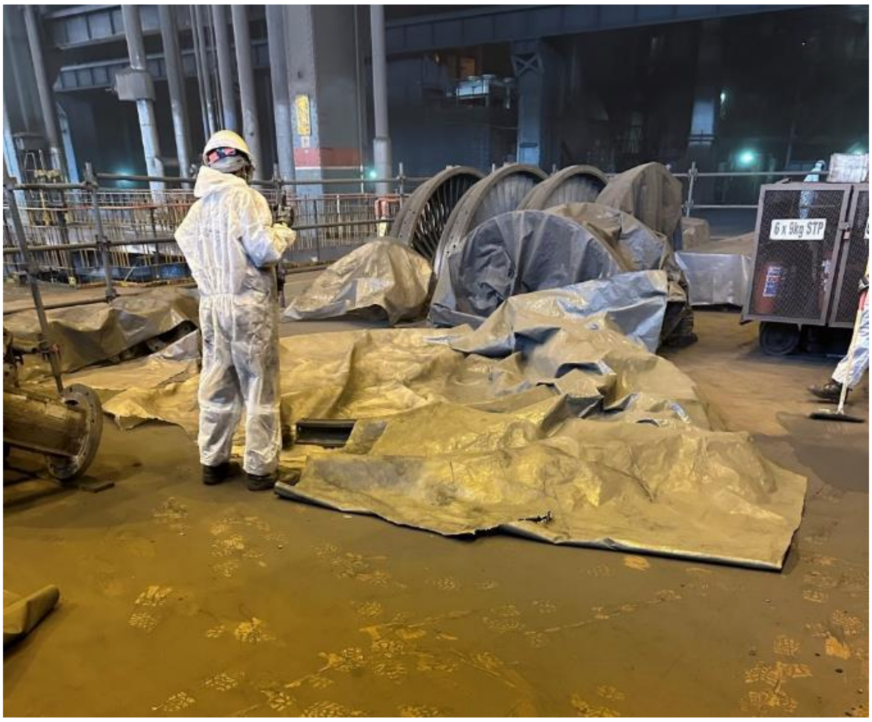


Figure 71: Turbine maintenance in dirty conditions at Grootvlei

During philosophy outages, high pressure cleaning is undertaken. Nevertheless, small condenser tube leaks occur sporadically (leak rate < 10 litres per hour) and require the unit to be shut down so that the affected tubes can be located.

Cooling water treatment (acid, anti-scalant, corrosion inhibitor, biocide, ultrafiltration and reverse osmosis (RO)) plant are installed for cooling water treatment. A partial flow of the recirculating cooling water is treated by a desalination plant and there is intermittent dosing of acid, as well as dosing of biocide and dispersants. Unfortunately, the availability of the RO plant is affected by the availability of the ash plant, because the RO plant brine is discharged into the ash sump, together with the clarifier sludge.

Another problem is that waste water, containing ash and oil from plant operations, enters into the cooling water system. This is done in order to reduce raw water usage and to manage the ash dam capacity. Ash and oil negatively affect the availability of the desalination plant.

However, not all basins in the pre-treatment for turbidity reduction have been sufficiently cleaned yet. This will be done during the next outage. As can be seen in the photo, the algae in the tank are causing the water to be loaded with total organic carbon.

In summary: The treatment of cooling water needs special focus in order to avoid clogging and leakage formation in the condenser tubes.

Figure 72: Pre-treatment of Grootvlei's cooling water

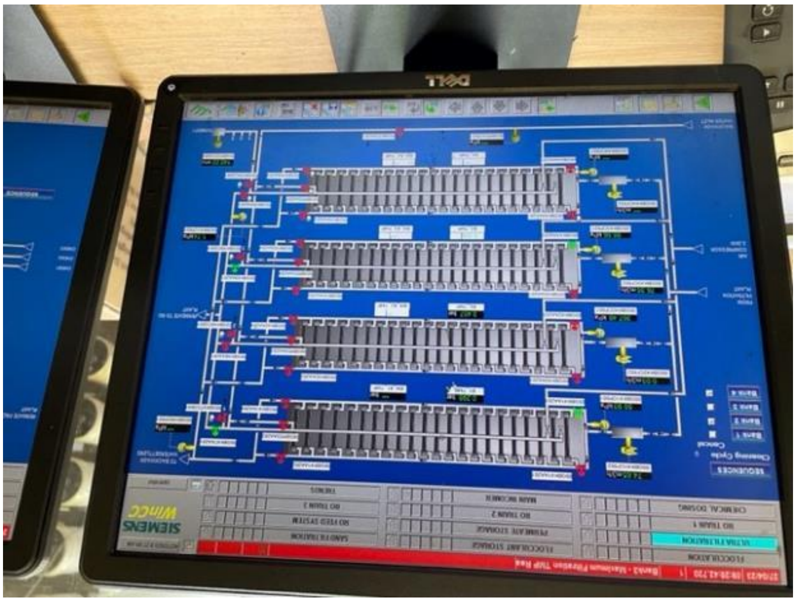


Figure 73: Ultrafiltration of Grootvlei's cooling water

Machinery at a glance:

- Clean working conditions should be ensured for turbine maintenance activities.
- The cooling water treatment needs permanent monitoring and quality assurance.
- Ash and oil ingress into the cooling water system needs to be avoided.

5.6.2.3 Technical Status Electrical and C&I

The C&I system was supplied by Honeywell. According to Grootvlei's operational plan, there are some projects in the pipeline to upgrade the technical status. These projects range from the installation of an additional oxygen analyser to firmware migration of the control systems and the replacement of the turbine OPC server and HMI.

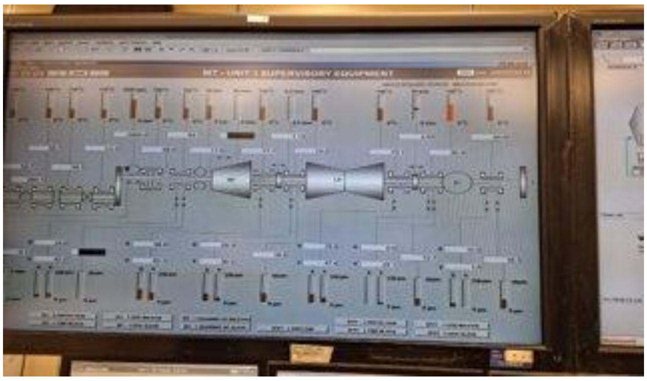


Figure 74: Screenshot of Grootvlei's control system

However, no issues were reported with respect to the C&I or the electrical system (generator and transformer).

5.6.2.4 Technical Status of the Water Treatment Plant

The central make-up water plant was visited during the site walk. The raw water source is surface water coming from the Vaal dam.

At times, the capacity of the make-up water plant is not sufficient to meet the site's consumption with water of adequate quality. This is due to high losses caused by steam and water leakages at the plant and in the cooling system.

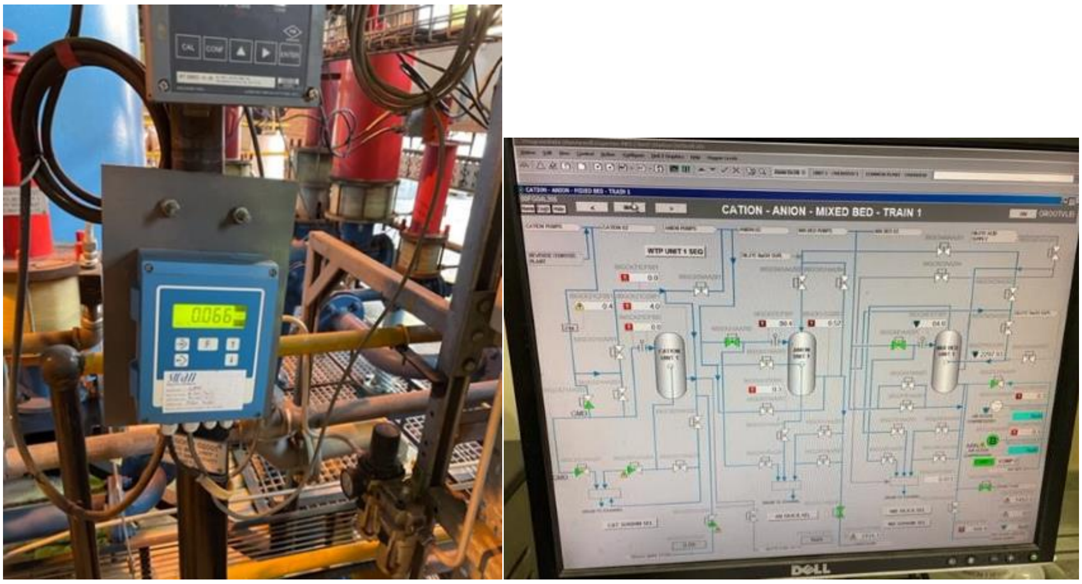


Figure 75: Measuring and monitoring instruments at Grootvlei's water treatment plant

The conductivity data (CACE) provided for feedwater, boiler water and steam indicates that the quality is not always sufficient, possibly caused by condenser tube leaks. This can lead to damage, such as BTL.

The feedwater is conditioned with ammonia (AVT), the boiler water with caustic soda (CT).

Water treatment at a glance:

- At times, the capacity of the make-up water plant is not sufficient, due to high losses caused by steam and water leakages at the plant and in the cooling system.
- The plant, therefore, is not always capable of producing water of adequate quality.
- More focus should be put on the neutralisation of regeneration effluents.

5.6.2.5 Technical Status of the Auxiliaries and other Systems

The coal and ash systems seem to be in an acceptable condition. The coal is transported via road and rail. The current stockpile is capable of storing enough coal for 19.8 days – based on three units on full load. The coal quality is analysed on a daily basis. The following figure shows the typical composition of coal at Grootvlei power plant.

Acceptable coal quality

	TM	IM	CV	GCV	Nett CV	Ash	Vol
	%	%	MJ/kg	MJ/kg	MJ/kg	%	%
	ar	ad	mf	ar	ar	mf	mf
	7.0	4.0	20.27	18.85	17.97	33.23	20.37
	8.0	4.0	20.74	19.08	18.18	32.08	20.59
	9.0	4.0	21.63	19.68	18.79	29.86	21.01
	10.0	4.0	22.53	20.27	19.37	27.64	21.43
Ave		4.00					20.85

Sizing

	Design	Rejection
Top size	25 mm	0% >60 mm & <5% >50 mm
-3.35 mm	-	> 15%
-1.0 mm	-	> 10%

SO_2 emission limit = 3800 mg/Nm³

SO_2 emission limit = 3040 mg/Nm³ with 20% Error

Rejection coal quality *Gross blr efficiency = 88.82%*

	TM	IM	CV	GCV	Nett CV	Ash	Vol	Sulphur	AI	HGI	Design FEGT	Assumptions (Blr) Sec A/H leakage	Furn in-leakage	Oxygen	Moisture load	Ash load	Sulphur load
	%	%	MJ/kg	MJ/kg	MJ/kg	%	%	%	mgFe/kg coal	-	°C	%	%	%	g/MJ_{mf}	g/MJ_{mf}	g/MJ_{mf}
	ar	ad	mf	ar	ar	mf	mf	mf									
	4.5	4.0	19.57	18.69	17.84	34.98	18.53	1.60	>450	<55	1138	18.0	12.0	3.0	2.300	17.876	0.818
	7.0	4.0	19.57	18.20	17.31	34.98	18.53	1.60							3.577	17.876	0.818
	8.0	4.0	19.85	18.26	17.36	34.28	18.67	1.60							4.030	17.269	0.806
	9.0	4.0	20.75	18.88	17.98	32.04	19.09	1.60							4.337	15.439	0.771
	10.0	4.0	21.58	19.42	18.52	29.99	19.49	1.60							4.634	13.898	0.741
Ave		4.00					<18.94	>1.60									

Figure 76: Coal composition at Grootvlei [19]

Emission situation: If the FFP is working properly, the emission values of the north stack for PM, NO_x and SO_2 can be met.

There is a **maintenance workshop** which is used by contractors, as the maintenance is fully outsourced at this station. It is spacious and well-equipped, although most machines are quite old. However, the facility should be used to as much as possible to fix the various defects at the plants.

[19] Eskom – file Station Overview 2023.pdf

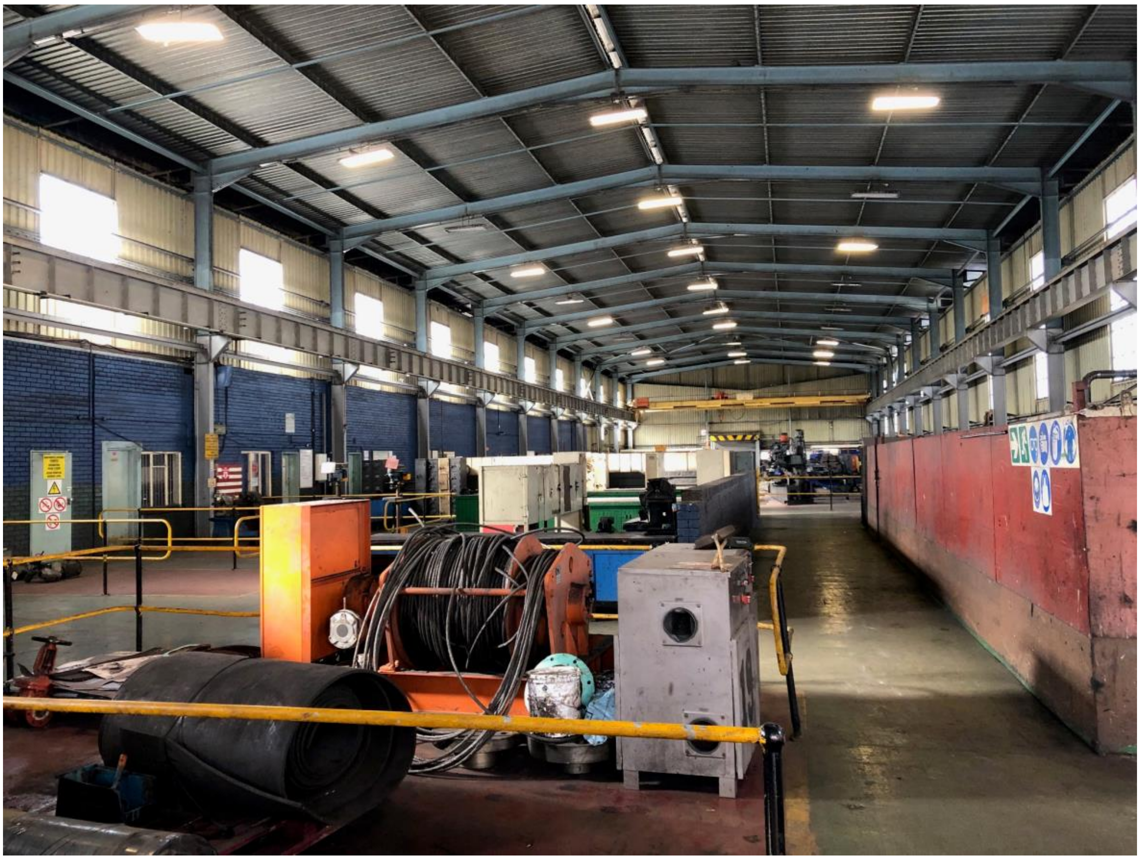


Figure 77: Maintenance workshop at Grootvlei

The spare-parts store was in poor condition – especially, with regards to the conditions in which components are stored. Many of them were covered in dirt and pigeon droppings. Also, high quality components, such as shafts with sealing surfaces, were partly corroded. In their current condition, these parts would not be fit to use. Hence, the vgbe team recommends improving the situation by reducing the number of birds (pigeons) in the store and covering the components. The stored components should also be checked to see whether they can still be used or what measures have to be taken to make sure that they can be used if they are urgently needed.

Figure 78: Dirty spare parts at Grootvlei

5.6.3 Technical Measures to Improve the Plant Condition

The maximum potential MW gain of the following measures is 58 MW**.**

The boiler, including the mills and the draught plant, is a key area requiring improvement.

The issues relating to the draught plant are due to air ingress in several places in the boiler area. They can be reduced via the following measures:

- Tighten the flue gas ducts.
- Tighten the air preheaters.
- Tighten other areas of the boiler with air ingress.

We strongly recommend inspection and repair of all other potential sources of air ingress. This can also be done during short stops and would lead to direct improvements. In addition to the locations already mentioned, we also recommend inspection of the wall penetrations of superheater, reheater as well as soot blowers. Moreover, the mills should be checked, serviced and repaired. A systematic programme needs to be implemented to technically recover all mills by maintaining a spare mill during operation, e.g. by fixing the gear box and reinforcing the foundations.

Furthermore, the water and steam leakages all around the plant need to be systematically repaired in order to improve plant efficiency and reliability – especially in view of the make-up water capacity constraints. Many repairs can be even carried out step-by-step during short standstills. Repair of the leaking safety valve needs to be a priority, as it is causing significant steam loss.

Machinery: The treatment of cooling water needs to be optimised. Outages should be used to clean the tubes and to optimise the cooling water treatment system. Furthermore, the conditions in the maintenance workshop need to be improved, e.g. by erecting tents to protect the area from dust and other pollution.

If the lifetime of the units is extended, the HP heaters should be brought back into operation.

Water Treatment: The regeneration effluent of the make-up water plant is currently drained to the channel. We strongly recommend neutralising the water, as the current situation may lead to damage to the concrete components.

The storing conditions at the **spare-parts warehouse** have to improve. Birds need to be prevented from entering the warehouse and there needs to be proper protection of components and equipment parts from dirt and dust (e.g. protective covering).

5.6.4 Power Plant Management

Currently, 367 people are working at the power plant – only 28 positions are currently vacant. According to Eskom's internal planning, the Grootvlei power plant is going to shut down Unit 1 in August 2026, Unit 2 in March 2026 and Unit 3 in September 2027. It should be noted that in 2017 the Eskom management took a strategic decision to shut-down the plant in 2019 and 2021. This has affected the planning and resulted in the reduction of maintenance, resources and spares procurement. The reduced funding has contributed to the current status of the plant. It affected the performance as the decision to ramp down was revised twice (2012 and 2021) which resulted in continued operation without maintaining the plant according to standards.

Currently it is under discussion to operate the plant until 2030. A short-term decision is necessary for strategic planning security, and an extension would encourage staff at the power plant to improve their maintenance activities and to execute outage work as per the defined scope. A clear decision would also mean that measures could be taken to immediately implement projects to reduce PLL. The measures needed for a lifetime extension project are outlined in section 5.1.4.2. Due to its temporary decommissioning, the power plant is by no means yet at the end of its lifetime. Moreover, many components and equipment parts were replaced or refurbished. These factors are promising indicators that a lifetime extension could make sense.

The uncertainty around the plant's future is a challenge for the management team – both with regards to the planning of upcoming outages and with regards to the approval of necessary budgets and human resource development.

Despite these circumstances, the team spirit of the management team seems to be good. The vgbe team believes that, if it is equipped with the according empowerment, perspectives and budgets, the team is capable of managing another lifetime extension and O&M according to industrial standards.

Maintenance

The maintenance work is 100% outsourced. The site team, with a headcount of 61, is focused on maintenance co-ordination and supervision. A total 400 contractors work at the site permanently. The MPI was reported to be good – one of the best in the Eskom fleet. However, this was not reflected in what we saw at the site - especially in the boiler house, at the maintained turbine and in the spare parts warehouse. This observation suggests that the maintenance KPI are not very reliable.

According to the site team, the procurement process for spare parts has been improved since 2020 – enough spares are available.

The insufficient servicing of mills has been one of the main bottlenecks in maintenance in the past. Very recently, a new contractor (Babcock) was engaged to permanently maintain the mills. The site team expects the health of the mills to improve significantly.

Operation

The operation department currently employs 117 people. There shifts are working on a 12-hour-cycle, with 25 people per shift. The Grootvlei power plant does not offer any simulator training, as the simulator is not available. According to the site team, the cost of fixing the plant simulator is in the range of R 11 million. Hence, the alternative plan is to use the simulator at Eskom's Academy of Learning or to relocate the Komati simulator. A simulator instructor is available.

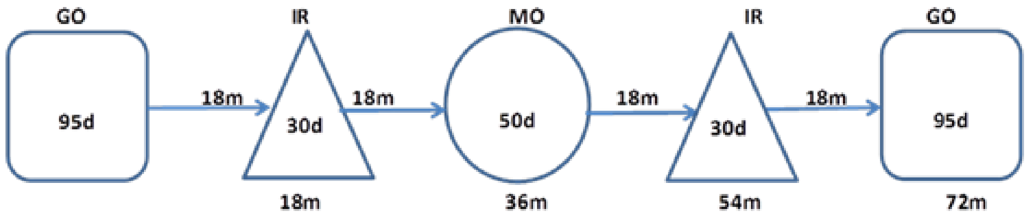
The vgbe team recommends reviving this simulator training as it is one of the most efficient ways of enhancing operating skills.

Outages

There are only three members of staff working in the outage department.

Since 2016, a proper outage philosophy has not been executed (due to the expected shutdown of the power plant). The current outage lifecycle is shown in the next figure.

All GOs are being reduced due to non-availability of funding because of the upcoming shutdown in 2026/27. The philosophy makes provision for outages at +18-month intervals, over a 5-year period, and includes 3 x 95-day GO interventions for major refurbishment work required based on statutory, mandatory and reliability compliance requirements.



Units	Year	Year	Year	Year	Year	Year	Year
	2022	2023	2024	2025	2026	2027	2028
Unit 01	18Jun **(GO)**		10 Aug **(IR)**	17 Sep **(LPT insp)**	16Aug **(DSD)**		
Unit 02	15Oct 21 - 12 Feb 22 **(GO)**	12 July **(IR)**		12 Feb **(LPT insp)**	21Mar **(DSD)**		
Unit 03		04 FEB **(GO)**	23May **(IR)**	21 Dec **(LPT insp)**		04Sep **(DSD)**	

Figure 79: Current outage lifecycle of Grootvlei power plant

In the past, outages have been started with an ORI of 60%. This should not be allowed to happen, as it is clear from the start that the maintenance activities cannot succeed due to lack of planning and to missing spares and service contracts.

5.6.5 Technical Profile of Main Plant Areas

Manufacturer	Babcock & Wilcox (Units 1–4, 6) Steinmüller (Unit 5)
Type	Natural circulation water tube boilers
Coal mass flow [t/h]	118
Pressure [bar, absolute]	110
Temperature [°C]	540
Firing system	
Number of burners	24 (Units 1–4,6), 18 (Unit 5)
Type of mills	BEC 8.5 E, Ball (Units 1-4, 6) Loesche, Roller (Unit 5)
Mill capacity [t/h] – per mill	28.8 (Units 1–4, 6), 25.9 (Unit 5)
Coal supply	
Coal supply (truck, mine)	Road and rail transport
Coal storage capacity on site (t)	138 877
Precipitators/ Flue gas cleaning	
Type	Fabric Filter Flue Gas Cleaning Plant completed 2017

Wet ash handling

Turbine	
Manufacturer	MAN
Type	Tandem-compound axial flow impulse type with 2 steam stop and 6 governor valves
Casings (HP-IP-LP, double/single flow)	1 HP, 2 LP (double flow)
Main steam pressure [bar, absolute]	105 bar
Main steam temperature [°C]	538 °C +8 °C for continuous use
Cold end	
Condenser	MAN
Cooling tower	3 natural draught wet cooling towers
Manufacturer	ASEA Brown Boveri
Terminal voltage	15.75 kV
Rating	222 200 kVA, 15.75 kV
Cooling system	Direct hydrogen cooled rotor and direct water-cooled stator
Transformer	
Manufacturer	Siemens
Terminal voltage primary/ secondary	15.75/400 kV

5.7 Hendrina Power Plant

Hendrina power plant, situated in the Mpumalanga Province of South Africa, is the oldest continuously operated power plant in the Eskom fleet. The first unit was commissioned in May 1970 and the last unit in December 1976.

The plant comprises 10 x 200 MW units – five units on the north side and five units on the south – with a total installed design generating capacity of 2 000 MW. During the 1990s, a life extension assessment was carried out, which revised the plant operating life to 50 years and, hence, the planned retirement/decommissioning of the units to between 2020–2026 (as indicated in the table below). At the time, mid-life refurbishment was deemed unnecessary, and refurbishment was limited to a C&I upgrade and pulse jet fabric filter plant retrofit (1996–2000, 2001–2005).

There are currently six units in operation with a total generating capacity of 1 158 MW_{gross} (1 098 MW_{net}); Units 2, 4, 5, 6, 7 and 10. Units 1, 3, 8 and 9 have been placed in extended “cold reserve” and are not planned to be returned to service. The units were removed from Generation’s asset base between FY2017/2018 and FY2019/2020.

Parameters	Value
Installed capacity, gross	10 x 200 MW
Units still in operation	6
Nominal installed capacity FY2022/2023 YTD	1 098 MWnet
Steam parameters (pressure/temperature)	110 bar/540°C
Efficiency at MCR (LHVnet)	34.2%

	Unit2	Unit 4	Unit 5	Unit 6	Unit 7	Unit 10
Commissioning date	01-Sep-71	12-May-70	13-May-71	12-Sep-73	15-Jun-74	23-Dec-76
Planned decom-missioning date	10-Feb-25	31-Mar-25	31-Dec-25	13-Sep-25	19-Mar-24	21-Mar-23

	Units in extended inoperability & not planned to be returned to service			
	Unit 1	Unit 3	Unit 8	Unit 9
Commissioning date	22-Sep-72	05-Aug-70	19-Jun-75	06-Apr-76

Table 23: Installed capacity and plant details of Hendrina power plant
Source Eskom

Hendrina has been incorporated into the “Just Energy Transition” strategy - repurposing and repowering power plants beyond shutdown programme. As per the adopted Gx 2035 Strategy, Unit 10 should be the first unit to shut down in March 2023, followed by Unit 7 in March 2024, Unit 2 in February 2025, Unit 4 in March 2025, Unit 6 in September 2025 and, last of all, Unit 5 in December 2025.

The deferral of general overhauls due to limited funding has significantly contributed to the current deteriorated condition of the plant. Every deferral is a lost opportunity for required maintenance.

Despite operational challenges, the remaining six operating units are in a good enough condition to keep the plant in operation for the next 5 to 7 years.

Timely approval of planned outages and timely release of adequate funding (both for planned overhauls and ongoing maintenance), along with accelerated lead times and delivery of spare parts, would allow for proper execution of outages and planned work, preventing yet more damage. A clear decision is needed so that projects to reduce PLL can be implemented immediately.

We also recommend that the plant have its own procurement department and thus be able to freely allocate pre-defined available budget.

A clear decision is needed on how long Hendrina will continue to operate. This would also significantly boost staff engagement and morale. More than 70% of the plant's 600 employees are willing and ready to continue their work, despite present uncertainties about Hendrina' s future. **The hard stop date of the plant operation is the ash dam capacity which makes an extension beyond 2030 impossible.**

The plant's management team did a study to investigate the possibility of extending the power plant's life span in the short term (5 to 7 years) to help mitigate the current electricity supply crisis in South Africa. The information from this study is summarised and included in this report at face value, because the information could not be assessed and verified within the scope of this assignment. We recommend that this should be the subject of an additional assessment study (see chapter 5.1).

Key technical issues which need to be addressed urgently include:

- Full refurbishment of the HP turbine in Unit 7 due to oil contamination
- HP turbine in Unit 10 needs urgent inspection
- Condensers need cleaning in Units 6, 7 and 10
- Refurbishment of the southern cooling towers, as well as CW system cleaning
- Spare parts for the ash pumps are urgently needed (only one of the four required ash pumps is operational)

5.7.1 EAF and PLL

Currently, four units are de-rated (with limited generating capacity; see Table 24). Units 2, 4 and 5 pose a significant safety risk due to general corrosion on the boilers' front furnace walls, while Units 2 and 4 are de-rated by 30 MW due to LP turbine stage 3 blade removal.

Capacity limitations

Unit	Reason	USO	Status	Duration
HD05	HP Turbine design deficiency Incorrect steam flow assumptions used in design calculations	181 MW	De-rating Approved	2021/05/31 - End of operational life
HD07	Cropping of LP Turbine Stage 3 blades	157 MW	De-rating Approved	2021/04/19 - 2024/03/31
HD02	In-service failure / indications CAUSE: • Resonance interference caused by speed fluctuations at 900 rpm setpoint • Speed governing system design	160 MW	De-rating Approval in progress	2023/04/01 - End of operational life
HD04		160 MW	De-rating Submission pending online capability test	2023/09/30 - End of operational life

Table 24: Hendrina's capacity limitation (MWnet)
Source: Eskom

Hendrina was a reliable power plant up until FY2010/2011 (see Figure 80), with the availability above 80%. However, in FY2012/2013 availability rapidly declined to 50%. There was slight improvement over the next few years, reaching 75% in FY2017/2018, but thereafter it experienced a drastic decline, back to 50% in FY2020/2021.

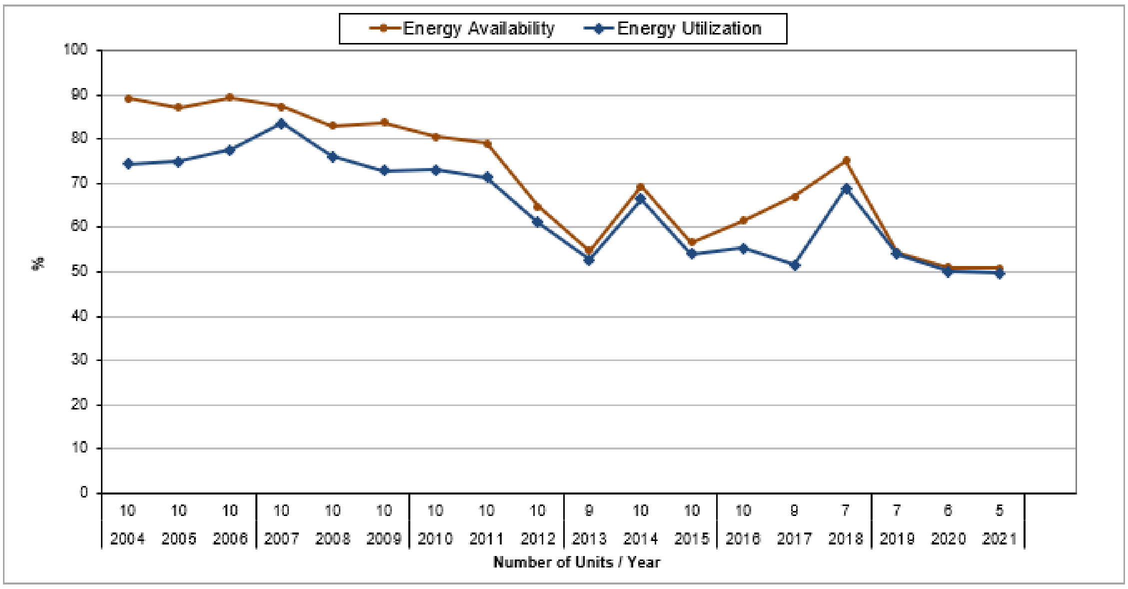


Figure 80: Hendrina power plant/availability and utilisation (FY2003/2004–FY2020/2021)
Source: KISSY

Figure 81, below, shows the availability of each of the ten units at Hendrina power plant in the period FY2003/2004–FY2020/2021. More recent information is provided in Table 25 and Figure 82.

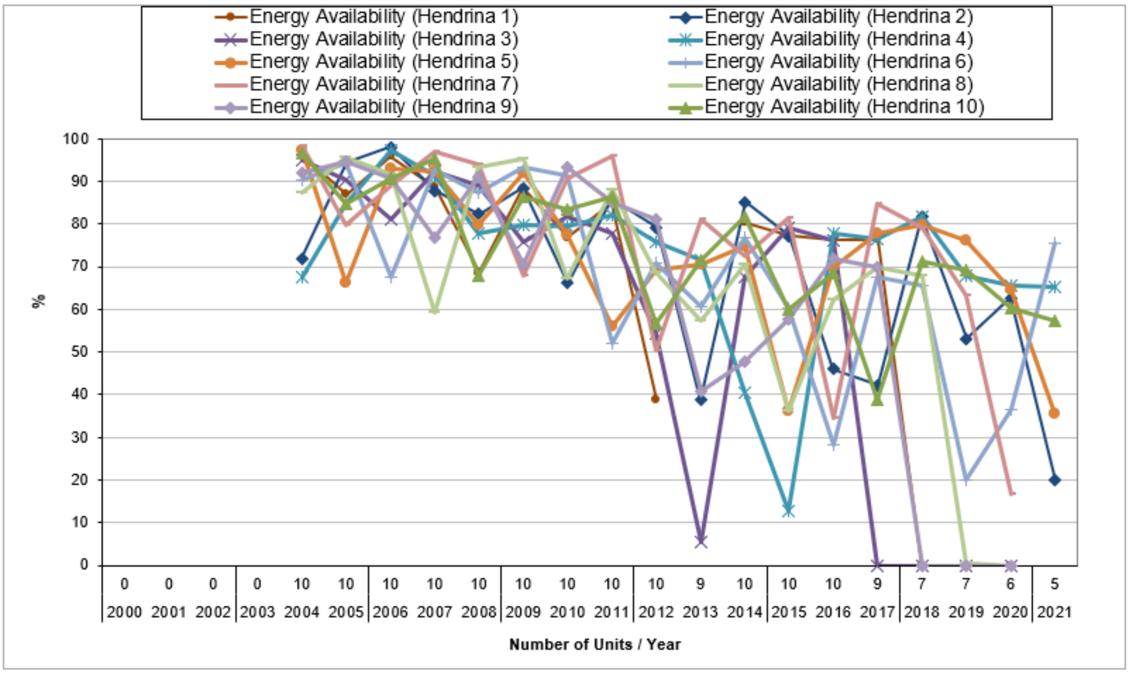


Figure 81: Hendrina availability, unit by unit utilisation (FY2003/2004–FY2020/2021)
Source: KISSY

	FY2018/2019		FY2019/2020		FY2020/2021		FY2021/2022		FY2022/2023 YTD	
	MW net	EAF %	MW net	EAF %	MW net	EAF %	MW net	EAF %	MW net	EAF %
Unit 1	0	0	0	0	0	0	0	0	0	0
Unit 2	**190**	**70.64**	**190**	**61.72**	**190**	**44.25**	**190**	**27.26**	**190**	**12.02**
Unit 3	0	0	0	0	0	0	0	0	0	0
Unit 4	**190**	**77.33**	**190**	**70.84**	**190**	**66.69**	**190**	**45.91**	**190**	**0**
Unit 5	**190**	**76.35**	**190**	**68.05**	**190**	**53.93**	**183**	**48.18**	**181**	**23.78**
Unit 6	**190**	**62.44**	**190**	**3.86**	**190**	**55.99**	**190**	**72.08**	**190**	**29.05**
Unit 7	**158**	**74.61**	**190**	**43.84**	**190**	**32.66**	**160**	**71.00**	**157**	**40.13**
Unit 8	190	47..28	32	0	0	0	0	0	0	0
Unit 9	93	62.26	0	0	0	0	0	0	0	0
Unit 10	**185**	**65.01**	**185**	**62.31**	**185**	**64.93**	**190**	**45.30**	**190**	**43.40**
Total Plant	**1386MW**	**67.16**	**1167MW**	**50.32**	**1135MW**	**53.03**	**1102MW**	**51.11**	**1098MW**	**24.27**

Table 25: Hendrina’s performance (FY2018/2019–FY2022/2023 YTD)
Source: Eskom

During the last five financial years, the EAF fell significantly from 67.16% in FY2018/2019 to 24.27% in February 2023. As of 14 March 2023, EAF was at 23.22%. In FY2022/2023, as shown in Figure 82, Units 2 and 4 had the greatest impact on the drastically reduced EAF of the plant, followed by Units 5 and 6.

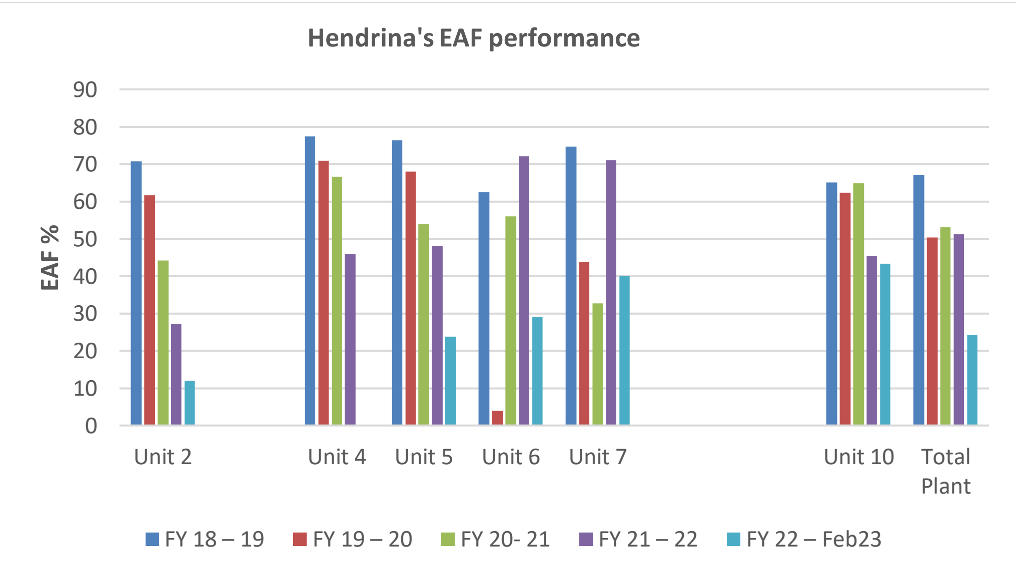


Figure 82: Hendrina EAF performance (FY2018/2019–FY2022/2023 YTD)

During the last two financial years, the total generation losses of the coal fleet increased significantly from 10 910 MW (5 313 MWs PLL and 5 597 MWs FLL) in February 2021 to 16 095 MW (6 559 MWs PLL and 9 536 MWs FLL) in February 2023. In the same period, Hendrina’s PLL was 132 MW in February 2021, 131 MW in February 2022 and 45 MW in February 2023.

In FY2022/2023 YTD, Hendrina experienced 59.34% full and part load losses, with the average 91MW loss contributing only 1.5% to the total MW loss of Eskom's coal generation fleet.

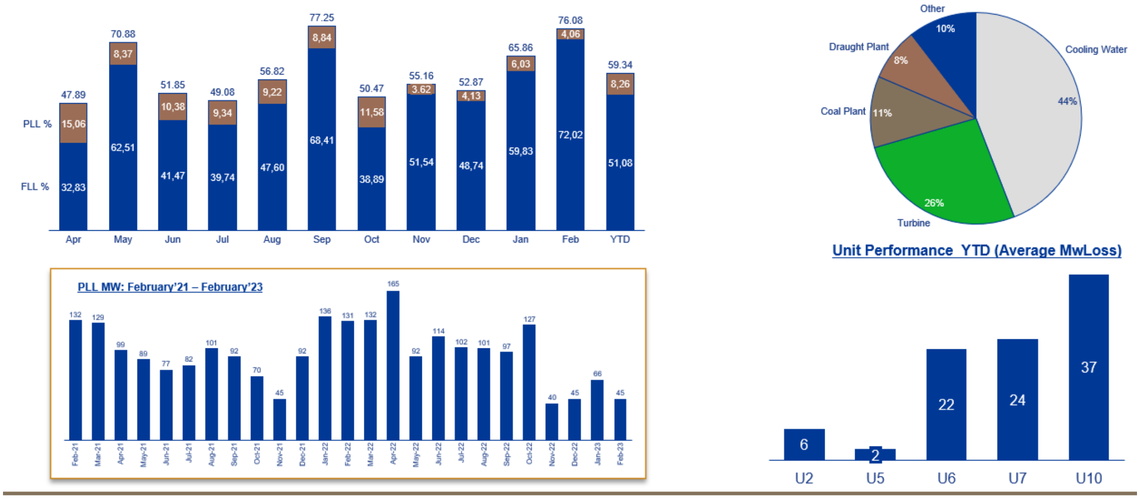


Figure 83: Hendrina performance (FY2022/2023 up until February 2023)
Source: Eskom

In FY2022/2023 YTD, as Figure 83 above shows, the largest contributor to Hendrina's units being taken offline for partial load loss repairs was the CW system, contributing 44% of lost MWs. Steam turbine (26%), coal plant (11%) and draught plant (8%) were also major contributors. The average MWs lost were 91MW, with Unit 10 as the highest contributor.

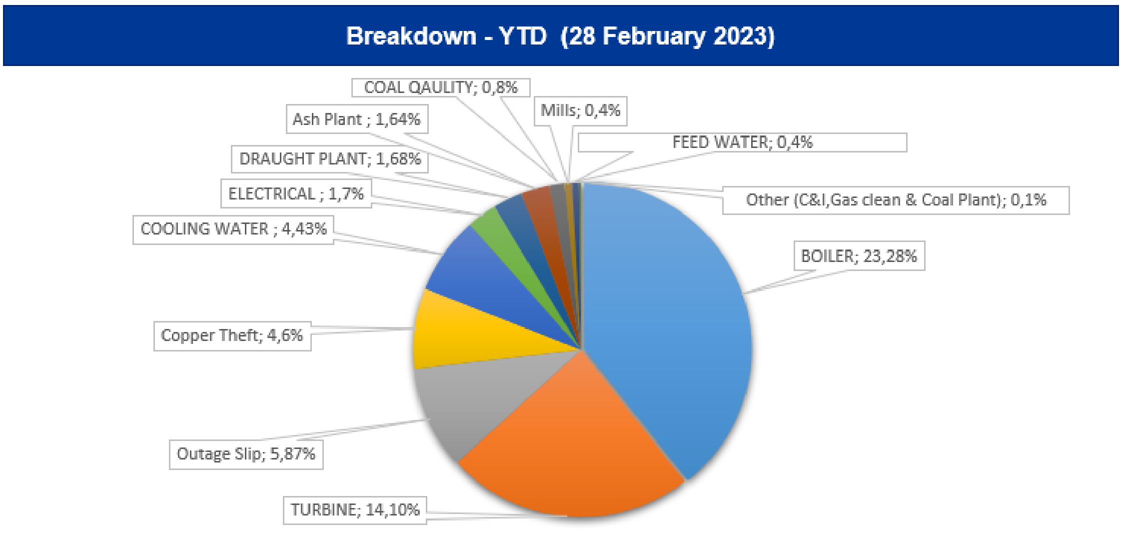


Figure 84: Hendrina's UCLF contributors (FY2022/2023 until 28 February 2023)
Source Eskom

The biggest contributors to the unreliable operation of the plant are the frequent BTL (23.28%), turbine blades failures due to high vibrations (14%), outage slip (5.87%), copper thefts (4.6%) and fouling of the CW system (4.43%).

5.7.2 Technical Status

5.7.2.1 Technical Status of the Boiler

During the visit, the team walked through the boiler house. In general, the housekeeping was acceptable (see Figure 59). Dust levels were not extreme and there were no visible leakages. No safety-related issues could be observed.

Figure 85: Hendrina boiler at 0 m level

The boiler design of Units 2, 4 and 5 is a Babcock El-Paso type, while Units 6, 7, and 10 are a Steinmüller tower type. Boilers performance differently, depending on their design and maintenance history.

Overall, the generation availability of the plant has been reduced by frequent BTF affecting plant reliability and output.

Currently, there are ongoing sporadic losses at Unit 10, including: 10 MW lost due to non-availability of spare parts (seal gasket for HP heater); 5 MW due to HP turbine stage 10 blades cropped; 27 MW due to reduced mill performance (due to low CV coal); 26 MW due to high condenser vacuum, caused by CW system fouling. As shown in Figure 7, below, over the last four financial years high BTL was registered on boilers at Units 2 (36) and 5 (37), compared to Units 7 and 10.

External corrosion was the dominant contributor to BTF (50%), followed by fly ash erosion (32%) due to high velocity of ash particles, fireside corrosion (7%), fatigue (7%), soot-blower erosion (2%) due to defective protection shields and mechanical damage (2%). External corrosion is mainly caused by boiler washing. The evaporator walls of the boilers at Units 2, 4 and 5 have been identified as high-risk areas.

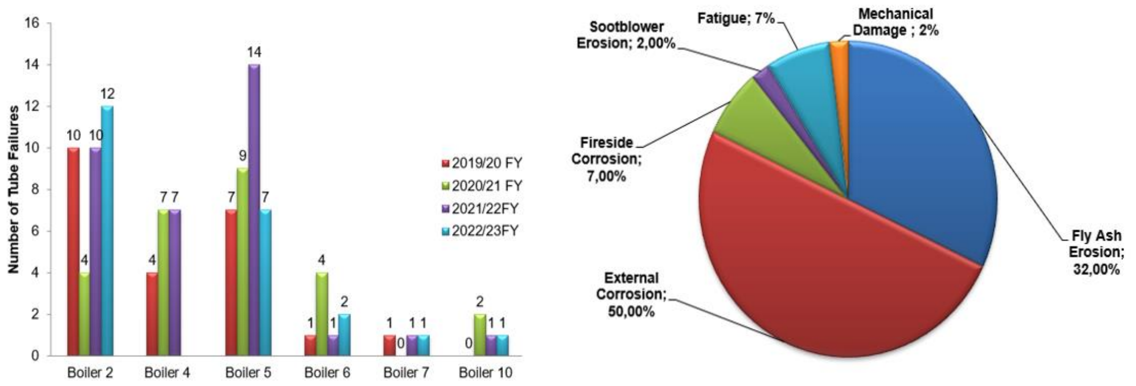


Figure 86: BTF performance & dominant BTF mechanisms at Hendrina
Source: Eskom

Based on the list of records for the period between 1 April 2015 and 4 September 2020, BTF experience has been as follows:

- Unit 2 – Inadequate and delayed boiler maintenance was the most common cause of BTL at the economiser, primary superheater, and evaporator section, and connecting tubes (26 records).
  Dominant failure mechanisms: fly ash erosion, external corrosion, fatigue corrosion.
  Total MWh loss: 747 900 MWh
  Outage time: 4 240.47 hours.
- Unit 4 – Inadequate maintenance strategy and poor workmanship was the most common cause of BTL at the evaporator, primary and secondary superheater section (26 records).
  Dominant failure mechanisms: fly ash erosion, external corrosion.
  Total MWh loss: 732 375 MWh
  Outage time: 3 854.6 hours.
- Unit 5 – Inadequate and insufficient boiler maintenance was the most common cause of BTL at the primary superheater, evaporator, and economiser section (29 records).
  Dominant failure mechanisms: fly ash erosion, soot blower erosion, external corrosion.
  Total MWh loss: 887 955 MWh.
  Outage time: 4 673.46 hours.
- Unit 6 – Inadequate boiler maintenance was the most common cause of BTL at the evaporator and superheater section (5 records).
  Dominant failure mechanism: short-term overheating.

Total MWh loss: 251 782 MWh.
Outage time: 1 325.16 hours.

- Unit 7 – Lack of maintenance and poor workmanship were the most common causes of BTL at the evaporator, superheater sections (9 records).
  Dominant failure mechanism: long-term overheating creep, welding-related defects.
  Total MWh loss: 182 842 MWh.
  Outage time: 1 125.29 hours.
- Unit 10 – Poor workmanship was the most common cause of BTL at the evaporator, superheater sections (9 records).
  Dominant failure mechanism: welding-related defects.
  Total MWh loss: 163 861 MWh.
  Outage time: 885.74 hours.

During FY2020/2021 and FY2021/2022, a total of 106 boiler-loss-of-fire incidents caused by BTL were registered. The main factor contributing to BTL was reduced scope of work during the previous outages. In the same period, total manual boilers shutdowns due to BTL were 13 (7 in FY2020/2021, 5 in FY2021/2022, 1 in FY2022/2023), with 3 more due to ashing/dusting behind (because of unstable flame in the boiler furnace) at Units 2 and 5 and turbine vibration at Unit 4.

The root causes of frequent BTF at Hendrina are well known. High-risk areas have been identified and the planned scope of work to be performed during the overhaul of the units has been prepared in detail. Since the main contributing factor to the increased BTF is the maintenance backlog (due to delayed overhauls and limited funding), considerable time and resources will be required to restore the reliable operation of the boilers at Units 2, 4 and 5.

There are no major problems with the boilers at Units 6, 7, and 10. The integrity of the boilers can be maintained by ensuring compliance with the maintenance and outage philosophy.

As for the **boiler mills**, we were told that the coal quality is severely impacting mill operations at Unit 10. Most of the time, only four mills are available, which reduces the possibility of 100% production capacity. It should be noted that each unit has six mills and full load could be achieved with five mills. The main problem affecting the availability of the mill is the unavailability of the necessary spare parts.

Eskom uses the **Thermal Index** (TI) to monitor thermal excursions on boiler outlet headers, main steam and hot reheat piping. Since TI is a long-term indicator of unit health, it can also be used to check the stability of boiler operation, as thermocouples indicate time spent above normal operating conditions.

The TI report from FY2022/2023 shows that the header temperatures are consistently above the tolerance limits and unacceptable, while the main steam and hot reheat pipework are well within the limits.

	SYSTEM	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23
HENDRINA	Header TI	1010	884	250		542	677	272	3826	173	414		0	55
	Main Steam TI	2	0	351		0	7	0	0	0	0		0	0
	Hot Reheat TI	0	0	0	0	0	0	0	0	0	0	0	0	0

Tolerance Limits for Thermal Index:	
< 35	Favourable
36- 73	Acceptable
> 73	Unacceptable

Figure 87: Extract from Hendrina's TI report

Boiler at a glance:

- Frequent BTF due to maintenance backlog because of limited funding and deferred overhauls.
- Considerable time and resources are needed to restore the reliable operation of the boilers at Units 2, 4 and 5.
- There are no major problems with the boilers at Units 6, 7 and 10.
- There is a reduced availability of the mills due to unavailable spare parts.

5.7.2.2 Technical Status of the Machinery

Turbines: Kraftwerk Union impulse-type HP and reaction-type double flow LP, double-casing condensing turbines have been installed. Approximately half of the turbine hall is reasonably clean. Steam leakages were visible on the valves/sealings in several places.

Figure 88: Turbine hall at Hendrina

Hendrina power plant has been running continuously for more than 50 years and the turbines have already reached their designed operating hours (see Table 80).

Unit	ST running hrs	
Unit 1	309 640.47 hrs	Reserve storage (Apr 2018), BPP
Unit 2	320 069.72 hrs	LP Turbine refurbished (Aug 2016 to May 2017, after 298 841.87 hrs)
Unit 3	310 967.06 hrs	Reserve storage (June 2017), generator internal fault
Unit 4	343 953.53 hrs	LP Turbine refurbished (Oct 2014 to Sept 2015, after 304 326.14 hrs)
Unit 5	331 807.63 hrs	LP Turbine refurbished, brand new HP Turbine was installed (Aug 2015 to Mar 2016, after 293 087.84 hrs)
Unit 6	339 810.11 hrs	LP Turbine refurbished (Jan 2016 to June 2016, after 303 765.78 hrs).
Unit 7	334 383.52 hrs	LP Turbine refurbished (May 2016 to Oct 2016, after 297 275.9 hrs)
Unit 8	307 986.82 hrs	Reserve storage (Jun 2019), LP blades failure
Unit 9	302 191.58 hrs	Removed from System (Oct 2018), LP running hrs depleted
Unit 10	338 308.97 hrs	LP Turbine refurbished (Jan 2017 to June 2017, after 301 073.65 hrs)

Table 26: Hendrina's turbine running hours since COD to Jan 2023 [20]

At LP turbine in Unit 4, due to high vibrations, the blades of stage 3 have been removed which resulted in unit de-rating of 30MW. Since 25 December 2021 following a step change in Turbine vibrations, Unit 4 has remained down to address the risk on boiler front furnace wall.

HP turbine at Unit 7 requires full refurbishment due to oil contamination. Since the unit is due to shut down in March 2024 (as part of Gx 2035 shutdown plan), no major unit outage is planned before then.

The plant is equipped with double-pass regenerative type surface condensers; one per turbine. All seven cooling towers are of natural-draught wet cooling type. Four northern cooling towers service Units 1 to 5, while the three southern towers service Units 6 to 10.

Units 6 and 7 have a poor condenser vacuum, due to condensers fouling (sludge and debris in CW system) and to the condition of the southern cooling towers, contributing 6% to total UCLF.

Refurbishment of the cooling towers on the south side and cleaning of the CW system are urgently needed. The continuous cleaning of condensers and maintenance of the cooling towers need to be improved.

[20] Data supplied by Eskom as part of the initial documentation package.

At Unit 10, there are ongoing sporadic load losses which have been mitigated by load reduction (10 MW loss due to HP heater, 5 MW loss due to HP turbine stage 10 blades cropping) and 26 MW loss due to high condenser vacuum. Condenser cleaning requires long-term planning and outages of more than 7 days.

The HP turbine at Unit 10 has not had an inspection for 12 years. Renewing all the HP turbines was part of the 60-year life plan, but only Unit 5 has had a new HP turbine installed in 2015-2016.

Northern cooling towers have been renewed, while the project for refurbishment of the southern cooling towers (servicing Units 6 to 10) has been stopped after investment approval.

Machinery at a glance:

- HP turbine at Unit 10 needs an urgent inspection.
- Full refurbishment of the HP turbine at Unit 7 is required due to oil contamination.
- Improved continuous cleaning of the condensers is recommended.
- Refurbishment of the southern cooling towers is required.
- CW system cleaning is required.

5.7.2.3 Technical Status of Electrical and C&I

Assessment and maintenance of the complete Electrical and C&I installations are conducted at regular maintenance intervals, while the tests are planned at annual intervals.

Generators are dependable, with spares available from decommissioned units. Between 1994 and 2002, originally installed protection relays of an electro-mechanical type were replaced with modern numerical type generator protection relays and numerical protection relays for generator transformers and unit transformers.

Medium Voltage (MV) equipment is obsolete and there is no direct technical support. Staff in the maintenance department are well trained and have sufficient knowledge to repair and refurbish (with Eskom Rotek support) MV switchgears to ensure they continue to work reliably. Some of the MV distributions need to be retrofitted, and coils in the MV compartment need replacement although the MW switchgear is not internal arc-proof as it should be. Taking into consideration the availability of spares for the MV switchgears from the four non-operational units, as well as spares in stock, along with purchasing of necessary equipment from the market, the MV switchgears at Hendrina may be able to operate for the next five to seven years.

Low Voltage (LV) equipment is in good operating condition and spares are available on the market. LV SGs outside of the unit buildings are obsolete and pose a risk to safety due to the condition of the components and equipment. Their replacement is required. LV SG at the units can continue to work without significant investment for a further 5 to 7 years. LV SGs outside of the plant should be refurbished/replaced in due time to contribute to plant production and keep EAF stable.

HV/MV and MV/LV Transformers: spares are available from the four non-operational units, as well as being in stock or available to purchase on the market. With further work on the availability and secure supply, the run of the HV and MV Transformers at Hendrina is possible for the next five to seven years.

DC System UPS / chargers / batteries are produced by Dura Power Vendor and were commissioned 15 years ago. The system is in poor condition and needs refurbishment. Batteries are from a variety of vendors (Panasonic, Willard, Chloride, Alcad, and Sonenshein). Due to age, they are in poor condition and need to be replaced.

Plant control system: The distributed control system (DCS) for all units was replaced with the Siemens Teleperm XP (Siemens SPPA T2000) DCS during the 1990s and 2000s. The DCS T2000 System is dependable and provides excellent quality of control and smooth integration of plant and operation interface. SPPA T2000 DCS at Hendrina can continue to operate for the next ten years with little expenditure.

WTP (Water Treatment Plant) local control: The WTP is controlled using Siemens' Simatic PCS 7 system, commissioned in 2008. Simatic PCS 7 is robust, of high quality and dependable. There are plans to upgrade PCS 7 computers to achieve further high availability. The stock of spares is low, but more are available on the market.

Turbine Governor & Unit Functional Safety: The boiler protection system is integrated into the SPPA T2000 system. The turbine protection unit is S5 PLC, electromagnetic with an electro and mechanical overspeed device. The system is user-friendly, available, and dependable. Spares are in stock.

Field Instruments/measurements/drives/C&I cables: The equipment is of premium quality and durable. Some of the older instruments need maintenance. Generally, the quality and durability are very good. Spares are in stock.

Electrical and C&I at a glance:

- The equipment is obsolete but well maintained; wear and tear are not significantly endangering proper operation of the equipment.
- Plant operator simulator system is working and can continue to be used for further staff training.
- Based on available documentation, the site assessment and interviews with plant maintenance, engineering, and production staff, Electrical, C&I and the DCS are capable of sustaining production for the next five to seven years without any need for major additional investment.

5.7.2.4 Technical Status of the Water Treatment Plant

Hendrina obtains raw water from the Komati water system, which catches water from the Nooitgedacht and Vygeboom dams. Other power plants supplied by the Komati system include Arnot, Komati and Duvha. As Hendrina provides potable water to the surrounding mines and some small residential areas, the raw water is first treated for domestic use and then subjected to further treatment for use as boiler feedwater (the water treatment plant is integrated with the demineraliser plant).

Hendrina operates wet cooling and wet ash systems. The effluents from the water treatment processes are used as make-up water for transporting ash from the plant to the ash dams.

The water usage of the plant is 74 Ml per day. Raw water from Nooitgedacht Dam has high sodium and total organic carbon content (due to farming), which has a significant impact on the performance of the ion exchange trains and the cost of producing demineralised water.

Raw water from Vygeboom Dam is predominantly characterised by high silica, which has a significant impact on the performance of the anion resins.

The capacity of the make-up water plant is adequate to meet plant consumption needs with water of sufficient quality. Water samples are taken and analysed twice a day to monitor key performance indicators.

Replacement of the acid tank was recently completed but upgrading of the regeneration bay is on hold. Lining the raw water reservoir, identified as a major issue, is also on hold.

Water treatment at a glance:

- The capacity of the demineralised water plant is sufficient, despite the high losses due to steam and water leakages at the plant.
- Replacement of the acid tank was recently completed but upgrading of the regeneration bay is on hold.
- Raw water reservoir lining required.
- The plant is capable of producing water of sufficient quality

5.7.2.5 Technical Status of the Auxiliaries and other Systems

Coal supply to the plant is 100% via road haulage from various mines. Daily coal burn per unit is 2 261 tons. The storage capacity of coal is usually 20.51 days of unit operation (stockpile 18.33 days, live 2.23 days, seasonal 4.57 days, strategic 11.53 days; in total 20.51 days). In line with the Gx 2035 shutdown plan, there are no more long-term contracts for the coal supply.

The coal is pre-certified from various sources. Coal sampling is done daily. Table 81 shows the typical coal specifications (Reference: Coal Quality Specification 240-71273834).

Coal Specification		Units 1-7		Units 8-10	
Attribute	Unit	Acceptable	Rejection	Acceptable	Rejection
Calorific Value	MJ/kg	22.74	21.36	24.48	22.65
Sulphur	%	1.55	1.55	1.55	1.55
Volatile Matter	%	20.73	19.10	21.55	19.71
Ash	%	24.60	28.02	20.28	24.83
Total Moisture	%	9	9	9	9
Abrasiveness Index	mgFe	450	>450	450	>450
AFT (IDT)	°C	1340	1340	1340	1340
Size grading (+30 mm)	%	5	-	5	-
Size grading (-3.4mm)	%	20	>20	20	>20
Size grading (-0.1 mm)	%	15	>15	15	>15

Table 27: Hendrina's coal specification
Source Eskom

The overall condition of the coal handling plant was acceptable.

The ash plant: The hard stop date for the plant is decided by the ash dam capacity, which will prevent extension beyond 2030. To be able to continue to 2030 "step-in and go higher project" needs to be completed in FY2026. Environmental license renewal will need attention. Due to the unavailability of spare parts to refurbish the pumps, only one (1) of the four required ash pumps is operational.

Emissions: Based on the 2018 Minimum Emissions Standard Amendment and the assumption that the plant will be decommissioned before 2030, in accordance with the Integrated Resource Plan (IRP), Hendrina power plant was granted leniency with regards to environmental compliance. Should the plant be considered for operation beyond 2030, it will need to comply with the new plant standards for PM, SO_2 and NO_X before being allowed to operate beyond 2030[21].

ELV	North Stack – units 1 ÷ 5	South Stack - units 6 ÷ 10
NO_x (mg/Nm^3)	**1 200**	**1 200**
SO_2 (mg/Nm^3)	**3 500**	**3 500**
PM10 (mg/Nm^3)	**75**	**75**
Atmospheric Emission Licence 17/4/AEL/MP313/11/16		

Table 28: Hendrina emission limit values (ELV)[2]

[21] 474-12865 Air Quality Control Generation Engineering Strategic Report 2023 (Rev 1)

All the Hendrina units were retrofitted with pulse jet fabric filters with a design capacity of approximately 384 m^3/s gas flow and outlet PM concentration of less than 50 mg/Nm^3. Projected bag life is ~ 40 000 hours (PPS fabric). No gaseous emission reduction systems (e.g. for SO_2 and NO_x) have been installed on these units. The automated measuring system instruments for measuring emissions were supplied and installed on Hendrina's south and north stacks by SI Analytics.

Hendrina has no problems with meeting the above emission limits. Monthly and annual emissions reports are publicly available on the internet. The next correlation PM tests and parallel measurements for gaseous emissions are expected in 2023.

Replacement of fabric filter bags is planned during scheduled outages at Unit 4 on 1 January 2024, at Unit 6 on 1 November 2023 and at Unit 7 on 1 January 2025. However, filter bag replacement and expansion of the cages is on hold: This requires proper attention.

The spare parts warehouse and maintenance workshop were also visited. The workshop is clean but has limited options for repair work. There is a lack of spare parts due to budget cuts and inadequate funding. There are not enough spare parts for running and preventive maintenance of all units. Some critical spare parts are no longer available on the market, but it should be noted that their production is possible. There are spares at the decommissioned units and these could be used for mechanical, electrical, and C&I equipment.

Auxiliaries at a glance:

- The coal and the ash handling plant are in an acceptable condition.
- The coal is not of appropriate quality for the operation of the mills, especially for the mill design at Unit 10 (fossil fuel firing regulations restriction on mill throughput due to coal CV).
- **The ash dam capacity will not allow operation beyond 2030.**
- Hendrina has no emission compliance issues unless it should operate beyond 2030.
- There is lack of spare parts for running and preventive maintenance due to budget constraints. There are spares at the decommissioned units that could be used for mechanical, electrical, and C&I equipment.

5.7.3 Technical Measures to Improve the Plant Condition

Boiler: The root causes of frequent BTF at Hendrina are well known. High-risk areas have been identified and the planned scope of work to be performed during the overhaul of the units has been prepared in detail. The main contributing factor to the increase of BTF is the maintenance backlog due to delayed overhauls and limited funding for repair work. Hence, considerable time and resources will be required to restore the boilers at Units 2, 4 and 5 to reliable operation.

There are no major problems with the boilers at Units 6, 7 and 10. Operation of the boilers can be maintained by ensuring compliance with the maintenance and outage philosophy.

Machinery: The steam turbine at Unit 10 needs urgent inspection on its HP section. Full refurbishment of the HP turbine of Unit 7 is required due to oil contamination.

Improved continuous cleaning of the condensers is required, especially at Units 6, 7 and 10. Refurbishment of the southern cooling towers is necessary. The cooling water system needs cleaning.

Generator: Taking into consideration the availability of spares from the four non-operating generators and their auxiliaries (hydrogen & water cooling, excitation plant, protection devices), as well as spares in stock and equipment available on the market, the six generators and their auxiliaries could operate for the next five to seven years.

5.7.4 Power Plant Management

Currently, around 600 employees are working at the power plant. In general, the management team is stable and seems to be very capable and efficient in addressing the operational issues facing the power plant.

There are knowledgeable and experienced people in most technical areas of the plant, especially in the maintenance department. The engineering manager has been working at the plant for a long time.

Due to budget cuts and inadequate funding, there is lack of spare parts to maintain and even keep units running (key reason for low EAF). The plant management does not have freedom to make its own decisions regarding the necessary contracts for procurement of works, services, and supplies. **This must change**.

Timely release of adequate funding for outages, accelerated lead times and delivery of spares would all facilitate the execution of the outages and planned scope of work, which are essential to avoid further deterioration of plant reliability.

A clear decision must be made regarding Hendrina's operational lifespan. This would also significantly boost staff engagement and morale. More than 70% of the 600 employees are willing and ready to continue their work even though Eskom's management has given them no information about the future of the power plant. A clear decision on how long the plant will operate would also determine the appropriate level of maintenance work to be done.

Maintenance

The maintenance team is responsible for providing adequate resources to meet repair and servicing requirements reported by the operation team. The scoping is defined by the engineering department. The maintenance group takes care of spare parts and consumables inventory and planning, as well as being responsible for the training and development of the work force. The maintenance and warehouse system are fully integrated into the SAP system.

Approximately 70% of all maintenance work is outsourced: 50% of the coal plant maintenance work is carried out by external companies, while maintenance of the ash plant, water plant and execution of construction work is carried out entirely by external companies.

We recommend that the maintenance of the mills be carried out by the plant's own personnel or by OEM staff, as is the case at the other power plants.

Operation

Operation of the units is managed by senior plant operators. The plant operation staff are of the belief that the plant will shut down in 2025, since there has been no employee training since 2019. There is an employment gap at operational level. A total 56 persons are needed to run the shifts. Shift operators are missing as well. The shift handover takes 15 minutes, at the beginning and at the end of each shift. Plant operation staff are working a lot of overtime. Training of the operation staff was stopped because of the decision to shut the plant down in 2025. Recruiting and education of new operation staff is recommended, as well as engaging more qualified trainers to teach the staff.

Outages

The planning of the outages at Hendrina power plant is in accordance with the outage philosophy revised to be in line with the Gx 2035 shutdown plan. The scope and frequency of outages are based on a short-term strategy (12–18 months) that ensures statutory compliance.

The last big outage was carried out in 2017 at Unit 2, when all boiler pressure parts were refurbished.

The next major overhaul is planned for Unit 5 on 30 August 2023.

Unit 4 is on the forced outage, the works on the replacement of the boiler's furnace front wall are in progress. The planned return to service of the unit, by 30 March 2023, could not be fulfilled due to unavailability of materials. Unit 2 outage is planned for June 2023. Unit 6 outage was completed in March 2023.

The plant still has no conformation regarding the execution of future planned outages (see Table 29). Necessary time for outage planning is 24 months. Timely execution of planned outages would prevent further damage occurring.

WEEK 16	
5 Year Outage Listing	
FromDate	2023/04/18
ToDate	2028/04/17
Export Date	2023/04/18 15:35

OutageID	Outage Code	Station	Unit	Planned/Actual Start Time	Planned/Revised End Time	MW Loss	MW Loss Percent	Outage Description	Status	Planned Duration
43487	HD06UST-19-04-2023	Hendrina	6	2023/04/19 22:00:00	2023/04/20 03:59:00	190	100	TPU test	ROLLSCHED	0,25
14318	HD02UST-30-06-2023	Hendrina	2	2023/06/30 00:00:00	2023/09/23 23:59:00	190	100	ST - RBI, BPP	ROLLSCHED	86,00
14309	HD04UST-05-02-2024	Hendrina	4	2024/02/05 00:00:00	2024/03/03 23:59:00	190	100	ST - RBI, BPP	ROLLSCHED	28,00
14253	HD06UST-28-04-2024	Hendrina	6	2024/04/28 00:00:00	2024/05/25 23:59:00	190	100	ST - RBI, BPP	ROLLSCHED	28,00
14298	HD02UST-01-05-2024	Hendrina	2	2024/05/01 00:00:00	2024/05/28 23:59:00	190	100	ST - FFP	ROLLSCHED	28,00
14321	HD05UST-01-07-2024	Hendrina	5	2024/07/01 00:00:00	2024/08/23 23:59:00	181	100	ST - RBI, BPP	ROLLSCHED	54,00
35833	HD07UIN-04-09-2027	Hendrina	7	2027/09/04 00:00:00	2027/10/01 23:59:00	190	121	IN2	SCHED	28,00
35834	HD06UIR-06-11-2027	Hendrina	6	2027/11/06 00:00:00	2027/12/03 23:59:00	190	100	IR1	SCHED	28,00

Table 29: Hendrina's 5-year outage listing

Projects

Current Situation: Currently, projects at Hendrina that exceed R 10 million have been put on hold after investment approval, while others have been stopped before investment approval.

SAP Project Code	Project Title	ERA Value
C.GHE0140	PDD-Hendrina Turbine Project	R6 000 000 000
C.GHE0182	Replacement of the Cooling Tower Splash	R16 234 185
C.GHE0183	Replacement of Cooling Tower Distribution Packs	R13 450 000
C.GHE0209	Generator Rotor Earth Fault Protection	R35 500 000
C.GHE0223	Coal Staithe Bypass	R 59 530 000
C.GHE0350	Building a new structure and new crane	R 15 500 000
C.GHE0554	Simulator Upgrade	R10 500 000
C.GHE0691	Construction of Weigh Bridges & Access	R15 400 000
C.GHE0180	Generator Fault Recorder Replacement	R20 200 000
C.GHE0190	HP Heater Tube Bundle Replacement	R34 000 000
C.GHE0207	Perform a second rewind on units1,5,8	R155 399 998
C.GHE0199	Generator Rotor Rewind	R43 235 006
C.GHE0377	Replacement of Pyrometers Units 1-10	R16 000 000
C.GHE0694	Boiler Modular Replacement	R85 000 000
	TOTAL	R 6 514 949 189

Table 30: Hendrina's projects parked after investment approval
Source: Eskom

SAP Project Code	Project Title
C.GHE0018	Repair to the Fabric Filter Plant Structure
C.GHE0019	Boiler and Turbine House Structures Rehabilitation
C.GHE0053	Historian Upgrade - Phase 2
C.GHE0068	Construction of waste disposal dam-Leachate
C.GHE0086	Replacement of 16.5kV And 400kV Surge Arrestors, Station only responsible for 16.5kv
C.GHE0089	Online vibration monitoring on ID, FD and PA fans
C.GHE0114	Installation of Station Access Control
C.GHE0118	Gaseous Emission Monitor replacement (Phase 2)
C.GHE0121	Water Plant HMI Replacement - Phase 3
C.GHE0133	Turbovisory Replacement- Phase 2
C.GHE0143	Maturation Pond - Cleaning and Lining of Pond
C.GHE0146	Replacement of Coal Moisture Analysers (Phase 1)
C.GHE0147	Stator Coolant Continuous Monitoring Equipment- P2
C.GHE0167	Dust Emissions Monitor Replacement - Phase 1
C.GHE	MV Switchgear Upgrade

Table 31: Hendrina’s projects parked before investment approval
Source: Eskom

Shutdown Deferment Scenario: The power plant management team did a study to investigate the possibility of extending the power plant life span in the short term (5 to 7 years) to help mitigate the current electricity supply crisis in South Africa[22]. This study takes into consideration what the deferment limits are and what is required to extend the plant life to the limit dates. A date map, KPI projection and estimated budget is provided. The information from this study is included below at face value because it could not be assessed and verified within the scope of this assignment. It is recommended that this should be the subject of an additional assessment study.

The limiting factors for plant life extension are environmental licenses that will require statutory relaxation beyond 2026. The hard stop is, however, the ash dam capacity limit which, in accordance with the Eskom study, will limit plant operation to September 2030 as seen in Table 32 below.

[22] Eskom HND Shutdown Deferment Scenario document 28 February 2023.

	Gx 2035 Plan	Defer	ENV Licenses	ASH DAM Limit
Unit 2	2025/02/10	2026/04/20	2026/04/20	2030/09/01
Unit 4	2025/03/31	2028/04/21	2026/10/31	2030/01/21
Unit 5	2025/12/31	2028/11/30	2026/11/30	2030/02/28
Unit 6	2025/09/13	2027/01/12	2026/12/15	2030/01/01
Unit 7	2024/03/19	2030/05/01	2026/07/04	2030/05/01
Unit 10	2023/03/31	2030/06/15	2026/10/15	2030/06/15

Table 32: Hendrina's unit shutdown deferment scenarios, 28 February 2023
Source Eskom

The intervention plan only includes the six units that are currently still operational and is based on the intervention due-date schedule in Table 34, below. It is clear from these dates that, as far as a decision regarding extension of the plant's lifespan is concerned, time is of the essence.

The planned interventions, which would enable the plant life extension, are necessary for statutory compliance with regards to plant running hours until 2030. The current compliance limits dictate plant shutdown in accordance with the shutdown dates in Table 33, below.

	Commissioning Date	Decommissioning Date	Accumulative Running Hours
Unit 1	1972/09/22	2022/09/22	309640
Unit 2	1971/09/01	2021/09/01	320370
Unit 3	1970/08/05	2020/08/05	310967
Unit 4	1970/05/12	2020/05/12	343954
Unit 5	1971/05/13	2021/05/13	331808
Unit 6	1973/09/12	2023/09/12	339810
Unit 7	1974/06/15	2024/06/15	334384
Unit 8	1975/06/19	2025/06/19	307987
Unit 9	1976/04/06	2026/04/06	302192
Unit 10	1976/12/23	2026/12/23	338639

Table 33: Hendrina's 50-year life plan
Source: Eskom

	HP (100kH)	LP (45kH)	GEN	PER / RBI	HEP	Reference Date
Unit 1	RS	RS	RS	RS	RS	2018/04/01
Unit 2	2026/11/11	2026/04/20	2026/04/20	2023/06/30	2024/02/06	2023/02/28
Unit 3	EI	EI	EI	EI	EI	2017/06/01
Unit 4	2030/01/21	2028/04/21	2028/04/21	2023/10/20	TBC	2023/02/28
Unit 5	2030/02/28	2028/08/30	2028/08/30	WIP	TBC	2023/02/28
Unit 6	2027/01/12	2024/09/02	2024/09/02	2023/09/13	TBC	2023/02/28
Unit 7	2024/05/06	2026/07/04	2024/05/06	2023/11/11	TBC	2023/02/29
Unit 8	RS	RS	RS	RS	RS	2019/06/01
Unit 9	RS	RS	RS	RS	RS	2018/10/01
Unit 10	2023/03/06	2024/02/20	2027/01/31	2025/08/30	2025/08/30	2023/02/28

Table 34: Hendrina's intervention due dates
Source: Eskom

The additional CAPEX required (over and above the current situation) for the deferment plan is presented in Table 35, below. According to Eskom, the total CAPEX required to extend the life of Hendrina to 2030, including the current situation CAPEX, is R 10 475 million.

CAPEX	2024 Budget	YTD Actual 2023	2025	2026	2027	2028	2029	2030
Outage Capital	295.5	688.0	414.0	1090.0	660.0	60.0	60.0	40.0
Tech Plan Capex (incl IDC)	43.4	49.3	43.4	56.5	43.1	12.7	10.0	10.0
Asset Purchases	22.6	0.2	5.8	8.5	5.0	5.0	5.0	2.0
Total Annual Capex	**361.5**	**737.4**	**463.3**	**1155.0**	**708.1**	**77.7**	**75.0**	**52.0**
Total Annual Capex	**3 960.5**							

Table 35: Hendrina's deferment scenario CAPEX requirement (over and above current)
Source: Eskom

The deferment plan also includes KPI projections for the plant. If the deferment plan is implemented as indicated above, the projection is that overall EAF could improve to 49% in FY2023/2024 and reach >80% levels by FY2025/2026. The corresponding UCLF forecast is 18.5% by FY2023/2024 and <6% from FY2024/2025 onwards. The projected PLL for FY2023/2024 is 10.5%, with <3% from FY2024/2025 onwards.

5.7.5 Technical Profile of Main Plant Areas

Boiler and related Plant Area: There are currently six units in operation at Hendrina power plant. These are Units 2, 4, 5, 6, 7 and 10. The boiler design of Units 2, 4 and 5 is that of a Babcock El-paso type, while Units 6, 7 and 10 are a Steinmüller tower type.

Coal supply to the plant is 100% via road haulage from various mines, whilst raw water supply is from the Komati water scheme, which is fed by the Nooitgedacht and Vygeboom dams. Coal is delivered by a duplicate overland conveyor system to four coal staithes behind the plant or, alternatively, to an emergency stockpile. Two systems of incline conveyors, north and south, deliver the coal reclaimed from their respective staithes to the boiler bunkers, of which there are six per boiler.

Boiler Manufacturer	Units 1-5: Babcock Units 6-10: Steinmüller
Type	Unit 1: Tower Units 2-5: El-Paso Units 6-10: Tower
Coal mass flow [t/h]	13 566 t/day (total plant)
Main Steam Pressure [bar, a]	110
Main Steam Temperature [°C]	540
Firing system	
Number of burners	24 per unit
Number of mills	6 per unit Units1-7: Babcock & Wilcox 8.SE Units 8-10: PHI MPS 140
Type of mills	Units 1-7 Vertical spindle (ball and ring) Unit 8-10: Vertical spindle (roller type)
Mill capacity [t/h] – per mill	Units1-7: 24 t/h Units 8-10: 21.3t/h
Coal supply	
Coal supply (truck, mine)	100% via road haulage
Coal storage capacity on site (t)	100 000 t (coal staithe capacity) 100 000 t (stockpile capacity)
Boiler bunker capacity (t)	478 t (2 868 t/unit)
Flue gas cleaning	
Manufacturer	Howden
Type	Pulse jet fabric filters plant
Wet ash handling	

Machinery and Electrical:

Kraftwerk Union impulse-type HP and reaction-type double flow LP, double-casing condensing turbines are still the original installed equipment. The plant is equipped with double-pass regenerative type surface condensers; one per turbine. All seven cooling towers are of natural-draught wet cooling type. Four northern cooling towers service Units 1 to 5, while the three southern towers service Units 6 to 10.

Turbine	
Manufacturer	Kraftwerk Union (KWU/AEG)
Casings (HP-IP-LP, double/single flow)	HP, IP, double flow LP
Steam flow to HP cylinder (kg/s)	202 (at 200MW)
Main steam pressure [bar, a]	110
Main steam temperature [°C]	540
Cold end	
Condenser	Double pass regenerative type surface condenser
Cooling tower	Hyperbolic natural-draught wet cooling type
Generator	
Manufacturer	Kraftwerk Union Siemens
Terminal voltage	16.5 kV
Rating	222.2 MVA
Cooling system	Hydrogen at 400 kPa
Transformer	
Manufacturer	HV: Oerlikon, Alstom, Bruce Peebles MV: ASEA, ASGEN
Terminal voltage primary/ secondary	16.5kV / 420kV
Placement	Between units and HV yard

5.8 Kendal Power Plant

The Kendal power station is one of the largest and most important stations in South Africa. Its installed capacity is 4 116 MW gross and generates 3 840 MW net. It includes six units, each with a capacity of 686 MW gross and generating 640 MW in net output. The plant was built between 1982 and 1993. Design efficiency at MCR is 35.30%.

The power station is located in the Mpumalanga coal-mining area. Its coal source is AEMFC's coal mine at Khutala, near Ogies, which supplies more than 80% of the coal used at the power plant.

The commissioning dates, along with the key design parameters, are shown in the following table. More design details are provided in Section 5.8.5 of this report.

<table>
<tr><th colspan="4">Parameter</th><th colspan="3">Value</th></tr>
<tr><td colspan="4">Installed capacity (MW)</td><td colspan="3">6 x 686 (4 116)</td></tr>
<tr><td colspan="4">Available capacity (for Maximum Continuous Operation)</td><td colspan="3">3 840</td></tr>
<tr><td colspan="4">Number of units (no.)</td><td colspan="3">6</td></tr>
<tr><td colspan="4">Start of operation (year)</td><td colspan="3">1993</td></tr>
<tr><td colspan="4">Units still in operation (no.)</td><td colspan="3">6</td></tr>
<tr><td colspan="4">Planned end of life of first unit (year)</td><td colspan="3">2044</td></tr>
<tr><td colspan="4">Planned end of life of last unit (year)</td><td colspan="3">2044</td></tr>
<tr><td colspan="4">Steam parameter (pressure/temperature)</td><td colspan="3">165 bar/535 °C</td></tr>
<tr><td colspan="4">Source of coal</td><td colspan="3">Vlakfontein Collery</td></tr>
<tr><th>Commissioning and life of plant</th><th>Unit 1</th><th>Unit 2</th><th>Unit 3</th><th>Unit 4</th><th>Unit 5</th><th>Unit 6</th></tr>
<tr><td>Commissioned</td><td>1988</td><td>1989</td><td>1990</td><td>1991</td><td>1992</td><td>1993</td></tr>
<tr><td>Expected de-com. (estimated)</td><td>09/2039</td><td>01/2041</td><td>12/2042</td><td>12/2042</td><td>12/2043</td><td>12/2044</td></tr>
</table>

Table 36: Installed capacity and station details at Kendal power plant

The plant is fifth in the dispatch order and has black start capabilities to restart the power grid in case of black-out.

Kendal has been reliable in the past, but over the last four years it has shown signs of its age and of a lack of adequate maintenance. One of the best operating plants in the system in 2018, it reached 46% EAF in 2022. Deferred general overhauls have contributed substantially to its recent unreliable performance. After 30 years in operation and considering that it is expected to operate for another 20 years, it is due for a mid-life rehabilitation.

The situation and condition at the station have, however, already much improved since May last year[23]. Although the improvements are not yet visible in the EAF, they should be seen soon. The main areas of improvement are management, dust, and ash handling plant performance, with resulting improvement in emissions, as well as in spray valve condition and use.

Key technical issues which need to be addressed urgently include:

The water treatment plant needs urgent refurbishment or even replacement. Also, an effort needs to be made to reduce water consumption (water consumption has been reduced from 30 Ml/day to 18 Ml/day, but the target should be 8 Ml/day).

The draft system needs to be improved by rehabilitating and upgrading the ESP (to comply with the required 50 mg/Nm^3 and reduce dust loading through the ID fan), the primary air heater (PAH) and secondary air heater (SAH) baskets need to be repaired, air-in leakage reduced and excess O_2 optimised.

The ash handling system needs urgent attention, including the performance of the ESP (see above, including ESP hoppers), conveyor capacity, ash dump facility capacity, etc. The O&M contractor is underperforming and needs to be replaced.

The mills urgently need spare parts. Also, the O&M contractor needs to be replaced.

The steam turbine at Unit 6 needs urgent overhaul; HP turbine leak causes 300 MW PLL presently. Eskom has decided to engage the OEM to improve the quality of service provided.

Variable speed drive motors for six feedwater pumps are needed.

Also, gas turbines used for black start need replacement or substantial rehabilitation.

Spare parts are needed for the transformer (AT) and the generator rotor.

Three 3kV transformers need replacement at first opportunity.

Plans should be made to address how the plant will comply with NO_x and SO_2 requirements by April 2025. Decisions need to be made this year (2023).

Finally, plans should be made to replace the DCS at first opportunity because the existing DCS is obsolete.

Furthermore, several actions are needed on power plant management aspects. The new plant manager and the new engineering manager have brought in a positive approach to managing the plant and have already achieved positive results. This needs to continue and be expanded.

Noteworthy actions required:

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[23] Comparison with situation described in the Generation Turn around Matla and Kendal Eskom Presentation dated 19 May 2022.

Staff morale is improving but 60 vacancies need to be filled. Training needs to increase for both existing and new staff.

Better management of O&M contractors is needed, in terms of selecting those best qualified for the job and ensuring that they perform well.

5.8.1 EAF and PLL

Up until 2017, Kendal was a very reliable power station, as Figure 89Figure 159 shows. Availability was above 90%, except for the period 2012-2016 when it declined to 80–90%. However, after 2017 it experienced a drastic decline to its current availability of 40–50%.

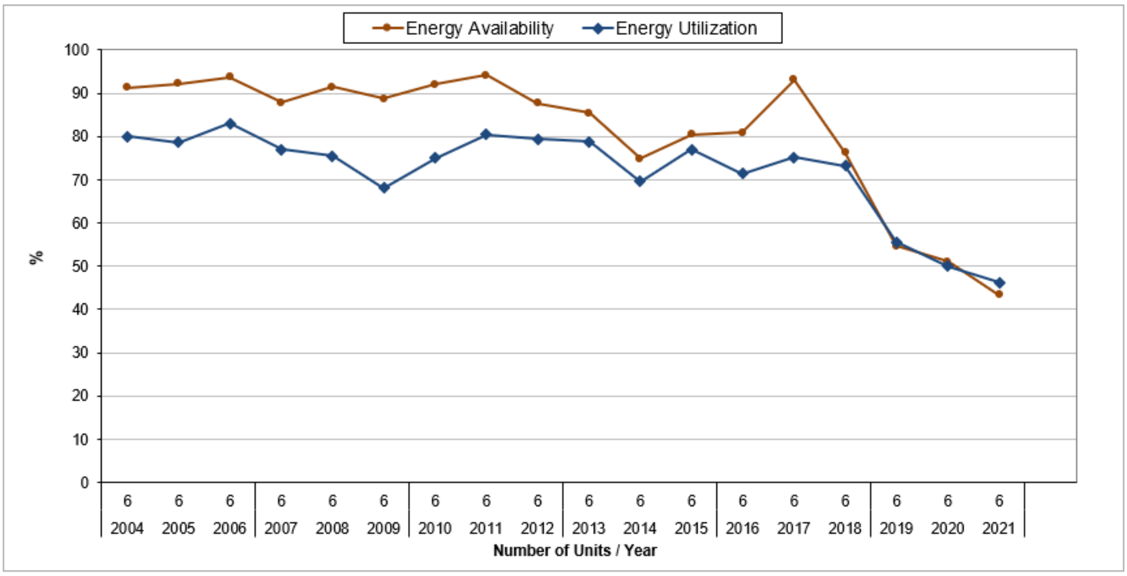


Figure 89: Availability and utilization at Kendal (FY2003/2004–FY2020/2021)
Source: KISSY

Figure 90 shows the availability and utilization of each of the six units of the Kendal power station for the period 2004–2021. More recent information is provided in Figure 91 below.

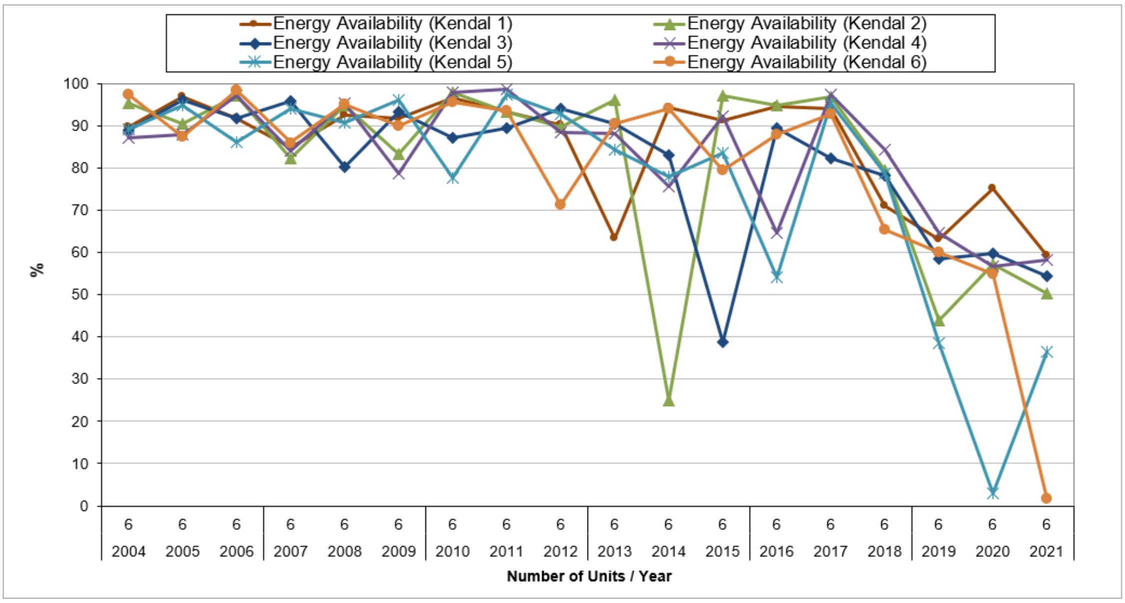


Figure 90: Unit-wise availability and utilization at Kendal (FY2003/2004–FY2020/2021)
Source: KISSY

In 2015, Kendal was the best performing station in Eskom's coal fleet and in 2018 its EAF was 91.71%, earning it an award for good performance. By 2021-2022, Kendal's EAF had deteriorated to 46% (see Figure 91).

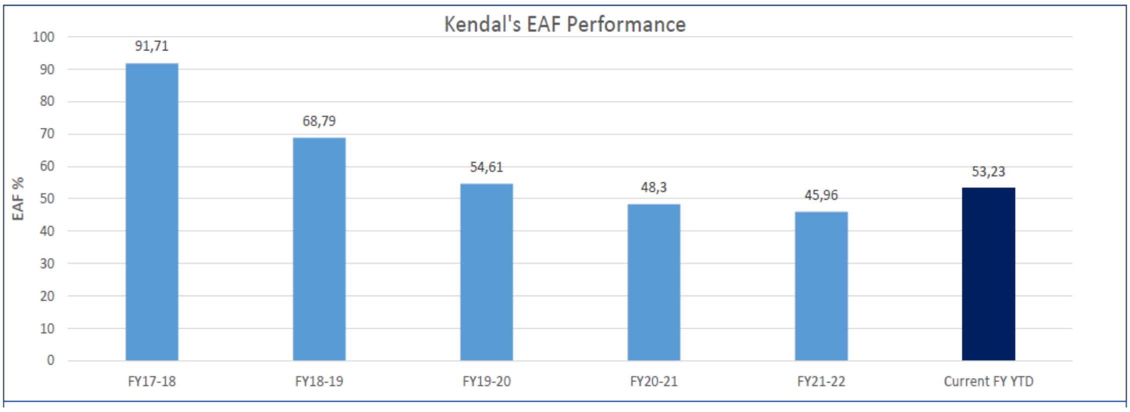
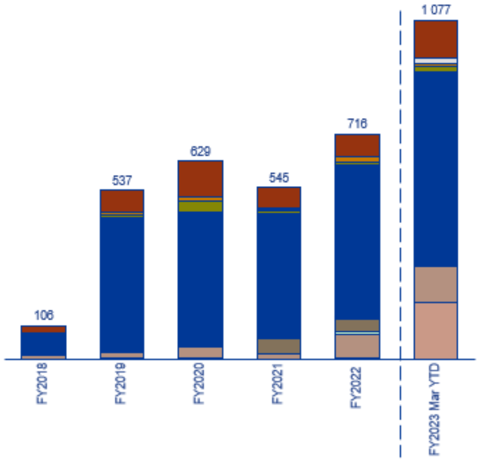


Figure 91: Kendal's EAF performance trend
Source: Eskom

During FY2022/2023 YTD, forced outages and PLL system-wide continued to break records in South Africa. In January, total losses were 15 615 MW, increasing to 16 096 MWs in February. The Kendal station had 42.55% full and part load losses and the unfortunate distinction of being the highest contributor to PLL (with 18% of the total among South Africa's coal plant fleet). As the next figure shows, 1 077 MWs have been lost in FY2022/2023 YTD (including February 2023), compared to 716 MWs in FY2021/2022. The lost MWs have been increasing steadily since 2018.



Mwloss	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023 March YTD
Ash Plant	23.79	71.58	114.63	65.96	71.66	120.12
Auxiliary System	0.69	0.00	0.13	2.26	0.03	17.29
Boiler	3.40	6.71	13.51	4.96	20.31	8.09
C & I	0.00	0.01	0.17	0.58	0.44	0.30
Coal Plant	4.80	8.76	33.33	7.95	5.95	19.59
Cooling Water	0.00	0.04	0.35	0.00	0.44	0.00
Draught Plant	56.38	420.42	417.10	396.48	485.03	607.67
Electrical	0.87	0.62	0.32	0.09	1.11	0.03
Feed Water	0.92	0.73	2.85	0.49	3.54	4.09
Fuel Oil	0.00	0.00	0.00	0.70	0.00	3.39
Gas Cleaning	0.03	1.98	1.89	0.20	2.16	1.74
Generator	3.15	3.66	4.85	48.11	37.83	0.14
HV Yard	0.00	0.05	0.00	0.02	6.82	0.00
Mills	10.93	19.27	38.12	15.55	78.01	115.03
Turbine	1.09	2.97	1.96	1.00	2.92	0.00
Reverse Osmosis						179.51
Waterways	0.00	0.00	0.00	0.43	0.00	0.00
Total	106	537	629	545	716	1077

Figure 92: PLL contributors at Kendal power plant (FY2017/2018–FY2022/2023)
Source: Eskom

Figure 162 and Figure 163 provide the most recent reliability parameters for Kendal power station (YTD up to March 31, 2023).

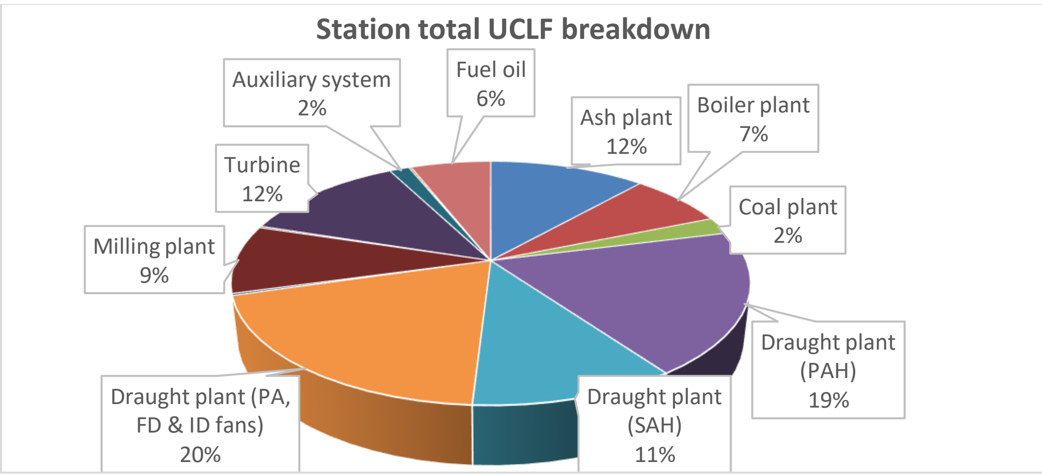


Figure 93: Kendal's reliability UCLF summary (FY2023 YTD)
Source Eskom

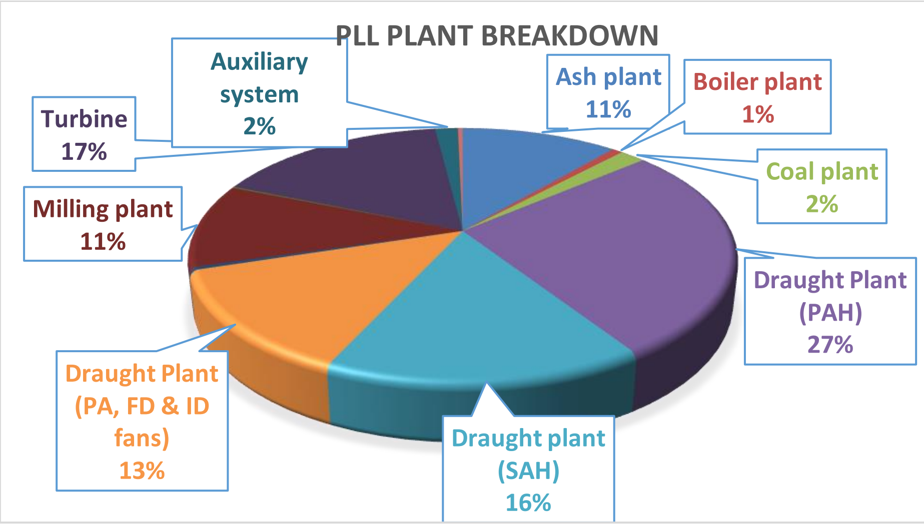


Figure 94: Kendal's reliability PLL summary (FY2023 YTD)
Source Eskom

The highest contributor to Kendal's unreliable operation is the air draft system, contributing 56% of the lost MWs during FY2022/2023 YTD. The steam turbine (16%), ash handling system (12%) and mills (11%) were also major contributors. Table 37 below highlights the key areas requiring urgent attention (colour red).

Electrical	Q1 FY'22	Q2 FY'22	Q3 FY'22	Q4 FY' 22
Protection and AVR	Green	Green	Green	Yellow
BFP's	Green	Green	Green	Yellow
MV Motors	Yellow	Yellow	Green	Yellow
Switchgear	Green	Green	Green	Green
Transformers	Green	Green	Green	Green
Generators	Yellow	Yellow	Yellow	Green
Essential Systems	Yellow	Yellow	Yellow	Yellow
22KV GCB	Green	Green	Green	Green

Turbine	Q1 FY' 22	Q2 FY' 22	Q3 FY'2 2	Q4 FY' 22
Turbine Centreline	Yellow	Yellow	Yellow	Yellow
Turbine and Generator Auxiliaries	Green	Green	Green	Green
Main Cooling Water	Yellow	Green	Yellow	Green
Condensate and Feedwater	Green	Green	Green	Green
Gas Turbine	Red	Red	Yellow	Yellow

Control and Instrumentation	Q1F Y'22	Q2F Y'22	Q3FY '22	Q4 FY' 22
Boiler Auxiliaries system (C&I System 23)	Yellow	Yellow	Yellow	Yellow
Ash Plant C&I	Green	Green	Green	Green
Auxiliary Cooling C&I	Yellow	Yellow	Yellow	Yellow
Coal Handling Plant C&I	Yellow	Yellow	Yellow	Yellow
Compressed Air Plant C&I	Yellow	Yellow	Yellow	Yellow
Fire Detection System	Yellow	Yellow	Yellow	Yellow
SO3 Plant C&I	Yellow	Yellow	Yellow	Yellow
Water Treatment Plant C&I	Red	Red	Red	Red
Training Simulator	Green	Green	Green	Green
Feed Water, MCW and condensate	Green	Green	Green	Green
Building Management System	Red	Red	Red	Red
Continuous Emissions Monitoring System(CEMS)	Green	Yellow	Yellow	Yellow
Turbine control, protection & Supervisory	Green	Green	Green	Green
Tube Leak Detection System	Blue	Blue	Yellow	Yellow
Draught Group	Green	Green	Green	Green

Excellent (Blue)	Improvement Required (Yellow)
Acceptable (Green)	Unacceptable (Red)

Boiler	Q1 FY'22	Q2 FY'22	Q3 FY'22	Q4 FY' 22
Pressure Parts	Green	Green	Green	Green
HP Piping	Green	Green	Green	Green
Boiler Valves and BWCP	Yellow	Green	Green	Green
Mills	Red	Red	Red	Red
Boiler Auxiliaries	Yellow	Yellow	Yellow	Yellow
SSC	Red	Red	Red	Yellow
Flue Gas Conditioning & Cleaning	Yellow	Yellow	Yellow	Yellow
Draught Plant	Yellow	Yellow	Yellow	Yellow

Auxiliary Plant	Q1 FY'22	Q2 FY'22	Q3 FY'22	Q4 FY'22
Bulk Fuel Oil Plant	Yellow	Yellow	Yellow	Yellow
Hydrogen Production Plant	Red	Red	Red	Red
LPG Plant	Green	Green	Green	Green
Coal Plant	Yellow	Yellow	Red	Red
Auxiliary Cooling Plant	Yellow	Yellow	Yellow	Yellow
Compressed Air	Yellow	Yellow	Yellow	Yellow
Civil and Structures	Yellow	Yellow	Red	Red
Outside Ash Plant	Yellow	Red	Red	Red
Water Treatment Plant	Yellow	Yellow	Yellow	Yellow
Fire Protection	Red	Red	Red	Yellow
Inside Ash Plant	Yellow	Yellow	Yellow	Yellow
Air Conditioning and Ventilation	Yellow	Yellow	Yellow	Yellow

Table 37: Kendal's power plant system health overview
Source Eskom[24].

[24] Eskom/Kendal turnaround strategy, May 19, 2022

Further observations regarding the issues affecting EAF and the potential solutions are provided in the next two sections of this report.

In the meantime, it is important to point out that the Kendal power plant has been in operation for roughly 30 years and is due for a major rehabilitation ("mid-life upgrading"), especially since it is expected to operate for another 20 years (until roughly 2044). Furthermore, Kendal ranks fifth in the dispatch order of the power system and is aiming to achieve 75% EAF by March 2024. Hence, substantial maintenance and rehabilitation is urgently needed, especially since past overhauls have been postponed/deferred, as can be seen in Table 38 and Table 41.

Unit No	Originally Planned	Postponed to
1	2018	2024
2	2022	2025
3	2023	8/2023 – 1/2024
4	2023	Current, completion due July 2023
5	2020	2026
6	2020	2021 HP steam leak outage Nov 2023 (90 days)

Table 38: Kendal's current major overhauls (GO) schedule
Source Eskom[25]

5.8.2 Technical Status

5.8.2.1 Technical Status of the Boiler

During the visit, the team walked through the boiler house. **Housekeeping** was not completely in order. Excessive amounts of dust, ash and coal is still present in Unit 2, but we were told that this will be removed during the next outage. No excessive amounts of dust, ash or coal were present in the same areas of Unit 4, which is currently in a major overhaul (see photos below). Boiler reliability was good. The number of boiler tube leaks was limited, and a good boiler tube leak prevention program is in place. Finally, we were able to establish that there were no safety-related issues.

[25] Information obtained during site visit from station management team.

Figure 95: Kendal Unit 2 – PAH duct covered in ash and dust (April 2023)

Figure 96: Kendal Unit 4 – same PAH duct not covered in ash and dust (April 2023)

Lost MWs due to the **draft system** have increased from 52.38 MWs in 2018 to 596.84 MWs in 2023, a substantial increase. The draft system is operating at maximum capacity. The operating issues are mostly related to the ID (Induced Draft) fans, which are affected by increased erosion due to increased dust loading (at the exit of the ESP): Thinning of the ID fan blades has been reported and requires urgent attention. Also, ID, PA and SA fans are handling increased air and flue gas flow due to high air-in leakage (through the ducts and the air preheater), which has not yet been evaluated to identify the location and magnitude of air-in flow.

Air leakages were identified in the PA heater during the 2021–2022 period, as well as damage to the SA heater. Also, some of the SAH packs have eroded. Finally, the boiler is operated at O_2 levels which are pre-set and likely to be above the optimum level, resulting in higher-than-necessary air flows.

Figure 97: Back of Kendal's boiler at ash handling plant
Ash everywhere with water covering the floor. Dust in the air visible: May 2022[26]

[26] World Bank Power Station Assessment Presentation August 2022

Figure 98: Kendal station covered in a dust cloud: May 2022

Figure 99: Kendal's ESP clean and dust cloud is completely gone: April 2023

Figure 100: Ash in Kendal's boiler house

It has not been completely addressed but certainly much better than 12 months ago: April 2023

ESP performance has improved since last year, so the impact on the ID fan is expected to be less, but the air-in leakage still needs to be addressed.

The replacement of pressure parts at Units 1 & 6 was not fully executed during outages in 2018 and 2021, due to unavailability of economiser tubes. This is a risk, as tube leaks may occur causing both forced outage and damage to neighbouring equipment.

Mills were one of the four top factors causing PLL losses to increase from 10.93 MW in 2018 to 114.38 MW in 2023. Plant staff struggled to keep six mills per unit in good working order, mainly due to the lack of spare parts. Maintenance of the mills is 100% outsourced and there are usually issues and delays in signing contracts and getting the support needed. Lack of spare parts and (in some cases) use of old spare parts contribute to underperformance and plant derating.

Coal quality is good and does not seem to cause any problems. Coal samples are taken once a day and analysed; there is some variability in coal quality but within the limits of boiler design specifications.

The **Thermal Index** report (June 2021) indicated that the header temperatures and steam pipes were operating at design levels (Table 39 and Table 40 below). The boilers at Kendal have a design capacity of 800 MW, which allows for a large amount of operating room and is a significant contributing factor to the good thermal index figure (the best in the fleet).

KENDAL POWER STATION

Component	***Design Temperature***	***Calculated Reference Temperature***	***Thermal Index Reference Temperature***
SHFPF Outlet Header	545	543	**543**
RHFPT Outlet Header	543	548	**543**
Main Steam Pipework	545	543	**543**
Hot Reheat Pipework	543	546	**543**

Table 39: Steam operating temperature at Kendal
Source Eskom

	SYSTEM	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23
KENDAL	Header TI	6	1	0	0	0	0	0	0	0	0	0	1	0
	Main Steam TI	6	1	0	0	0	0	0	0	0	0	10	0	0
	Hot Reheat TI	0	0	0	1	0	0	0	0	0	0	2	0	0

Table 40: Kendal power station Thermal Index results (FY2022/2023)

Boiler at a glance:

- Overall boiler operating condition is good.
- The most serious issue is limitations in the draft system (PA, SA, and ID fans) due to a combination of air-in leakage and high excess air (O_2). This is the highest contributor to PLL and needs immediate attention. Air-in leakage needs to be reduced; PAH and SAH needs urgent maintenance attention.
- Spare parts for the mills are an urgent issue. Also, associated contracts for mill maintenance need to be expedited.

5.8.2.2 Technical status of the machinery

Turbine: As indicated in Figure 161, the steam turbine is reliable and not causing any consistent outages. The exception is the Unit 6 steam turbine, which has been leaking since 2022. The unit was taken offline and inspected but was put back in service with the leak because the power network needed the additional capacity: Repair work would have required a 90-day outage. As a result, the unit was de-rated by 300 MW (in January 2022) until proper maintenance is carried out.

Poor execution of steam turbine maintenance was reported. As a result, Eskom has decided to involve the OEM throughout the maintenance process (planning through to implementation). Also, it plans (appropriately) to establish a QC (quality control) system.

The variable speed drive motors of six feedwater pumps are not working properly and need replacement. We understand that this project has been included in the short-term action plan and will be addressed in 2023.

Kendal is the main "*Black Start* station" to re-instate the power grid after a blackout event. Black out start equipment comprises gas turbines that are not in good condition but are still in working condition (rather old) and need replacement. Unit islanding and black start procedure is tested regularly. Seven (7) operators with operation teams know the process well and do regular training.

Machinery at a glance:

The steam turbine of Unit 6 needs an urgent outage to eliminate the leak; HP stop valve is needed.

Feedwater pumps need urgent replacement of variable speed drive motors.

Gas turbines used for black start need replacement or rehabilitation to ensure that they are in good working condition.

5.8.2.3 Technical Status Electrical and C&I

Assessment and maintenance of all electrical and C&I installations are carried out at regular maintenance intervals and tests are carried out annually.

The **generators** are reliable, although there is winding fretting on Units 2 & 4 after stator rewinding. The generator rotors are overdue for mid-life refurbishment. The Unit 5 generator rotor has an inter-turn fault. One defective spare rotor and stator are available for emergency use and an additional spare rotor is currently being purchased.

Medium voltage (MV) spares are available in stock and in the market, even though some are obsolete. The MV equipment is of excellent reliability. The variable speed drives (VSD) for feed water pumps are in very poor working condition and need to be replaced with new ones.

The low voltage (LV) equipment is of excellent reliability. Spares are available even though some of the equipment is obsolete. There are no spare incomers or isolators. The LV system and equipment outside of the unit are reliable, although the life span of the equipment is reduced due to the impact of environmental conditions.

HV/MV unit transformers and MV/LV generator transformers are of good reliability, although there was a big generator transformer failure in 2021. There are no spares, but a spare transformer – to be shared with the Kusile power plant – is on order. The unit transformers and service transformers are in good condition and only the tap changers are currently awaiting replacement/repair.

Batteries have been gradually replaced over the course of the 2010s, carried out via national contract. DC and UPS systems are in good condition.

Plant control system (DCS): The obsolete ABB Procontrol P13 system will be replaced by a new state-of-the-art DCS system.

Local control for Balance of Plant, water treatment plant, ash handling: Spare parts are available, the systems are reliable, and the maintenance department is very familiar with the systems.

Turbine governor and unit functional safety: The system is user-friendly and reliable. Modules that fail are repaired with no danger to the process.

Field instruments / measurements / drives: Equipment is of good quality, although some of the older instruments need additional maintenance or replacement. There are spares in stock, but some inventory needs to be replaced. Basic to intermediate maintenance and engineering expertise is provided by the site team.

The **electrical and C&I plant** equipment is well maintained. General wear and tear are not endangering the proper functioning of the equipment in any significant way. Based on available documentation - the site assessment, interviews with plant maintenance, engineering, and production staff, - the following issues need to be addressed:

- DCS (ABB Procontrol) obsolete – needs to be replaced.
- Unit transformer – spare transformer needs to be purchased.
- VSDs for feed water pumps need to be replaced.
- Generator rotor – a spare rotor needs to be purchased.
- 3,3 kV station transformers – need to be replaced.

Electrical and C&I at a glance:

Key spares need to be added to the inventory, in particular a generator transformer and generator rotor.

3.3 kV transformers need to be replaced at first opportunity.

Plans need to be made to replace the DCS system, which is obsolete.

5.8.2.4 Technical Status of the Water Treatment Plant

The water treatment plant had not caused any problems until last year. The reverse osmosis unit failed in 2022 and reduced the available plant output by 170.29 MWs. Also, the condensate polishing plant is out of service, resulting in a high volume of blowdown at all six units. Presently, the water treatment plant is not in good operating condition and urgently needs to be refurbished.

To be able to carry out the refurbishment, the power plant must make a serious effort to reduce water consumption, so that it can run with just one water treatment train. Alternatively, a temporary mobile plant will be required to enable the refurbishment. Water consumption reached 30 Ml/day and efforts have been made to bring it down to the 18 Ml/day level. The target should be 8 Ml/day.

Water treatment at a glance:

The water treatment plant needs urgent refurbishment.

Efforts should be made to reduce water consumption further (to the target 8 Ml/day).

5.8.2.5 Technical Status of the Auxiliaries and other Systems

The ash handling equipment is impacting reliability and over the last 15 years its contribution to PPL has increased constantly. For example, in 2018 the ash handling system contributed 23.79 MW to PLL, while in FY2022/2023 it was 130.68 MW. In fact, over the last four years it has consistently contributed 70–130 MWs. Figure 101 and Figure 102 show the energy (GWh) and capacity (MWs) lost during 2021–2022.

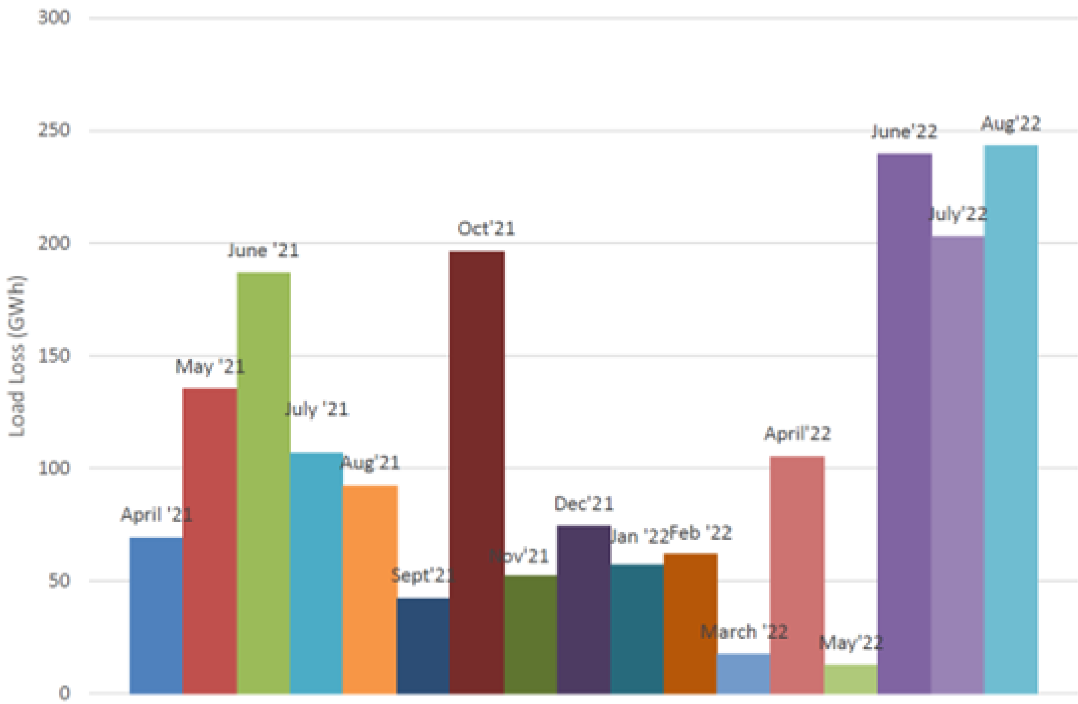


Figure 101: Monthly load loss (GWh) due to ash removal constraints at Kendal
Source Eskom

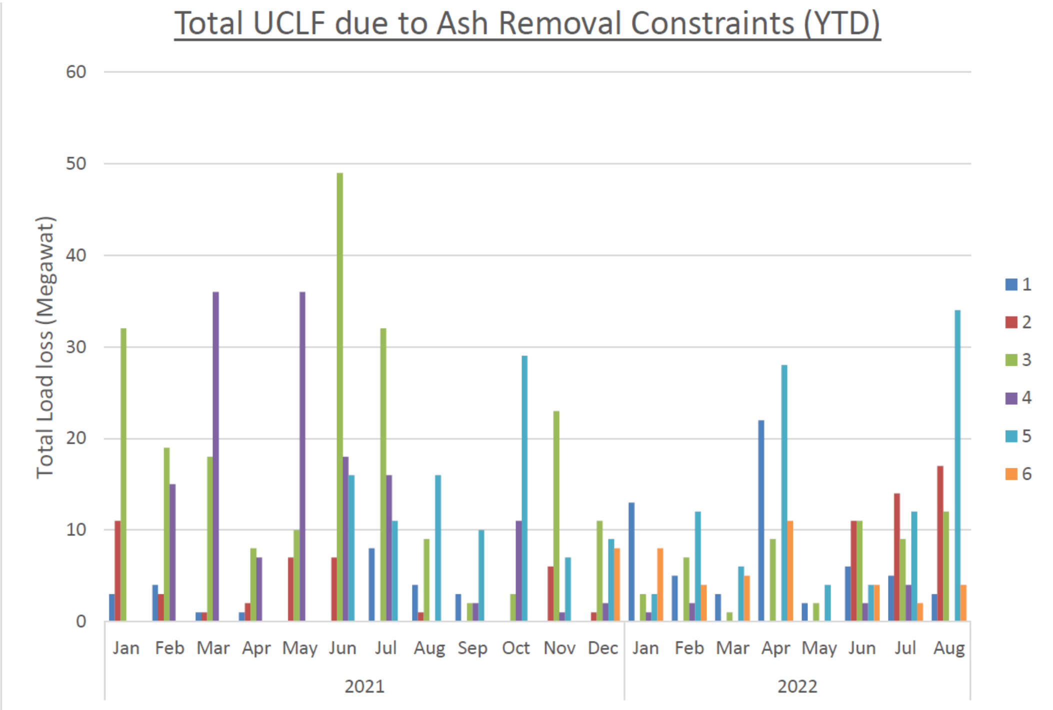


Figure 102: Monthly load loss (MW) due to ash removal constraints at Kendal
Source Eskom

As the "*Q3 DHP System Health Report for 2022*" indicates, the ash plant has not been performing well since 2017 and is getting worse. There are problems throughout the ash handling system, resulting in outages and plant derating (lost MWs). (See photos above).

ESP performance must improve as it emits more than 100 mg/Nm^3 and the required level of emissions is 50 mg/Nm^3 (see Paragraph 5.8.2.6 below). Also, the ESP hoppers are causing frequent operating problems. The average particulate emission at the Kendal station had been reduced to the 100 mg/Nm^3 level at the end of 2020. However, some of the units started performing poorly one year later. For example, particulates from Unit 2 spiked at the 1 500 mg/Nm^3 level in the November 2021 – February 2022 period and some other units had particulate emissions at the 200 mg/Nm^3 level. These issues have now largely been addressed, as already mentioned.

Dust control has improved significantly but fly ash is still piled up in a small number of places around the power plant (see photos above).

Also, space limitations at the ash dump facility, coupled with limited redundancy of the conveyors, affects the throughput of the conveyors, resulting in plant derating (lost MWs).

Poor execution of planned maintenance, poor performance of the ash contractor, deferred maintenance and technical upgrading and replacement of equipment are still all affecting the ESP and ash handling system's performance substantially. However, some system improvements have been achieved over the last 8 months.

The coal handling system is in good working order and no issues have been identified. As mentioned previously, coal quality has been maintained within the required specifications, with approximately 80% of the coal coming from the local mine and 20% from other mines.

Auxiliaries at a glance:

- Maintenance of the ash handling system is needed urgently. Also, the capacity of the ash handling plant in general needs to be assessed, and potential upgrading may be needed.
- ESP needs to be upgraded to reduce particulate emissions below 50 mg/m3. This will help the ID fans too.

5.8.2.6 Emissions [27]

Kendal has emission compliance issues which are expected to get worse unless action is taken. The plant does not comply with particulate matter (PM) emission requirements. The required limit is 50 mg/Nm^3 and the plant emits above 100 mg/Nm^3. It is understood that some actions have been taken (e.g. replacement of high frequency transformers), but a comprehensive upgrade of the ESPs is needed.

NO_x emissions are required to be kept below 1 100 mg/Nm^3 and the plant complies marginally with this requirement. By April 2025, NO_x emissions need to be kept below 750 mg/Nm^3. This could be achieved with low NO_x burners at a cost of \$ 20−30/kW. Replacing the burners also provides the opportunity to optimise combustion. This should result in lower excess O_2 and lower overall air flow through the system, which should help the draft (PA, SA, and ID) fans.

As we understand, presently the Kendal plant complies with SO_2 requirements (2 600 mg/Nm^3), but it will not be able to comply with the reduced requirements of 1 000 mg/Nm^3, which come into effect in April 2025. 50−60% SO_2 reduction is needed, which can be achieved by reducing the sulphur content of the coal or by installing SO_2 control equipment. Lower sulphur content coal may be available from other mines, or it can be obtained through selective mining and coal clean-up. Alternatively, 50–60% SO_2 reduction can be achieved by using dry SO_2 control technologies (given the lack of water in the region).

[27] Information taken from Eskom business plan 2022-23

Emissions at a glance:

- ESP upgrading is needed urgently, both to comply with 50 mg/Nm^3 and to improve ID fan performance.
- The plant needs to lower NO_x emissions by April 2025; low NO_x burners seem to be the preliminary option of choice.
- Kendal needs to assess how it will comply with SO_2 control requirements (1 000 mg/Nm^3, which come into effect in April 2025). Alternative options (lower sulphur coal and SO_2 control technologies) need to be evaluated.

5.8.3 Technical Measures to Improve the Plant Condition

The power plant has now been in operation for more than 30 years and is due for a major rehabilitation/mid-life technical maintenance. Deferred outages in some of its units in the last few years make this need even more urgent.

The air and flue gas draft system, the water treatment system, ESP, and ash handling, as well as the mills all require special attention. Also, Unit 6 requires urgent maintenance of the steam turbine to eliminate the leaks and recover 340 MWs of de-rated capacity.

The air draft system is operating at maximum capacity and an effort needs to be made to reduce both air-in leakage and the amount of air coming into the system. The former will require a detailed evaluation of where air is entering the system. The investigation should start with an inspection of the most obvious places (e.g. PA and SA heaters, duct joins, the boiler).

Furthermore, excess O_2 set points should be reviewed and possibly revised. An optimization program should be able to reduce the excess O_2 without adversely affecting unburned carbon and overall performance of the boiler. O_2 optimization can be achieved in one of the following ways:

1. Set up O_2 measurements in multiple locations along the boiler (combustion zone, exit of the economizer, exit of the air heater); also, set up CO monitors at the exit of the unit (e.g. at the stack or wherever is convenient after the air heater). By monitoring CO emissions and unit performance, an optimum O_2 level can be established for each of the key loads that the unit is operating in (e.g. O_2 set points at 100%, 75%, 50%).
2. A neural network-based system can be used to optimize unit performance, including identification of optimum setpoints for excess O_2. Such a system would require similar instrumentation as Option 1 (especially CO monitors).

The performance of the ESP should be addressed urgently, both because particulate emissions need to be reduced and because of its adverse impact on ID fan reliability.

Maintenance of the water treatment system is also a high priority and needs to be addressed as soon as possible. In parallel, every effort should be made to reduce the required amount of water being consumed at the power plant.

Obtaining spare parts and maintenance of the mills is another urgent item. Additional items that need to be addressed at first opportunity:

- Variable speed drive motors for six feedwater pumps.
- Replacement or rehabilitation of the gas turbines used for black start.
- Key spare parts need to be added to the electrical system inventory, in particular a unit transformer (AT) and a generator rotor.
- 3.3 kV transformers need to be replaced at first opportunity.
- Plans need to be made to replace the DCS system which is obsolete.
- The training centre needs to be revitalized and staffed appropriately.

5.8.4 Power Plant Management

Currently 705 employees are working at the power plant. The management team seems to be very capable and efficient, addressing the chronic issues facing the power plant. The plant manager was brought in only eight months ago and he seems to be turning things around with a new leadership style and focus on people and results. The engineering manager was replaced too. There have been substantial improvements both in employees' spirits and in the results achieved.

A limited number of motivational initiatives have been introduced, including performance contracts, training, mentorships, awards, etc. This is not enough, though, and more is required but is not achievable within the current management and operational structure.

Maintenance

The maintenance team is responsible for fixing the problems reported by the operation team. The scoping is defined by the engineering department. Moreover, the maintenance group takes care of spare part planning.

A substantial proportion of the plant maintenance is carried out by outside contractors. Approximately 63 contracts are needed, with the top five covering the mills, fuel oil, water treatment plant, coal handling plant and ash plant. However, only two thirds of the required contracts are actually in place. As shown in Figure 103, delays in signing these contracts are a frequent occurrence.

Figure 103: Kendal stock contract summary
Source: Eskom

Operation

The operation team works in five shifts, 24/7. Forty-two employees are active per shift, 210 is the headcount target for operation. Hence, there are about 60 vacancies now. Efforts are underway to fill the vacancies.

Occupational hazards also need to be reduced: Particular attention should be paid to fire risk management and to providing emergency response and medical services.

Outages

Since 2016, all major overhauls have been deferred (see Table 38 and Table 41). The effect of these deferrals has already been explained in the report, above.

It is evident that system supply constraints and performance requirements have taken priority over good plant maintenance and management. This very short-sighted approach has resulted in severe deterioration in the condition and performance of the plants. In the last 12 months, this situation has improved. Table 41 shows that the only GO still open and necessary to normalize the situation is the overhaul of Unit 3 and this is currently in progress.

From what we have seen and mentioned already, it is evident that more complete maintenance is now carried out during outages. The plant management team has indicated that it is aiming to have EAF back at 75% by April 2024. This seems possible but will require a 90 days outage to repair the HP steam leak on Unit 6 (300 MW PLL).

Unit	Original Scheduled Date	Actual Start date	Times Moved	Deviation(Days)	Explanation
1	2016/11/04	2018/10/18	28	713	Eskom Management Decision
2	2019/01/04	2022/01/08	8	1100	Eskom Management Decision
3	2020/08/07	2023/08/05	7	1093	Unit 3 moved to accommodate unit 4 stress corroison cracking risk.
4	2021/09/04	2023/01/23	6	506	Eskom Management Decision
5	2020/02/01	2020/07/20	5	170	Eskom Management Decision
6	2017/04/07	2020/11/20	13	1323	Moved to accommodate units 1 and 2 to address stress corrosion cracking

Table 41: Kendal GO deferral schedule
Source Eskom

Capital Project Plan and Expenditure Budget

The current capital investment project schedule for Kendal power station is based on the 2044 plant decommissioning strategy as per the current Eskom shutdown schedule.

This strategy is acceptable and fits within the long-term JET plan for the country. Between 2023 and 2027, the station has 37 approved capital investment projects scheduled. The total estimated capital investment required for these projects is **R 2 239.6 million**. In addition to this, they have another **34** unfunded projects that require **R 5 559.3 million** in investment. The five projects in Table 42 are from the unfunded list but already have ERA approval and are deemed to be critical. The investment required for these projects is **R 508.83 million**.

SAP PS Project Name	Required Budget Total R FY2023-2027	ERA Approval Status and Planned date	Comments
Mobile Demin Plant	136 340 000	Approved	No Fund Allocation & IM release. Commercial process delayed.
Unit 1&3 supply and installation of Secondary Air heater element packs	98 288 289.26	Approved	No Fund Allocation & IM release. Commercial process delayed.
Replacement of Boiler Feedpump VSDs	288 000 000	Approved	No Fund Allocation & IM release. Commercial process for Sole Source approval in progress.
Coal Plant Chutes refurbishment	194 830 000	Approved	No Fund Allocation & IM release. Commercial process delayed.
Diesel Generator Control Panels	26 000 000	Approved	No Fund Allocation & IM release. Commercial process delayed.
Total (million)	**508 830 000**		

Table 42: Critical unfunded projects FY2022/2023–FY2026/2027 at Kendal
Source: Eskom (approved ERAs)

The total critical investment required at Kendal from FY2022/2023 to FY2026/2027 is R 2 748.43 million for the approved and critical unfunded projects. Including all the unfunded projects, it is **R 7 798.9 million**.

5.8.5 Technical Profile of Main Plant Areas

The following table provides the key design data, types of key equipment and suppliers.

Boiler Manufacturer	Combustion Engineering (General Electric)
Type	Forced circulation, sub-critical
Coal mass flow [t/h]	98.67 kg/s
Pressure [bar, absolute]	185 – steam drum
Temperature [°C]	360 – steam drum
Firing system	
Number of burners	5 Mills, 4 corners each, upper and lower pipes on each corner
Type of mills	Ball-tube mills
Mill capacity [t/h] – per mill	103
Reheat system	
Pressure [bar, absolute]	37.962
Temperature [°C]	540
Coal supply	
Coal supply (truck, mine)	Mine & Trucks
Coal storage capacity on-site (t)	3 760 000
Boiler bunker capacity (t)	Silos & Bunkers – 35 000 (50% capacity)
Precipitators	
Manufacturer	Walter & C&E
Type	Sigma type CE plates
Ash handling	

Machinery and Electrical

Turbine	
Manufacturer	Siemens
Type	Tandem compound reaction
Casings (HP-IP-LP, double/single flow)	HP (single)-IP (double)-LP (four)
Steam volume (kg m/s)	577
Main steam pressure [bar, a]	165
Main steam temperature [°C]	535
Reheat steam pressure [bar, a]	37.962
Reheat steam temperature [°C]	535
Cold end	

Condenser	2 – 13.6kPa backpressure at MCR
Cooling tower	Indirect dry cooled
Generator	
Manufacturer	KWU - Siemens
Terminal voltage	22kV
Rating	686 MW Normal, 729 MW Max
Cooling system	Hydrogen
Transformer	
Manufacturer	Siemens
Terminal voltage primary/ secondary	420+6/-10x1.56%/22 kV
Placement	Between Units and HV Yard

5.9 Kriel Power Plant

The Kriel power plant is more than 47 years old. Insufficient maintenance causes significant power losses at the plant: In March 2023, PPL accounted for 548 MW of the power plant's installed gross capacity of 3 000 MW. Furthermore, three units have been permanently de-rated by 70 MW each, due to coal-related slag formation and emission issues.

One of the key PLL contributors is the poor vacuum conditions caused, in the main, by the malfunctioning of the cooling towers. The water chemistry is the root-cause for this malfunction as the alkalinity of the water cannot be sufficiently controlled due to insufficient lime treatment. This resulted in scale build-up in the ducts and flakes that block the cooling tower fills. As the fills cannot be cleaned effectively due to the design, a complete change is required. The retrofit of the two cooling towers will require operations to be halted at three units. However, the MW gain from this measure is worth the effort. In the course of the cooling tower retrofit, the chemistry regime for the cooling water treatment needs to be optimised and the condenser tubes should be cleaned.

Another cause of PLL is the draught plant. Even if operated at maximum load, the capacity of the ID fan is inadequate to guarantee appropriate pressure in the furnace. This can be largely mitigated by tightening the flue gas ducts and air heaters. We also strongly recommended inspection and repair of all other potential sources of air ingress on the boiler.

A significant reduction in the steam temperature was noted, caused by leaky spray injection valves. We strongly recommend changing or repairing the valves on a priority basis. Besides the PLL, these leakages also risk causing damage due to thermal shock.

Many more water and steam leakages were visible throughout the plant. We recommend systematically repairing leaking valves, pumps, etc., in order to improve the plant’s efficiency and reliability. Moreover, the HP heaters should be brought back into full service – either by repairing them or replacing them.

The standstill period for the cooling tower retrofit would be a very good opportunity to fix all defects in the affected units.

The site team reported that keeping highly-qualified personnel at site is a challenge – this refers to the management as well as to the workforce. This is mainly due to the fact that the power plant is regarded as an unattractive workplace, situated remotely far away from urban areas such as Pretoria and Johannesburg. The vgbe team therefore recommends the development of an incentive programme that includes elements that address the issue, such as rewards for good performance and the provision of accommodation near the power plant.

Despite these circumstances, the team spirit of the management team seems to be good. The vgbe team believes that, equipped with the necessary empowerment and budgets, the team would be able to manage the turnaround. Management needs some positive signals with respect to recognition of good work and planning security.

5.9.1 EAF and PLL

The Kriel power plant comprises six 500 MW coal-fired units (gross capacity). Units 1 to 3 were supposed to be supplied by a new underground mine developed by Eskom. However, this mine has not been made operational and so the power plant needs to use alternative coal that is of poorer quality than originally planned. This has resulted in an additional derating of about 70 MW per unit – 210 MW in total.

Unit	1	2	3	4	5	6
Commissioning Date	05/1976	05/1976	01/1978	08/1978	03/1979	11/1979
Gross installed capacity [MW]	6 x 500					
Nom. installed capacity [MW]	6 x 475					

Table 43: Key figures for Kriel power plant

Over the past five years, the **EAF** was in the range of 50.75% (FY2021/2022) to 60.78% (FY2018/2019). For FY2022/2023, the value is currently at 49.39%.

Year	Plant	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
2018/2019	60.78 %	69.65%	43.52%	51.66%	54.31%	69.52%	76.01%
2029/2020	52.34 %	52.64%	67.57%	23.43%	65.14%	53.57%	51.66%
2020/2021	52.48 %	41.16%	54.74%	50.06%	56.03%	51.41%	61.47%
2021/2022	50.75 %						
2022/2023 YTD	46.38 %						

Table 44: EAF at Kriel power plant (FY2018/2019–FY2022/2023 YTD)
Source: KISSY database, vgbe / Eskom

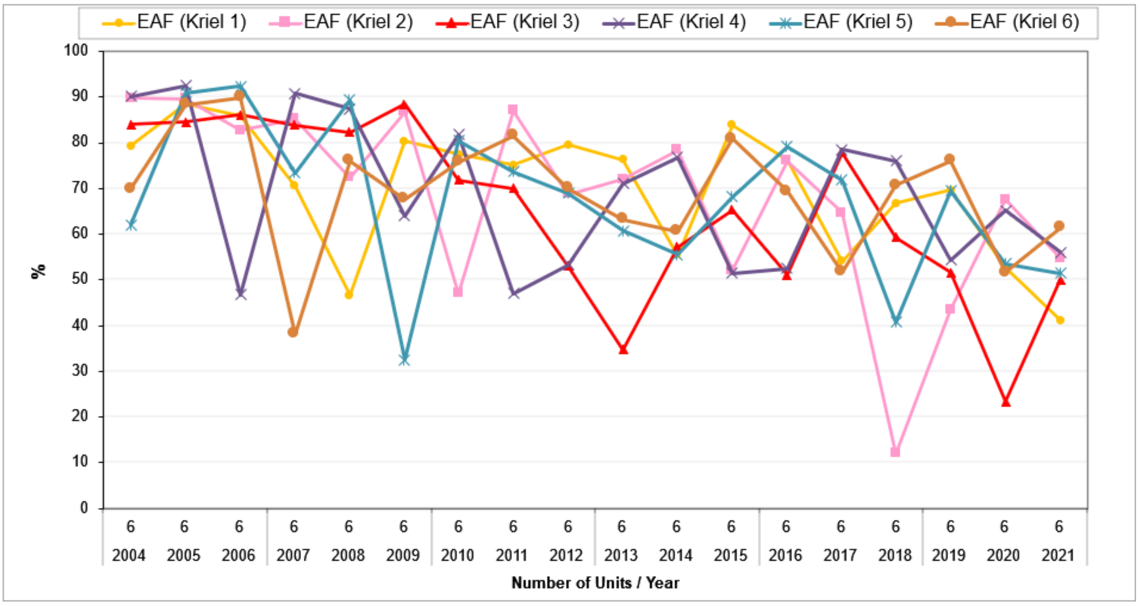
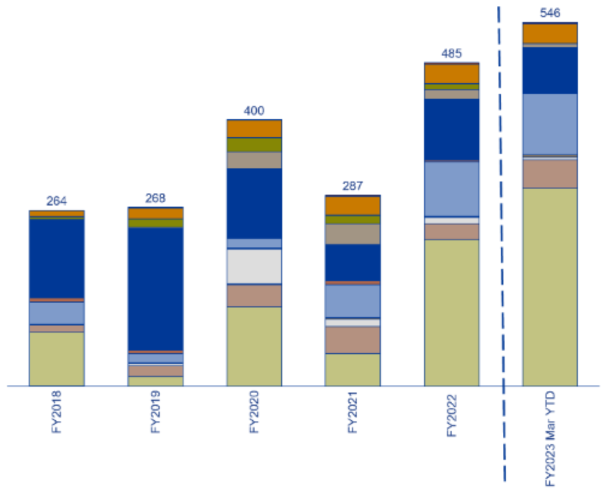


Figure 104: EAF at Kriel power plant (FY2003/2004–FY2020/2021)
Source: KISSY database, vgbe

The low EAF is mainly caused by significant PLL and a lot of trips. The main PLL sources are shown in the next figure, below. As can be seen, many different components impact PLL – the main components are the turbine, the draught plant, the feedwater, the boiler and the mills. The absolute numbers of the PLL for the individual components have fluctuated over the years, increasing again since FY2021/2022. A further increase in PLL this fiscal year has been caused by additional losses in the turbine. During the site visit, even higher losses were reported, caused by the poor vacuum at the turbine: Up to 1 000 MW, which corresponds to one third of the installed gross capacity.



Mwloss	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023 March YTD
Ash Plant	0.00	0.37	0.13	1.90	2.19	2.41
Auxiliary System	0.55	0.24	0.31	0.11	0.30	0.11
Boiler	9.00	16.26	26.24	28.31	28.65	29.30
C & I	0.35	0.43	0.21	0.33	0.45	0.24
Coal Plant	3.93	12.44	20.81	12.40	8.29	0.20
Cooling Water	0.96	2.12	25.93	31.18	15.14	6.37
Draught Plant	116.30	182.47	103.13	54.82	90.95	67.28
Electrical	6.34	5.33	1.31	5.54	2.11	0.99
Feed Water	33.71	13.10	14.11	49.15	82.21	91.90
Fuel Oil	0.19	0.00	0.33	0.11	0.11	0.00
Gas Cleaning	0.00	1.04	0.96	2.49	1.60	3.84
Generator	0.77	3.30	52.65	10.35	8.86	3.91
HV Yard	0.00	0.00	0.66	0.11	0.00	0.11
Mills	10.97	16.96	34.04	41.16	24.18	42.70
Turbine	80.58	14.29	118.79	48.90	220.10	296.88
Waterways	0.38	0.00	0.02	0.11	0.00	0.00
Total	**264**	**268**	**400**	**287**	**485**	**546**

Figure 105: PLL contributors at Kriel power plant (FY2017/2018–FY2022/2023 YTD)
Source: Eskom

5.9.2 Technical Status

The plant has been running for more than 45 years. Over the years, maintenance and outages have often either been deferred and/or not executed to their full extent, due to the tight supply situation. The main problem for the plant is the poor vacuum caused by insufficient functionality of the cooling towers.

5.9.2.1 Technical Status of the Boiler

The **housekeeping** in the units seems to be reasonably good. Many employees were cleaning the boiler house while we did our site walk. The ash handling plant (wet system) is reportedly running without problems but, if there are problems, the ash is temporarily dumped on the ground. This situation appears to happen approximately once a month. The housekeeping team is advised to immediately react to such situations, which are followed up by intensive cleaning.

The **mills** contribute 42 MW to PLL. During the site walk, an abnormal noise was noticed at two of the mills at Unit 2. The vgbe team recommends checking these mills, as it is likely that they are close to breaking down. Moreover, all mills need to be investigated more closely, in order to plan appropriate maintenance measures.


Figure 106: Clean boiler house at Kriel power plant

In total, a maximum of three units were running during our visit. All the others were shut down, due to trips.

The boiler for the running units showed some signs of damage along with many steam and water leakages throughout the boiler house.

Figure 107: Example of cracked plaster insulation at a pipe in Kriel's boiler house

Figure 108: Water and steam leakages in Kriel's boiler house

Moreover, the fire protection equipment was identified as a safety risk. The inspection deadlines for some of the extinguishers had been exceeded and others were simply lying on the grating.

Besides these water and steam leakages, there are also a lot of air leakages that contribute to PLL. The air ingress to the ducts and the boiler mean that the draught plant contributes 67 MW to the PLL. This is because the air ingress limits the capacity of the draught plant, preventing operation of the unit at full load, as this would lead to a situation in which the flue gas could not be sufficiently removed from the boiler.

In the control room, we noted that all running units were operating at a significantly reduced reheat temperature (447°C instead of 510°C, see next figure). This 60 K temperature deficit has a significant impact on plant efficiency and represents a loss in power output of some 50 MW. This kind of reduction can also lead to problems with turbine operation, such as trips caused by excessively low temperatures. The low temperature was being caused by excessive spray water (>1.2 kg/s) entering the system due to **leaky spray injection valves,** even though both spray injection valves were completely closed.

As already mentioned, Units 1 to 3 have to use coal of lower quality. In order to avoid slagging of the boiler, the power output was de-rated. Moreover, it was reported that the **soot blowers'** availability was in the range of 65% of their full capacity. Operating soot blowers in lower capacities might result in clinker formation and BTL. The availability and effective operation of the soot blowers during operation are key to successfully removing the slag at an early-enough stage, so that it does not damage the boiler.

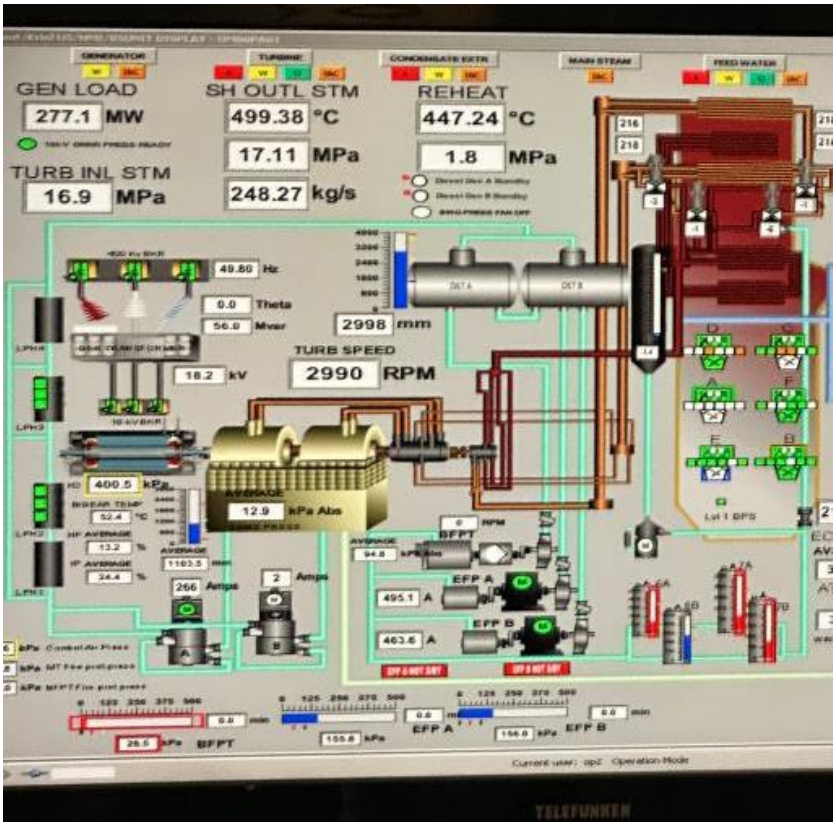


Figure 109: Low reheat temperatures at Kriel

Eskom uses a **Thermal Index** (TI) to track the thermal excursions on boiler outlet headers, main steam pipework and hot reheat pipework. The TI is a long-term plant health indicator for the high temperature/high pressure components. The data for the TI can also be used to check the operational stability of the boiler, as the thermocouples indicate the time spent above normal operating conditions. More detailed information about the TI can be found in section 5.1.4.5.

The TI report for Kriel for FY2022/2023 shows that the TI limits are frequently exceeded on all the monitored components. This is probably caused by the boiler over-firing as a result of the unavailability of the feed-water heating and air-heater leakages. Additionally, poor vacuum on the condenser side contributes to the overall situation of an inefficient boiler operation mode. The over-firing has significant long-term implications for the creep life of the high pressure/high temperature components.

Tolerance Limits for Thermal Index:	
< 35	Favourable
36- 73	Acceptable
> 73	Unacceptable

		Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23
KRIEL	Header TI	177	255	20	29	6	12	5480	4357	17	169	4902	0	1246
	Main Steam TI	464	359	415	112	148	427	10320	4	327	152	7	85	85
	Hot Reheat TI	112	8	85	132	25	46	7	9	22	49	0	0	82

Table 45: Extract from the Thermal Index report for Kriel

Boiler at a glance:

- During site visits, only three units were in operation due to several trips.
- Housekeeping is adequate.
- There are a large number of water and steam leakages, as well as air ingress.
- Combustion needs to be optimised to avoid over-firing und BTL.
- The coal band needs to be checked and optimised to reduce clinker.
- Mills at Unit 2 make an unusual sound – urgent servicing is needed. A close monitoring is required.
- Leaky spray injection valves cause low reheat temperatures, impacting PLL.

5.9.2.2 Technical Status of the Machinery

The housekeeping in the **turbine** area is acceptable. However, some parts of the turbine are not completely insulated. Moreover, there are vibration issues at the turbine plant that are linked to an improper maintenance of turbine oil systems resulting in malfunction of oil system. Specific reasons of the vibrations cannot be evaluated precisely. Nevertheless, on site we were told that oil drains were clogged and may disturbed oil circulation. Another possible root cause could be foreign contaminations of oil during refilling and/or maintenance work in the oil station. In this regard it is very likely that additionally some equipment failure e.g. of jacking oil system also contributed to turbine bearings vibrations. Usually the turbine oil systems (jacking oil, lube oil, hydraulic oil) are serviced from one common oil handling plant.

Figure 110: Clean turbine area at Kriel

Figure 111: Oil station at Kriel's HP bypass

A massive leakage at the feedwater pump is contributing to the PLL. In addition to this, many HP heaters are not in service due to defects. These problems need to be addressed short-term, either by repairing or replacing the defective equipment.

One of the main causes of losses in the turbine area is the poor vacuum, due, in main, to the poor performance of the four **cooling towers**. The water chemistry is the root-cause for this malfunction as the alkalinity of the water cannot be sufficiently controlled due to insufficient lime treatment. This resulted in scale build-up in the ducts and flakes that block the cooling tower fills. As the fills cannot be cleaned as per design, a complete change is required. The vgbe team strongly recommends refurbishment of the cooling towers as soon as possible. Although this requires the shut-down of three units for approximately two weeks, it will pay off, leading to a gain of up to 500 MW (as reported by the site team). During the shut-down, all other defects (not only those relating to the cooling system) should be fixed as well.

In addition to the issues with the cooling towers and the consequences for the condenser tubes, problems with the cooling water chemistry were also identified. An unsuitable chemistry regime has caused scaling on the condenser tubes. They need to be cleaned during the cooling tower retrofit. Furthermore, the chemistry regime – especially the lime treatment – needs to be optimised. This requires several measurements (e.g. acid capacities). The process is also affected by high temperatures, sunlight exposure, TOC etc. Further information is available in the vgbe standard "Cooling Water Systems and Cooling Water Treatment" (S-455-00-2022-12-EN). The vgbe team recommends engaging a specialised water treatment company to carry out the adjustment and optimisation on site.

Machinery at a glance:

- There are vibration issues at the turbine that are likely to associated to improper maintenance of the turbine oil system.
- Poor vacuum is one of the key PLL drivers. The root cause of this problem is the cooling towers.
- Scaling on condenser tubes resulting from improper cooling water chemistry.
- Many HP heaters are not in operation, also leading to PLL.

5.9.2.3 Technical Status Electrical and C&I

The Siemens Teleperm C control systems on Units 1 to 6 have been replaced as part of a full control and instrumentation upgrade supplied by Siemens, including a new Human Machine Interface (HMI), controllers and the SPPA-T3000 DCS control system. All units are controlled from one central control room – the electrical operations are still controlled from the old control room.

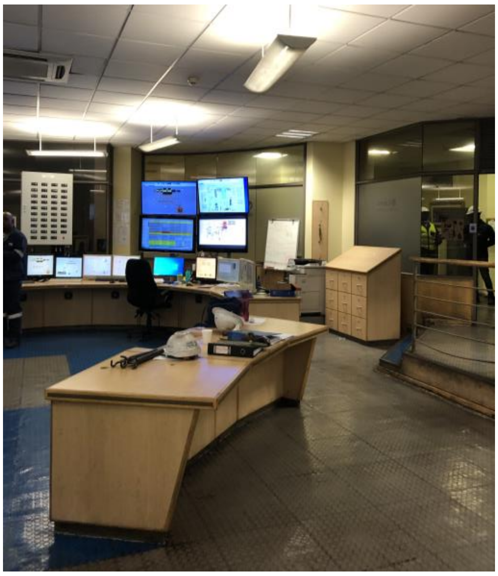


Figure 112: Control room at Kriel

Hence, the C&I system seems to be acceptable. No issues were reported with respect to generators and transformers. However, a replacement of the Unit 4 generator is planned for 2025. The site team stated that Units 1, 3 to 6 generators are operating outside their design life and hence, a generator replacement is required. However, only generators for Unit 4 and 6 will be replaced due the limited remaining lifetime of the plant (as per current planning).

5.9.2.4 Technical Status of the Water Treatment Plant

The power plant has a central make-up water plant, which we visited during the site walk. The capacity of the make-up water plant is adequate to meet the site's consumption needs with water of sufficient quality.

Raw water is supplied by the Usutu and Vaal dams and pre-treated (filtration, flocculation, sand filter).

The make-up water plant consists of three parallel trains. Each train consists of cation and anion exchangers followed by a mixed bed with a flowrate per train of 198 m^3/h.

The water treatment plant is in good condition. Also, the pumps that transport the water to other areas of the plant seem to be in an acceptable condition – only a few were leaking when we visited. However, we recommend that any leaking pumps be repaired. New measuring instruments have been installed and housekeeping is good. However, not all the installed online measuring instruments are working.

The offline sampling is carried out by the site team. Water samples are taken and analysed regularly to measure key performance indicators.

The regeneration of the anion and cation exchanger is carried out with sulfuric acid caustic soda. During the site visit, the team learnt that neutralisation of the regeneration effluents is not carried out. The effluents are discharged into the plant's channel system without any treatment. This poses a high risk of damage to pumps and foundations (sulphates can badly damage/erode concrete). This risk remains, even if channels are lined, except if there is a regular and consistent check of their state.

Figure 113: Water treatment plant at Kriel

Figure 114: Measurement at Kriel’s water treatment plant

Water Treatment at a glance

- Capacity and quality of the make-up water plant is sufficient, even with high steam loss.
- The plant, including the measurements, seems to be in an acceptable condition.
- Neutralisation of the regeneration effluents is required before they are dumped.
- Better integration of online measurements into DCS and better visualisation of trends is needed to optimise the technical status.

5.9.2.5 Technical Status of the Auxiliaries and other Systems

The coal comes from various locations – from underground and from an open-cast mine. The coal composition is shown in the next figure.

Parameter	Unit	Underground	Current	Opencast	Curren t
Total moisture	%	9 5	8	8 32	8
Inherent moisture	%	4 5	3	3 32	3
Ash content	%	21 77	23 18	30 67	33 12
CV	MJ/Kg	24 54	23 54	20 34	21 1
Volatile matter	%	24 2	23 3	21 27	21 3
Sulphur	&	1 23	0 8	1 09	0 8
Hardgrove Index	54	>60	54	>54	
Abrasiveness Index	MgFe/Kg	170	<450	350	<450
Initial Deformation Temperature	Deg Celsius	1225	>1300	1225	>1300

Figure 115: Coal composition at Kriel
Source: Eskom

The boilers 1 to 3 were designed to use coal from the underground mine, which is of similar good quality as the coal used in Units 4 to 6. Due to supply constraints (as has already been mentioned in previous chapters), often a mixture of different coal types is used, causing a de-rating of the affected units. The different coal types have very different ash content and abrasiveness indexes, as can be seen in the coal analysis. The ash deformation temperature is very similar across all coal types. This does not explain the need to reduce the load because of bad clogging and slagging behaviour. Rather, it would explain a capacity problem of the ash handling plant due to higher ash content compared to the design values.

However, the overall condition of coal plant and the ash plant is acceptable.

Emission situation: Electrostatic precipitators are installed to reduce dust emissions. The emission behaviour of particulate matter is close to or above the ELV of 50 mg/Nm³. The SO_3 feed into the electrostatic precipitator needs to be improved. For NO_x, there were problems with malfunctioning of the online monitoring system, but it looks like the limits can be met. For

SO_2, all operating units meet the current ELV but will not reach the 2025 ELV without retrofitting measures.

The **spare-parts warehouse** and **maintenance workshop** were also visited. We identified no issues with regards to spare parts – the warehouse was in reasonable order. The workshop is well-equipped and clean. It provides many options to conduct repair work at the site, although there were few signs of activity.

Figure 116: Maintenance workshop at Kriel power plant

5.9.3 Technical Measures to Improve the Plant Condition

Boiler: The maximum potential MW gain of the following measures is 138 MW**.**

There are several issues relating to the boiler that, if repaired, would lead to immediate improvements in PLL. As discussed in previous chapters, the draught plant is one of the components contributing most significantly to the high PLL. Even if operated at maximum load, the capacity of the ID fans is inadequate to guarantee appropriate pressure in the furnace. Therefore, to compensate this, the boiler load has to be reduced. The following measures would improve the situation:

- Tighten the flue gas ducts.
- Tighten the air heaters.
- Tighten boiler openings.

We strongly recommend inspecting and repairing all other potential sources of air ingress. This can also be done during short stops and would lead to direct improvements. In addition to the locations already mentioned, we also recommend inspecting the wall penetrations of the superheater, reheater and soot blowers. Moreover, there are many other water and steam leakages around the plant. We recommend systematically repairing leaking valves, pumps, etc., in order to improve the efficiency and reliability of the plant. Many repairs can even be carried out step-by-step during short standstills.

Moreover, the mills need to be checked, serviced and repaired. A systematic programme to technically recover all mills by maintaining a spare mill during operation should be implemented, e.g. by fixing the gear box and reinforcing the foundations.

The HP heaters need to be brought back into full service – either by repairing them or replacing them. Their poor performance causes low feedwater temperatures, which affect operating conditions in the boiler and increase the potential for BTL.

The vgbe team recommends that the spray water valves be checked, repaired and, eventually, replaced. The steam temperature controls should be also checked. All the measures should aim to achieve operation at steam temperatures as per design.

The soot blowers should be inspected and repaired on a regular basis to ensure proper functioning and to avoid the building of clinker formations and resulting BTLs.

Machinery: The maximum potential MW gain of the following measures is 296 MW**.**

One of the areas in most need of improvement is the cooling towers. Hence, we recommend immediately conducting a cooling tower retrofit with a replacement of the fills which have got blocked due to insufficient cooling water chemistry. The retrofit of two cooling towers requires the standstill of three units. However, the MW gain resulting from this action makes it worth the effort. During the cooling tower retrofit, the chemistry regime for the cooling water treatment also needs to be optimised and the condenser tubes need to be cleaned.

Water Treatment: The vgbe team recommends the neutralisation of effluents.

The **maintenance workshop** needs to be used more and the vast possibilities for repairing and manufacturing parts in-house should be exhausted.

5.9.4 Power Plant Management

Currently, 726 employees are working at the power plant. This is close to the plan figure of 740 (operational plan FY2022/2023). In addition to this, 815 contractors are active at the Kriel power plant. Some management level staff members have only been on site for a few months – some of them have been there for more than ten years. The site team reported that this situation is mainly due to the fact that the power plant is regarded as an unattractive workplace. One key aspect is that that there have not been any salary increases or other bonusses over the last few years. Some persons also mentioned that it is a challenge to find suitable accommodation near the power plant.

Initiatives to incentivise people to come and work at the power plant need to be implemented, in order to attract qualified personnel. This is an essential managerial task which is also addressed in chapter 5.1 and chapter 5.2.

The team spirit of the management team seems to be good. The vgbe team believes that, equipped with appropriate empowerment and budgetary freedom, the team would be able to manage the turnaround. The management team needs some positive signals with respect to appreciation of good work and planning security.

Maintenance

In total, 421 Eskom staff, including 11 managers, are working in the maintenance department. Outage planning readiness index: There are 41 contractors active on site. One of them is Rotec – this company has engaged 100 people on-site.

Given the fact that there are relatively frequent unplanned standstills due to trips or breakdowns, the maintenance is mostly done reactively. Due to this, fire-fighting mode defects are not repaired systematically – which is reflected in the low EAF. This unhealthy plant state has become a normality in which insufficiencies are just accepted.

The maintenance team finds the procurement process far too complicated, too inflexible and not market oriented. This situation results in a non-availability of spare parts.

Operation

The headcount in the operation department is approx. 210, of which roughly half are operators.

The Kriel power plants suffers from a high number of trips. During the site visits, only three units were in operation (at times, it was even only one unit) due to unforeseen events that led to shutdowns. This erratic failure behaviour is an indicator of poor plant health which requires a high level of operational skills to keep the plant running despite all this unexpected interference. Moreover, the operation team seems to have accepted multiple insufficiencies in the plant status as a normal situation – e.g. with respect to leakages and malfunction of valves.

This is why, the vgbe team recommends the establishment of an intense simulator training programme for the operating team in order to further revive a spirit of excellence and to further develop the know-how and practical skills.

Outages

There are 23 people working in the outage department – 9 of these positions are currently vacant. In order to ensure the quality of contracting staff, skills audits are carried out. Moreover, 11 quality controllers are responsible for overseeing the contractors' work. However, the post-outage performance is not sufficient.

The outage team does not consider the Outage Readiness Index to be a useful KPI, as this tool is too complicated and somehow misleading. It does not reflect the accumulated condition of outage preparation but only achievements during a set period. This view is shared by the vgbe team, as stated in previous chapters.

One of the biggest challenges, according to the outage team, is the timely placement of outage service contracts and spare part procurement, which is dependent on the following key players:

- Engineering team, which needs to submit required contract scopes on time.
- Procurement team, which needs to place all orders on time based on improved processes.
- Materials management team, which needs to effectively manage stocks.
- Finance team, which needs to ensure timely release of outage funds.

The alignment between the different departments is key to successful outage planning.

5.9.5 Technical Profile of Main Plant Areas

Boiler and related plant area: All six boilers at Kriel have the same design. They are designed as once-through Benson type boilers and include circulating pumps in a combined circulation design. Boilers 1–3 are designed to use coal from the underground mine, which is of a higher quality than the coal from the open-cast mine, which is used for boilers 4–6. In practice, due to supply constraints, boilers 1–3 sometimes use a mixture of underground and open-cast coals.

Manufacturer	L&C Steinmuller (Afrika) (Pty) Ltd
Type	Benson
Coal mass flow [t/h]	1 584
Pressure [bar, absolute]	171
Temperature [°C]	516
Firing system	
Number of burners	36 per unit
Type of mills	Vertical pressure type
Mill capacity [t/h] – per mill	Unit 1–3: 47, Unit 4–6: 60
Reheat system	
Pressure [bar, a]	31.65
Temperature [°C]	510
Coal supply	
Coal supply (truck, mine)	Mine, opencast and trucks Boilers 1 – 3 are designed to use coal from the underground mine (higher quality) Boilers 4 – 6 open-cast mine
Coal storage capacity on site (t)	1 700 000 tons

Precipitators/ Flue gas cleaning	
Manufacturer	Brandt Engineering, Electrostatic (with SO_3 pre-treatment)
Type	Unit 1–3 three fields ESP Unit 4–6 four fields ESP
Wet ash handling	

Machinery and Electrical:

Turbine	
Manufacturer	Brown Boveri/ CIE, Electro Mecanique (CEM)
Type	Multi-cylinder impulse reaction
Casings (HP-IP-LP, double/single flow)	1 HP, 1 IP, 2 LP (double flow)
Steam volume (kg m/s)	415
Main steam pressure [bar, absolute]	161
Main steam temperature [°C]	510
Reheat steam pressure [bar, absolute]	31.65
Reheat steam temperature [°C]	510
Cold end	
Condenser	Dual pressure surface - conduction
Cooling tower	4x concrete construction natural draught
Generator	
Manufacturer	BBC/CEM
Terminal voltage	18 KV
Rating	555 MVA
Cooling system	Stator demineralised water Rotor H_2
Transformer	
Manufacturer	SMIT (units), WEG/GEC/ABB (station)
Terminal voltage primary/ secondary	18/420, 18/11

5.10 Kusile Power Plant

Kusile power plant can achieve 4 800 MW_{gross} generation capacity with all six boilers in operation. It should be noted that the units at Kusile are still in various stages of commissioning. At present, four units have reached the stage of commercial operation: Of these, three units are in long-term shutdown owing to the collapse of the flue gas duct, while the remaining unit, Unit 4, is being operated by Mitsubishi.

Design gross efficiency at rated turbine MCR is 41.84%, The plant cost of generation is 755 R/MWh[28], making it the fourth most cost-efficient plant in the Eskom fleet after Matimba, Lethabo and Medupi power plants.

Coal supply deviates from the original design intent as a mine mouth plant with a designated coal quality. The current coal supply comes from various mines and, as a result, shows inhomogeneous characteristics. This presents a significant challenge to the plant operation.

The plant has real potential to achieve an EAF of 85 %, with 10% planned and 5% unplanned outages. This compares to a current EAF of just 36.6% and equates to a constant generation capacity of 3 672 MW, up from just 600 MW at present.

Currently, achievable plant capacity is restricted due to:

- Water supply and discharge restrictions
- Coal supply restrictions
- Ash discharge restrictions

As long as the plant is limited by any one of these restrictions, its generation capacity is limited to operating a maximum four units simultaneously.

Please note that, in addition to the delay in completing construction of Unit 5 and Unit 6, there are also other facilities, important to the functioning of the plant as a whole, that have not yet been erected or commissioned.

[28] Eskom: Life Cycle Planning Life of Plant Plan (LOPP) FY2025. Kick-off Session 1 March, 2023

Essential to achieving the higher EAF is a change in leadership[29] and in the decision-making processes, to enable efficient use of assets and resources. All other factors needed to reach higher EAF are available or can be managed. Compared to international benchmarks, the budget is adequate, the technical design and condition of the plant are both good, and there are enough qualified people in South Africa to fill job vacancies.

Kusile plant management attributes the plant low performance to design issues rather than to its own failure to manage the challenging task of running a complex, high-tech plant with demanding technologies, such as supercritical boiler specifics and a sensitive flue gas treatment plant. The plant operation by the boiler OEM of Unit 4 reaches above 90% of EAF for a period longer than one year. This clearly demonstrates that competent and prudent plant operation and maintenance makes a difference.

The decision by Eskom to involve GE (the OEM for the flue gas treatment plant) in the operation and maintenance of the flue gas treatment plants, and to declare GE as sole source, is not supported by the experts: There is a potential conflict of interest, as existing design flaws may not be corrected. Further two units need to be handed over to Eskom and any correction in the flue gas desulphurisation (FGD) of Units 1, 2, 3 and 4 will become a liability of GE for Units 5 and 6. Instead, we recommend engaging an independent expert for design modifications and, in parallel, taking steps to immediately strengthen operation and maintenance of the FGD in order to achieve lasting improvements in plant performance.

While equipment design issues are hampering EAF, the damage to Unit 1 flue gas stack is solely due to Eskom deviating from prudent operation and maintenance practices. A continuation of this approach, together with obvious gaps in competency, risks leading to similar catastrophic damage again in the future and to further and completely unnecessary plant deterioration. Eskom's organisational structure, which gives plant management very limited authority to make decisions and permits a high degree of interference by Eskom head office, is another factor that contributes to low plant performance. The plant is not operated as a profit centre but is part of a portfolio, so profits and budget overruns are diluted throughout the coal fleet. Decisions made by plant management require approval on several levels within Eskom Generation's management structure, which does not serve the day-to-day requirements of a

[29] The term *leadership* is used to describe the ability of the organisation to enable groups of people to work together and to accomplish what they could not do working individually. Leadership includes the motivation influencing and guidance of the team, setting of visions and goals, it defines the suitable organisation, the procedures and the communication and decision-making requirements and governance rules in the organisation. The difference to management is that leadership challenges and changes the existing organisation, procedures and decision making and drives towards the real needs to achieve the goals. Leaders do not stop at the limits of the job description but take-up tasks where necessary to achieve the goals. The use of leadership in the reports is not meant to pointing at individuals in the organisation of Eskom but describes the business culture which is reflected by different levels of Eskom management personnel, the limitation of authorities and empowerment of managers (leaders) in the organisation.

plant that needs to be able to act immediately in case of a malfunction or defect. One example is the coal supply arrangement, which is not within the remit of plant management.

The Eskom philosophy of outsourcing all services to outside parties leads to a high degree of dependency on such service providers, as well as to a compromise on quality and speed (due to administration and mobilisation times) and, finally, to high costs.

We highly recommend the hiring in-house staff to maintain key equipment such as PJFF, FGD, mills, etc.

The plant has a very young workforce, with inadequate knowledge of the plant, equipment and system behaviour (in particular for PJFF and FGD).

We have carried out a detailed analysis of the impact of the various factors causing significant deviation from best-practice performance of the plant. Recommended steps to address the problems are given below. Prudent operation and maintenance of the plant and quick decision management to correct key issues would boost plant performance. The issues that pose the greatest risk need to be addressed as a top priority by Eskom head office, and contingency plans need to be made in case of emergency.

Moving forward, Kusile needs to prioritise the implementation of measures to eliminate the constraints on water supply, coal supply and ash discharge and to improve key areas that pose challenges, such as FGD operation and maintenance. It is also crucial to address the issues pertaining to maintenance contracts, staff turnover, and the lack of incentives to drive improved performance.

5.10.1 EAF and PLL

Since 2019, plant performance has deteriorated and UCLF rose to 56% in the last financial year, which is too high. The breakdown of FY2022/2023 UCLF is shown in Table 46, based on data provided by the power plant. It is evident from the data that the FGD system, gas cleaning system, boiler and draft plant are the areas that contributed most significantly to losses over the year.

Year	EAF %	UCLF %	PCLF %	UAGS Trips
2018	76.51	12.29	11.19	21
2019	45.32	18.42	34.62	38
2020	50.44	45.04	4.52	45
2021	66.57	19.47	13.94	55
2022	39.78	32.82	27.11	85
2023	36.20	55.79	8.0	81

Table 46: Operating performance of Kusile power plant (FY2017/2018–FY2022/2023)

The absolute loss of EAF in percent is presented in the following Table 47, while the UCLF is shown in Figure 117.

System	% of UCLF	EAF loss in %
FGD System	50	27.9
Gas Cleaning System	23	12.8
Boiler	8	4.4
Draught System	8	4.4
Mills	4	2.2
Ash Plant	4	2.2
Feed Water	2	1.1
Turbine	1	0.5
TOTAL	**100**	**55.5**

Table 47: Kusile EAF per system

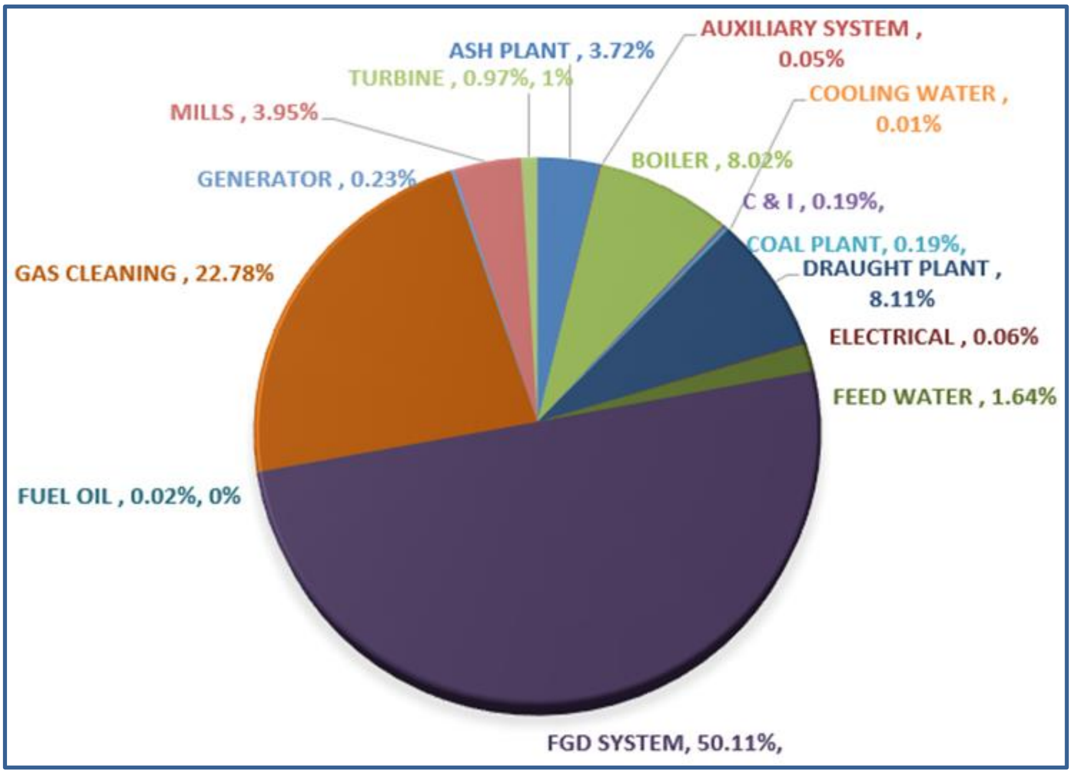


Figure 117: Kusile UCLF breakdown (FY2022/2023)

5.10.2 Technical Status

5.10.2.1 Top Issue List

During the visit, only Unit 4 was operating and Units 1, 2 and 3 were out of service due to the collapse of flue gas duct. Based on the work carried out at the unit, housekeeping was found to be poor. Even though the plant has been in commercial operation since 2017, it is still in the stabilisation phase.

FGD Issue

- UCLF loss due to FGD: 27.9% (FY2022/2023). Unit 1's FGD duct collapsed due to an excessive weight of slurry deposited in the flue, resulting in the failure of the flue chimney that also houses the flue gas ducts for Units 2 and 3.
- Higher flue gas volume flow (15%-30% higher than the FGD design)[30].
- Mist eliminator gets damaged frequently.
- Poorly maintained absorber recirculation pumps due to missing isolation valves.
- Doubtful design of absorber recirculation pump suction strainers leading to plugging of absorber spray nozzles, higher wear and tear in the pumps and inefficient quenching of flue gas.

PJFF Poor Availability and Compressor Refurbishment

- UCLF loss due to PJFF: 12.8% (FY2022/2023). High Pressure loss across PJFF, short life of PJFF bags due to erosion. High flue gas temperature entry to PJFF.
- PJFF high hopper levels.
- Leaks in PJFF bags.
- High gas heater outlet temperatures causing high demand for air attemperation and subsequently acid formation.
- Dew points of compressed air for pulsing jet on higher side. Water is contained in the compressed air.
- Premature failure of filter bags due to:
  - Acid degradation
  - Thermal degradation
  - Poor flow distribution - uneven bag utilization

[30] Eskom claims the boiler design is the cause of the higher flue gas flow. This needs to be verified by an independent expert in detail.

Boiler Tube Leakage and Boiler Critical Valve Issues

Eskom claims that boiler design issues[31] are leading to high spray water requirement, high boiler end temperature and issues on PJFF and FGD performance. Below pictures show the frequent failure of FGD equipment in Units 1, 2 and 3.

Figure 118: Butterfly valve rubber liner damaged at Kusile

Figure 119: Damaged rubber liner at Kusile

Figure 120: Choked spray nozzle at Kusile

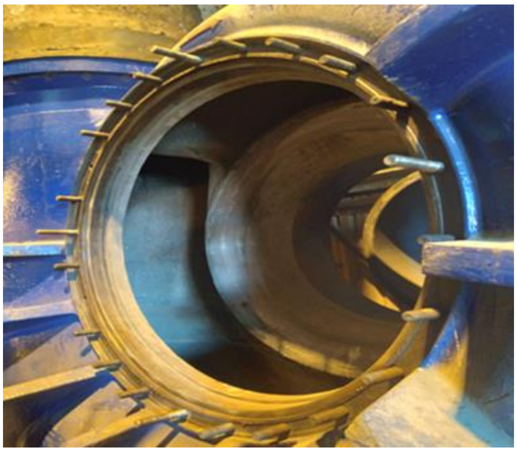


Figure 121: Pump liner failure at Kusile

- UCLF loss due to boiler trips and valve passing: 4.4% (FY2022/2023). Boiler tube failure, boiler trips, boiler spray water valves, HP-bypass valves and boiler valve passing.

[31] Eskom position cannot be confirmed by the experts.

Boiler Spares

- No available spares for critical boiler equipment, e. g. boiler tubes, valves, PJFF bags, soot blower spares, mill parts, etc.

Milling System

Eskom attributes the mill issues to design issues[32]. Previously, the milling plant loss was around 13%, according to site personnel, and now it is down to approximately 4%. Mill refurbishment is planned for July 2023.

- UCLF loss due to mills: 2.2% (FY 2022/2023). Non-availability of mills and coal feeders, mill low through-put, mill feeder conveyor failures and loss of mills due to loss of scanners, belt slips.
- Coal quality, issues with foreign material and rocks.

Draught Systems

Two ID fans draw the flue gas out of the boiler to the chimney. ID fans run out of capacity. This is caused by Eskom's safety margin of excess air, air ingress, leaks in the air heater and choking of gas air heater. According to plant personnel, the coal quality has a higher effect on boiler performance, as well as on the draught system since the plant received higher ash content coal. However, based on the coal report available[33] from the plant, the composition of the coal is well within the design limit. Moreover, all boilers are designed with worst coal (with ash content varying from 28% to 36.5%).

- UCLF loss due to draught system: 4.4% (FY2022/2023). Gas air heater choking and overloading of ID fans, due to duct leakages, acid due point corrosion.
- Eskom requirement to add safety margin on the excess air over and above the OEM intend is leading to higher flue gas flow with an adverse impact to the PJFF and FGD performance.
- ID fan blade erosion.

Steam Temperature

At Unit 4, boiler outlet main steam is maintained close to design (560°C, operating at 563°C). The reheater temperature is maintained at 572°C, compared to design 570°C. There is high reheater spray water consumption (spray flows 25–28 kg/s vs design 5–7 kg/s)[34].

[32] This statement by Eskom is not plausible since the same mill design is operating satisfactorily at Medupi power plant. We assume the coal quality issues and the contamination of the coal with foreign material and rock are significant contributing factors. A detailed assessment by an independent party is recommended.

[33] Coal quality recording is unreliable. The sampling system is not in operation.

[34] Eskom's safety margin of excess air is contributing to this effect.

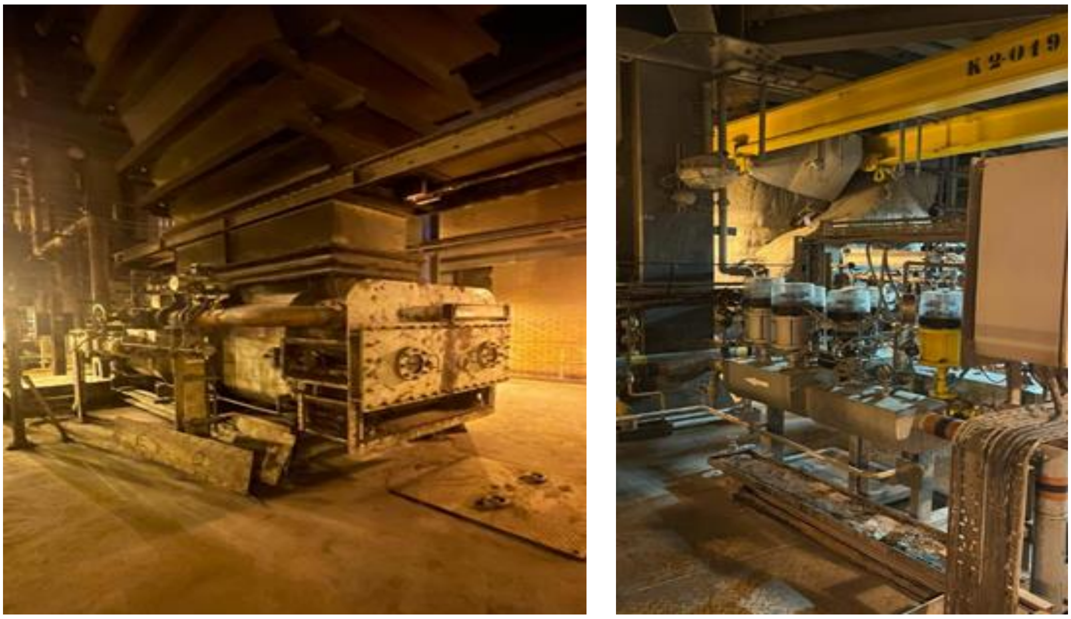


Figure 122: Poor housekeeping at Kusile

Air Heater

Choking leads to significant load loss (SLL) and overloading of ID fans and ash carryover. According to site personnel, there had been acid due point corrosion. This led to ID fan blade erosion. The steam air preheater control logic is changed which is based on sulphur content at the FGD inlet as a temporary measure. The effects are fouling and wear/ abrasion, resulting in higher loading on mills and fans.

Thermal Index (TI)

Kusile's TI report shows that the header temperatures are above limits and unacceptable, while the main steam and hot reheat pipework is well within limits. This has significant long-term implications on the creep life of the headers. The below trend shows an alarming situation for the TI. The primary impact is due to boiler combustion and heat transfer in pressure parts which results the higher furnace exit gas temperature.

Headers	Unacceptable
Main Steam	Acceptable
Hot Reheat	Acceptable

Table 48: Assessment of areas exceeding the Thermal Index at Kusile

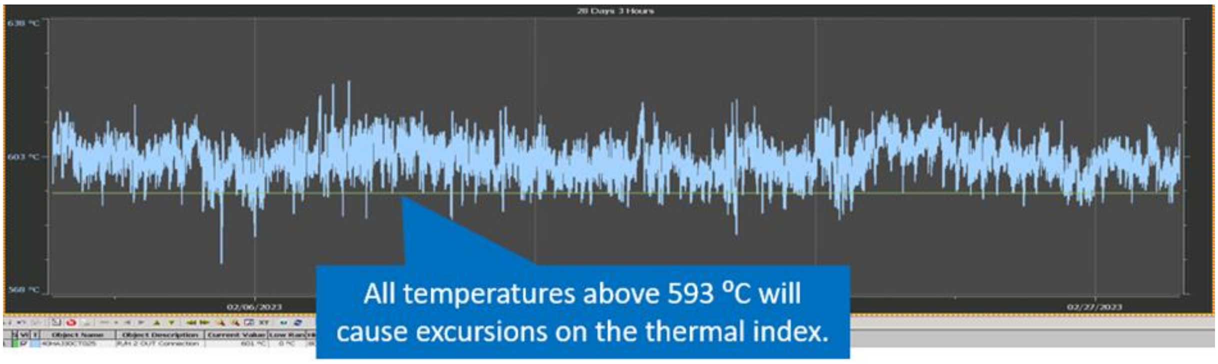


Figure 123: Exceeding Thermal Index at Kusile

Boiler at a glance:

- PJFF plant reliability is below industrial standard due to a combination of coal quality variations, design, maintenance and operation. It causes SLL – there needs to be a concerted effort to improve performance.
- Silo area exposed to heavy ash leakage.
- Mill feeder conveyor failures and loss of mills due to loss of scanners, belt slips
- Gas air heater is facing ash carryover and acid due point.
- Higher boiler end temperature.
- Higher spray water requirement.
- Coal quality variation effects boiler performance.

5.10.2.2 Technical Status of the Machinery

Units 1, 2 and 3 are not in operation.

EAF loss of 1.6% due to turbine issues and feed water issues.

- Valve passing (mainly drain and vent valves) leads to higher water consumption.
- Condenser system: The poor condenser vacuum has a severe impact on operations, mainly because of the unavailability of ACC fan spares. This leads to higher condenser back pressure and, consequently, loss in generation.

Machinery at a glance:

- The turbine seems to be operating properly.
- There is no load loss due to feed heater.
- ACC spares unavailability causes vacuum losses.

5.10.2.3 Technical Status of Electrical and C&I

Generator Excitation Failures

The plant is experiencing repeated failures on the excitation system: Unit 1 generator tripped five times between 20 and 22 September 2022. Unit 2 has also experienced similar faults in the past. The root cause of these faults is still under investigation with GE (OEM). Replacement is planned as per LOPP plan.

Generator H_2 Leaks

Various hydrogen leaks have occurred at the plant since Units 1 and 3 were commissioned, and recently, on 22 July 2023, the same problem was observed at Unit 4, due to failure of a hydrogen cooler “O” ring.

Generator Partial Discharge

Elevated high partial discharge activity has been recorded for short periods of time before returning to acceptable levels. The source of the discharge activity is still unknown, but possible causes include insulation degradation, voids, and dirt/contaminants.

A full and in-depth offline PD assessment using IRIS test equipment needs to be conducted on Unit 4’s generator, to determine the source of the partial discharge activity. Additionally, Eskom management recommended that Units 5 and 6 undergo a partial discharge assessment before handover.

PJFF Pulsing System

Controller spares for the system are not available, and the software is locked, as the supplier does not want to assist in causing the FF pulsing system to stop functioning. Spare parts for the solenoids and their components are also not available for repairs.

Non-Availability of Critical Spares

Non-availability of these spares may lead to generation loss: PLC HMI Legacy Series spares, 3rd part communication PLC spares, ABB and ALSPA TG Control system spares, BMS control spares, BFP minimum flow skid spares SIEMENS S7-200 spares (obsolete), DCS operating system software and hardware (obsolete) spares (upgradation planned), PJFF controllers.

High Turnover of Experienced Staff

C&I section is experiencing high turnover of experienced staff, as they are leaving the company, due to its remote location. Therefore, as an immediate measure, we recommend hiring staff from other countries to maintain the desired skill set requirement.

Shortage of Calibration Instruments

A C&I laboratory needs to be equipped with the minimum required calibration instruments for complete calibration, as per OEM recommendation, to ensure reliable control and protection. Currently, the department is totally dependent on external agencies for calibration, resulting in incomplete calibration of instruments, which may impact on generation loss and safety of the system.

5.10.2.4 Technical Status of the Water Treatment Plant

Issues relating to the water system.

- Water treatment plant is not fully commissioned.
- Excursion in chemical parameters indicates that these are within the limit (K_{25} quality index 0.61 and SiO_2 as 0.64). See Table 49.

The water treatment plant erosion rate is high, as shown in Table 49. It needs to be coated with anticorrosive paint and plans should be made to replace badly corroded parts.

System	Parameter	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Condensate	DCACE				0.70		
	K25				0.18		
	DO2				5.18		
Feedwater	DCACE				0.90		
	DO2				0.11		
	Fe				1.00		
	Na				0.37		
Steam	DCACE				0.91		
	Cl				2.98		
	SO4				0.87		
	SiO2				0.78		
	Na				0.38		

Table 49: Chemical parameters for Kusile's Unit 4 (sample from March 2023)

Figure 124: Bad condition of Kusile's water treatment plant

5.10.2.5 Technical Status of the Auxiliary and other Systems

Infrastructure/Civil Engineering

- Not completed fully.
- Workshop and warehouse are not yet completed.

Ash Handling Plant (AHP)

- Contributes an UCLF loss of 2.2% in FY2022/2023 due to AHP issues.
- Project not completed. Currently, the site is preparing a temporary ash handling plant for 10 years of operation.

Coal Handling Plant

- Contributes an UCLF loss of 0.19% in FY2022/2023 due to CHP issues.
- Coal hopper construction in progress. Delays due to slow construction progress, commercial issues and resource instability.
- Supplied coal characteristics vs contractual coal characteristics.
  - Volatile matter in the coal is as per the contractual limit of 16.5% to 22%.
  - As per the contract, percentage of ash content is 34.4%. However, values vary from 32% to 34%.

- As per the contract, sulphur values have their contractual limits of 0.9% but operating values > 1.1%.
- As per contract, HGI is 55, however it varies from 41 to 60.
- As per contract, abrasive index is 350 mgFe, operation is within the limit.

Coal and Ash

As the coal is delivered from a variety of nearby mines, sustaining the quality in the long term is a concern. Presently, the coal is trucked into the plant. Figure 125, below, shows the current status of the coal handling plant, which is still incomplete. Overall condition of the coal plant is not satisfactory.

Figure 125: Water logging in Kusile's coal handling plant

5.10.3 Technical Measures to Improve the Plant Condition

Kusile power plant wants to achieve a high level of reliability and availability of all units by FY2026/2027. The target set by the plant is to achieve 85% EAF, 10% PCLF and 5% UCLF. The plant is currently performing far below the set target.

5.10.3.1 Short-Term and Long-Term Measures to improve EAF

The plant has the potential to increase its generation by 1 540 MW by the end of December 2023, by constructing a temporary chimney for Units 1, 2 and 3. Further, it has the potential to additionally generate 1 040 MW by the end of the current financial year, by commissioning Units 5 and 6. Hence, Kusile can achieve an EAF of 65% in FY2024/2025. By implementing short-term and long-term measures, the plant could potentially achieve EAF of 75% in FY2025/2026 and 85% in FY2026/2027

With the above objectives, we have made short-term and long-term recommendations for improving system reliability and Kusile's EAF, which can be found below.

FGD issues contributing EAF loss of 27.9%

The major contributor to Kusile's reduced EAF is the FGD. Needless to say that the malfunction of the mist eliminator was the main cause of the damage at Units 1, 2 and 3, although the issue could have been prevented by timely shutting down of the units. However, there are other factors which also contribute to the low EAF. Below are some issues (non-exhaustive) that need to be addressed in the Kusile FGDs.

- The mist eliminators should be kept in clean condition for reaching MCR within the maximum permissible DP. Study to be conducted for improved mist eliminator design. Site engineering is currently in discussion with Munters (OEM), but there are other alternatives on the market that perform better.
- FGD absorber pump suction strainers are collapsing, allowing bigger foreign material parts to enter the absorber circulation pumps, damaging the ceramic impellers and silicon carbide casing cladding.
- Passing of absorber circulation pump suction valves, in addition to the absence of discharge valves, makes maintenance difficult to impossible during operation.
- Kusile personnel admitted lack of experience in engineering, maintenance and operation and have requested support by third party in order to enhance their knowledge.

Besides the above, there are other factors listed below, that will limit the EAF in the future unless addressed:

- All units have a higher water consumption than designed. The water treatment plant will not be capable of catering for the needs of six units. Leakages must be identified and passing valves need to be maintained.
- To date, the plant does not have a completed permanent infrastructure for ash disposal. This will limit the output of the plant to approx. 3 200 MW, as all ash disposal is carried out by wheel loaders and trucks.
- A similar issue exists for the coal supply. The conveyor from the mine to the plant is not due to be finished until after the commissioning of the last unit, which makes it almost impossible to truck in enough coal to run all units.
- Ancillary buildings such as storage, maintenance workshop, chemical lab are not yet completed, which is affecting plant maintenance and supervision of water quality, coal quality and FGD chemistry control.
- Waste water treatment plant is not commissioned, which will make it difficult to maintain a zero-discharge balance once units return from outage or are commissioned.

However, these are all medium-to-long-term measures, which would only visibly impact the EAF after this winter season.

The following short-term interventions can be addressed as a priority:

The problems faced by the FGD system urgently need addressing, especially with regards to the mist eliminators and the management of the chemical process - from the lime feed to the end of the vacuum filter belts – in order to ensure operation within acceptable parameters and to address the current 120 MW load loss on Unit 4. However, we question whether GE can support FGD: They might be able to help marginally, but their current support on Unit 4 has led to no significant improvement. We further recommend that MHI continues to operate Unit 4 for at least the winter season, to ensure stability and intensified attention.

PJFF (Gas Cleaning System) Issues contributing EAF Loss of 12.8%

Short-Term Solutions

The choking of the gas air heater can be avoided by implementing the following operational practices:

- The tempering of flue gas at the inlet of the PJFF Section is to be done as the last alternative. The flue gas temperature should ideally be controlled through operational practices, so that flue gas flow remains close to the design value.
- The dew point of the compressed air needs to be monitored regularly, so that it is maintained as per design. The healthiness of compressor dryers and auto moisture drain valves must be ensured.
- The critical spares for the compressors need to be procured as a priority, so that compressors are serviced and overhauled as planned.
- The skill sets of personnel (both Eskom employees and outsourced) deployed for PJFF need to be upgraded continuously for the O&M of the PJFF.

Long-Term Solutions

- Development of PJFF bags suitable for higher flow gas temperature needs to be a priority to avoid frequent failure.
- Sufficient spares for solenoids and its components, as well as for pulsing controllers, need to be kept in reserve. Presently, controllers and solenoids are not available for replacement, leading to inefficient pulsing operation of bag filters and high emissions.

West Chimney Recovery after Stack Failure

In October 2022, Unit 1's lobster back entry to the west stack failed. Kusile Gx Engineering conducted a root cause analysis for the collapse of the Unit 1 lobster bend flue duct. Mitsubishi Power Africa completed an initial inspection, and ICC carried out a chimney internal inspection. The failure of the entry duct was attributed to the carryover of sludges from FGD, causing excessive overloading.

There are multiple units under outage due to failure of the common flue gas duct supporting structure to the west stack. Eskom has decided to construct a temporary chimney for each unit, so that the units are back in operation as soon as possible.

Short-Term Solutions

Construction of three numbers temporary chimney:

- On 10 January 2023, a decision was made to proceed with the construction of temporary stacks, due to uncertainty regarding the repair work on the permanent stacks and whether the repair was possible.
- On 20 February 2023, ad hoc the Gx Board approved the construction of three temporary stacks pending environmental approval by the DFFE.
- Instruction to Concor to order material for all three flues and to make the first flue; This is to mitigate the risk whilst awaiting response from DFFE.
- Placement of purchase order on stack ducting fabrication was done in March 2023.
- Piling design and pile cap for construction finalised. The current Kusile contractor has been engaged to conduct the work.
- Full concept stack design is in progress to include horizontal tie-ins and other interfaces to the permanent stack.
- Approval obtained on 17 March 2023 for construction to take place parallel to the environmental approval process.
- Concor has been issued instruction to proceed with the construction of three temporary flues.

1st stack	Unit 3	28 November 2023
2nd stack	Unit 1	11 December 2023
3rd stack	Unit 2	24 December 2023

Table 50: Project schedule for temporary stacks at Kusile

Long-Term Solutions

The plant has already taken steps to recommission the stack.

- Continue monitoring the instrumentation of the permanent stack to ensure stability and detect any abnormal activity or movement.
- Engage the DOEL to lift the prohibition notice on the stack, indicating that it is safe for repairs to proceed.
- Procure the necessary equipment, to access the main stack for repairs. Concor has been tasked with this procurement.

- Acquire jacking equipment to stabilise the 151 m level platform and strengthen the bottom of the shield. A concept design is to be made for the purpose.
- Evaluate and consider high-pressure water jet techniques for cleaning the flue duct as part of the repair process.

Risks

- **Stabilisation risk -** Inability to stabilise the 151 m level platform from the 180 m level platform. There is a risk that the permanent stack may not be recoverable if the stabilisation of the 151 m level platform cannot be achieved. Prioritize the procurement of jacking equipment and carefully execute the concept design to strengthen the bottom of the shield.
- **Prohibition notice delay -** The commencement of site construction works, including permanent stack repairs, is dependent on the lifting of the prohibition notice. Ensure effective coordination and communication with the DOEL to expedite the process and mitigate any potential delays to the return of units to service.
- **Mitigate project schedule risks -** Develop a detailed project plan that considers the interdependencies between the permanent stack repairs and the construction of temporary stacks. Identify potential risks and incorporate mitigation measures to minimise the impact on the overall project schedule, ensuring timely completion and return of the units to service.
- **Regular monitoring and evaluation -** Establish a robust monitoring system to track the progress of both the permanent stack repairs and the temporary stacks construction. Regularly assess the status of the lifting of the prohibition notice and environmental approval to address any potential bottlenecks promptly. Maintain open communication channels with relevant stakeholders to ensure a coordinated and efficient approach throughout the entire process.

Boiler Tube Leakage (BTL), Boiler Trips and Valves Passing Issues Contributing EAF Loss of 4.4%

Short-Term Solutions

- The amount of time needed to the repair of BTL is high compared to international standards and there is scope for this to be reduced. It is a standard practice to attend BTL in first pass water wall tubes/second pass economiser/LTSH in 40-50 hours, whereas Kusile is taking 96-120 hours. For platen and final superheater area, with prudent practices for BTL can be attended in 60-80 hours, whereas the plant is taking 120-144 hours.
- The BTL repair time can be brought down to the average time taken internationally by ensuring proper mobilisation of manpower, T&P and other resources with round-the-clock supervision by Eskom. This will improve the plant EAF substantially.

- The recommendations from the BTL standing committee are to be implemented and monitored on a monthly basis.
- Grounding of signal cable shield to be checked (only one side ground is recommended) to avoid spurious tripping caused by lightning, which in turn causes the vibration level of fans to exceed the tripping level or causes invalid signal (bad signal), though the system is protected by 2V3 vibration logic but all three are going high or bad at a time resulting in tripping of fans which leads to further unit trips.
- All critical instruments need to be calibrated as per OEM guidelines and C&I laboratory needs to be set up so that inhouse calibration can be carried out, to avoid slippage in the calibration schedule.
- Strengthening of drainpipe joints and piping responsible for frequent leakages of hot water/steam is required. The hot water/steam is entering into the HPBP (Manostats) controller and leads to further boiler trips due to malfunction of HPBP on controller faults.

Long-Term Solutions

- Ensure availability of all the spares for the boiler pressure parts.
- Replace weak/eroded piping and components from the process tapping point (drain point connection) up to the HPBP controller, to stop steam leaks and improve the reliability of the system, as components are failing due to heat exposure and water ingress caused by steam/hot water leaks.
- Ensure availability of spare HP bypass valve, as most of the failures which have happened in the past are owing to a shortage of spares.
- Kusile's reheater/superheater spray capacity needs to be enhanced, as per the recommendation of OEM, to control the temperature excursion of reheater/superheater.

EAF Loss of 4.4% due to Draft System Issue

Short-Term Solutions

- The choking of gas air heater can be avoided by implementing following operational practices:
- The soot blowers for the gas air heaters need to be available and operated regularly. The operation of soot blowers is mandatory during cold startup of the boiler as per the standard operating procedure.
- Defective oil burners need to be rectified for proper atomisation of oil and combustion in the furnace.
- Whenever the sulphur content in the coal increases beyond the limit of 1.3%, it needs to be ensured that the temperature of the flu gas at the gas air heater outlet is above the dew point of the flue gas.

- The mixing of tempering air in flue gas before PJFF is to be avoided, by implementing prudent operational practices, so that the temperature at the PJFF inlet is maintained as per design.
- The leaking flue gas ducts / expansion bellows are to be inspected at every available opportunity and to be repaired as per the requirement.
- Gas air heater seal leakages are to be measured at regular intervals and the seals should be adjusted to correct them whenever the opportunity arises.
- If the opportunity arises during a short shutdown of the unit, the duct leakage should be rectified.
- De-ashing system for economiser and gas air heater should be made available immediately.
- The oxygen percentage in flue gas at the inlet of the gas air heater is to be measured to ensure the combustion excess air levels. All air ingress to the boiler is to be stopped. Air ingress points need to be checked (after first removing insulation at suspected areas) via air pressure tests and then sealed, to reduce air ingress and ID fan loading.

Long-Term Solutions

- The plant has reported very high erosion of flue gas ducts. This erosion needs to be located and repaired with material that is resistant to erosion and can provide longer life.
- The availability of these materials must be ensured before the outage of the unit.
- The CFD test and GD test are to be conducted to balance the air flow along all the ducts and passes entering PJFF section.
- During the planned outage, all the seals are to be checked and rectified. Further, basket elements are to be replaced using the weight-loss method.
- Water washing of APH during available opportunities. Ensure thorough cleaning by continuous washing until the inlet and outlet water PH levels match. Dry out the APH after washing, by running ID and FD fans.
- APH baskets are to be removed and cleaned very carefully with a high-pressure water jet. This can be done during major overhauls/ outages. Inspection of baskets for erosion/ damage and replacement of the same, if necessary.
- Condition based replacement of the baskets during overhauls. Ensure contract with capable agency for the replacement of the basket with proper seal setting. After the baskets are taken out of their position and cleaned, and if the weight loss is 20% or more, then the baskets should be replaced.
- Replacement of APH seals and proper seal setting during every major opportunity to reduce/minimise leakages.

- Air ingress from APH outlet to ID fan inlet should be checked by air pressure test to identify leakages. All expansion joints for the ducts are to be checked for leakages and repaired during overhaul.

EAF Loss of 2.2% due to Mills

Short-Term Solutions

- The plant has identified the issues for the lower throughput of the mills and made a rolling plan for rebuild/replacement of components of all the mills. The contract for the services along with spares needs to be awarded.
- The plant has to start rebuilding the mills as soon as possible.
- The issue of wear on components of mills is a continuous process and the rolling plan for rebuild/replacement needs to be continued.
- Technical capability for mill operation and maintenance is to be developed.
- All the mills are to be checked for design defects and repaired, under the supervision of mill experts or OEM support, whenever the unit shuts down.
- Mill to be tested for clean and dirty air, to balance the speed and flow in all three PA pipes.
- Iso-kinetic sampling may be adopted for representative sampling and true fineness values.

Long-Term Solutions

- The specifications for the spare grinding tires/grinding ring segment and other critical spares are to be developed and procured, to meet the overhaul requirements of the mills. The budget requirement for procuring the spares is substantial. The process should be started at least one year in advance, to ensure the critical spares are available on time.
- A maintenance strategy for coal pipes and bends needs to be devised, to ensure no generation loss/fires due to leaking pipes.
- Availability of spares and contracts to execute full mill overhaul during planned outages.
- Design drawing for dampers and gates to be developed, along with specifications, in order to prepare the relevant part list required for reliable mill operation.

EAF Loss of 2.2% due to Ash Plant Issues

Short-Term Solutions

Following actions are recommended during spontaneous shutdown/planned short shutdown.

- Check healthiness of the all-hopper heaters for maintaining the ash temperature in hoppers at design temperature.
- All FF hopper level switches must be in good condition, to ensure reliable evacuation.
- The dew point of the compressed conveying air is to be monitored regularly so that it is maintained as per design. The healthiness of the compressor dryers and auto moisture drain valves must be ensured.
- The fluidising pads installed at the FF hoppers are to be regularly checked and re-placed periodically.
- All defective pulsing controllers need to be replaced/repaired, as a matter of priority. Presently, spares are not available.
- Thickness surveys of the ash conveying pipes are to be done at regular six-monthly intervals and pipes and bends that show a reduced thickness need to be replaced, to prevent ash leakages.
- Health of water spray facilities needs to be ensured, to prevent dust emission from the ash dumping facilities.

Long- Term Solutions

- Maintenance strategy for ash conveying pipes is to be reviewed, as these pipes are prone to high wear and tear.
- Geomembrane cover for disposed ash at ADF by 2025, to comply with environmental regulations and meet regulatory requirements for operation of the plant.
- Completion of construction of balance ADF in time-bound manner.

EAF Loss of 1.6% due to Turbine Issues and Feed Water Issues

Short-Term Solutions

No major TG failures have been reported. However, the following measures are advisable, to improve the reliability of the system and reduce the chances of failure.

- Ensure oil quality as recommended by OEM by carrying out online filtration. Oil filters of the right quality are to be procured. The specifications need to be developed with quality vendors.
- Valve passing is an issue at the plant and make-up water consumption is very high. The issue of valve passing needs to be addressed as a matter of priority.
- Valve torque settings are to be done as per OEM recommendation.

- Frequent walk downs to map the passing valves and attend to them, as a matter of priority.
- Valves should not be procured from vendors whose performance has been established as unsatisfactory.
- Skills for repair and maintenance of HP valves/critical valves need to be developed in-house.

Long-Term Solutions

- Critical valves to be cut and sent to a capable vendor/OEM for repair.
- Valves to be procured from established manufacturer.

Incomplete Construction/Infrastructure Facilities

- There are incomplete facilities because construction is not taking place and because systems, such as fire detection, CBM systems, coal hopper, mine conveyor, truck offloading facility, 10-year ADF, ash conveyor extension to ADF, gypsum conveyor and 60-year ADF, drains for the coal stock yard, workshops, electrical and C&I laboratory, liquid waste treatment plant, etc., have not been commissioned. This is putting constraints on plant operation.
- There should be a time-bound program to complete the balance facilities with an adequate budget.
- Regular monitoring and facilitation by the plant management is needed for timely completion.

Unavailability of Auxiliary Steam for the Plant

As Unit 4 is the only unit running at present, with Units 1, 2 and 3 expected to be operating by the end of 2023, the outage of Unit 4 would mean that the plant has no auxiliary steam. The return to operation of Units 1, 2 and 3 and the commissioning of new units will take even longer if the existing auxiliary boilers are not functioning.

Recommendations

The auxiliary boiler should be kept in a healthy condition and ready for use, and trial light-up of the auxiliary boiler should be carried out regularly.

Non-Availability of Spares of Critical Equipment

Short-Term Solutions

- Most of the spares are stock-controlled items with minimum, maximum and re-ordering levels. This, however, does not match the actual requirement, resulting in frequent unscheduled procurement on the one hand and a huge inventory of slow-moving items on other. An FSN/ABC analysis needs to be conducted urgently, as well as an immediate review of minimum, maximum and reordering levels as a one-time exercise, and then every six months thereafter. We also recommend monitoring the shelf life of spares and consumables in the ERP system and implementing an automated first-in, first-out philosophy.

- List of critical spares to be reviewed in every quarter for all the system by the concerned department.
- As the current practice of global tendering is delaying the procurement process considerably, we advise issuing tenders only to prequalified vendors with appropriate technical competence and appropriate financial background.
- Single-source or sole-source suppliers should be identified for critical spares and the single/sole source approval should be given without limitation of the validity of said approval.

Long-Term Solutions

- Develop specifications and drawings for key spares (for example, for mills) to widen the network of suppliers and reduce dependence on OEM and their agencies.
- The present procurement process is cumbersome and time consuming, due to approval at multiple stages. This needs to be revisited to accelerate the process and to ensure timely availability of spares and resource engagement and mobilisation.

HR Issues

Short-Term Solutions

- Training to be organised for all newly appointed O&M staff, as most of the systems at this plant are new and need to be operated by properly trained staff.
- Reward and recognition systems need to be enhanced by clear criteria, alignment with organisational goals and effective communication, with a variety of rewards.
- The training department must ensure that lessons learned from plant incidents are built into the training materials for the plant operators.
- The skill set of employees (Eskom/business partner) need to be continuously improved through training and counselling. Operating manpower skills, HP welders, grinder men, boiler tube fitters, HP valve repairs and maintenance skills, millwright fitters for pumps and fans and their alignment, skilled technicians for compressors, HVAC technicians all need training and development.

Long-Term Solutions

- Adequate experienced mid-level staff need to be recruited by granting special bonuses for those working in O&M.
- Non-availability of specialists at plant level can be resolved by ensuring there are experts for all O&M functions based at Eskom headquarters.

5.10.4 Power Plant Management

Maintenance

The maintenance work is mainly carried out by outsourced maintenance personnel. The ratio of own maintenance personnel to outsourced personnel is not healthy. We highly recommend insourcing maintenance personnel.

Planning: The planning and execution of maintenance activities is carried out locally by RWM teams, in consultation with all the departments. A daily meeting is conducted with maintenance, the production/operating department and engineering to decide the work priorities. Maintenance strategy varies from system to system, based on criticality, i.e., some maintenance is planned, some is condition-based and some activities are run-to-failure. There is a lack of overall condition monitoring reports shared with the plant, and there are no clear limits set for individual reports. Additionally, there is no consolidated matrix of indicators for equipment condition and no system health report.

Further, the plant's maintenance and outage departments have long-term contracts with prequalified contractors in order to meet the requirements for carrying out planned and unplanned work.

Findings

- Planned maintenance is held back by belated approval of funding and unavailability of spares in line with requirements.
- The procurement process takes too long time (in general, more than six months). Placement of service contracts takes considerable time, which does not fit with urgent plant needs. There are instances of overhaul projects being deferred by six months or more due to budgets not being approved in time, which affects unit performance adversely. Such delays are not acceptable considering the criticality of the plant.
- The Kusile units still at the commissioning stage continue to face unresolved teething problems. To achieve stable operation at their rated capacity, additional efforts, resources, and budget are required.
- Feedback on equipment performance from operations, maintenance and other personnel, is not an integral part of the strategy to maintain long-term equipment reliability. This needs to be changed.
- Budgets are not fully aligned to the requirements of the final scope of the planned work. Furthermore, there is inadequate approval of proposed budgets.
- The majority of load loss is caused by improper planning and execution of maintenance of boiler pressure parts, PJFF, FGD and ash plant. The available resources are not used efficiently.
- The skill levels of the staff need to be improved and updated on a continual basis through effective training.

- Training programmes for improvement in skill sets, people management and succession planning, etc., need to be organised at regular intervals.

Critical and Strategic Spares Planning

Attendance of meetings relating to management of spare parts is inconsistent and the meetings lack effectiveness. A finalised list of critical and strategic spares for every system has not been made available. A list of budget approvals and procurement plans also urgently needs to be finalised.

The issue of spares unavailability has been repeatedly discussed in various meetings, including schedule freeze, plant focus and production meetings. The lists of critical spares for FGD, compressors, PJFF, mills, boiler pressure parts, ACC fans, DHP plant and coal handling plant, etc., need to be reviewed every quarter and to be expedited for their procurement.

Below is a list of strategic parts, based on their criticality. The plant needs to finalise this as per the status of the equipment status.

Quality

For quality control, the SAP system generates work sampling orders for managers/supervisors to verify the work done on different plants as per the respective approved QCPs. As the checking of compliance with QCPs is only carried out on a random basis, shortfalls in the quality of the work executed. This sometimes leads to a need for remedial work or to unreliability. Quality control checks need to be carried out by skilled technicians/engineers on all work carried out by contractors, in order to ensure that it is up to standard and value for money. It is best practice to separate the quality control from the execution.

Findings

- There needs to be quality control of every job executed. Quality control on a sample base is not advisable, especially if the majority of maintenance jobs are outsourced.
- A department for quality control and quality assurance is not available.
- Approved QCPs are in place but need to be strengthened.
- Inspection of HT Motors, MCA, Tan Delta test, DPT of fan motor rotor bars, MDBFP motor in-situ inspection of overhang portion of stator bars/DPT of impeller blades should be carried out during overhauls.
- Some machine spares are stored in open yards and some spares are placed in open sheds exposed to sun, rain and dust are becoming damaged. Vulnerable items need to be shifted inside the covered store and the preservations schedule needs to be followed.
- Currently, there is no prequalification of vendors with regards to approval of single sourcing/open tendering.
- The unit has a rolling overhaul schedule for IN, IR, MGO and GO, as per their outage philosophy. However, the scope of the work must be frozen well in advance, so that

resources are procured/managed in time. Otherwise, quality issues are not properly addressed.

- There is a high risk of the plant losing its operation permit, due to improper ash disposal, high emissions, overflow of dams, etc.
- Proper housekeeping is a prerequisite to safety and quality maintenance and needs to be addressed immediately.

Resources

At the Kusile plant, there are 32 people working each shift, on a five-shift cycle. Currently, 26 critical positions, including operators, are vacant. This is a huge gap, affecting operation quality, and needs to be addressed immediately.

In the event of sickness, other shift members cover their duties through overtime arrangements.

Regular plant walks are conducted by operators on a shift basis, using check sheets to monitor the plant. Presently, there is a shortage of quality and experienced operating staff.

Further, only one field operator is posted for the entire boiler, milling system, draught system and TG and auxiliaries. We recommend that at least three field operators are present on each shift to monitor the systems separately: one for boiler, one for the milling and draught systems and one for TG and auxiliaries.

Work authorisation procedures are in place to ensure that the work is properly authorised and to guarantee that the maintenance activities are carried out safely. However, the authorisation process needs more attention, in order to ensure that work is carried out efficiently and safely.

Artisans are qualified with trade tests (N2-N6). Technical supervisors and engineers have the required National Technical Diploma/B Tech degree. The works are executed by contractors under the supervision of Eskom technician supervisors and engineers. The plant follows a clear hierarchy level as per Eskom structure which is very exhaustive in terms of managerial roles.

- The current Eskom organisational structure does not empower the generating plant management, which faces a high degree of intervention and control from head office.
- Adequate experienced middle-level staff need to be recruited, particularly in maintenance, including C&I and Electrical. This is not the case at present.
- There are challenges in retaining experienced employees due to lack of a proper reward and recognition scheme and failure to motivate them. Issues like housing, schooling, etc., are big concerns for the employees.
- The average length of stay of employees is too short, which severely hinders the transfer of skills from experienced to junior staff.
- There is a non-availability of specialists at plant level to resolve critical issues.

- The mechanical workshop at the plant has not been commissioned yet, which poses a severe constraint on repair and refurbishment activities.

Third Party Resources

The current Eskom tendering process does not include a prequalification process prior to submission of request for proposal. Any party can participate in the tendering process, irrespective of qualification or previous procurement history. This leads to significant delays in the procurement process and does not assure that sufficiently qualified companies are even considered in the bidding process. Rejection of potential venders leads to retendering, which causes additional delays in mobilisation of vendors. Such a system encourages the contracting of inadequately qualified vendors, as plant personnel is forced to choose between quality of work and timely execution.

Current Subcontractors

The plant has entered into 34 maintenance contracts for different functions. We recommend that each contract specify the required skill set of the contractor and that they are approved only after a performance test.

Spare Parts

Concerns relating to spare parts can be divided into two main categories:

- Timely procurement of spare parts: This is adversely affected by tendering of proposals to potential vendors irrespective of their technical or financial capabilities. This can lead to one or more retenderings, even after an extended period.
- Quality of spares due to absence of proper quality control plan with sufficient holding points. As reported by plant personnel, there are occasions when quality control only takes place after delivery to the site. This forces the plant personnel to compromise on the quality of spares, as rejection would cause substantial delays in the availability of said spare part.

The following is a list of all the main concerns:

- Spare-part management is a major issue impacting EAF.
- There are gaps in ordering, receiving, and maintaining adequate spare parts in order to avoid delay in maintenance and load loss.
- Only OEM-related spares and services are provided by/procured from the respective OEM/their agency on sole source basis.
- Even though sharing of spares is done with other plants, this is a grey area which is currently a big concern for the concurrent load loss.
- The stock level is not adequately maintained.
- A dedicated quality assurance department is not available.

- The long procurement process and unavailability of critical spares increases the high risk of downtime and, consequently, load loss.
- Valves passing is a major concern and, even post outage, rectification is not yielding desirable results, which results in loss of energy and abnormally high DM water consumption. Non-availability of spares for FGD, PJFF, mills, Compressors, DHP, rotating equipment and soot blowers is a big concern for the equipment reliability.

Additional Spare Parts Recommendations

- Besides the correction of the above-mentioned points, we recommend that the adequacy of min/max values and safety stock in the plant be reviewed every six months. At least on annual basis, the plant should conduct FSN/ABC analysis to identify high value and non-moving items and to establish whether it is necessary to keep such items in stock. The use of an automated first-in, first-out system, with monitoring of shelf-life time is highly recommended.
- A strategic list of spares /unit assemblies needs to be finalised between all plants that have similar units/OEM.
- List of critical spares to be reviewed in every quarter for all the system by the concerned department.
- Develop specifications and drawings for the spares.

Operation

Quality

The plant operates around the clock with five groups of operating staff. Each shift is 12 hours and there are two shifts in a day. Shift handover takes place during the change of shifts. Shift handover work instructions are available with shift in-charge. Operating instructions are referred to from the work instructions (SOP) and technical specifications from OEM. Plant operational logs are maintained by the operators in an electronic logging system.

Recording of the plant performance analysis needs improvement so that the findings and related issues of load loss and efficiency parameters are well mapped to the respective equipment/systems. This is a necessity to mitigate the gap between the current and design performance. The schedule of testing for performance monitoring for different equipment/systems needs to be well defined on daily/monthly/quarterly/half yearly and annually basis. The punch points made for the equipment/systems need to be monitored at regular intervals for facilitating the resources, so that they are addressed in a definite time frame by the respective departments.

The coal conveyor from Anglo Inyosi Coal mine is under construction and expected to be operational by the end of 2024. Hence, coal from different mines is currently being transported to the plant by road. Coal quality management procedure is followed as per the coal supply agreement between Eskom and Anglo Inyosi Coal. The plant uses a coal management system to capture data on coal quality parameters, and the laboratory uses LIMS (laboratory information management system). Coal samples are taken at the source before it is shipped to the power plant. Verification is also done at the power plant after delivery. The results of the two labs are compared and accepted only when the deviations between the two reports are within the permissible limits.

The quantity and quality of the coal for the plant is guaranteed by the following documents, system, and liaison meeting between Eskom and Anglo Inyosi Coal:

- Contractual monthly minimum dispatches, as per coal supply agreement.
- Weekly coal demand for the plant shared with Anglo Inyosi Coal by Eskom.
- Operation report for dispatch of coal per shift.
- Weekly operational meetings between Eskom and Anglo Inyosi Coal (maintenance teams, coal manager and counterpart form the mine).
- Monthly technical liaison meetings for any technical issues.
- Main liaison meeting between Kusile and Anglo Inyosi Coal Senior Management.
- Centralised system: Coalapps and LIMS (Eskom system).

The OPEX is tracked by comparing actual vs budgeted expenditure on monthly and YTD basis. PSGM holds a monthly review meeting.

The budget for the plant is prepared on an annual basis and takes the volumes of generation, different activities to be executed and outage plans into consideration. Although the system is established, no record is available for system wise budget declaration.

Monitoring

C&I System Integration

The Kusile plant has an integrated ABB instrumentation and control (C&I) system. The system serves as an operational historian, providing real-time information. Some modifications are required in the controls and display on the Human-Machine Interface (HMI), but the system is functional and integrated with the plant's operations.

Alarms Handling

At Kusile, alarms are classified into different categories and displayed on the HMI screen with audible alerts. A separate critical alarm screen is constantly open to ensure immediate attention to critical alarms. The efficient handling of alarms will help in addressing potential issues promptly and minimising risks to the plant's operations.

Condition Monitoring System

Kusile has implemented a condition monitoring system. It monitors temperatures, vibrations, and other parameters to prevent plant failures. The system enables continuous monitoring of generator vibrations, including stray flux and end-winding vibrations. It also monitors partial discharges and performs dissolved gas analysis (DGA) for unit and generator transformers. This proactive approach to condition monitoring allows for early detection of abnormalities and timely maintenance interventions.

Periodical Risk Assessment

Kusile follows a periodical risk assessment procedure to identify and manage potential risks effectively. This systematic approach allows for the identification of risks and the implementation of appropriate mitigation measures to ensure the safety and reliability of plant operations.

Unburnt Carbon in Ash Monitoring

The performance and testing department at Kusile monitors unburnt carbon in ash. This monitoring helps assess the plant's combustion efficiency, so that combustion processes can be optimised and energy generation maximised.

Overall, the monitoring systems and procedures at Kusile demonstrate a proactive approach to ensure the efficient and safe operation of the plant.

Outage Management

Planning

At Eskom power plants, the TG operational running hours drive the unit outage philosophy. There are different types of outages as per the outage philosophy, which have been summarised below with interval running hours, duration and main activities to be done during the respective outage period.

The outage philosophy, as well as the outage intervals, are given in detail in Figure 126 and Figure 127.

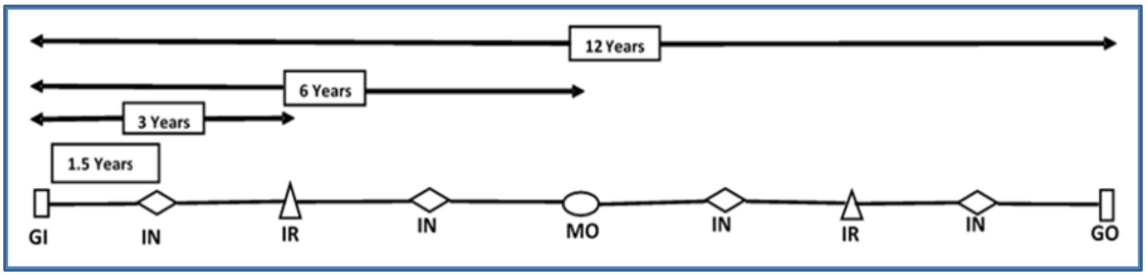


Figure 126: Outage philosophy at Kusile

Symbol	Outage type	Interval Years	Interval Hours	Duration (days)	Main activities
□	GO	12	100000	90	HP, IP and LP cylinder overhaul
◇	IN	1.5	12 500	26	Boiler and Draught Group inspection
△	IR	3	25 000	35	Boiler and Turbine Auxiliaries inspection and repairs. Turbine valves overhaul (HP& IP steam admission valves, TAL, LP Bypass, PACV)
○	MO	6	50 000	56	HP, IP and LP cylinder overhaul HP and LP regenerative heaters CEP overhauls, inspections, and repair. Boiler statutory inspections Generator stator and rotor inspections

Figure 127: Outage intervals at Kusile

Modified Outage Philosophy at Kusile

As there are frequent outages of FGD that require inspection and repair every year for an outage duration of 25 to 30 days, the plant has the planned outages of all the units at an interval of 1 year (instead of 1.5 years, as at other Eskom plants). Thus, all the units at the plant require planned outage of 25 to 30 days every year. FGD has been installed at Kusile power plant for the first time in South Africa. This technology is new to Eskom.

There is a shortage of skills and experience for O&M of the FGD, as this technology is new to Eskom. The outage philosophy is governed by the maintenance requirement of FGD plant.

The plant management is of the opinion that the plant can achieve EAF of 85%, UCLF of 5% and PCLF of 10% by FY2026/2027.

The monitoring for the preparedness for the outages starts 24 months prior to the start of overhauling. However, the preparation of outages, particularly with regards to finalising the scope of work, award of contracts and procurement of spares, is not done as per the outage timelines and there is bunching of activities, which leads to delays in supply and services.

The plant lacks a dedicated quality control and quality assurance department, relying on line engineers for quality control, which is not a standard practice. While there are approved QCPs in place, they need further improvement and strengthening.

There is a shortage of skilled manpower for critical tasks such as high-pressure welding and servicing of HP valves, compressors, and pumps, FGD, mills, fans, etc.

During the outage planning, the outage scope is prepared based on the type of outage as per outage philosophy and the prevailing issues and concerns of the unit. The individual scope of work is signed off for each outage.

Handling of additional manpower during outage is managed through manpower curve to meet the scope of work of the outage and task order submissions prior to outage.

Funding approval process for OPEX is met through MFIC, and CAPEX requirements are sent to head office. This needs to be approved at T-24 for proper planning.

Findings

- The duration of outage for IR, MO and GO is very long compared to the international standard. There is substantial potential for improvement in EAF by optimising the duration of outage. Thus, we recommend that the duration of IR, MO and GO respectively be changed to IR about 30 days, MO about 50 days and GO about 56 days.
- the preparation for outages, particularly with regards to finalising the scope of work, award of contracts and procurement of spares, is not done as per the outage strategy and there is last minute rush to award contracts.
- The plant prepares the overall outage budget, but a systematic budget estimate was not available for review. This needs to be done meticulously for all the systems matching the requirements of the finalised scope of work.
- Budget approval takes an extremely long time, which delays the procurement of spares and award of contracts. Although manpower resources are sufficient to handle outages, implementation of outages is often impacted by shortage of spares, time-consuming procurement processes and system constraints.

Main reasons for outage slippage are:

- There are number of surprises, which require change of scope leading to time consuming processes like awarding of contracts, spares procurement/refurbishment and budget approval.
- Even after completion and return of PTW, the recommissioning of the unit takes 10 to 15 days which is too long and needs to be optimised.

Short-Term Solutions

- Ensure compliance of preparations for outage with outage philosophy.
- The slippage of outage caused by unexpected developments can be minimised by planning for spares and services for worst case scenarios.
- The resources (manpower, spares, consumables, expert services etc.,) are to be made available before the start of overhaul by contracting in time.
- Budget preparation needs to be made systematically and approval needs to take place within a specific time frame.

- Even after completion and return of PTW, the recommissioning of the unit takes 14 to 15 days, which is too long. There is potential to reduce the same to increase PLF.
- Presently, the quality control during outage is carried out by the line manager. Since intense quality supervision is required over a short period of time, the quality control group needs to be augmented for the period of the outage.

Long-Term Solutions

- The durations for MO and GO are 56 rand 90 days, respectively, and higher than the best international practice. The durations should be reviewed and optimised to the minimum required duration.
- Currently the FGDs require an annual outage of 14 to 18 days, which consequently requires the related unit to be shutdown. After stabilisation of the FGD operation, there is potential to reduce the outage frequency to 1.5 years.
- The monitoring for the preparation for the outages starts 24 months prior to the start of the overhaul. However, the preparation for outages, particularly with regards to finalising the scope of work, award of contracts and procurement of spares, is not carried out as per the outage timelines and there is bunching of activities, which leads to delays in supply and services.
- The plant lacks a dedicated quality control and quality assurance department, relying on line engineers for quality control, which is not a standard practice. While there are approved quality control plans (QCPs) in place, they need further improvement and strengthening.
- There is a shortage of skilled manpower for critical tasks such as high-pressure welding and handling valves, compressors, and pumps.

Quality

For outage management, ORI are conducted, assessing submission tracking of QCP's, defining hold points, witnessing quality interventions etc. The technical issues are addressed in the technical resolution meetings and execution meetings.

Findings

- Quality control and quality assurance departments do not exist at the plant. Currently quality is controlled by line engineers, which is not an international standard practice.
- Approved QCPs are in place but need to be further strengthened.
- Currently there is no prequalification of vendors in case of approval of single sourcing/open tendering.
- Shortage of skilled manpower for the critical jobs (high pressure welding, valves, compressors, pumps etc.)

- Achieving full load and uninterrupted operations of the unit after completion of overhaul also need to be considered as criterion for quality overhaul.

Procurement

The procurement process is a combination of local and centralised purchase systems. The placement of orders for spares and service contracts are done locally. However, a list of spares and service contracts are processed centrally.

Open tender process is adopted for the items that are over R 1 million, and quotes are requested for items below R1 million.

The procurement process is cumbersome and time consuming, due to approval requirements at multiple stages. It needs to be revisited to accelerate the process and to enable timely availability of spares and engagement and mobilisation of resources. There is no proper vender prequalification process in place to ensure that only (technically and financially) pre-qualified vendors participate in the bidding process. The lack of a prequalification process means that vendors that cannot cater to Eskom's requirements also participate in bids.

Leadership

Kusile plant management attributes the low plant performance to design issues rather than to its own failure to manage the challenging task of a complex high-tech plant with demanding technologies, such as supercritical boiler specifics and a sensible flue gas treatment plant.

The plant operation by the OEM for Unit 4's boiler has achieved an EAF of over 90% for longer than one year. This clearly demonstrates that competent and prudent plant operation and maintenance make a difference.

The damage to Unit 1's flue gas stack caused the non-availability of Units 1, 2 and 3 and was solely due to deviation by the plant's O&M team from prudent operation and maintenance practices.[35]

The attitude that allowed for this deviation from prudent practice, along with obvious competence gaps, will very likely lead to repetition of such catastrophic damage, as described hereinafter in derail the consequence of current operation and maintenance practice leads to further unnecessary plant deterioration.

To achieve sustainable operation of the plant, the following challenges have to be addressed:

- Inability to evacuate ash and gypsum from TH09 to the 10-year ADF when more than three units are running concurrently, due to delays in the construction of a 60-year ADF and leading to possible de-load/shutdown of units.

[35] Eskom currently is finalising the RCA on the damage. At the time of Opera assessment no comprehensive report was available.

- Inability to maintain coal supply and ash evacuation for more than four units, due to incomplete construction of mine conveyors and ADF. This may lead to shortages during commissioning of Units 5 and 6, if Units 1, 2 and 3 are recommissioned with temporary stack, in accordance with the provided schedule.
- Risk of collapse of western flue gas ducts on load (inclusive of the 55 m and possibly at 155 m platforms and roof). The supports and the platform at 55 m, and possibly at 155 m, were damaged by overloading with slurry while running with Unit 1 in October 2022.
- Overflow of ash contaminated water from transfer houses 8 and 9, and radial stacker due to blocked drainage system leading to a legal contravention and non-compliance.
- Delays in completion of construction and commissioning of facilities for fire detection, CBMS, coal hopper, mine conveyor, truck off-loading facility,10-year ADF, ash conveyor extension to ADF, gypsum conveyor and 60-year ADF, drains for the coal stock yard, workshops, electrical and C&I laboratories, liquid waste treatment plant, chemical laboratory, etc. This is putting constraints on plant operations.
- Non-availability of a public address system may lead to delayed announcement in case of an emergency and to unsuccessful evacuation.
- Prolonged outage of the units due to the unavailability of auxiliary steam in the past. Issues with auxiliary boiler were addressed.
- The coal supply contract is on a take-or-pay basis. Due to the delay in commissioning of the different units and low EAF, the contracted minimum quantity of coal could not be consumed. Coal is stored in an area that now needs to be cleared, as the area is due to be used for ash disposal.
- The present procurement process needs to be revisited, to address the time-consuming procurement process.
- Lack of detailed budgeting for each system of O&M and its timely approval.
- Shortage of skilled trained manpower particularly in FGD.

The basic challenge that management faces is to establish an appropriate maintenance practice and introduce a robust monitoring system. Even though the first unit achieved commercial operation in 2017, it appears that such systems have not been established for the first four units, as records of the preventive maintenance schedules were found to be incomplete.

The essential requirement for sustainable operation is an appropriate maintenance plan. This must be derived from the design and maintenance manuals of the equipment installed at site and these have, in many cases, not yet been supplied by the project management team. The creation of a department with competent maintenance engineers and planners will be one of the major leadership challenges that needs to be addressed urgently.

The current leadership is overly dependent on the EPC contractors and Mitsubishi for O&M of the plant. Unless there is a planned transition with identified key resources in place, the risk of catastrophic failure, as was experienced with the collapse of flue gas ducts, is high. Various gaps in skills can be identified in the report and immediate study is required to address the organisational and human resource requirements.

Risk Management

Kusile has an integrated risk management work directive, which complies with the integrated risk management standard (doc. no. 32-391) of Eskom's enterprise risk and resilience policy. While the risk management process works on paper, in reality the implementation of risk mitigation measures appears to be confronted by a large number of activities that are not executed in a timely manner. Risks are recorded in the Cura system. However, the system cannot be fully used to the full due to software license restrictions.

The plant faces various risks in generation, construction, emissions compliance, zero discharge, equipment reliability, safety culture, manpower shortage, employee motivation, documentation management, critical spares specifications, comprehensive systematic budgeting, streamlined procurement, and knowledge forums.

Mitigating these risks is essential for ensuring the sustainable operation of the plant and achieving long-term success.

5.10.5 Technical Profile of Main Plant Areas

Kusile power plant comprises six 800 MW identical supercritical coal-fired generating units with a total generating capacity of 4 800 MW. This plant is the first in Eskom's fleet, and in South Africa, to use flue gas desulphurisation technology. Each of the six boilers feeds its own turbine with steam. At present, Units 1, 2 and 3 are not operational due to FGD duct collapsed. This leaves Unit 4 as sole unit in working condition for the plant. Units 5 and 6 are not online but are expected to be running by FY2023/2024. The actual dates of commercial operation of the units are shown in Table 51.

Parameter	Value					
Gross plant capacity (MW)	6 x 800 (4 800)					
Available capacity (for Maximum Continuous Operation)	3 200 MW (excluding Units 5 and 6)					
Number of units (no)	6					
Start of operation (year)	2017 (Unit 1)					
Units still operation (no)	1 (Unit 4)					
Steam parameter (pressure/temperature)	24.1 MPa/560°C					
Commercial operation	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6

Parameter		Value				
COD	08/2017	10/2020	03/2021	05/2022	NA	NA

Table 51 Kusile power plant details

Source of Fuel

Anglo Coal's subsidiary, Anglo Inyosi Coal, was contracted to supply the necessary fuel to the Kusile power plant. Approximately 17 million tons of coal are supplied annually by Anglo Inyosi Coal, agreed for a period of 47 years. In addition, coal will also be supplied from the New Largo reserve. At the moment, coal from different mines such as Manungu, Mzimkhulu, Vlakfontein, Wescoal Moabs is trucked to the plant.

Source of Water

Raw water is supplied from the Vaal dam. The site has a raw water reservoir capacity of 687 500 m^3.

Source of Emergency Fuel

Diesel is used on-site for the coal moving equipment, the diesel-driven fire water pumps, emergency demineralised water pumps, diesel-driven compressors and emergency generators.

Total Operation Hours for Each Unit YTD

The total operating hours for each unit, since commissioning, are shown in Table 52.

Units	Boiler Running Hours	Generating Hours
Unit 1	34 683	31 649
Unit 2	22 842	21 577
Unit 3	19 378	18 588
Unit 4	10 156	9 772
Unit 5	56	0
Unit 6	0	0

Table 52: Kusile's unit running hours since commissioning

Coal Composition (including Heating Value)

Kusile's coal composition for March 2023 (monthly average) is shown in Table 3 (based on the Kusile step report, March 2023). The CV of operating coal is better than the design (18.8 MJ/kg). While the key parameters of coal quality are in a reasonable range, the sulphur content variation and over-stepping of contractual values contributes to operational challenges and potential load loss.

Coal analysis	March 2023 data	Contract data (ARB)
CV as received (MJ/kg)	19.66	18.80
Total moisture (%)	7.06	7.00
Ash (%)	30.86	34.40
Volatile matter (%)	21.32	18.40
Fixed carbon (%)	40.30	40.20
Sulphur in coal	**1.04**	0.9

Table 53: Kusile's coal composition in March 2023 vs. contracted data

5.11 Lethabo Power Plant

The Lethabo power plant is one of the best performing and continuously operated power plants in the Eskom fleet. Situated in the north, in Free State, at an altitude of 1460m, Lethabo lies approximately 10 km south of Vereeniging and 25 km east of Sasolburg.

Unit 1 went into commercial operation in December 1985 and the last of the six production units was commissioned in December 1990. The station comprises 6 x 618 MW units with a total installed design generating capacity of 3 708 MW.

Parameter	Value
Installed capacity (MW)	6 x 618 MW
Available capacity (for maximum continuous operation)	3 708
Number of units (no)	6
Start of operation (year)	1985
Units still operation (no)	6
Planned end of life of first unit (year)	2041
Planned end of life of last unit (year)	2041
Steam parameter (pressure/temperature)	17.32 MPa/540°C
Source of coal	Seriti Mine &Coal Stockyard

Commissioning and life of plant	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Commissioning dates	12/1985	05/1986	02/1987	10/1987	05/1989	12/1990
Expected decommission (estimated)	12/2036	07/2037	03/2037	12/2038	06/2040	12/2041
Lifetime operating hours as on 1 June 2023.	265,815	257,989	258,317	263,235	247,485	241,077

Table 54: Installed capacity and station details for Lethabo power plant
Source Eskom

Lethabo has been reliable in the past, but during the last two years it has shown signs of its age and the lack of adequate maintenance and mid-life upgrades. From being the best operating plant in the fleet in FY2021, its EAF reached 60.38% in February 2023. Deferred general overhauls (mainly due to lack of adequate power supply in the country) contributed substantially to its recent unreliable performance. After 30 years of operation and considering that it is expected to operate for another 20 years, mid-life rehabilitation was already planned for FY2016–2021 but very little of this refurbishment and technical upgrading has actually taken place.

The main areas of necessary improvement are tube leaks on boilers, draught plant and gas cleaning. Key technical issues which need to be addressed urgently include:

- The whole station needs a mid-life upgrade/rehabilitation for all units, to secure reliable operation until planned decommissioning in 2041.
- The water treatment plant needs urgent refurbishment and replacement of the most damaged items like tanks or valves.
- The draught system needs improvement by rehabilitating and upgrading the HTF (Unit 2-5 completed, 1 and 6 scheduled), ESP components need replacement/upgrade, SO_3 plant needs refurbishment (except Unit 4), reduce air-in leakage and optimise excess O_2.
- BTF at Unit 5 and Unit 2 should be given maintenance priority to get 18 MW (each) of load back.
- Limitations on ID fan Unit 3: urgent repair is needed on precipitator ducts to get back 18 MW of load.
- Part of the draught plant on Unit 1 must be repaired, following an accident (duct fire).
- Inconsistent coal supply is impacting all production units, mainly in the rainy season. A coal reserve adequate for at least 2 weeks of full load production should be established on-site, and efforts should be made to maintain consistent quality of dry coal. The establishment of additional covered coal storage should be looked into, because it would improve EAF and plant efficiency.
- The main control system Teleperm C and protection system Iskamatic B, that are currently in operation, are obsolete and should be replaced.

On the plant management side, timely approvals of planned outages, timely release of adequate funding and timely access to spare parts would improve the plant's availability. The plant management at Lethabo has a positive approach to managing the plant. Senior and management staff have, however, recently been poached by other stations like Grootvlei, which is concerning. The reasons for this need to be investigated and the problem addressed.

The following actions are particularly important:

- Release of funding for technical projects and adherence to scheduled outages. The funding should ideally be secured at least two years before execution of the outages.
- Staff morale is improving, but employees need to be given incentives that acknowledge and reward their hard work and good station performance.
- The procurement & supply chain procedures must be improved, and the decision/approval timing must be reduced.
- HR processes are not efficient, and HR is unable to deliver headcount numbers requested by managers. Also, there is high staff turnover and a high retirement rate. Additionally, it is necessary to reinstate and authorise progression procedure. Currently, there are 134 senior managers and 42 open vacancies.

5.11.1 EAF and PLL

Lethabo was an exceptionally reliable power station until FY2011 (refer to Figure 128) with an availability above 90%. Over the last few years, the availability has declined to 70%–80%, with a small improvement in the period FY2015 to FY2016, with availability rising above 80% in FY2016. In FY2021, it was also operating at around 80%.

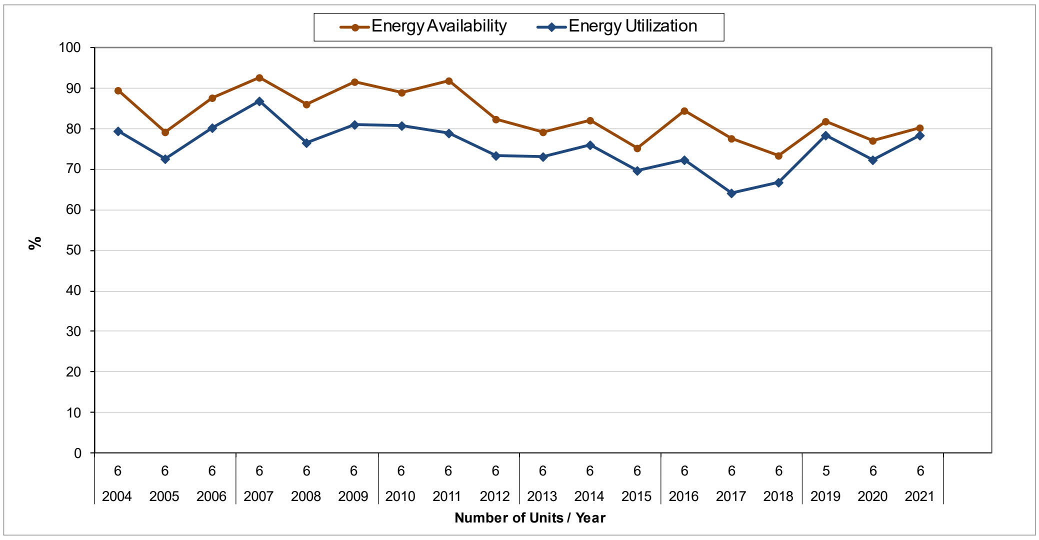


Figure 128: Lethabo's availability and utilisation (FY2003/2004–FY2020/2021)
Source: KISSY

Figure 129, below, shows the availability for each of the ten units at the Lethabo power station for the period FY2004–2021. More recent information is provided in Figure 130 and Figure 131.

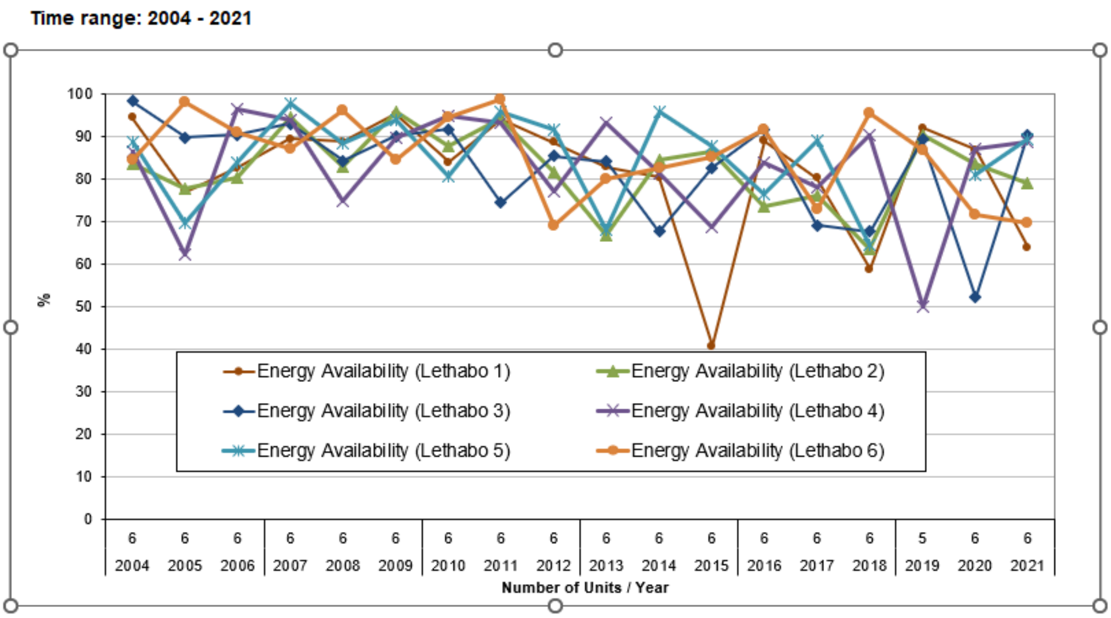


Figure 129: Unit-wise availability at Lethabo (FY2003/2004–FY2020/2021)
Source: KISSY

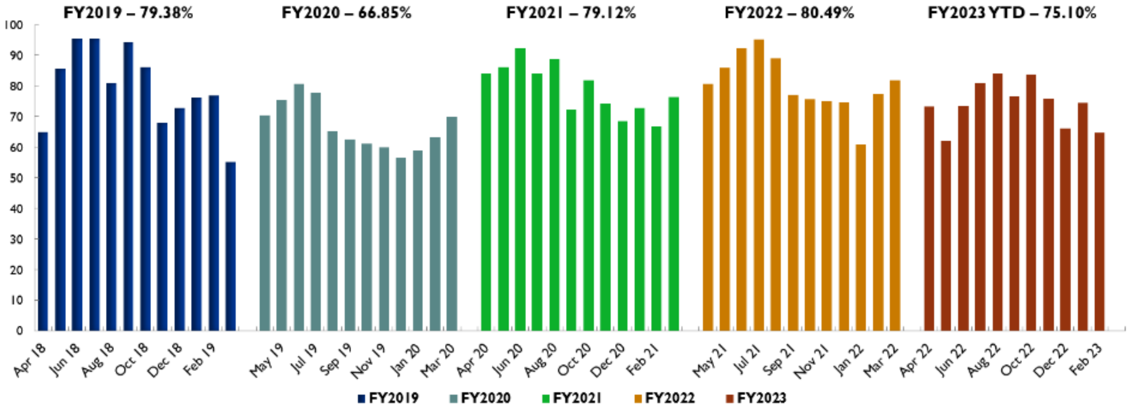


Figure 130: Lethabo's EAF performance trend

As Figure 130 shows, over the last four years EAF was around 80%. In FY2020, there was a drop to 66.85% and in FY2023 to 75.10%. During FY2023 YTD, as Figure 131 shows, the largest contributors to Lethabo's reduced availability have been boiler tubes (35.8%), draught plant (12.6%), gas cleaning (12.6%) and mills (8.7%).

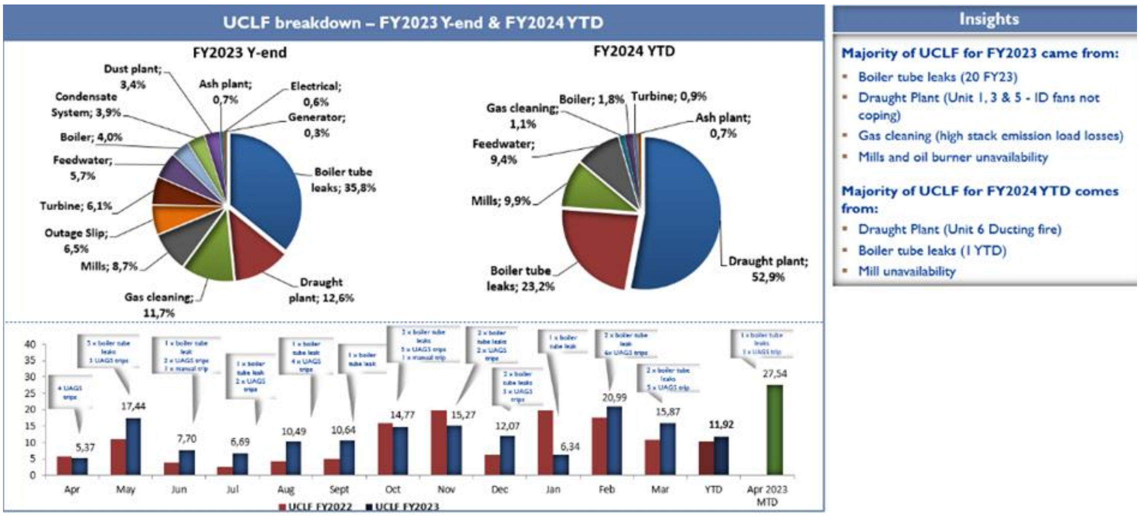


Figure 131: Lethabo's UCLF contributors (FY2022/23–YTD)
Source Eskom

Similarly, in FY2024 YTD, the major contributors to the unreliable operation of the plant were draught plant (52.9%), BTF (23.2%), mills (9.9%) and feed water (9.4%). An average of 27.54 MW was lost, for in FY2022/2023 and FY2024 YTD.

Table 55, below, highlights major contributors for UCLF from the last five years FY2017/2018–FY2021/2022:

Top 5 UCLF Contributors	FY18	FY19	FY20	FY21	FY22
1	Generator	Boiler	Boiler	Boiler tube leaks	Boiler tube leaks
2	Boiler tube leaks	Outage slip	Boiler tube leaks	Boiler	Outage Slip
3	Outage slip	Boiler tube leaks	Dust Emissions	Dust Emissions	Boiler
4	Boiler	Dust Emissions	Outage slip	Turbine and Condenser	Dust Emissions
5	Turbine and Condenser	Generator	Bottom Ash Removal	Generator	Turbine and Condenser

Table 55: Major UCLF contributors at Lethabo (FY2017/2018–FY2021/2022)
Source Eskom

Table 56 provides a summary of hours lost due to planned and unplanned shutdowns.

	Planned			Unplanned		
	Hours Loss	MWh Loss	LF	Hours Loss	MWh Loss	LF
Total (6 years)	30450	18056662	58	27278	16175943	52
Ratio of Planned vs Unplanned = 1: 0.90						

Table 56: Review of unit shutdowns at Lethabo (593 MW)
– both planned and unplanned events, source Eskom

More observations regarding issues affecting EAF and the potential solutions are provided in the next two sections of this report.

5.11.2 Technical Status

5.11.2.1 Technical Status of the Boiler

During the visit, the team walked through the **boiler house**. In general, the housekeeping was in order. There was no high amount of dust, and no visible leakages or safety-related issues were observed.

Figure 132: Lethabo's Unit 6 boiler house

The overall generation availability of the station has fallen due to frequent BTF (20 in FY2023, see Figure 133), affecting both station reliability and output. The boiler tube mid-life refurbishment programme was deferred from FY2010, and it is still uncertain when it will take place. There is a current backlog of boiler tube maintenance and this, as well as boiler tube spares not being available, has resulted in tube replacements not being completely carried out during outages. The current lead time for boiler tubes is 5 months. Budget approval, procurement of spares and completion of the full scope of work are essential. The current situation poses a paramount risk to station performance.

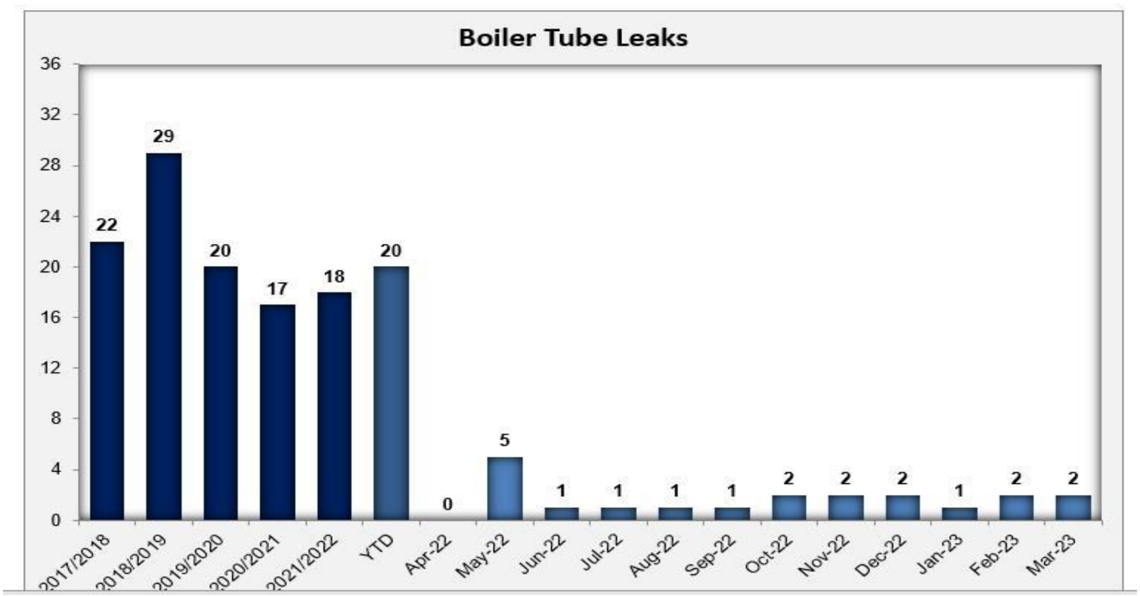


Figure 133: Lethabo's BTL per year and month
Source Eskom

Finally, no safety related issues were observed.

Currently, there are ongoing sporadic losses at several units. Unit 2: 18MW lost due to high pressure heater A bank, which is offline; Unit 3: 18 MWe PLL due to air leakage (causing ID fan limitations); Unit 5: 28MWe PLL due to air leakage and feedwater high pressure heater B bank offline; Units 1 and 6: out of operation for repairs.

Lost MWs due to the **draft system** (see Figure 131) have increased from 12.64% in FY2023 to 52.9% in FY2024 YTD, a substantial increase. Load losses due to ID fan issues have ranged from 18 to 68 MWs for extended periods.

Figure 134: Lethabo ID fan Unit 1

The draft system is not operating at maximum capacity. The operating issues are mostly related to the ID fans, which are affected by increased erosion due to increased dust loading (at the exit of the ESP). Also, thinning of the ID fan blades has been reported, which requires urgent attention.

Variable and out-of-specification coal quality have a major impact on the operation of the **mills** and were among the four highest contributing factors to UCLF in FY2023 (increasing to 8.9%), as shown in Figure 131. Plant staff struggled to keep enough mills in good working condition, mainly due to the lack of spare parts. Maintenance of the mills is outsourced and there are usually issues and delays in signing contracts and getting the support needed. The recent establishment of spares contracts for mill liners should help the situation.

Eskom uses the **Thermal Index** (TI) to monitor thermal excursions on boiler outlet headers, main steam and hot reheat piping. TI is a long-term indicator of unit health and, as such, can also be used to check the stability of boiler operation, as thermocouples indicate the time spent operating over and above normal operating time. The TI report from FY2023 shows that the header temperatures at Lethabo are consistently above the tolerance limits, while the main steam and hot reheat pipework are mostly within the limits.

LETHABO	Header TI	112	94	160	114	66	47	13	133	227	99	75	311	530
	Main Steam TI	13	18	7	4	14	5	89	9	33	16	2	14	14
	Hot Reheat TI	15	3	21	16	17	40	10	21	22	9	276	22	179

Tolerance Limits for Thermal Index:	
< 35	Favourable
36- 73	Acceptable
> 73	Unacceptable

Figure 135: Extract from the Lethabo's Thermal Index report

Boiler at a glance:

- Poor coal quality is putting stress on both the boilers and mills. The coal supplied is consistently below the design coal specified for the plant, especially with regard to CV and moisture content.
- Frequent BTF is caused both by high operating temperatures and maintenance backlog. Tube replacement needs to take place as per maintenance philosophy.
- Availability of mills is low for several reasons: reduced heating value of coal results in higher throughput required to meet full load output; reduced maintenance and availability of spare parts make the situation worse.
- Effort should be made to assess the actual air-in leakage throughout the boiler and try to reduce it, as well as to optimise combustion, which should reduce excess air.
- ID fans experiencing blade thinning need urgent attention; improved ESP performance should help the ID fans, too.

5.11.2.2 Technical Status of the Machinery

Lethabo power station has been running continuously for more than 30 years, and the turbines have already reached their designed mid-life operating age with 300 000 operating hours. To extend their life to 350 000 operating hours, it will need a general overhaul with parts replacement.

Figure 136: Turbine hall at Lethabo power plant

Turbines are MAN impulse-type HP, IP and reaction-type double flow LP, triple-casing condensing turbines have been installed. The turbine hall is reasonably clean. Dust is present on all equipment, but it is not as bad as at some of the other stations we visited. As can be seen in Figure 131, turbines represented only 6.1% of UCLF in FY2023 and are well maintained and generally in good condition.

The **generator** rotors at Lethabo and Matla are the same design and interchangeable. This assists spares availability, because when rotors need to be replaced, the spare rotor from either station is installed and that rotor is then sent to ERI or the OEM (currently Toshiba) for refurbishment. The most current rotor replacement was at Lethabo Unit 1, in Jan 2022. The rotor used for this replacement was a spare that had been at the ERI workshop for a very long time. The rotor that was removed was refurbished and will be installed at Matla Unit 6. Matla’s rotor will, in turn, then be refurbished and available for the next replacement. Rotor replacements need to be carefully planned and coordinated between the two stations. Stator are handled similarly. Generally, rotor and stator maintenance is carried out as per OEM guidelines, although outages are often deferred, resulting in extended running hours. As can be seen in Figure 131, generators represented only 0.3% of UCLF in FY2023 and are well maintained and generally in good condition.

Machinery at a glance:

- The repair of defective HP control valves 3 and 4 on Unit 5 is required.
- Turbines perform well and are in good running condition. Maintenance is carried out in accordance with maintenance philosophy.
- Generators perform well and are in good running condition. Maintenance is carried out in accordance with maintenance philosophy. Some deferred maintenance seems to have since been resolved.

5.11.2.3 Technical Status of Electrical and C&I Installations

Assessment and maintenance of the complete electrical and C&I installations are carried out at regular maintenance intervals and tests are planned at annual intervals.

Generators and auxiliaries are reliable, and no issues have been reported. Generator protection devices are of numerical relay type AREVA and MICOM.

Medium Voltage (MV) spares are available in stock and on the market, even though some are obsolete. The issue of spares is being addressed with breaker retrofits. MV equipment is of excellent reliability.

Low Voltage (LV) spares are available in stock and on the market, even though some are obsolete. The issue of spares is being addressed with breaker retrofits. There are no spares on incomers and isolators. LV equipment is of excellent reliability.

HV/MV Transformers are of high quality and reliability. The quality of some of the spares in stock is questionable: Employees are not confident they would be reliable in operation and, as such, are hesitant to use them. MV transformers (MV/MV) are very reliable with no failures to date.

SoMV/LV Transformers are reliable with no failures. Spares are available.

Plant Control System:

Lethabo’s main control system is Siemens Teleperm C with Iskamatic B protection. The system is obsolete, and no spares are available. Lethabo’s own maintenance team carries out maintenance and repairs. DCS needs to be replaced. Also, the functional safety system Iskamatic B needs to be replaced.

Electrical and C&I at a glance:

- The equipment is partially obsolete but well maintained; wear and tear are not significantly endangering proper functioning of the equipment.
- Based on information drawn from documentation, site assessments and interviews with plant maintenance, engineering and production staff, the electrical plant and C&I, needs further investment in spares and replacement of the obsolete main DCS Teleperm C, as well as the obsolete protection system Iskamatic B.
- Control and protection systems (DCS and fail safe) C&I systems are obsolete, and no spares are available. DCS needs to be replaced.

5.11.2.4 Technical Status of the Water Treatment Plant

Lethabo power station obtains raw water directly from the Vaal river and consumption is 120 ML/day. The water treatment plant did not cause any problems until last year when its performance started deteriorating; urgent refurbishment is needed. In the past, designed capacity of the demineralised water plant was sufficient for stable and failure-free operation of the power station, especially the boiler plant. Now, its performance is too poor to supply the plant because of high water and steam leakages and system failures.

Upgrading of the water treatment plant DCS system is also required.

Figure 137: Lethabo’s water treatment plant in May 2023

In addition to refurbishment, serious efforts are needed to reduce water consumption. It will have to be reduced significantly to be able to run the power plant with one water treatment train; alternatively, a temporary mobile plant would be required.

The capacity of the make-up water plant is sufficient to cover the consumption of the plant with water of adequate quality. Samples are taken and analysed twice a day and they are one of the key performance factors of the plant.

Water treatment at a glance:

- The capacity of the demineralised water plant is not sufficient, mainly caused by losses due to steam and water leakages at the plant.
- There is an urgent need for refurbishment of the whole plant.

5.11.2.5 Technical Status of the Auxiliaries and other Systems

Coal supply to the plant is 100% via conveyer belts from the Serti mine. Due to severe rainfall in February 2023, mining activity was negatively affected to such an extent that no coal could be delivered to the power station and some units needed to be shut down until coal was available. The recurrence of this problem poses a major risk to continuous operation. Currently it is alleviated by keeping the live stock piles as full as possible prior to the rainy season and by conducting monthly risk assessments for handling plant and equipment.

Daily coal burn is 50 000 tons for all 6 units, 2 100 tons coal/hour. The capacity of the coal stockpile is only sufficient for 3.2 days of plant operation. Live piles for more than 10 days and strategic piles for more than 20 days are necessary in order to ensure reliable fuel supply for all units.

The coal sampling is carried out on a daily basis. Table 57 provides the coal quality specification[36] and Table 58 the quality of contracted coal.

Gross Boiler Efficiency = 88.15%

	TM	IM	GCV$_v$	GCV$_v$	Net CV$_v$	Ash	Volatiles	Sulphur	Nitrogen	AI	HGI	Design FEGT	Milling Capacity
	% AR	% AD	MJ/kg MF	MJ/kg AR	MJ/kg AR	% MF	% MF	% MF	% MF	mg Fe	-	°C	%
Expected	11.00	5.50	18.15	16.15	15.43	38.50	19.36	0.83	1.12	>450	<50	1089	90.00
Distress	11.00	5.50	17.28	15.38	14.65	40.66	18.95	0.79	1.08				95.00
Original Design	10.50	4.50	18.34	16.41	15.71	34.97	21.70	1.12	-	335	65	1210	87.69
Acceptance Unit 1 1986	11.17	5.23	17.10	15.19	14.46	39.54	22.02	0.62	-	-	63	-	95.96

Assumptions (Boiler)				Max. Mill Output
Secondary A/H leakage %	Primary A/H leakage %	In-furnace leakage %	Oxygen %	T/hr
13	5	5	2.85	80.0
		Nominal mills for full load		5/6

Table 57: Coal quality specification for Lethabo power plant
Source Eskom[36]

[36] Coal Quality Specifications for Eskom Power Stations at Staithe/Silo Inlet Standard: 240-71273834

Contractual Coal Qualities		
	Unit	Range
Calorific value (as-received)	MJ/kg	13.7 – 15.7
Total Moisture	%	7.0 – 15.0
Ash (as-received)	%	38.0 – 41.0
Volatiles (as-received)	%	16.0 – 23.0
Abrasiveness Index		130 – 800

Table 58: Contracted coal specification at Lethabo
Source Eskom

Actually, Lethabo has never received coal consistent with design quality. In particular, the heating value is consistently below the design coal quality (16.41 MJ/kg(AR)) and the moisture content above the design coal (10.5%). As a result, the plant experiences lower plant efficiency and higher coal flow rate per MWh produced than designed. The latter stresses the mills and adds more dust loading on the ESP. So, the impact due to low coal quality is both direct and indirect.

The overall condition of the coal handling plant is in order.

The ash handling equipment is not causing any major reliability problems. For example, in FY2023 and FY2024 YTD, the ash handling system contributed only 0.7% of UCLF. Extensive repairs are planned, and minor repair work is being carried out on a daily basis.

The spare parts warehouse and maintenance workshop were also visited. The workshop is clean but its scope with regards to repair work is limited (see Figure 138). It has limited capacity and most of the repair work needs to be outsourced.

Also, there is a shortage of spare parts due to budget constraints. Some critical and operational spare parts are not available in stock. Late approval of outage budgets means that spares are being procured during outages. This is completely unacceptable practice, because it is a cause of outage slip that is a big problem in general.

We recommend the development of a strategic warehouse with security fencing and camera surveillance.

Spares procurement is still a problem, although some progress has been made. The purchasing department is under resourced and unpowered at present.

Proactive procurement of spares is currently a key aim and area of focus at the station.

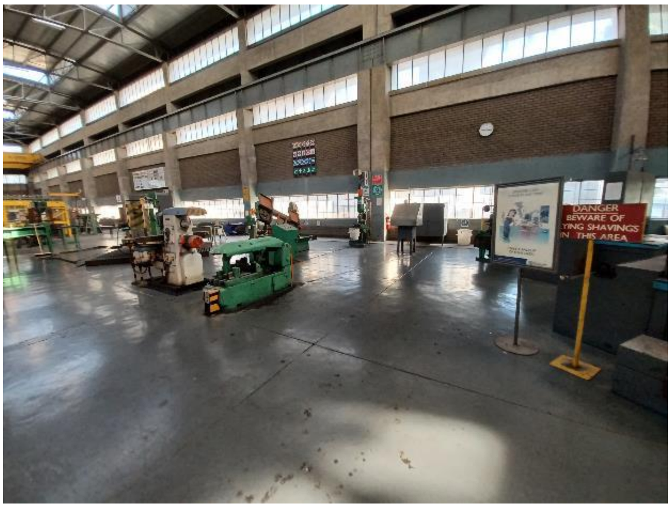


Figure 138: Lethabo warehouse

Auxiliaries at a glance:

- Overall, the coal and the ash handling plant are in good working condition.
- Coal quality is consistently low/poor. In fact, Lethabo has never received coal consistent with design specifications. While this variability has not affected EAF directly, it increases the loading of the mills and ESP, and lowers plant efficiency.
- There is low availability of critical and operational spare parts. Stores need upgrading and security. More buyers are needed, and timely budget availability is critical.

5.11.2.6 Emissions

Lethabo power station has been treated leniently with regards to environmental compliance. The plant does not comply with PM requirements. Presently, the required limit is 100 mg/Nm^3 and the plant emits more than 100 mg/Nm^3. Steps are being taken (a high frequency transformer project is in progress – Units 1 and 6), but a comprehensive upgrade of all the ESPs is needed. The emissions exceedance reasons for PLL for high stack emissions in FY2023 are presented in Figure 139, below:

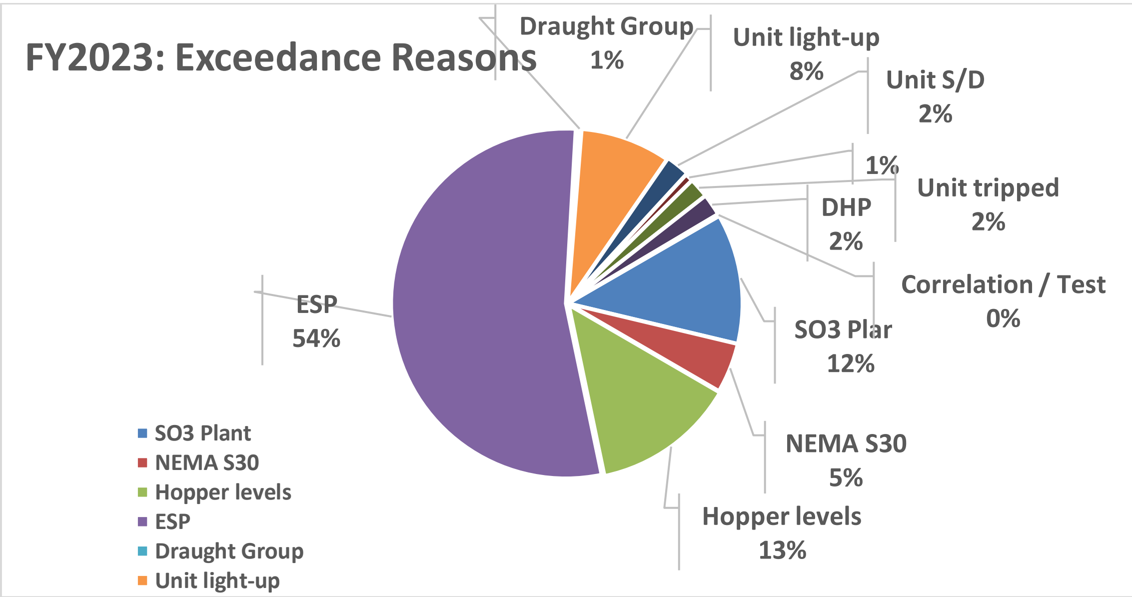


Figure 139: Emissions exceedance reasons at Lethabo
Source Eskom

The biggest challenge will be to comply with the new emissions limits by 2025. The old and future emission limits for PM, SO_2 and NO_X are presented below, in Table 59.

ELV	Current limits	Future limits (2025)
NO_x (mg/Nm^3)	**1100**	**750**
SO_2 (mg/Nm^3)	**3500**	**1000**
PM10 (mg/Nm^3)	**100**	**50**

Table 59: Lethabo emission limit values (ELV)

The station needs to install low NO_x burners to reduce NO_x from the present level of 1 000−1 200mg/Nm^3 below the future limit (750 mg/Nm^3).

Presently, Lethabo power plant complies with SO_2 requirements (3 500 mg/Nm^3), but it will not be able to comply with the reduced requirement of 1 000 mg/Nm^3 which comes into effect in 2025. 50−70% SO_2 reduction is needed, which may be achieved by reducing the sulphur content of the coal and/or through installation of SO_2 control equipment. Lower sulphur content coal may be available from other mines, or it may be achieved through selective mining and coal clean-up. Alternatively, 50−60% SO_2 reduction could be achieved through dry SO_2 control technologies (recognising the lack of water in the region).

Emissions at a glance:

- ESP upgrading is urgently needed, both to comply with 50 mg/Nm^3 (by 2025) and to improve ID fan performance.
- SO_3 plant needs an upgrade.
- The plant needs to lower NO_x emissions by 2025; low NO_x burners seem to be the preliminary option of choice.
- Lethabo needs to assess how it will comply with SO_2 control requirements (1 000 mg/Nm^3, which comes into effect in April 2025). Alternative options (lower sulphur coal and SO_2 control technologies) need to be evaluated.

5.11.3 Technical Measures to Improve the Plant Condition

Boiler: The root causes of frequent BTF at Lethabo are well known, high-risk areas have been identified, and the planned scope of work to be performed during the overhaul of the units has been prepared in detail. Since the main contributing factor to the increase in BTF is delayed overhauls and limited funding for maintenance, considerable time and resources will be required to restore the reliable operation of the boilers on Units 2 and 5. Other areas that need urgent maintenance attention are oil burners and boiler internal steam circuit replacements.

Machinery: Turbine maintenance needs to continue as per outage philosophy. Improved regular cleaning of the condensers is required, especially at the units 3.

Generator: Generator maintenance needs to continue as per outage philosophy and spare rotors need to be refurbished in time for next replacement. Spares need to be procured well in advance and to be available for maintenance of generators and generator auxiliaries (hydrogen, water cooling, excitation plant, protection devices).

5.11.4 Power Plant Management

Currently, 716 employees are working at the power plant. The management team is very capable and efficient, addressing the chronic issues facing the power plant. The plant manager focuses on people and results, but he needs more power to make decisions relating to efficiency. He should have the power to incentivise personnel without having to follow tedious motivational requests that get blocked by HR. To increase morale of employees, a self-funding bonus program should be initiated (achieving additional 1% EAF every month will release funding to incentivise station employees).

Timely release of adequate funding for outages, at least two years before schedule, accelerated lead times, and spare deliveries would enable the execution of the outages and planned scope of work so that plant reliability is ensured.

Lethabo has only 66% of the required senior staff to run the station, 134 people are needed but currently there are 42 vacancies. In addition, 32 senior operators are between 61 and 65 years old and due to retire at 65. Planning is currently underway to address this but it may be too late and could result in a loss of operational skills and knowledge. We recommended looking into whether it is possible to retain some of the critical skills and knowledge of the retiring staff by encouraging them to take on a mentorship role or sign short-term contracts.

Maintenance

The maintenance team is responsible for providing adequate resources to meet repair and servicing requirements on the issues reported by the operation team. The scoping is defined by the engineering department. The maintenance group takes care of spare parts and consumables inventory and planning, as well as for planed outage activities. The maintenance and stockroom systems are fully integrated in the SAP System.

Approximately 70% of the maintenance work is outsourced, but generally maintenance at Lethabo is carried out to good standards, although the targets are not always in line with the needs. The replacement of boiler tubes (already discussed) is a good example. Engineering staff at Lethabo report that OEM suppliers are struggling to provide the required spares on time and that they generally favour well-performing stations over others.

Operation

The operation team normally work five shifts (24/7 – 12 h per shift). 165 is the headcount target for operation. There are about 33 vacancies at present. Efforts are underway to fill the vacancies. To cope with the vacancies, Lethabo decided to move to four shifts from 1 May 2023. This effectively meant the training shift was omitted and replaced by taking persons from the duty shift to training. This cannot be sustained and is only a short-term solution that, in our opinion, also creates risks.

Improvements are also needed in reducing occupational hazards; particular attention should be paid to fire risk management and providing emergency response and medical services.

Outages

The planning of outages at Lethabo power station should be carried out in accordance with outage philosophy, and outages should not be delayed. The scope and frequency of the outages are based on a 10-years strategy (FY2020–2033) with ensuring statutory compliances. Table 60 provides the current five-year outage plan based on this strategy.

WEEK 20	
5 Year Outage Listing	
FromDate	2023/05/16
ToDate	2028/05/15
Export Date	2023/05/16 16:53

OutageID	Outage Code	Unit	Planned/Actual Start Time	Planned/Revised End Time	Outage Description	Status	Planned Duratio
24441	LT01UIR-13-03-2023	1	2023/03/13 09:45:00	2023/05/22 09:44:00	IR - HFT	EXREQEXT	70,00
17917	LT02UMG-12-01-2024	2	2024/01/12 00:00:00	2024/05/10 23:59:00	MGO ESP,C&I	ROLLSCHED	120,00
42180	LT02UST-10-11-2023	2	2023/11/10 00:00:00	2023/11/23 23:59:00	HP Piping Inspection	SCHED	14,00
24589	LT05UIR-27-05-2024	5	2024/05/27 00:00:00	2024/09/23 23:59:00	IR - ESP	SCHED	120,00
24446	LT03UIR-07-10-2024	3	2024/10/07 00:00:00	2025/02/03 23:59:00	IR - ESP,C&I	SCHED	120,00
17911	LT04UIR-17-02-2025	4	2025/02/17 00:00:00	2025/06/16 23:59:00	IR - Stator Rewind, C&I upgrade & ESP	SCHED	120,00
29808	LT01UGO-11-08-2025	1	2025/08/11 00:00:00	2025/12/08 23:59:00	GO4 ESP	SCHED	120,00
29810	LT02UGO-05-01-2026	2	2026/01/05 00:00:00	2026/05/04 23:59:00	IR Gen slot liner replacement & C&I Upgrade	SCHED	120,00
24591	LT05UIR-14-09-2026	5	2026/09/14 00:00:00	2026/12/02 23:59:00	IR HSSD	SCHED	80,00
24596	LT06UIR-14-09-2026	6	2026/09/14 00:00:00	2027/01/11 23:59:00	IR Gen slot liner replacement & C&I Upgrade	SCHED	120,00
29812	LT04UIR-14-09-2026	4	2026/09/14 00:00:00	2026/12/22 23:59:00	MGO-Slot Liner Replacement & HSSD	SCHED	100,00
24447	LT03UGO-01-02-2027	3	2027/02/01 00:00:00	2027/05/31 23:59:00	MGO-C&I Upgrade	SCHED	120,00
17878	LT01UIR-18-10-2027	1	2027/10/18 00:00:00	2028/02/14 23:59:00	IR C&I Upgrade	SCHED	120,00
36673	LT02UGO-07-03-2028	2	2028/03/07 00:00:00	2028/05/29 23:59:00	GO 04	SCHED	84,00

Table 60: Lethabo 5-year outage plan for all units
Source Eskom

The funding for planned maintenance should be secured at least two years before the outage is planned, to give enough time for procurement processes.

Investment Projects

Investment projects are generally not currently on hold, although Eskom have financial constraints. Projects are generally only funded after investment approval, but funded projects could be moved to the unfunded list due to prioritisation and proper motivation and vice versa. The C&I upgrade project have now been deferred several times and now needs to become a high priority refurbishment project.

Table 61 provides a list of funded projects that are already planned and have Eskom investment approval for FY2023 and FY2024. The fact that they are approved projects indicates that the projects are required and deemed necessary. Some of the projects are awaiting the release of project funding to enable implementation. If you look at the outage dates provided, some projects were deferred, which poses a risk to the reliability and good performance of the station.

SAP PS Project Code	SAP PS Project Name	Allocation FY2023	Allocation FY2024	YE Forecast	ERA status	Commercial process	Execution phase	Tender status	Outage related?	Outage date	Actual YTD	Commitments
C.GLE0035	Sewage Maturation Pond Lining Replacement	7 550 000	24 310 000	7 550 000	Approved	Contract awarded	Not started	Issued once	No	N/A	0	24 913 143
C.GLE0113	Re-tubing of BFPT Condenser Tubes	4 230 000	30 000 000	4 230 000	Approved	Out on tender	Not Started	Issued once	Yes	2022/07/22, 2022/10/22	0	0
C.GLE0271	Primary Air Heaters Short Bank Retubing	32 819 934	34 926 095	61 535 521	Approved	Contract awarded	In progress No risk	Issued once	Yes	2022/03/26, 2022/07/22	11 885 292	49 482 095
C.GLE0282	Replacement of all battery chargers	9 495 025	11 797 874	9 495 025	Approved	Out on tender	Not Started	Issued twice	Yes	2022/07/22, 2022/10/22	0	48 484 506
C.GLE0337	Upgrade of turbine hall cranes	0	4 000 000	400 000	Approved	Contract awarded	In progress Risk of delays	Issued once	No	N/A	0	0
C.GLE0352	Demin Plant Refurbishment	0	9 000 000	0	Approved	Contract negotiation	Not Started	Issued twice	No	N/A	0	0
C.GLE0429	Fire Detection System Replacement	23 290 000	46 430 000	23 290 000	Approved needs revision	Contract negotiation	Not started	Issued once	Yes	2022/08/08, 2022/10/29, 2022/12/05, 2023/01/05, 2023/08/04, 2023/12/04	0	0
C.GLE0486	Upgrade of Bently Prot and Cond monitoring system	5 000 000	15 000 000	5 000 000	Approved	Out on tender	Not Started	Issued once	Yes	2023/08/04, 2023/12/04	0	0
C.GLE0501	Smoke stack lifts	3 126 000	0	3 126 000	Approved	Contract awarded	Completion phase	Issued twice	No	N/A	0	0
C.GLE0502	Lethabo Mill Trunnion Scroll Liner Replacement	10 570 000	5 050 000	10 570 000	Approved	Not started	Not started	Sole source	Yes	2022/12/05, 2023/01/05, 2023/08/04, 2023/12/04	0	0
C.GLE0571	Main Generator transformer Cooler supply	3 000 000	0	3 000 000	Approved	Contract negotiation	Not Started	Not Issued	Yes	2022/10/22, 2023/01/14	0	0
C.GLE0578	Siemens Sicomp M70 Replacement	1 100 000	3 189 181	980 000	Approved	Contract awarded	Awaiting Outage No risk	Issued once	Yes	2022/04/08	0	6 172 886
C.GLE0579	MCC Panel Relocation	2 178 975	2 073 970	2 178 975	Approved	Contract awarded	Awaiting Outage No risk	Issued twice	Yes	2022/04/08, 2023/01/05	0	1 790 376
SAP PS Project Code	**SAP PS Project Name**	**Allocation FY2023**	**Allocation FY2024**	**YE Forecast**	**ERA status**	**Commercial process**	**Execution phase**	**Tender status**	**Outage related?**	**Outage date**	**Actual YTD**	**Commitments**
C.GLE0584	Main Turbine and Boiler Feed Pump Turbine (BFPT) Oil Purifier Replacement	3 271 732	10 625 000	3 271 732	Approved	Out on tender	Not Started	Issued twice	Yes	2022-10-22	0	0
C.GLE0609	Conveyor Protection Replacement Project	0	6 360 000	0	Approved	Not Started	Not Started	Not Issued	No	N/A	0	0
C.GLE0618	Lethabo pH and Dissolved Oxygen (DO) Online Analysers	2 410 000	0	2 410 000	Approved	Not started	Not started	Not Issued	Yes	2022/08/08, 2022/10/29, 2022/12/05, 2023/01/05	0	0
C.GLE0619	Supply and Installation of Surveillance Equipment on Ash belts and Submersible Scraper Conveyors (SSC's).	2 250 000	0	2 250 000	Approved	Not started	Not started	Not Issued	No	N/A	0	0
C.GLE0644	Auxiliary Bay Suspended Ceiling (28m level) Replacement Project	3 470 000	5 970 000	3 470 000	Approved	Not Started	Not Started	Not Issued	No	N/A	0	0
	Sub Total	**113 761 666**	**208 732 120**	**142 757 253**							**11 885 292**	**130 843 007**

Table 61: Lethabo list of funded projects
Source: Eskom

Table 62 provides a list of the unfunded projects. Nine (9) of the projects were already on the FY2022 project list and twelve (12) form part of the FY2023 project list or are roll-over projects from FY2022. From the information provided in Table 61 and Table 62, it is evident that Eskom is not currently investing enough capital to ensure the reliability, performance and good health of the station.

Allocation	IRM Risk Score	Project Code	SAP Project Code	Project Title	Sum of LOPP TOTAL	Sum of Total 2022-31	Sum of Total PR2022-26	Sum of MYPD5 Total PR2023-27	Sum of PR2022	Sum of PR2023	Sum of PR2024	Sum of PR2025	Sum of PR2026	Sum of PR2027
Must Do	8	P1699279	C.GLE0600	AIR HEATER PACK REPLACEMENTS U1 -6 (Cycle 3)	199	199	99	166			33	33	33	66
Must Do	16	P1538056	C.GLE0463	Sec.A/Htr Pack Replacement Units 1,2,5,6 (Cycle 2)	40	40	40	31	9	31				
In Target	8	P1825237	C.GLE0615	Primary Air Heater Long Bank Re-tubing U1-6	463	463	131	154					131	23
In Target	16	P99910	C.GLE0271	Primary Air Heaters Short Bank Retubing	176	176	176	141	35	60	46		35	
In Target	20	P99733	C.GLE0078	Economiser elements bank replacement	1 324	1 324	1 324	1 324		441	441	221	221	
In Target	15	P2057815	C.GLE	Hot Reheat Piping System Replacement	1 985	1 985	1 654	1 655	330	563	430		331	331
In Target	16	DP417912	C.GLE0478	Main Steam Piping Replacement	1 655	1 655	1 324	1 655			430	563	331	331
In Target	16	P1635	C.GLE0075	Generator Rotor Upgrade and H2 cooler replacements	526	526	526	244	282	188	56			
In Target	16	P210871	C.GLE0070	Upgrade of Generator Auxilliary Systems	217	217	145	181		36	72		36	36
In Target	20	P1658263	C.GLE0486	Upgrade of Bently Prot and Cond monitoring system	46	46	46	24	22	13	12			
In Target	25	P1602	C.GLE0032	C&I upgrade	1 258	1 258	629	943				314	314	314
In Target	12	P962	C.GLE0091	Service transformer replacement	146	146	146	121	24	49	49	24		
Must Do	12	P1074604	C.GLE0282	Replacement of all battery chargers	80	80	80	68	12	26	28	14		
In Target	10	P1034325	C.GLE0182	East CW Ducts - Corrosion repairs	190	190	190	190			190			
In Target	16	P1437702	C.GLE0429	Fire Detection System replacement	63	63	63	41	22	41	0			
In Target	10	P282278	C.GLE0216	Extend WA16 & WA26	85	85	85	61	24	61				

Table 62: Lethabo unfunded projects list
Source Eskom

5.11.5 Technical Profile of Main Plant Areas

All six units at Lethabo power station are currently in operation. The boiler design of all units are Babcock and Wilcox type. Coal supply to the plant is 100% via conveyor from the next door Seriti mine, whilst raw water supply is from the Vaal River running past the station. Coal is delivered by a duplicate overland conveyor system to coal bunkers in the station. The following table provides the key design data, types of key equipment and suppliers.

Manufacturer	Babcock Engineering Contractors (Pty) Ltd
Type	Natural circulation
Coal mass flow [t/h]	2 100 – 2 400
Pressure [MPa, absolute]	17.32
Temperature [°C]	540
Firing system	
Number of burners	36 per boiler
Type of mills	Horizontal tube mills
Mill capacity [t/h] – per mill	80
Reheat system	
Pressure [bar, absolute]	3.98
Temperature [°C]	540

Coal supply	
Coal supply (truck, mine)	Mine
Coal storage capacity on-site (t)	Coal silo (5 off) 27750, coal stockyard 3 820 000.
Boiler bunker capacity (t)	28 800
Precipitators	
Manufacturer	Brandt Engineering, now Babcock
Type	Electrostatic high frequency
Ash handling	Conveyer system with stackers

Machinery and Electrical

Turbine	
Manufacturer	MAN AG (618 MW)
Type	Multi-cylinder impulse-reaction
Casings (HP-IP-LP, double/single flow)	Double flow
Steam volume (kgs)	492
Main steam pressure [MPa, absolute]	16.1
Main steam temperature [°C]	535
Reheat steam pressure [MPa, absolute]	3.674
Reheat steam temperature [°C]	535
Cold end	
Condenser pressure	6.51kPa/4/45kPa (abs)
Cooling tower	Hyperbolic natural draught
Generator	
Manufacturer	Alstom
Terminal voltage	20 kV
Rating	618 MW nominal, 697MW Max
Cooling system	Hydrogen 400kPa
Transformer	
Manufacturer	Asea (700MVA)
Terminal voltage primary/ secondary	20/300Kv
Placement	In between turbine hall and HV yard

5.12 Majuba Power Plant

The age of Majuba power plant is in the range of 22 to 27 years, but due to insufficient maintenance the plant already suffers from a high amount of power losses. In April 2023 almost 40% (1 506 MW_e) of the installed net capacity of 3 807 MW_e was not available due to PLL.

One of the main PLL contributors are the fabric filters used to extract ash from the flue gas. Due to signs of wear and tear, the filters cause a significant pressure loss limiting the flue gas flow. It is necessary to replace and upgrade the existing fabric filters in all units to avoid gas volume flow reductions and, thus, a decrease in power output. Our clear recommendation is to refurbish the filters immediately and identify further PLL causes afterwards.

The draught fans of Unit 5 were identified as a major contributor to high PLL, due to problems with stall and limitations of the ID fans. As a result, it is recommended to replace the components and investigate further damage of the existing vents.

Due to poor coal quality, rocks in the coal and a missing on-line measurement a rapid degradation of coal mills are given. To avoid this a rock separation system and/or incoming coal quality improvement needs to be implemented. The online coal analysis system needs to be renewed in order to determine the coal quality before entering the combustion.

In order to increase power plant output maintenance needs to be executed to the full extent and duration of outages should be optimised. This requires an according investment into necessary spare parts (e.g. filters, mills, ID fans). Some of the repairs and improvements can be done also during short stops.

Generally, the atmosphere among employees at the plant is harmonious. Staff are knowledgeable and experienced and there is a comprehensive understanding of plant issues.

5.12.1 EAF and PLL

The Majuba power plant consists of 6 coal fired boilers, which each feed their own turbine. The entire power plant has a total nominal net capacity of 3 843 MW_e and the installed gross capacity of the power plant is as per design 4 108 MW_e. Units 1 to 3 are cooled via air cooled condensers (ACCs) and are, in theory, able to produce 657 MW_e . Units 4 to 6 are cooled by cooling towers and produce up to 713 MW_e each. The station with its the first unit was commissioned in 1996. The latest unit commissioning occurred in 2001 (see Table 63).

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Commissioning date	1996	1997	1998	1999	2000	2001
Planned decom-missioning	2046	2047	2048	2049	2050	2051
Gross installed ca-pacity [MW_e]	657	657	657	713	713	713
Net power [MW_e]	612	612	612	669	669	669

Table 63: Key figures for Majuba power plant

In the years 2017 to 2021, the EAF of the total power plant was between 88.45% (2017) and 62.55% (2021). During this period, fluctuations in EAF increased (see Figure 140) and there was an almost steady decrease in total EAF through to 2022, when EAF for the plant as a whole fell to 47.95% (see Table 64). Recent steps, undertaken to improve the plant's EAF again, lead it to rise to 63.03% in FY2023.

FY	Plant	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
2017	88.45	82.40	91.21	93.81	90.08	84.25	91.73
2018	83.51	84.56	78.41	84.93	81.16	82.50	84.41
2019	72.74	81.62	79.19	54.22	67.51	77.25	83.09
2020	73.52	67.26	59.60	88.31	62.57	75.90	73.57
2021	62.55	73.45	66.55	66.19	33.83	71.21	68.09
2022	47.95	53.39	57.39	31.26	60.04	29.82	55.65
2023	63.03	61.27	64.80	56.87	65.82	72.55	56.88

Table 64: EAF of Majuba power plant (FY2016/2017–YTD)
Source: Eskom[37]

The EAF of the units were taken from the vgbe KISSY database. The data for this is supplied by Eskom on a yearly basis. The data for 2022 has not been transferred as of April 2023. The EAF values for FY2022 and FY2023 were provided by Eskom during the site visit.

[37] Majuba GM presentation, pages 11 and 26, dated: 24 April 2023 and Eskom head-office documents

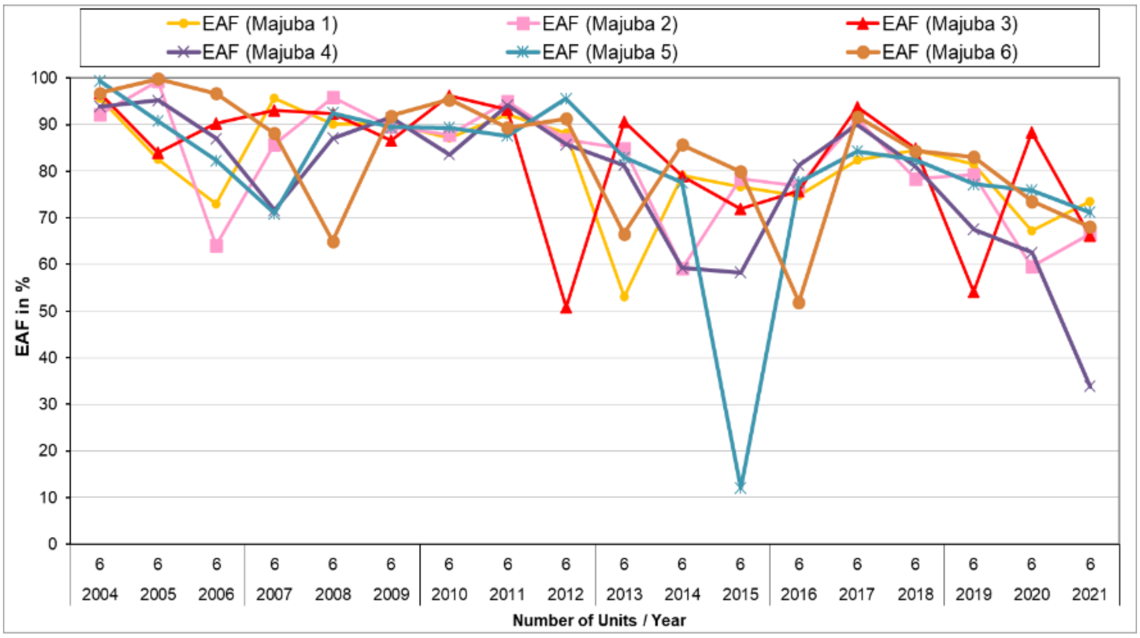


Figure 140: EAF of Majuba power plant (FY2003/2004–FY2020/2021)
Source: KISSY database, vgbe

The main reason for the low EAF has been the significant PLL, accounting for approximately 61% of the total unplanned capacity loss factor (UCLF). The main sources of PLL are depicted in Figure 141. As can be seen, an array of components influences PLL – the main components are the mills (54%), the gas cleaning (20%), the draught plant (11%), the turbine (8%) and the boiler (3%). The PLL for the individual components has fluctuated over the years but increased steadily in the period FY2018-2020, with a slight improvement in FY2021. In FY2022, there was a sharp increase of approximately 47%. At the beginning of FY2023, there was a significant increase in PLL, to 78% of total load losses, caused by a dramatic increase in losses at the milling plant, which had had almost no negative impact on the system up until FY2021.

The PLL values given by Eskom, together with the figures provided for the contributing factors, are in stark contrast to those given by the power plant general manager on 20 April 2023. This deviation between the data given by Eskom (see Figure 141 and Table 65) and the numbers provided during the site visit can partially be explained by mill repairs carried out over the last few months and by increasing wear and tear on the filter bags. But, overall, many factors have played a part and, for the time being, cannot be clearly identified.

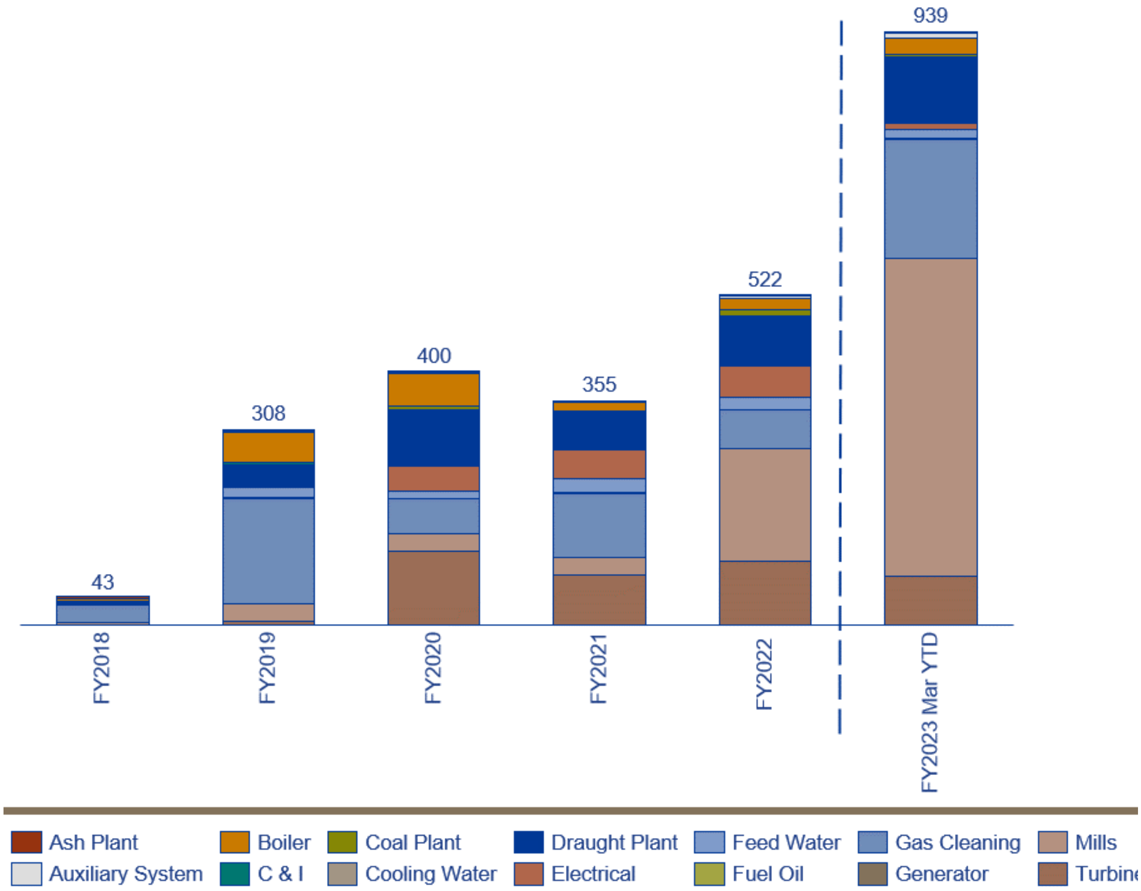


Figure 141: PLL contributors at Majuba power plant (FY2017/2018 to 3/2023)
Source: Eskom

MW_e Loss	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023 March
Ash Plant	0.38	1.92	0.19	2.26	1.36	2.96
Auxiliary System	1.34	1.93	1.53	0.58	4.37	7.46
Boiler	4.37	47.38	51.42	13.82	16.88	26.08
C&I	0.41	2.99	0.67	0.36	0.81	0.69
Coal Plant	0.19	0.76	5.37	0.52	9.55	2.42
Cooling Water	0.00	0.81	0.87	0.01	0.00	0.26
Draught Plant	2.73	33.64	88.44	59.34	78.75	105.52
Electrical	0.62	1.04	40.56	46.41	50.18	10.68
Feed Water	1.11	16.20	10.36	22.37	18.67	12.67
Fuel Oil	0.18	0.88	0.64	0.15	0.89	2.55
Gas Cleaning	26.80	167.70	55.55	102.63	60.71	187.12
Generator	0.10	0.17	0.33	0.12	0.30	0.16
Mills	3.66	27.42	27.11	26.43	177.41	503.76
Turbine	1.17	5.64	117.40	79.76	102.09	76.99
Waterways	0.00	0.00	0.00	0.00	0.00	0.00
Total	**43**	**308**	**400**	**355**	**522**	**939**

Table 65: PLL contributors at Majuba power plant (FY2018–3/2023)
Source: Eskom

5.12.2 Technical Status

5.12.2.1 Technical Status of the Boiler

Housekeeping: During the visit, the team walked through the boiler house. The housekeeping was not in order. High amounts of dust, ash and coal were present (Figure 142). Safety-related issues could occur due to bad housekeeping.

Steam leakages: No major steam leakages could be established within the boiler house. However, Eskom has recorded total power losses of 38 MW_e relating to auxiliary steam valves passing.

Figure 142: Majuba boilers with a lot of dust due to bad housekeeping

Steam temperatures: The steam temperatures at the boiler outlet are in line with the design, as a result around, 535°C (see Figure 143). No significant temperature differential between the different sides of the boiler could be observed.

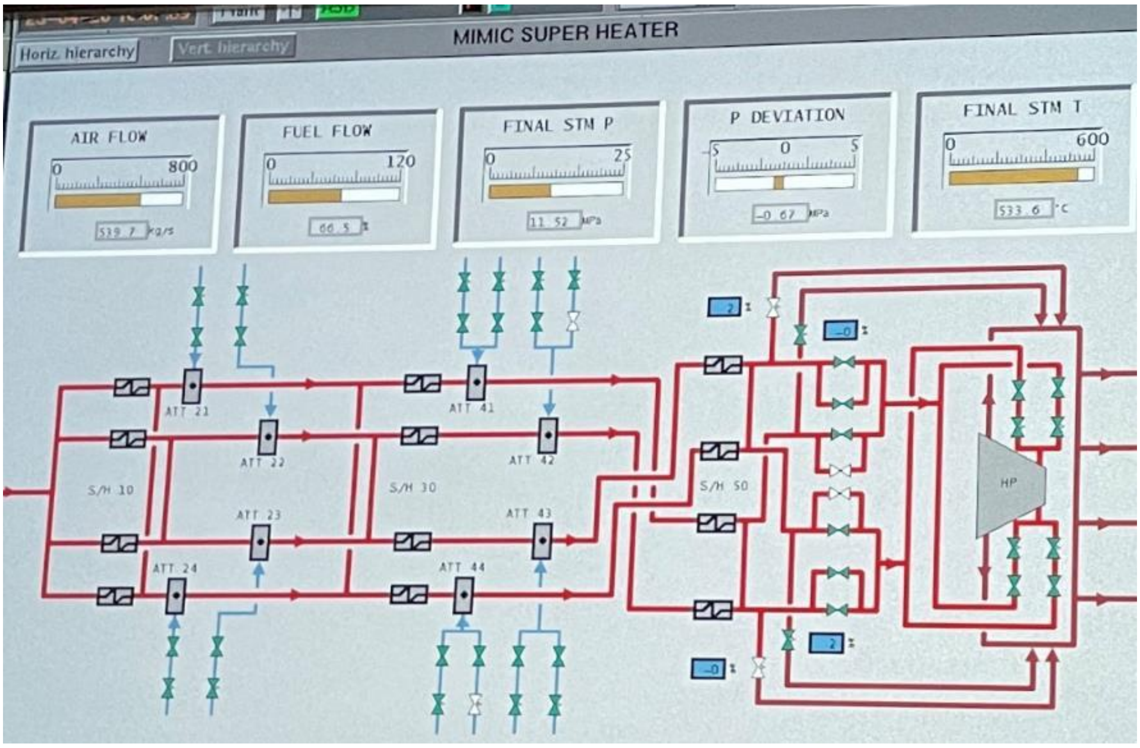


Figure 143: Steam conditions – air flow and fuel flow at Majuba power plant

Boiler tubes: There has been only minor boiler tube failures in the past. This failure was recorded and used as a lesson learned. One exception are the evaporators, which need to be replaced in every unit in the next MO, due to fatigue.

Draught plant: Two induced-draught (ID) fans per boiler draw the flue gas out of the boiler to the chimney and are only causing minor problems. An exception here are the ID fans of Unit 5, which account for approximately 101 MW_e or 11% of the total PLL due to fan stall and limitations. The two force-draught (FD) fans per boiler are currently running without major issues most of the time. Major limitations are currently caused by the fabric filters. In the case of solving the fabric filter issues (see below) it could be possible that restrictions by ID and FD fans could be solved as well.

Air leakages: The fans in the draught group that are running well are currently compensating the air leakages within the system - mainly located within the air preheater and the air ducts. The leakages lead to an increase in required air volume, which results in an increase in consumed electricity by the fans, as well as higher wear and tear on the machines.

Fabric filters: Besides the fan and air leakage issues, there are major problems with the installed fabric filters, which are used to clean the flue gas and, as such, play a key role in achieving the local emission limits. The condition of the fabric filters is monitored by measuring differences in pressure over the filter (delta p). Delta p is influenced by the amount of ash contained within the filter, as well as by the flue gas volume and the filter condition. The maximum pressure difference is defined by the manufacturer and cannot be changed without exchanging the parts. An increase in ash in the flue gas, which is caused by poor coal quality, as well as an extension of maintenance intervals, leads to an increase in pressure loss and overflow of the ash extractors (see Figure 144). Another reason for the high delta p, which is affecting Unit 1 and Unit 2, is the filter bags blinded by fuel oil carry-over. Most of the FFP filter bags at units 3 to 6 have reached end of life and need to be replaced. The total amount of flue gas has been reduced to keep delta p below the limit. This is done by decreasing the fuel and primary air, which leads to a drop in total power output. The decrease in power output is estimated to be between 970 MW_e and 1 122 MW_e in total, varying from 93 MW_e to 312 MW_e per boiler (04/2023).

Figure 144: Majuba’s ash extraction, emergency disposal – poor housekeeping

Mills: The mills were reported as the biggest issue. The coal is trucked-in or delivered by train from 14 different mines. As a result, the coal shows quite inhomogeneous characteristics. However, the coal energy density is within the design range. Problems at the gearboxes of the mills is caused by high rock content, which leads to higher wear, abrasion and damage. In FY2023, the average power loss caused by this was about 504 MW_e (see Figure 145).

Due to the amount of time needed to analyse the incoming coal – about 24 hours – the results are usually not available until after the coal has been burned. As a result, it is currently not possible to avoid problematic coal segments or blend them properly to reduce the negative impact, even though the coal stockpile is well managed and in order (see Figure 154).

Figure 145: Coal mill at Majuba Unit 1 with patchy canals and overall bad condition

Thermal Index (TI): Eskom uses a TI to track the thermal excursions on boiler outlet headers, main steam pipework and hot reheat pipework. The TI is a long-term plant health indicator for the high temperature/high pressure components. The data for the TI may also be used as a check on the operational stability of the boiler, as the thermocouples indicate time spent above normal operating conditions (see Table 66).

Majuba's TI report for FY2023 shows that the header, as well as the main steam and the hot reheat temperatures, are far above limits and unacceptable. This is the result of constant over-firing in order to counteract the flue gas filtration problems and increase the power output. It has significant long-term implications for the creep life of the entire boiler and piping system and should be resolved.

Tolerance Limits for Thermal Index:	
< 35	Favourable
36- 73	Acceptable
> 73	Unacceptable

SYSTEM	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23
Header TI	495	794	277	1214	1708	5252	206	24		94	717	3083	1277
Main Steam TI	195	479	283	658	1013	852	1890	446		789	1287	551	551
Hot Reheat TI	93	691	111	189	392	212	3391	2467		535	158	60	175

Table 66: Extract from Majuba's TI report FY2023

Boiler at a glance:

- The Majuba boilers themselves are fit for operation.
- The ID fan at Unit 5 is causing problems and should be renewed but apart from that the fans are working fine.
- The air ducts and air preheaters are not fully tight and need to be sealed.
- The flue gas fabric filters are the main reason for part load operation and should be replaced as soon as possible.
- There are few-to-no steam leakages in the boiler house.
- Coal sites are well managed, ash handling is poor.
- Coal analyses are not available in time for the unit operator to make appropriate composition changes to the coal quality change before it is burned.
- Coal mills are degrading rapidly and should be overhauled.

5.12.2.2 Technical Status of the Machinery

Cold end: With respect to the cold end, no problems with the condenser or its auxiliary systems were apparent and investigable during the visit. However, it should be noted that any partial power losses at the condenser was overlapped by the reduced performance of the fabric filters in the flue gas cleaning system.

Eskom itself reported condenser issues at Unit 5 caused by blocked tubes, resulting in a PLL of 65 MW_e. This problem was recently fixed.

Cooling water: The cooling water used for cooling units 4 to 6 was optically in good condition. According to Eskom employees, it contains no suspended particles or foreign objects. A reason for the good quality of the cooling water is the pre-treatment process of the untreated water, which includes clarifying of the sludge content. The cooling water is also injected with acid and limestone, to adjust its properties accordingly. A cooling water analysis is carried out on a daily basis, which ensures the quality.

Cooling towers: The cooling towers of units 4 to 6 are in good condition, not showing signs of biofouling or missing or damaged end caps as far as visible. The spray pattern was as expected (see Figure 146). Based on our assessment, the cooling towers are not expected to negatively impact power plant operations or lead to reduced power output. However, it should be noted that the plant was running at partial load at the time of our visit.

Figure 146: Majuba cooling towers without biofouling and with a proper spray pattern

Air cooled condensers (ACC): The ACCs at units 1 to 3 were in good general condition, with most of them working during the visit (Figure 147). The ACCs have problems with reaching their design efficiencies in certain unfavourable wind conditions. These wind conditions can cause some of the condenser units to suck back in already heated up exhaust air of nearby cooling units or inhibits sufficient suction of fresh cooling air. The consequence of these incidents can be cooling power losses and, as a result, efficiency losses. Furthermore, the ACC fans are arranged in a concrete construction several meters above the ground and are losing grease and oil, possibly due to the rotation of the fans. This has led to the soiling and complete wetting of the underlying structures and electrical equipment, such as the transformers (Figure 148).

The steel structures need to be repainted, and the concrete and metal structures need to be cleaned of grease and oil.

Figure 147: ACC units at Majuba power plant with visible oil residue

Figure 148: Soiled transformer at Majuba power plant
Covered in grease and oil from the ACC fans

Cooling water pump: The cooling water pump house was generally in good condition. Out of the six installed pumps, five were used for the operation of units 4 to 6, thus leaving one pump as a redundancy backup. Furthermore, two spare pumps and two spare motors were stored on side, for a further exchange, which ensures that plant operation and power output will not be limited by insufficient cooling water supply. The condition of the cooling water piping looked good, with three out of four discharge lines running during operation and one as a redundancy. The valves were in good condition. No blocking bolts were placed at shutoff valves for maintenance purposes because of the aforementioned availability of spares.

Turbine: First of all, the turbine hall was reasonably clean, as the housekeeping was conducted well (see Figure 149). The overall condition of the turbines was good, with only a few negative occurrences limiting the power production in the past. According to Eskom staff, the only notable influence was given by the turbine drive train of Unit 6, which caused a power loss of 17 $MW_{e,}$ and sound problems at Unit 4, which caused a power loss of 78 MW_e. The power losses on Unit 6 are mainly driven by an inefficient steam flow through the HP turbine, due to deposits on the turbine blading. The reason for the deposits couldn't be investigated during engine operation. Water quality does not seem to be the source of the problem because no other engines and parts are affected. On some units, slight traces of coked oil were noted on the bearing pedestals and on the lower turbine casings. This was probably caused by small oil leakages or oil dust, which can be largely considered as normal, given the age of the plant. The turbines were operating within the norm. Online vibration monitoring, bearing temperatures and steam parameters were within design range. No obvious leakages could be identified at the on-site inspection.

However, the spare-part handling for an upcoming turbine overhaul was sloppy. Stop and control valves that had already been refurbished and were awaiting use in the overhaul were lying unprotected in the turbine hall, exposed to dirt, dust and foreign particles, which were also found in the replacement valves.

HP, IP and LP heaters: The general condition of the HP, IP and LP heaters was good. An exception, here, were the Unit 6 heaters, which showed minor leakages that need to be fixed. There were no obvious failures during the site visit and a noticeable operating behaviour could not be observed in the control room.

Figure 149: Reasonably clean turbine hall at Majuba power plant

HP piping: The HP piping itself was in a visual ordinary condition when we visited the site. However, some of the spring hangers were in a blocked position which can lead to tensions in the piping when the affected unit is ramping up and down. The direction of the thermal expansion was not obvious. In the worst case, the stress limits will be exceeded. Furthermore, the positioning of the spring hangers and the way they are mounted isn't optimal and, as a result, the indication scale is not visible on some of them. One explanation given for this was that poorly conducted maintenance had been carried out by a third party.

Machinery at a glance:

- There are no condenser problems.
- There are no cooling tower or ACC issues.
- Cooling water and cooling water pumps are in a good condition.
- No steam leakages can be found in the turbine hall.
- The turbines seem, generally, to operate properly.
- Poor care of spare parts for major turbine components could be observed.

5.12.2.3 Technical Status of Electrical and C&I

Generators: In the past, operation of the generators has been unproblematic and as a result, play almost no role in outages or PLL.

C&I system: The C&I system at all units and the outside plant are outdated and thus require refurbishment. The HMI mosaic panel is not up to date, either, and needs to be upgraded (see Figure 150).

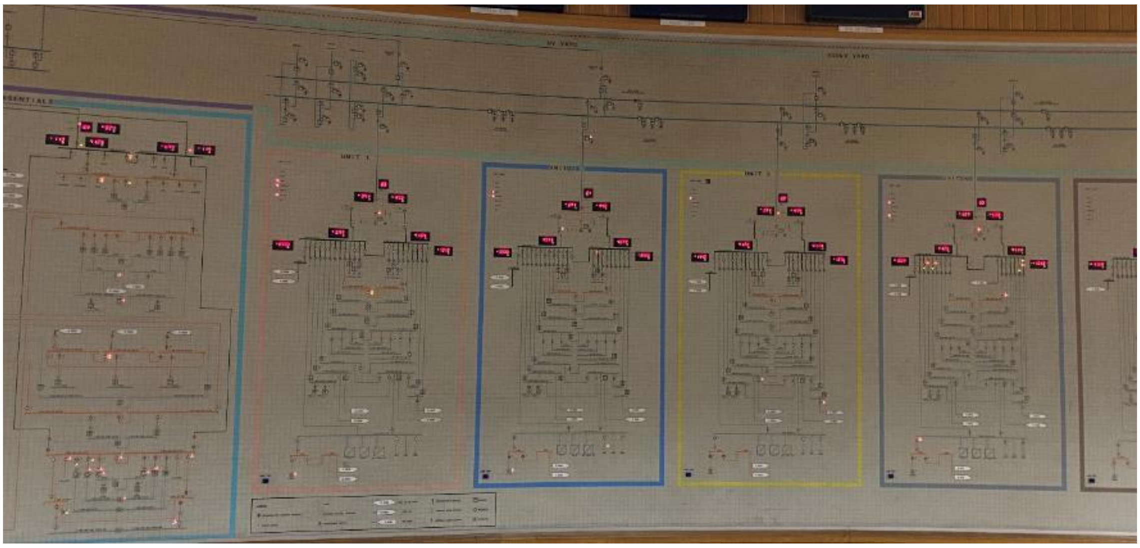


Figure 150: Obsolete HMI mosaic panels at Majuba power plant

MV & LV Switchgear: Poor housekeeping and environmental conditions within the board rooms were visible in the switchgear building (see Figure 151).

Figure 151: Poor housekeeping within the switchgear building at Majuba power plant

HV transformer: The HV transformers at units 1-3 suffer from contamination by oil and dust (see Figure 148). A contaminated transformer can potentially pose an increased fire safety risk, due to impediment of heat dissipation, insulation problems, oil contaminations and arc-ing.

Electrical and C&I at a glance:

- Generators are in a good condition.
- The C&I system is outdated and requires refurbishment.
- The switchgear rooms require better housekeeping.
- HV transformers at units 1 to 3 suffer from contamination.

5.12.2.4 Technical Status of the Water Treatment Plant

Make-up water plant: The central make-up water plant was visited during the site walk. The building of the water treatment plant was clean and, all in all, in order (see Figure 152). The capacity of the make-up water plant is sufficient to cover the the site’s needs with water of sufficient quality.

Figure 152: Water treatment plant at Majuba power plant

According to the power plant staff, the water make-up plants are generally in good condition. All of the water measurements are running properly, and in all parts of the power plant the measurements are online (see Table 67). For this reason, it is possible to operate the water treatment in a safe and automated manner.

The raw water source is surface water coming from the Zaaihoek dam.

Location	pH	Spec. Cond.	Acid Cond.	Deg. Cond.	O_2	Fe	Si	Na	Cu	Org.
Makeup water	Both	On.	On.	---	On.	Off.	On.	Both	Off.	Off.
Conden-sate	Both	On.	On.	---	On.	Off.	On.	Both	Off.	Off.
Feed water	Both	On.	On.	---	On.	Off.	On.	Both	Off.	Off.
Boiler water	---	On.	On.	---	On.	Off.	On.	Both	Off.	Off.
(HP) live steam	Off.	Off.	Off.	---	Off.	---	Off.	Off.	---	---

Table 67: Types of water measurements at Majuba power plant

Filters: The water filters are in good condition as well, not showing major signs of aging and working as intended.

Figure 153: Sand filters at the water treatment plant at Majuba power plant

Water treatment at a glance:

- Capacity of the make-up water plant is sufficient.
- The plant is capable of producing water of sufficient quality.
- Water treatment plant is in a good condition.
- Online measurements are working resulting properly.

5.12.2.5 Technical Status of the Auxiliaries and other Systems

Coal and Ash: The coal is trucked-in or delivered by train from 14 different mines. As a result, the coal shows quite inhomogeneous characteristics. The quality of the air-dried coal is mostly within the low heating value (LHV) design range. The ash content according to the plant analysis from January 2023 to April YTD was within the design specification. The coal that is supplied has high stone/rock content, which causes increased wear and abrasion on the mills. This leads to the aforementioned problems (chapter 5.5.2.1). The content of volatiles and sulphur within the coal is moderate and within the range of specifications.
Pre-specification is carried out by the mines themselves and Eskom's PDE department verifies it on-site. The installed online analyser for LHV, moisture, ash and sulphur is out of service. The only way of analysing coal is with a coal analysis report, which takes about 24 hours to arrive, which means that a timely reaction to the coal quality is not possible. Table 68 shows the design range of the coal of Majuba plant (source: Eskom, "240 Coal Spec").

Fixed carbon %	n/a
Volatile matter %	21.98 (moisture free)
Total moisture %	10.10 (as received)
Ash %	~33
Gross calorific value MJ/kg	21 (moisture free)

Table 68: Major design coal composition at Majuba power plant
Source: Majuba power plant

Coal handling site: The coal handling site is generally well managed but too small to stockpile enough coal to enable it to postpone using the coal until it has been analysed (see Figure 154).

Ash handling area: The ash handling area has poor housekeeping, due to an extraction overload resulting from increased ash content in the coal (see Figure 144).

Figure 154: Stockpile at Majuba power plant

OEM parts: The spare parts warehouse was also visited. Spare parts that had already been refurbished were not covered and protected against dust, but the warehouse was otherwise in reasonable order. Of the 28 most important spare parts, 14 were currently not available.

Workshop: The equipment in the maintenance workshop was in order. The housekeeping and the cleaning of the machines was neglected. Due to maintenance work at the spare parts warehouse, some spares were stored at the mechanical workshop.

Auxiliaries at a glance:

- The coal quality is inhomogeneous and has high ash content-
- The coal handling site is small but well managed-
- The ash handling site is overflowing-
- The availability of spare parts depends heavily on the type of plant parts-
- The maintenance workshop is equipped properly but poorly maintained-

5.12.3 Technical Measures to Improve the Plant Condition

Filters: The potential MW gain of the following measures is up to approximately 1 050 MW_e.

The fabric filters used to extract ash from the flue gas are a major cause of PLL at Majuba power plant. The status of the fabric filters is monitored with pressure difference measurement (delta p) over the filter. Delta p is affected by the amount of ash contained within the filter, as well as the filter condition and flue gas volume. Due to ingress of oil into the filters during starts, as well as normal signs of wear and tear, a sharp increase of delta p was observed. In order to counteract this increase in pressure loss, the gas volume needs to be reduced, to stay within the operating range of the filters.

It is necessary to replace and upgrade the existing fabric filters in all units to avoid gas volume flow reductions and, thus, a decrease in power output. This should be a priority, given that it is relatively easy to do and can, potentially, significantly boost power output.

Boiler and draught group: The potential MW gain of the following measures is up to 140 MW_e.

There are several areas within the boiler where repair work would lead to immediate improvements in PLL. As discussed in the previous chapters, the draught fans of Unit 5 were identified as a major contributor to high PLL. Due to problems with stall and limitations of the ID fans, a power loss of up to 100 MW_e was observed. As a result, it is recommended to replace the components and investigate further damage of the existing vents.

Another cause of PLL is steam loss within the boiler system. Similar loss has been identified on a smaller scale in the Unit 1 boiler and in the HP bypass of Unit 2. The power losses account for approximately 38 MW_e in total and can be fixed by replacing leaking valves, pipes and gaskets.

Machinery: The potential MW gain of the following measures is up to approx. 110 MW_e.

The turbine and machinery parts generally only caused minor problems and, as a result, are not the main cause of PLL and outages. One of the minor problems is ACC inefficiency in certain unfavourable wind conditions, which prevents the plant from running at full load due to a lack of cooling capabilities in Units 4 to 6. Due to the high effort which is required to adapt the ACC's and due to the minor impact, on improving power output, we do not recommend any measures. The leakages of grease and oil from the ACCs gearboxes should be checked to protect the machinery underneath.

A few minor leaks within the condensate tank and the condenser tubes were identified and should be sealed step by step during future outages, to prevent further problems. The HP heaters were generally in good order. An exception, here, were the Unit 6 heaters, which showed minor leakages and need to be fixed.

The lack of condenser vacuum has been a regular problem in the past but has already been fixed by cleaning the condenser tubes. The condensers should be further investigated, to identify further blockages or leaks.

Mills: The potential MW loss prevention of the following measures is up to 340 MW_e.

The mills were another major cause of outages, affecting full load loss (FLL) and PLL alike, with a share of more than 54% of the total PLL in FY2023, according to Eskom. The high impact on PLL was caused by a lack of mills available for redundancy in combination with an abrasive coal. The lack of redundancy lead to a power loss of approximately 150 MW_e per mill out of order. It is necessary to return all five mills per boiler to operation, in order to achieve the design redundancy of the plant and to prevent further PLL and FLL by mill outages. On top of that, the storage of additional spares is recommended.

Coal handling: The abrasive coal with its high stone and ash content, is one of the main causes of the aforementioned rapid wear and tear of the coal mills. This problem needs to be addressed, which means that the online coal analysis system needs to be renewed. Alternatively, stockpiling the coal for at least 24 hours (until the coal analysis is available) would also solve the problem.

5.12.4 Power Plant Management

Currently 636 employees are working at the power plant. There are over 100 vacancies, but the number of employees is expected to rise to 680 by the end of the year. Staff turnover has increased within the last year, up to 9.1%.

Generally, the atmosphere among employees at the plant is harmonious and as one would expect. However, staff in some areas showed signs of solo mentality. Staff working in the functional areas upon which this assessment focused are knowledgeable and experienced and there is a comprehensive understanding of plant issues. Key performance data (e.g. PLL) is available, ensuring transparency with regards to the condition of the plant. There is an extensive reward and incentive scheme in place, based on yearly and monthly performance.

Employee training is regular and organised centrally by the training department, based on various departmental needs. In total, there are approximately 700 employee training sessions per year.

Maintenance: The maintenance team is responsible for fixing issues reported by the operations team. The scope is defined by the engineering department. Moreover, the maintenance group takes care of spare part planning.

Currently, the maintenance department has a staff of 171, as well as approximately 680 further contracted staff working on-site. According to the operational plan for FY2023, the target for own maintenance staff is significantly higher, with 67 unfilled vacancies at present.

There are seven maintenance KPIs for FY2023:

Inspections per year:	30 173
Annual maintenance budget specific costs: [total; per MW_e; per MW_e/h]	R993.3 million; R258 500/MW_e; R813.8/(MW_e/h)

Intervals between failures:	13 hours
Failures per year:	1 015
Maintenance FTE/MW:	n.a.
Share of outsourced maintenance:	Approx. 80%
Maintenance Contracts in place:	25 out of 27 (92.6%)

Operation: The operations team works in four shifts, 24/7, with 35 people on each shift. The operations team is relatively well staffed and there are currently only 15 critical positions vacant.

There are 79 trips per year, so about seven trips per month, across the whole plant. Of these trips, 40 are caused by operating failures and 39 by unsuccessful starts and forced outages. Due to intensive monitoring of performance data, there is high transparency with regards to the condition of the plant.

There are six operational KPI's for FY2023:

Efficiency (design @full load):	35.3% (Units 1–3); 37.7% (Units 4–6)
Coal consumption:	1 750 t/h
Auxiliary Power consumption:	260 MW_e
Startup time for a cold start:	12 h
Number of damages due to bad operation:	200
Number of trips due to bad operation:	40

Outage: Majuba's outage planning is in accordance with Eskom's outage philosophy and the running hours of low-pressure parts. A general overhaul (GO) is planned every six years. In theory, this is based on the scope and timing of the outage activities. However, in practice the outage philosophy is not always pursued, especially in terms of timing, due to the high grid demand and the resulting reduced available times for maintenance. Majuba site has adapted the Eskom standard outage philosophy to fit its needs.

Figure 155 shows Majuba power plant's modified outage plan. The addition of the so-called interim repairs (IR) was necessary to refurbish the fabric filter systems within the units. Due to a lack of procurement and/or financing, a lack of filter bag fabric caused an IR delay, which was one of the main reasons for the high PLL notable at the power plant at the time.

The latest mini overhaul including outage at Unit 5 was postponed by 7 months and conducted in August 2022. There was also performed interim repairs at Unit 3 in December 2022, which were postponed by 5 months. The MO at Unit 6 and the IR work at Unit 1, which were due to take place in early 2023, were postponed until the end of 2023 because of national electricity capacity constraints.

Most of the outage work is outsourced to OEMs (GE, Steinmüller, Kulkoni, PCB, etc.). From the department point of view, resources are mostly sufficient. Currently 18 employees work in the outage department and there are 2 vacancies.

The funds are allocated according to the defined philosophy scope. A request for extra funding was required. The only challenge is the late release of funding, which jeopardises the return to service of the unit as per plan.

Procurement is partially organised local and partially carried out centrally, depending on the total value of the contract.

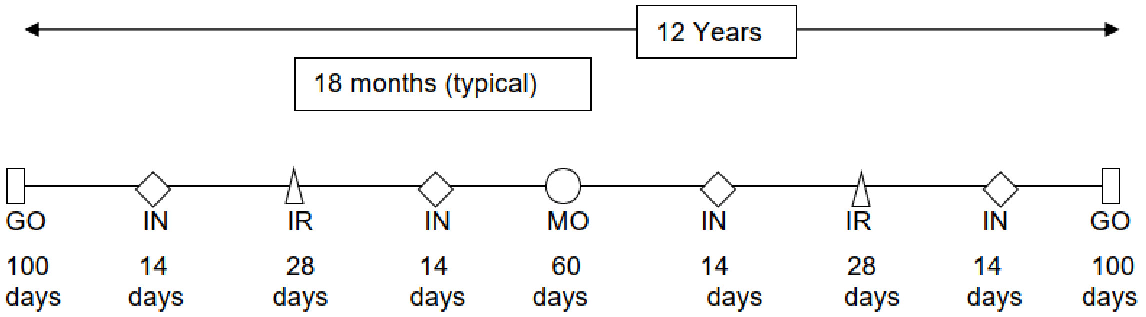


Figure 155: Outage sequence at Majuba power plant
Source: Eskom

5.12.5 Technical Profile of Main Plant Areas

Boiler and related Plant Area:
The six boilers at Majuba station have the same design. They are designed as once-through Benson type boilers. Each boiler possesses a bunker system to store enough coal for 22.5 hours operation at full load. This means that even malfunctioning of the conveyor system or problems related to coal production would not generally directly impact operations. Five mills are installed per boiler. Using coal of the specified quality, a maximum of four mills are needed at full load operation. One mill was therefore designed to be used as redundancy. The pulverised coal is burned by 30 Steinmüller PF-burners at 5 elevations in a circular vortex configuration.

Firing System	
Manufacturer	Steinmüller
Type	PF Burners
Number of burners	30
Coal mass flow [t/h]	1 750
Pressure [bar, a]	171
Temperature [°C]	540

Mills	
Manufacturer	Stein Industrie
Type of mills	Ball Tube Mill, BBD 4760
Mill capacity [t/h] – per mill	102.6 t/h per mill, required 400 t/h in total
Coal supply	
Coal supply (truck, mine)	Truck, train
Coal storage capacity on-site [t]	6 million.
Boiler bunker capacity [t]	54,000
Precipitators/ Flue gas cleaning	
Type	Bag filter (FFP)

Machinery and Electrical:

Turbine	
Manufacturer	Alstom
Type	GEC, 4 Cylinder Turbogen
Casings (HP-IP-LP, double/single flow)	1 HP (single flow), 1 IP (single flow) 2 LP (double flow)
Steam volume (kg m/s)	577
Main steam pressure [bar,a]	161
Main steam temperature [°C]	535
Reheat steam pressure [bar,a]	37.3
Reheat steam temperature [°C]	535
Cold end	
Condenser	3 x 50% Dual-pressure surface type
Cooling tower	Hyperbolic natural draught, wet cooling, U4-6; ACC, dry cooling, U1-3
Generator	
Manufacturer	Alstom
Terminal voltage	22 kV (50 Hz)
Rating	U1-3: 730 MVA, U4-6: 792 MVA
Cooling system	Stator core: Hydrogen Stator windings: Demineralised Water
Transformer	
Manufacturer	Siemens
Terminal voltage primary/ secondary	22kV/400kV
Placement	outside

5.13 Matimba Power Plant

Matimba power plant, with a 3 990 MW_{gross} generation capacity and current EAF of 75.79%, has realistic potential to achieve an EAF of more than 85% and thereby gain constant 367 MW generation capacity. This level was regularly achieved by the plant prior to 2021.

The plant cost of generation is R 515/MWh[38], making it the least costly plant in the Eskom fleet.

The key precondition to achieving the higher EAF is a change in leadership and in the decision-making process, to allow efficient use of assets and resources, since all other factors needed in order to reach higher EAF are available or can be managed. Compared to international benchmarks, the budget to operate the plant is sufficient, qualified personnel is available and the technical design and condition of the plant are good.

The root cause of the low performance of the plant is Eskom's organisational structure. Plant management has very limited decision-making authorisation and there is a high degree of interference from Eskom's head office. The plant is not operated as a profit centre but is part of a portfolio, so profits and budget overruns are diluted throughout the coal fleet. Decisions by plant management require endorsement at several stages within Eskom Generation. This does not serve the day-to-day requirements of the plant, which needs to be able to act immediately in case of a malfunction or defect.

The Eskom philosophy of outsourcing all services to outside parties leads to a high degree of dependency on such service providers, which impacts quality, slows processes due to administration and mobilisation periods and drives up costs.

We highly recommend the insourcing of several own maintenance personnel for the key equipment.

The plant is fortunate to have a highly experienced workforce with extensive knowledge of the plant, equipment, and system behaviour. However, the risk of losing this asset is imminent, and it appears to be impossible to attract skilled personnel to serve in certain areas of the plant (e.g. C&I specialists).

While both plant management and key personnel are well aware of the issues, one concern is the observed lack of discipline and urgency in plant recovery and maintenance, resulting in a deterioration of various areas within the plant. Additionally, pressure from national control authorities often hinders maintenance work and the completion of necessary repairs during outages. The inability to extend outages for proper repairs and additional work uncovered during these periods poses a challenge to maintaining the plant's optimal condition.

[38] Eskom: Life Cycle Planning Life of Plant Plan (LOPP) FY2025 Kick-off Session, 1 March 2023

The various contributing factors causing the decrease in performance of the plant have been analysed in detail and are presented below, along with recommended measures for improvement. By applying prudent plant operation and maintenance and fast-tracking management in eliminating key gaps, the plant's performance can be lifted without major investment.

Please note, the raw water treatment plant poses a significant threat to the continued operation of the entire plant. It is being operated far beyond its design limits and requires urgent and significant equipment refurbishment.

The other key risk is the slow progress in constructing a desulphurisation plant, which is a legal requirement for operation of the plant beyond 2025.

The key risk aspects need to be addressed as top priority topics by Eskom's head office, with an emergency implementation arrangement.

Moving forward, Matimba needs to prioritise the implementation of improvement measures such as the recovery and improvement of the dust handling plant. It is also crucial to address the issues pertaining to maintenance contracts, staff turnover, and the lack of incentives to drive improved performance. By addressing these concerns, Matimba can enhance its operational efficiency and return to its position as a reliable power plant.

5.13.1 EAF and PLL

Matimba power plant aims to achieve a high level of reliability and availability of all its units. The target set by the plant is to achieve 90% UCF, 7% PCLF and 3% UCLF. Matimba was performing near to the set target until 2020, as can be seen in the data shown in Table 69.

Year	Net Gen. GWh	EAF %	UCF %	UCLF %	PCLF %	UAGS Trips
2018	26,369	90.47	92.31	2.12	5.57	8
2019	26,678	87.89	90.18	2.02	7.8	6
2020	26,704	87.48	90	4.34	5.66	8
2021	23,533	80.25	81.73	6.97	11.3	23
2022	23,180	75.48	80.02	13.23	6.75	60
2023	20,559	75.79	79.68	13.15	7.17	36

Table 69: Operating performance of Matimba plant (FY2017/2018–FY2022/2023)

At present, the plant is losing approximately 575 MW on an annual basis due to the issues listed below.

From 2020 onwards, plant performance has deteriorated and UCLF increased to 14% during the last financial year, which is too high. The breakdown of FY2022/2023 UCLF is shown in Figure 156.

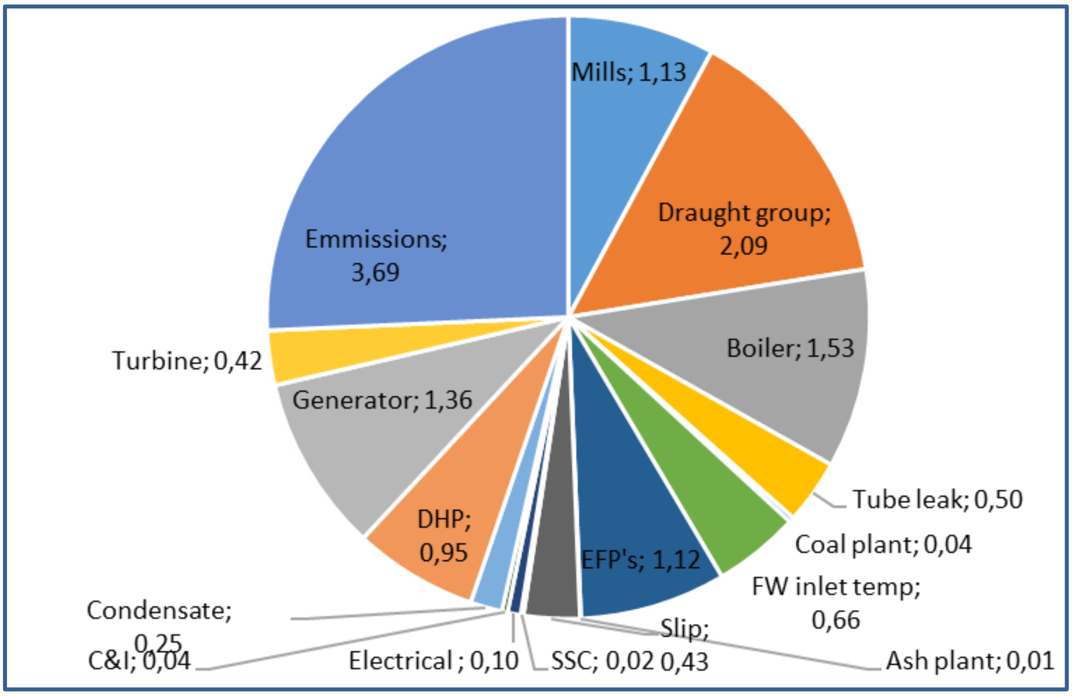


Figure 156: Matimba UCLF breakdown for FY2022/2023

5.13.2 Technical Status

5.13.2.1 Top Issue List

Dust Handling Plant

UCLF loss due to DHP: 0.95% (FY2022/2023). The drag chain link and bucket conveyor for ash conveying are not performing at the required level for evacuation of ash from ESP hoppers.

Emission System

UCLF loss of 3.69% due to high emission. All the units were running at approximately 70% loading due to poor evacuation of ESP hoppers. Actual contribution: 3.69% FY2022/2023 vs 2.54% PFY.

Main reasons are:

- Choked hoppers are leading to very high emission.
- Plant is forced to reduce load due to HH levels of ESP hoppers with high emissions.
- The ash flow control valves below the ESP hoppers are not operating freely during the operation of the units, leading to poor evacuation of hoppers. The hopper levels are going very high, even to the ESP-field level, sometimes even beyond HH levels,

which is leading to very frequent shutdowns of ESP fields. Thus, emission levels are very high.

- The ash conveying from ESP hoppers to transfer points is done using drag chain conveyors until the transfer junction, from where it is lifted to the ash silo by bucket conveyors. There is frequent choking of the drag chain conveyor and the transfer junction.
- One major cause is that skilled manpower left the organisation during the Covid pandemic.

Draught System

UCLF loss of 2.09% in FY2022/2023, due to tube leakage and choking of tubular gas air heater, which leads to overloading of PA and ID fan. Actual contribution: 2.09% in FY2022/2023 vs 0.92% in the previous financial year. The plant reported that the abrasive index of the coal supply has increased due to high quartz and silica content, leading to more erosion of the components. The tubes of the air preheater in Unit 4 and Unit 6 are eroded, leading to short circuiting between air and flue gas. This leads to overloading of PA and ID fans.

Unit 5 and Unit 6 are running with load losses and scopes were finalised for the outages. However, the Unit 5 outage was moved from December 2022 to April 2023.

Boiler Pressure Parts

UCLF loss of 2.03% in FY2022/2023, due to boiler issues and tube leakage. Actual contribution: 2.03% in FY2022/2023 vs 2.37% PFY.

There are outages of units due to boiler trips and BTL. The repair time of boiler tube leak at the plant vis-à-vis international practice has been detailed out in the chapter describing short term recommendations. There are standing committees for BTL and boiler trip analysis.

Electric Feed Pump

UCLF loss of 1.74% (FY2022/2023) due to non-availability of electric feed pump (pump cartridge, gear box, motor and transformer).

There have been frequent outages of the electric feed pump system, due to breakdown of pump cartridge, gear box, motor and transformer. The failure of cartridge, gearbox and motor were due to poor workmanship, and non-functioning of HVAC in switchgear lead to failure of transformers. Till a few months back, all the units were running with two out of three pumps available. The situation has improved and, at present, only Unit3 is running with two out of three electric feed pumps.

Milling System

UCLF loss of 1.13% in FY2022/2023, due to repeated breakdown and capacity reduction of mills. Actual contribution: 1.13% CFY vs 0.53% PFY.

Top mill E was not put in service after consultation with OEM due to metal temperature excursion (high VM coal). This leads to loss in generation, in case of problems in any of the running mills.

Feed Water System

UCLF 0.66% in FY2022/2023 due to feedwater inlet temperature. Unit 2 24 MW and Unit 3 48 MW standing load loss. There are losses of UCLF due to tube leakages in HP heaters leading to non-availability of HP heaters.

Turbine Generator

UCLF loss due to turbine generator issues: 0.42% UCLF in FY2022/2023.

Turbine main steam stop valve leak repairs, Unit 6 HP bypass failure issue, EH oil contamination (Unit 6 UCLF: 0.49%) and valve issues and refurbishment.

Unit trips due to TG.

Investigations conducted and actions raised. Though there has been a reduction in trips over the last two years, tripping due to human error is a point of concern.

ACC Fans

UCLF loss of 0.62% CFY due to ACC fan outages (actual contribution: 0.62% CFY vs 0.39% PFY).

There are 48 ACC fans in each unit. The gear box and motors frequently fail, due to ageing and running in hot and humid conditions. The condition monitoring is being carried out by the plant and corrective action for repair/refurbishment and replacement of gear boxes is being done.

Generator Transformer System

UCLF loss of 1.36% in FY2022/2023.

Unit 1 generator transformer gas formation, which has been replaced with spare generator transformer.

Unit 4 exciter issues and high vibration issues and Unit 6 generator issues are planned during Unit 6 outage, as units are running with vibration under control and close monitoring is exercised.

5.13.2.2 Technical Status of the Boiler

During the visit, the team walked through the boiler house. As shown in Figure 157: Poor housekeeping in Matimba's boiler house, below, housekeeping was poor. High amounts of dust, ash or coal were present.

Figure 157: Poor housekeeping in Matimba's boiler house

Steam temperature at the boiler outlet is maintained close to the design of 535°C (in the range of 533–534°C). The temperature differential between the different sides of the boiler is within the limit. Not much tube failure has been observed in the past.

Mill issues are repeated breakdown and capacity reduction of mills. Coal quality seems to be quite in order. Due to metal temperature excursion, the operation of the top mill (mill E) has stopped since commissioning. As reported by plant personnel, there was a problem with high wear rates of the mills of Unit 6.

Air heater tube leakage and choking of tubular gas air heater leads to SLL and overloading of fans.

Draught system: Two ID fans draw the flue gas out of the boiler to the chimney. ID and PA fans run out of capacity. This is caused by air ingress and tube leaks in the primary air heater and choking of tubular gas air heater.

5.13.3 Technical Measures to Improve Plant Condition

The plant has the potential of gaining 300 MW in the short term and an additional 275 MW in the long term by implementing the solutions set out below.

<u>Emission System</u>

Short-Term Solutions

The following actions are recommended during the opportunity shutdown/planned short shutdown:

- Deployment of skilled manpower with Eskom supervision around the clock.
- All defective valves are to be replaced for the first two fields of all passes, to ensure trouble-free operation. For the remaining three fields, all the valves are to be serviced, if possible, or replaced.

- The ash flowability from hoppers to drag chain conveyor needs to be ensured by:
  - checking the effectiveness of the hopper heaters and maintaining the hopper design temperature
  - checking that effectiveness of fluidising air blower and fluidising pad at hopper is guaranteed
- All the defects of the ash conveying system, including hopper level switches from ESP hopper to ash silo, need to be rectified.
- All the accumulated ash in hopper and ESP field area needs to be cleaned.
- ESP fields (transformer, collecting, emitting electrode and the controller) need to be checked/rectified, so that all the fields develop designed voltage.
- Ensure the healthiness of the rapping mechanism.

Long-Term Solutions

- Thorough overhauling of complete ESP and associated conveying system during the planned outage.
- Availability of capable agency for the overhaul.
- Availability of all the spares required for overhaul.

Draught System

Short Term Solutions

- At first opportunity, during a short shutdown of the unit, the leaking tubes of gas air-heater need to be identified and blanked.

Long-Term Solutions

- During the planned outage, all the blanked and leaking tubes need to be replaced. Further, thickness survey of the tubes needs to be conducted for replacement of tubes.
- Ensure availability of air preheater tubes and related materials before the planned outage.
- Ensure contract with capable agency for the replacement of the tubes.

Boiler Pressure Parts

Short-Term Solutions

- The time taken for the repair of BTL is high, compared to international standards, and there is scope for reduction. It is a standard practice to attend to BTL in first pass water wall tubes/second pass economiser/LTSH within 40-50 hours, whereas the plant is taking 80-96 hours. For platen and final superheater area, with prudent practices the BTL can be attended in 60-80 hours, whereas Matimba is taking 120-144 hours.

- The repair time for BTL can be brought down to standard time taken internationally through proper mobilisation of manpower, T&P and other resources, with supervision by Eskom around the clock. This will improve plant EAF substantially.

Long-Term Solutions

- Ensure availability of certified high-pressure welders.

Electric Feed Pump

Short-Term Solutions

- Action to restore the electric feed pumps has been taken and corrective action to improve EAF is underway. However, electric feed pump 3B is expected to be restored by 31 December 2023.
- The action plan for the revival of this pump system appears to be realistic.
- The skilled manpower in maintenance should be deployed to carry out quality work.

Long-Term Solutions

- The plant has a minimum of two sets of standby unit assemblies for of the main pump and booster pump cartridges, gear box, electric feed pump motors and transformer.

Milling System

Short-Term Solutions

- All the mills need to be checked and repaired at the next opportunity, during a shutdown of the unit.
- More than six different motor bearings failed as a result of lube oil failure. Since the plant lacks mill redundancy, the oil lubrication system must be improved, as it is currently underperforming and causing load losses owing to failure of the mill's motor bearings.

Long-Term Solutions

Availability of spares and contracts to execute full mill overhaul during the planned outage.

Feed Water System

Short-Term Solutions

- Isolation valves for the HP heaters needs to be repaired, to enable maintenance of the HP heater during operation. At first opportunity, during a short shutdown of the unit, the leaking tubes of HP heaters need to be identified and blanked.

Turbine Generator

Short-Term Solutions

- Valve repair/servicing to be carried out by capable agencies, to ensure quality of work.

- Ensure skilled manpower.
- Ensure oil quality as recommended by OEM by doing online filtration.
- Valve torque settings to be done as per OEM recommendation.
- Frequent walk downs, to map the passing valves and attend to priorities.
- Valves not to be procured from vendors whose performance is not found to be satisfactory.
- Inhouse development of skills for repair and maintenance of HP valves/critical valves.

Long-Term Solutions

- Critical valves need to be sent for repair to a capable vendor/OEM.
- Valves need to be procured from established manufacturer.

ACC Fans

Short-Term Solutions

- The workshop has the ability to overhaul the gear box, which the plant is currently doing. However, it needs to be done to high standards and more swiftly, to meet requirements.
- Ensure availability of spares as a priority.

Long-Term Solutions

- The plan for procurement of 300 gearboxes with upgraded oil cooling facility is underway. Should the failure rate of the old/new gearboxes not improve, the spare/rotating quantity per unit should be increased from the current 2 to 8, to allow for one per ACC fan row plus 2 spares. Storage of the rotating spare at the ACC fan level should be considered, to reduce replacement time.

Spares Planning, Availability and Development of Specifications

Short-Term Solutions

- Most of the spares have been declared stock-controlled items with minimum, maximum and reorder quantities. This does not match actual demand, which has resulted in frequent unscheduled procurements on the one hand, and a huge inventory of slow-moving items on other hand. As such, an FSN/ABC analysis is needed and an immediate review of minimum, maximum and reordering levels as a one-time exercise, and then every six months thereafter. We also recommend monitoring the safe lifetime of spares and consumables in the ERP system and implementing an automated first- in, first-out philosophy.
- List of critical spares to be reviewed in every quarter for all the system by the concerned department.

- As the current practice of global tendering is delaying the procurement process considerably, we advise that tenders only be issued to pre-qualified vendors with appropriate technical competence and appropriate financial background.
- Single source or sole source suppliers should be identified for critical spares and single/sole source approval should be given without limitation of the validity of said approval.

Long-Term Solutions

- Develop specifications and drawings for key spares to widen the network of suppliers and reduce dependence on OEM and their agencies.
- Pooling and consolidated procurement of spares /unit assemblies between plants with similar units/OEM and steps to improve their availability and optimise prices.
- Present procurement process is cumbersome and time consuming, due to approval at multiple stages. The process needs to be accelerated, for timely availability of spares and engagement and mobilisation of resources.

HR Issues

Short-Term Solutions

- There is a huge shortage of operational staff (120 out of 170). Recruitment and training need to happen on an immediate basis as a top priority.
- Reward and recognition system needs to be enhanced by clear criteria, alignment with organisational goals, effective communication with variety of rewards.
- Recognition and reward of individuals and teams for their outstanding contributions in demonstrating creativity and innovation.
- The training department needs to ensure that lessons learned from plant incidents are built into the training materials for the plant operators.
- The skills of the staff (Eskom/business partner) need to be continuously improved through training and counselling. Operating manpower skills, HP welders, grinder men, boiler tube fitters, HP valves repair and maintenance skills, millwright fitters for pumps and fans and their alignment, skilled technician for compressors, HVAC technicians need to be trained and developed.

Long-Term Solutions

- Adequate experienced middle-level maintenance staff (including C&I and Electrical) need to be recruited by granting special remuneration for the remote location.
- Non-availability of specialists at plant level can be resolved by having experts for all the functions of O&M based at Eskom headquarters.

Major C&I System Obsolescence

Long-Term Solutions

- Most of the unit and common plant control systems installed are facing problems relating to unavailability of spares due to obsolescence, and there is no support from OEM. The plant personnel have presented LOPP for the upgrading of the C&I systems which should be followed as per plan.

Switch Gear (MV&LV)

Short-Term Solutions

- Water seepage from the roofs needs to be stopped permanently, to avoid water egress inside the breaker cubical causing failure of control cards and other components of feeders.
- Defective fire seals of breakers can be sealed properly to avoid flashover inside breakers, due to condensation of steam entering through cable trenches flooded by overflow from drain water. Availability of sump pump also needs to be ensured, to avoid overflow from drains.

Long-Term Solutions

- The MV and LV air insulated switchgear for indoor use was installed between 1985 and 1989. Even though there have been few MV failures, all the MV and LV switchgears need to be replaced over the next 8 years. The MV and LV scope also includes the installation of a new protection scheme. All MV and LV protection should consist of IEDs for a reliable system.

5.13.4 Power Plant Management

Maintenance

Maintenance work is mainly carried out by outsourced maintenance personnel. The ratio of own maintenance personnel to outsourced personnel is not healthy. We highly recommend insourcing maintenance personnel.

Planning

Plant maintenance management is executed via the SAP system. A MSMW system is used as a tool to establish reliability-based maintenance. As this is a new initiative of Eskom's, recently implemented in SAP, the planning and execution of maintenance work on-site is carried out by the routine work management team, in consultation with the maintenance department. There is a daily meeting with maintenance, production/operating department and engineering to decide the work priorities. Maintenance strategy varies from component to component, based on criticality, i.e. some maintenance is planned, some is condition-based and some is run-to-failure. Further, the plant maintenance and outage departments have long-term contracts with pre-qualified contractors to meet the requirements to perform planned and unplanned maintenance.

Findings

- The constraints on planned maintenance are lack of adequate funding, belated approval of funding and unavailability of spares in line with requirement.
- The procurement process until the order is placed takes too long (in several instances, more than six months. In limited cases, up to 24 months), even for critical part and services. Such delays are not acceptable given the criticality of the plant.
- Plant mid-term renovation of the facilities is due, which is reflected in the LOPP. Therefore, the plan should be prepared once the proposed budget has been reviewed.
- There are instances of deferment of overhauls by six months or more, due to non-approval of budget in time, adversely affecting unit reliability and performance.
- Majority of load loss (approximately 70%) is due to improper planning and execution of maintenance of ash plant. Close coordination between dust handling plant O&M and main plant O&M, in particular ESP O&M, is required, as limitations in the DHP will have adverse impact on ESP performance. Sufficient reasonably qualified resources are currently unavailable, especially for the ESP and ash conveying plant.
- The skill level of the staff needs to be enhanced on a continual basis through effective training.
- Training programmes for improvement in skill sets, people management and succession planning, etc., need to be organised at regular intervals.
- The current budget is not prepared in enough detail. Therefore, it is difficult for management to track maintenance expenses per activity, or to detect shortfalls in planning while budget preparation is still underway. This can lead to insufficient budget allocation for certain activities and, subsequently, to delays in budget approval.

Quality

For quality control, the SAP system generates work sampling orders for managers/supervisors to verify the work done at different plants, as per the respective approved QCPs. As the checking of compliance with QCPs is only done on a random basis, there can be shortfalls in the quality of the work executed and in subsequent rectification work. Quality control checks need to be carried out by skilled technicians/engineers on all work carried out by contractors, in order to ensure that it is up to standard and value for money. It is best practice to separate the quality control from the execution.

Findings

- Quality control and quality assurance departments are not available.
- Inspection of HT Motors, MCA, Tan Delta test, DPT of fan motor rotor bars, MDBFP motor in-situ inspection of overhang portion of stator bars/DPT of impeller blades should be carried out during overhauls.

- Currently, there are no prequalification criteria for selecting vendors in single sourcing/open tendering.
- The plant has two industrial cleaning contracts to assist with issues of housekeeping.
- The unit has a rolling overhaul schedule for IN, IR, MGO and GO based on their outage philosophy. However, the scope of the work needs to be frozen well in advance, so that resources are procured/managed in time. Otherwise, it leads to outage slippage.
- There is a high risk of losing the permit to operate due to the incorrect use of pressure part materials, improper ash disposal, high emissions, overflow of dams, etc.
- Proper housekeeping is a prerequisite to safety and quality maintenance and needs to be addressed immediately.

Resources

The plant's resource planning is as follows.

There are 27 employees working per shift, excluding the operation staff for the water treatment plant. If shift staff are unavailable (due to leave/sickness), either staff stay on and do overtime, or replacements are organised from the spare group, which impacts the training schedule.

During every shift, a walk-down survey is conducted as per the checklist. Presently, there is a shortage of qualified and experienced operating staff, with only 120 out of 170 positions filled. This shortfall needs to be addressed immediately, as it takes time to qualify the operators. Plant operators need to be in the plant and interacting with maintenance supervisors more often, to ensure plant walk downs are properly carried out and recorded.

For a general description of resources qualifications et al, please refer to the description for Kusile power plant.

Third Party Resources

The current Eskom tendering process does not include a prequalification process prior to submission of request for proposal. Any party can participate in the tendering process, irrespective of qualification or previous procurement history. This can lead to significant delays in the procurement process and does not assure that sufficient qualified companies are even considered in the bidding process. Rejection of potential venders can lead to retendering, which generates additional delays in mobilisation of vendors. This system is enabling inadequately qualified vendors to pitch for and even to execute jobs, as plant personnel is forced to weigh up the need for quality work against the need for timely execution.

Spare parts

Concerns relating to spare parts can be divided into two main categories:

- Timely procurement of spare parts: This is adversely affected by tendering of proposals to potential vendors irrespective of their technical or financial capability. This can lead to one or more retenderings, even after an extended period of time.
- Quality of spares due to absence of proper quality control plan with sufficient holding points. Plant personnel have reported that, at times, quality control only takes place after the delivery to site. This forces the plant personnel to compromise on the quality of spares, as rejection would cause substantial delays in the availability of said spare part.

Additional Spare Parts Recommendation

- Besides the correction of the above-mentioned points, we recommend that the adequacy of min/max values and safety stock in the plant be reviewed every six months. At least on annual basis, the plant should conduct FSN/ABC analysis to identify high value and non-moving items and to establish whether it is necessary to keep such items in stock. The use of an automated first-in, first-out system, with monitoring of shelf-life time is highly recommended.

Operation

Quality

The plant is operated around the clock with five groups of operation manpower. Four groups are engaged in the round-the-clock operation of the plant. The 5th group reports to the training department for simulator training and other training. Shift handover takes place during the change of shifts.

Monitoring of operational performance by KPIs is done by the performance and testing division. However, recording of plant performance analysis needs improvement so that the findings and related issues of load loss and efficiency parameters are well mapped to the respective equipment/systems. This is a necessity, to mitigate the gap between the current performance and design performance.

Coal quality management procedure is followed as per the coal supply agreement between Eskom and Exxaro. The plant uses a coal management system to capture data on coal quality parameters, and the laboratory maintains LIMS. Coal sampling is done at an automated sampling plant situated at the Exxaro end. The coal sampling is prepared jointly by Eskom and Exxaro and each party hands a sample of coal over to their respective laboratories for chemical and physical analysis before the coal is dispatched to the plant. The results of the two labs are compared and accepted only when the deviations between the two reports are within the permissible limits.

The quantity and quality of the coal for the plant is guaranteed by the following documents, system and liaison meetings between Eskom and Exxaro:

- Contractual monthly minimum dispatches as per coal supply agreement.
- Sharing of weekly coal needs by Eskom with Exxaro.

- Operation report for dispatch of coal per shift.
- Weekly operational meetings between Eskom and Exxaro (maintenance teams, coal manager and counterpart from the mine).
- Monthly technical liaison meeting for any technical issues.
- Main liaison meeting between Matimba and Exxaro senior management.
- Centralised system: Coalapps and LIMS (Eskom system).

The OPEX is tracked by comparing actual vs budgeted expenditure on month to month and YTD basis. PSGM holds a monthly review meeting.

The budget for the plant is prepared on annual basis and takes the volumes of generation, different activities to be executed and outage plans into consideration. Although the system is established, no record is available for system wise budget declaration.

Monitoring

Each control room is currently manned by one senior control engineer, which appears to be insufficient to cater for an emergency situation, based on the rate of atomisation and the control room layout. Inexperienced staff, in particular, will face problems, as information is not available at one single location. An up to date DCS will reduce the probability of human errors, once implemented.

The system is obsolete, as detailed in section 3, and needs to be replaced with an upgraded system. The existing system is running with a shortage of spares and without OEM support. The plant has a historian for real time data, but the storing capacity is limited and not meeting the present requirement.

A simulation procedure is in place and followed as per defined procedure, and relevant parameters are transferred to the control system. However, due to the old system, it is a time-consuming, cumbersome process when malfunction of parameters occurs. The complete simulation procedure needs to be adapted to bridge the gap.

Presently, only critical instruments are calibrated by an external accredited certified agency during IR and MGO. We recommend the calibration of all the instruments in a systematic manner, either at a scheduled time or when an opportunity arises.

CBM is in place and carried out by external personnel stationed at plant. CBM is done for oil quality, thermography, vibration measurement analysis and water quality. Coal analysis is done at the in-house laboratory by the chemistry division. In case of discrepancies, manual verification is carried out by the Performance and Testing group. A VA view system is installed to track the plant’s physical parameters (like temperature, pressure, flows, vibration etc.). However, the online plant performance monitoring system is needed to identify the grey areas, and daily performance assessments are needed to schedule the maintenance requirement for underperforming equipment.

The condition monitoring results are usually analysed for deviations and recommendations. However, the corrective measures are not monitored and implemented in the SAP system.

Outage Management

The principal outage management is similar to Kusile power plant's and is described there.

Leadership

The challenges faced by plant leadership in order to achieve sustainable operation of the plant are as follows:

- To operate the plant within the emission limits of South Africa emission regulatory body.
- To achieve zero discharge by stopping overflow of dams and controlling the process water wastage.
- Reliable operation of the critical equipment/system (like electric feed pumps and auxiliaries, ACC system, generator and exciter, plant emergency DC system, ash dumping facilities, etc.).
- Advancing the safety culture among the employees of Eskom and business partners.
- Shortage of skilled trained manpower.
- Reestablishing the motivation of Matimba employees which has been severely affected by COVID.
- Management of documentation and its transfer from OEM's/construction department to O&M of the plant.
- Development of specifications and drawings for the critical spares.
- Comprehensive budgeting for each system of O&M and timely approval
- Restructuring of present procurement processes to address the time-consuming procurement process.
- Development of a knowledge forum at Eskom central level for each function of O&M, to resolve technical issues.

The main cause of low performance at the plant is Eskom's organisational structure, which severely limits the authority of the plant management to make its own decisions and involves a high degree of interference by Eskom's head office.

The plant is not operated as a profit centre but is part of a portfolio, so profits and budget over-runs are diluted in the coal fleet.

Decisions by plant management require endorsement at several stages within Eskom Generation. This does not serve the day-to-day requirements of the plant, which needs to be able to act immediately in case of a malfunction or defect.

One excellent example is a hypothetical situation that the vgbe team discussed with the Matimba plant management: Imagine the procedure if, for instance, a single component at the plant was found to be defective and, as a consequence, the entire unit needed to be shut down. The scenario assumed that the damaged component was not in stock or available anywhere in South Africa but, instead, had to be ordered from an OEM-supplier in Europe. The cost of the equipment was R1 million.

For Matimba, the loss of revenue with one unit out of operation is R14.8 million per day.

For a plant manager in India or Europe, the emergency order to the European OEM would be initiated the same day and the spare part would be flown in in the coming days. The repair preparation would be carried out and the plant put back in operation within five days of the incident. This would represent a total loss to Eskom of approximately R 79 million, for 5 days outage, plus the spare part and repairs, and plant EAF would drop 0.2%.

Matimba's management then described the Eskom internal emergency process applied in such scenarios: This assumes an outage period of about 10–15 days until the spare part is available, if at all. Furthermore, external contractors for repair would have to be mobilised, so the loss to Eskom would be about R 150 million, with a drop in the EAF of 0.45%. This example, which is quite realistic, shows how the EAF and cost efficiency in operating the plant are unnecessarily hampered by Eskom's internal procedures.

Another example of where the central organisation hampers effective plant operation is the centralised coal supply management, which prevents direct communication about and optimisation of the coal supply quality and logistics.

We highly recommend that the authority of the plant management be augmented: An immediate improvement can be managed with the support of an independent interim management team.

Eskom plant management and experts have no direct operative influence over the speed and quality of maintenance activities because all services are outsourced.

In case of nonperforming service companies, there is no Plan B – e.g. stepping in with own personnel possible.

The Eskom philosophy of outsourcing all services to outside parties leads to a high degree of dependency on such service providers, as well as a lack of quality, loss of speed because of time delays caused by administration and mobilisation and, finally, high costs.

We highly recommended that Eskom consider insourcing a team of own maintenance personnel for key equipment.

People Management

- The work culture at Matimba is impacted by the following:
  - During and after Covid, the work culture has adversely affected and there is still a lot of work to be done to return to normality.

  - Lack of ownership, which needs to be addressed by improving the quality of leadership.
  - Employee involvement through employee engagement initiatives, e.g. info sessions and empowering the employees to create and enforce a winning culture.
- Employee Motivation
  - Assure the attractiveness of the remote work location by providing incentives such as free housing, free schooling and other incentives that consider the specifics of the location. It appears that Eskom has no specific incentive scheme for remote work locations, so that personnel is moving to more attractive plants with nearby cities and good infrastructure (e.g. Kusile being close to Pretoria). It is common practice in Europe and, also, in India to support local personnel with attractive infrastructure and incentives so that they take on the burden of moving to and staying in such remote areas. There is sufficient Eskom accommodation available (most of it is unoccupied and not used for years) in Lephalale. However, due to taxation on fringe benefits, it is not attractive for Eskom employees to use such Eskom housing. The coal mining company Exxaro, which operates the nearby coal mine, seems to have obtained a waiver for fringe benefits and it would be worthwhile for Eskom to study the options and consider an exemption for Eskom employees in the region.
  - Though a reward and recognition system exists, it needs to be further enhanced by clear criteria, alignment with organisational goals, effective communication and a variety of rewards.
  - Recognise and reward individuals and teams for their outstanding contributions in demonstrating creativity and innovation.
  - Foster employee motivation by organising fun activities and celebrations.

H&S Management

The plant is ISO 45001:2018 certified, actively striving to meet the standards requirements. A SHEQ policy outlines leadership commitment and expectations. Effectiveness is reviewed through management reviews and quarterly audits.

Incident investigations are organised following the requirement of 32-95 Eskom incident management procedure. All incidents are investigated within seven days of occurrence unless the injured party is not yet fit to attend. The number of incidents per year are summarised in Table 70.

FY 2022-2023	LTI	Medi-cals	First Aid	Near misses	MVA	Total
H&S incidents per year			79			
Eskom Employees	0	6	3	10	9	28
Business Partners	3	12	10	16	10	51

Table 70: Incidents per year at Matimba

Business Partner Engagement for Safety Evaluation

Business partner/third-party companies submit safety files for evaluation by the safety department. After approval, they can proceed with site establishment and work. Third-party companies fully comply with legal requirements mentioned on the safety file evaluation checklist.

Risk Management

Matimba has an integrated risk management system which complies with the integrated risk management standard (doc. no. 32-391) in Eskom's enterprise risk and resilience policy. While the risk management system is administered in accordance with the standards, the implementation of agreed risk mitigation measures lacks speedy processing for a variety of reasons.

The plant faces various risks in emissions compliance, zero effluent discharge, equipment reliability, safety culture, manpower shortage, employee motivation, documentation management, critical spares specifications, comprehensive budgeting, streamlined procurement, and knowledge forums.

Mitigating these risks is essential for the sustainable operation of the plant and achieving long-term success.

While the risk management process appears to be well structured and maintained, the mitigation activities at and beyond plant level appear to be doubtful.

Two key risks have been taken out of the list and are discussed in Table 71, below.

Losing the operation permit in 2025	If no flue gas desulphurisation plant is built, Matimba will lose its operation permit. This topic is now being given more priority in the planning division at Eskom's head office. However, there is no visible management structure responsible for actively implementing FGD plants at various Eskom power plants, including Medupi and Matimba. At Matimba, there is no team actively involved in the planning and implementation of the FGD plants. There is not enough time to build Matimba's FGD system before Matimba's operation permit becomes invalid because of the new emission standards. There is no information available about an exemption from minimum emission standards or about whether a suspension of compliance will be granted by the National Air Quality Officer. The implications of failing to install the FGD are very complex and beyond the understanding gained by the vgbe team. It is however a) feasible, b) common practice in nearly all countries in the world operating coal-fired power plants and c) practicable to continue operating with high EAF if installation of advanced flue gas cleaning technologies is underway. Thus, from an operation, maintenance and plant performance perspective, there is no reason not to install the FGD plant at Matimba. The impact of the tie-in and disturbances during erection of the facilities can be mitigated by intelligent optimisation of the outage schedule. The tie-in, however, will have some impact on the EAF, which needs to be considered in the generation capacity planning.
Water treatment plant	Due to passing valves and leakages, current water demand is far exceeding the design range of the treatment plant. Aside from higher costs, this also accelerates the aging of plant components and puts the plant at risk of failure (single component failure). The vgbe team has not been able to establish the existence of any risk mitigation or implementation plans for these issues at Eskom headquarters.

Table 71: Discussion of key risks at Matimba

5.13.5 Technical Profile of Main Plant Areas

Matimba power plant is a base load power plant with subcritical and once-through boilers. The plant comprises six identical units of 665 MW each and total installed capacity of 3 990 MW. The units were commissioned between 1988 and 1993. The plant uses air cooled condensers (ACC) to cool the exhaust steam from the LP turbines. The condensers, supplied by GEA air cooled systems, represent a major advance in the application of dry cooling technology for power generation. Design gross efficiency at rated turbine MCR of 38.10%. Coal is supplied from the adjacent Grootegeluk colliery on the Waterberg coalfield via a conveyor system. The commissioning dates along with plant details are shown in Table 72.

Parameter	Value
Installed capacity (MW)	6 x 665 (3 990)
Available capacity (for Maximum Continuous Operation)	3 990
Number of units (no)	6
Start of operation (year)	1987
Units still operation (no)	6
Planned end of life of first unit (year)	2048
Planned end of life of last unit (year)	2052
Steam parameter (pressure/temperature)	16.1 MPa/535°C

Commercial operation	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Commissioned	1987	1987	1988	1989	1990	1991
Expected decommission	2048	2048	2049	2050	2051	2052

Table 72 Matimba power plant details

Source of Fuel

The adjacent Grootegeluk colliery has sufficient coal reserves to guarantee supplies to Matimba for a minimum lifespan of 35 years, at 2 100 – 2 130 tons of coal per hour, with the possibility of extending to 50 years. The coal is supplied directly by overland conveyor from Exxaro's Grootegeluk mine, 5.5 km away. The plant consumes an average of 41 109 tons of coal per day, or about 14 mill tons per year.

Source of Emergency Fuel

As secondary fuel/oil and emergency oil HFO is used. HFO is used to light up boilers and for flame stabilisation during normal operation. HFO is delivered by road tanker to the offloading bay to the northwest of the plant. There are four tanks, each with a capacity of 1 000 m^3.

Diesel is used on-site for coal moving equipment and for the diesel-driven fire water pumps, emergency demineralised water pumps, diesel driven compressors and emergency generators. There is a 30 m^3 storage tank.

Source of Water

Raw water is supplied from the Mokolo dam, 35 km away. The dam is filled by the Mogol River providing a reliable supply. The site has a substantial raw water reservoir which provides a good buffer against supply disruptions.

Apparently, the current raw water supply is not sufficient to serve the plant in case of the installation of an FGD plant. The plan to enhance the capacity of raw water supply was reported to be not realistic. Consequently, the implementation and operation of a FGD system, which is mandatory after 2025, is unrealistic.

Without a waiver or realistic implementation plan, the operation of the plant after 2025 must stop in accordance with the legislation.

Ash Dump

The total footprint where the Matimba ash dump is located is 1 200 ha and 698 ha is used for ash disposal. To date, approximately 475 ha has been covered with ash to a volume of 171,904,317 m³. The remaining footprint is 223 ha with a volume of 227,920,382 m³ still remaining until the end of life of the plant.

Total Operation Hours for each Unit YTD

The total operating hours of each unit, along with the number of start-ups, are shown in Table 73. The running hours during the last five years are shown in Figure 158.

Compared to Units 4, 5 and 6, Units 1, 2 and 3 have a greater number of shutdowns which causes generation losses.

Year (1987-2023)	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Running hours	261 447	264 937	262 103	264 705	255 233	245 330
Cold starts	122	98	110	87	89	101
Hot starts	315	277	234	199	173	157

Table 73: Matimba's unit running hours since commissioning

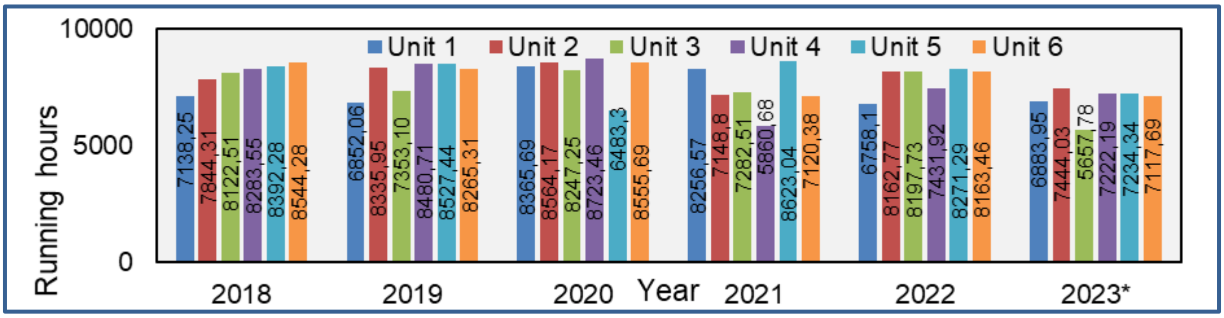


Figure 158: Running hours of each unit over last five years at Matimba

Coal Composition (including Heating Value)

Detailed coal trends have been reviewed. These trends depict the comparison of Exxaro and Matimba laboratory analysis reports. There is a good correlation between the reports and the Matimba analysis is found to be in line with the Exxaro analysis.

Supplied coal characteristics vs contractual coal characteristics are described in the following:

- Ash content goes up to 38% (as per contract ash content is 35.5%).
- Sulphur values have no contractual limits. However, they seem to regularly exceed the desired limits of < 1.5 to 1.8%, with values varying from 1.25% to > 3%.
- Abrasiveness trending above the contractual value (240 mg Fe). It varies from 210 to > 310 mg Fe.

While the key parameters of coal quality are in a reasonable range, the sulphur content variation and excursions above contractual values contribute to operational challenges and potential load loss.

5.14 Matla Power Plant

The Matla (a Sotho word meaning “strength” or “power”) power station was the first of the giant 3600 MW coal-fired power stations in the world with a concrete boiler house superstructure. The unusual design evolved because of a world-wide steel shortage during the design stages. The installed capacity is 3600 MW gross (six units, 600 MW each), but the licensed nominal capacity is 3450MW net. Design efficiency at MCR is 37.6% (LHV net).

The power station is located in Mpumalanga coal-mining area near the town of Kriel. The first of the six units started operating in December 1979 and the last in 1983. Matla was designed with an operating lifespan of 30 years, but substantial coal reserves exist to extend this to 50 years and beyond. After 40 years of operation and considering that it is expected to operate for another 20 years, it was due for a mid-life rehabilitation (2010 to 2013). This rehabilitation did not happen, but some technical upgrades were carried out. The commissioning dates along with station details are shown in Table 74.

Parameter	Value
Installed capacity (MW net)	6 x 600 (3 600)
Available capacity MW gross (for Maximum Continuous Operation)	3450
Number of units (no)	6
Start of operation (year)	End of 1979
Units still in operation (no)	6
Planned end of life of first unit (year[39])	2030
Planned end of life of last unit (year[39])	2034
Steam parameter (pressure/temperature)	16.1 MPa/540ºC
Source of coal	Matla Exxaro colliery

Commissioning and life of plant	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Commissioned	08/1979	06/1980	12/1980	10/1981	08/1982	07/1983
Expected decommission	08/2030	06/2031	12/2031	10/2032	08/2033	07/2034
Operating hours (as of March 2023)	306 936	299 412	307 042	296 599	291 079	294 277

Table 74: Details of Matla power plant

[39] Based on current Eskom coal power plant shutdown date schedule, dated March 2023

The station was equipped with a wet ash and dust extraction system, but it was later converted to a dry dust extraction system. Coal is supplied from the adjacent Matla Exxaro colliery (60%) via a conveyor system; the remaining 40% is trucked into the station. More details about the plant are provided in subsection 5.14.5**.**

In the past, Matla was a reliable and consistently well-performing station, but it has been in steady decline since 2007. This decline started accelerating in 2018, due to deteriorating coal quality and lack of adequate maintenance. From one of the best operating plants in the fleet in 2017 (82.2% EAF), it reached 53.3% EAF by the end of FY2022/2023.

The situation and condition of the station has, however, improved since May 2022[40], although the improvements are not yet visible in EAF data. One of the reasons is the fire at Unit 6, resulting in a long UCLF outage. However, this unit was returned to service in May 2023. The principal areas of improvements are the upgrading of the cooling towers, catch-up on deferred outages and more complete maintenance during outages.

Key technical issues which need to be addressed urgently include:

- **Coal quality needs to be improved urgently and as a priority**, as it affects BTFs, ESP and ash handling system performance, ID fan reliability, etc. Coal blending should be considered until the Exxaro colliery can supply coal according to design specifications (estimated by 2028). Better coal quality may help achieve SO_2 compliance at a lower cost. If coal quality is not improved, the plant may be derated until coal can be delivered that meets design specifications. The current PLL – resulting from bad coal - is estimated to be 100MW on each unit.
- **The boiler suffers from frequent tube failures.** Poor coal quality and deferred maintenance are the main causes. Air-in leakage throughout the system is suspected to be making things worse and needs to be assessed and controlled.
- **Mills suffer from reduced reliability and result in plant derating** due to lack of spare parts and inadequate maintenance. Improved coal quality will help the mills too, but systematic and timely maintenance is needed. The replacement of the feeder pipes needs immediate attention.
- **The steam turbine and associated equipment are suffering as a result of deferred maintenance**. The plant staff have made all the necessary preparations for maintenance; so, it is a matter of deciding to implement the maintenance and providing adequate funding.
- **Emission control equipment needs upgrading, some of it immediately and some in order to comply with tightening regulations.** The ESP is not complying with current particulate (PM) requirements; so, ESP upgrading is needed urgently. SO_2 and NO_x controls would be needed, too, by 2025. A comprehensive study is recommended to evaluate the various options. Low NO_x burners should be adequate to

[40] Plant turnaround strategy presentation 19 May 2022 was used as the reference for this assessment.

meet NO_x requirements. SO_2 controls require more careful examination, as there are multiple technologies and the final decision will depend on the required level of compliance, the sulphur content of the coal (which can also be reduced through coal cleaning and/or selective mining) and the availability of water.

- **The ash handling system is affected by the increased ash volume causing frequent failures.** Better coal quality (with lower ash content) should help, but some components need urgent maintenance and refurbishment.
- **The electrical and C&I systems:** The turbine governor needs to be replaced; there is lack of spares for some MV and LV SG's; it would be wise to purchase reserve generator rotors and generator transformers for Units 3-6.

Key recommendations:

- Most importantly, Eskom needs to decide on the retirement of Matla. Presently, 2035 is the official retirement date, but it is understood that a delay until 2040 or 2045 is being considered. If so, this should be decided urgently because it will have a significant impact on what type of maintenance and rehabilitation needs to be done. It will also have a positive impact on staff morale at the plant since they are expecting a 2035 retirement.
- The power plant management has the capacity to manage the power plant efficiently, but it also needs decision-making control on procurement of works, services, and supplies.
- Presently, outsourced staff outnumber plant staff by a factor of 2-to-1. This balance should change in favour of more plant staff.
- In general, the plant needs to hire more staff; for example, it needs 24 supervisors, but it has only 18; also, more operators are needed.
- Funding related to maintenance should be released in a timely manner.
- **A detailed study is recommended to assess the effect of coal quality and the resulting ash and dust issue, and to make recommendations.**
- **On-site mentoring via a small dedicated technical mentoring team is recommended.**

5.14.1 EAF and PLL

Matla was a very reliable power station until 2013; availability was consistently above 80% with a high of 93.6% in 2006, as Figure 159 shows. In 2014, the availability took a deep dive to 69.4% but then improved again to 82.2% in 2017. However, since 2018 the station EAF has shown a steady deterioration every year, reaching 53.3% by the end of FY2022/2023.

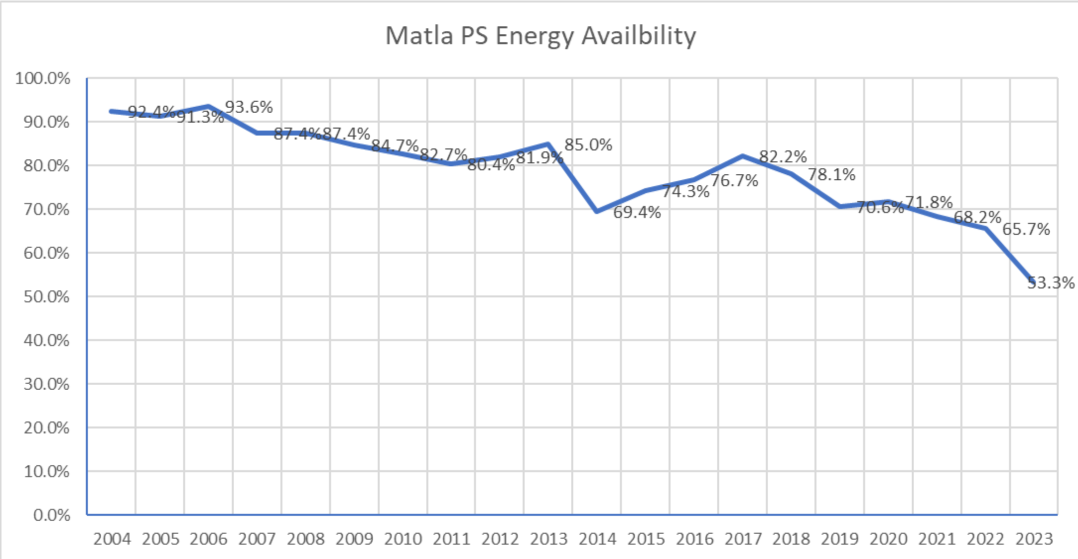


Figure 159. Matla's availability (FY2003/2004–FY2002/2023)
Source: KISSY & Eskom [41]

Figure 160 shows the availability and utilisation of each of the six units at the Matla station for the period 2004 – 2021. The information per unit shows that the availability decline was consistent across all units and not only related to specific units.

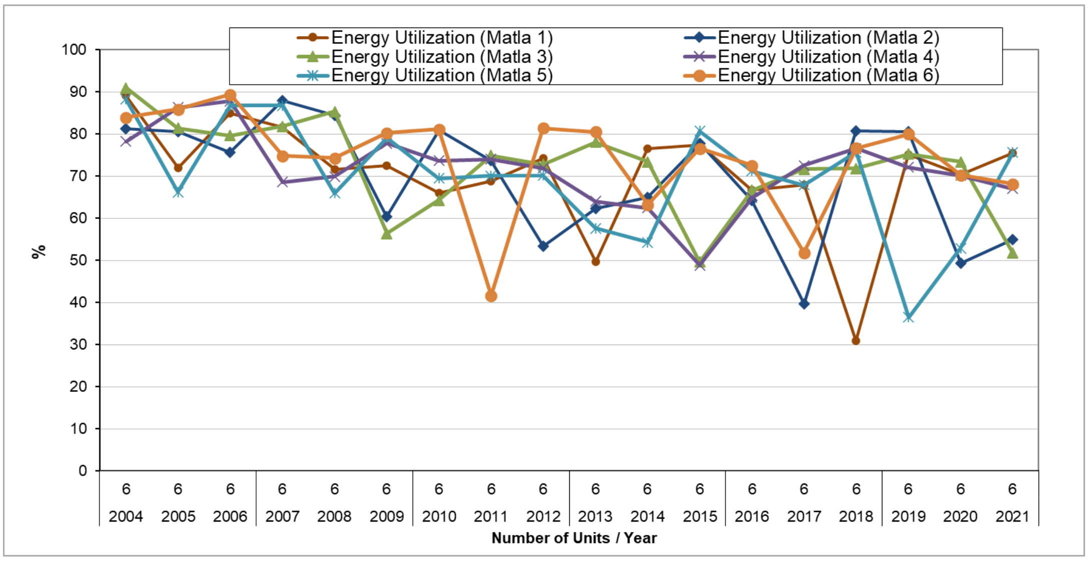
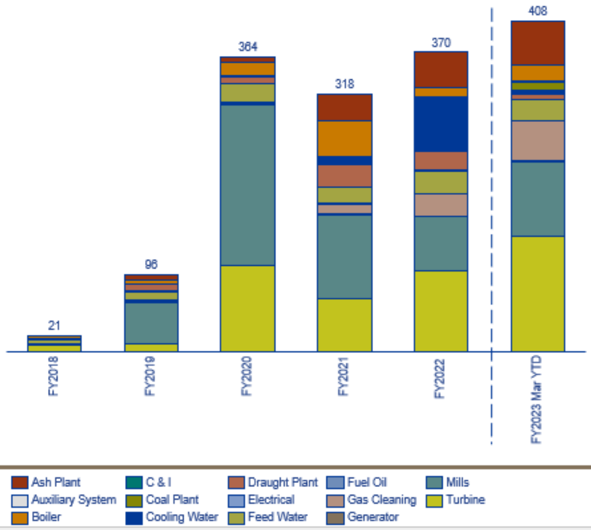


Figure 160: Unit-wise availability and utilization at Matla (FY2003/2004–FY2020/2021)
Source: KISSY

[41] 2004 to 2009 is based on KISSY information 2010–2023 is based on Eskom end year report information.

The combined PLL and UCLF for Matla was 25.47% for FY2022/2023, with PLL contributing about 46% of the station’s total UCLF losses, which is substantial. For the FY2022/2023, Matla contributed 7% of the total generation fleet PLL and UCLF, which is below average for the fleet at present, but this only highlights how badly the fleet is performing. As Figure 161 shows, MWs lost were 408 MWs during FY2022/2023 and 370 MWs during FY2021/2022. The lost MWs have been increasing steadily since 2018.



Mwloss	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023 March YTD
Ash Plant	0.00	7.51	7.07	34.12	43.70	54.37
Auxiliary System	0.00	0.08	0.00	0.00	0.13	0.00
Boiler	3.34	4.32	17.05	43.55	10.97	20.30
C & I	0.05	0.08	0.00	0.06	0.24	0.51
Coal Plant	0.00	0.57	0.96	2.09	2.28	10.46
Cooling Water	0.00	0.23	0.99	8.09	65.14	5.64
Draught Plant	2.17	8.06	6.65	26.71	22.72	5.90
Electrical	0.66	0.35	0.37	0.59	1.24	0.66
Feed Water	4.71	9.89	22.70	20.30	27.72	24.79
Fuel Oil	0.00	0.43	0.03	0.11	0.10	0.23
Gas Cleaning	0.03	2.49	1.70	12.53	28.14	50.15
Generator	0.00	0.38	1.48	0.83	0.86	0.38
Mills	2.02	51.75	198.83	103.53	65.92	91.97
Turbine	7.87	9.77	106.13	65.69	100.51	142.64
Total	21	96	364	318	370	408

Figure 161: PLL contributors at Matla power plant (2018–2023)
Source: Eskom

Figure 162 to Figure 164 provide the most recent reliability parameters for Matla power station (YTD up to 31 March 2023).

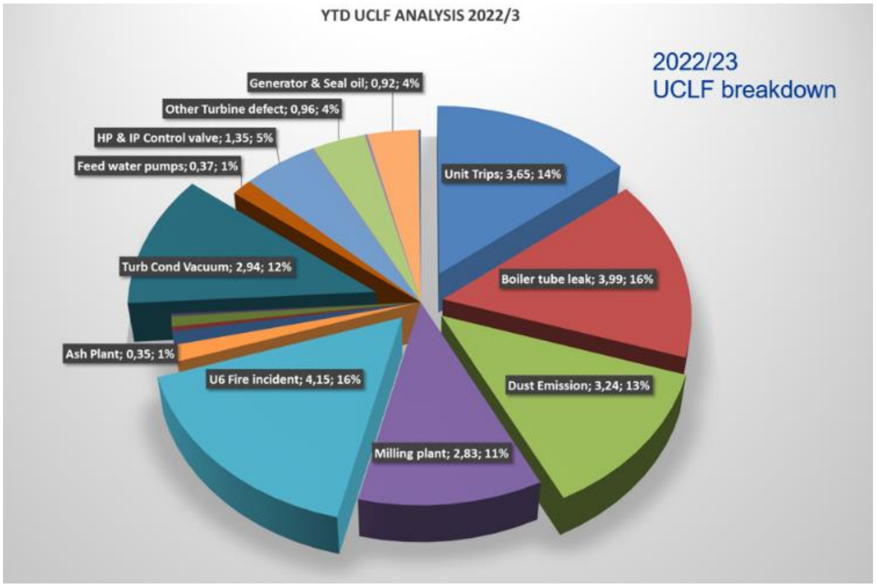


Figure 162: Matla UCLF analysis for FY2022/2023
Source Eskom

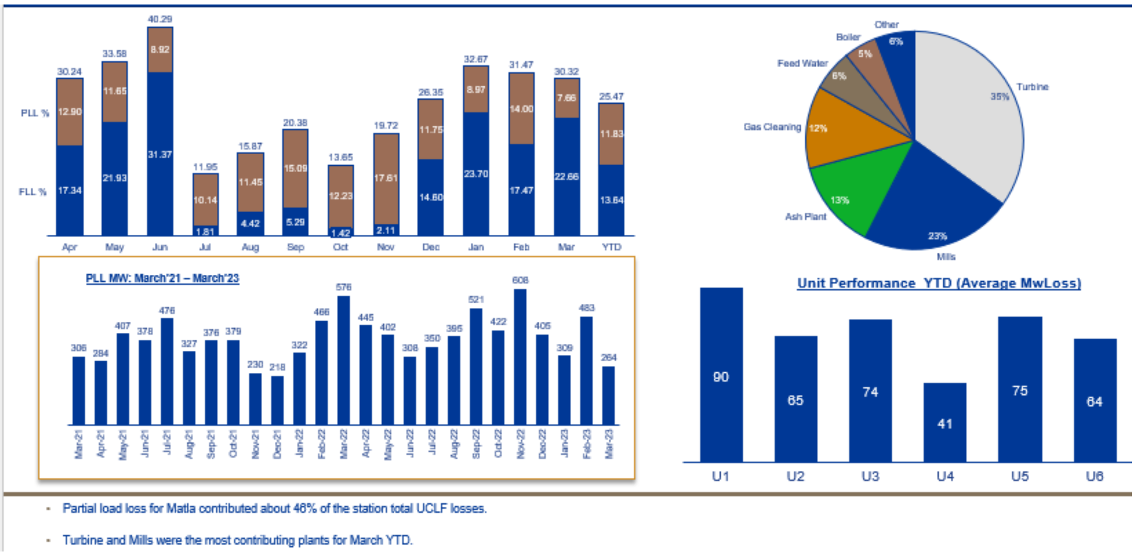


Figure 163: Matla reliability summary (FY2022/2023 YTD)
Source Eskom

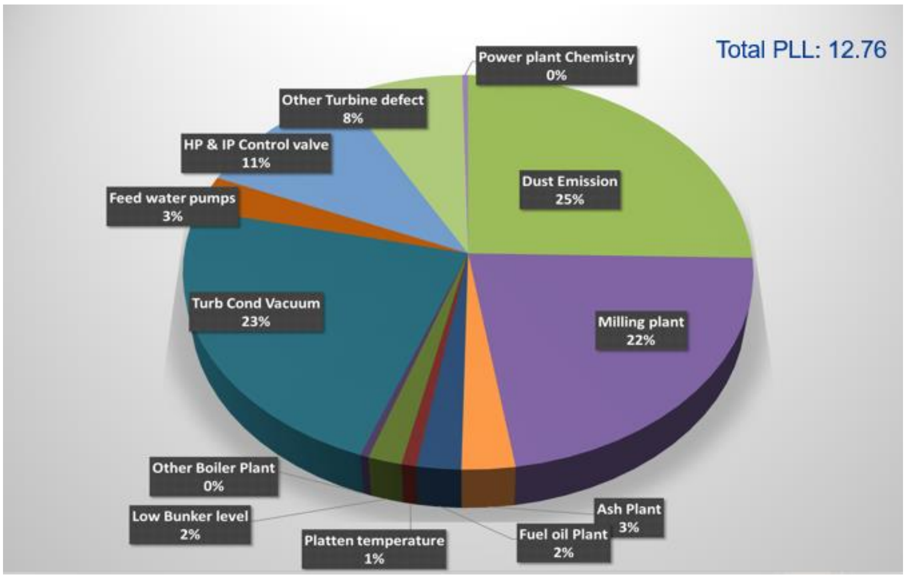


Figure 164: Matla PLL analysis (FY2022/2023 YTD)
Source Eskom

The highest contributor to Matla's unreliable operation in FY2022/2023 YTD was the turbines (including the CW system), contributing 35% of the lost MWs. Mills (23%) and the ash handling system (13%) were also major contributors. Table 75 below highlights the top five UCLF contributors for FY2017/2018 to FY2021/2022. Boiler tube leaks, vacuum, dust emissions and mills have consistently been among the top five over the past five years. The cooling towers have now been upgraded and therefore the vacuum problems should now be resolved.

	FY18	FY19	FY20	FY21	FY22
1	Boiler tube leaks	Mills	Mills	Gen Rotor Failure	Boiler tube leaks
2	Vacuum	Boiler Tube Leaks	Boiler tube leaks	Vacuum	Vacuum
3	Mills	Vacuum	Vacuum	Dust Emissions	Dust Emissions
4	Feedwater	Gen Rotor Failure	Emissions	Mills	Mills
5	Gen Rotor Failure	Emissions	Gen Rotor Failure	Bolier Tube Leaks	Gen Rotor Failure

Table 75: Matla Top 5 UCLF contributors (FY2017/2018 to FY2021/2022)
Source Eskom

Table 76 lists the current load losses per unit and the major constraints at the power station.

Current Load Losses	❑**Unit 1** – 100MW *Coal quality* ❑**Unit 2** – 100MW *Coal quality* ❑**Unit 3** – Planned Outages As on 21.03.2023 - 23.04.2023 (for High pressure pipe work inspection and replacement) – Day 7 / 35 – Repairs in progress; No Risk to RTS ❑**Unit 4** – 100MW *Coal quality* ❑**Unit 5** – 100MW *Coal quality* – 210 MW for the Mills unavailability ❑**Unit 6** – Unplanned outage from the 14.12.2022 – 01.05.2023 (Fire damage repair and doing outage in parallel – cooling tower refurbishment and centre line haul) – *As on 28.03.2023 – Day 103 / 135 - Repairs in progress; Risk identified to be cable installation for the protections; RTS on the 01.05.2023 @ 23:00*
Major Constraints	❑**Coal Availability -** Poor Coal Qualities low , Calorific Value ❑**Mills Unavailability / Reliability** - Overdue Services and overhauls Backlog - Unavailability of Spares ❑**High Stack Emission -** Dust/Ash Plant Unavailability / Reliability

Table 76: Matla current load losses and major constraints (FY2022/2023)
Source Eskom

Also, it is important to point out that the Matla power plant has been in operation for roughly 40 years and was due for a major rehabilitation ("mid-life upgrading"), which should had taken place in 2010–2013. However, this didn't happen, and it is a major reason for the deteriorating performance of the power station. Furthermore, major overhauls have been postponed as indicated in Table 77 below. Considering the power shortage in South Africa in the short to medium term, it will most likely be necessary to look at extending the life of Matla to 60 years (roughly 2044). This makes it even more urgent and important to carry out substantial maintenance and rehabilitation on this plant, especially since past overhauls have been postponed/deferred.

Unit No	No of Delays	Duration of delay	Timing	Reasons for delays
1	2	24 Months	2016-2018	System Constraints & Outage backlog
		24 Months	2021-2023	System Constraints , Outage backlog & ESP readiness
2	1	16 Months	2019-2021	Covid Regulations
3	1	26 Months	2021-2024	System Constraints & Outage backlog
4	2	29 Months	2013-2015	System Constraints
		42 Months	2019-2022	System Constraints, Outage backlog & Precip Readiness
5	2	24 Months	2017-2019	System Constraints & Outage backlog
		24 Months	2022-2024	System Constraints & Outage backlog
6	1	26 Months	2021-2023	System Constraints & Outage backlog

Table 77: Major outage deferrals at Matla (May 2022)
Source: Eskom technical status

5.14.2 Technical Status

More observations on the issues affecting EAF, PLL and the potential solutions are provided in the next two sections of this report.

5.14.2.1 Technical Status of the Boilers

During the visit, the team walked through the **boiler house**. The housekeeping was generally poor in the areas that are not easily accessible to clean and on ground level. Pulverised coal and ash dust was piled up on equipment. This presents a serious fire hazard. The fire in Unit 6 is no surprise and, if housekeeping is not improved, the station will remain at risk. Areas that are easily accessible are generally kept clean (e.g. the mill feeder area at 16m elevation; see Figure 59 and Figure 166). There is high amount of dust and visible pulverised coal leakages coming from mill feeder pipes. No other safety-related issues were established.

Figure 165: Coal dust on pipes and cable trays at Matla’s boiler house

Figure 166: Matla’s mill feeder floor at 16m level

The poor quality of the coal has a negative impact on the overall availability of the station (Table 76), leading to frequent BTF, amongst other things, and thus affecting station reliability. More information about the poor coal quality will be provided later.

As shown in Figure 167, below, the extent of BTF varied over the last six financial years, with 2018 seeing the highest number of leaks and 2022 the lowest. However, it does not indicate an increasing trend.

An analysis of 14 tube leaks in FY2022/2023 is provided in Figure 168. Short-term overheating and fatigue were the dominant failure mechanisms (29% each) followed by material flaws and long-term overheating (14% each), fireside corrosion due to defective protection shields (7%) and unknown causes (the remaining 7%).

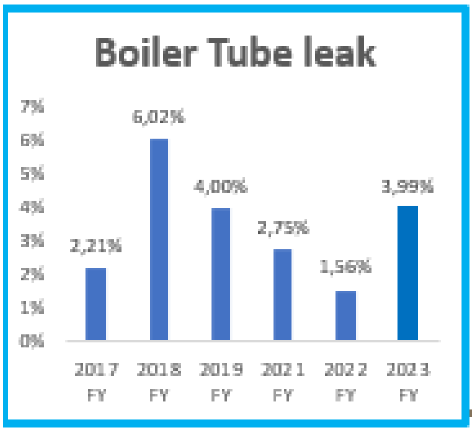


Figure 167: BTF as a percentage of Matla's total UCLF (FY2017/2017–FY2022/2023)
Source Eskom

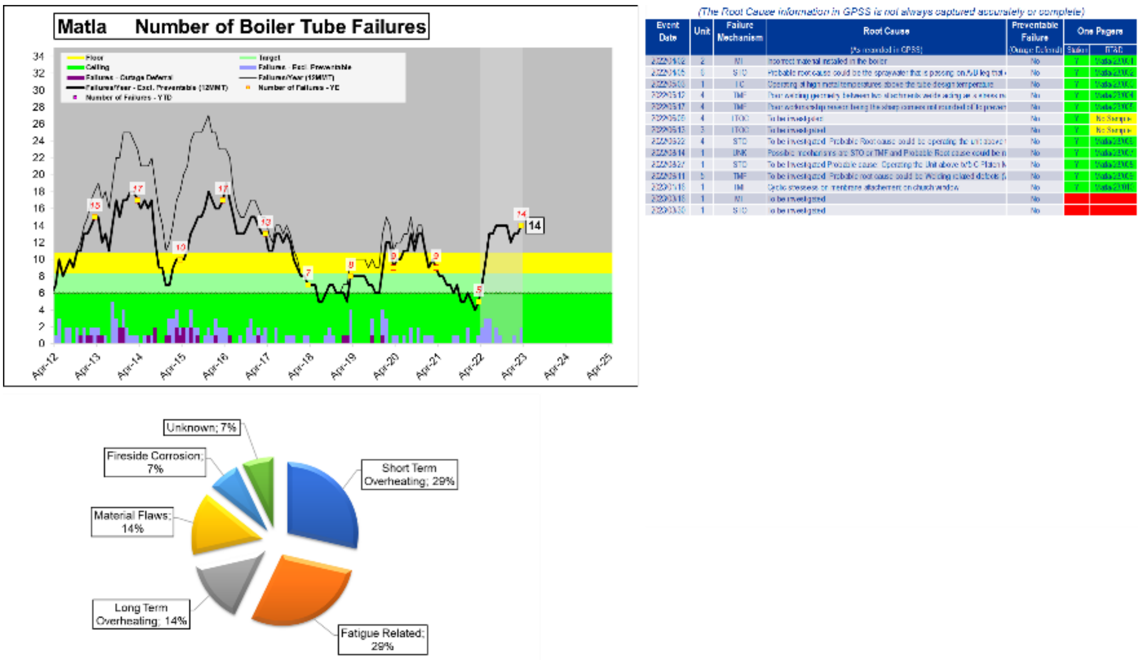


Figure 168: BTF performance and dominant BTF mechanisms at Matla
Source Eskom

The root causes of BTF at Matla are well known and documented (see Figure 169). High-risk areas have been identified with the secondary reheat being the highest risk area (see Figure 170). The planned scope of work to be performed during the overhaul of the units has been prepared in detail. One of the main contributing factors to the increase in BTF is the maintenance backlog due to delayed overhauls. Dedicated time and resources will be required during future outages to restore the reliable operation of the boilers. The work is already completed and the unit EAF has increased substantially.

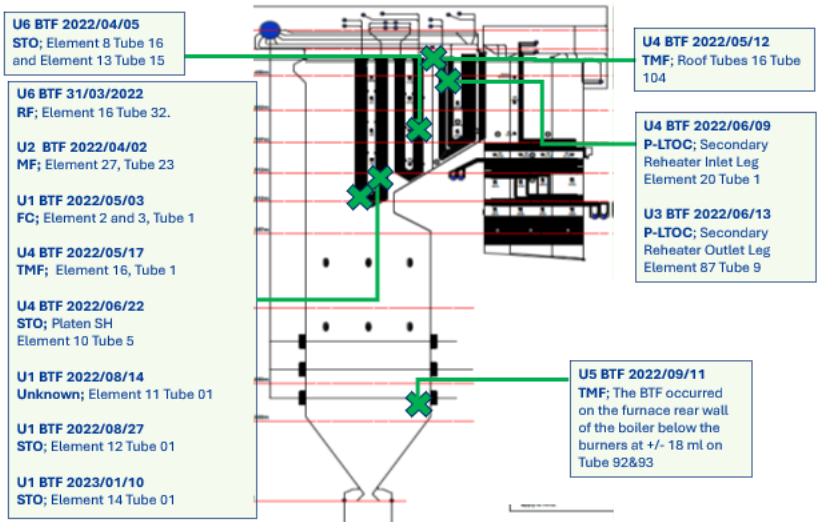


Figure 169: Boiler tube failures at Matla (FY2022/2023)
Source Eskom

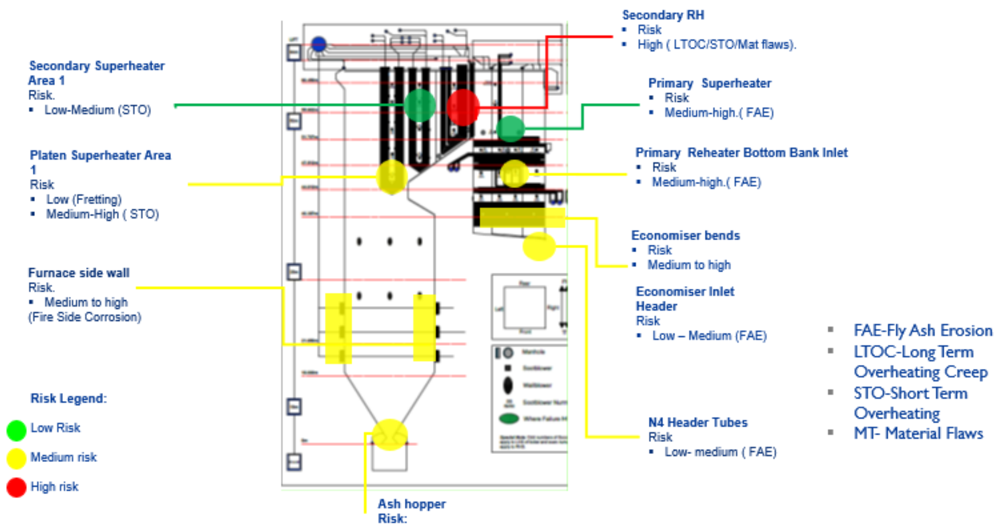


Figure 170: Matla's Unit 1–6 risk mapping
Source Eskom

Each boiler is fitted with six Babcock E Type ball mills. The station was designed to operate with four **mills** to produce 492.2 kg/s of steam (600 MW). Each mill has a capacity of 72 ton/h, but due to gearbox problems (vibrations), the mills were de-rated to 67.6 ton/h. With the design coal quality of 21.59 MJ/kg (AR), the coal flow would be around 264 ton/h; during acceptance testing, the heating value of the coal was 20.38 MJ/kg (AR), which then translated to 279.6 ton/h. Both these quantities were achieved while operating four mills. Currently though, the heating value of coal is in the 15.55–18.54 MJ/kg (AR) range, requiring five mills for full load operation.

This increases the operating hours of the mills, increasing the need for more frequent maintenance and the likelihood of failures. In fact, most of the time only four mills are available, which reduces the ability of the plant to operate at full load; derating is necessary. Also, corrosion has been experienced in the mill feeder pipes, resulting in leaks and risking fire hazards. Mill feeder pipes are now being replaced as part of the reconditioning of the mill. Lack of spare parts and poor contractor performance are additional contributing factors to mill unavailability.

The **draft plant** is in a reasonable to good condition. The secondary air heater elements have all been replaced (except for at Unit 1, where it will be done during the next long outage). The primary air heater piping needs to be replaced; preparation and planning for this has already been completed, but project funding is not yet allocated. Finally, the PA fans often operate at maximum capacity and contribute to load losses (see Figure 174). Limited capacity of the PA fans is likely to be caused by poor coal quality and high air-in leakage. According to design specifications, air-in leakage of SA should be around 13%, 2% of the PA and 5% through the boiler casing. Most likely, these values are exceeded, but there are no measurements to confirm it. A systematic assessment of the air-in leakage is recommended, as it has the potential to improve the performance of many plant components (e.g. fans, boiler, ESP, air preheaters, etc.).

Eskom uses the **Thermal Index (TI)** to monitor thermal excursions on boiler outlet headers, main steam piping and hot reheat piping. Since TI is a long-term indicator of the health of a unit, it can also be used to check the stability of boiler operation, as thermocouples indicate time spent above normal operating conditions.

The extracts from the TI report from FY2022/2023 (Table 78 and Table 79) show that the header and main steam temperatures are consistently above the tolerance limits, while the hot reheat pipework is well within the limits. This confirms the fact that bad coal quality is putting more stress on the boilers.

Component	***Design Temperature***	***Calculated Reference Temperature***	***Thermal Index Reference Temperature***
Platen Superheater Outlet Stub Boxes	535	529*	**529**
Secondary Superheater Outlet Stub Boxes	567	561*	**561**
Secondary Reheater Outlet Stub Boxes	571	574*	**571**
Main Steam Pipework	540	548	**540**
Hot Reheat Pipework	540	537	**537**

** Based on 100 000 hours nominal life*

Table 78: Steam operating temperatures at Matla
Source Eskom

	SYSTEM	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23
MATLA	Header TI	685	546	353	1454	531	363	20	187	846	1529	270	0	2381
	Maln Steam TI	89	78	119	128	104	104	252	71	89	110	68	62	62
	Hot Reheat TI	21	16	21	30	26	21	68	36	36	18	36	0	33

Tolerance Limits for Thermal Index:	
< 35	Favourable
36- 73	Acceptable
> 73	Unacceptable

Table 79: Extract from Matla’s Thermal Index report

Boiler at a glance:

- Bad coal quality is putting stress on both the boilers and mills. Systematic overheating in the boiler is also a sign of coal that is below specified quality and air flow rates outside specified limits.
- BTF is often caused by both high operating temperatures and maintenance backlog. More resources are needed to ensure reliable operation of the boilers and mills.
- Availability of mills is low due to a number of reasons; reduced heating value of coal results in higher throughput required to meet full load output; as a result, 5 (instead of 4) mills are required to operate at full load, increasing the operating hours of each mill. Reduced maintenance and availability of spare parts make the situation worse.
- Efforts should be made to assess actual air-in leakage throughout the boiler and try to reduce it. Also, combustion needs to be optimised, as this should reduce excess air.

5.14.2.2 Technical Status of the Machinery

Turbines: MAN impulse-type HP, IP and reaction-type double flow LP, triple-casing condensing turbines have been installed. The turbine hall is reasonably clean. Dust is present on all equipment but is not as bad as some other stations visited.

Figure 171: Turbine hall at Matla power plant

Matla power station has been running continuously for more than 40 years, and the turbines are currently on their designed operating hours (300 000 hours) for 30-year operation (refer to Table 80). Midlife refurbishment to extend the turbine operational life is essential.

Unit	Commissioning date:	Total Operating Hours Since First Commissioning
1	23/08/1979	306936
2	30/06/1980	299412
3	12/12/1980	307042
4	16/10/1981	296599
5	24/08/1982	291079
6	21/07/1983	294277

Table 80: Matla's turbine running hours since start to 01/2023 [42]

The steam turbine (along with associated equipment) has contributed to 6.54% of the total UCLF in FY2022/2023 (see Figure 172).

[42] Data supplied by Eskom as part of the initial documentation package.

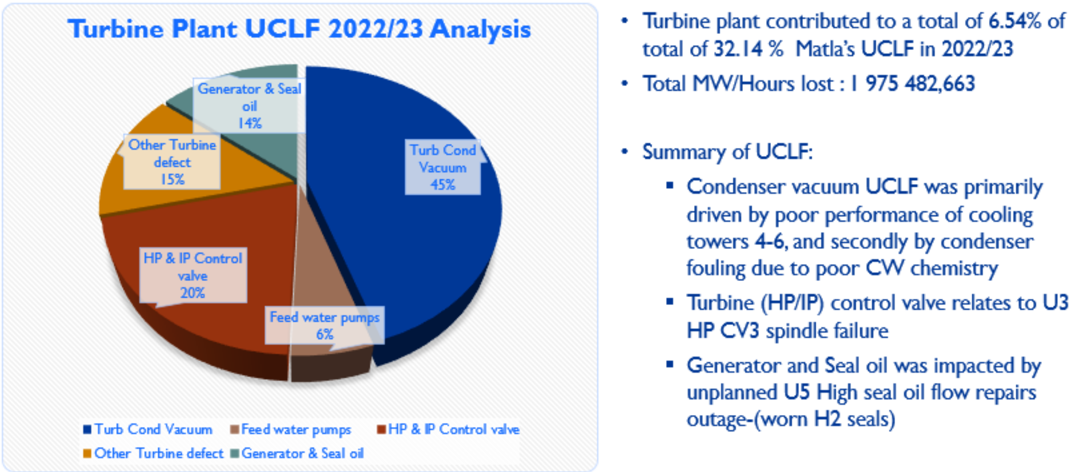


Figure 172: Matla's turbine plant UCLF FY2022/2023 analysis
Source Eskom

Refurbishment of all the **cooling towers** and the cooling water system is nearly complete and expected to improve reliability. The improvement of the vacuum UCLF after the completion of the cooling tower refurbishment project can be clearly seen in Figure 15.

Other components of the steam turbine system need attention too; mitigation measures and recovery plans are in place, but they need funding and outages to be implemented. Top priority projects are control air compressor replacement, LP pump house leak repair projects, Unit 2 standby generator B replacement, BFPT condenser retubing, turbine HP and IP loop pipes and flanges restoration and turbine IP bypass upgrading.

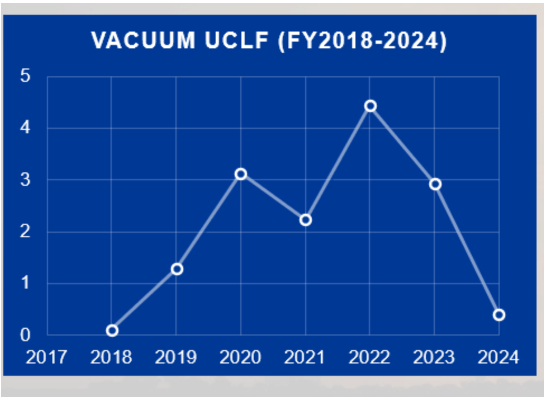


Figure 173: Vacuum UCLF at Matla (FY201/2018–YTD)
Source Eskom

Machinery at a glance:

- Improved maintenance is evident compared to May 2022.
- Upgrading of the cooling towers and cleaning of the cooling water system has reduced vacuum UCLF tremendously.
- Maintenance postponement and deferrals impacted heavily on turbine plant performance.
- Several upgrade and refurbishment projects are now at an advanced planning stage and, once implemented, will contribute to turbine plant performance improvement and PLL reduction.

5.14.2.3 Technical Status of the Electrical and C&I part

Assessment and maintenance of the complete electrical and C&I installations are carried out at regular maintenance intervals, while the tests are planned at annual intervals. Spares are in stock and available on the market unless otherwise indicated.

The **generators** at Matla power plant are manufactured by Alstom and cooled with hydrogen gas (rotor and stator) and demineralised water (stator only).

Rewinding was performed on the stators of all six units between 1997 and 2000. Electromagnetic Core Imperfection Detection testing was carried out on three generators between 2021 and 2023. The remaining three generator stators will be tested in 2023 and 2025 during unit GO’s (General Overhaul).

With the exception of the generator rotor defects at Units 4 and 6, no major investment in generators and auxiliary equipment is expected. Relevant work is planned for 2024. It should be noted that there is no spare generator rotor; one is due to be procured in 2024.

Medium voltage switchgears: The majority of medium voltage distribution boards, MV STN boards were replaced with new MV equipment during mid-life upgrading. The Operation/Protection MV board dates to 1978 and it is difficult to obtain spare parts.

Existing old medium voltage boards and switchgears at the ash handling plant (regardless of condition) need to be replaced, because there is a lack of spares, and the risk of failure needs to be reduced. Plans for refurbishment of the outside medium and low voltage switchgear are in place, but funding has not yet been allocated.

Low voltage switchgears: All LV boards were replaced/refurbished between 2010 and 2018. Only the Operation/Protection boards are the original. Existing old Operation/Protection boards, regardless of their condition, need to be replaced due to the lack of spares. Water treatment plant and slurry low voltage equipment needs to be replaced. Plans for refurbishment of the outside medium and low voltage switchgear are in place, but funding has not yet been allocated.

HV/MV unit transformers. The high voltage (HV) generator transformer for Unit 5 failed in 2017 with 30 days outage for reparation/replacement of the transformer. A spare generator transformer for Units 3-6 is scheduled to be purchased in 2024.

DC System UPS/chargers/batteries. DC System for Operation/Protection boards is obsolete and needs replacement.

Plant control system (DCS). The DCS Systems were commissioned in the period 2008 – 2018. Basic to intermediate maintenance and engineering expertise is available from the site team. Complex activities are still executed by the OEM (ABB). Partial replacement or migration to 800xA HMI and PGM is necessary in future.

Local control of the water treatment plant and ash handling. Spares are obtained from other power plants. The site team provides basic maintenance and engineering expertise with some support from third parties. The local Siemens Step5 system needs to be upgraded to Step7. The systems are obsolete and need refurbishment or replacement.

Turbine governors (turbine governing & control): The governors are obsolete and need replacement in all six units. The functional safety system (ESD) (HIMA vendor) is supported until the end of station life. Basic to intermediate maintenance and engineering expertise is available within the site team.

Field instruments are of poor to good quality; spares from ABB are available, but Siemens spares are scarce. For some aged instruments, maintenance or replacement is necessary (especially obsolete water treatment plant and slurry plant equipment).

PP drives are supported until the end of station life. Generally, they are of very good quality and durability. Spares are available in stock. Basic to intermediate maintenance and engineering expertise is available within the site team.

C&I cables and cable traces were refurbished between 2008 and 2018. The outside plant needs replacement.

Electrical and C&I at a glance:

- The equipment is well maintained; wear and tear are not significantly endangering the proper functioning of the equipment.
- Based on available documentation, site assessment and interviews with plant maintenance, engineering, and production staff, at the Electrical Plant, and C&I and DCS departments, the following topics and actions need to be considered in order to ensure reliable station operation:
    - Water treatment plant and slurry plant obsolete C&I field equipment need to be replaced.
    - Turbine governor is obsolete and needs to be replaced.
    - MV SGs and LV SGs - lack of spares for some obsolete SGs.
    - Purchasing of reserve generator rotor and generator transformer for Units 3-6.

5.14.2.4 Technical Status of the Water Treatment Plant

The raw water for Matla is obtained from the Vaal and Usutu River systems. The Vaal supply is relatively plentiful, but the water normally contains a high amount of suspended and dissolved solids. This increases the costs of water treatment and demineralisation.

Usutu water is substantially cleaner than Vaal water, but its supply to Matla depends on the level of consumption by Kriel and Kendal power stations. Usutu water costs less than Vaal water to treat, particularly to demineralise. However, Eskom’s allocation of this water is insufficient to meet Matla’s needs. The shortfall is therefore made up by using Vaal water. The water usage of the station is 3500 Mℓ per month at full load. Potable water is supplied to Matla from Kriel power station via a pipeline that is currently not in good condition and needs to be repaired.

Matla operates wet cooling and a wet ash system. The effluents from the water treatment processes are used as make-up water for transporting ash from the power station to the ash dams.

The capacity and quality of the make-up water plant is sufficient to cover the plant’s consumption needs. Samples are taken twice a day and the water’s key performance factors analysed.

The cooling towers were very recently replaced, as already mentioned, and a recovery plan is in place to ensure the full cooling water system is in good operating condition by August 2023.

Several refurbishment projects are planned between 2024 and 2028. These include the following unfunded projects: demin trains refurbishment p2, demin resin replacement p1 and p3, unit online analysis replacement, sand filters refurbishment p1 and the dosing station refurbishment. The following projects, which already have funding, are also included: Kriel Matla filtered water pipeline repairs, Matla Mobile RO plant, CPP resin replacement p3 and water treatment plant valves replacement.

Water treatment at a glance:

- The capacity of the demineralised water plant is sufficient despite high losses due to steam and water leakages.
- Upgrading and/or refurbishment of the water treatment plant is required and has been planned for. However, a large number of the projects are still unfunded.
- The plant is capable of producing water of sufficient quality and quantity if fully operational.

5.14.2.5 Technical Status of the Auxiliaries and other Systems

Coal supply to the plant used to be 100% from the Matla Exxaro mine, next to the station. The mine had three sources: Shaft 1 underground, as well as mines 2 and 3, both open cast mines. In 2018, Shaft 1, with the best coal quality, was closed. This reduced the coal supply from the mine to the Matla station to 60% of what is needed; the remaining 40% is now supplied via road haulage from various mines. The coal burned at the station varies from 600 000 to 1 200 000 tons per month depending on the MW produced. The average coal consumption of the station per year is around 12 million tons per year with FY2022/2023 being an exception with less than 10 million tons used. The Matla Exxaro mine is developing a new shaft to mine good quality coal but this shaft will not be operational before May 2025.

As Figure 174 indicates, high coal flow is the largest load loss contributor at the station with nearly 17 000 MWh lost in FY2022/2023. Station management claims bad coal quality could account for as much as 7–9% of EAF lost, but this would require further investigation to confirm. However, we can certainly confirm that it does have a substantial negative affect.

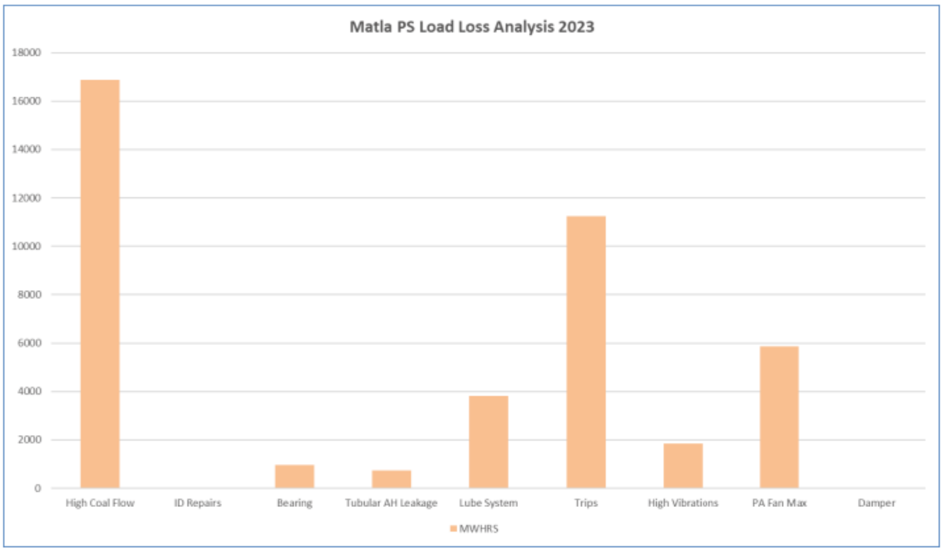


Figure 174: Matla load loss analysis FY2022/2023
Source Eskom[43]

Based on the mine's projected coal quality and supply tonnage and Matla's coal specification (Table 81)**,** the following can be concluded:

- Coal currently supplied by the mine does not meet design quality coal requirements. The heating value is low, and the ash is very high.
- The volume of coal received from the mine will be reduced to below 50% of the coal volume required in 2025, but the quality coal will meet the design specifications.
- Not until 2028 will the mine again be able to supply the full coal demand with the required coal specification.
- After 2035, coal from other mines will be needed once again but at much lower volumes than at present.

Gross Boiler Efficiency = 89.92%

	TM	IM	GCV_v	GCV_v	Net CV_v	Ash	Volatiles	Sulphur	Nitrogen	AI	HGI	Design FEGT	Milling Capacity
	% AR	% AD	MJ/kg MF	MJ/kg AR	MJ/kg AR	% MF	% MF	% MF	% MF	mg Fe	-	°C	%
Expected	9.00	4.00	21.60	19.65	18.89	29.94	20.99	1.07	0.99	>450	<55	1143	90.00
Distress	9.00	4.00	20.62	18.76	18.00	32.38	20.53	1.03	0.95				94.43
Original Design	9.90	5.00	24.00	21.62	20.83	19.10	24.80	1.11	-	200	50	1170	82.01
Acceptance Unit 1 1982	10.12	5.20	22.78	20.47	19.67	25.75	24.49	1.22	-	-	-	-	86.32

Assumptions (Boiler)				Max. Mill Output
Secondary A/H leakage %	Primary A/H leakage %	In-furnace leakage %	Oxygen %	T/hr
13	2	5	3.55	67.6
		Nominal mills for full load		5/6

Table 81: Matla coal specification

43 Draught group's Generation Engineering strategic report 2023: 474-12883

Source Eskom[44]

The overall condition of the **coal handling plant** was in order, with some maintenance and refurbishment already planned.

The ash and dust plant: The environmental license renewal will need attention, but station management is already working on this. As mentioned earlier, the coal supplied to the plant is of lower quality than the design coal. The ash content of the design coal is in the 19–25% range (see Table 82), whereas the plant is currently using coal with ash in the 30–40% range. As Table 82 indicates, the ash loading has increased substantially (60–70% increase), testing the limits of both the dust control and ash handling equipment.

	CV MJ/kg(ARnet)	CV MJ/kg(ARGross)	Ash %(AR)	Coal Feed Rate Required for 600MW ton/h	Ash Loading ton/h
Design Coal	20.84	21.59	24.61	264.03	64.97
Acceptance	19.69	20.38	27.65	279.66	77.32
240 Coal Spec Acceptance CV	18.93	19.58	29.66	291.06	86.32
240 Coal Spec Reject CV	18.30	18.92	31.33	301.23	94.36
Daily lower ranges of coal variability{	16.24	16.76	36.77	340.09	125.07
	15.09	15.55	39.82	366.49	145.93
	13.94	14.35	42.86	397.33	170.29

Table 82: Coal feed rate required and ash loading at Matla
Source Eskom

As a result of the addition of the dry dust pilot plant and selling ash to various users, the dust load has actually reduced at the ash plant. However, the particulate control system cannot handle the increased ash volume and does not comply with emission standards; upgrading of the particulate control system is needed. Finally, the ash pump needs maintenance attention.

[44] Eskom reference: Coal quality specification 240-71273834

Figure 175: Dust pilot plant at Matla

Auxiliaries and other systems at a glance

- Low coal quality and high ash content are limiting factors and the highest cause of UCLF and PLL at the station.
- This also leads to limitations in ash and dust capacity and handling. A detailed investigation is needed to identify short and long-term solutions for these problems.

5.14.2.6 Emissions

The Matla power station needs to comply with the new plant standards for PM, SO_2 and NO_X by 2025, in order to be allowed to continue operating[45]. Figure 176 shows the required emission levels by 2025 (note: originally planned for 2020 but compliance extended).

[45] 474-12865 air quality control Generation Engineering strategic report 2023 (Rev 1)

Station	Compliance status immediately on decision			MW loss
	PM (limit)	NOx (limit)	SO_2 (limit)	
Duvha	50	1100	2300	200
Grootvlei	50	1100	3500	0
Kusile	50	500	750	0
Lethabo	50	1100	2500	3558
Matla	50	750	2800	3450
Arnot	50	1000	2500	0
Hendrina	50	1100	3200	0
Matimba	50	750	3500	0
Medupi	50	750	3500	600
Tutuka	100	1100	3400	3510
Camden	50	1100	3200	0
Kendal	50	1100	2600	3840
Kriel	100	1100	2800	800
Komati	100	1100	2600	0
Majuba	50	1300	3200	0
Acacia	50	600	500	0
Port Rex	75	600	500	0
Total				15958
Comply with limit	Not comply		Risk of non-compliance	

Station	Compliance status April 2025			MW loss
	PM (limit)	NOx (limit)	SO_2 (limit)	
Duvha	50	750	1000	2875
Grootvlei	50	1100	3500	0
Kusile	50	500	750	0
Lethabo	50	750	1000	3558
Matla	50	750	1000	3450
Arnot	50	1000	2500	0
Hendrina	50	1100	3200	0
Matimba	50	750	1000	3690
Medupi	50	750	1000	4320
Tutuka	50	750	1000	3510
Camden	50	1100	3200	0
Kendal	50	750	1000	3840
Kriel	100	1100	2800	800
Komati	100	1100	2600	0
Majuba	50	750	1000	3843
Acacia	50	1300	3200	0
Port Rex	50	1300	3200	0
Total				29886
Comply with limit	Not comply		Risk of non-compliance	

Figure 176: Minimum emission standards/postponement decision (30 October 2021)
Source: Eskom[45]

Presently, the plant does not comply with PM requirements. The required limit is 100 mg/Nm^3 and the plant emits above this level. PM needs to be reduced below 50 mg/Nm^3 before 2025. This could be achieved by upgrading of the particulate control system; also, reduction in the ash content of the coal would be helpful.

NO_x emissions need to be kept below 1 100 mg/Nm^3 and the plant complies marginally with this requirement. By 2025, NO_x emissions need to be kept below 750 mg/Nm^3. This could be achieved with low NO_x burners at a cost of \$ 20–30/kW. Replacing the burners is an opportunity to also optimise combustion which should result in lower excess O_2 and lower overall air flow through the system, which should help the draft (PA, SA, and ID) fans.

We understand that, presently, the Matla plant complies with SO_2 requirements (3 50 mg/Nm^3), but it will need to comply with the reduced requirement of either 500 or 1 000 mg/Nm^3, which comes into effect in 2025. Reaching 1 000 mg/Nm^3 would require approximately 70% SO_2 reduction, which could be achieved through installation of SO_2 control equipment. For this level of SO_2 reduction, dry SO_2 control technologies would be applicable. If the limit is 500 mg/Nm3, nearly 85% SO_2 reduction would be needed, which most likely requires wet FGD. Coal with lower sulphur content may help, but it depends on whether it is available and at what price.

Emissions at a glance:

- ESP upgrading is urgently needed on Unit 1 to comply with 50 mg/Nm^3. High frequency transformer replacement required on three units.
- The plant needs to lower NO_x emissions by 2025; low NO_x burners seem to be the first choice.
- Matla needs to assess how it will comply with SO_2 control requirements. The applicable limit needs to be clarified (whether it is 1 000 mg/Nm^3 or 500 mg/Nm^3). SO2 controls would be needed; dry SO_2 control technologies for 500 mg/Nm^3 and wet FGD for 1 000 mg/Nm^3. Low sulphur coal, if available, could help too. A more detailed evaluation is needed.

5.14.2.7 Spare parts warehouse and maintenance workshop

We also visited the spare parts warehouse and maintenance workshop. The workshops are clean, well equipped and have the necessary staff to carry out repair work. They are even the go-to workshop for other stations like Kriel and Kendal, assisting them with repair work.

There is a lack of spare parts due to budget cuts and inadequate funding. There are not always enough spare parts for the running of the units and for preventive maintenance. Some critical spare parts are no longer available on the market, but it should be noted that their production and procurement is possible.

Spares at a glance:

- There is a lack of spare parts for running and preventive maintenance programs. OEM spares for mills are a good example.
- The costume-sized crane needed for mill maintenance is beyond economic repair and a replacement is urgently needed.

5.14.3 Technical Measures to Improve the Plant Condition

Coal Quality: To address the coal quality problem in the short term, the quality specification of the road-hauled coal should be improved, and measures should be implemented to blend this coal with the mine-supplied coal, to obtain a blend that meets the design requirements. Alternatively, the station performance requirement needs to be de-rated until 2028, when the mine can again provide the required volume of compliant coal. A study to unpack this and the related ash handling constraints and then make recommendations is recommended.

Boiler: The root causes of frequent BTF at Matla are well known. High-risk areas have been identified and the scope of work to be carried out during the overhaul of the units has been planned in detail. The main contributing factor to the increase in BTF is reduced coal quality and the resulting increase in coal flow, as well as the maintenance backlog due to delayed overhauls.

Mills: According to the station management, mill maintenance has increased by 50% as a result of the increase in coal flow because of lower-than-specified coal quality. Mill feeder pipes now also need to be replaced regularly. Inadequate availability of OEM spares to maintain the mills is a large constraint at present.

Machinery: The postponement and deferral of upgrade projects impacted heavily on turbine plant performance. Several upgrade and refurbishment projects are now at an advanced planning stage and, once implemented, will contribute to turbine plant performance improvement and PLL reduction.

Ash and dust plant: Reduced coal quality has a significant impact on the volume of ash and dust produced (60–70% increase). The dust plant is not in good condition, cannot handle the ash volumes produced, does not comply with emission standards, and needs to be refurbished or replaced. Ash pump maintenance is an area in need of maintenance attention.

Emission controls: By 2025, the plant will have to comply with stricter SO_2 and NO_x emission requirements. SO_2 emission controls are likely to require FGD of some type (dry or wet), depending on the specific requirement (1 000 or 500 mg/Nm^3), and the ability to reduce the coal's sulphur content. A comprehensive assessment of the options is recommended. NO_x emission requirements will likely call for low NO_x burners, which should be adequate to meet the emission standards.

5.14.4 Power Plant Management

Currently, around 690 employees are working at the power plant. The management team is stable and seems to be very capable and efficient when it comes to addressing operational issues at the power plant. The confidence and performance of the management team has improved since May 2022.

There are knowledgeable and experienced people in most technical areas of the plant, especially in the maintenance department. Staff turnover is 7%, which is acceptable but should be lower.

The plant management has no ability to make its own decisions regarding the necessary contracts for procurement of works, services, and supplies. This needs to change.

Timely release of adequate funding for outages, accelerated lead times and spare deliveries would enable the execution of outages and planned repair work, which are essential to avoid further deterioration of plant reliability. The situation has, however, already improved significantly since May 2022, when deferred and delayed outages had a major impact on plant performance.

A clear decision must be made as to whether the power plant will continue to operate after 2035. This would give the staff clarity regarding the future of the station.

Maintenance

The maintenance team is responsible for providing adequate resources to meet repair and servicing requirements reported by the operation team. The scope is defined by the engineering department. The maintenance group is responsible for spare parts and consumables inventory and planning, including for training and development of the work force. The maintenance and storage system are fully integrated in SAP System.

Maintenance work is heavily outsourced. The maintenance contracting staff at Matla outnumber Eskom employees by 2 to 1 (577 contracting staff vs 256 own staff members). This situation needs to be changed because core expertise is vested in contractors and IP is being lost, and there is no continuity in the maintenance department. This situation is particularly evident in the maintenance and operation of the milling department. To make matters worse, only 18 supervisors are available to supervise and coordinate the work but a minimum of 24 is required. The current senior technicians will be trained and authorised to do contract supervision.

We recommend that maintenance of the mills be carried out, in the main, by the plant's own personnel.

In the past, it was not uncommon for maintenance on units to be deferred or delayed by 16 to 42 months. (Table 77 provides this detail). In addition to this, the quality of work done was inadequate, resulting in units returning to operation with defects. Unit 4 was the first unit where the all the necessary maintenance was carried out. - Its performance after the overhaul shows the difference: EAF 80%, UCLF 3% and OCLF 8%.

In terms of maintenance, Matla is evidently shifting from crisis management mode to reliability mode, which is how it should be.

Operation

Operation of the units is overseen by lead plant operators. The plant operation staff are doing a good job and only 3 of the 68 trips in FY2022/2023 were operator related. There are still a number of operator vacancies at each unit that needs to be filled as soon as possible. Shift operators are missing as well. There are 15 minutes of handover-overlap at the start and end of each shift, so 30 minutes of overtime on every shift. Overtime is very high. Training and mentoring, as well as a new up-to-date simulator, are required and need to be a priority.

Outages

Planning for outages at Matla power station is in line with the outage philosophy, which was revised to be in line with the Gx 2035 shutdown plan. The scope and frequency of outages are based on the 12-year remaining lifespan as per the Gx 2035 plan with ensuring statutory compliances. The funding for interventions and technical upgrading is based on 12-year remaining lifespan return on investment. This principle makes some upgrades or refurbishment projects unviable, which is not a true reflection of their operational situation.

Unit 6 was put on forced outage due to a fuel oil fire on14 December 2023 and was returned to service in May 2023. The GO on this unit was due in August 2020 but was postponed 16 times until the fire. The UCLF outage was used as an opportunity to carry out HP and IP turbine assembly maintenance and stub box replacement (3 off), which was part of the GO scope of work. The full GO could not be done due to low readiness. The plant's 5-year outage listing is provided in Table 83 below, but all these outages still need confirmation. The preparation time necessary for outage planning is 24 months. If outages were carried out as planned, damage would not be exacerbated, the planned overhaul work could be executed, and good plant performance restored.

OutageID	Outage Code	Unit	Planned/Actual Start Time	Planned/Revised End Time	Outage Description	Planned Duratio
43905	ML06UST-17-06-2023	6	2023/06/17 00:00:00	2023/06/18 23:59:00	Cold R/H NRV Inspections and repairs	2,00
42200	ML05UIN-23-06-2023	5	2023/06/23 00:00:00	2023/07/06 23:59:00	IN	14,00
24403	ML01UMO-15-12-2023	1	2023/12/15 00:00:00	2024/06/11 23:59:00	MO + ESP Upgrade	180,00
38247	ML02UIR-21-12-2023	2	2023/12/21 00:00:00	2024/01/07 23:59:00	HPPW Inspections	18,00
43888	ML03UST-22-12-2023	3	2023/12/22 00:00:00	2024/01/01 23:59:00	T1 & T2 HSSD	11,00
43891	ML05UST-27-03-2024	5	2024/03/27 00:00:00	2024/04/02 23:59:00	Spherical Header Inspections	7,00
24428	ML05UGO-07-08-2024	5	2024/08/07 00:00:00	2024/10/25 23:59:00	GO	80,00
38253	ML04UIP-22-09-2024	4	2024/09/22 00:00:00	2024/10/05 23:59:00	IR	14,00
38255	ML06UIR-07-11-2024	6	2024/11/07 00:00:00	2024/11/20 23:59:00	IR	14,00
24410	ML02UMO-01-12-2024	2	2024/12/01 00:00:00	2025/01/25 23:59:00	MO	56,00
24415	ML03UGO-08-05-2025	3	2025/05/08 00:00:00	2025/07/26 23:59:00	GO	80,00
24429	ML05UIR-25-10-2025	5	2025/10/25 00:00:00	2025/11/07 23:59:00	IR	14,00
24434	ML06UMO-10-05-2026	6	2026/05/10 00:00:00	2026/06/21 23:59:00	MO	43,00
24423	ML04UGO-10-06-2026	4	2026/06/10 00:00:00	2026/08/28 23:59:00	GO	80,00
24412	ML02UIR-03-10-2026	2	2026/10/03 00:00:00	2026/10/23 23:59:00	IR	21,00
24405	ML01UGO-05-12-2026	1	2026/12/05 00:00:00	2027/02/22 23:59:00	GO	80,00
38251	ML03UIR-08-12-2026	3	2026/12/08 00:00:00	2026/12/21 23:59:00	IR	14,00
38248	ML02UMO-24-04-2028	2	2028/04/24 00:00:00	2028/06/18 23:59:00	MO	56,00
24417	ML03UMO-10-06-2028	3	2028/06/10 00:00:00	2028/08/04 23:59:00	MO	56,00

Table 83: Matla 5-year outage listing
Source Eskom

Project Schedule

The current capital investment project schedule for Matla power station is based on the 2035 plant decommissioning strategy. From 2023 to 2032, the station has 82 capital investment projects scheduled, with a total estimated capital investment requirement of R 6 005 million. Table 84 provides the annual capital expenditure required, based on Eskom's 50-year plant life plan.

Financial Year	Capital Required (Million)
2025	R2 349
2026	R1 522
2027	R801
2028	R519
2029	R417
2030	R264
2031	R132
2032	R2
Total	**R6 005**

Table 84: Matla's annual capital requirement based on 50-year life plan
Source Eskom

National Treasury requested that the 60-year plant life or 2045 investment plan information also be provided. The information provided by Eskom on this is three years old but should provide an indication of what could be expected. According to this plan, the station has 181 capital investment projects scheduled between 2024 and 2043, with a total estimated capital investment requirement of R 48 078 million. Table 85 shows the annual capital expenditure requirement based on Eskom's 60-year plant life plan.

Financial Year	Capital Required (Million)
2024	R3 309
2025	R4 320
2026	R3 374
2027	R4 256
2028	R5 037
2029	R5 921
2030	R6 811
2031	R3 965
2032	R4 597
2033	R1 082
2034	R1 190
2035	R916
2036	R981
2037	R368
2038	R351
2039	R333
2040	R300
2041	R308
2042	R324
2043	R336
Total	**R48 078**

Table 85: Matla's annual capital requirement based on 60-year life plan
Source Eskom

5.14.5 Technical Profile of Main Plant Areas

The following table provides the key design data, key types of equipment and suppliers.

Boiler Manufacturer	Babcock Engineering
Type	Drum boiler
Coal mass flow [t/h]	2100 t/h (total station)
Pressure [MPa, absolute]	16.1 – superheat
Temperature [°C]	540 – main steam
Firing system	
Number of burners	4 to 5 mills, 48 burners per boiler
Type of mills	Babcock E type ball-mills
Mill capacity [t/h] – per mill	72
Reheat system	
Pressure [MPa, absolute]	3.84
Temperature [°C]	535
Coal supply	
Coal supply (truck, mine)	Mine & trucks
Coal storage capacity on-site (t)	130 000 tons
Boiler bunker capacity (t)	7000 tons per boiler
Precipitators	
Manufacturer	Lurgi
Type	Sigma type CE plates
Wet ash handling and dry dust handling	

Machinery and Electricals

Turbine	
Manufacturer	MAN
Type	Multi-cylinder impulse reaction
Casings (HP-IP-LP, double/single flow)	HP (single)-IP (double)-LP (four)
Steam volume (kg m/s)	492
Main steam pressure [MPa, a]	17.2
Main steam temperature [°C]	540
Reheat steam pressure [MPa, absolute]	3.84
Reheat steam temperature [°C]	535

Cold end	
Condenser	Dual-pressure surface type
Cooling tower	Hyperbolic natural draught, wet cooling
Generator	
Manufacturer	Alstom
Terminal voltage	20 kV
Rating	689 MW normal
Cooling system	Hydrogen @ 400 kPa
Transformer	
Manufacturer	ASEA Electric
Terminal voltage primary/ secondary	420+6/-10x1.56%/22 kV
Placement	Between units and HV yard

5.15 Medupi Power Plant

The Medupi power plant has a generation capacity of 4 764 MW_{gross}. However, a portion of this capacity, specifically 794 MW, is at present unavailable due to the unfortunate H_2 explosion of the Unit 4 generator in 2021. It is anticipated that the unit will require several more months until it becomes operational again.

The plant has a design gross efficiency of 41.36% when operating at its rated turbine MCR. Currently, the plant maintains an EAF of 70.80%. However, there is potential for improvement, and it is realistic to aim for an EAF higher than 85%. Achieving this goal would result in a consistent increase of 563 MW in generation capacity.

Significant progress has been made at Medupi over the past year, with a particular focus on critical areas and proactive maintenance initiatives. The reduction of unit trips has led to notable improvements in overall performance, and the MSMW programme is advancing well, already demonstrating its positive impact. The most critical areas of concern, such as the mills, dust handling plant, PJFFP, and spray water valve plants, have been effectively addressed.

The precondition to achieve the higher EAF is a change in leadership[46] and the decision-making process, to allow efficient use of assets and resources, as all other factors needed for higher EAF are available or can be managed. Compared to international benchmarks, the budget to operate the plant is high enough, the technical design and plant condition are both good and qualified personnel are available in South Africa.

The root cause for the low performance of the plant is Eskom's organisational structure, which gives plant management very restricted authority to make decisions and which and enables a high degree of interference by Eskom head office. The plant is not operated as a profit centre but is part of a portfolio, so profits and budget overruns are diluted throughout the coal fleet.

Decisions by plant management require endorsement at several stages within Eskom Generation. This does not serve the day-to-day requirements of the plant, which needs to be able to act immediately in case of a malfunction or defect.

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[46] The term *leadership* is used to describe the ability of the organisation to enable groups of people to work together and to accomplish what they could not do working individually. Leadership includes the motivation influencing and guidance of the team, setting of visions and goals, it defines the suitable organisation, the procedures and the communication and decision-making requirements and governance rules in the organisation. The difference to management is that leadership challenges and changes the existing organisation, procedures and decision making and drives towards the real needs to achieve the goals. Leaders do not stop at the limits of the job description but take-up tasks where necessary to achieve the goals. The use of leadership in the reports is not meant to pointing at individuals in the organisation of Eskom but describes the business culture which is reflected by different levels of Eskom management personnel, the limitation of authorities and empowerment of managers (leaders) in the organisation.

A philosophy of contracting OEMs, while including the spares supply under these maintenance contracts, has been adopted to enhance the efficiency of the maintenance services delivered in specific plant areas. However, it is important to note that this approach primarily yields short-term benefits, as the long-term gains of capturing the spare parts usage data within the ERP system, while not managing the spares procurement and issuing through the stores, are lost.

Medupi seems to have made significant progress in shifting away from blaming problems on original design and plant construction and is starting to take ownership of the plant and its performance. The drive to implement the maintenance strategies has already led to considerable improvements.

Improving the level of experience within the outage department is crucial to improving their ability to inspect, assess and scope the required maintenance work. We recommend allocating more senior management personnel to mitigate and manage risks effectively, as identified risks during outages often seem to be managed solely by the outage manager. Additionally, addressing the lack of aggressive quality control on the work performed by contracted or internal maintenance staff requires focused attention, training and disciplined management practices.

Within the maintenance department, there is significant room for improvement in terms of the ownership exhibited by maintenance supervisors towards the plant. Further development is needed to ensure complete ownership and understanding of constantly ensuring plant availability. Disciplined management and quality control practices are also lacking and should be improved, to ensure the correct execution of work and to leave the plant in a better condition after every maintenance intervention.

The understanding and management of the spare parts procurement process within the maintenance department needs improvement, to enable better specifications, streamline the procurement process and enhance overall efficiency.

In terms of staff compensation, Eskom needs to consider the additional costs and hardships faced by personnel working in remote locations. Failing to acknowledge and value their dedication may lead to valuable human resources responsible for plant operation, maintenance and support engineering being lost to more enticing job opportunities.

We recommend strengthening the operation maintenance and outage departments with experienced personnel or strong technical advisors and project managers, to stabilise Medupi during the winter season and reduce the downtime required for unit recovery after trips or maintenance.

The handover of plant documentation from Eskom Group Capital department to Eskom Generation has not taken place, resulting in the inability of the plant operation and maintenance teams to safely operate the plant and carry out prudent equipment maintenance.

The various factors contributing to the significant deviation from the best practice performance of the plant have been analysed and are presented in detail below, and recommendations for improvement the situation are made. By applying prudent plant operation and maintenance and fast-tracking efforts to eliminate key gaps, the plant's performance can be lifted without major investment.

Please note, the raw water treatment plant in Matimba, which also serves Medupi, poses a threat to the continued operation of the entire plant. It is being operated far beyond its design limits and requires urgent and significant equipment refurbishment.

The other key risk is the slow progress in constructing a desulphurisation plant, which is a legal requirement for operation of the plant beyond 2025.

The key risk aspects need to be addressed as top priorities by head office at Eskom, with an emergency implementation arrangement.

5.15.1 EAF and PLL

Table 86 shows the operating thermal performance of the units for FY2022/2023. The unit efficiency is in the range of 38.2% to 40.1% compared to design of 41.36%.

Parameters	Unit 6	Unit 5	Unit 4	Unit 3	Unit 2	Unit 1
Efficiency (%)	40.1	41.4	Not in operation	38.6	38.4	38.2
Calorific value (MJ/kg)	19.1	19.1		19.1	19.1	19.1
Coal burnt (M Tons)	1.5	2.2		2.6	2.3	2.7
Unit sent out (GWh)	3 199	4 793		5 303	4 587	5 365

Table 86: Operating performance of units at Medupi (FY2022/2023)

As shown in Table 87, the EAF value for FY2022/2023 is 70.5% (without Unit 4) for the plant compared to a target of 81.6%. Among all the units, Unit1's EAF is 90.9% whereas Units 2, 3 and 5 are in the range of 76.9% to 79%. Unit 6 shows the lowest EAF at 53%.

Parameters	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Plant
Energy availability factor (EAF)	90.9%	76.9%	87.9%	0.0%	79.0%	53.0%	70.5%
Energy availability factor target (EAF)	81.6%	81.6%	81.6%	81.6%	81.6%	81.6%	81.6%
Unplanned capability loss factor (UCLF)	8.2%	5.9%	10.1%	100.0%	18.6%	23.1%	21.1%
Planned capability loss factor (PCLF)	0.9%	17.2%	1.9%	0.0%	2.4%	24.0%	8.4%

Parameters	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Plant
Other capability loss Factor (OCLF)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Partial load loss (PLL - MW)	28	20	48	0	79	60	236

Table 87: Unit-wise EAF at Medupi power plant for FY2022/2023

Table 88 shows the EAF, UCLF, PCLF of plant for FY2019 to FY2023, for operation vs target. Over the years, EAF has improved from 59% to 70% for the plant as a whole, and the UCLF has dropped from 29% to 23%. However, it should be noted that the current UCLF percentage is very high for such units. The low EAF is caused, in main, by the high UCLF. The main UCLF sources are shown in the Figure 177.

Year	EAF %	UCLF %	PCLF %	UAGS Trips
2019	59.54	29.16	11.29	102
2020	64.44	26.23	8.89	78
2021	57.90	24.43	17.63	79
2022	62.96	26.30	9.06	92
2023	70.80	23.59	5.6	48

Table 88: Medupi's operating performance improvements (FY2018/2019–FY2022/2023)

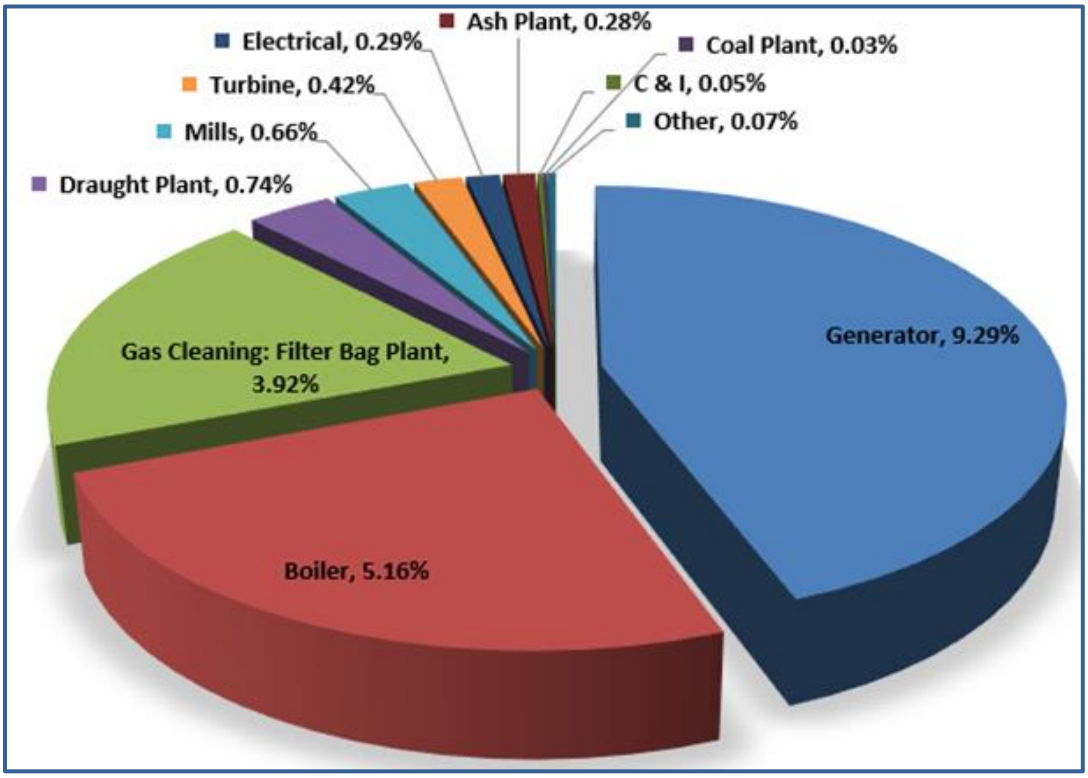


Figure 177: Medupi UCLF breakdown for FY2022/2023

Although all the plant subsystems have an impact on the higher UCLF, the major contributors are the generator, boiler, gas cleaning plant, the draught plant and the mills. The turbine, electrical system and ash plant are the other important areas responsible for higher UCLF. The unit within Medupi that contributes most to the high UCLF is Unit 6, followed by Unit 5, Unit 3, Unit 1 and Unit 2. There are many reasons for the high UCLF, including design, improper operation, lack of highly skilled staff, lack of spares, planning, etc.

5.15.2 Technical Status

5.15.2.1 Top Issue List

Presently, the plant maintains an EAF of 70.80%. There is considerable potential for improvement, with a realistic chance of surpassing an EAF of 85%.

To enhance system reliability and boost the EAF of Medupi, a combination of short-term and long-term solutions is recommended. In the short term, measures should be implemented to address the major issues currently hindering performance, which have the potential to increase generation capacity by 400 MW. Additionally, the restoration of Unit 4 alone could provide an additional 612 MW (720 MW reduced for 85% EAF). In the long term, further measures suggested could contribute an extra 360 MW.

PJFF

One of the major contributors to the UCLF of the boiler is the PJFF. PJFF has an UCLF of 3.92% for FY2022/2023.

The lifespan of the PJFF bags is very short, lasting less than a year. This is primarily due to high flue gas volume flow, caused by the increased excess air ratio, as well as the high flue gas inlet temperature caused by the choking of the gas air heater. In order to reduce the temperature, tempering air is mixed with the flue gas at the inlet of the PJFF, which increases the flue gas volume, which in turn leads to high airflow velocity across the bags and overloading of the ID fans. The high dew points of the compressed air used for pulsing the bags and conveying contribute to bag choking and high DP across the filter bags. Furthermore, increased moisture in the instrument air causes instrumentation malfunctions. The non-availability of critical spares results in lower throughput of the compressors.

It is understood that the PJFF plant design capacity is marginally adequate and that even the slightest degradation of the plant results in PLL and UCLF. When additional factors impact plant performance from upstream and downstream plants, impacting the conditions within the PJFF, large capacity losses are experienced.

The major design areas indicated are the overall filter material to air volume ratio (cloth-to-air ratio) which seems to be at the high end of acceptable design practice and the available redundant PJFF capacity (cells or chambers) at boiler MCR to allow maintenance work on the PJFF or to deal with associated plant breakdowns or bag failures. It is therefore critical that PJFF plant maintenance is of a high standard and that the associated upstream and downstream plants receive similar attention, to reduce the impact on the PJFF plant performance.

In addition, the high sulphur content excursions in the coal are detrimental to the PJFF performance if not managed decisively and persistently.

Short-Term Solutions

- Maintenance of the PJFF plant needs to be of a high standard, and breakdowns need to be attended to as soon as possible. Due to the capacity constraints, online bag replacement practices will have to be continued.
- Prioritise the procurement of critical spares for the compressors, to facilitate planned servicing and overhauls.
- Continuously upgrade the skill level of both Eskom and outsourced manpower deployed for PJFF operations and maintenance.
- The associated plant, including the GAH, DHP, ID Fans and compressor plant, needs to be afforded the same care and attention as the PJFF plant, to minimise the impact on the PJFF performance.
- Due to the high sulphur content excursions in the coal, exceeding 1.3%, it is critical to implement strict operating procedures.

- Regularly monitor the dew point of the compressed air and maintain it as per design. Ensure the proper functioning of compressor dryers and auto moisture drain valves.
- Avoid mixing tempering air into the flue gas before the PJFF section, to maintain the temperature at the PJFF inlet as per design.

Long-Term Solutions

- Maintain an adequate reserve of spares for solenoids, components and pulsing controllers. The availability of these items is crucial for the efficient pulsing operation of the bag filters and to minimise emissions.
- Improve the overall filter cloth-to-air ratio and increase the overall capacity, to increase the redundancy of the PJFF cells. The current indicated changes to modify the PJFF from a side entry design to a bottom entry design will only marginally improve the PJFF.

Draught System

There are two distinct issues within the draft group, which has an UCLF of 0.74% for FY2022/2023

The first is the performance of the gas air heater, which - similar to the PJFFP - seems to be due to the design. It was mentioned that the differential pressure across the GAH is high, adding to the increased load on the ID fans. Furthermore, the heat transfer through the GAH is not as high as required, leading to higher flue gas temperatures, which result in the mixing of tempering air in order to reduce the inlet air temperature into the PJFFP. Due to the high DP and the increased boiler Lambda value, the GAH has experienced high wear to the casing and outsides of the heat transfer packs. There are also clear indications of sulphur deposition, resulting in GAH choking.

The flue gas ash removal system, responsible for removing the coarser fly ash before the GAH, is either not commissioned or not operated regularly and optimally. The positioning of the system hoppers has the potential to overflow onto the GAH at the transition from the cold air to the hot flue-gas side.

The second area of concern is the excessive wear within the hot air ducting from the GAH to the mills and the boiler secondary air inlets at the burners. This is probably a result of the combination of large amounts of ash carryover from the flue gas ash removal system through the GAH and the additional air volume through the system.

Short-Term Solutions

- Regularly operate the soot blowers for the gas air heaters, especially during cold start-ups, as per the standard operating procedure.
- Install oil carry-over probes above the gas air heater to detect oil particles in the gas air heater baskets. Repair any defective oil burners to ensure proper atomisation of oil and combustion in the furnace.

- Arrest the points of ash carryover and immediately repair.
- The ash removal system ahead of the gas heater needs to be made available immediately.
- Regularly inspect leaking flue gas ducts and expansion bellows and perform repairs at every available opportunity.
- Measure gas air heater seal leakages at regular intervals and implement remedial action by adjusting the seal settings at regular intervals.
- Arrest additional air ingress to the boiler to ensure that the oxygen level measurement at the air heater is accurate and indicates combustion excess air levels.
- Prevent cable damage by properly laying them on cable trays and providing immediate protection until they can be rerouted to a safer zone, as they are currently exposed to harsh environmental conditions.

Long-Term Solutions

- Identify and repair high erosion areas of flue gas ducts with erosion-resistant materials for increased durability.
- Ensure availability of materials before unit outage, to avoid delays in repairs.
- Conduct GD tests to balance airflow in ducts entering PJFF.
- Wash the gas air heater with water regularly, ensuring thorough cleaning until inlet and outlet water pH levels match. Dry out the GAH by running ID and FD fans after washing.
- Remove and clean gas air heater baskets carefully with high-pressure water jets during major opportunities like overhauls or major outages. Inspect baskets for erosion or damage and replace them as necessary.
- Replace air heater seals and ensure proper seal setting during major opportunities to minimise leakages.

Boiler Pressure Parts

The boiler has an UCLF of 5.16% for FY2022/2023.

It has already been mentioned that the boiler excess air ratio (Lambda value) was increased within the context of ESKOM's revised operation parameters for the ESKOM fleet, which were implemented in response to the boiler explosion at Duvha's Unit 3. This deviation from international practice and the OEM design presents a multitude of process implications, significantly increasing the wear experienced by the boiler and its associated components, due to higher air velocity through the system. If there is an opportunity to revert the Lambda value back to the OEM design, it is plausible to anticipate enhanced component longevity and sustained boiler performance, leading to potential improvements in the UCLF.

While the number of tube leakages has decreased considerably and is relatively low, the time taken to repair and restore the unit to operation is longer, compared to international standards. Efforts have been made to address this issue. Participation in the Eskom Standing Committee for Boiler Tube Leaks and a detailed analysis of the root causes of BTL and trips would assist in reducing the UCLF associated with the boiler pressure parts, should the recommendations be implemented.

Short-Term Solutions

- Investigate the possibility to lower the boiler Lambda value back to the original OEM design value.
- The repair time for BTL is currently longer than international standards. To reduce repair time, the following actions can be taken:
  - Ensure proper mobilisation of manpower, tools, and equipment for efficient repair of BTL. With round-the-clock supervision by Eskom, the repair time can be brought down to international standards.
  - Ground the signal cable shield to avoid spurious tripping caused by lightning, which leads to excessive vibration levels of fans or invalid signals. This step ensures fan stability and prevents unnecessary unit trips.
  - Ensure calibration of critical instruments as per OEM guidelines. Establish a C&I laboratory calibration to prevent any slippage in the calibration schedule.
  - Strengthen joints and piping in the drain system to prevent frequent leakages of hot water or steam, which can lead to boiler trips due to controller faults.

Long-Term Solutions

- Ensure the availability of certified high-pressure welders for efficient repair of boiler pressure parts.
- Maintain an inventory of all spares required for boiler pressure parts, to minimise downtime during repairs.
- Replace weak or eroded piping and components in the affected areas, to prevent steam leaks and enhance system reliability.
- Procure adequate spares for the HP bypass valves, as they are a common cause of failure.
- Enhance the capacity of the reheater spray station, to meet temperature reduction requirements.

<u>Milling System</u>

The UCLF for FY2022/2023 is 0.66%.

The wear elements of the mills are expected to last around 10 000 running hours before major replacement or rebuild is required. A rolling plan for the rebuild or replacement of such components has been implemented and is yielding good results.

In addition to the normal replacement of wear parts, various improvements have been agreed with the OEM and are currently being implemented. This implementation requires longer outages for the mill rebuilds, where after it is expected that future rebuilds will normalise at a shorter outage duration.

Short-Term Solutions

- Develop the technical capability of mill operation and maintenance to enhance overall performance.
- Conduct thorough inspections at the specified 1 000 hours intervals and rectify the defects during that mill shutdown or during a unit shutdown.
- Perform mill clean-air and dirty-air tests to achieve velocity balance and balance the PA flow.
- Consider adopting an isokinetic sampling method for representative sampling, to obtain true fineness values.
- Cables in the milling plant area are susceptible to damage due to exposure to harsh environmental conditions. To mitigate this issue, the cables should be neatly laid on cable trays and provided with necessary protection until they can be rerouted to a safer zone away from the hot pulverised fuel and coal rejects.

Long-Term Solutions

- Develop clear specifications and procure critical spares, such as grinding tires/grinding ring segments, to meet mill overhauling requirements. Initiate the process at least one year in advance, to ensure the timely availability of critical spares at the site.
- Continue to develop mill improvements under the supervision of a mill expert or with the support of the OEM.
- Establish a maintenance strategy for PF pipes and bends, to prevent generation loss and fires caused by leaking pipes.
- Develop design drawings and specifications for dampers and gates and prepare the associated spare part list required for reliable mill operation.
- Replace the top and bottom reject gate valves of the mill reject system. Make certain to select valves that, when installed, ensure improved performance and reliability.
- Another recurring problem in the milling plant area is the frequent failure of mill seal air fan motors. These failures are primarily caused by continuous overloading of the motors due to the excessive demand for air.

- To reduce the overloading of the mill seal air fan motors, it is essential to address the leakages in the mill's internal seal air system promptly.
- In the long term, procurement of higher-rated motors equipped with standard bearings should be considered. Alternatively, exploring the possibility of using a high-delivery air fan and motor could also help mitigate this recurring issue.

Issues relating to the Generator H_2 Explosion

- The generator H_2 explosion occurred on 9 August 2021, caused by improper hydrogen purging in the absence of site-specific instructions.
- Consequently, substantial capital losses were incurred, necessitating property damage assessment, ERA preparation, contract placement for stripping and stator assessment, on-site and off-site stripping, and damage assessment for investment approval.
- Turbine hall civil roof and wall repair planned to be completed by 31 August 2023.
- As per plan, the manufacture of the new generator is expected to be completed by 15 July 2024 and installation and commissioning by 31 August 2024.
- An interim plan includes the procurement of an old generator from the Netherlands for the Medupi plant, as a temporary arrangement. The old generator, currently decommissioned in the Netherlands, is awaiting the release of a purchase order by Eskom.
- The old generator is decommissioned in the Netherlands. The purchase order for inspection of the old generator in the Netherlands needs to be released by Eskom. Delays in this process should be minimised as far as is possible, to bring Unit 4 back in operation as soon as possible.
- As Unit 4 has been out of operation for an extended period, many spares and equipment have been cannibalised for use in other active units. Therefore, simultaneous procurement of these spares and equipment is necessary to restore Unit 4.

Turbine Generator

Short-Term Solutions

- It is crucial to ensure the availability of skilled manpower who possess the necessary expertise to effectively operate and maintain the system.
- Establish OEM guidelines regarding the quality of oil. This can be achieved by implementing online filtration techniques and procuring oil filters of the appropriate quality from reliable vendors. It is essential to develop specifications for the filters in collaboration with reputable suppliers.
- The plant has issues with passing valves, and the consumption of make-up water is excessively high. Addressing the valve passing problem should be prioritised, to prevent further complications. We recommend addressing to the following problems:

- Adjust valve torque settings according to OEM recommendations.
- Conduct frequent walk-downs to identify and prioritise the repair of passing valves.
- Avoid procuring valves from vendors with unsatisfactory performance records.
- Develop in-house skills for the repair and maintenance of high-pressure and critical valves.

Long-Term Solutions

- Critical valves should be carefully examined and, if necessary, sent to capable vendors/OEMs for repair.
- When procuring valves, it is advisable to select established manufacturers known for their expertise and quality products.

5.15.2.2 Electrical System

In recent years, the units have suffered numerous trips caused by generator excitation failures/excitation system failures. These trips have been attributed to various faults, such as bridge loss, rotor earth fault and failures in excitation system components (including snubber circuits, current sensors, cubicle ventilation loss, module failures, and more). Unfortunately, due to the unavailability of spares, the system is currently operating with low protection configuration.

Short-Term Solutions

- Increase the effectiveness of the HVAC system in the excitation room.
- Ensure appropriate cooling is maintained, to prevent failures of electronic and electrical components in the excitation system caused by excessive temperature.
- Turn off the HVAC system during long outages, to let the temperature settle at the ambient temperature.

Long-Term Solutions

- Plan for the replacement of excitation systems as they approach the end of their lifespan (> 15 years).

Switch Gear (MV&LV)

The units have been experiencing a number of trips caused by ARC fault protection activation. Unit 5 experienced the most trips, with five trips occurring in the past two years. Four of the five trips were caused by ARC protection relays/protection malfunction. The malfunctioning and failures of the system are primarily due to HVAC issues and water ingress.

- The units are experiencing multiple failures/malfunctioning of the MV (switchgear) board arc protection systems.

- MV and LV (switchgear) board failures due to moisture ingress

Short-Term Solutions

- Defective fire seals of breakers should be sealed properly to avoid flashovers inside breakers, due to condensation of steam which then enters through cable trenches flooded by overflowing drain water. Availability of sump pump also needs to be ensured, to avoid overflow of the drains.
- Hot water passing from the drains is to be arrested as a priority.

Major C&I System

The unit and common plant control systems procured for Medupi in 2007 have become obsolete. Currently, the OEM does not offer support for spares and security patches to address bugs. Consequently, the reliability and safety of the equipment have been compromised. The affected systems include:

- Units 1 to 3: SiemensT3000 DCS System.
- Units 4 to 6, BOP SER ALSPA Series 6 DCS (GE Alstom).
- Boiler Protection Unit 1-6 Siemens T3000.
- SPPA-T3000, TG Control–Control steam, etc.

Short-Term Solutions

- To mitigate the situation until a replacement is implemented, the development of external agencies capable of repairing and reengineering electronic cards is necessary. Previously, the Eskom PTM group handled such issues, but support from this group is no longer available due to a lack of experienced staff.

Long-Term Solutions

- For a lasting resolution, the following main DCS control systems (Units 1 to 6), boiler protection system (SIEMENS T-3000), TG Control–Control steam, P320 AVR, and Water Canon –Siemens S7 400PLC need to be addressed. These systems are obsolete, and the OEM does not provide support or spare parts for them. Therefore, the plant personnel proposed upgrading the C&I systems, which is recorded on the LOPP.

High Turnover of Experienced Staff

The C&I section is facing a significant turnover of experienced staff, primarily due to retirement and the remote location of the company. To address this issue promptly, we recommend recruiting staff from other countries, to maintain the required skill set within the department.

Shortage of Calibrated Instruments

To ensure reliable control and protection, it is essential to establish a C&I laboratory equipped with the minimum required calibration instruments, as recommended by the OEM. Currently, the department relies entirely on external agencies for calibration, leading to incomplete calibration of instruments. This incomplete calibration can have adverse effects on generation efficiency and system safety.

Diesel Generator Set

Out of the three diesel generator sets, only DC set no 3 is available for use. Diesel generator sets 1 and 2 are currently unavailable, as they failed to start during a routine test. Immediate consultation with the OEM is necessary to rectify the issue and restore the functionality of these generator sets.

Coal Handling Plant

The UCLF was 0.03% loss in FY2022/2023 due to CHP issues.

During the rainy season, coal moisture increases, for which proper coal blending is required. The characteristics of the supplied coal vary slightly from the contractual coal characteristics.

- As per the contract, sulphur values have contractual limits of 1.3% but operating values vary from 1.02% to > 1.74%.

Ash and Ash Dumping System

The UCLF was 0.32%, in FY2022/2023. The loss was due to AHP defects.

The ash conveying system has been shut down repeatedly, due to leaking ash conveying pipes leakages.

The plant has been forced to reduce load due to HH levels of FF hoppers and this is also leading to high emissions.

There are several environmental compliance issues relating to ash dumping and there is a constraint on dumping ash due to the incomplete construction of the ADF. The dumped ash also needs to be covered by a geomembrane, as per the environmental norms, by 2025.

South Phase-3A, ash dumping facility construction has not yet been completed, resulting in an inadequate dumping facility.

Spares for submerged scraper conveyor and DHP are not available.

Short-Term Solutions

- Check the health of all hopper heaters and maintain the ash temperature in the hoppers at the design temperature.
- The fluidising pads installed at the FF hoppers need to be regularly checked and replaced periodically.
- Condition of all FF hooper level switches to be ensured, for reliable evacuation.

- The dew point of the compressed conveying air is to be monitored regularly so that it is maintained as per design. The health of compressor dryers and auto moisture drain valves must be ensured.

Thickness surveys of the ash conveying pipes are to be carried out at regular intervals of six months and reduced thickness pipes and bends are to be replaced, to prevent ash leakages.

The health of water spray facilities is to be ensured to prevent dust emissions from the ash dumping facilities.

Long-Term Solutions:

The maintenance strategy for ash conveying pipes is to be reviewed as these pipes are prone to high wear and tear.

Disposed ash at the ADF needs to be covered by a geomembrane by 2025, for environmental compliance, as it is related to consent to operate the plant.

Infrastructure/Civil Engineering

- Process water is overflowing.
- Dam overflow.
- Pumping to crocodile river.
- Recovering effluent at the water treatment plant.
- Focus on dirty water dams to achieve less than 60% level (9 December 2022 at 67%).
- Raw water, primary and secondary clarifiers not commissioned.
- The workshop facilities have recently been commissioned. These are needed for refurbishment/repair. Lack of skilled manpower for the workshop.

Fire Detection System

Not yet fully commissioned.

HVAC system

Incomplete commissioning and outstanding documentation handover.

Generator Hydrogen Plant

Not yet commissioned.

Incomplete Construction/ Infrastructure facilities

There are incomplete facilities, due to delayed construction and non-commissioning of facilities like ash dumping facilities, hydrogen generating plants, fire alarm systems, workshops, electrical and C&I laboratories, liquid waste treatment plants, etc. This is putting constraints on the reliable operation of the plant.

Short-Term Solutions

- These facilities need to be planned and executed in a time-bound manner. Progress needs to be monitored on a regular basis, to ensure that the necessary resources and budget are available.

Spares Planning, Availability and Development of Specifications

Short-Term Solutions

- Most of the spares have been declared stock-controlled items with minimum, maximum and re-ordering levels. This does not match the actual requirement, which has resulted in frequent unscheduled procurement on the one hand and a huge inventory of slow-moving items on other. An FSN/ABC analysis needs to be conducted, as well as an immediate review of minimum, maximum and reordering levels as a one-time exercise, and then every six months thereafter. The safe lifetime of spares and consumables in the ERP system should also be monitored and an automated first-in, first-out philosophy implemented.
- List of critical spares to be reviewed in every quarter for all the system by the concerned department.
- As the current practice of global tendering is delaying the procurement process considerably, we advise that tenders be issued only to pre-qualified vendors with appropriate technical competence and appropriate financial background.
- Single source or sole source suppliers should be identified for critical spares and single/sole source approval should be given without limitation of the validity of said approval.

Long-Term Solutions

- Develop specifications and drawings for key spares or examples mills, to widen the network of suppliers and reduce dependence on OEM and their agencies.
- Present procurement process is cumbersome and time consuming, requiring approval at multiple stages. It needs to be revisited, to accelerate the process and to ensure timely availability of spares and engagement and mobilisation of resources.

HR Issues

Short-Term Solutions

- Training and workshops need to be organised for newly appointed staff in C&I and Electrical, as most of the systems at this plant are new and require appropriate training.
- Reward and recognition system needs to be enhanced by clear criteria, alignment with organisational goals and effective communication with variety of rewards.

- The training department needs to ensure that lessons learned from plant incidents are built into the training materials for the plant operators.
- The skills of personnel (Eskom/business partner) need to be continuously improved through training and counselling. Operating manpower skills, HP welders, grinder men, boiler tube fitters, HP valves repair and maintenance skills, millwright fitters for pumps and fans and their alignment, skilled technician for compressors, HVAC technicians all need training and development.

Long-Term Solutions

- Adequate experienced middle-level supervisors and engineers need to be recruited in maintenance (including C&I and Electrical) by granting special allowances for the remote location.
- Non-availability of specialists at plant level can be resolved by keeping experts for all the functions of O&M at Eskom headquarters.

5.15.2.3 Technical Status of the Boiler

During the visit, the team walked through the boiler house. As shown in Figure 178, Figure 179and Figure 180, the housekeeping was poor. The plant is equipped to high technical standards but is still in the stabilisation phase, six years after the first unit, Unit 6, was taken over.

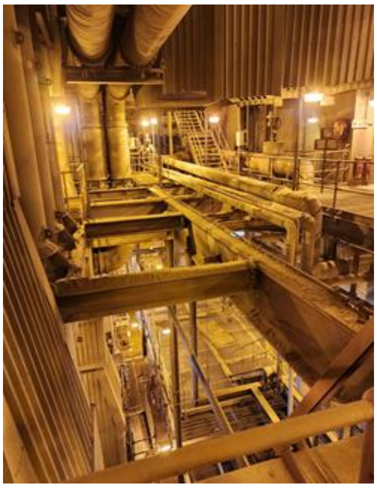


Figure 178: Ash accumulation in Medupi’s boiler house

Figure 179: Leakage in silo at Medupi

Figure 180: Reasonably clean feeder floor at Medupi

The steam temperature at the boiler outlet main steam is maintained close to the design of 560°C. The temperature differential between the different sides of the boiler is within the limit. However, there is high reheater spray water consumption. The reheater spray station capacity is below design and needs to be increased to maintain reheater temperature.

Air heater choking leads to SLL and overloading of ID fans and ash carryover. The sealing system is not reliable.

Two ID fans draw the flue gas out of the boiler to the chimney. ID fans do not operate at full capacity. This is caused by air ingress, leaks in the air heater and choking of gas air heater. The plants are operating with higher O_2 levels. The site team reported that the PA duct wear rate is very high due to ash erosion. Even though patch work has been done, the problem persists.

Boiler at a glance:

- Reliability of PJFF plant is below industrial standard due to combination of coal quality variations, design, maintenance and operation. It causes SLL – special effort is needed to improve the performance.
- Silo area shows heavy ash leakage.
- Reasonably clean mill floor and feeder floor.
- Gas air heater is facing ash carryover, choking and unreliability of sealing system. Gas heater duct leakage in all units.
- High wear rate of PA duct due to ash erosion.
- Frequent failure of boiler HP bypass valve.
- Reheater spray station under capacity.

5.15.2.4 Technical Status of the Machinery

The turbine hall was reasonably clean, as the housekeeping was conducted well.

Heaters are in good condition and the heater outlet temperature is maintained as per design specification. All the heaters are in service. There are no load losses reported due to heater issues.

Valve passing (mainly drain and vent valves) leads to higher water consumption.

With regards to the condenser system, the poor condenser vacuum has a major impact on operation, mainly because of the unavailability of ACC fan spares. This leads to higher condenser back pressure and, consequently, loss in generation.

Figure 181: Good housekeeping at Medupi's turbine hall

Machinery at a glance:

- The turbine seems to be operated properly.
- There is no load loss due to feed heater.
- ACC spares unavailability causes vacuum losses.

5.15.2.5 Issues related to Water System

Usage of demineralised water is higher than the allowable limits of 7.96 kg/s in Units 2, 3 and 6. Plant usage of raw water is higher than the allowable limits, leading to overflow of dams and environmental concerns.

5.15.3 Technical Measures to Improve the Plant Condition

The measures were already described in the previous chapter.

5.15.4 Power Plant Management

Maintenance

Medupi has outsourced maintenance to third parties. Of the plant's staff, 408 are inhouse and 1 129 are from third parties. The ratio is not healthy and does not ensure fast-track reactions to real plant requirements. We highly recommend insourcing personnel to enhance understanding of the real needs, speed of action and ownership.

Planning

Maintenance at the plant is carried out via the SAP system. MSMW system in place of reliability-based maintenance system has been recently implemented in SAP. Maintenance strategy varies from system to system, based on its criticality, i.e. some maintenance is planned, some is based on condition and some is run-to-failure.

There is a lack of overall condition monitoring reports shared with the plant, and there are no clear limits set for individual reports. Additionally, there is a missing consolidated equipment condition indicator matrix or system health report.

Further, the plant's maintenance and outage departments have long-term contracts with prequalified contractors in order to meet the requirements for carrying out planned and unplanned work.

Findings

- The constraints for planned maintenance are lack of adequate funding, belated approval of funding and unavailability of spares in line with requirement.
- The procurement process takes too long (approximately six months or more). Placement of service contracts takes a considerable amount of time, which does not fit with urgent plant needs. There are instances of work being deferred by more than six months because budgets haven't been approved in time. This affects unit performance adversely.
- The Medupi units that were commissioned in recent years continue to face unresolved teething problems. To achieve stable operation at their rated capacity, additional efforts, resources and budget are required.
- Feedback on equipment performance from operations, maintenance and other personnel is not an integral part of the strategy to maintain long-term equipment reliability. This needs to be changed.
- Budgets are not fully aligned with the requirements of the final scope of the work so that the approved budget is often inadequate.
- The majority of load losses are due to improper planning and execution of maintenance of boiler pressure parts, PJFF and ash plant. The available resources are not used efficiently.

- The skill level of the staff needs to be improved on a continual basis via effective training.
- Training programmes to improve skill sets, for people management and succession planning, etc., need to be organised at regular intervals.

Quality

Medupi is certified to ISO 9001. For quality control, the SAP system generates work sampling orders for line managers/supervisors to verify the work done on different plants as per the respective approved QCPs.

As the checking of compliance with QCPs is only done on a random basis, there can be shortfalls in the quality of the work executed and in subsequent rectification work. Quality control checks need to be carried out by skilled technicians/engineers on all work carried out by contractors, in order to ensure that it is up to standard and value for money. It is best practice to separate quality control from the execution of work.

Findings

- Quality control and quality assurance departments are not available.
- Approved QCPs are in place but need to be strengthened.
- Inspection of HT Motors, MCA, Tan Delta test, DPT of fan motor rotor bars, MDBFP motor in situ inspection of overhang portion of stator bars/DPT of impeller blades should be carried out during overhauls.
- Some machine spares are stored in open yards and some spares are placed in open sheds exposed to sun, rain and dust and are becoming damaged. Vulnerable items need to be shifted inside the covered store and the preservations schedule needs to be followed.
- Currently, there is no prequalification of vendors in case of approval of single sourcing/open tendering.
- The unit has rolling overhaul schedule for IN, IR, MGO and GO as per their outage philosophy. However, the scope of the work needs to be frozen well in advance, so that resources are procured/managed in time, otherwise quality issues cannot be properly addressed.
- High risk of losing operation permit due to wrong application of pressure part materials, improper ash disposal, high emissions, overflow of dams, etc.
- Proper housekeeping is a prerequisite to safety and quality maintenance and needs to be addressed immediately.

Resources

The resource planning of the plant is as follows:

There are approx. 27 employees working on shift operations. If shift staff are unavailable (due to leave/sickness), replacements are brought in from the spare group or shift staff do overtime.

During every shift, a walk-down survey is conducted as per the checklist. At present, there is a shortage of quality and experienced operating staff.

Currently, there are only 127 operating staff and 139 approved positions. The gap affects operation quality and needs to be addressed immediately.

Further, only one field operator is posted for the entire boiler, milling system, draught system and TG and auxiliaries. We recommend having at least three field operators for each shift to monitor the systems separately: one for boiler, one for milling and draught system and one for TG and auxiliaries.

For a general description of resources qualification et al, please refer to the Kusile power plant report.

Third Party Resources

The current Eskom tendering process does not include a prequalification process prior to submission of request for proposal. Any party can participate in the tendering process, irrespective of qualification or previous procurement history. This can lead to significant delays in the procurement process and does not assure that sufficiently qualified companies are even considered in the bidding process. If potential venders are rejected, then the retendering process needs to be restarted, which can lead to additional delays in the mobilisation of vendors. Such a system encourages the contracting of inadequately qualified vendors to execute jobs, as plant personnel is forced to choose between quality of work and timely execution.

- The plant has placed 22 maintenance contracts for different functions. We recommend that each contract specify the required skill set of the contractor and that they are approved only after a performance test.

Spare parts

Concerns about spare parts can be divided into two main categories:

- Timely procurement of spare parts: This is adversely affected by tendering of proposals to potential vendors irrespective of their technical or financial capability. This can lead to one or more retenderings, even after an extended period of time.
- Quality of spares due to lack of proper quality control plan with sufficient holding points. Plant personnel have reported that, on several occasions, quality control has only taken place after delivery to site. This forces the plant personnel to compromise

on the quality of spares, as rejection would cause substantial delays in the availability of said spare part.

Critical and Strategic Spares Planning

The spares management meetings lack effectiveness and attendance is inconsistent. A finalised list of critical and strategic spares for every system has not been made available but is needed immediately for budget approval and procurement planning.

The issue of spares unavailability has been repeatedly discussed in various meetings, including schedule freeze, plant focus and production meetings.

The strategic spares list, based on their criticality, is noted below which plant need to adopt as per the equipment status at the plant.

Findings

The following is a list of the concerns relating to spare parts:

- Spare part management is a major issue impacting EAF.
- There are gaps in ordering, receiving and maintaining adequate spare parts in order to avoid delay in maintenance and load loss.
- Only OEM-related spares and services are provided and procured from relevant OEM/their agency on sole source basis.
- Even though sharing of spares is done with other plants, this is a grey area which is currently a big concern for the concurrent load loss.
- The stock level is not adequately maintained.
- A dedicated quality assurance department is not available.
- The long procurement process and unavailability of critical spares increases the high risk of downtime and, consequently, load loss.
- Valves passing is a major concern and even post outage, rectification is not yielding desirable results, which results into loss of energy and abnormally high DM water consumption. Non-availability of spares for rotating equipment and soot blowers is a big concern for equipment reliability.

Additional Spare Parts Recommendation

- Besides the correction of the above-mentioned points, we recommend that the adequacy of min/max values and safety stock in the plant be reviewed every six months. At least on annual basis, the plant should conduct FSN/ABC analysis to identify high value and non-moving items and to establish whether it is necessary to keep such items in stock. The use of an automated first-in, first-out system, with monitoring of shelf-life time is highly recommended.

- Strategic list of spares /unit assemblies need to be finalised between all plants with similar units/OEM.
- List of critical spares to be reviewed in every quarter for all the system by the concerned department.
- Development of specifications and drawings for the spares is needed.

<u>Operation</u>

Quality

The plant is operated round the clock with five groups of operating teams.

Monitoring of operational performance via KPIs is done by the performance and testing division of the plant. However, recording of plant performance analysis data needs improvement, so that the findings and related issues of load loss and efficiency parameters are well mapped to the respective equipment/systems. The punch points for the equipment/systems need to be monitored at regular intervals to facilitate the resources, so that they are addressed in a definite time frame by the respective departments.

Coal quality management procedure is followed as per the coal supply agreement between Eskom and Exxaro. The plant uses a coal management system to record coal quality parameters, and the laboratory maintains LIMS. Coal sampling is done through an automated sampling plant situated at Exxaro. The coal sampling is prepared jointly by Eskom and Exxaro and each party does a chemical and physical analysis of the coal at their respective laboratories before the coal is dispatched to the plant. The results from the two labs are compared and accepted only when the deviations between the two reports are within the permissible limits.

The OPEX is tracked by comparing actual expenditure with budgeted expenditure on a monthly and YTD basis. There is a monthly review meeting by the PSGM.

The budget for the plant is prepared on an annual basis and considers the volumes of generation, different activities to be executed and outage plans. Although the system is established, no record is available for system wise budget declaration.

Monitoring

Real-time information can be accessed via the HMI and the system is integrated into the operational historian system, as the system was procured before 2007 and is therefore getting old and has issues with OEM support and non-availability of spares. Most of the hardware and software is becoming obsolete and the DCS system, boiler protection and turbine control need an upgrade. Simulation procedure is in place and followed as per defined procedure. All configured points are in line, except for a few forced signals due to operational issues. Auto loop status is given separately.

Presently, only critical instruments for IR and MGO are calibrated through external accredited certified agencies. We recommend that all instruments are calibrated in a systematic manner at scheduled times, or that a calibration schedule be uploaded and tracked via the SAP system.

Outage Management

The basic principles of outage management are similar to Kusile power plant's and are described there.

Leadership

Eskom's organisational structure, which severely limits the authority of the plant management to make its own decisions and involves a high degree of interference from Eskom's head office, does not serve the day-to-day requirements of a plant that needs to be able to react immediately in case of malfunction or defects. The plant leadership is faced with the following challenges for the sustainable operation of the plant:

- To operate the plant within the emission limits set by South Africa's emissions regulatory body AEL and to address unavailability of PJFF bags and compressor failures, which lead to major energy loss.
- Ash dumping facility South Phase-3A is still under construction. It is one of the major risks for the plant. The dumped ash also needs to be covered with a geomembrane in order to meet the requirements of the environmental regulatory body.
- Payment of penalties to the coal company because of reduced coal requirement on the back of low EAF.
- Revisiting the present procurement process to address the time-consuming procurement process.
- Malfunctioning of the hyper wave system, which might lead to loss of documented information (documents) due to system migration.
- The unreliable fire detection system poses a risk of delayed or undetected fires, potentially causing plant damage and endangering personnel safety.
- Development of specifications and drawings for the critical spares.
- Comprehensive budgeting for each O&M system and timely approval of budgets.
- To achieve zero discharge from overflowing dams and control the process water wastage.
- Improving the safety culture among the employees of Eskom and its business partners.
- Shortage of skilled trained manpower.
- Motivation level of Medupi employee needs to be raised, as it has been severely affected by COVID.

- Development of Eskom-wide knowledge forums for each function of O&M, for resolution of technical issues.

People Management

The work culture at Medupi is influenced by the following:

- Work culture at Medupi was adversely affected by Covid – both during and after the pandemic - and is still a long way from normalcy.
- The programme on Eskom values is conducted by plant management. The plant maintains its culture through induction processes, recognition and reward systems and networking initiatives.
- Lack of ownership needs to be addressed by improving leadership quality.
- Employee involvement through employee engagement initiatives, such as info sessions and empowering the employees to create and enforce a winning culture.
- Good stakeholder relations are to be developed through stakeholder participative structures.

Employee Motivation

- Though a reward and recognition system exists, it needs to be further enhanced by clear objectives, alignment with organisational goals, effective communication and a variety of monetary and non-monetary rewards.
- Recognise and reward individuals and teams for their outstanding contributions in demonstrating creativity and innovation.
- Foster employee motivation by organising fun activities and celebrations.

H&S Management

The plant is ISO 45001:2018 certified, actively striving to meet standards requirements. A SHEQ policy outlines leadership commitment and expectations. Effectiveness is reviewed through management reviews and quarterly audits. Incident investigations follow 32-95 Eskom incident management procedure. All incidents are investigated within 7 days of the occurrence unless the injured person is not fit to attend. Incidents per year are as summarised in Table 89.

Employee	Year	PD	MVA	FA	Medi-cal	LTI
Eskom	FY2022	2	4	2	4	0
	FY2023	3	2	4	0	0
Contractors	FY2022	9	4	10	10	6
	FY2023	6	3	6	12	4

Table 89: Incident summary for Medupi power plant (FY2022/2023)

Health and Safety Performance in FY2022/2023

Contractors are a cause for concern as the number of incidents has increased. The safety culture among the contractors needs to be improved through training and increased supervision by the safety officer and line managers. The recommendations made by the Investigation Committee need to be implemented.

Risk Management

Medupi has an integrated risk management system that complies with the integrated risk management standard (doc. no. 32-391) in Eskom's enterprise risk and resilience policy.

The plant faces various risks with regards to emissions compliance, zero discharge, equipment reliability, safety culture, manpower short-age, employee motivation, documentation management, critical spares specifications, comprehensive system wise budgeting, streamlined procurement, and knowledge forums.

Mitigating these risks is critical for the sustainable operation of the plant and the achievement of long-term success.

Mechanisms for learning and for implementing actionable points must be monitored and complied with on a monthly basis.

5.15.5 Technical Profile of Main Plant Areas

Geographical Location: The Medupi power project is located on an 883ha-site near Lephalale, in the Waterberg district of Limpopo, approximately 350km north of Johannesburg, South Africa.

Installed Capacity and Station details: Medupi Power Station is a dry-cooled coal-fired power station built by Eskom near Lephalale in Limpopo province, South Africa. The station comprises of 6 generating units with a capacity of 794 MW each bringing the total installed capacity of 4764 MW. 794MW is unavailable due to unit 4 exploding in 2021 and is not expected to be operational for years to come. Each unit consists of a steam turbine and generator along with an air-cooled condenser supplied by GE, and a supercritical boiler supplied by Mitsubishi Hitachi Power Systems (MHPS), apart from the associated control and instrumentation system and other auxiliary equipment. Design gross efficiency at rated turbine MCR 41.36%. Coal is supplied from the adjacent Grootegeluk colliery on the Waterberg Coalfield via a conveyor system. The commissioning dates along with station details are shown in the next table.

Parameter					Value	
Gross Installed capacity (MW)					6 x 794 (4 764)	
Available capacity (for Maximum Continuous Operation)					3 970 (excluding U4)	
Number of units (no)					6	
Start of operation (year)					2015	
Units still operation (no)					5	
Planned end of life of first unit (year)*					2066	
Planned end of Life of last unit (year)*					2069	
Steam parameter (pressure/temperature)					24.1 MPa/560°C	
Source of coal					Grootegeluk colliery	
Commissioning and life of plant	**Unit 1**	**Unit 2**	**Unit 3**	**Unit 4**	**Unit 5**	**Unit 6**
Commissioned	05/2020	05/2019	10/2018	12/2017	05/2017	09/2015
Expected de-com-mission*	2069	2069	2068	2068	2067	2066

Table 90: Details of Medupi power plant
Source: Eskom, *based on 50 years of service

Source of Fuel: Coal is sourced from the local coalfields and delivered to the power station via conveyor belts. The Exxaro Mine, formerly known as the Grootegeluk Coal Mine located north of the site supply coal. Eskom placed a contract with Exxaro to supply 14.6 MT of coal per year.

Source of water: Raw water is supplied from the Mokolo dam 35km away. The dam is filled by the Mogol River providing a reliable supply. The site has a substantial raw water reservoir which provides a good buffer against supply disruptions.

Coal composition (including heating value):

Coal composition (dry basis) of Medupi for March 2023 monthly average is shown in Table 2 with comparison between Exxaro and Medupi station laboratory.

Parameters	Exxaro	Medupi
Fixed Carbon %	29.1	29.5
Volatile Matter %	26.4	25.9
Total Moisture %	9.2	9.2
Ash %	35.2	35.3
Gross Calorific Value MJ/kg	20.7	20.7

Table 91: Medupi's coal composition (March 2023)

5.16 Tutuka Power Plant

The newest boiler at Tutuka power plant is 33 years old. Due to insufficient maintenance the plant suffers from a high number of losses. In April 2023 approximately 13% (461 MW_e) of the installed net capacity of 3 510 MW_e was not available due to PLL. Another 67% (2 340 MW_e) were unavailable due to full load losses (FLL) during the visit.

The main PLL contributors in the last FY was the electrostatic precipitator (ESP), feedwater and vacuum of condenser. Also, there were some instances on Unit 3 and 4, which led to a shut-down the units due to high ID fan vibrations causing a malfunction of the ESP. It is strongly recommended to also inspect and repair all other potential sources of air ingress at the boiler. This can be mitigated mainly by tightening the flue gas ducts and air heaters.

The superheated live steam temperatures at the boiler outlet observed during the visit were lower, as per design. This leads to power and efficiency losses. The reasons for this temperature difference are complex and can also occur in a concatenation, such as a limitation of coal feeders, air leakages in the preheaters and a faulty turbine and/or coal supply control. The power loss is already counteracted by over-firing the boilers, which causes a decreased life expectancy.

One of the main areas of improvement are the condenser vacuum and the cooling towers. In order to solve both problems, it is necessary to overhaul scaled condensers, to improve the cooling water chemistry and to refurbish existing cooling tower system.

A lack of mills and spare parts in combination with a high content of rock in the incoming coal are another cause of outages. To prevent further power loss due to mill outages, the coal quality should be improved, and the mills need to be refurbished.

To achieve a significant increase in power output of the plant the maintenances and outages need to be executed to the full extent. This requires an according investment into necessary spare parts (e.g. mills, condensers, HP heaters). Many of the repairs can be done also during short stops and could lead to direct improvements.

The housekeeping in most parts of the power plant was in a poor condition (especially in the boiler house). It is recommended to take measures as soon as possible to minimize the risk for man and machine.

There is a massive lack of engineering staff caused by uncertainty regarding the future of the site, leading to staff migration and low morale. Despite these challenges, the team is managing to keep the plant in operation.

5.16.1 EAF and PLL

Tutuka power plant consists of six coal fired boilers, which each feed their own turbine. The entire power plant has a total nominal net capacity of 3 510 MW_e and the installed gross capacity of the power plant is, as per design, 3 654 MW_e. All units are cooled by cooling towers and produce up to 585 MW_e each. Of the total six units, only two are currently able to produce electricity because Units 1, 2, 3 and 6 are currently undergoing inspections or repairs.

The two units in operation (Unit 4 and Unit 5) can only operate in part load due to technical issues (see Table 92). The station and the first unit were commissioned in 1985. The latest unit commissioning occurred in 1990. Based on the 50-year plan, the units should continue operating until 2041. However, the GX 2035 plan foresees the end-of-life of the entire power plant in 2030.

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Commissioning date	1985	1986	1986	1987	1988	1990
Planned decom-missioning	2030	2030	2030	2030	2030	2030
Gross installed capacity [MW_e]	609	609	609	609	609	609
Nominal installed capacity [MW_e]	585	585	585	585	585	585

Table 92: Key figures for Tutuka power plant

In the period FY2017-2021, the EAF ranged between 73.86% (FY2017) and 40.40% (FY2021). The relatively steady decrease in EAF led to a minimal plant availability of merely 25.78% in FY2023 (see Table 93).

FY	Plant	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
2017	73.86	58.79	90.94	90.64	72.07	90.34	57.46
2018	65.41	75.16	56.28	54.95	79.40	69.27	48.25
2019	57.99	42.22	40.00	47.72	61.88	17.07	65.46
2020	43.00	34.79	38.50	38.33	44.08	37.90	34.75
2021	40.40	33.84	32.13	22.93	42.57	25.64	44.55
2022	30.06						
2023	25.78						

Table 93: EAF of Tutuka power plant (FY2016/2017–YTD)

The EAF of the units was taken from the vgbe KISSY(Kraftwerk-Informationssystem) database. The data for this is supplied by Eskom on a yearly basis. The data for FY2022 had not yet been transferred as of April 2023. The plant EAF values for FY2022 and FY2023 were provided by Eskom during the site visit.

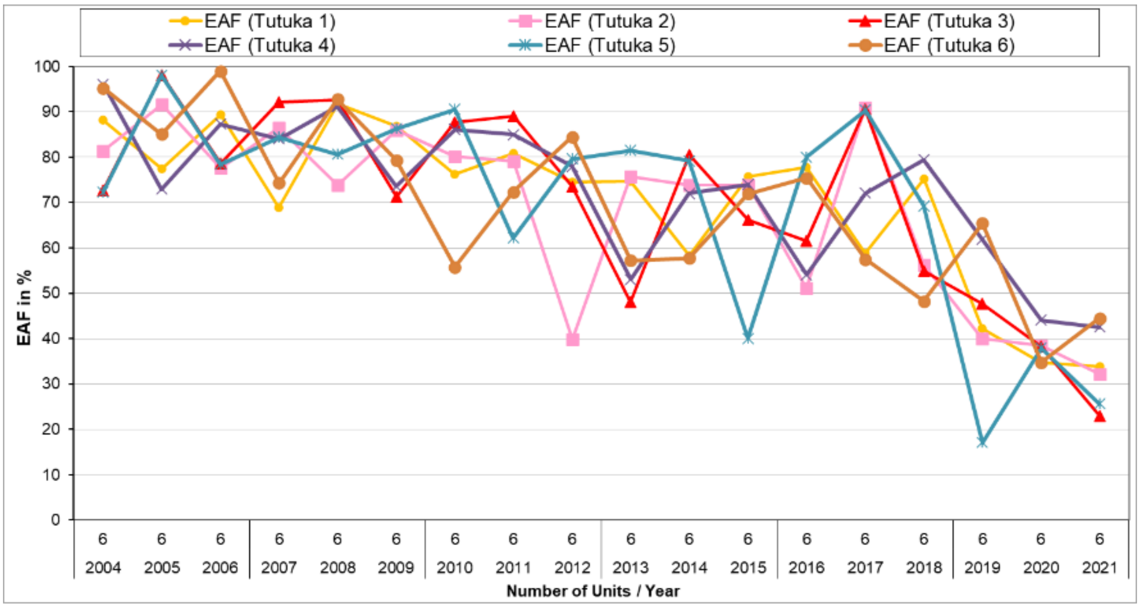


Figure 182: EAF for Tutuka power plant (FY2003/2004–FY2020/2021)
Source: KISSY database, vgbe

The low EAF (see Figure 182) and, as a result, the high unplanned capacity loss factor (UCLF) of 65.37% in recent years is mainly the result of full load losses (FLL), which account for 77% of the losses. The main contributors to UCLF are the boiler (22.74%), the turbine (13.04%), the ash plant (7.51%), the feedwater plant (6.68%), the generator (4.62%) and the draught group (4.06%). There was a significant difference between the UCLF breakdown structure given by Eskom[47] and the power plant[48].

The main sources of PLL are shown in Figure 183 and Table 94. Many different components have an influence on PLL – the main ones being the feed water plant (31%), the ash plant (22%), the mills (17%), the turbine (15%) and the boiler (8%). While PLL for each of the individual components has fluctuated in recent years, overall, it increased steadily between FY2018 and FY2021. Cooling water repairs led to a noticeable improvement in FY2022 and there was also a slight improvement in the current FY2023.

[47] Source: Eskom "UCLF Partials_YTD.pptx"
[48] Source: Tutuka GM presentation "RWE Visit.pptx”

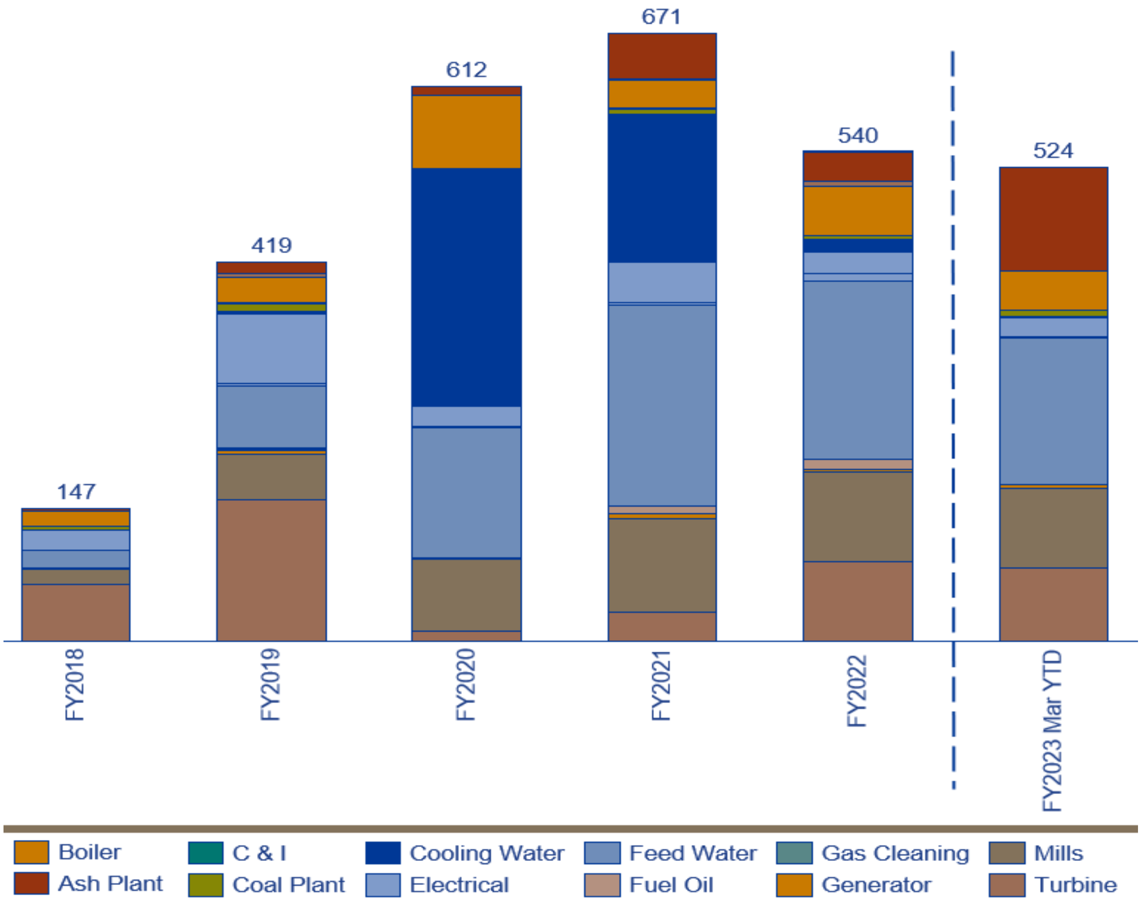


Figure 183: PLL contributors at Tutuka power plant (FY2017/2018–FY2022/2023)
Source: Eskom

MW_e Loss	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023 March
Ancillary System	0.00	0.00	0.00	0.00	0.13	0.00
Ash Plant	2.60	12.52	9.33	49.43	31.23	114.50
Auxiliary System	0.16	4.71	0.17	1.38	6.02	0.32
Boiler	15.96	28.18	80.92	31.77	54.40	42.90
C&I	0.07	0.48	0.27	0.43	0.56	0.38
Coal Plant	4.24	9.34	1.02	5.79	3.16	6.98
Cooling Water	0.05	2.59	260.94	162.78	14.40	1.22
Draught Plant	22.42	75.82	21.51	45.20	23.72	20.86
Electrical	0.33	2.90	1.86	3.19	8.48	0.86
Feed Water	19.62	69.29	143.89	221.34	196.34	162.17
Fuel Oil	0.09	0.94	0.52	8.57	11.20	0.43
Gas Cleaning	0.16	1.06	0.18	0.18	0.32	0.20
Generator	1.32	4.50	0.10	5.69	2.28	4.00
Mills	16.08	50.33	79.91	102.35	98.85	87.75
Turbine	63.54	156.16	11.64	32.71	88.62	80.96
Waterways	0.00	0.13	0.00	0.00	0.16	0.00
Total	**147**	**419**	**612**	**671**	**540**	**524**

Table 94: PLL contributors at Tutuka power plant (FY2018−2023)
Source: Eskom

5.16.2 Technical Status

5.16.2.1 Technical Status of the Boiler

Housekeeping: During the visit, the team walked through the boiler house. Housekeeping was not in order (refer to Figure 184): Very high amounts of dust, ash or coal covered the floor and machinery. Safety-related issues could occur due to bad housekeeping.

Figure 184: Massive dust pollution at Tutuka's boiler house

According to staff, the main reason for not cleaning the boiler house is because the dust would end up in the waste water, which pollutes the cooling water. Dust particles in the water flow of the cooling towers cause problems (see also 5.16.2.2). However, we were unable to witness this phenomenon ourselves during the visit, so it needs to be confirmed.

Steam leakages: Records show that many tube leakages have been reported within the furnace.

Steam temperatures: During our visit, the superheated steam temperatures at the boiler outlet were lower than per design. The desired operational temperature is 535°C but the temperature achieved within the boilers is between 507°C and 517°C (see Figure 185). A downward deviation from the design parameters leads to losses in efficiency and power. The reasons for this difference are complex and can also occur in a concatenation, such as a limitation of coal feeders, air leakages in the preheaters and a faulty turbine and/or coal supply control. This has to be assessed in further detailed investigations. The power loss can be counteracted by increasing the boiler temperature, but this increases the header temperature, which leads to a decreased life expectancy.

Figure 185: Boiler and steam conditions at Tutuka: air flow and fuel flow

Boiler tubes: Boiler failures and especially boiler tube failure are the main reasons for FLL. Units 2 and 6 were shut down during our visit for boiler tube leak repairs. It was reported that the site has a good knowledge of past boiler tube leakages. Four dominant mechanisms causing tube leaks have been identified: pitting corrosion, soot blower erosion and long-term and short-term overheating of the system, which is visible in the power plant's thermal index (TI).

Draught plant: There are two induced-draught (ID) fans per boiler that draw the flue gas out of the boiler to the chimney. At Tutuka plant, the ID-fans have very high vibration levels and are not able to provide sufficient air during full load because of operating with high ash levels in the coal and the malfunction of the electrical precipitator (ash hoppers of the ESP). Furthermore, reducing the air leakages will relieve the ID fan but the problem due to high ash content will remain. One way to fix this problem would be to overhaul and upgrade the ID fans (see Figure 186).

Air leakages: Another recommendation is to seal the air preheaters and the air ducts on the individual units, as these are the main source of leakages. The leakages lead to an increase in required air volume, which results in an increase in electricity used by the fans, as well as higher wear on the machines. Fixing these problems could bring fan requirements back into the design range of the boiler and would reduce the amount of dust that leaks into the boiler hall.

Figure 186: FD fan at Tutuka power plant

Electrostatic Precipitators (ESP): The ESP, which are used to remove ash from the flue gas, are performing poorly and are a frequent cause of outage. They are the main reason for high particulate emissions. To combat these high emissions, it is necessary to reduce the flue gas volume. This leads to a reduction in power and, as a result, to massive PLL.

Mills: The mills were also reported by the power plant to be a major cause of problems. The coal is delivered to the coal storage site by truck and train. After some homogenisation, the coal is then transported along a conveyor belt. The coal quality, which is mainly based on the lower heating value (LHV), is on average 10% to 15% below the design range, which leads to higher coal consumption. In addition to the poor quality of the coal, it also contains high amounts of stones/rocks, which increase wear and abrasion on the mills. Since no change in coal quality can be expected, it is necessary to adapt the mills and the boiler.

Thermal Index (TI): Eskom uses a TI to track thermal excursions on boiler outlet headers, main steam pipework and hot reheat pipework. The TI is a long-term indicator of plant health with regards to the high temperature/high pressure components. The data for the TI can also be used to establish the operational stability of the boiler, as the thermocouples indicate time spent above normal operating conditions.

Tutuka's TI for FY2023 shows that the header, as well as the main steam temperatures and the hot reheat temperatures are way above limits and unacceptable. This is the result of constant over-firing in order to counteract the flue gas filtration problems and increase power output. It has significant long-term implications for the creep life of the entire boiler and piping system and needs to be resolved.

Tolerance Limits for Thermal Index:	
< 35	Favourable
36- 73	Acceptable
> 73	Unacceptable

SYSTEM	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23
Header TI	100	2582	2979	4654	5774	2087	2237	2890	1505	2844	4855	10162	3253
Main Steam TI	223	731	219	493	89	215	128	109	139	389	1658	223	223
Hot Reheat TI	2463	886	476	494	540	679	4604	281	218	654	1245	669	570

Table 95: Extract from Tutuka's TI report FY2022/2023

Boiler at a glance:

- The housekeeping in the boiler rooms is very poor.
- The boilers have severe tube leaks and are the main reason for UCLF.
- The boilers require major overhauls.
- The excess air ingress is quite high.
- The draught fans cannot provide air for full load.
- There are many steam leakages in the boiler house.
- Coal handling is in order.
- The mills and the boiler need to be adjusted towards the decreased coal LHV.
- The temperature range within which the boiler outlet headers, main steam pipework and hot reheat pipework operate is too high.

5.16.2.2 Technical Status of the Machinery

The general condition of the equipment below the level on which the turbines are located and down to the ground level is poor. At the time of the site visit, everything was covered with dust and ash and lighting was almost non-existent. There were steam, water and oil leakages visible almost everywhere, impacting the whole plant. Water and/or oil was dripping on instrumentation and electrical equipment (Figure 187). With all the dirt, dust and poor lighting, it was almost impossible to conduct a visual inspection of the plant and localise the positions of the leakages.

Eskom said the poor housekeeping was due to deterioration of the cooling water condition after boiler house cleaning activities. The amount of suspended solids is afterwards increased, which enhances the wear in the cooling water equipment like the condensers. In this case, we recommend that a vacuum cleaner be used to remove the dust in the boiler house.

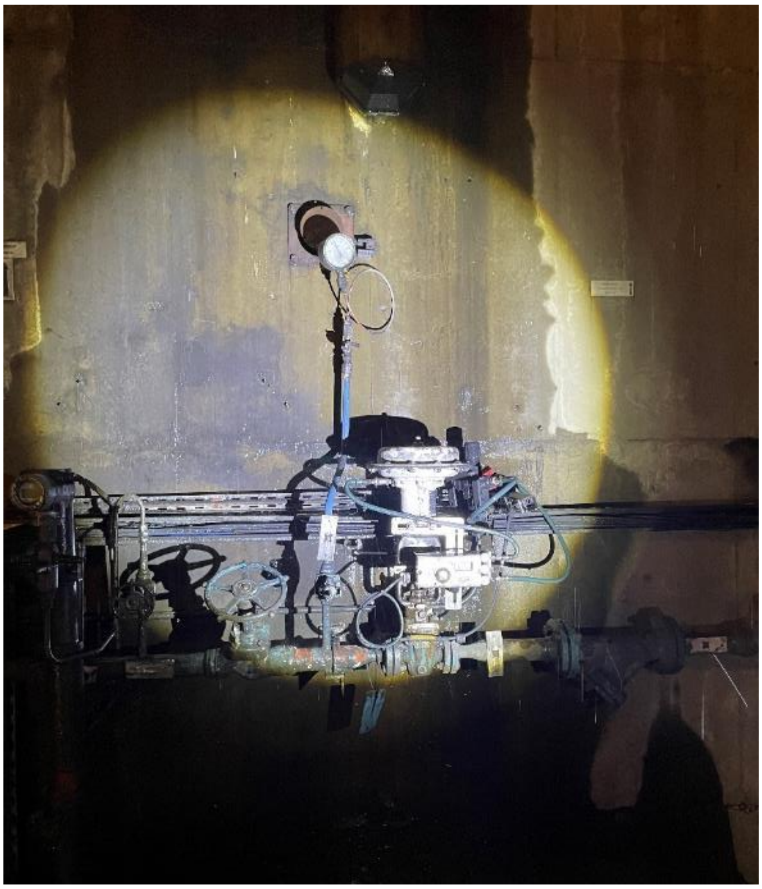


Figure 187: Water/oil leaking on instrumentation and electrical equipment at Tutuka

Cold end: With respect to the cold end, the condenser vacuum is not adequate, which has a severe impact on operations. In some instances, the problem has become so serious that steam ejectors are permanently in full operation to keep the vacuum on a level that enables continued operation due to air ingress in the condenser.

One issue contributing to the problem is blockages in the condenser tubes. In FY2023, maintenance work to remove blockages (acid cleaning) has already been carried out three times. Another issue is condenser tube leakages caused by erosive wear of the tube bundles from the poor quality of the cooling water carrying suspended solids. There were also leakages in the condensate piping. However, the overall condition of the condensers could not be assessed, as 4 out of 6 units were out of service and the remaining two were only operating in part load. As such, the extent of the power loss due to the condenser issues is currently not precisely quantifiable.

The condensate extractions pumps are generally working in a reliable manner, with only smaller issues on the drive motors.

Cooling towers: Another reason for the insufficient condenser vacuum could be the poor performance of four of the six cooling towers. These four cooling towers were in a visibly bad condition: A high content of biofouling was visible on the structures within the towers. During the site visit, only the three cooling towers on the east side were in operation, to support the operation of Units 4 and 5. The underperformance of the towers may be caused by missing and/or damaged end caps within the cooling towers (Figure 188), which has a massive impact on efficiency. The coarse strainers were in good condition but not adequate to ensure good quality of the cooling water, leading to clogged nozzles. The two cooling towers 1 and 6 have already been refurbished and are well maintained. The spray pattern of the refurbished cooling towers was in an excellent condition, in comparison to the other towers. During the visit, cooling towers 1, 2 and 3 were out of operation. Cooling towers 4, 5 and 6 were in operation, with tower 6 accounting for approx. 70% of the cooling performance.

We recommend the refurbishment of the remaining cooling towers 2, 3, 4 and 5 to overcome the problems and reduce PLL. However, the degree to which the refurbishment would impact PLL also depends on interaction with other necessary plant upgrades. The vacuum problems will continue to impact PLL to the value of about 240MWe.

Figure 188: Water distribution and structure of a cooling tower at Tutuka

Cooling water: The overall quality of the cooling water was poor. It contained a lot of floating matter and a high level of suspended solids and was brown in colour (see Figure 189). As already mentioned at the beginning of the chapter, the cooling water is negatively impacted by the high level of suspended solids, which causes clogged nozzles and leads to condenser tube leaks, caused by increased erosive wear. The cooling water circuit needs to be checked and the entrance point of the solids, suspended in the waste water, should be identified.

Addressing this problem would not only protect water cooling equipment, it would also make it easier to conduct proper housekeeping. As a result, this measure could improve the overall plant condition.

Figure 189: Condition of the cooling towers and cooling water at Tutuka

Cooling water pump: The housekeeping of the cooling water pumps and their housing is poor. The overall condition could not be fully assessed due to the part load operation of the plant. The cooling water pumps often show signs of problems with the valves. A lack of spare-parts availability jeopardises possible full load operation.

Turbine: The turbine hall was not clean, which is a sign of poor housekeeping. Some steam leakages were visible within the turbine hall, but there were only 2 out of 6 turbines running at the time. The turbines themselves were barely cleaned and the spray insulation of the turbine casing was cracked (Figure 190).

The turbines have been one of the main contributors to FLL and PLL in recent years, leading to repair work on turbine bearings (possibly damaged by vibration) both in March to May 2022 and January to April 2023. In one case (Unit 3), an electrical fault (loss of 24 V DC supply to the C&I panels) on the AC pump (supporting lube oil pump) and DC pump (emergency lube oil pump) had caused the turbine to run dry without lubrication.

Another possible root cause for increased vibration behaviour could be the poor housekeeping. The widespread presence of ash and dust in the machinery hall leads to a carbon film on shaft bushings, such as the gland seals. High amounts of ash and dust, as well as leakages and high temperatures, can all cause the centering guide pedestal of the turbine casings to become blocked. If this pedestal gets blocked, an undisturbed axial thermal expansion isn't possible as required and can lead to a noticeable impact on operating behaviour. Furthermore, we were informed that poor workmanship during outages had resulted in a rotor not being properly balanced and aligned, causing a high degree of vibration.

However, cracked insulation can also cause increased vibration. Cracks are visible in most of the units. Cracks in insulation can lead to temperature differences, especially between the upper and lower parts of the casing. These can cause the turbine casing to buckle, and it is this that can cause vibration.

During the site visit, we also noticed heavy leaking of the firefighting system on the turbine's drive shaft. It could not be verified that in an emergency case the system will work as intended. As such, this is a potential safety issue.

Figure 190: Poorly-cleaned turbine with cracked spray insulation at Tutuka

The turbine lube oil system is also a source of damage and often results in FLL. As already mentioned above, an electrical malfunction of an AC pump and a DC pump led to the loss of Unit 3. During the visit, Unit 4 was operating with a low level of oil in the lube oil tank. The drop in the level of oil in the tank was the main cause of damaged pumps (AC), due to the pumps running dry without lubrication. Also, the DC pumps often experience problems with the drive motors. Spares are not always available, and their procurement is challenging for the plant. For this reason, Tutuka site ordered a completely new set of pumps and spares.

Signs of poor housekeeping and maintenance were also visible in the turbine lube oil tank room. All the equipment was covered with dust. Several leakages of oil and water made the floor very slippery (see Figure 191). Given the risk to safety, this needs to be remedied and proper maintenance conducted.

Figure 191: Tutuka's tank room for turbine lube oil – with poor housekeeping

HP heaters: The HP heaters at Units 1 to 4 are currently unavailable, leading to a power loss of approximately 50 MW_e per unit, or 200 MW_e in total. In order to overcome this problem, a replacement of the HP heaters is necessary.

HP Piping: The HP piping was very difficult to assess during the visit, due to the dust and ash pollution, especially underneath the turbines located at the ground floor. Steam leakage was visible in the HP heater piping and the general steam piping. The spring hangers couldn't be assessed because of the poor lighting and all the ash and dust, which made it difficult to locate them and impossible to read the indicator scale.

According to the site staff, metallurgical tests are carried out at regular intervals. The lack of header material used for repairing the piping within the power plant is another problem that needs to be addressed. Especially the economiser header material 15NiCuMo causes problems.

Machinery at a glance:

- The cooling towers and condensers should be refurbished to increase the condenser efficiency
- The cooling water circuit and the waste water path should be checked
- The housekeeping in general needs to be improved
- The turbines should be overhauled and the root cause of vibration needs to be eliminated (further investigations needed)

5.16.2.3 Technical Status Electrical and C&I

Generator: The housekeeping around the generators was moderate. According to Eskom, the generator was the main cause of unavailability within the turbomachinery in this last financial year 2023. There have been two major generator repairs: The first was the repair of generator rotors in September to December 2022, and the second repair took place during the current outage of Unit 1. This led to a total outage time of over 4 600 hours, which is reflected in the UCLF share of 4.62%. Another reason for poor generator performance could be the poor quality of the cooling water.

C&I system: With respect to the C&I system, Units 4 to 6 have been modernised with an ABB system and a new control room. Spares are available for these upgraded systems and the systems are still supported by the OEM. The control room and control systems of Units 1 to 3 have not yet been refurbished. As a result, there are still a lot of outdated control elements (Figure 192) and mosaic panel HMI boards (Figure 193) in use. There are no spares available for these old C&I systems. This outdated technology leads to regular unit trips and means a slower return to service afterwards.

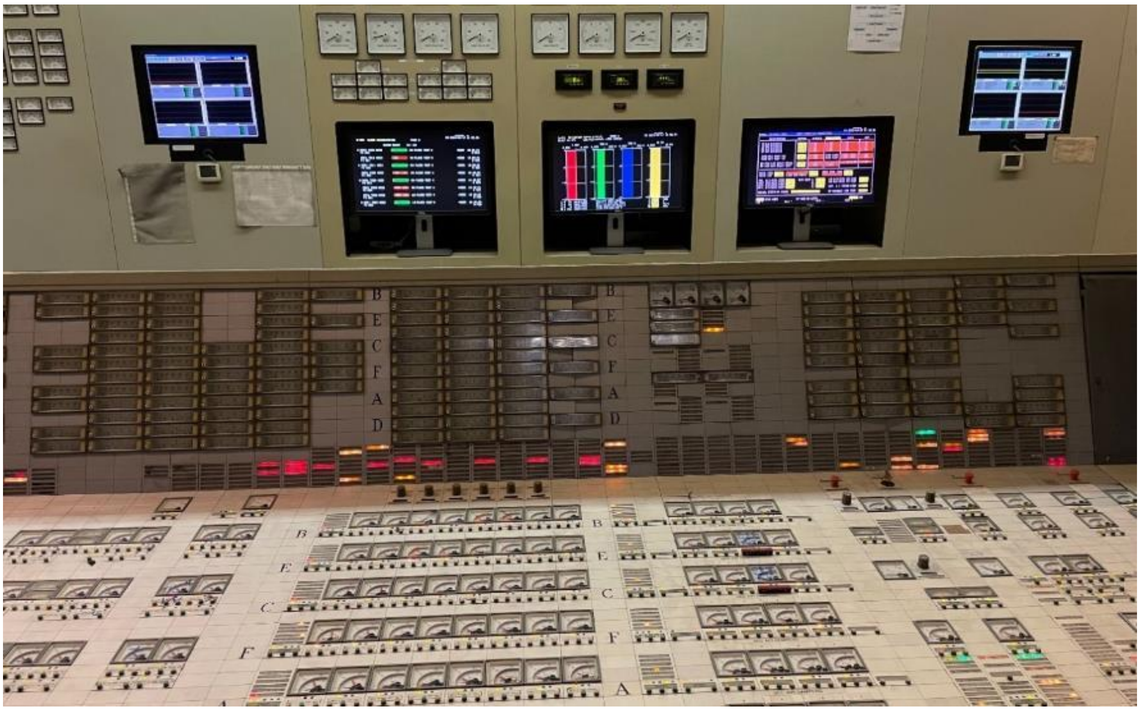


Figure 192: Control room for Units 1 to 3 at Tutuka power plant

Figure 193: Mosaic panel HMI board at Tutuka power plant

MV & LV Switchgear: The medium voltage switchgear at Unit 6 has been refurbished (Figure 194), but the remaining Units 1 to 5 have not yet been updated and, as such, do not meet international safety standards. The low voltage switchgear has not been refurbished in any of the units so far. During the visit, we came across some open MV board equipment while construction work was underway nearby. This should be avoided to prevent contamination of internal electrical equipment.

Figure 194: Refurb. MV switchgear (left), non-refurb. switchgear (right) at Tutuka

Electrical and C&I a glance:

- Several generator incidents caused unit trips, leading to respective decreases in EAF.
- The C&I system for Units 4 to 6 is in order.
- The C&I system for Units 1 to 3 require refurbishment.
- The MV switchgear for Unit 6 is in order but all other MV and LV switchgears need to be upgraded to meet safety standards.

5.16.2.4 Technical Status of the Water Treatment Plant

Make-up water plant: The water treatment plant was visited during the site walk. The capacity of the make-up water plant is sufficient to cover the needs of the site and the water quality is acceptable. The water treatment plant was refurbished recently and is in good order (see Figure 195). The water treatment plant’s Distributed Control System (DCS) is from Yokogawa and was also installed recently.

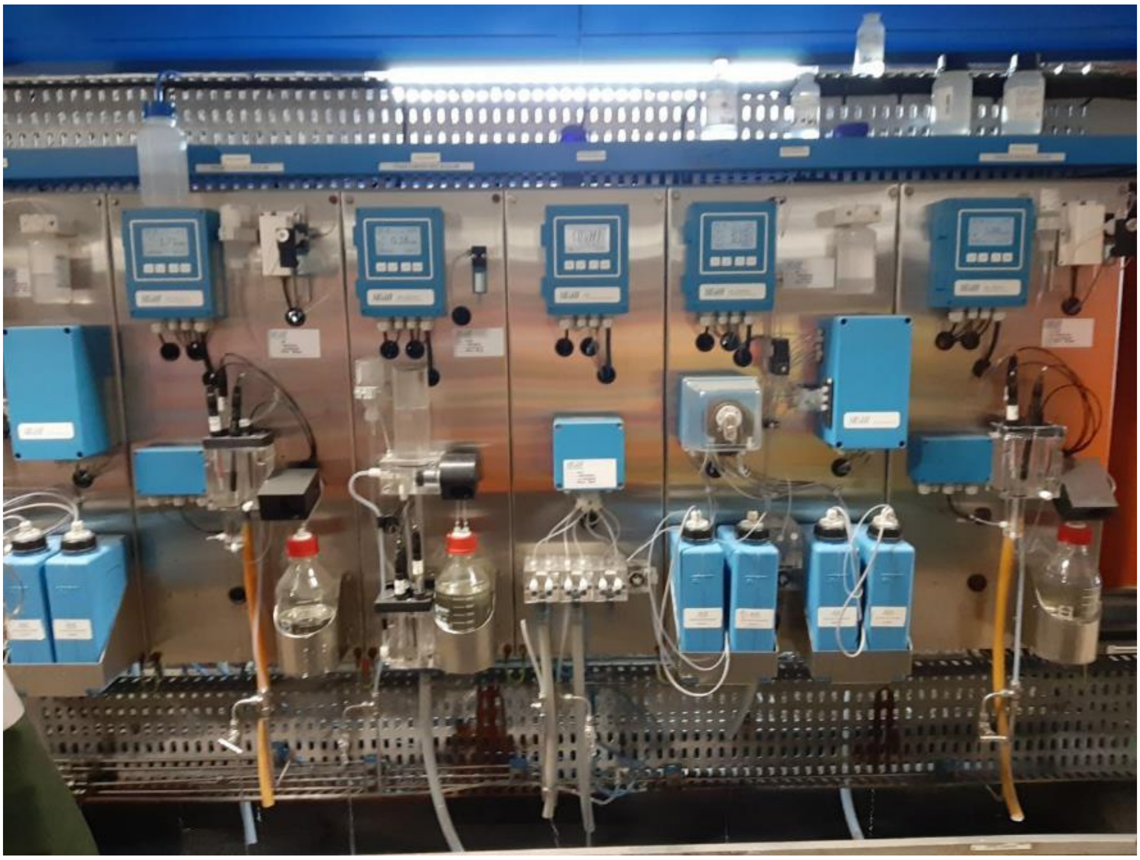


Figure 195: Measurements at the Tutuka water treatment plant

According to the power plant staff, all the water measurement equipment is running properly, and in most parts of the power plant the measurements are online (see Table 96). For this reason, it is possible to operate the water treatment in a safe and automated manner.

The raw water source is surface water coming from the Grootdraai Dam and the Usutu-Vaal system.

Location	pH	Spec. Cond.	Acid Cond.	Deg. Cond.	O_2	Fe	Si	Na	Cu	Org.
Makeup water	Off.	Off.	---	---	---	---	Both	Both	---	Off.
Conden-sate	Off.	Off.	On.	---	On.	Off.	Both	Both	Off.	---
Feed water	Off.	Off.	On.	---	On.	Off.	Both	Both	Off.	---
Boiler water	Off.	Off.	On.	---	---	---	Off.	Off.	---	---
(HP) live steam	Off.	Off.	On.	---	---	---	Both	Both	---	Off.

Table 96: Types of water measurements at Tutuka power plant

Water treatment at a glance:

- Capacity of the make-up water plant is sufficient.
- The plant is capable of producing water of adequate quality.
- The water treatment DCS is in order.
- Automated operation working as intended.

5.16.2.5 Technical Status of the Auxiliaries and other Systems

Coal and Ash: The coal is delivered by truck and train to the coal storage site. After some homogenisation, the coal is delivered using a 7 km-long conveyor belt. The quality is partially inconsistent. The next table shows the coal composition ranges during March 2023.

Fixed Carbon avg. in %	41.0
Volatile Matter min. in %	23.0
Volatile Matter max. in %	24.4
Total Moisture min. in %	5.8
Total Moisture max. in %	7.2
Ash min. in %	26.2
Ash max. in %	30.5
Gross Calorific Value min. in MJ/kg	21.88
Gross Calorific Value max. in MJ/kg	23.64

Table 97: Coal composition at Tutuka power plant (March 2023)
Source: Tutuka power plant

The coal quality, which is mainly based on LHV, is 10% to 15% below the design range, which leads to higher coal consumption. Furthermore, the coal contains a lot of stones/rocks. This increases wear and abrasion on the mills and coal ducts to the burners. To reduce the impact of these negative coal properties it is necessary to analyse the coal and, if possible, mix it. In order to do this, an online automatic coal sampler has been installed but is currently not being used, which means that the coal needs to be sampled and analysed manually. This takes approximately 48 hours per sample. Pre-specification is done by the mines themselves and Eskom's PDE department carries out the verification on-site.

There is enough space to store the coal for at least 48 hours on-site, which enables the boiler operator to react to the incoming material before needing to burn it. This is only possible thanks to the well-organised coal stockpile.

Ash handling area: The ash handling plant is quite unreliable, which is reflected in its 22% share of PLL and 7.51% share of UCLF. The main problem is the regular failure of the submerged scraper conveyors, which is caused by inadequate design of the submerged scraper conveyor drive, resulting in ash accumulation. To solve the problem, it is necessary to upgrade the submerged scraper conveyor.

OEM parts: The spare-parts warehouse was visited. The warehouse was reasonably in order. Nevertheless, there are challenges getting all the spare parts needed.

Workshop: The maintenance workshop was also visited. It is well-equipped and reasonably clean and provides many options to carry out repair work at the site.

Auxiliaries at a glance:

- The coal stockpile is in order.
- The coal quality is 10%−15% below specification and abrasive.
- The coal analysis is carried out manually.
- The ash plant is unreliable.
- The maintenance workshops are adequately equipped.
- Lack of spare parts is an issue.

5.16.3 Technical Measures to Improve the Plant Condition

Boiler and draught group: The potential MW gain is estimated to be around 700 MW_e.

Within the draught group, which includes the ID fan, FD fan, PA fan, preheater and ESP, there are several areas requiring repair work. Repairs would lead to immediate improvements and a positive impact on PLL. As discussed in the previous chapters, the draught plant is a major contributor to high PLL. Even if operated at maximum load, the ID fan's capacity is not great enough to guarantee the necessary pressure in the furnace. This means the boiler load has to be reduced. The following measures would improve the situation:

- Upgrading the ID fans
- Tightening or replacing the flue gas ducts
- Tightening or replacing the air heaters

Upgrading the design capacity of the ID fan would increase the airflow and may, thus, solve the problem. This would lead to an increase of required auxiliary energy and should be combined with the other proposed measures, to reduce this negative aspect. The option of upgrading ID fans would require upgrading the electrostatic precipitators as they would need to match the increased volume flow.

It is strongly recommended that all potential sources of air ingress be inspected and repaired. This work could be carried out during short stoppages and would probably lead to immediate improvements. It is also recommended to inspect the wall penetrations of the superheaters, reheaters and soot blowers.

This would enable many water and steam leakages to be identified at many positions across the plant. We recommend the systematic repair of leaking valves, pumps, etc., in order to improve plant efficiency and reliability.

PLL is also impacted by the limits set by dust emission regulations, currently at 300 mg/m^3 but due to be further tightened to 100 mg/m^3 in April 2025. To achieve this threshold and avoid power loss, the ESPs need to be in order. It is recommended to refurbish the ESPs in all units. If the emissions limits cannot be achieved, we recommend checking the possibility of suspending or at least temporarily increasing the emission limits for a limited period of time.

Machinery: The potential MW gain of the following measures is approx. in the range of 440 MW_e to 750 MW_e.

The main areas in need of improvement are the condenser vacuum and the cooling towers. In order to solve both problems, it is necessary to check the cooling water circuit and identify the cause of waste water entrance. An overhaul of the existing condenser by cleaning or replacing the condenser pipes would also lead to an increase in capacity. A full replacement and refurbishment of cooling towers 2 to 5 is also recommended to stabilise the condenser vacuum. Here, we strongly recommend adherence to the vgbe norm S 455 “Cooling Water Systems and Cooling Water Treatment”.

The HP heaters of Units 1 to 4 are currently unavailable, leading to a power loss of approximately 50 MW_e per unit or 200 MW_e in total. In order to overcome this problem a replacement of the HP heaters is necessary.

Mills: The maximum potential MW gain of the following measures is approx. 320 MW_e.

The mills have been another cause of outages, accounting for 17% of total PLL in FY2023, according to Eskom. A lack of mills and spares, in combination with an abrasive coal, have been the main problem here. To prevent further power loss due to mill outages, the mills need to be refurbished and mill drum liners replaced. To achieve a redundancy within the units it is necessary to bring all six mills per boiler back into operation. We also recommend the storage of additional OEM spares.

Generator: To ensure proper quality assurance for generator components, inspections and tests according to vgbe norm S 166 “Quality Assurance in the Manufacture of Generators” should be considered.

Electrical and C&I: The MV and LV boards at Units 1 to 5 are outdated and a safety risk. As a result, they need to be refurbished to meet applicable standards. Also, procurement of relevant spare parts is an issue for those outdated boards.

The C&I system used for Units 1 to 3 is severely outdated and, as a result, is no longer provided with spares, which leads to regular trips. The system needs to be refurbished in the same manner as for Units 4 to 6.

Ash handling: The design of the submerged scraper conveyor used at the power plant is inadequate and needs to be upgraded to avoid blockage and plant outages.

5.16.4 Power Plant Management

Currently, 720 employees and 1 736 contractors are working at the power plant. The staff turnover rate has increased over the last few years from 7% up to 12%. There is a massive lack of engineering staff caused by uncertainty regarding the future of the site, leading to staff migration and low morale. We recommend that a decision is made as soon as possible regarding the future of the power plant.

Despite these challenges, the team is managing to keep the plant in operation. There are knowledgeable and experienced staff in the operational areas upon which this assessment focused, and there is a comprehensive understanding of the issues at the plant. Furthermore, there is transparency regarding all key performance data for the plant (e.g. PLL). However, communication in the plant could be improved. There is no workers council and no reward or incentive scheme, due to lack of funding. The employee training is moderate and carried out based on a training matrix for each discipline.

Maintenance: The maintenance team is responsible for fixing the problems reported by the operations team. The scope is defined by the engineering department. Moreover, the maintenance team takes care of spare-part planning. Currently, 183 people are working in the maintenance department. There are seven maintenance KPIs for FY2023:

Inspections per year:	n.a.
Annual maintenance budget specific costs: (total; per MW_e; per MW_e/h)	R829 million.; R236 182 /MW_e; R984.74 /(MW_e/h)
Intervals between failures:	n.a.
Failures per year:	n.a.
Maintenance FTE/MW:	no measurement of maintenance hours

Share of outsourced maintenance:	Approx. 60%
Maintenance contracts in place:	21 out of 54 (38.9%)

Operation: The operations team works in five shifts, 24/7, with 32 people on each shift. The operations team is quite badly understaffed, with about 30% of the operator positions and critical positions vacant.

There are 69 trips per year, so about six trips per month, for the whole plant. These trips can be categorised as follows: operation caused trips (6); unsuccess full starts and forced downs, etc. (60). Due to intensive monitoring of performance data for Units 4 to 6, there is high transparency regarding plant status in these areas. The outdated C&I system of Units 1 to 3 means that detailed data logging is not possible here.

There are six operation KPIs for FY2023:

Efficiency (design @full load):	27.76%
Coal consumption:	1 830 t/h
Auxiliary power consumption:	75 MW_e
Startup time for a cold start:	16 h
Number of damages due to bad operation:	6
Number of trips due to bad operation:	7

Outage: Tutuka's outage planning is organised according to Eskom's outage philosophy and to running hours of the low-pressure turbine (in average every six years GO). In theory, the planning addresses the scope and timing of the outage activities (see Figure 196). In practice, the outage philosophy cannot always be adhered to, especially in terms of timing, due to the high grid demand and the resulting reduced available times for maintenance. The latest outage was conducted at Unit 6. This outage was postponed because spares and contracts were not yet ready.

Most of the outage work is outsourced to OEM (GE, Steinmüller, Kulkoni, PCB, etc.). Eskom has enough people, in terms of numbers, but they lack the expertise. The lack of spares and material, caused by a lack of funding in some areas of the power plant, is the main reason for incomplete or delayed outages.

Procurement is partially carried out locally and partially organised centrally, depending on the total value of the contract, as well as the requirement specified on the tender.

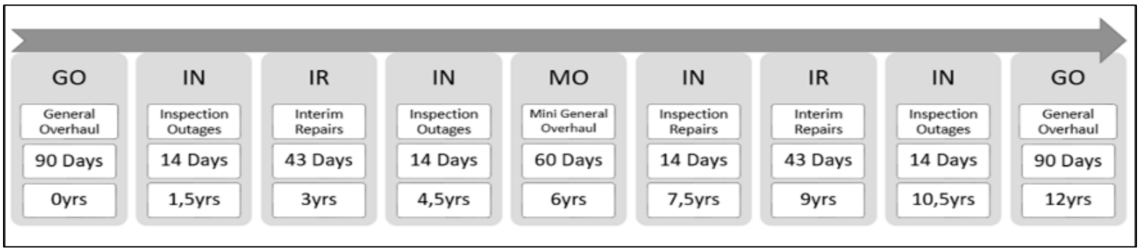


Figure 196: Outage sequence at Tutuka power plant
Source: Eskom

5.16.5 Technical Profile of Main Plant Areas

Boiler and related Plant Area:

All six boilers at Tutuka station have the same design. They are designed as once-through Benson type boilers. Each boiler possesses coal bunkers with a total capacity of up to 4 000 tons, which can supply the boiler for up to 16 hours at full load. This means that even a malfunction of the conveyor system or of coal production in general would not directly result in operational restriction. Six mills are installed per boiler. Using coal of the specified quality, a maximum of five mills are needed at full load operation. One mill was therefore designed to be spare. The pulverised coal is burned by 24 Steinmüller PF-burners that are positioned horizontally opposite each other.

Firing System	
Manufacturer	Africa (Pty) Ltd
Type	PF Burners
Number of burners	24
Coal mass flow [t/h]	1 830
Pressure [bar, absolute]	171
Temperature [°C]	540
Mills	
Manufacturer	Stein Industries
Type of mills	Tube mill
Mill capacity [t/h] – per mill	65 t/h per mill, required 305 t/h in total per boiler
Coal supply	
Coal supply	Open cast mine with belt transport
Coal storage capacity on-site [t]	27 000
Boiler bunker capacity [t]	24 000
Precipitators/ Flue gas cleaning	
Manufacturer	

Type	Electrostatic Precipitator (ESP)

Machinery and Electrical:

Turbine	
Manufacturer	GEC Turbine Generators Ltd.
Type	Multi-cylinder, impulse reaction
Casings (HP-IP-LP, double/single flow)	1 HP (single flow), 1 IP (single flow), 2 LP (double flow)
Steam volume [kg m/s]	501
Main steam pressure [bar, absolute]	161
Main steam temperature [°C]	535
Reheat steam pressure [bar, absolute]	40
Reheat steam temperature [°C]	535
Cold end	
Condenser	Barlow Heavy Engineering Ltd
Cooling tower	Hyperbolic natural draught, wet cooling
Generator	
Manufacturer	GEC Turbine Generators Ltd
Terminal voltage	22 kV (50 Hz)
Rating	609 MW_e
Cooling system	Stator core: Hydrogen Stator windings: Demineralized Water
Transformer	
Manufacturer	Siemens
Terminal voltage primary/ secondary	22 kV/420 kV
Placement	outside

6 Transmission Grid Assessment

This chapter includes the main results of the transmission grid assessment workstream. More details of the findings are part of the Appendices (refer to chapters 9.2. to 9.4).

6.1 Scope of Work

The main task was to assess South Africa's transmission system in relation to the unsatisfactory performance of the power system with daily load shedding throughout the country. The focus was on the assessment of the overall condition of the transmission system, with the emphasis on reliability, availability, security, and sufficient capacity.

The assessment should provide information that could form the basis for the development of measures to address network modernisation and the expansion of capacity over the next ten years. The client named three areas for analysis, with the focus on improving the connection possibilities of IPP and renewable energy power plants (RES):

- Age-related replacement / upgrading of substations and lines in the transmission grid.
- Expansion / new construction of substations and lines in the transmission grid, to eliminate capacity bottlenecks.
- Expansion / new construction of substations and lines in the transmission grid, to connect new IPP and RES

Based on the information gathered during this assessment, it is necessary to establish whether the existing planned projects and approved designated budgets already meet the required modernisation and network-expansion needs. The planned timelines for network upgrades are to be assessed in the context of available budget and to be prioritised, based on the importance of network expansion and modernisation requirements.

6.2 Methodology of Assessment

The methodology of the assessment required special measures and approaches due to the project's very tight time frame. The preparation time spanned only a few weeks and was used to intensively prepare for the on-site visit and to gather information in advance (see 6.3).

Gathering the necessary information for a high-quality assessment, despite the short preparation time and the short time on-site, was done via three main sources (see Figure 197):

- Evaluation of received documents describing the current state and development of the company, as well as questionnaires sent in advance.
- On-site interviews with managers and departments of strategic importance for the operation of the transmission system (Transmission Group Executive, System Planning, Asset Management, System Operator, Maintenance, Finance).

- On-site visits for first-hand assessment of the network condition and to confirm information received orally or in writing.

All data obtained from the three sources were analysed and evaluated, to obtain a full picture of the performance, technical condition and economic situation of the transmission system. Due to the restrictions placed on carrying out the assessment (time and personnel), it was only possible to examine a limited sample of asset categories, structural units and processes relating to the operation of the transmission system. All assessments were checked for plausibility by carrying out cross-comparisons between the areas examined. The interfaces between cooperating departments were analysed by way of example and provided further indications for the generalisation of assessments made in individual analyses.

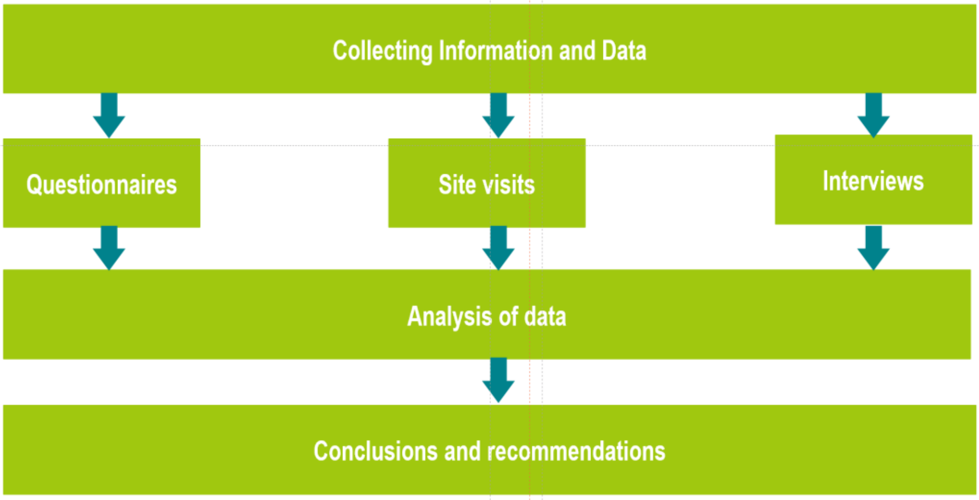


Figure 197: Methodology of assessment of the transmission system

Several substations and line sections were visited to act as a further building block in creating the basis for an overall assessment of the transmission system. During these on-site inspections, the condition of the sites was recorded using a defined methodology. This enabled a systematic analysis of the condition of the plant afterwards, allowing a comparison of the components and of the plants as a whole. This enabled an extrapolation on the overall condition of the transmission system. This exemplary assessment also enabled a review of the assessments made of the process organisation and management as well as the validation of the strategic and planning orientation of the transmission system.

By using several data sources and analysing them in conjunction with extrapolating the results of selected subareas to the company as a whole, a qualitatively good assessment result was achieved for the transmission system business. This made it possible to draw appropriate conclusions and recommend measures for the further development of the transmission system and possible improvements.

6.3 Provided Information

Requested information and answers on questionnaires:

- Data of selected equipment transmission
    - List of transformers
    - List of lines
    - List of substations
- Organisational structure of Eskom
    - Employees
    - Structure
- Maps of transmission grid
- Single line diagrams of visited substations.
- Economic data of transmission business
    - Budget for investment
    - Budget for maintenance
    - Energy export/import
- System performance KPIs
    - Failure statistics
    - Grid losses
- Strategy reports
    - Transmission business plan
    - Transmission development plan 2023 to 2032
    - Investment projects 2013 to 2022

Additional information received during the interviews.

- Presentation and additional documents of interviewed department
    - Transmission Grid Planning & Development
    - Asset Management Systems Update
    - Transmission Operations & Maintenance
    - Transmission Plant Performance KPIs – FY2022
    - Questionnaires for the Financial Department
    - Transmission Pricing_CostReflective_response
- Information about Asset Management and Asset Strategy
    - Organisational structure – roles and responsibilities
    - Asset Management Policy and Strategic Asset Management Plans
    - Asset Strategy Priorities
    - Asset Master Data Assessment
    - Examples of applied asset strategy to selected HV equipment.
        - Transformers
        - Capacitors
        - Protection for feeders
        - Voltage transformers
        - Disconnectors
        - Transmission's Strategic Spares of Transformers and Reactors

6.4 General Description of the Eskom Transmission Grid

Eskom Transmission network consist of approximately 33.200 km of transmission lines, 171 substations, 568 transformers with a total capacity of 160 514 MVA. The voltage levels operated by Eskom are:

- 88 kV,
- 110 kV,
- 132 kV,
- 220 kV,
- 275 kV,
- 400 kV,
- ±533 kV (DC),
- 765 kV.
- The two lowest voltage levels are of minor importance for the transmission grid, which is reflected in the length of the lines operated at this voltage, Table 98. Most of the transmission lines are operated at 275 kV and 400 kV. 1032 km of DC line connect the Apollo HVDC converter station with the supply station in Mozambique.

Rated voltage, kV	88	110	132	220	275	400	±533	765
Length, km	17	6	652	1352	7494	19916	1032	2784

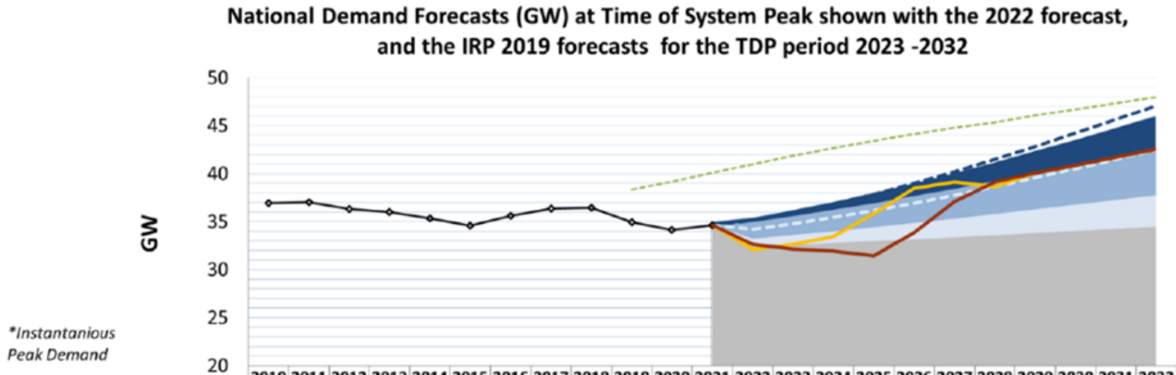
Table 98: Eskom Transmission line length depending on the rated voltage.

Table 99 presents the number of substations according to their highest voltage level. 275 kV and 400 kV are the most common highest voltage levels at Eskom's substations.

Rated voltage, kV	88	132	220	275	400	±533	765
Number	Nil	3	15	59	84	1	9

Table 99: Number of Eskom Transmission substations
according to the highest operated voltage level

According to data presented in Eskom's Transmission Development Plan (TDP) 2023−2032 the peak load demand in 2021 was close to 35 GW and for planning purposes it is forecast to grow continuously to 43 GW in year 2032. The minimum load demand in the year 2021 was 18.5 GW and the contracted energy 227 TWh, Figure 198. On the generation side, there was close to 56 GW of installed power, most of it – 40 GW contributed by coal power plants. Other important technologies were wind, pumped storage hydropower and gas power plants, contributing around 10.5 GW together. The installed generation capacity in 2032 is forecast to be around 97.5 GW. The increase in the generation capacity will be contributed, in the main, by the further development of wind and photovoltaic installations, which should reach 47 GW.



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
2022 Tx High												35	35	36	37	38	39	40	41	42	44	45	46
2022 Tx Moderate High												35	35	36	36	37	38	38	39	40	41	42	43
2022 Tx Medium EE / EI												35	33	34	34	34	35	35	36	36	37	37	38
2022 Tx Low												35	33	33	33	33	33	33	34	34	34	34	34
2019 IRP HLI Demand (GW)										38	39	40	41	42	43	43	44	45	45	46	47	47	48
2021 Tx High												35	35	36	37	38	39	40	41	43	44	46	47
2021 Tx Moderate High												35	34	35	35	36	37	38	39	40	41	42	43
Actual Peak Demand (GW) *	37	37	36	36	35	35	36	36	36	35	34	35											
Constrained Scenario 1												35	32	33	33	36	38	39	39	40	41	42	43
Constrained Scenario 2												35	33	32	32	31	34	37	39	40	41	42	43

Figure 198: 2022 national demand forecast scenarios
Actuals, the 2021 forecast, and the Integrated Resource Plan (IRP) 2019 demand forecast as reference. Scenario 2 is considered for TDP 2023 to 2032 input.[49]

There are several challenges that the Eskom transmission grid faces. One stems from geographic conditions in South Africa. The bulk of the generation capacity, which are currently the coal power plants, are in the north-east region, which is historically closest to the largest load centre. That, however, does not correspond to the potential of renewable generations in South Africa, since their potential, as well as the interests of investors, are spatially towards the southwest part of the country see Figure 199. This will require energy from renewables to be transported to the historical load centres over long distances. This problem will gain in importance with the decommissioning of the coal power plants and rollout of the IPP projects. Plans to tackle this issue are being developed by Eskom Transmission. Another much more urgent problem is the low EAF of the operating power plants, which leads to controlled rotational load shedding as a countermeasure to blackout. However, although the availability of power generation has a major impact on grid operations, it is outside of Eskom Transmission's operating range.

[49] Source: Eskom, "Transmission Development Plan 2023-2032" ("2 - Transmission Development Plan 2023-2032.pdf")

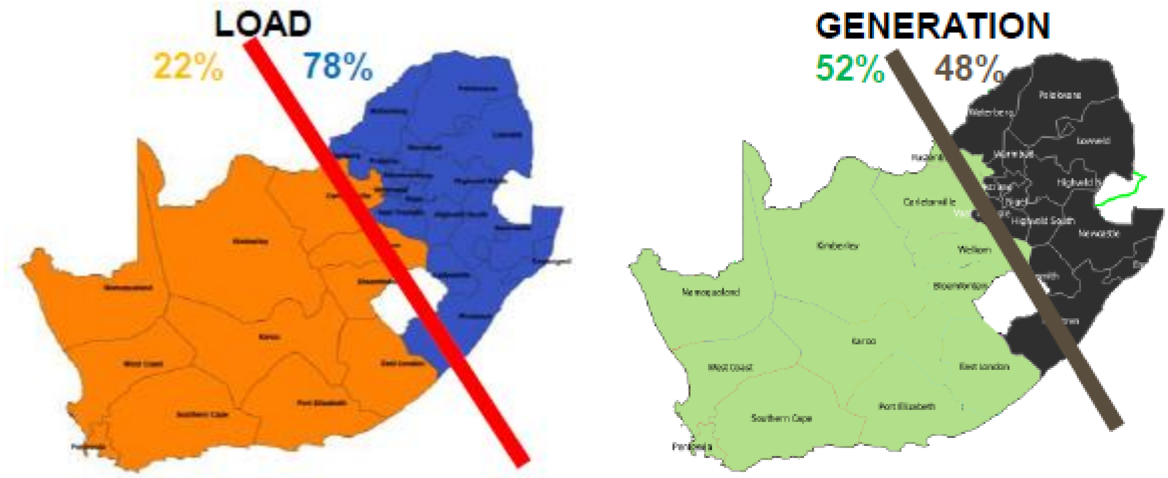


Figure 199: Spatial load (left) and generation (right) distribution in Eskom's Transmissions grid.[50]

6.5 Analysis of Received Data

6.5.1 Assessment of the Substations

Eskom has provided a list of all substations currently in operation on the transmission system for the assessment of the transmission system substations. Eskom currently operates 171 extra-high voltage substations on its transmission system. The number of substations corresponds to the structure of the grid and the characteristics of the transmission grid which transmits energy over a very large area with some densely populated regions, some of which are far away from each other. A large part of the country is sparsely populated but must also be connected to the transmission system. The age of the substations varies within a relatively wide range. The oldest substation was commissioned as early as 1956. In the last 30 years, 10 to 18 new substations were built every decade. This is relatively few in relation to the 171 existing substations. The usual lifespan of substations is about 50 years, so that three to four new substations would have to be built every year to maintain good grid condition. This is also reflected in the fact that more than 60 substations are over 50 years old and would have to be replaced soon (see Figure 200). This illustration shows that there is a high need for renewal, which has probably been neglected over the last 30 years due to financial reasons.

[50] Source: Eskom, The Eskom Transmission Development Plan (TDP) 2023 – 2032, 27 October 2022 ("3-TDP Presentation.pdf")

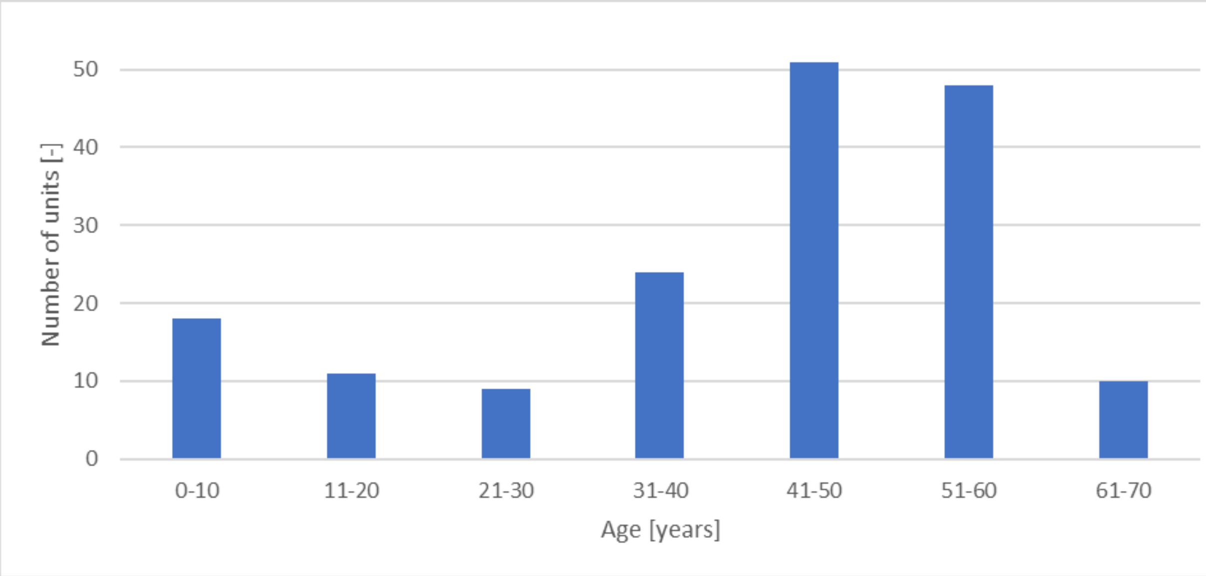


Figure 200 Distribution of age classes of Eskom transmission substations

The impression of a modernisation backlog derived from the information obtained from the list of substations provided was put into perspective by the observations made in the substations visited during the on-site visit. In the interviews conducted with network planning and asset management, further information about modernisation programmes for all asset classes - some already implemented, others planned - was presented and discussed (see 6.6). Modernisation programmes exist for many components that significantly influence the reliability and availability of the substations. A high percentage of the high-risk circuit breakers have already been replaced. Poor condition instrument transformers, which act as a link to the grid protection, have also largely been replaced by new devices. Similarly, for the protection devices, a modernisation programme is ongoing and, as stated by the maintenance department, about 70% of installations are microprocessor-based technologies (see 6.6).

Thanks to the modernisation programmes that have been initiated, old substations are also in good condition and have been brought up to the current state of the art through partial modernisation. Some modernisations (e.g. substation Apollo DC and AC) have also been extended to include the replacement of structural components and correspond more to a new replacement construction than a partial modernisation. As these modernisations were not marked in the substation list, it can be assumed that other older substations have also been modernised according to this methodology. This means that a larger number of very old substations which have been modernized are probably in a condition that corresponds to a new building at the time of the ex-tensive upgrading in the respective substation.

We recommend the continuation of all modernisation programmes that have been started. Sufficient budgets need to be provided for this in the annual planning (see 6.5.5). Against the background of the planned expansion of large wind and solar power plants, as well as the connection of independent power plants to the transmission system, grid expansion needs to take place, to enable the integration and connection of these additional generation capacities to the transmission system.

6.5.2 Assessment of the Transmission Transformers

For the purpose of the assessment, Eskom Transmission provided a list of the transmission transformers owned. According to the list, there are 301 transmission transformers (nominal voltages of both sides are not lower than 132 kV) with a total capacity of about 129 GVA and 156 transmission-to-distribution transformers (nominal voltage of the high side is not lower than 132 kV and nominal voltage of the low side is below 132 kV) with a total capacity of about 26 GVA. Due to the many voltage levels in Eskom's transmission grid, see 6.4, there are multiple configurations of primary and secondary voltages, further extended by tertiary or auxiliary voltages. Within this subsection, the transformers are only classified in terms of voltage according to combinations of primary and secondary voltages and the focus is on the transmission transformers.

Figure 201 presents the classification of the transmission transformers according to age. The majority of them, 181, are no more than 30 years old. The other 120 have already reached the typical lifetime of a power transformer, which is 40 to 50 years, or they will reach it in next few years. There are also 8 units that are over 50 years old. Age distribution according to the levels of transformed voltage is shown in Figure 202. The worst situation, in terms of age, is among the group of 275/132 kV, where most of the units are over 30 years old. Furthermore, all the oldest transformers (>50 years old) are in this group. The oldest transformers have capacities below 350 MVA, see Figure 203. In the capacity categories, it is the 351−600 MVA category that has the best selection of transformers, in terms of age.

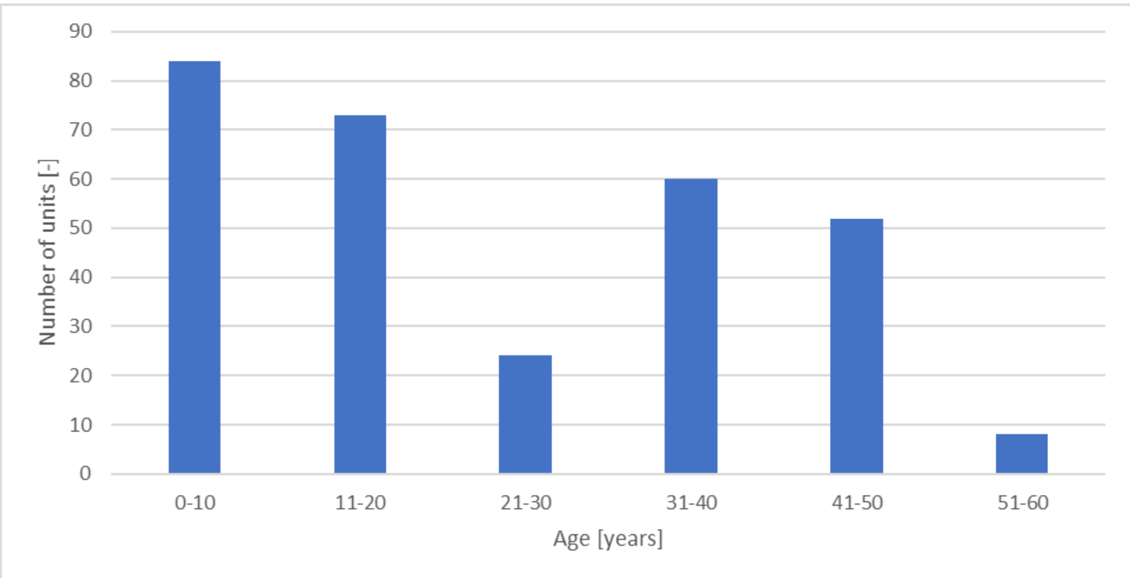


Figure 201: Age classes of Eskom transmission transformers (sec. voltage ≥ 132 kV)

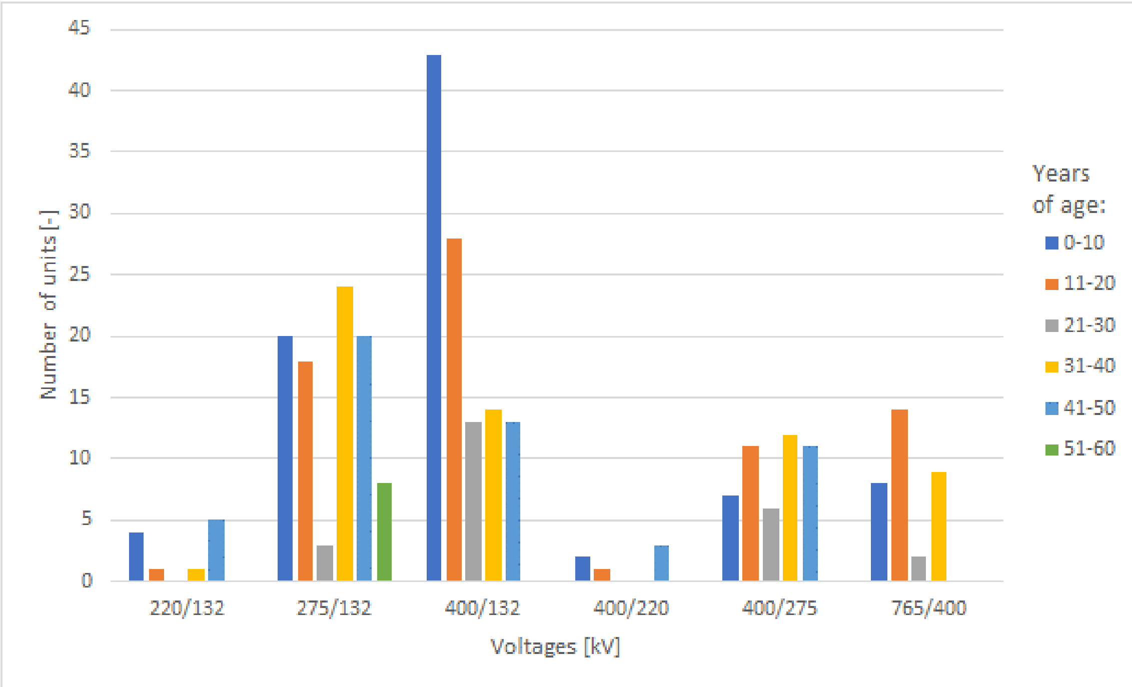


Figure 202: Age classes of Eskom transmission transformers depending on voltage

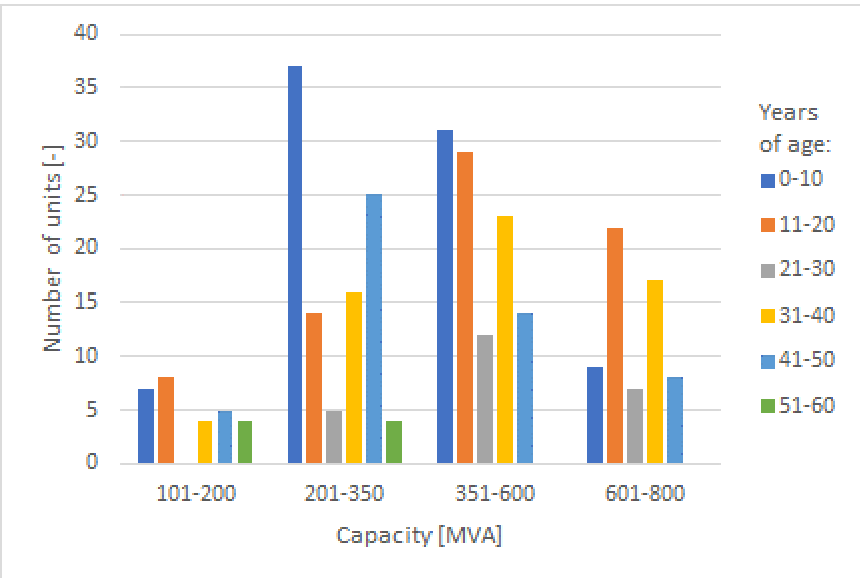


Figure 203: Age classes of Eskom transmission transformers dep. on the capacity

According to Eskom's Asset Management Policy, described in 6.5.5, Eskom Transmission monitors the state of the transformers, so that their age is not a direct indicator of their need for refurbishment. In the case of transformers, the analysis of gas in oil is the basic criterium for the condition assessment. Figure 204 shows that a large majority of the transmission transformers are in very good condition. Except in the age classes 21–30 years and 51–60 years, the distribution of the results is comparable. It is important to note that even within the youngest class of analysed assets, there are units in very poor condition, and these units should be given more attention. In comparison, none of the units in the oldest age classes (41 years old and older) had critical values in the gas in oil inspection. Nevertheless, the state of the oldest assets can change more rapidly than in the case of younger units, and proper countermeasures should be prepared for such instances. Figure 205 and Figure 206 show that the critical units are distributed almost independently of voltage level and unit capacity. It should be noted that in the group with the biggest transformers (601–800 MVA in Figure 206), the ratio between units rated as “very good” and “fair”, “poor” and “very poor” is the lowest.

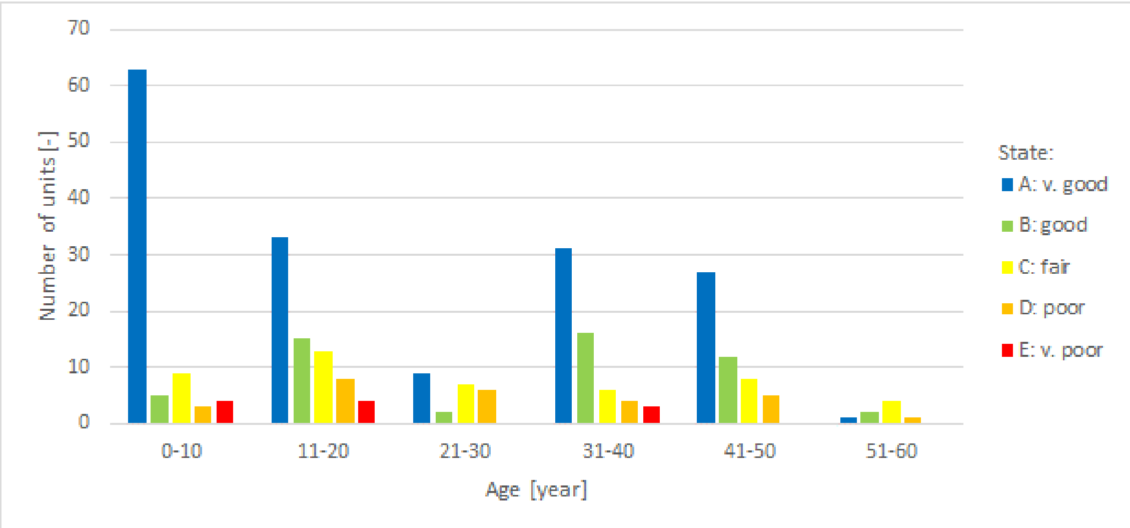


Figure 204: State classes of Eskom trans. transformers (≥132 kV) dep. on the age

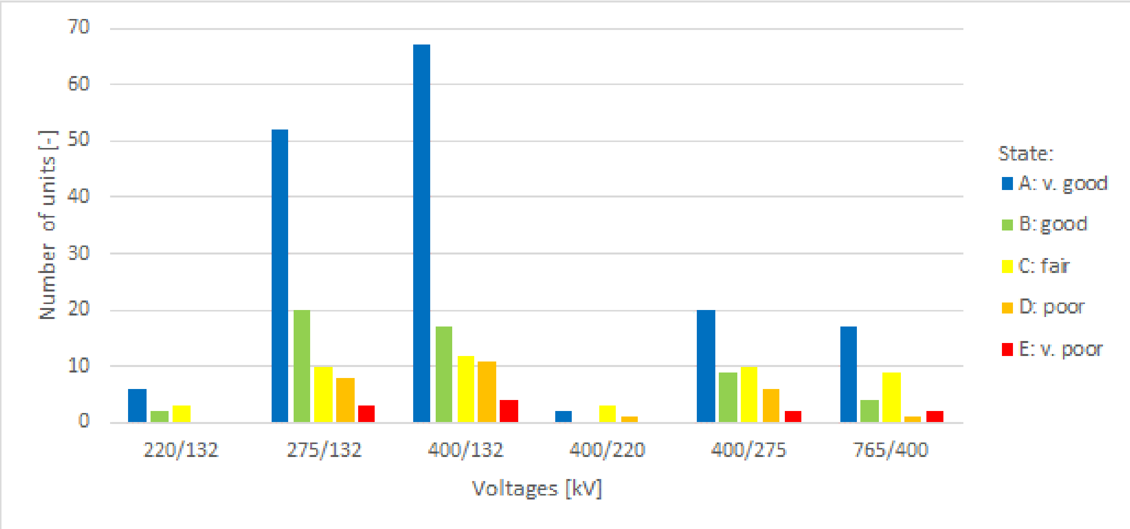


Figure 205: State classes of Eskom trans. transformers (≥132 kV) dep. on voltage levels

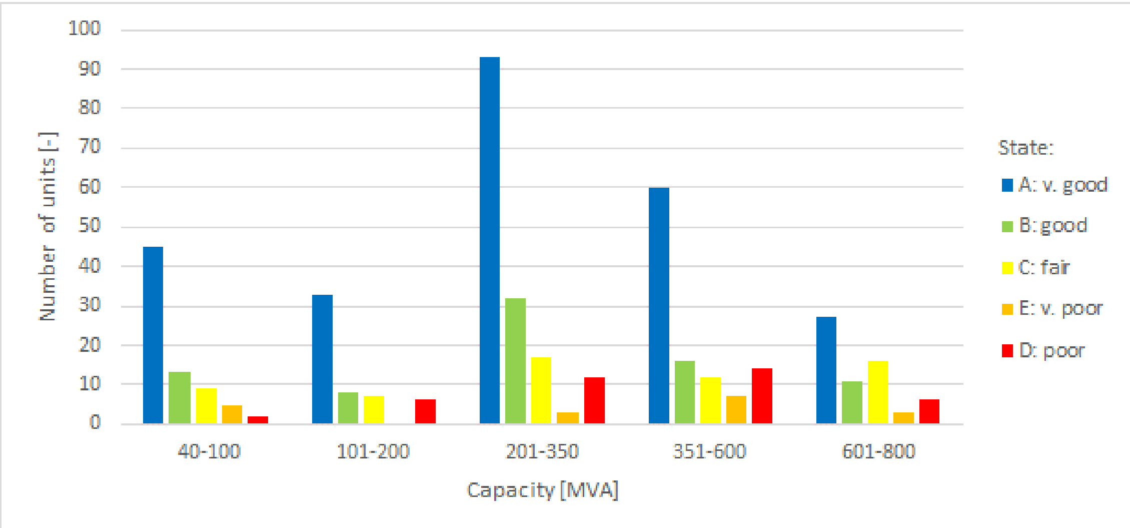


Figure 206: State classes of Eskom trans. transformers (≥132 kV) depending on cap.

Condition-based refurbishment is the state-of-the-art assessment method, and it is recommended to continue with this approach. When preparing for the refurbishments, plans need to take into consideration the fact that the degradation of the older units can accelerate and, due to the age structure, multiple units could require refurbishment at the same time.

6.5.3 Assessment of the Transmission Lines

For the transmission lines system assessment, Eskom provided a list of all lines currently in operation on the transmission system. Eskom currently operates 368 extra-high voltage lines in the transmission system. All transmission lines are overhead lines (OHL). Cables are not used. Within the substations, short cables are used to connect GIS (Gas Insulated Switch-gear) and transformers, but these are not relevant to the assessment and are not taken into consideration in this report.

Eskom operates about 32,500 km of overhead lines with voltages from 220 to 765 kV. Approximately 650 km of overhead lines with 132 kV are operated under the responsibility of the Transmission System Operator (TSO) but are classified as distribution voltage level and are not taken into consideration in the report.

The dominant voltage level of the nationwide transmission system is the 400-kV level. 169 400-kV-OHLs, with a length of almost 20 000 km, are operated by Eskom. These lines form a meshed transmission system and are used in all 6 national regional grids.

The ten lines at the 765 kV level form a high-capacity transmission corridor between the central north-east (Johannesburg area) and the south-east (Cape Town region), as well as some other connections to distant substations. This backbone is an essential support for power exchange and system stability between the Johannesburg and Cape Town load centres.

In the Central Grid in the Johannesburg/Pretoria region, the transmission system is operated at 275 kV. The 400 kV level is of less importance in the area. This particular voltage level is mainly operated in this region and stems from the historical development of this load centre. In the other parts of the country, the 275 kV voltage level and such OHLs are rarely used.

Furthermore, a 2-pole DC line with 533 kV is operated to Mozambique, which connects a big hydropower plant (1800 MW), 1400 km away, to Eskom's transmission system. The DC line runs across approx. 1000 km of South African territory.

Fifteen OHLs are operated with a voltage of 220 kV, running a total length of approx. 1350 km. The use of these voltage levels is an exceptional case and is only used locally in some places. They are an exception in the transmission system and are not dealt with further in this assessment.

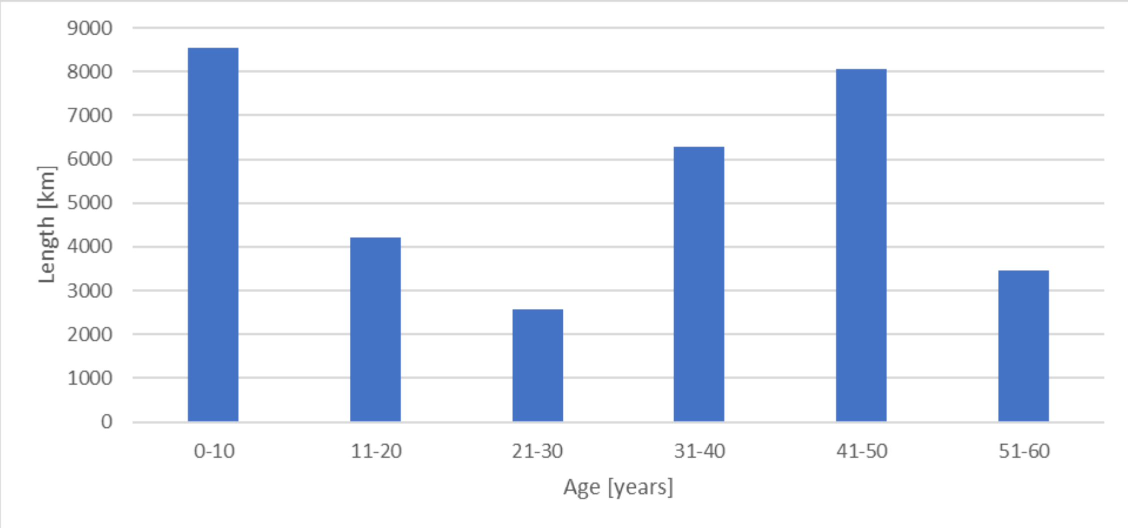


Figure 207: Age classes of Eskom transmission lines (voltage ≥ 132 kV)

The line length of approx. 32 500 km corresponds to the structure of the grid and the characteristics of the transmission system, which transmits energy over a very large area. The age of the overhead lines ranges from lines erected in 1965 up to the present day. About one third of the overhead lines were built more than 40 years ago. In the last ten years, 25% of the overhead lines have been newly built or added (see Figure 207). The continuous increase in the construction of new lines is probably due to the need to expand the grid, because of increased energy demand and the start of grid expansion for the integration of RES.

The age structure of OHL, despite one third of old OHL, is not critical, as OHL can still be operated safely and reliably after 40 years if they are well maintained. Eskom keeps the OHL in good condition with a package of maintenance measures. Monitoring of the overhead line is carried out cyclically with inspection flights. Eskom maintains its own helicopter squadron for this purpose. Defects that are detected are repaired at short notice by maintenance teams. OHL's good maintenance condition was noted during the visit to South Africa during random inspections of line sections and connecting lines at substations.

It is recommended to continue the good maintenance programmes for OHL plus cyclical monitoring. Sufficient budgets are to be provided for this in the annual planning (see 6.5.5). Against the background of the planned expansion of large wind and solar power plants, as well as the connection of independent power plants to the transmission system, further grid expansion is required, to enable the integration and connection of these additional generation capacities to the transmission system.

6.5.4 KPI

In order to better assess the performance of Eskom's transmission grid, a few KPIs delivered by Eskom Transmission were compared with similar, publicly available indicators published by the German TSOs. The first one was the technical losses in the transmission grid. Eskom reported this value to be 2.31% in the period between April 2021 and March 2022. For similar periods, for example in 2021 and 2022, values of 2.1% and 2.6% respectively were reported by one of Germany's TSOs, TransnetBW GmbH[51]. Considering the long distances spanned by Eskom's grid, the reported value shows good performance.

Another performance indicator is the line fault per 100 km of overhead lines. Eskom Transmission reported 12-Monthly-Moving-Index (12MMI) for March 2022 at the level of 2.565/100km, with the target value of 2.2/100km. For the sake of comparison, analogue values of German TSOs are shown in Figure 208. The average value for all four German TSOs was around 1.5/100km between 2018 and 2022.

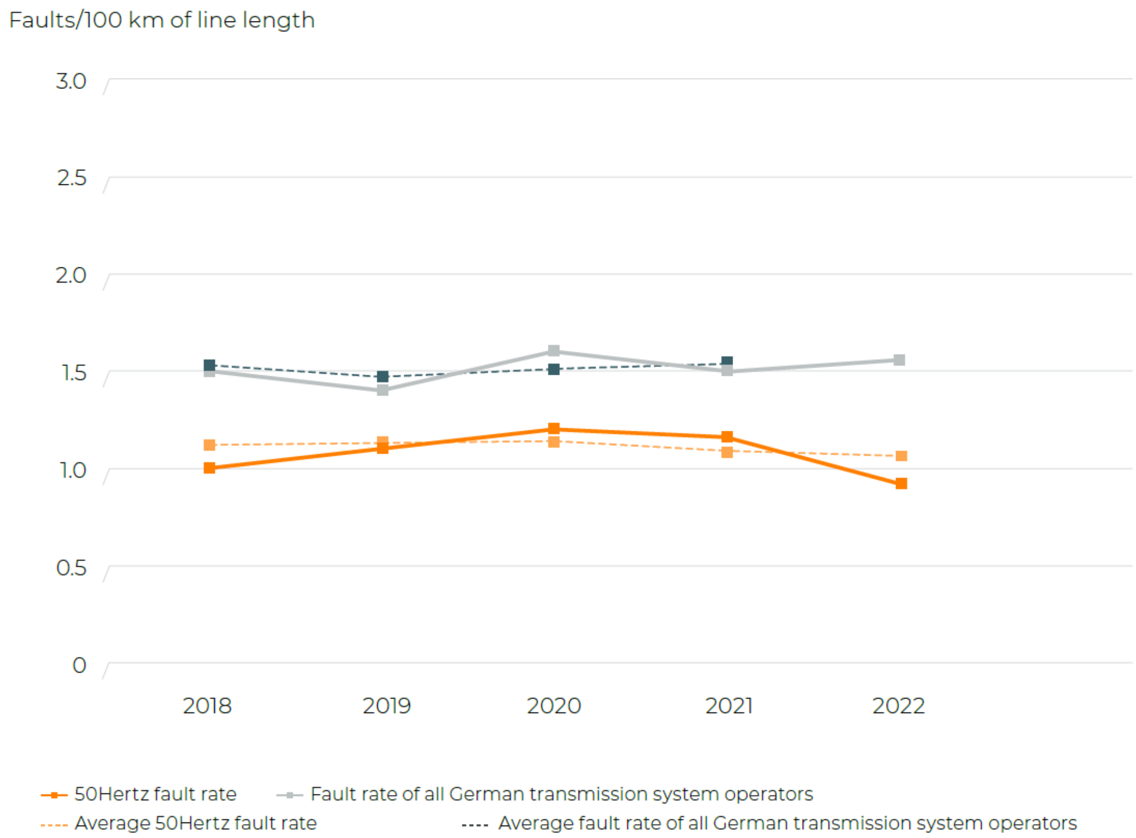


Figure 208: Line faults per 100km of line length in the German transmission system[52]

The third performance indicator was system minutes (SM) lost, which reflects the time needed for the annual peak power to generate energy which was not supplied due to interruptions. Performance in the period 2013-2022 is shown in Figure 211. This specific indicator

[51] https://www.transnetbw.de/en/transparency/market-data/structure-data

[52] 50Hertz Transmission GmbH, "Almanac 2022. Accelerated grid expansion. Successful energy transition."

is not reported by German TSOs; however, an average interruption time (AIT) is. AIT is the time of the year proportional to the rate between estimated energy not supplied and yearly energy consumption. For the TSO TransnetBW, there were 2'20'' in year 2008 and 2'08'' in year 2013. Otherwise between 2007 and 2022, the ATI values were zero[51]. The different interruption times at Eskom and TransnetBW might, on the one hand, be the result of the slightly higher number of line faults per kilometre at Eskom. On the other, it might be because the German transmission system fulfils the (N-1)-criterium, whereas there are regions in Eskom's transmission grid that do not. It is important for Eskom to seek a compromise between strengthening the grid towards (N-1) and creating additional capacity for the connection of new generations.

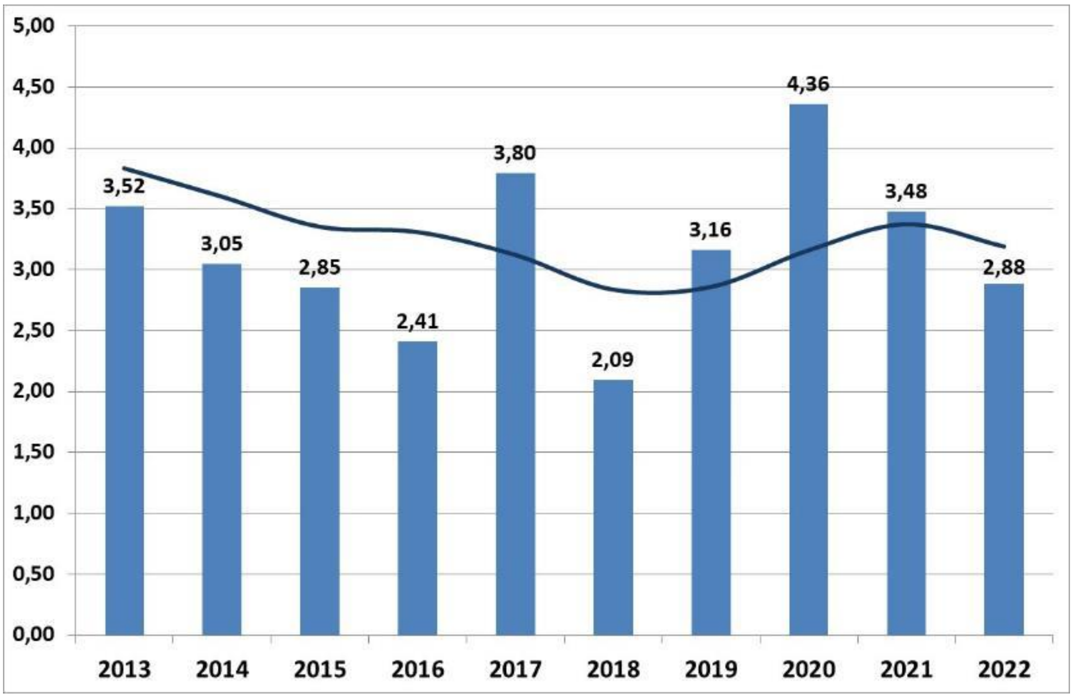


Figure 209: System minutes for the incidents of less than 1 minute [53]

6.5.5 Transmission Development Plan 2023

The Eskom Transmission Development Plan (TDP) is an annual report published by Eskom Transmission, informing stakeholders about the current situation, and giving a 10-year perspective on grid planning. The edition 2023-2032 was provided by Eskom for the purpose of the assessment.

[53] Source: Eskom, "10. System performance KPIs.xlsx"

Grid Expansion and Integration of RES and IPP

One of the key topics addressed in the TDP is the grid expansion required to enable the connection of renewable energy generated by independent power producers (IPP), who apply for the connection within the independent power producer procurement programme (REIPPPP).

The generation capacity connection assessment (GCCA) for the current planning year 2024 resulted in the numbers presented in Figure 210 , which show free capacities for the transmission grid. It should be noted that the south-west of the country has lower capacities in comparison to the north-west, especially Northern Cape, which has no free capacity. The results from Figure 210 should be compared with the diagram showing renewables potential, presented in Figure 211. It is clear that the transmission grid needs to be expanded in the Northern Cape, as well as elsewhere in the southwest. This problem was addressed in the Strategic Grid Study and is presented in Figure 212.

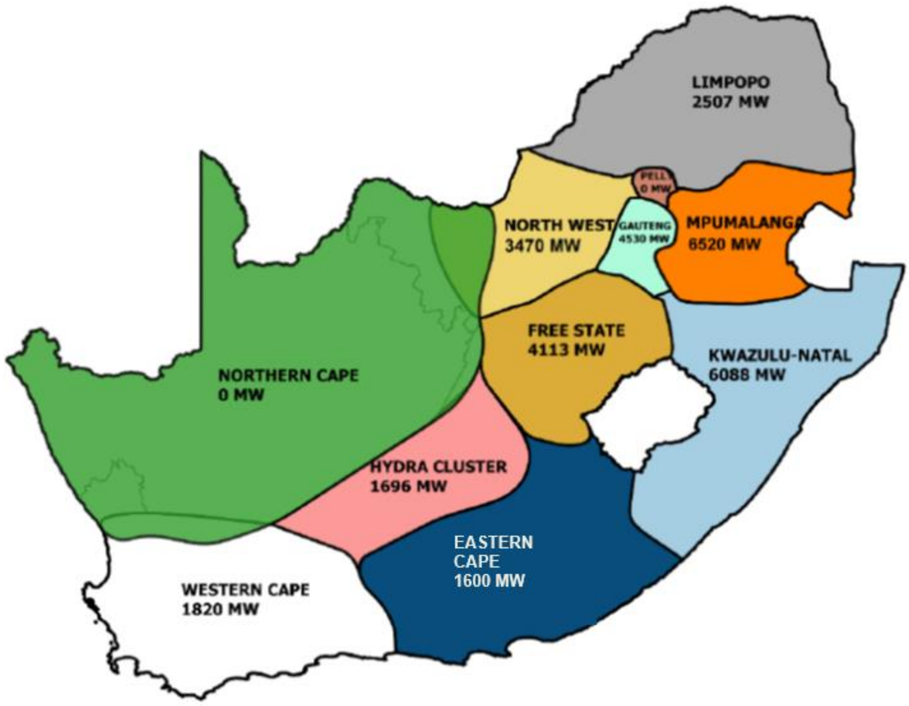


Figure 210: Generation connection capacities in the transmission grid for the year 2024 [54]

[54] Source: Eskom, “Transmission Generation Connection Capacity Assessment of the 2024 Transmission Network (GCCA – 2024)”, Reference No.: GP_22/52, March 2022

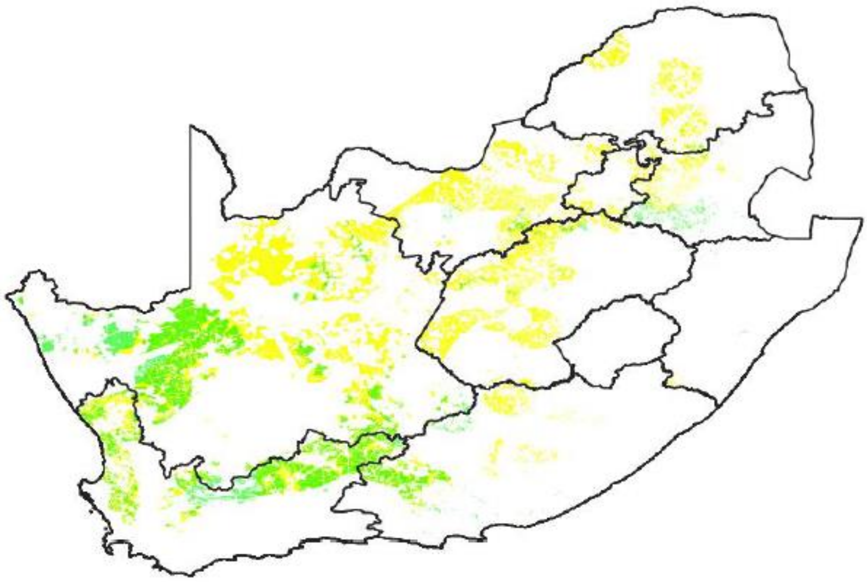


Figure 211: Areas suitable for PV (yellow) and wind power plants (green)

The environmental impact assessment was considered in the Eskom report [55] .

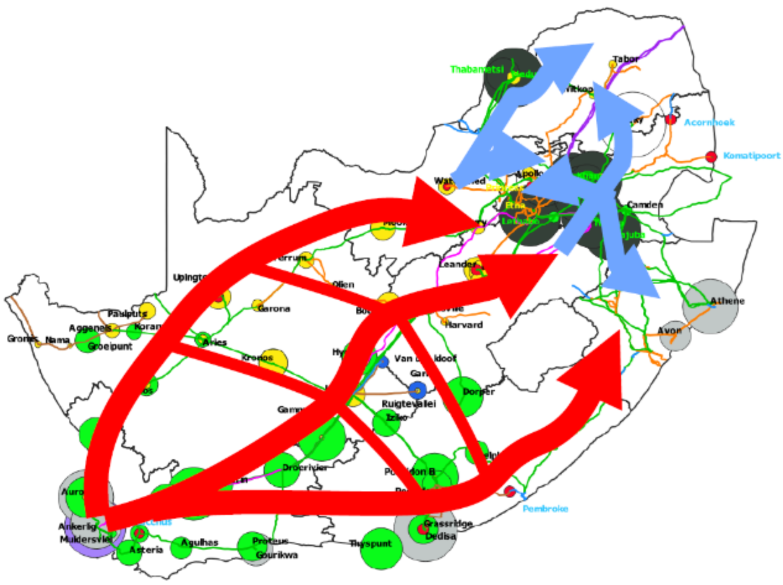


Figure 212: Planned transmission corridors for renewable power to the load centers[50]

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[55] Source: Eskom, "Transmission Generation Connection Capacity Assessment of the 2024 Transmission Network (GCCA – 2024)", Reference No.: GP_22/52, March 2022

Table 100 compares the generation connection capacity prepared for 2024 with the grid expansion plans for each of South Africa's provinces, as set out in the TDP, which should also be consistent with the development of the transmission backbone and associated regional power corridors. The expansion plans are divided into two-time horizons: 2023−2026 and 2027−2032. In the first period, most of the efforts related to expanding transmission lines are focussed on Northern Cape, which is the response to the high potential for renewables in the region and to the complete lack of GCC in this region. In the second period, this expansion intensifies and in addition to 1 313 km of 400 kV lines, a further 440 km of 765 kV lines are to be constructed. In this second period, the focus is clearly on those regions with the lowest GCC.

In terms of transformer capacity, the main focus needs to be on Western Cape in the first planning period, 2023-2026. In the second period, there are plans to install around 30 GVA of transformer capacity in the south-west of the country.

For both transmission lines and transformers, and in almost every province (except lines in Kwazulu-Natal), the expansion plans for the second period are even more extensive.

	Northern Cape	Eastern Cape	Western Cape	Limpopo	North West	Free State	Gauteng	KwaZulu-Natal	Mpumalanga
Generation Connection Capacity 2024*									
GCCA, MW	0	1600	1820	2507	3470	4113	4530	6088	6520
Overhead lines									
2023-2026									
275 kV, km	-	-	-	-	-	14	-	-	-
400 kV, km	1242	41	39	276	140	-	63	580	136
765 kV, km	-	-	40	-	-	160	-	-	-
Total, km	1242	41	79	276	140	174	63	580	136
2027-2032									
275 kV, km	-	-	-	150	-	-	19	-	-
400 kV, km	1313	1061	464	845	240	144	135	316	593
765 kV, km	440	1010	510	-	-	270	-	188	-
Total, km	1753	2071	974	995	240	414	154	504	593
Transformers									
2023-2026									
no. units	3	9	16	7	3	6	9	9	13
Total capacity, MVA	1315	2284	4925	1115	860	2130	3202	1980	5170
2027-2032									
no. units	20	16	14	8	6	12	25	4	14
Total capacity, MVA	11020	10250	9520	4015	2745	9752	10626	2110	7385

*Hydra Cluster and Pelly not considered

Table 100: Comparison of gen. connection capacity and provincial grid expansion plans

Refurbishment and maintenance

As already mentioned in chapters 6.5.1 to 6.5.3, the transmission grid's key assets are already relatively old and many are approaching their nominal life span. In such a situation, the expansion of the system described in the previous section only makes sense if it is supported by a strategy of focussed capital investment and targeted efforts that ensure the continued stable and safe operation of the current grid. Eskom Transmissions worked out an asset management system, which is graphically summarised in Figure 213, to address this issue. Part of the system incorporates the asset management policy (AM Policy), which, together with Transmission business plan, provides the basis for the creation of strategic and tactical plans, as well as their implementation.

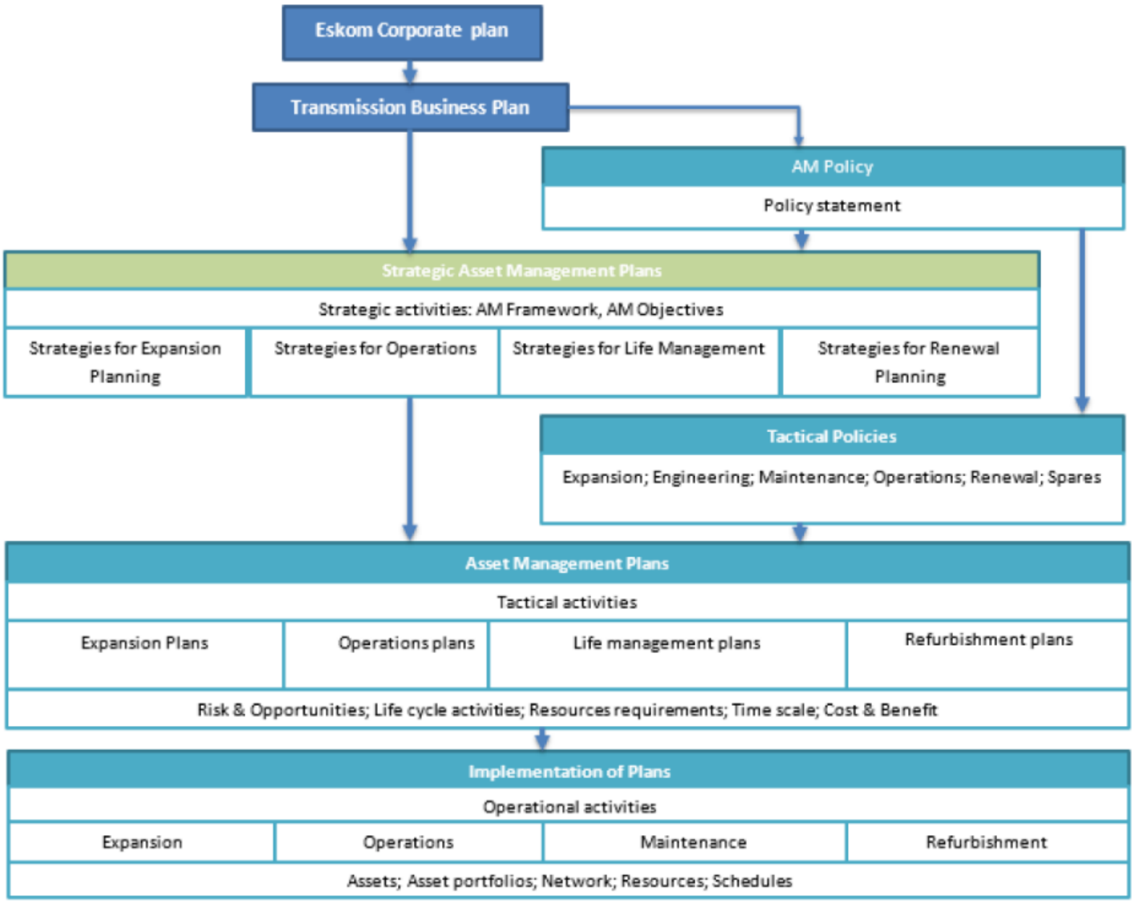


Figure 213: Eskom Transmission asset management system[56]

One of the outcomes of the AMS is the 10-year refurbishment plan. Refurbishment decisions are based not only on the age of the assets but also on an assessment of their actual condition, along with asset criticality and network risk and prioritisation. This approach is in line with current international best practices. An overview of Eskom's 10-year refurbishment plan until 2032, with 10 asset categories, is presented in Table 101. There are 81 transformers due to be replaced, which corresponds well with the conclusion drawn from the results presented in Figure 204 and, therefore, is assessed as plausible.

[56] Source: Eskom, "Strategic Asset Management Plan (SAMP)", document identifier: 240-160174092, rev.1

CATEGORY	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	Grand Total
CAPACITOR	1	3	1	5	2		4	6	2	4	28
CIRCUIT BREAKER	26	102	81	86	43	37	98	83	77	174	807
CURRENT TRANSFORMER	99	325	351	142	292	165	336	462	367	511	3,050
DC & STANDBY	62	183	40	14	11	13	8	45	8	5	389
ISOLATORS	90	302	269	150	165	79	268	464	263	642	2,692
PROTECTION	29	118	100	43	80	55	101	161	76	182	945
REACTOR						2	3	7	2	2	16
SURGE ARRESTER	45	201	192	74	173	163	243	334	242	549	2,216
TRANSFORMER	5	2	5		4	4	11	17	13	20	81
VOLTAGE TRANSFORMER	45	118	45	41	115	51	147	198	135	291	1,186
Grand Total	**402**	**1,354**	**1,084**	**555**	**885**	**569**	**1,219**	**1,777**	**1,185**	**2,380**	**11,410**

Table 101: Overview of the assets planned for replacement according to Eskom Transmission's 10-year refurbishment plan.[50]

Budget development for grid expansion

The transmission budget for the period FY2024−2028, as well as the budgets for other divisions, is given in the document "Eskom Holdings Corporate Plan FY2024 to FY2028 Rev. 13". For the execution of the expansion, refurbishment and strengthening project, R 74.2 billion is planned. The annual allocation during this period is presented in Figure 214. In total R 38 billion is planned for network expansion over the next five years, and R 36 billion for maintenance. Within the next three years, this budget will increase from R 5.7 billion to almost R 20 billion. While the planned financial resources for FY2024 and FY2025 are predominantly earmarked for maintenance, network construction will become increasingly important in FY2026 to FY2028. The defined KPIs for grid expansion in this period are summarised in Table 102.

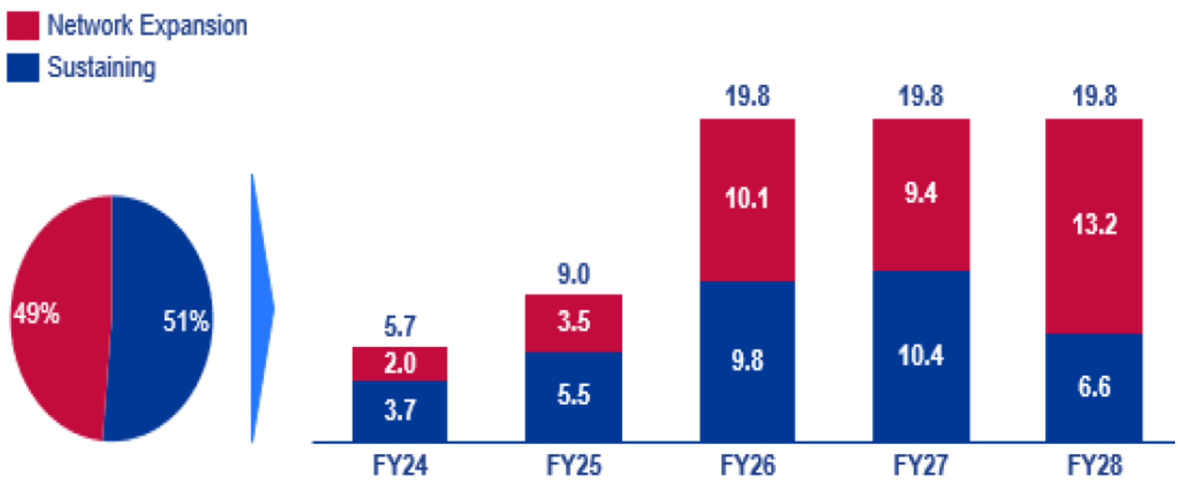


Figure 214: Eskom Transmission's budget allocation for FY2024-2028[57]

KPI	FY24	FY25	FY26	FY27	FY28	Total:
Transmission lines installed, km	166	186	489	896	1 447	3 184
Transformer capacity commissioned, MVA	1,600	2,630	4,000	2,630	5,975	16,835

Table 102: KPIs for new assets in the period FY2024−FY2028[57]

The KPIs for new construction of OHL and procurement of new transformers for the next five financial years correspond to the planned budget increase (see Table 102). This proves that the modernisation measures and grid expansions that have already been started are included in the medium-term budget plan. Moreover, the budget has been adjusted to the expected increase in RES and IPP.

The defined KPIs should be also compared to the requirements resulted from the network planning calculations. These requirements for FY2024−FY2028 were not available for this report, but they were available for the previous year and, therefore, for the period FY2023−FY2027. Table 103 summarises the network requirements needed to meet growth in generation and demand in South Africa.

As one can see, the defined KPI for installed transmission lines, which is 3,184 km, is above the requirement of 2 893 km for the period FY2023−FY2027. However, it needs to be noted that the TDP 2022 forecast a requirement for the installation of almost 2 500 km of lines in FY2028 (see Figure 215), which was not included in the FY2023−FY2027 forecast but should now be included in the KPI for FY2024−FY2028. Furthermore, one can see that the total required capacity of new transmission transformers in FY2023-FY2027 is 26,970 MVA, which is about 1 000 MVA above the KPI for the years FY2024−FY2028. Figure 216 clearly shows that the requirement for new installed capacity grows significantly towards the end of the analysed period. The increase in the planned funding corresponds to the modernisation and expansion measures identified in the TDP. R 2 billion is currently planned for the expansion measures in FY2024. A five-fold increase to R 10.1 billion by FY2026 is an enormous increase and challenge and requires corresponding staff resourcing at Eskom Transmission. Further annual increases in network expansion are to be aligned with the capacity to implement the projects through Eskom Transmission's internal resources. At the same time, it

[57] Source: Eskom, "Corporate Plan FY24 to FY28: Revision 13" ("2023 March 31 Eskom FY24 Corporate Plan Rev. 13.pdf")

needs to be noted that Eskom is impacted by the Ministry of Finance's debt relief and is not able to increase investments beyond a certain level.

Furthermore, expansion plans need to consider not only the requirements generated by the forecast IPP installations but also the fact that only a limited number of contractors are in a position to carry out the construction work to an adequate standard.

Transmission Assets Nationally	New Assets expected 2023 - 2027	New Assets expected 2028 - 2032	Total New Assets: 2023 - 2032
Power lines (km)			
765 kV	200	6128	**6328**
400 kV	2679	5019	**7698**
275 kV	14	178	**192**
Total length (km)	**2893**	**11325**	**14218**
Transformers			
Number of units	60	110	**170**
Total capacity (MVA)	26970	78 895	**105865**
Capacitors			
Number of units	11	29	**40**
Total capacity (MVar)	560	2 140	**2700**
Reactors			
Number of units	6	46	**52**
Total capacity (MVar)	600	14 113	**14713**

Table 103: Network requirements of South Africa[50]

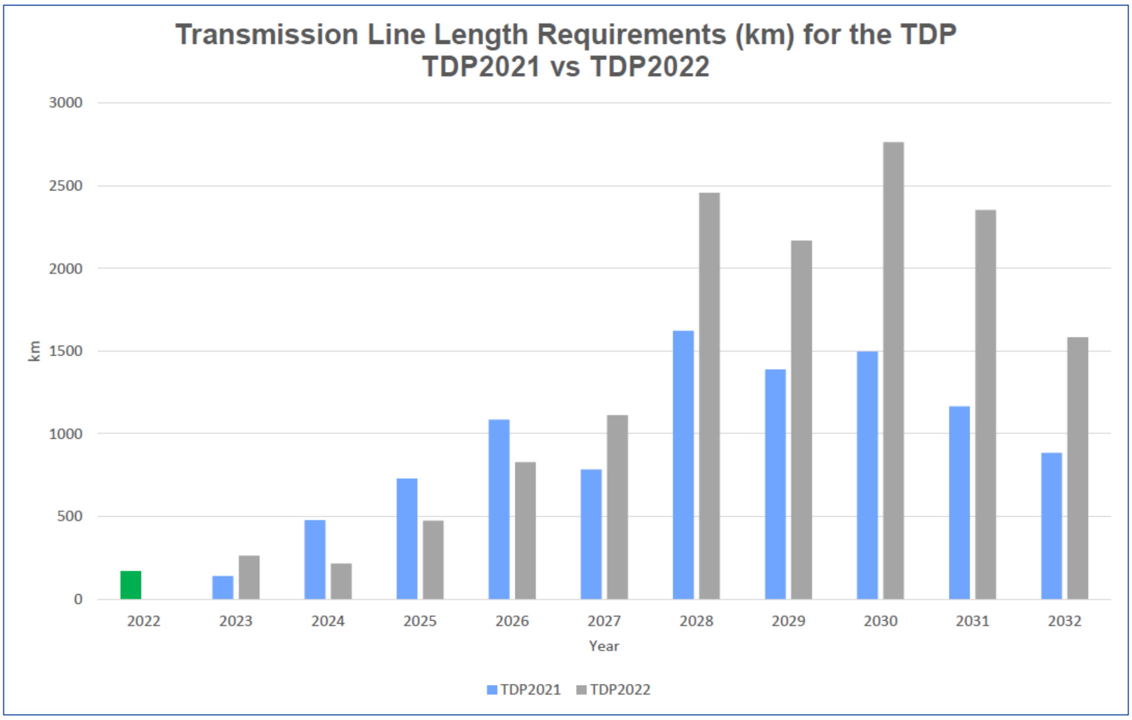


Figure 215: Required transmission lines until 2032 according to TDP2021 (blue) and TDP2022 (grey)[50]

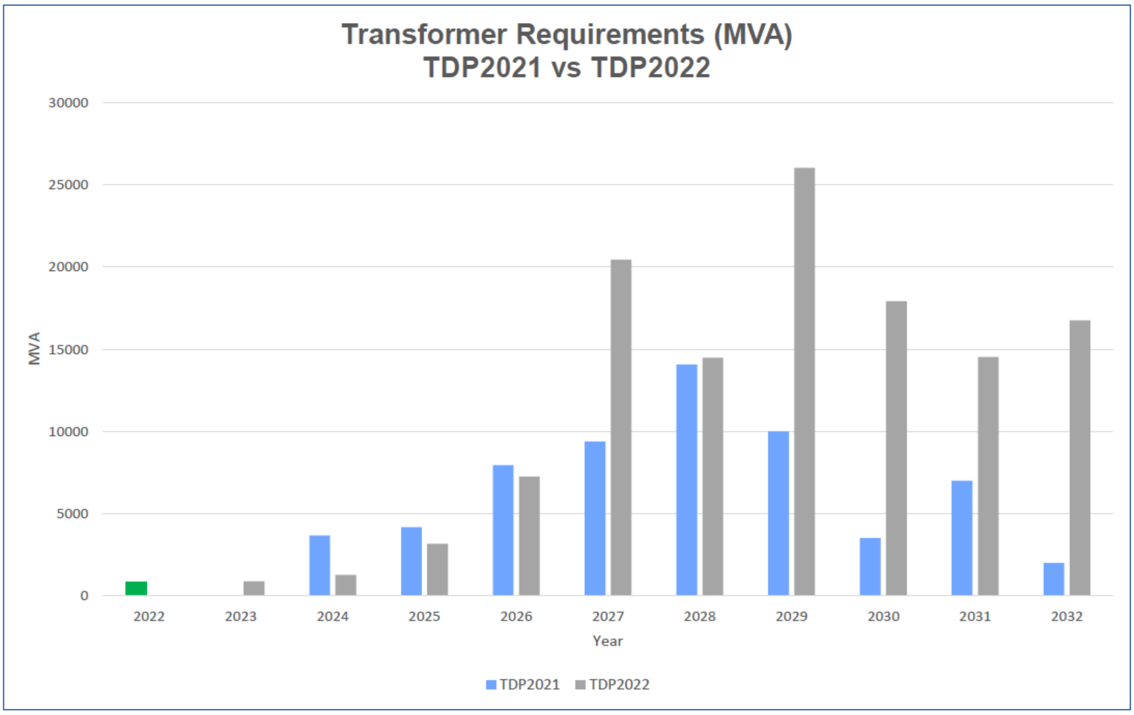


Figure 216: Required transformer capacity until 2032 according to TDP2021 (blue) and TDP2022 (grey).[50]

Budget development for sustaining the grid

The planned maintenance budget for the period FY2024−FY2028 is around R 36 billion, Figure 214, and is perceived by Eskom Transmission to be sufficient to keep the quality of maintenance at the current level. During the site visits, see chapter 6.7, the assessment team observed a very good quality of maintenance. Based on interviews with Eskom representatives and observations made on-site, as well as on the asset management system presented in previous subsection, it can be concluded that the budget for sustaining the network is sufficient for FY2024−FY2028.

Tariffs for unbundling and transmission

Eskom Holding is currently undergoing an unbundling process, shifting it away from a vertical company towards a horizontal organisation with separated generation, transmission, and distribution businesses. This process has been successful in many other countries and experience shows that it has a positive impact on the efficiency of the power system and on the energy prices. The unbundling is also necessary for establishing a liberalised energy market, which is operated by an independent market operator and where Eskom's generations business will not cross-subsidise the transmission business or vice versa. This should increase the incentive for the private sector to erect generation units and access the transmission grid as IPP. Given the current generation shortages, this would be an important step towards reducing the load shedding. According to Eskom Holding's corporate plan FY2024 to FY2028

Rev.13, the process of unbundling is already advanced and trading on the independent market is planned from 1 November 2023. Those efforts should be continued.

Given that, after the unbundling, the cross subsidisation between Eskom's businesses should cease, appropriate tariffs need to be developed to ensure sufficient revenues for the transmission system business. These tariffs should secure the maintenance of the current system but also allow for refurbishment and network expansion to create additional capacities. Therefore, the tariffs will need to be adjusted on a regular basis, to reflect the prevailing situation in the transmission grid. As set out in the Energy Pricing Policy, tariff developments should be approved by a regulator whose task is to ensure that the revenues are sufficient for sustainable operation and development of the network but do not impose unjustified costs on customers. Furthermore, the fact that tariff levels impact the rate of return on IPPs also needs to be considered. Such considerations are already made in existing legislation and so these should be applied when designing the tariffs. The transmission tariffs of the National Transmission Company should be designed with the following objectives in mind:

- Open access to the transmission services with fair, non-discriminatory prices for all customers
- Pricing levels that recover the approved revenue requirements of service providers
- Predictable development of prices over time for customers
- Pricing signals that reflect the cost structure of the services provided
- Optimal asset utilisation
- Unbundling of service offerings and cost-reflective pricing of each service component"

6.6 Interviews

During the on-site visit to Gauteng, discussions were held with experts from the departments responsible for network operation and development. As only one and a half days were available for these interviews, it was not possible to talk to all relevant departments and a selection had to be made. The following interviews were conducted:

- Managing Director Transmission – Mr. Segomoco Scheppers
- Grid Planning and Development – Mr. Jacob Machinjike
- Asset Management – Mr. Prince Moyo
- System Operator – Mrs. Isabel Fick
- Operation and Maintenance – Mr. Mbulelo Kibido
- Financial Transmission – Mrs. Ragini Ramkumar
- One aim of these interviews was to clarify open questions from the questionnaires and documents received for the network evaluation. At the same time, further information from the interviewed departments was to be gathered through direct exchange, and an impression of the management system and the management culture was to be gained. Questions and discussion topics were sent to the interviewees in advance, for preparation.

- All invited persons were excellently prepared for the talks. The discussions were complemented by the participation of further experts from the departments. The discussions provided a lot of additional information and allowed a good insight into the job profiles and organisation of the departments.

Conclusions from the Interviews: The interviews provided a great deal of additional information and contributed significantly to the understanding of the documents submitted and the management of Eskom Transmission. The main conclusions from the six interviews with Eskom Transmission experts are listed below. Further details on the content of the interviews are included in the Appendix Transmission Interview documentation.

Interview with Eskom Transmission's Grid Planning and Development Business Unit

- Long-term planning transmission development plan (TDP)
    - The TDP is an expedient and useful tool to carry out network planning according to demand.
    - The annual update of the TDP allows for a quick readjustment of the network development to changing requirements.
    - The TDP sets out the guidelines for action for the medium and long-term expansion of the network and indicates the financial resources required.
    - In practical implementation, there is a discrepancy between the planned measures and their timely implementation.
- Securing the necessary land has a high strategic value.
- Relationships with customers are managed through network planning.
- Network calculation is carried out according to the state of the art and is an integral part of network development planning.
- The future connection of planned renewable energy generation projects has been identified as a major challenge. Grid expansion planning is being oriented towards these requirements, even though little has currently happened in grid expansion and RES project development.
- Project development: Network expansion projects are developed in the department, prepared for implementation, and monitored during realisation so that planned measures are also implemented as expected.

Interview with Eskom Transmission's Asset Management Business Unit

- Asset strategy ensures maximum utilisation of the possible operating time of the equipment used.
- Regardless of the asset strategy currently in use, modernisation should be pushed forward, and corresponding financial resources planned in the next few years in order to avoid critical conditions:
    - Old equipment in use can fail in large quantities once it reaches a certain age.
    - Spare parts are no longer available in sufficient quantities or are no longer procurable.

    - Maintenance costs for obsolete technology increase exorbitantly and can no longer be implemented economically.
- The strategy of replacing equipment after the end of life should be combined with useful life indicators.
- The permanent switching for load shedding led to increased wear of the circuit breakers used for this purpose. Circuit breaker failure will thus become more likely in the future and can lead to critical situations in the grid.
    - Upstream switches must become active - large-scale shutdowns in the event of grid faults.
    - N-1 criterion can be endangered.
    - Grid stability can be endangered.

Interview with Eskom Transmission's Group Executive

- Budgets for modernisation are required in the next few years, otherwise there is a risk that critical network infrastructure will not meet the requirements for system stability and supply reliability (see asset management).
- The unsatisfactory situation of permanent load shedding results from the unavailability of sufficient generation capacities and is necessary for stable grid operation.
- The transmission system is responsible for stable grid operation, not for providing sufficient power plant capacities.
- The change process in the energy industry requires a clear regulatory framework:
    - unbundling process – tariffs for the services of the TSO
    - increasing number of renewables – budgets for grid extension, infeed tariffs for the RES and financing model of the tariffs
    - aging of the asset – budgets for modernisation
- Securing highly qualified staff through
    - competitive salary
    - recruitment of young good skilled employees
    - transfer of knowledge to new employees

Interview with Eskom Transmission's System Operator Business Unit

- Grid control is stressed by permanent load management.
- Grid control is well organised.
- All staff at the network control centre receive ongoing training in operation and trouble-shooting / trouble management.
- Remote control is possible for almost all switching devices. The switching operations are instructed by the Control Centre but carried out by the staff on-site. Potential for efficiency improvement with transition to remote control by the Control Centre in the future.

Interview with Eskom Transmission's Grids Operation and Maintenance Business Unit

- Maintenance is well organised and, except for special tasks (protective relays, circuit breakers, etc.), is largely carried out by substation staff. Special tasks are executed by skilled internal maintenance teams per region.
- The strategic guidelines for maintenance are set by asset management. Compliance with these guidelines is monitored by asset management (see asset management).
- The unsatisfactory situation of permanent load shedding has a negative impact on the execution of maintenance.
- Securing highly qualified staff is important for the quality of maintenance and should be supported by
    - competitive salary
    - recruitment of young good skilled employees
    - transfer of knowledge to new employees

Interview with Eskom Transmission's Finance Department

- The transmission system is currently financially managed as a cost centre.
- Until the transmission system is established as an independent company, a tariff structure must be created. The tariff structure is currently being prepared.

6.7 Site Visits

During the site visits, six substations, five lines and the National Control Centre were visited. The list and locations of visited sites are presented in Figure 217. The substations were of different voltage levels, 400 kV and 275 kV on the primary side and 275 kV, 132 kV, and 88 kV on the secondary side. One substation, Craighall, was of GIS type. In Apollo, a HVDC converter station was visited. The commissioning year of the visited substations ranges from around 1970 to 2014; however, the older ones dominated.

In terms of transmission lines, the site visit was conducted in the neighbourhood of tower number 13 of the Apollo-Thuso (400 kV) line. Eskom's National Control Centre in Simmerpan was visited and an interview conducted with the national operations chief engineer. There is no photographic documentation of the control room due to restrictions, as the national control centre is one of South Africa's National Key Points (key national assets of critical infrastructure).

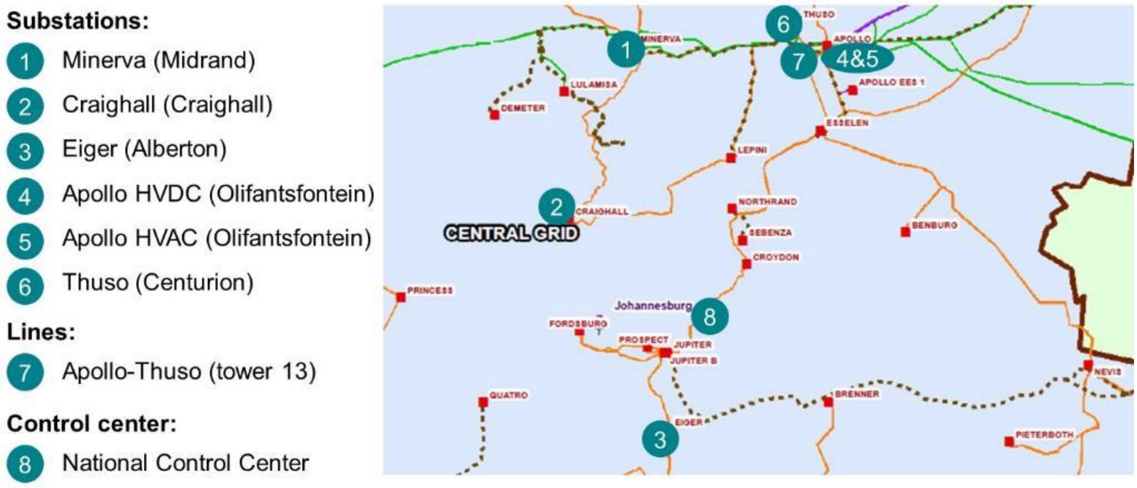


Figure 217: Location of visited substations, lines and control centre

6.7.1 Methodology of Assessment

A detailed analysis of the condition of all technical components was carried out in the selected substations and on the selected overhead lines sections. The analysis of the substation condition is based on a visual on-site assessment of it, a comprehensive questionnaire about each of the substations and an evaluation of past maintenance and documents handed over from the specification as well as the life cycle records of the equipment (if available). The following process steps are carried out for each assessment of the selected asset examples:

- Basic evaluation
- Determination of the condition
- Condition assessment
- Development of recommended measures

The first objective of the baseline assessment was to identify the type and technical design of the substations selected for the assessment and to adapt the assessment matrix according to the existing components. The basis for this was the single line diagram of the switchgear. Furthermore, information was collected about essential modernisation and repair work undertaken in the past. The focus was on assessing existing and prior damage, maintenance and modification measures.

Based on the first assessment step, the current condition as well as individual damages of substation components were recorded by registration of the observed results in the assessment matrix and underlined by photographically documentation. The primary, secondary, and civil engineering components were evaluated based on four classifications:

- Wear and Tear Classification (WTC)

- Compliance with Standards Classification (CSC)
- Safety and Environment Classification (SEC)
- Operating Age Classification (OAC)

A detailed description of the classifications and evaluation criteria is given below.

As part of the condition assessment, the documented conditions were evaluated for their impact on usability and stability of the assessed component. For evaluation, a grade of one to four was awarded for each classification.

If necessary, additional detailed investigation of individual constructions or components will be proposed in respect to the description of required measures. Required measures will be proposed in conclusion of the condition assessment. The intensity or the priority of the measures is represented by the activity classification (AC). This assessment method used here was originally developed to assess the condition of civil engineering construction work (in German: BAW-Merkblätter Bauwerksinspektion und Schadenklassifizierung an Verkehrswasserbauwerke) and transferred and adapted to the complex topic of condition assessment of substations. It has been successfully used in several assessments of substations already.

6.7.2 Classification

The classification is designed to ensure that the same content and criteria for each of the components to be evaluated are evaluated according to a uniform grading. As a result, the comparability of the selected substations and line sections is given later, but also overall within the classifications or for components.

For the assessment will be introduced the following four classifications:

- Wear and Tear Classification (WTC)
- Compliance with Standards Classification (CSC)
- Safety and Environment Classification (SEC)
- Operating Age Classification (OAC)

The average of these four classifications results in the activity classification (AC). All components will be assessed by a rating score between 1 and 4. The awarding of the assessments classification by rating score is only in whole numbers. Thus, it is possible to reduce subjective valuation uncertainty by clearly selection of the ranking score to each other and to increase the objectivity of the evaluation results. Only the average determination in each classification and for the whole substation is made with one decimal place.

Only ranking scores of 1, 2 and 4 will be awarded for safety and environment classification (SEC) as an exception to the scores of other classifications. The scores 2 and 3 are combined as score 2 to clearly define the score of the safety and environment criteria within the class.

Table 104 shows examples of rating groups and associated classifications with the available rating ranges.

Assessment group	WTC	CSC	SEC	OAC	AC
High voltage switchgear	1 – 4	1 – 4	1, 2, 4	1 – 4	1 – 4
Power transformers					
Operation building	1 – 4	1 – 4	1, 2, 4	1 – 4	1 – 4
Secondary Technology	1 – 4	1 – 4	1, 2, 4	1 – 4	1 – 4
AC/DC systems	1 – 4	1 – 4	1, 2, 4	1 – 4	1 – 4
Battery systems	1 – 4	1 – 4	1, 2, 4	1 – 4	1 – 4
Streets/Footpaths/Fences	1 – 4	1 – 4	1, 2, 4	1 – 4	1 – 4
Cable ducts	1 – 4	1 – 4	1, 2, 4	1 – 4	1 – 4

Table 104: Ranking score structure

6.7.3 Wear and Tear Classification (WTC)

Visually assessed wear and tear is assessed for its impact on the serviceability and/or viability of the relevant part of the installation. This affects the rating subjectively. However, since a large number of individual components assessed from different viewing directions leads to the overall result, the subjective reservation related to a single object is relativized and an objective overall rating is achieved. For known wear and damage, existing life cycle file information will be included. However, the current state of the components must always be considered.

The ranking scores for tear and wear classification will be defined as follows:

WTC 1: No noticeable wear and tear or damages detectable, respectively wear and tear or damage currently does not affect the usability and / or operation capacity and will probably not affect it in the future. These can be e.g. wear and tear or damage that exist since the start of operation and have not changed since then.

WTC 2: Wear and tear or damage that currently does not or only slightly affects the usability and / or operation capacity but will be a negative effect on suspected development. Another observation within the intended test cycle is sufficient.

WTC 3: Wear and tear or damage that currently affect the usability and / or operation capacity, but both are still provided. The wear and tear limit have been reached, but not exceeded. There are restrictions in the operation, or it is to be expected on a frequent damage and disturbance. In the event of faults, there is a risk of consecutive fault. It is necessary to check if further observation within the intended test cycle is sufficient or if a shortening of the interval is necessary.

WTC 4: The usability and / or operation capacity of the component is no longer given, or the wear and tear limit are exceeded. Wear and tear, which represents an acute danger to the safety of people or the environment and / or make the use of this component no longer possible. In case of faults, a consecutive fault is very probable. Immediate measures are required that exclude or prevent the hazard of injury or death of human.

6.7.4 Compliance with Standards Classification (CSC)

Another evaluation criterion is the visually discoverable component status. For this purpose, the individual substation components are compared with the current regulations or the generally recognized rules of technology. Discrepancies are included in the valuation and are described in the report. The resulting differences between the current situation and valid regulations / rules of technology are also evaluated in respect of their impact on usability and limitation of operation capacity as well as of the impact of probable damage. The ranking scores for compliance with standards classification will be defined as follows:

CSC 1: The current situation at least meets the requirements of valid regulations / rules of technology.

CSC 2: The current situation does not meet the requirements of valid regulations / rules of technology. However, the discrepancy is to be classified as safe in terms of usability and operation capacity or in terms of possible damage events.

CSC 3: The current situation does not meet the requirements of valid regulations / rules of technology. The discrepancy can influence the usability or lead to local damage events. There is a significant risk of losing the tolerable discrepancy of compliance to the standard.

CSC 4: The current situation does not meet the requirements of valid regulations or the rules of technology. The discrepancies are significant or constitute a violation of legal foundations. The effects on the usability or operation capacity are of great relevance or can lead to major damage events.

6.7.5 Safety and Environment Classification (SEC)

Furthermore, all substation components were assessed in respect to safety at work, operation safety and environmental safety. In particular, the following standards and regulations are considered:

- IEC 61936 – Power Installation Exceeding 1 kV.
- EN 50110-1 Operation of Electrical Installation
- IEC 61508 Functional Safety

The ranking scores for safety and environment classification will be defined as follows:

SEC 1: Operational safety and safety at work as well, as the fulfilment of environmental protection requirements, are in place or can be achieved through organisational measures (e. g. switch off and disconnection of live parts).

SEC 2/3: Operational safety and safety at work, as well as the fulfilment of environmental protection requirements, are only partly in place. Technical or organisational measures are required to meet safety and accident prevention regulations or environmental standards.

SEC 4: Operational safety and safety at work, as well as the fulfilment of environmental protection requirements, are not in place (e.g. damage of insulation with risk of a breakdown and arc). Immediate technical and organisational measures must be taken.

6.7.6 Operating Age Classification (OAC)

The age of the components is classified at four age levels for evaluation to consider aging processes. The usual normative technical service life of the respective components is set for the evaluation as 100% value. The percentage classification according to Table 105 is intended to consider the increasing likelihood of failure of technical equipment and systems at the end of life due to aging and wear and tear.

Operating Age Classification	Service life
OAC 1	≤ 70%
OAC 2	≤ 80%
OAC 3	≤ 95%
OAC 4	> 95%

Table 105: Operating age classification independent of service life

6.7.7 Activity Classification (AC)

The activity classification is determined by the average of the scores from each of the classifications: wear and tear; compliance with standards; safety and environment; operating age. The activity classification is made for each category of components (sorted by functional components). The following definitions shall be applied to the interpretation of the activity classification:

AC 1: There are to be planned, respectively to be expected, no or only long-term measures. Measures will be required only for standard maintenance or in case of unexpected failures due to poor quality of product. The classification of the component or the part of substation is rated as very good. Future discrepancies from the normal state cannot be predicted now.

AC 2: Measures are to be expected for the component in the medium term, as minor wear and tear weaknesses were indicated in the components. The condition is good and can be kept by regular maintenance. The continuously inspection and documentation of the condition is recommended.

AC 3: Short-term measures beyond the regular maintenance effort are necessary to secure the operation of the component or to maintain the operational safety of the substation. Limitations in operation can occur. It must be evaluated what measures are to be initiated for improvement the condition to achieve activity classification 1 or 2. Sufficient spare parts shall be available for the respective components. An economic evaluation of the increased technical and economic maintenance effort is required taking into account the supply contract and given operational limitations.

AC 4: Immediate measures are required to restore safety of personal or environment. The respective part of the substation is to be taken out of operation immediately. The condition of a (sub-) component is insufficient and minimum requirements are gone below or the technical service life is significantly exceeded. Safe operation cannot be achieved by organizational measures alone. There is an acute risk of personal injury or environmental damages.

6.7.8 Assessment Matrix

The scores for the classifications for each category of component in the assessment matrix will be collected during the on-site assessments. The activity classification is calculated automatically for each category of components by forming the mean value from the scores of the classifications. An exception is the case in which one of the classifications is rated to a score of 4. In this case, the activity classification always receives the value 4 - regardless of the scores of the other classifications. This ensures that significant deficiencies that constitute a hazard can be immediately recognized and eliminated.

Summarised scores are also calculated in the assessment matrix for parts of the substation as well as for the whole substation. Such summarised scores are calculated as average of all directly subordinate components. An exception is the evaluation of a component with the score 4. If a component that is included in a substation part is rated 4, the substation part as a whole and, ultimately, the entire substation in the corresponding classification is rated 4.

A clear overview of the overall state of the substation parts and the whole substation is provided in a graphic as spider web diagram. The aggregated scores of each classification are drawn for each substation part.

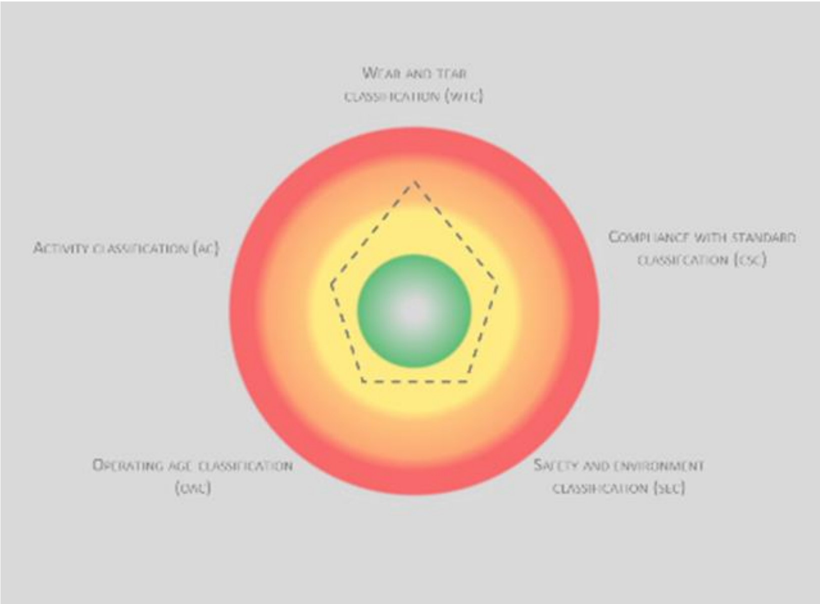


Figure 218: Example of classification diagram

The diagram is a pentagon. Each diagram axis represents a classification. The diagram is placed over a circle. The centre of the circle represents the score 1 and the outer edge of the circle the score 4. Thus, the further one angle of the pentagon is from the centre of the circle, the worse the substation performance in the corresponding classification. This is underscored by the colour of the circle from green inside the circle (score 1) to red in the outer ring (score 4). Figure 218 shows an example of the diagram.

6.7.9 Substation Minerva

Brief description of the substation

- Air insulated switchgear 400 kV double busbar (4x overhead line bays; 4x transformer bays, 2x cross coupling bays and 1x lengthwise coupling bay in busbar 2, all bays equipped with circuit breakers, see Figure 219)
- Air insulated 275 kV switchgear double busbar (6x overhead line bays; 4x transformer bays, 2x cross coupling bays and 1x lengthwise coupling bay in busbar 1, 2x capacitor banks, all bays equipped with circuit breakers, see Figure 219)
- 4 power transformers (TRFR) 400/275 kV,
    - TRFR 1 720 MVA
    - TRFR 2 800 MVA
    - TRFR 3 800 MVA
    - TRFR 4 720 MVA
- Year of commissioning 1977

- 4 auxiliary transformers 22/0,4 kV connected to the tertiary winding of the two power transformers.
  - TRFR 1 300 kVA
  - TRFR 2 315 kVA
  - TRFR 3 500 kVA
  - TRFR 4 315 kVA
- On-site inspection on 12 April 2023

The summarised assessment extract is attached in the appendix Assessment Matrix of Evaluated Transmission Assets. The substation condition details are described below.

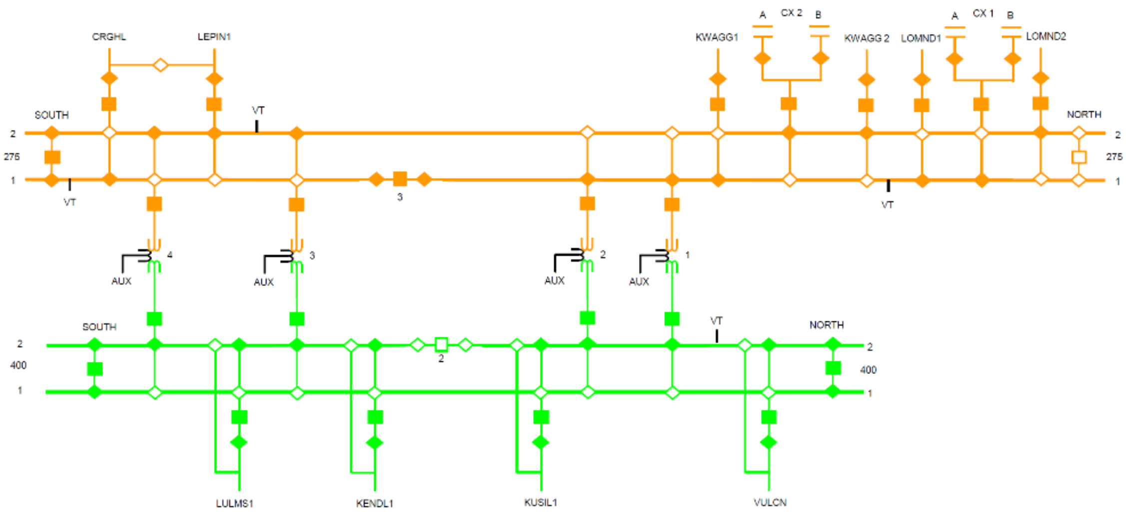


Figure 219: Single line diagram substation Minerva

Switchgears

Activity class of switchgears classification 1,86: Age-related wear and tear, slight signs of rust on steel structures, equipment has been partially replaced by new equipment, no urgent measures required, modernisation must be continued in the medium term (see Figure 220).

- Large part of circuit breakers is replaced by SF_6-circuit-breakers. AC classification 2 – Old low-oil circuit breakers should also be replaced.
- Large part of the disconnectors is replaced by new ones. AC classification 2 – Old disconnectors should also be replaced in medium term.
- Large part of instrument transformers is replaced by new ones. AC classification 2 – Old instrument transformers should also be replaced in medium term.
- Conductor ropes are slightly corroded due to age. AC classification 1 – Age-related wear and tear, refurbishment measures are not necessary.
- Steel construction slight signs of rust. AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.

- Basements with some tear and wear. AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Groundings visually inspected at random, slight visual signs of wear. AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.

Due to its age, the switchgear shows wear and tear. Major components have been replaced with new equipment. Due to the excellent maintenance of the switchgear, it is fully functional despite its high operating age. Further modernisation measures are to be carried out in the medium term (see Figure 221).

Figure 220: 400 kV switchgear substation Minerva

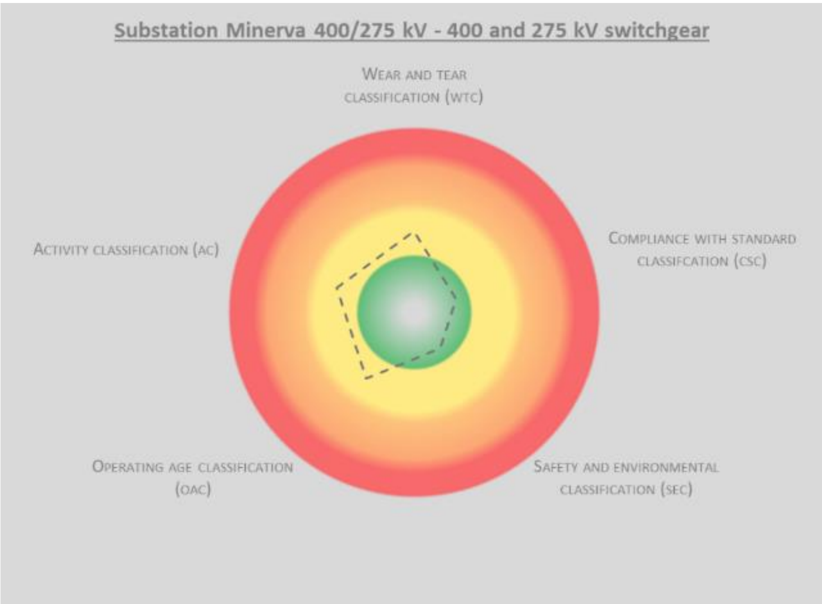


Figure 221: Evaluation graphic of 400 and 275 kV switchgear substation Minerva

Power Transformers

Activity class of Power Transformers (in operation between 1982 and 2009) classification 1,44: Age-related wear and tear. The oil leakage of transformer 4, which has been in operation since 1982, must be monitored. In the case of the relatively new transformers 1 and 2, the comparatively poor values of the gas-in-oil analysis can still be observed. If the values continue to deteriorate, replacement/repair may have to be considered. Condition without findings, no measures necessary (see Figure 222).

- General impression of inspection: AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Gas in oil analysis (all four transformers last test of 09.12.2022, TRFR1 and 2 D poor, TRFR 3 C fair, TRFR 4 A very good). AC classification 2 – Age-related wear and tear, monitoring of Gas in oil analysis results.
- Bushings, AC classification 1 – Age-related wear and tear, refurbishment measures are not necessary.
- Tank, AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Oil leakage, AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Fire protection walls, AC classification 1 – Age-related wear and tear, refurbishment measures are not necessary.
- Groundings randomly inspected. AC classification 1 – Age-related wear and tear, refurbishment measures are not necessary.
- Steel construction, radiators etc., AC classification 1 – Age-related wear and tear, refurbishment measures are not necessary.
- Basement, oil leakage sump. AC classification 1 – Age-related wear and tear, refurbishment measures are not necessary.

No refurbishment measures are currently required for the transformers. The poor gas-in-oil analysis results of the relatively new transformers 1 and 2 must be monitored. Cleanliness and maintenance conditions are excellent (see Figure 223).

Figure 222: Power Transformer in substation Minerva

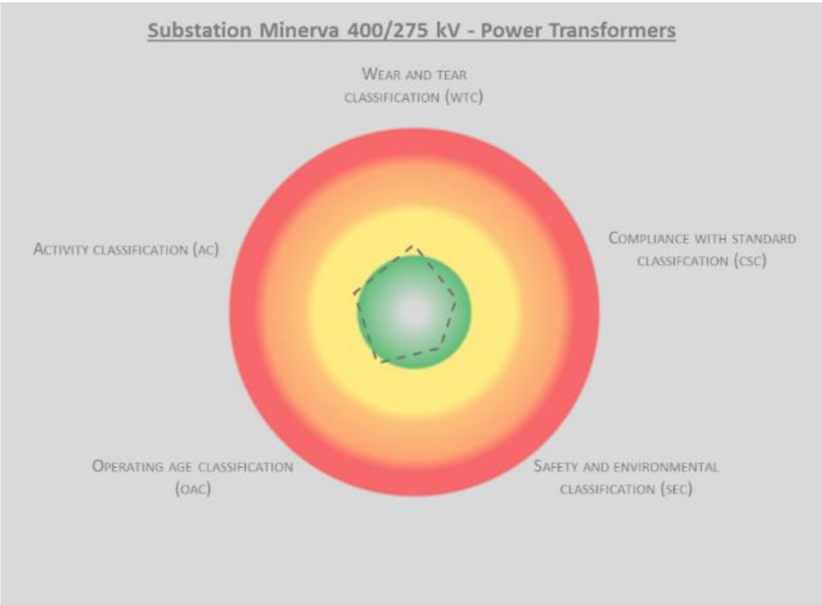


Figure 223: Evaluation graphic Power Transformers substation Minerva

Operation Building

Activity class of the operation building, classification 1,21 – Slight wear due to age, condition without findings, no measures necessary (see Figure 224).

- Outside general impression of inspection, AC classification 2 – Slight wear due to age, condition without findings.
- Roof visual inspection from the ground, AC classification 1 – condition without findings.

- Walls, AC classification 1 – condition without findings.
- Basement, AC classification 1 – condition without findings.
- Surface, AC classification 2 – Slight wear due to age (dusty), condition without findings.
- Waterproofing visual inspection, AC classification 1 – condition without findings.
- Lightning protection visual inspection from the ground, AC classification 1 – condition without findings.
- Inside general impression of inspection, AC classification 1 – condition without findings.
- Emergency exits, place for exit, AC classification 1 – condition without findings.
- Ventilation, AC classification 1 – condition without findings.
- Illumination, AC classification 1 – condition without findings.
- Cleanness, AC classification 1 – condition without findings.

Despite its many years of use, the operation building is in excellent condition. Cleanliness and maintenance condition are excellent (see Figure 225).

Figure 224: Operation building substation Minerva

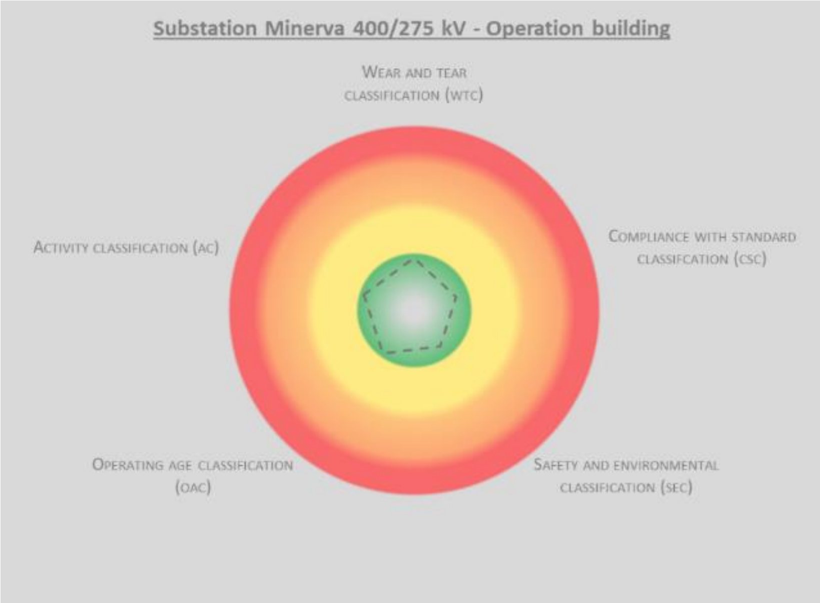


Figure 225: Evaluation graphic for the operation building substation Minerva

Secondary Technology

Activity class of Secondary Technology, classification 1,5: Some switch panels have already been renovated in terms of secondary technology. The majority are still equipped with old electromechanical protection technology. This is no longer state of the art and should be replaced in the medium term (see Figure 226).

- SCADA Connection to Control Centre available, AC classification 1 – Partly modernised, further modernisation required in the medium term.
- Protection relays are partly digital, AC classification 2 – further modernisation required in the medium term.

A high percentage of the secondary technology is still electromechanical. With further modernisation around primary technology, the devices of the secondary equipment are also to be replaced by modern digital technology. Cleanliness and maintenance condition are excellent (see Figure 227).

Figure 226: Example of protection/control cabinet substation Minerva

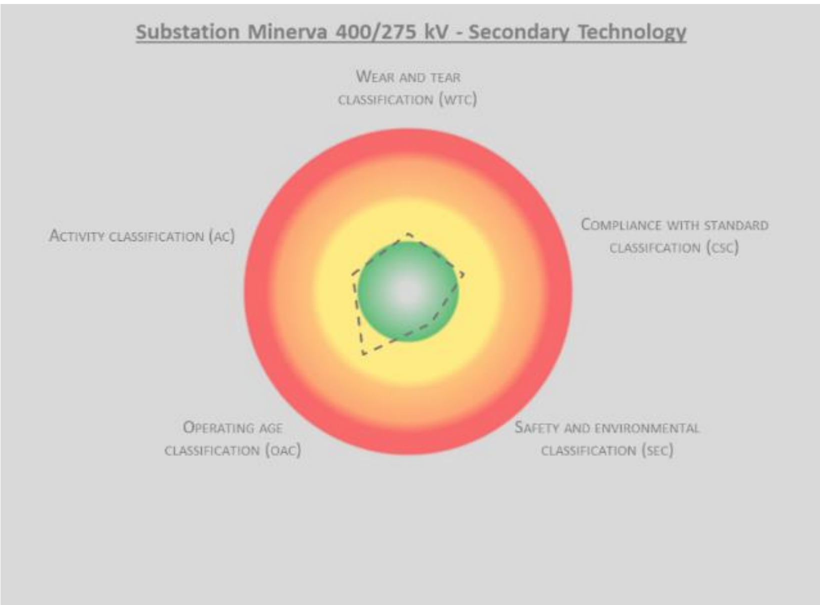


Figure 227: Evaluation graphic of secondary technology substation Minerva

AC/DC systems

Activity class of AC/DC systems, classification 1,33: Age-related wear and tear, partly re-newed (see Figure 228).

- AC system including auxiliary transformers and AC-distribution, AC classification 1 – Age-related wear and tear, partly renewed, no measures required.
- DC-distribution, AC classification 1 – Age-related wear and tear, partly renewed, no measures required.
- AC/DC converters, AC classification 1 – Age-related wear and tear, partly renewed, no measures required.

The AC/DC systems are in very good condition for their operation age. Cleanliness and maintenance condition are excellent (see Figure 229).

Figure 228: Auxiliary transformer substation Minerva

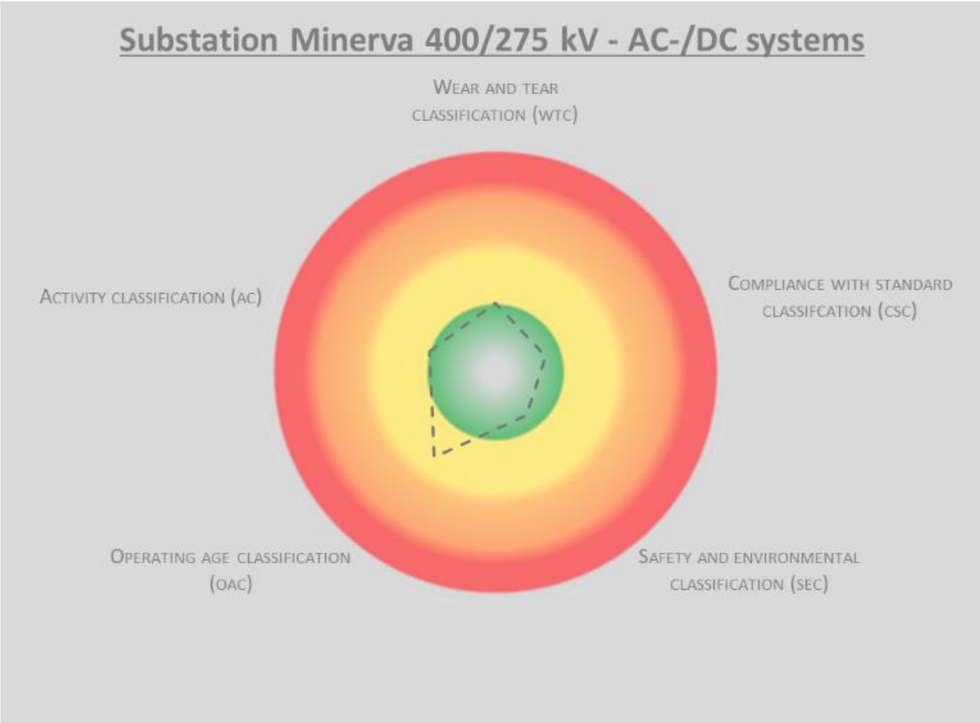


Figure 229: Evaluation graphic AC/DC systems

Battery Systems

Activity class of battery systems, classification 1 – condition without findings, no measures necessary (see Figure 230).

- 220 V Batteries AC classification 1 – condition without findings
- 50 V Batteries AC classification 1 – condition without findings

The battery systems were renewed cyclically during operation. The current status corresponds to the state of the art. Cleanliness and maintenance condition are excellent (see Figure 231).

Figure 230: 220 V Battery substation Minerva

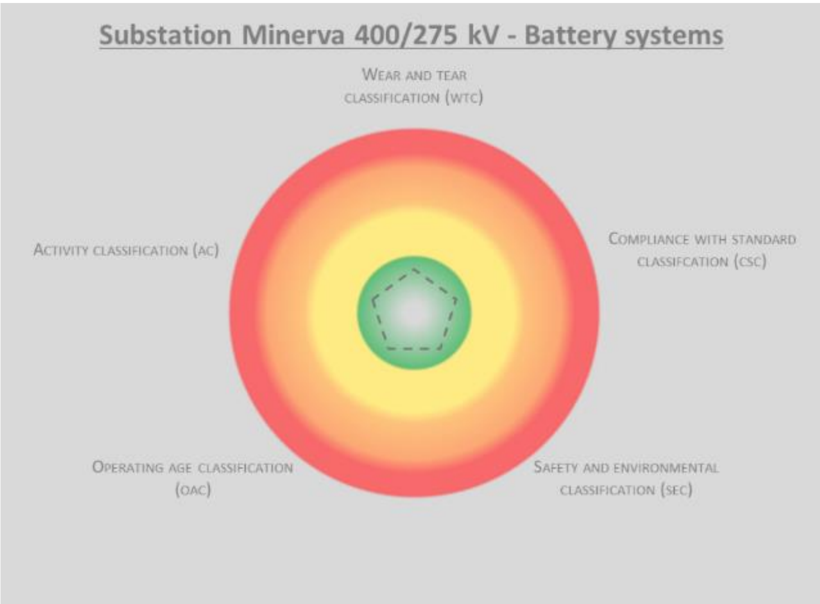


Figure 231: Evaluation graphic battery systems substation Minerva

Streets/Footpaths/Fences

Activity class of streets, footpaths and fences, classification 1,33: Age-related wear and tear but in a very good state of maintenance (see Figure 232).

- General condition, AC classification 2 – Age-related wear and tear, no measures required.
- Fences and security, AC classification 1 – Age-related wear and tear, no measures required.

- Dimensioning, AC classification 1 – Age-related wear and tear, no measures required.

The streets, footpaths and fences are in good condition. No measures are required. Cleanliness and maintenance condition are excellent (see Figure 233).

Figure 232: Transportation street and fences substation Minerva

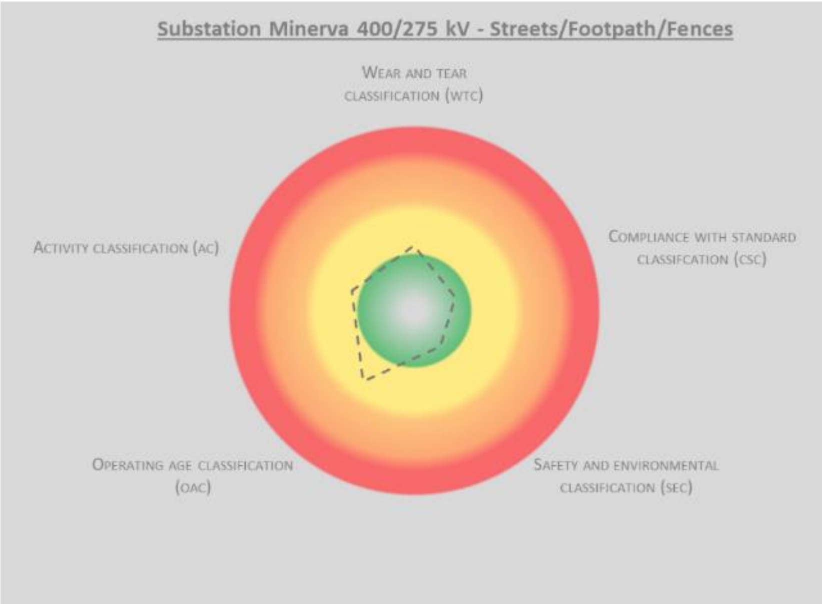


Figure 233: Evaluation graphic streets/footpaths/fences substation Minerva

Cable Ducts

Activity class of cable ducts, classification 2: Age-related wear and tear but in a very good state of maintenance (see Figure 234).

- Ducts, AC classification 2 – Age-related wear and tear, no measures required.
- Covers, AC classification 2 – Age-related wear and tear, no measures required.
- General condition, weathering, AC classification 2 – Age-related wear and tear, no measures required.

The cable ducts are in good condition. No measures are required. Cleanliness and maintenance condition are excellent (see Figure 235).

Figure 234: Example of cable duct substation Minerva

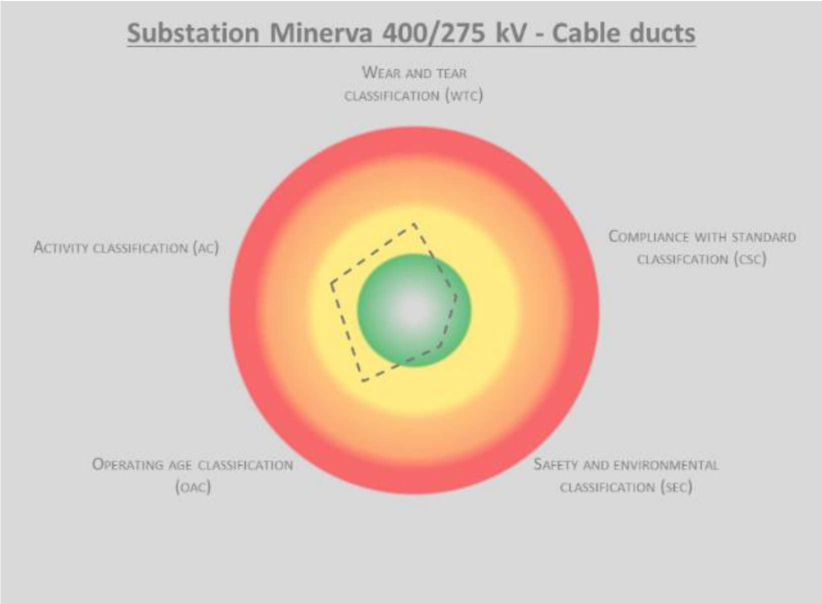


Figure 235: Evaluation graphic cable ducts substation Minerva

Summary Substation Minerva

The Minerva substation was commissioned in 1977. During the years of operation, essential components such as power transformers, circuit breakers, instrument transformers and disconnectors were gradually replaced. The last modernisation measure was carried out in 2010 as part of an expansion of the switchgear for the connection of new overhead lines. Despite 46 years of operation, the substation is in a very good condition (see, for example, Figure 236). This is due to the permanent renewal of worn components and excellent maintenance of all substation components. Accordingly, the substation can continue to operate safely for several years if the current strategy is continued by replacing worn parts and intensively maintaining all components. The total evaluation results in an AC 1,45 (see Figure 237).

Figure 236: 275 kV switchgear substation Minerva

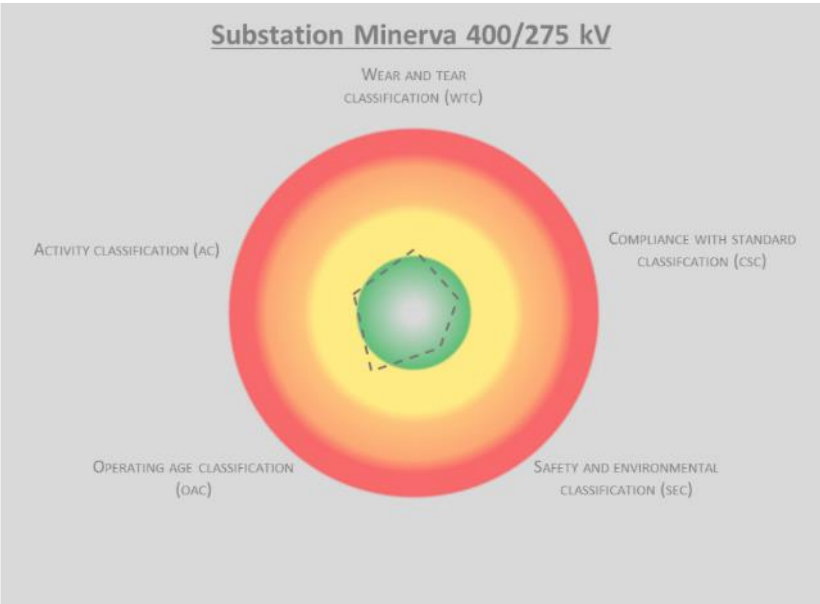


Figure 237: Evaluation graphic total substation Minerva

6.7.10 Assessment of other Inspected Substations

The five other substations inspected:

- Substation Craighall,
- Substation Eiger,
- Substation Apollo HVDC,
- Substation Apollo and
- Substation Thuso

were assessed using the same procedure as the Minerva substation. A detailed summary of the assessment is attached to the report in the appendix Assessment of other Inspected Substations. The findings and assessment results obtained during the site visits to the substations have been integrated into Eskom Transmission's assessment.

6.7.11 Overhead Lines

Assessment methodology

- On-site inspection and assessment of an overhead line section in detail.
- Use of an adapted assessment matrix of the substation assessment for a quantified assessment of the overhead line section.
- Parallel line sections were assessed with visual observation. The general impressions of the parallel line sections were compared with results of details assessed line sections for summarised assessment of all lines.
- To further check the plausibility of the assessments made, based on the example of the one-line section, other overhead line sections connected to substations were inspected and visually assessed.

Brief description of overhead line section

- 400 kV overhead line Thuso - Apollo
- Tower 1APO/THU013 and connected line sections.
- Additional 4 parallel OHL visual inspected

The summarised assessment extract is attached in the appendix Assessment Matrix. The assessment condition details are described below.

Tower 1APO/THU013 of overhead line section

Activity class of tower 1APO/THU013, classification 2: Age-related wear and tear, no measures required (see Figure 238).

- Basements, AC classification 2 – Age-related wear and tear, no measures required.
- Steel construction, AC classification 2 – Age-related wear and tear, no measures required.
- Coating, AC classification 2 – Age-related wear and tear, no measures required.
- Groundings, AC classification 2 – Age-related wear and tear, no measures required.

The mast is in good condition. Age-related wear and tear are visible but does not impair the function. Damage caused by vandalism has been professionally repaired and preventive measures taken to avoid further damage (see Figure 239).

Figure 238: Tower 1APO/THU013

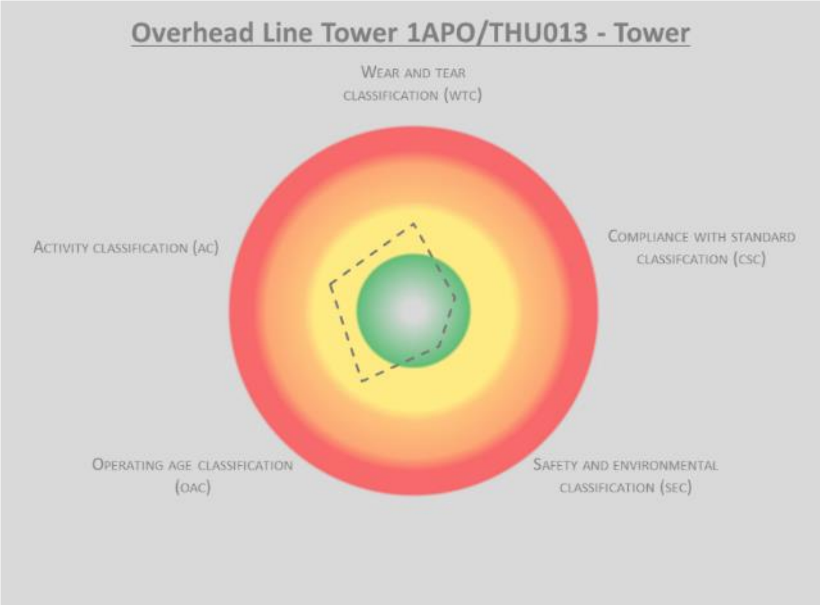


Figure 239: Evaluation graphic tower 1APO/THU013

Security

Activity class of security tower 1APO/THU013, classification 2 – Age-related wear and tear, no measures required (see Figure 240).

- Prevention of unauthorised climb up, AC classification 2 – Age-related wear and tear, no measures required.
- Prevention of vandalism, AC classification 2 – Age-related wear and tear, no measures required.

Climbing prevention measures are installed to prevent unauthorised climbing. Self-locking nuts used for bolting at the base of the towers to prevent steel theft. These measures should provide sufficient protection against further damage caused by vandalism (see Figure 241).

Figure 240: Self-locking nuts to avoid steel theft tower 1APO/THU013.

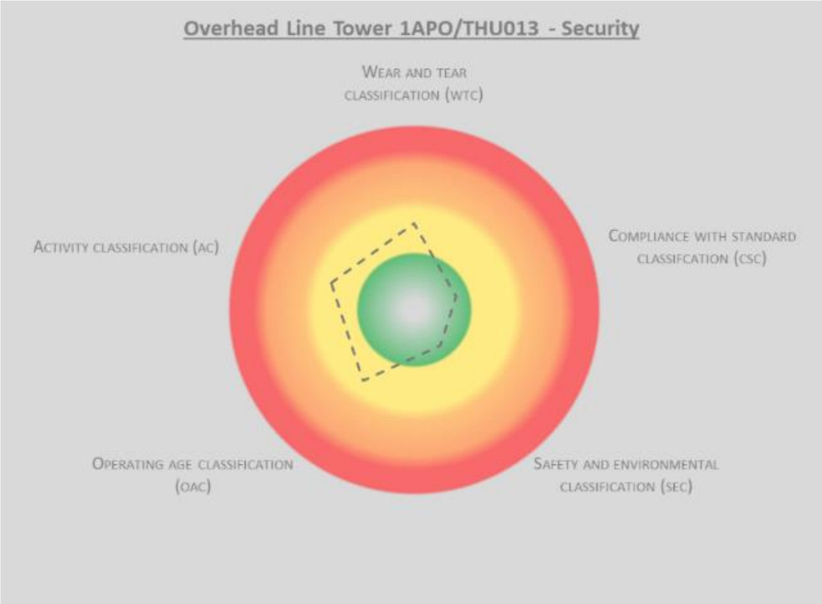


Figure 241: Evaluation graphic security tower 1APO/THU013

Insulation Chains

Activity class of insulation chains tower 1APO/THU013, classification 1 – condition without findings (see Figure 242).

- General condition, AC classification 1 – condition without findings
- Cleanness, AC classification 1 – condition without findings
- Glass cups condition, AC classification 1 – condition without findings

The glass cap insulating chains were visually inspected from the ground for the inspected OHL and the parallel OHL. The condition was perfect (see Figure 243).

Figure 242: Insulation chains of 400 kV OHL

Figure 243: Evaluation graphic insulation chains tower 1APO/THU013

Labelling of OHL

Activity class of marking OHL tower 1APO/THU013, classification 1 – condition without findings (see Figure 244).

- Label condition, AC classification 1 – condition without findings
- Name of line, AC classification 1 – condition without findings
- Number of towers, AC classification 1 – condition without findings

The marking of the tower was visually inspected. The condition was perfect (see Figure 245).

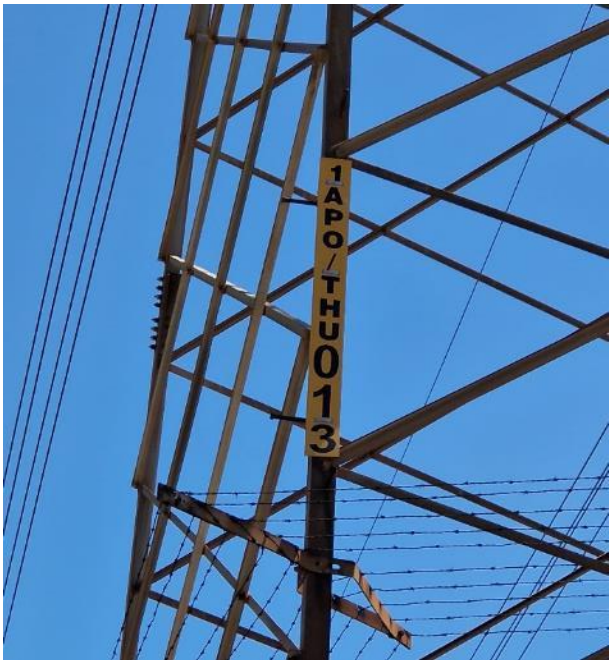


Figure 244: Marking of tower 1APO/THU013.

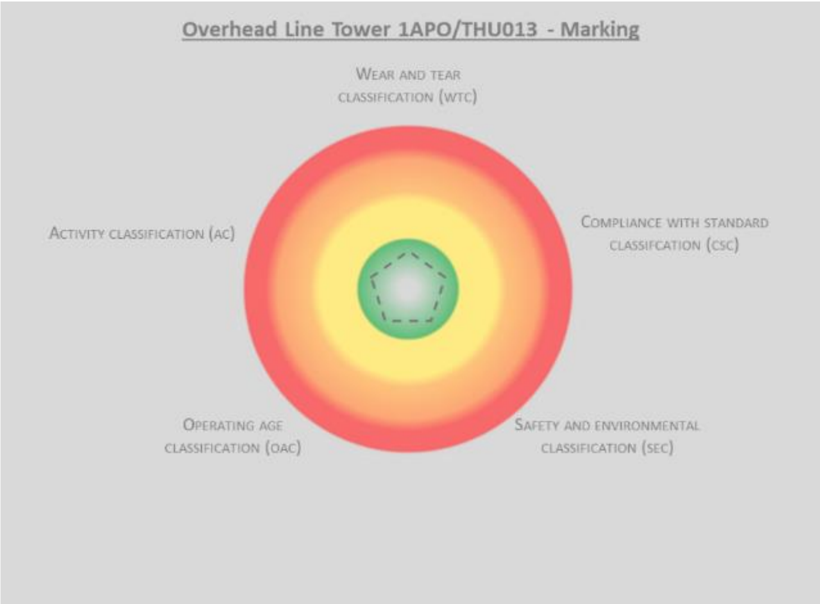


Figure 245: Evaluation graphic of marking tower 1APO/THU013

Summary Inspection of OHL

Both the inspected line section with 5 parallel 400 kV OHL (see Figure 246) and the OHL connected to the inspected substations (see Figure 247) were in a very good state of maintenance. The wear and tear of the steel structures was mostly age-related, but the insulating chains were in very good condition everywhere. Defective glass caps were not found on any overhead line. This good condition was also visible on other OHLs in the transmission system during trips. This is the result of good maintenance. All lines are flown over on a regular basis for inspection. Any defects found are eliminated at short notice. Eskom has its own team and helicopters for flying the lines. This ensures that access to that team is always available and that the inspections are carried out to a high standard. Although a large number of the overhead lines have been in operation for many years, the good maintenance of the overhead lines ensures that they are in good condition, which in turn ensures a high level of reliability and availability of the OHL. Currently, several OHLs from the 1960s – with a total length of about 1300 km - are still in operation. The overall condition of the inspected OHL is rated very good, AC 1.5 (see Figure 248).

Figure 246: Inspected OHL section tower 1APO/THU013

Figure 247: 400 kV OHLs connected to substation Minerva.

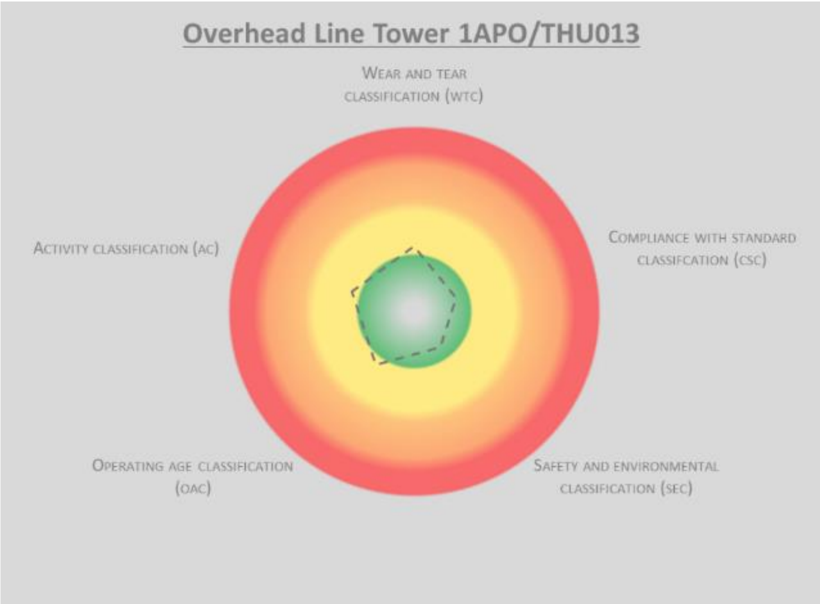


Figure 248: Evaluation graphic total of inspected OHL section tower 1APO/THU013

6.7.12 Summary site visit

The 6 substations visited were all in very good technical condition. Although 5 of the 6 substations were built in the 1970s, the activity classification for all substations was rated below 2 (see Figure 249). This means that no urgent upgrading measures are required in any of the substations. The operational capability is fully given and there is a high level of reliability and availability.

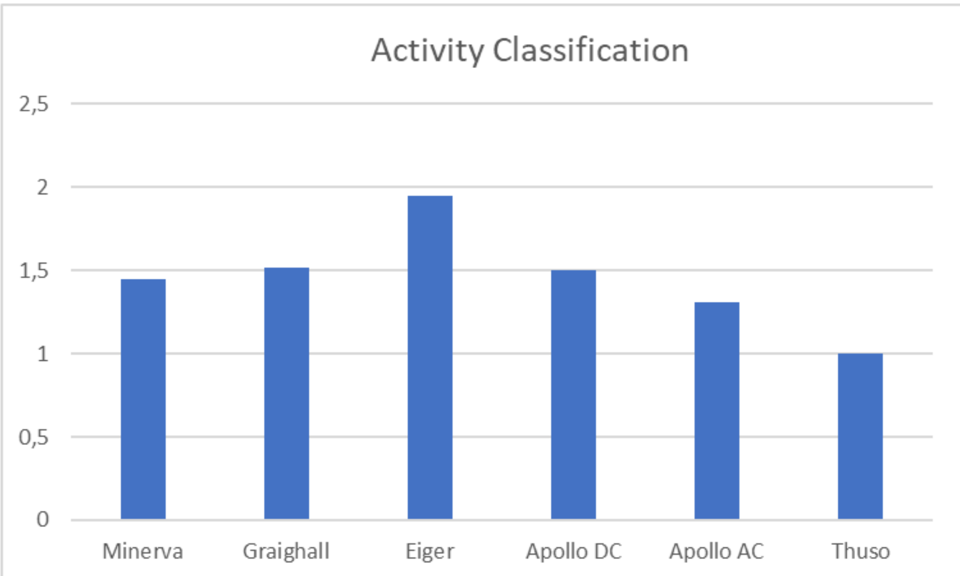


Figure 249: Activity Classification of inspected substations

This good condition of the plant, despite its high operating age, is mainly the result of excellent maintenance. The staff in all inspected substations were very committed and highly motivated. Questions about the condition of the plant and its maintenance were answered very competently, which is evidence of the very good level of training of the staff. The substations are operated according to clear regulations, which are strictly followed. In addition to the maintenance measures, upgrading measures were carried out in all transformer stations. Essential components were replaced by new ones, so that the measures correspond to a partial replacement. For example, almost all old circuit breakers were replaced, instrument transformers were renewed, and disconnectors were replaced.

Substation	**Commissioning year**	**AC**	**Remark**
Minerva	1977	1,45	
Craighall	1978	1,52	Extension of Block B in 2008
Eiger	1973	1,95	
Apollo DC	1977 - 1979	1,50	Last intensive refurbishment activity 2013/14
Apollo AC	1970	1,31	Last intensive refurbishment activity 2017
Thuso	2014	1,00	

Table 106: List of inspected substations

A modernisation programme was launched for secondary technology equipment, of which about 70% of installations are now microprocessor-based technologies. This also corresponds to the inspection results in the 6 transformer stations. In some substations, not only equipment was replaced, but also the structural installations were renewed or comprehensively refurbished (e.g. Apollo DC). The substation parts upgraded in this way can be classified as new replacements (Table 106).

The overhead lines are also very well maintained. No defects were found during the on-site inspection of a line section.

The good condition of the transmission system found on-site confirmed the analysis results obtained from the condition assessment based on the documents provided by Eskom and the information from the interviews carried out with Eskom experts.

6.8 Conclusions and Recommendations

The technical condition and the status of the grid development planning were analysed based on the extensive information and documents provided by Eskom Transmission. The results of the analysis were used to derive an initial status assessment of the transmission system and the network expansion planning and associated measures. The assessment results were further strengthened by additional information from the on-site interviews with

Eskom Transmission management and technical experts. The overall result of Eskom Transmission's condition assessment obtained in this way was verified and plausibility checked by on-site inspections in 6 substations and on some line sections.

Through this approach, a consistent assessment of the entire transmission system was achieved. On this basis, conclusions, and recommendations for the further development of the transmission system were derived.

1. The unsatisfactory situation in the South African power system, with multiple load shedding every day, is not the result of a poor condition of the transmission system. The permanent load disconnections result from insufficient available power plant capacity, although sufficient power plant capacity has been installed. The lack of required power plant capacity is not the responsibility of the transmission system operator (TSO). The power shortage is managed by the TSO with the planned load shedding in an excellent way and thus ensures secure and available grid operation within the scope of the possibilities. The danger of a blackout is largely excluded by this network operation method.

2. A high portion of the transmission system's facilities are relatively old, and an above-average proportion have reached the end of their operating life compared to European transmission systems, for example. Despite the high proportion of old equipment, the overall condition is excellent due to intensive maintenance measures. Nevertheless, it is essential to continue the modernisation process of these outdated plant components, which has been underway for several years. If this modernisation is neglected, an accumulation of equipment failures in a short period of time can be expected in the near future, which can lead to a critical situation in the operation of the transmission system. Sufficient financial resources must be made available for these modernisation measures, in order to ensure the safe and reliable operation of the transmission system in the future. The urgent need for these measures has already been recognised by management. This has led to an increase in approved investment budgets in recent years and has been included in the Transmission System Development Plan.

3. The good overall condition of all parts of the transmission system is mainly due to the excellent maintenance that was observed in all areas visited. This is based on well-trained and highly motivated personnel. The management of the transmission system is very well organised and the cooperation between top and middle management down to the working staff is very good. All relevant processes are laid down in work instructions and are stringently applied. This efficient working environment should be secured through sufficient qualification measures, competitive wages, recruitment of young staff and knowledge transfer to the newly hired employees.

4. The transmission system development plan is a very good tool for planning the development of the transmission system. It is updated annually for the following ten years and thus ensures permanent updating and adaptation to changing conditions. Modernisations are planned with reference to the condition and age. Necessary grid expansion measures resulting from additional demand or new power plant connections in RES and

IPP are taken into account in the grid development, with corresponding grid expansions. TSO stakeholders should use the measures described in the TDP as a guide for their decisions on how to control the company.

5. The Integrated Resource Plan (IRP) provides essential input data for the annual update of the TDP. The current TDP is based on the status of the IRP as of 2019. It is recommended to use more up-to-date sources of information for the update of the TDP in addition to the IRP, in order to be able to react more quickly to new requirements for network expansion.

6. It is recommended that the process of spinning off the transmission system from Eskom into an independent company be continued and completed quickly. This will strengthen the position of the transmission system operator and prepare for the development of a free electricity market. For the transmission system to operate as an independent company, cost-based tariffs for the use of the transmission system and the services to be provided with it must be approved. A regulatory framework must be developed that regulates the provision of balancing power from the power plants for the stable operation of the transmission system and describes a corresponding remuneration for this power.

The increasing generation of electrical energy by RES and IPP requires a significant grid expansion to be able to connect the additional generation capacities to the grid. This energy turnaround initiated by the government has been incorporated into TSO's medium- and long-term grid planning and supported by numerous grid expansion projects (see TDP). The grid expansion projects are included in the budget planning. By FY2028, R 74.2 billion of financial resources are planned for upgrading and expanding the network. The network expansion budget increases from R 2 billion in FY2024 to R 10.1 billion in 2026. Implementing the associated expansion measures is a major challenge for Eskom transmission and requires sufficient internal human resources.

7 Skills Assessment

For the successful operation of a coal-fired power plant, it is essential to have well-qualified personnel. Only well-qualified and skilled personnel have the knowledge required to understand the technical aspects of power plant operation, as well as the specific requirements of the plants. Human resources play a central role in the optimisation of operations at the plants and in ensuring maximum efficiency and performance. Qualified staff are essential for effective monitoring of equipment, quality maintenance, optimisation of processes and troubleshooting technical problems. Skilled personnel can reduce downtime, lower operating costs and guarantee better overall power plant performance.

With the right knowledge, the team is in a position to identify and carry out preventive maintenance, thus avoiding potential technical failures, as well as detect early signs of malfunction and respond quickly to problems when they arise. Hence, qualification is key to reducing PLL and improving the EAF.

Overall, well-qualified personnel help ensure the safe, efficient and environmentally sound operation of power plants. They play an essential role in optimising performance, complying with regulations, and minimising risks associated with power plant operations.

Due to the importance of highly qualified staff, the vgbe consortium was asked to carry out a skills assessment of the personnel working in Eskom's coal-fired power plants. The point of the evaluation was to establish the skill levels, in order to identify potential areas for improvement which would have a direct positive impact on plant performance.

For this assessment, two groups were looked at individually:

1. Managers
2. Non-Managers

The managers were interviewed on site. In addition, they were asked to participate in an online test which focussed on general knowledge, as well as on leadership skills.

The assessment concept for non-management was different. They were asked to participate in three tests. The first test was a "logic test" looking at the mental abilities of individuals – that is, their ability to think logically. The second test assessed their general knowledge of the different disciplines required in a power plant, such as electrical, C&I or chemical. The third and final test was specific to the participants' jobs and contained job-specific questions.

Here, it should be pointed out that, in the course of the evaluation, it became clear that the current situation has many negative consequences for the workforce. A heavy workload with long working hours, in a demanding environment where good performance is not rewarded, results in a poor working atmosphere. In many power plants, blame shifting and a lack of personal responsibility were found to be widespread. This mentality leads to low morale and lack of team spirit. However, there are also power plants in the fleet where motivation is high due to good management.

7.1 General Situation: Skills at the Power Plants

The skills assessment focused on assessing the competencies of the managers, shift supervisors, operators and technicians. The review also considered implemented training, as well as staff development and various other factors affecting staff performance. European job descriptions and job requirements for the same positions were used as a benchmark for purposes of comparison.

7.1.1 Procedure of the Assessment

As mentioned before, the staff were divided into two different groups for the assessment:

- manager level, which included the assessment of the manager team at the sites.
- non-manager level, which covered the following jobs and positions: *maintenance C&I technician; maintenance electrical technician, operating technician, technician for performance and testing, senior shift supervisor, shift supervisor, control room operator, plant operator, site simulator trainer.*

Manager level:

At management level, the focus was on technical competencies and leadership skills. Due to the limited time available, the procedure for reviewing the levels of competency was based on somewhat subjective opinions. These were gained by asking managers about personnel issues, such as motivation and fluctuation of employees. The KWS team, which was reviewing the technical performance and status of the plant, also listened carefully to how confidently and knowledgeably managers responded to the questions about these matters.

Non-manager level:

The assessment of the non-management staff was strongly resisted by the unions right from the start. It was not really accepted by the plants and was not communicated correctly. The poor uptake of the assessment also reflects and reflects the unwillingness to cooperate with central HR.

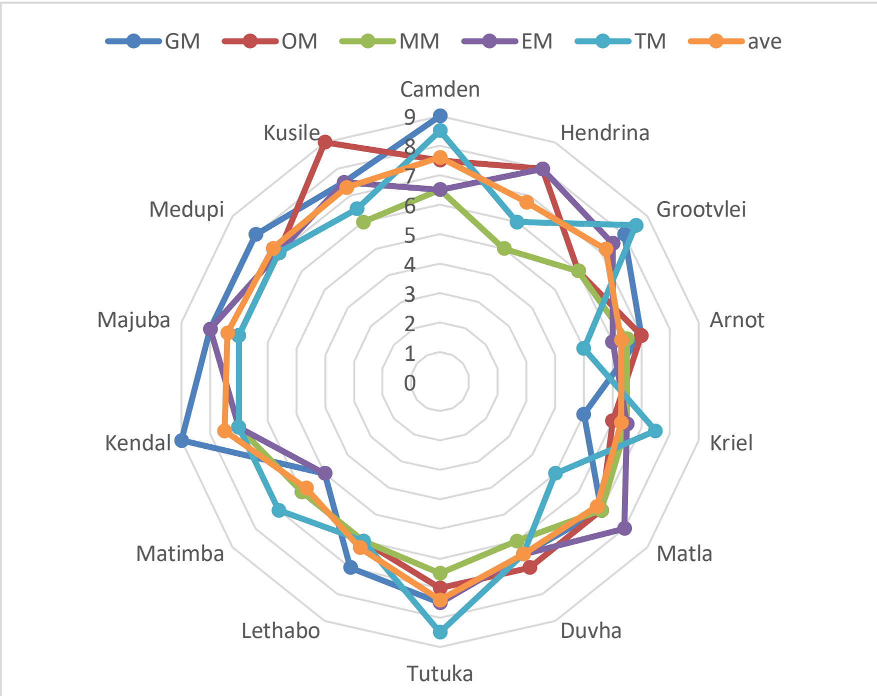
KWS had planned to conduct both a written and an oral examination of performance, but this was, in fact, not feasible.

The result of the pushback was that the assessment of non-management has now been based on the results of just a few written tests submitted by a small number of participants, together with observations made during the site visits.

7.1.2 Participation and Results

Manager level:

Within the scope of the evaluations, the majority of management showed a high degree of theoretical knowledge. This was also reflected in the results of the written assessment, with an average score of 78% (pass mark 50%). With regards to practical knowledge, however, the picture was very different. With regards to implementation of projects and measures, opinions and knowledge varied considerably. Differences in opinions were particularly visible between plant management and management at headquarters. This lack of agreement makes the implementation process even harder than it already is.



Legend:

GM – General Manager

OM – Operation Manager

MM – Maintenance Manager

EM – Engineering Manager

TM – Training Manager

Ave – Average of the Power Plant

Figure 250: Test result at Manager level

Figure 250 shows and compares the results of the individual mangers at each of the power plants. A score of zero (0) represents a very poor result, whereas a score of 10 stands for top performance. All in all, the results are quite homogeneous.

Non-manager level:

Test participation:

Figure 251 gives an overview and breakdown of the participation and completion of the three tests at the various stations. As can be seen, not once was overall participation of even 50% achieved. However, there were significant differences between stations. Whereas 92% of the anticipated participants at Camden decided to take the tests, at Hendrina it was only 13%. Overall, 63% of non-management participants reacted to the assessment by at least starting the tests. However, only 34% actually completed them fully. The plants with more than a 60% completion rate are highlighted in green.

The reasons for the poor participation/completion and the below average results in the written assessment are unclear but there are several possible explanations:

- poor communication.
- a lack of motivation.

− fear of underperformance. (This would be a logical explanation as to why many participants turned up for the tests but either broke off very quickly or did not start working on them at all).

No	Site	all Tests	2 Tests	1 Test	0 Tests	Participants incl. Managers	percentage total completion	percentage participation	tests made
1	Arnot	7	1	3	12	23	30%	48%	36%
2	Camden	9	9	4	2	24	38%	92%	67%
3	Duvha	7	5	2	8	22	32%	64%	53%
4	Grootvlei	11	3	1	6	21	52%	71%	62%
5	Hendrina	3	0	0	20	23	13%	13%	11%
6	Kendal	5	2	5	10	22	23%	55%	31%
7	Kriel	10	6	2	3	21	48%	86%	65%
8	Kusile	8	2	3	7	20	40%	65%	48%
9	Lethabo	8	3	3	7	21	38%	67%	53%
10	Majuba	5	4	3	11	23	22%	52%	36%
11	Matimba	7	2	2	11	22	32%	50%	40%
12	Matla	7	4	7	3	21	33%	86%	51%
13	Medupi	11	6	3	2	22	50%	91%	69%
14	Tutuka	6	3	3	13	25	24%	48%	40%

Figure 251: Participation and completion of tests in the written assessment

Results of the Written Assessment:

All tests were reviewed and authorised by Eskom HR (non-management: three tests comprising a logic test, a general technical test and a test of job-related competencies; manager level: one assessment looking at job-related competencies).

The diagram below shows the average of the test results across all power plants. Only those participants who answered at least one question were included in these results.

An assessment only works if the participants take part in the complete exam which, unfortunately, was very often not the case here. Those who completed all the tests achieved a score of 65% or more, which indicates very solid level of basic know-how. However, the poor participation at many plants made it difficult to draw the right conclusions from these test results.

As already mentioned above, the low scores are mainly due to a lack of motivation and communication. Some of the participants answered only a few questions, but they were still included in the assessment.

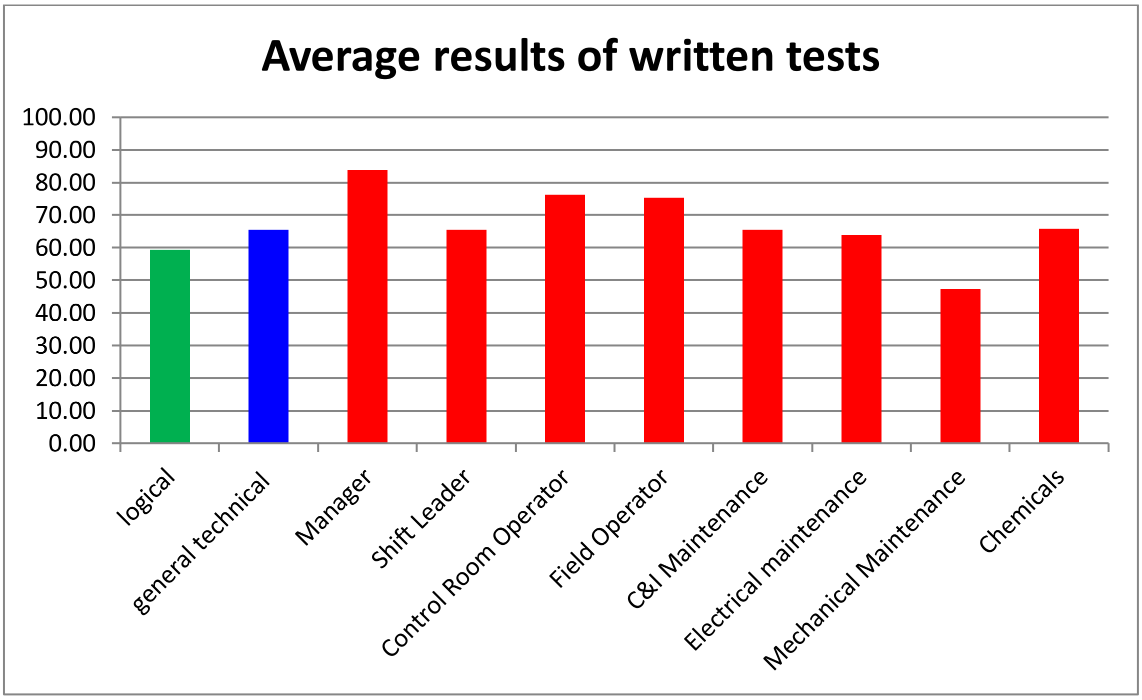


Figure 252: Average results of written assessment across all plants

(job-related tests in red)

7.2 Special Findings and Recommendations at the Power Plant Sites

7.2.1 Arnot Power Plant

Results of written assessment:

At the **Arnot** plant, 23 participants (4 managers and 19 technical staff members) had been preselected to take a total of 61 tests.

Altogether, 22 of the 61 tests were completed, representing 36%. Seven participants (30% of the planned participants) completed the tests. One participant opened a test but did not conclude it. A total 12 participants (52%) did not even start the tests.

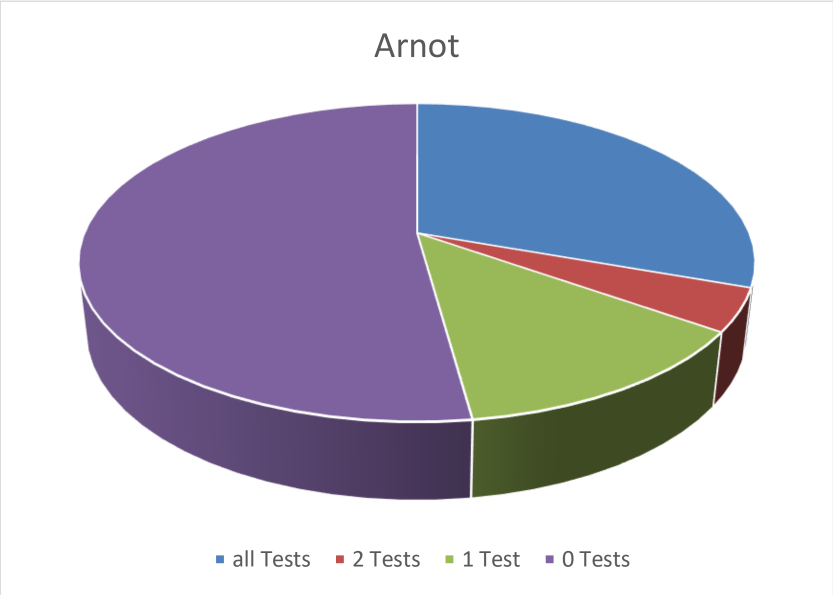


Figure 253: Participation of Arnot power plant staff

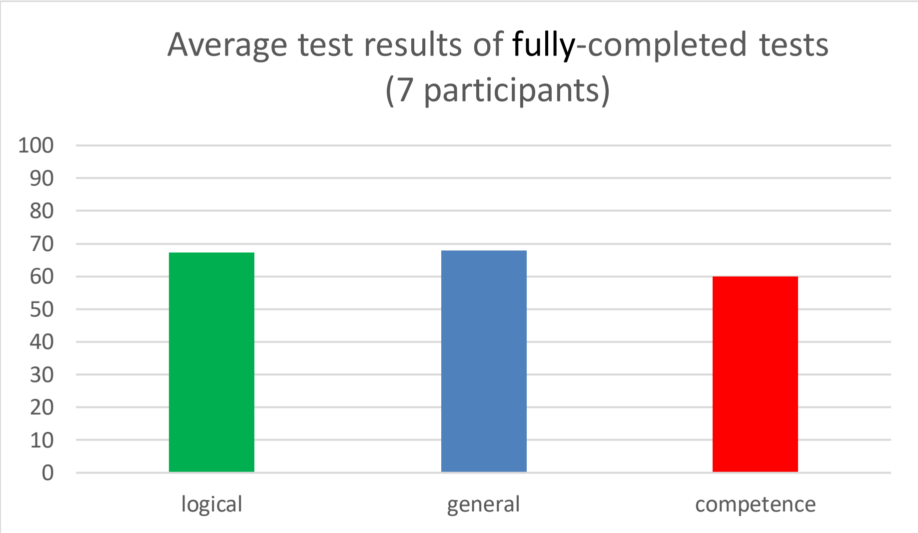


Figure 254: Average results of fully completed tests at Arnot power plant

The results of the fully completed tests are summed up the Figure 254. All results are above 60%, indicating a good basic level of know-how among participants who submitted their tests. However, due to the low participation rate, these results cannot be considered representative for the whole plant.

General observations from the interviews on site:

Findings:

There seem to be no clear plans for the systematic implementation of operator training.

Recommendations:

Responsibility for operator training should be assigned to the operating department in order to be more effective and for it to become an integral part of the work programme.

7.2.2 Camden Power Plant

Results of written assessment:

At the **Camden** plant, 24 participants (4 managers and 20 technical staff members) had been preselected to take a total of 52 tests.

In all, 43 tests (67% of the total) were completed, with nine members of staff (38% of the anticipated participants) completing all the tests and a further nine completing two tests. One participant opened a test but did not conclude it. Two participants (8%) did not even start the tests.

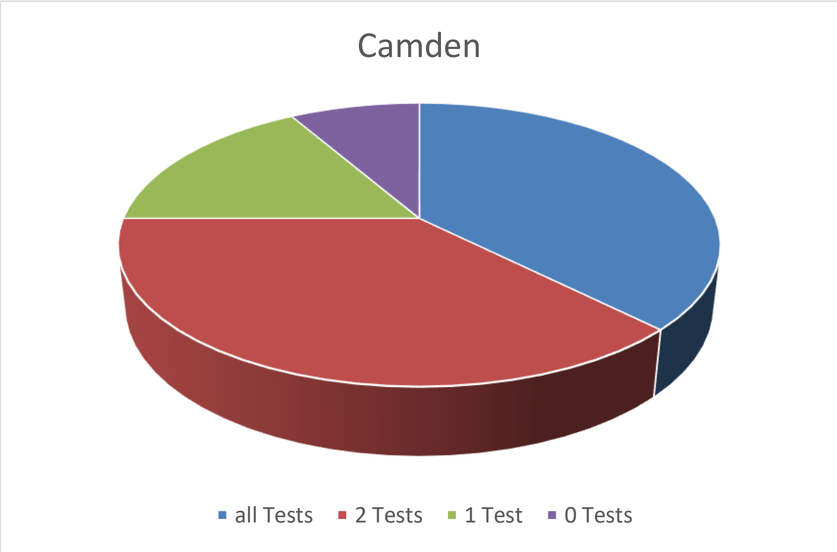


Figure 255: Participation of Camden power plant staff

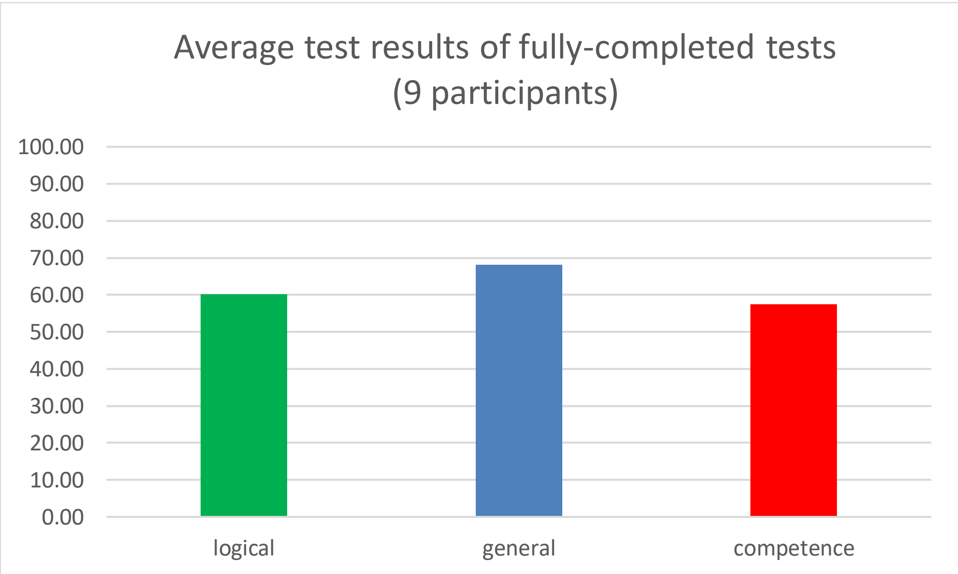


Figure 256: Average results of fully completed tests at Camden power plant

The evaluation of the fully completed tests for Camden is shown in Figure 256. Logical and general test scores were slightly above 60%, whereas there was an average score of 57.4% on the competence tests. In general, participants who submitted their tests showed a good basic level of know-how. However, due to low participation, these results cannot be considered representative for the whole plant.

General observations from the interviews on site:

Findings:

Low staff morale is visible.

The simulator on site has a maintenance contract but there is no service agreement in place – the utilisation rate is approximately 42%, while the availability rate is about 72%.

Course attendance is a problem and line managers need to take responsibility for this. Finding new training providers poses another challenge, as any new contractors need to undergo theoretical and practical training, as well as a competency assessment, before they can be accredited. This can take some time if new contractors are not familiar with the site requirements.

Recommendations:

A service agreement should be put in place for simulator maintenance.

Operator trainee intake should be reviewed.

Accreditation of all training providers should be ensured.

7.2.3 Duvha Power Plant

Results of written assessment:

At the **Duvha** plant, 22 participants (4 managers and 18 technical staff members) had been preselected to take a total of 58 tests.

In all, 31 of the 58 tests were completed (representing 53%). Of the participants, seven (32%) completed all the tests, while three participants started a test but did not conclude it. Eight participants (36%) did not even start the tests.

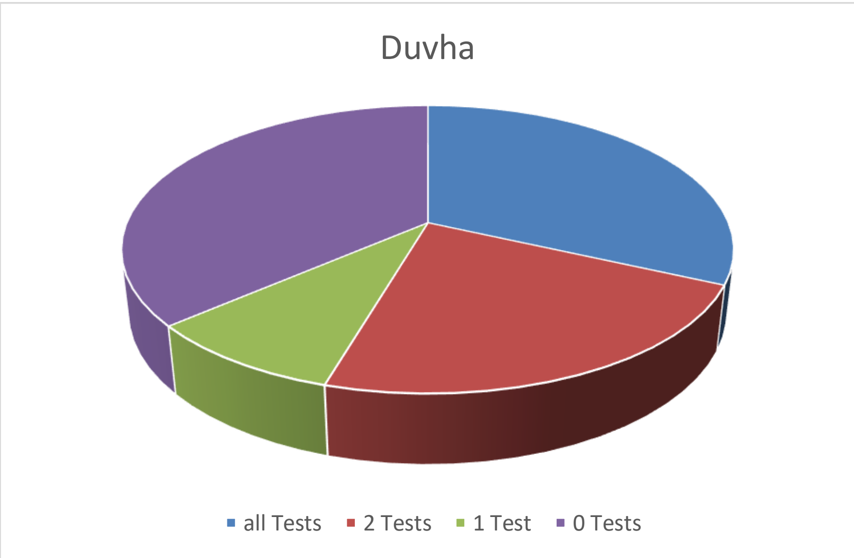


Figure 257: Participation of Duvha power plant staff

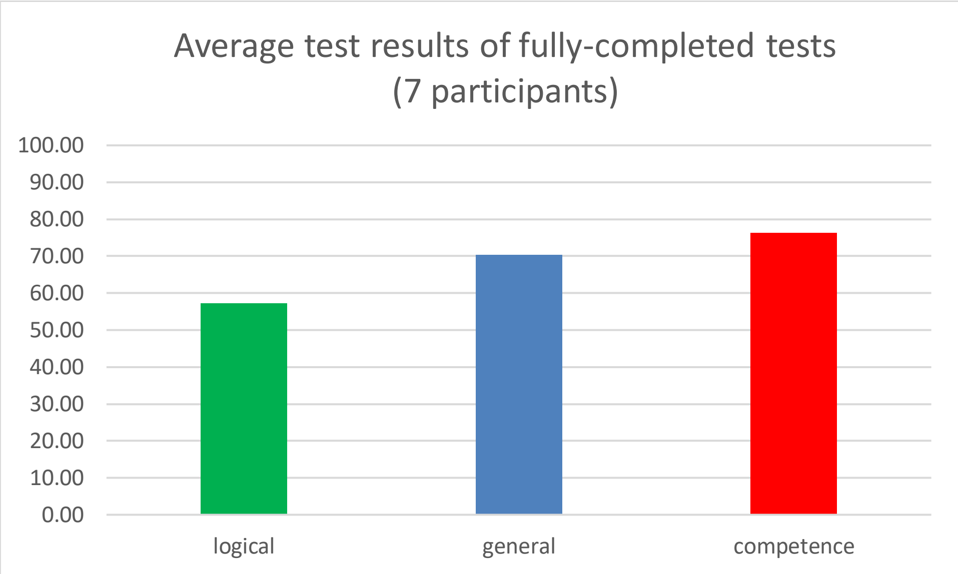


Figure 258: Average results of fully completed tests at Duvha power plant

The summary of the fully completed tests can be found in Figure 258. An average score of over 70% was achieved in the general test and of just over 75% in the competence test. The logic test score was a little lower than 60%. All in all, these participants showed a good basic level of know-how. The results of the competence test are particularly encouraging. However, due to the low participation, these results cannot be considered representative for the whole plant.

General observations from the interviews on site:

Findings:

The simulator training is carried out by two instructors. One is seconded from the shift, the other is a pensioner, who is engaged on a contractual basis. The simulator is being kept up to date with plant modifications.

There have been at least six major incidents at Duvha over the last 12 to 15 years, including turbine overspeed, fuel oil fire, cable fire, H_2 fire and a boiler explosion. This indicates a serious lack of competencies and discipline in various areas.

Recommendations:

A proactive operation philosophy should be implemented with regards to simulator training.

7.2.4 Grootvlei Power Plant

Results of written assessment:

At the **Grootvlei** plant, 21 participants (4 managers and 17 technical staff members) had been preselected to take 55 tests in total.

In all, 34 tests were completed (62% of all tests) and 11 participants (52% of those planned to take part) completed all the tests, while seven staff members (33%) did not even start the tests.

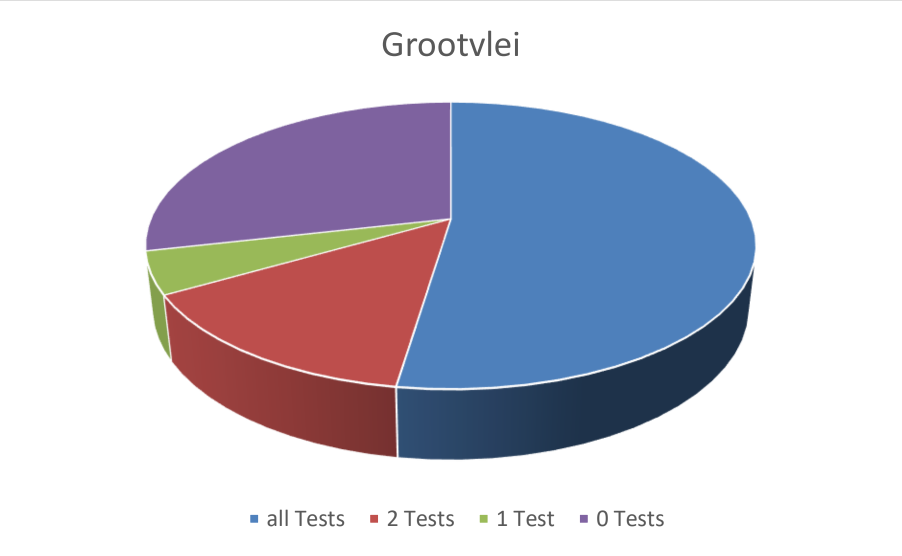


Figure 259: Participation of Grootvlei power plant staff

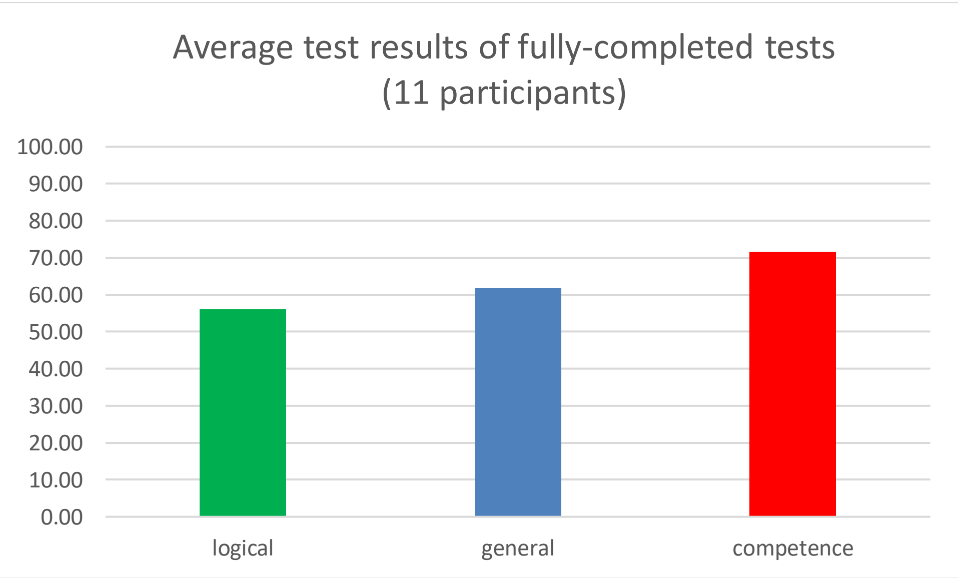


Figure 260: Average results of fully completed tests at Grootvlei power plant

The results of the fully completed tests are shown in Figure 260. It is encouraging that the average competence test score was above 70%. The general test score was in the range of 60%, whereas the average score for the logic test was 56%. These results indicate a good basic level of know-how among those participants who submitted their tests, especially looking at the competence tests. However, due to the low participation, these results cannot be considered representative for the whole plant.

General observations from the interviews on site:

Findings:

The simulator has not been operational for the last five years. However, the facility condition is very good.

Recommendations:

The EAL simulator needs to be used, or the Komati simulator needs to be relocated to the site for on-site training.

7.2.5 Hendrina Power Plant

Results of written assessment:

At **Hendrina,** 23 participants (4 managers and 19 technical staff members) had been preselected to take a total 61 tests.

However, in the end just 7 tests (11% of the total) were completed by a total of just three participants (13%). Twenty staff members (87%) did not even start the tests.

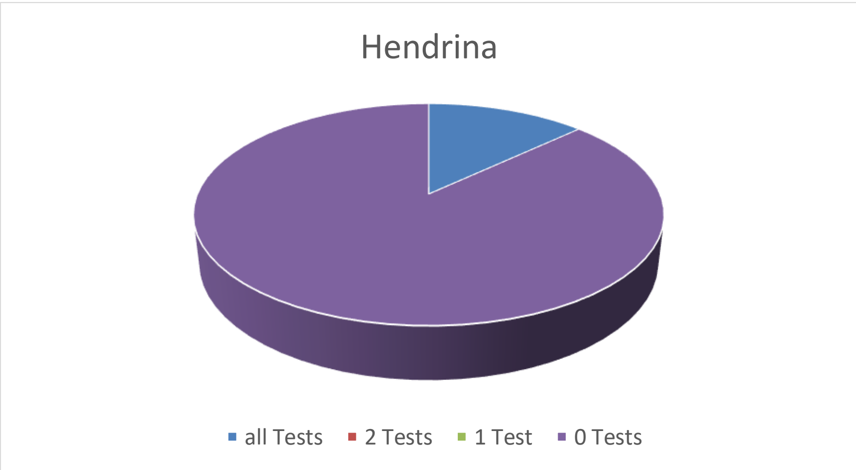


Figure 261: Participation of Hendrina power plant staff

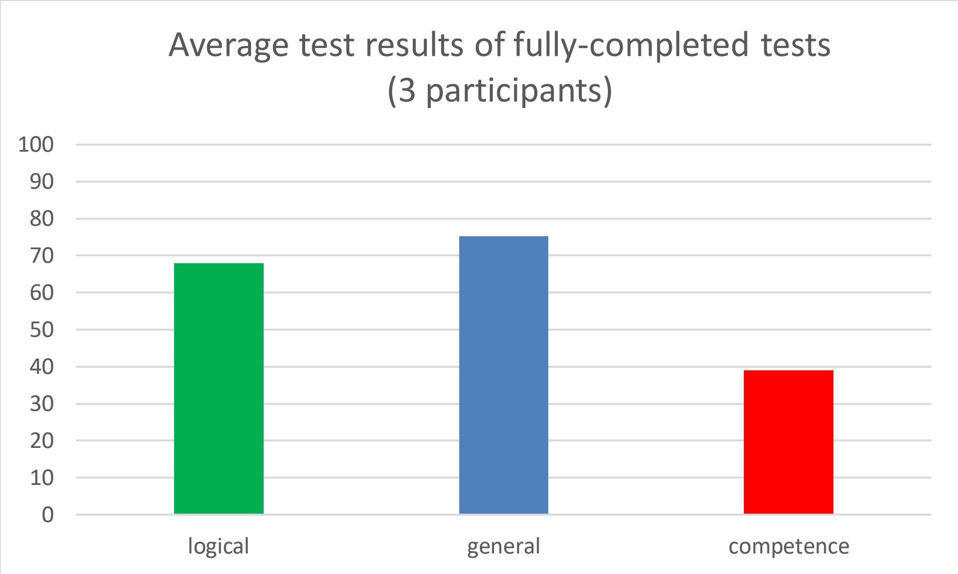


Figure 262: Average results of fully completed tests of Hendrina power plant

The results of the fully completed tests are summed up in Figure 262. Good scores were achieved in the logical test (68%) and general test (75%). This proves that the participants who did the tests had a good basic level of know-how. However, the results of the competence test were quite poor. The reasons for this are not clear. Due to the very low participation (only three completed tests), these results cannot be considered representative for the whole plant. If, at a later stage, these results are found to be representative of the whole plant, then staff will need training tailored to the needs of their individual jobs.

General observations from the interviews on site:

Findings:

In general, staff members appear to be reasonably competent but very demotivated. They seem not to see any value added by their work. As with every successful organisation, they really do need a strong leader (PSGM) to inspire and guide them, in order to bring the plant back to an acceptable level of performance.

Recommendations:

The general micro-managing interference from Megawatt Park has to stop. The numbers of staff and contractors should be seriously redefined and adjusted.

7.2.6 Kendal Power Plant

Results of written assessment:

At the **Kendal** plant, 22 participants (4 managers and 18 technical staff members) had been preselected to take a total of 58 tests.

In the end, just 18 tests out of 58 were completed (31%). Five participants completed the tests in full (23% of the total), while one participant opened a test but did not conclude it. Ten participants (45%) did not even start the tests.

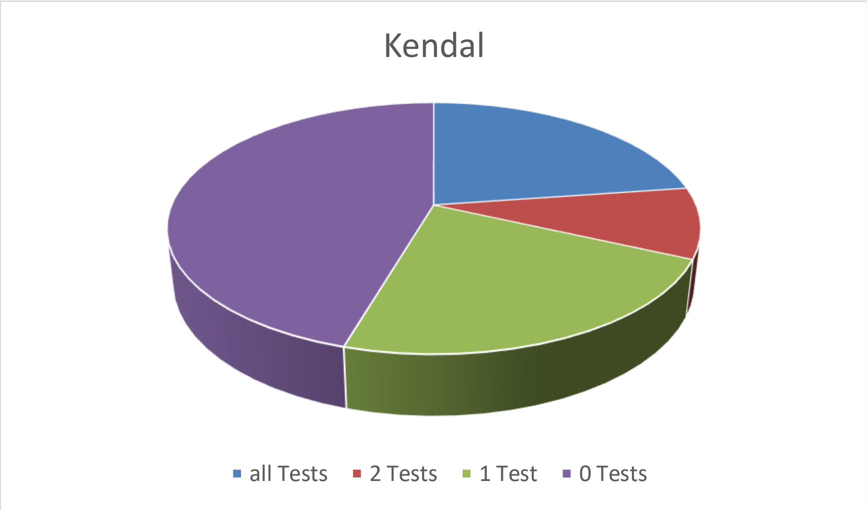


Figure 263: Participation of Kendal power plant staff

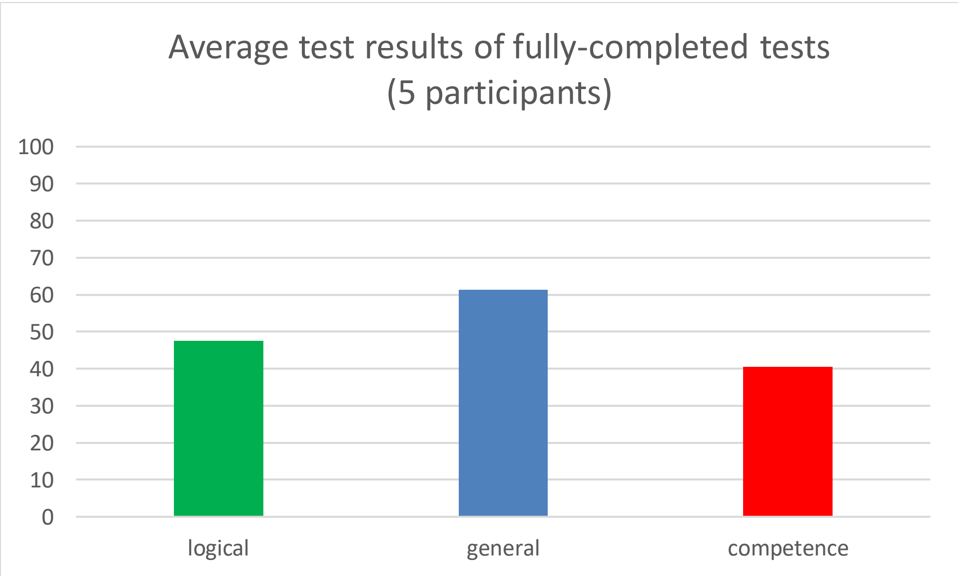


Figure 264: Average results of fully completed tests at Kendal power plant

The results of the fully completed tests are presented in Figure 264Figure 262. They show a fairly basic level of know-how among those who completed the tests. The results of the competence test, in particular, were not good - an average score of just 40%. The logic test, too, produced an average score of less than 50%, also quite poor. Due to the very low participation (only five fully completed tests), these results cannot be considered representative for the whole plant. If, at a later stage, the results of the competence test are found to be representative of the entire plant, then staff will need training that is better tailored to their individual jobs.

General observations from the interviews on site:

Findings:

The fact that the operator-training section reports to the training manager in the central HR department, rather than to plant management, is a huge drawback. This is also an issue at other plants. They are unable to entice staff members with excellent - or even good - operating experience to become instructors because they would thereby lose their shift allowance and promotional prospects.

The PSGM is attempting to solve this problem by contracting retired operators. However, the operator-training section currently has only one person who knows how to operate the excellent simulator.

Recommendations:

We recommended that responsibility for training is assigned to the operating department. The manager can then second the best operators as instructors and thereby ensure better training quality.

7.2.7 Kriel Power Plant

Results of written assessment:

At **Kriel,** 21 participants (4 managers and 17 technical staff members) had been preselected to take 55 tests.

In total, 36 of the 55 tests were completed (65%). Ten (48%) of the 21 planned participants completed all the tests, while three participants (14%) did not even start the tests.

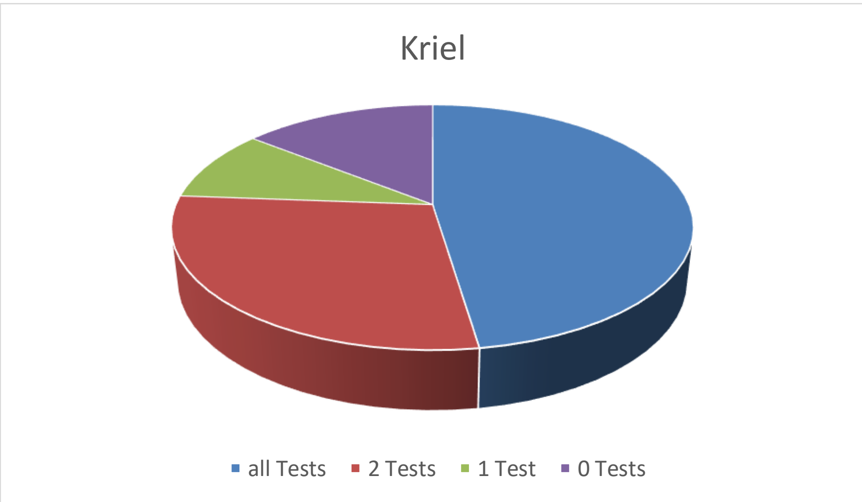


Figure 265: Participation of Kriel power plant staff

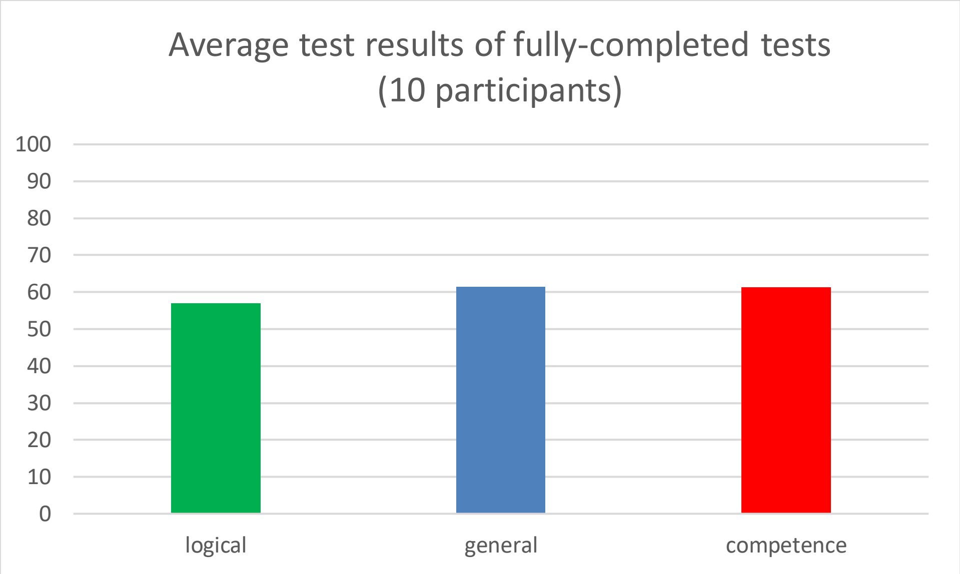


Figure 266: Average results of fully completed tests at Kriel power plant

The summary of the results of the fully completed tests is shown in Figure 266. Those who completed the tests showed a good level of basic know-how, with the scores of the general knowledge and competence tests slightly above 60% and the logic score slightly below 60%. However, due to the low participation, these results cannot be considered representative for the whole plant.

General observations from the interviews on site:

Findings:

There is absolutely no hand-over for new appointees to jobs because the previous incumbents have already left their posts.

Awareness of training needs is inadequate and, therefore, individual development plans are a bit of a paper exercise.

It is very difficult to recruit trainers for the training department from within the organisation due to overtime payment and shift allowance which is offered in the operation department.

Refresher training for operators is not going very well, as not enough staff are taking part: Due to a high number of vacancies, many staff members are working overtime and cannot find the time for training. There has been a drive to recruit more staff for operating and maintenance over the past year, but the situation is not yet resolved. This difficult situation needs to be resolved so that employees can get the refresher training they urgently need.

Recommendations:

Managers need to engage in leadership training and take responsibility for their teams.

HR should implement retention strategies and curb high turnover, especially at top-management level. Training policies need to be enforced to ensure that employees take part in trainings.

7.2.8 Kusile Power Plant

<u>Results of written assessment:</u>

At the **Kusile** plant, 20 participants (4 managers and 16 technical staff members) had been preselected to take a total of 52 tests.

In all, 25 of the 52 were completed, representing 48%. Ten participants (48% of the planned participants) completed all the tests, and six participants (30%) did not even start the tests.

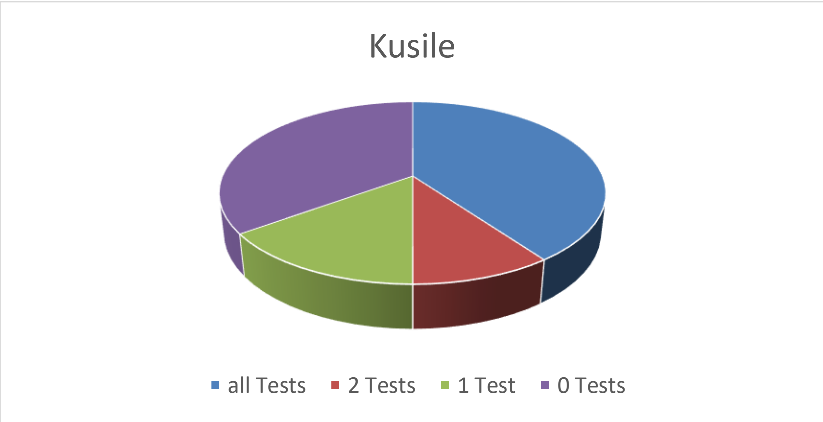


Figure 267: Participation of Kusile power plant staff

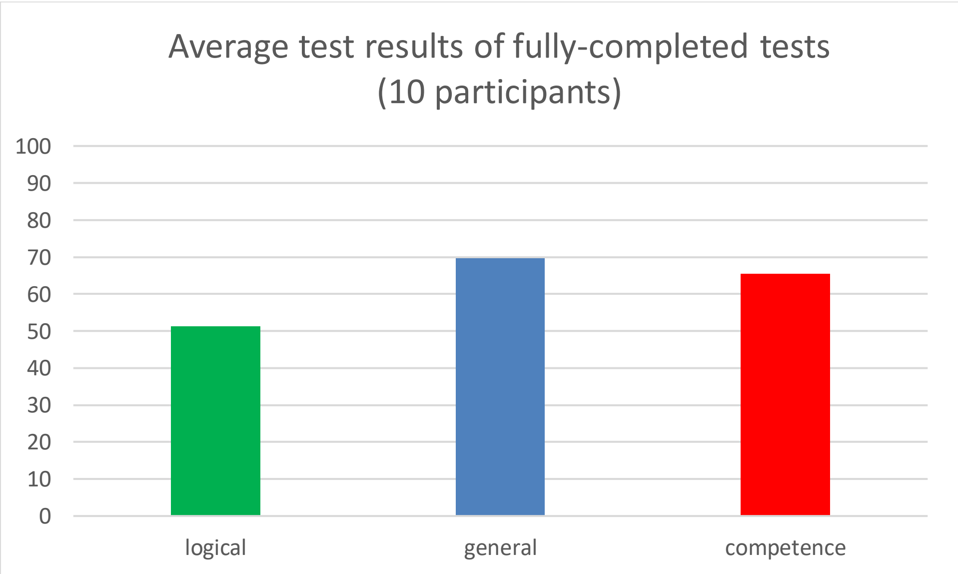


Figure 268: Average results of fully completed tests at Kusile power plant

The results of the fully completed tests are shown as a summary in Figure 268. The average score for the general test was nearly 70%, and for the competence test it was 65%, which are good results that reflect a good basic level of know-how among those participants who submitted their tests. The scores for the logic test, however, averaged 50%, which was a little disappointing. Due to the low participation, these results cannot be considered representative for the whole plant.

General observations from the interviews on site:

Findings: The staff seems to lack incident investigation skills and are not as competent as they ideally need to be at analysing root causes or at developing and implementing corrective actions.

Also, operating department staff have not been trained adequately on how to operate the new technology, which has not been introduced at any of the other Eskom plants yet.

Recommendations:

Kusile's Unit 4 achieves an EAF of > 90 %. This unit is currently operated by the boiler OEM. This team has successfully demonstrated that it is possible to achieve a high EAF in the newer plant units. It is a perfect opportunity for knowledge and best practice transfer to Eskom's future O&M team. This learning opportunity should be seized immediately.

Training with respect to FGD technology should be provided for the whole Kusile team. This should be complemented by simulator training courses for the FGD operators.

7.2.9 Lethabo Power Plant

Results of written assessment:

At **Lethabo,** 21 participants (4 managers and 17 technical staff members) had been preselected to take a total of 55 tests.

Altogether, 29 of the 55 tests were completed, representing 53% of the total. Eight participants (38%) completed all the tests, while seven participants (33%) did not even start the tests.

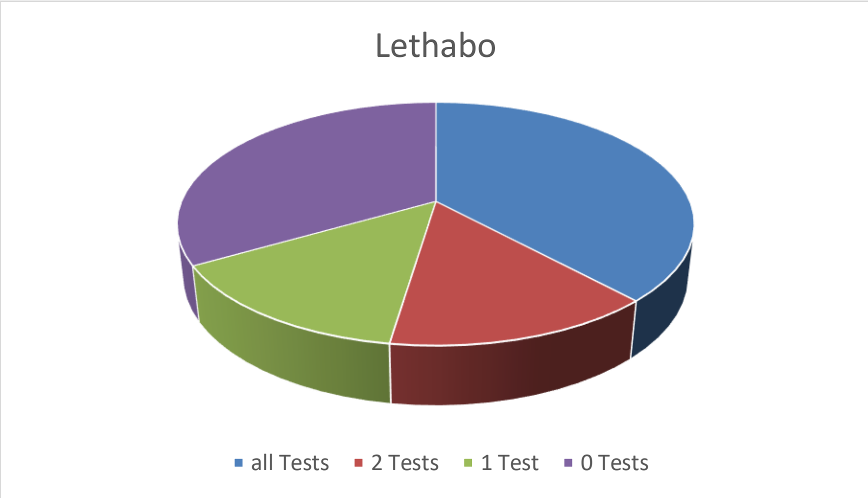


Figure 269: Participation of Lethabo power plant staff

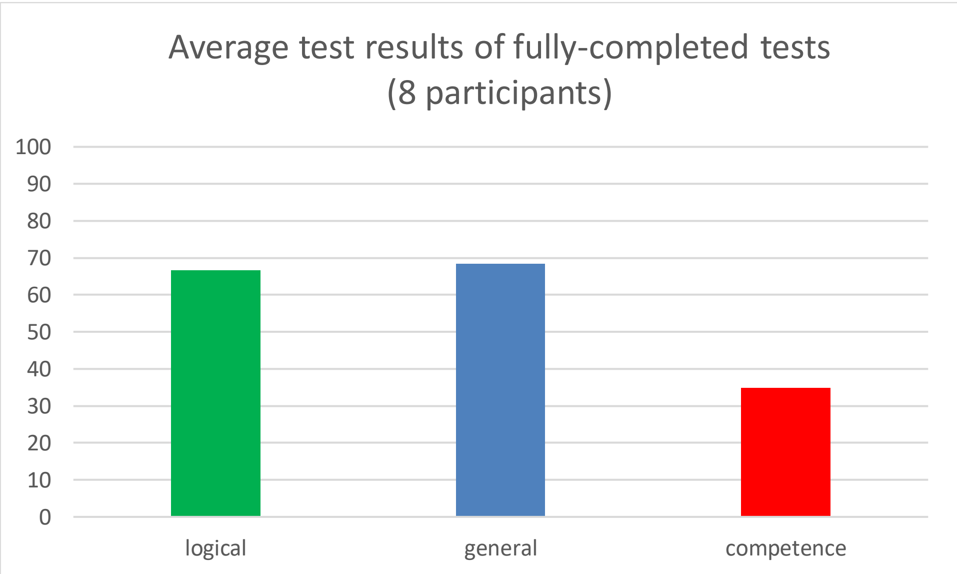


Figure 270: Average results of fully completed tests at Lethabo power plant

The results of the fully completed tests are summed up in Figure 270. In the logic and general tests, an average score of approximately 70% was achieved, which is a good result and proves that these participants have good basic know-how. The average score for the competence test was, however, very poor at just 35%. The reasons for this low score are unknown. However, due to the low participation, these results cannot be considered representative for the whole plant. If, at a later stage, these results are found to be representative of the whole plant, it will be important to give the staff more focussed training for their individual jobs.

General observations from the interviews on site:

Findings:

The average age at Lethabo is relatively low but, in the operating team in particular, there are quite a few employees nearing retirement age. If these older employees are excluded from calculations, then the average age of operating staff is quite low. The plant stated that Eskom is now permitting 19 learners per plant, which is not adequate.

Recommendations:

Individual training programmes need attention, to address competency gaps properly. Execution then needs to be managed properly with regular reviews and updates.

Staffing of the training department, including simulator instructors, and the maintenance of the ex-Matla simulator need special attention.

7.2.10 Majuba Power Plant

Results of written assessment:

At the **Majuba** plant, 23 participants (4 managers and 19 technical staff members) had been preselected to take a total of 61 tests.

In all, 22 of the 61 tests were completed (36%). Five participants (22% of the planned participants) completed the test, while 11 participants (48%) did not even start the tests.

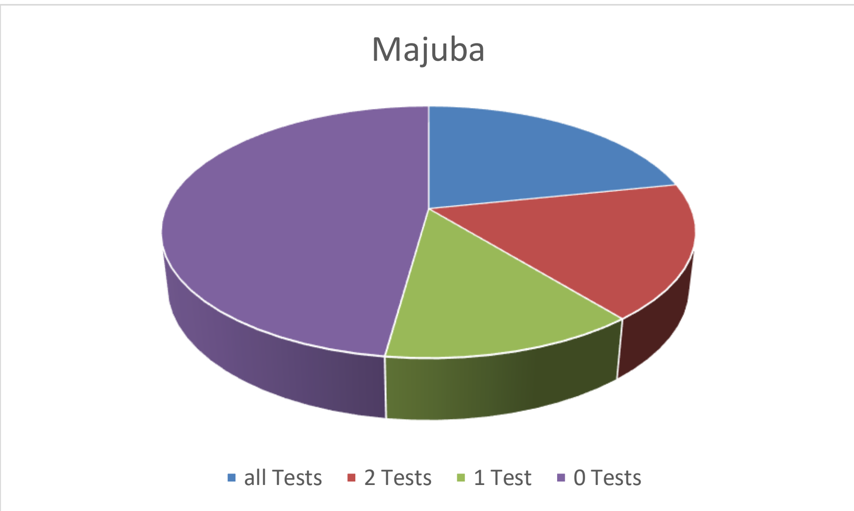


Figure 271: Participation of Majuba power plant staff

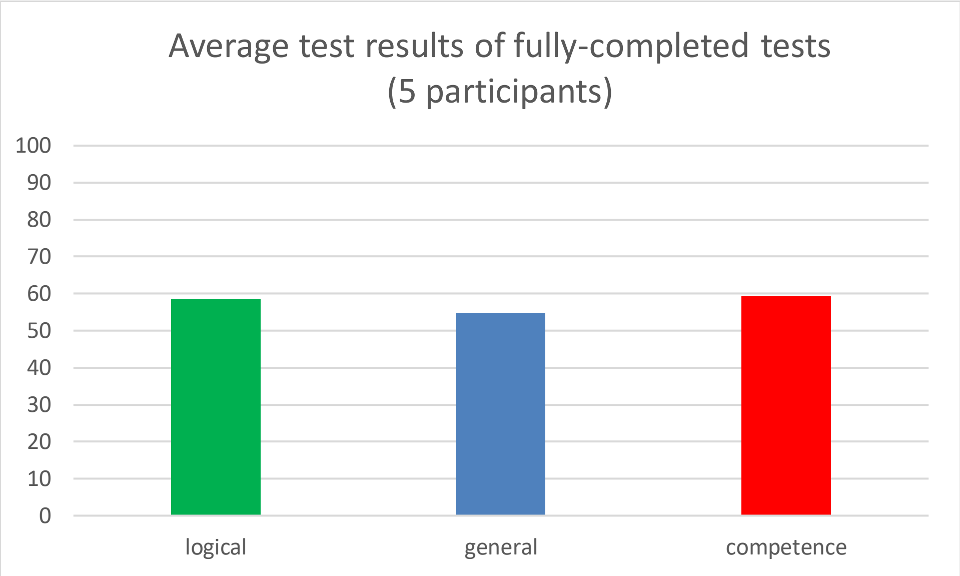


Figure 272: Average results of fully completed tests at Majuba power plant

The results of the fully completed tests are summed up in Figure 272. Scores for all three tests were slightly below 60%, indicating a fair level of basic know-how among those participants who submitted their tests. However, due to the low participation, these results cannot be considered representative for the whole plant.

General observations from the interviews on site:

Findings:

The operating simulator upgrade has not yet been conducted.

Recommendations:

The existing competency training matrices for all functions should be implemented.

Investment in workshop development is necessary, so that internal staff can be trained to enable own maintenance of resources.

7.2.11 Matimba Power Plant

Results of written assessment:

At the **Matimba** plant, 22 participants (4 managers and 18 technical staff members) had been preselected to take a total of 58 tests.

In all, 23 (40%) of 58 tests were completed. Seven participants (32% of the participants) completed all the tests, while 11 participants (50%) did not even start the tests.

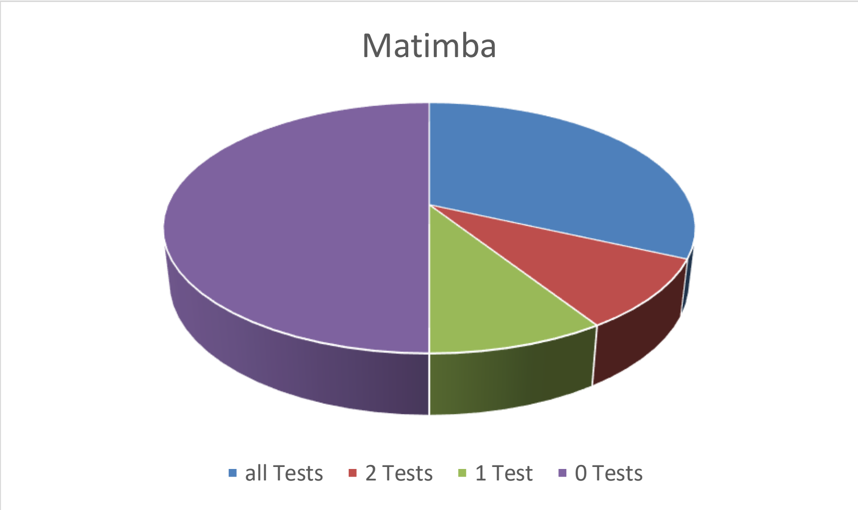


Figure 273: Participation of Matimba power plant staff

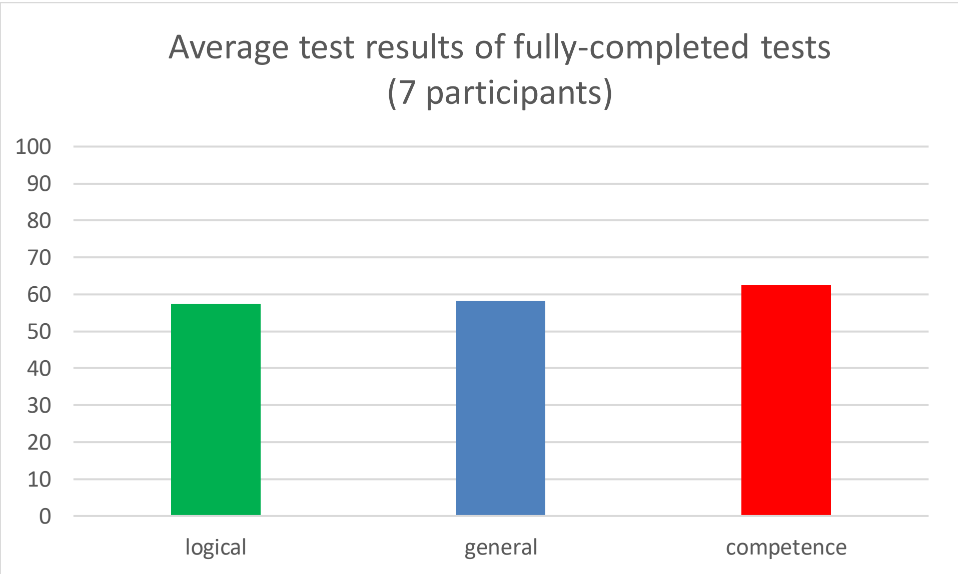


Figure 274: Average results of fully completed tests at Matimba power plant

A summary of the results of the fully completed tests can be found in Figure 274. The scores of the logical and general tests came in slightly below 60%, whereas the competence test score was slightly above 60%. These results show a fair level of basic know-how among those participants who submitted their tests. However, due to the low participation, these results cannot be considered representative for the whole plant.

General observations from the interviews on site:

Findings:

The operator training has only been conducted to full extent.

No training activities were taking place at the maintenance training centre.

The current instructors will all be retiring from their jobs within the next three years.

An upgrade of the operator training simulator has not been applied.

Recommendations:

Competency training matrices for all functions should be implemented.

Investment in workshop development is necessary, so that internal staff can be trained to enable inhouse-maintenance of resources.

New trainers should be recruited as soon as possible.

7.2.12 Matla Power Plant

Results of written assessment:

At **Matla,** 21 participants (4 managers and 17 technical staff members) had been preselected to take a total of 55 tests.

In all, 28 of the 55 tests were completed, representing 51% of the total. Seven participants (33% of the planned participants) completed the tests in full. Two participants opened a test but did not conclude it, while 3 participants (14%) did not even start the tests.

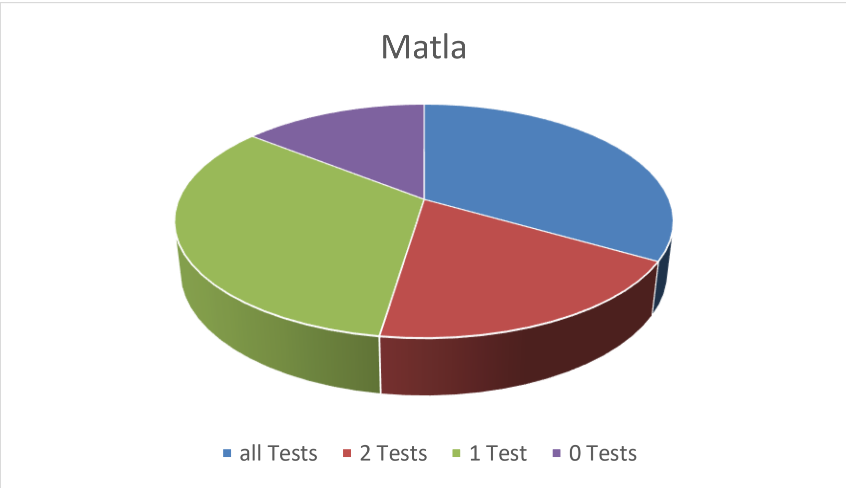


Figure 275: Participation of Matla power plant staff

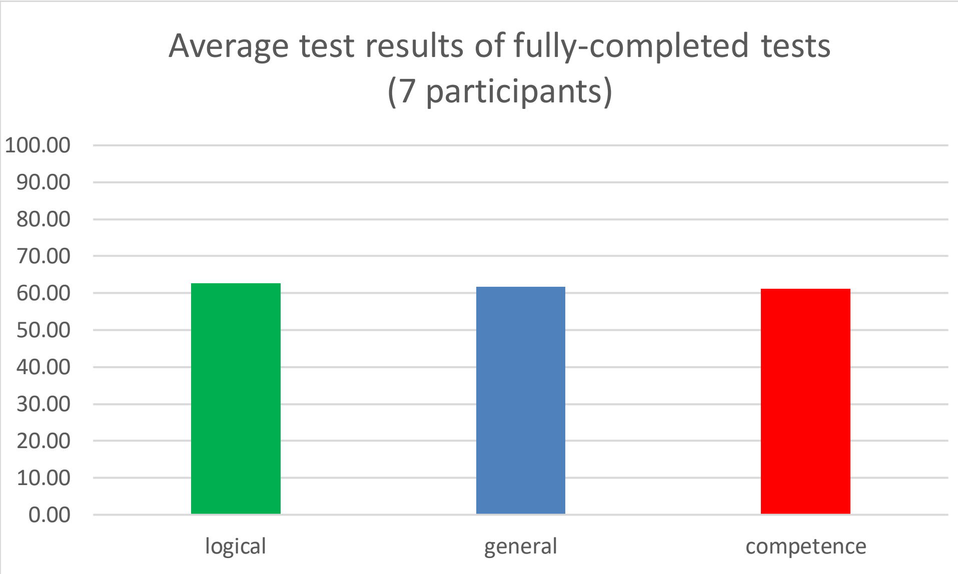


Figure 276: Average results of fully completed tests at Matla power plant

The results of the fully completed tests are summed up in Figure 276. Scores for all the tests were slightly above 60%, indicating a good level of basic know-how among those participants who submitted their tests. However, due to the low participation, these results cannot be considered representative for the whole plant.

<u>General observations from the interviews on site:</u>

<u>Findings:</u>

There are not enough learners in the pipeline.

There is a lack of simulator trainers and simulator maintenance.

<u>Recommendations:</u>

Operating training is not satisfactory and needs serious attention. The pipeline needs to be extended and instructors need to be recruited, in particular simulator instructors.

The training building and offices need refurbishing. It can be expected that on-the-job refresher training become a normality, as long as the learner pipeline is sustained.

7.2.13 Medupi Power Plant

Results of written assessment:

At the **Medupi** plant, 22 participants (4 managers and 18 technical staff members) had been preselected to take a total of 58 tests.

At Medupi, 40 of the 58 tests were completed, which represents a total of 69%. Eleven participants (50% of the planned participants) completed all the tests, while three participants (14%) did not even start the tests.

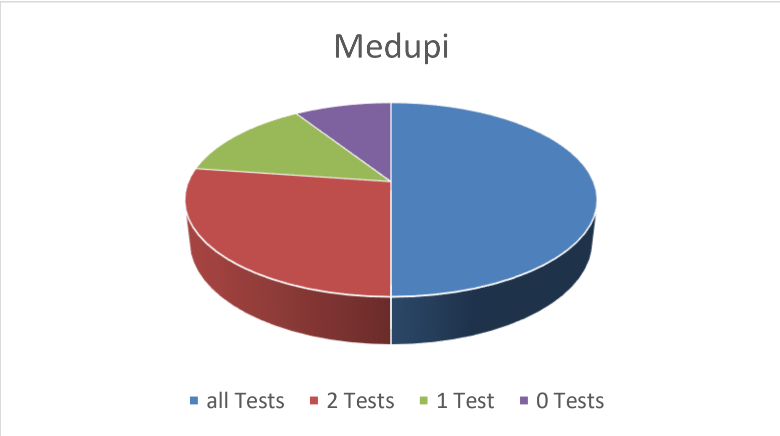


Figure 277: Participation of Medupi power plant staff

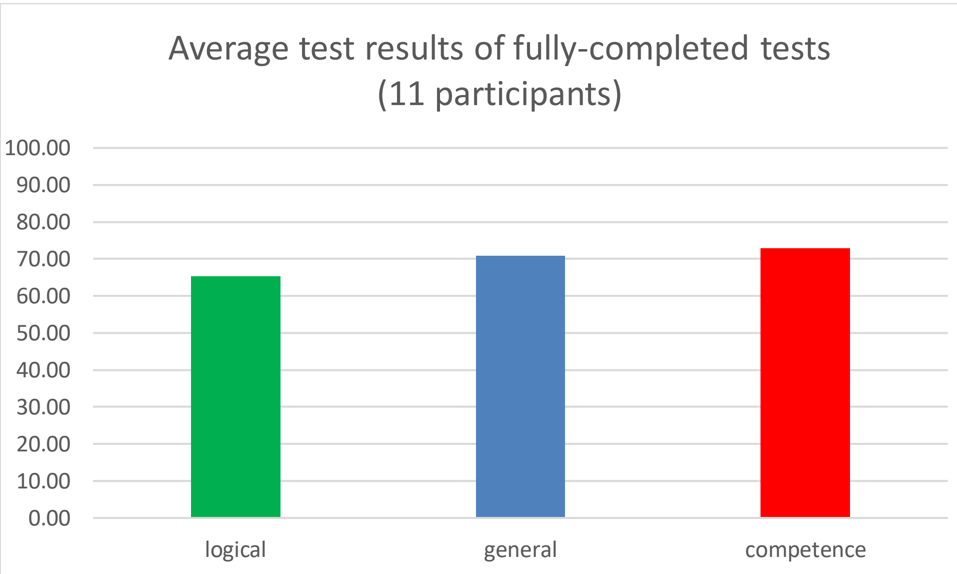


Figure 278: Average results of fully completed tests at Medupi power plant

The results of the fully completed tests are shown in Figure 278. In the logic test, the average score was 65%, while it exceeded 70% in the general and competency tests. This indicates a good level of basic know-how among those participants who submitted their tests. However, due to the low participation, these results cannot be considered representative for the whole plant.

General observations from the interviews on site:

Findings:

Both the simulators - Siemens and GE Alstom – are problematic. As of yet, there are no maintenance service agreements in place with the suppliers.

Although the operating and training managers are both very confident that their staff are well trained, it cannot be ignored that the explosion of generator 4, in 2021, was a direct result of operating errors.

A great deal of effort is being put into managing the supplier contracts. However, contract management competencies do not seem to be as strong as they should be. This is a serious issue, as most of the maintenance work is outsourced.

Recommendations:

A skills matrix, plant training plan and individual development plans need to be implemented.

Competency enhancement should include not just technical staff but also all non-technical staff as well.

The competencies of contracted staff also need to be improved. A robust methodology to assess contractor competencies is required.

7.2.14 Tutuka Power Plant

Results of written assessment:

At **Tutuka,** 25 participants (4 managers and 21 technical staff members) had been preselected to take a total of 67 tests.

Only 27 of the 67 tests were completed, representing 40% of the planned total. Six participants (24% of the total) completed all the tests, while 13 participants (52%) did not even start the tests.

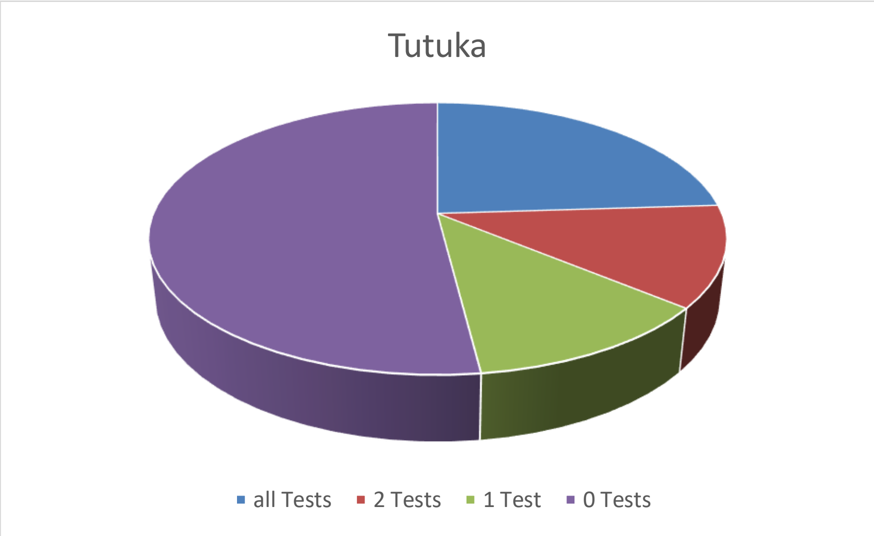


Figure 279: Participation of Tutuka power plant staff

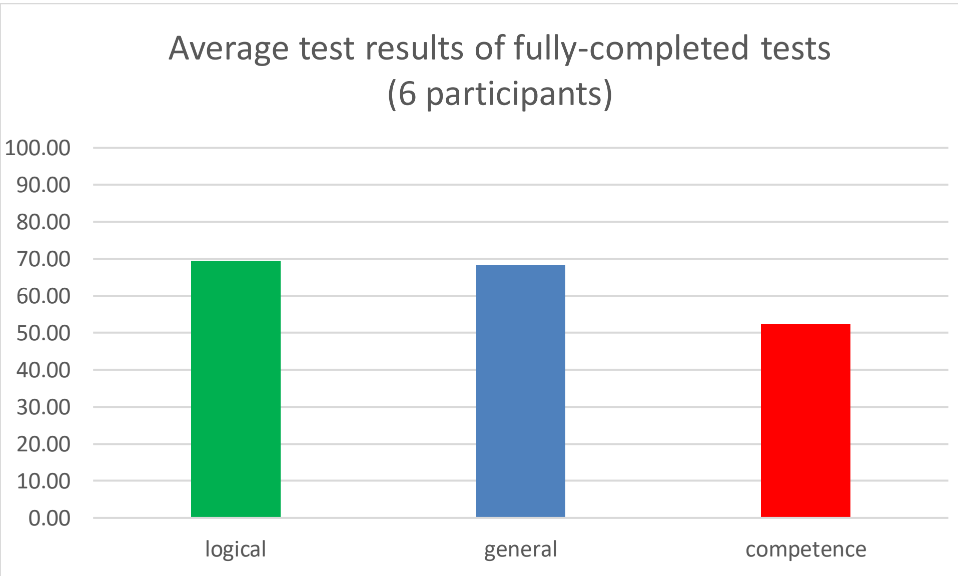


Figure 280: Average results of fully completed tests at Tutuka power plant

The results of the fully completed tests are shown in Figure 279. The scores for the logic and general tests were at about 70%, which is good, while an average of 52% in the competence test represents only a fair result. All in all, the participants who submitted their tests possess a good level of basic know-how. However, due to the low participation, these results cannot be considered representative for the whole plant.

General observations from the interviews on site:

Findings:

There is high staff turnover: People take a job just to get into Eskom and then look for a transfer.

No one wants to be associated with the "worst performing plant", which leads to low morale.

It was reported that training has been in shambles. There has not been a full-time technical training manager for a long time and there are no training plans in place, even though skills matrices are available. As a result, intake of learner operators has been low for some years.

Recommendations:

Skilled and motivated simulator instructors have to be recruited. The current simulator instructor is due to retire soon.

We recommend that management staff attend leadership development programmes, to strengthen their skill sets.

7.3 Summary of Findings for the Written Tests

As already mentioned, several times, the number of participants who actually completed the tests was disappointingly low. Therefore, the significance of the results is only representative to a limited extent. Nevertheless, the available results were evaluated and assessed by the KWS team. In principle, the following can be said:

Manager level:

- The results basically fall within a good range.
- Significant differences or conspicuous deviations in the competency levels of the managers at the different power plants could not be established.

Non-manager level:

- The results ranged from acceptable to good.
- With the exception of a few power plants, the results indicated a reasonable level of know-how.

However, because these results are not necessarily representative, we recommend taking a closer look at staff competence, especially at those power plants where the results were only fair, rather than good. To this end, we recommend that this study be repeated in more detail and with a larger group of personnel. These results could then be used to develop a detailed, tailor-made training programme with the aim of improving specialist skills among the power plant teams.

7.4 Training and Development

In general, the surveys showed that there is a skills deficit among the staff in operation, maintenance and engineering of between 15% and 25%. In general, learner pipelines are in urgent need of more learners. Operation training, in particular, needs more learner plant operators in order to maintain a healthy pipeline. The simulators in several power plants are not in a good working order. There are too many open positions for simulator instructors. One to two trainers per unit are recommended.

Operator training at all plants is accredited with the South African National Qualification Framework (NQF). Medupi is accredited up to NQF6, other plants NQF5.

In general, the training centres at all plants are sufficiently equipped with classrooms, laboratories and simulators (international benchmark). Especially in the area of operator training. The Eskom Academy of Learning (EAL) is potentially one of the best training facilities in the world, but it requires much better resourcing.

Lack of funding over the last 10 years has meant that only a few learner plant operators have been recruited. This has resulted in operating structures being understaffed and non-existence of a fifth shift, which would enable operators to be relieved of shift duties and undergo regular refresher training. The situation here is critical and needs to be addressed after plant modifications and major incidents.

Manager level:

Generally, there is a need for leadership development. Development programmes (see EAL training programmes for managers) which used to be conducted centrally, are no longer taken advantage of by the Generation Division, even though they are still available at EAL. Specific areas of training, such as legislative training and New Engineering Contract (NEC) training, are not covered.

Suitable training management systems and templates are in place, such as a training matrix, a training plan and individual development plans. However, this tends to be a bit of a paper exercise, as there is no formal recognition of training that has been undertaken. Furthermore, plant issues require constant attention.

Non-manager level:

Training is not provided as often as necessary or possible. Usually, training should be conducted once or twice a year. Depending on the subject, some training, like HSE, is mandatory on, for example, a yearly basis. Further training should be coordinated across all plants in cooperation with EAL.

in co-operation with

Gx Operating Training Statistics: Formal & Refresher Training Performance 2022.

Eskom

Business Unit	Operating Training Mandays (Formal & Refresher Training Days)			
2022-2023	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter Total
Kusile	1.31	4.69	9.66	12.52
Medupi	2.91	7.06	12.96	16.27
Duvha	4.68	9.72	12.84	15.74
Kendal	0.27	3.93	1.17	8.68
Lethabo	1.32	4.23	7.58	10.04
Matimba	3.75	11.37	14.32	15.95
Matla	0.89	1.77	2.43	2.74
Tutuka	0.44	2.86	5.02	6.83
Arnot	0.17	1.34	2.50	3.39
Camden	2.28	6.94	10.53	12.77
Grootvlei	0.16	2.19	7.18	8.19
Hendrina	1.67	6.49	10.44	16.27
Komati	1.58	2.98	2.22	7.37
Kriel	3.37	5.92	6.66	7.88
Majuba	0.80	1.54	3.09	4.76

FY2023 Annual Target Spread

Annual Performance					
Measure/Metric/KPI	Formal & Refresher Training				
Unit of Measure	Training days per person				
Source of Evidence	SAP LMS				
Weight (%)	20				
Target Setting Spread	Floor	Kick-in	Norm	Stretch	Ceiling
	1	2	3	4	5
Generation Coal					
Fossil PS	6	7	8	9	10
Peaking	6	7	8	9	10
Koeberg	*				
Generation					

Achievements:
The following Power Stations achieved Ceiling in 2022 (Kusile, Medupi, Duvha, Lethabo, Matimba, Camden and Hendrina)

Areas of concern:
The following Power Stations did not achieve above floor: Matla. Tutuka, Arnot, Majuba and seven of the Nine peaking stations.

Business Unit	Operating Training Mandays (Formal & Refresher Training Days)			
2022-2023	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter Total
GX PEAKING ACACIA	0.00	0.64	1.70	1.70
GX PEAKING ANKERLIG	0.00	0.00	3.01	3.01
GX PEAKING DKB	0.12	1.98	3.43	3.43
GX PEAKING GARIEP	0.00	8.13	8.13	10.59
GX PEAKING GOURIKWA	1.05	9.88	10.31	10.70
GX PEAKING INGULA	1.35	1.56	4.71	4.93
GX PEAKING PALMIET	0.00	0.64	1.72	1.72
GX PEAKING PORT REX	0.00	0.00	0.36	1.96
GX PEAKING VANDERKLOOF	2.19	6.64	6.64	6.64
Peaking South	0.18	1.68	3.48	3.48
Peaking North	0.88	2.31	4.45	4.45
Peaking Consolidation	0.53	2.00	3.97	4.18

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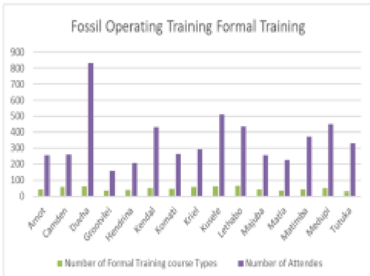
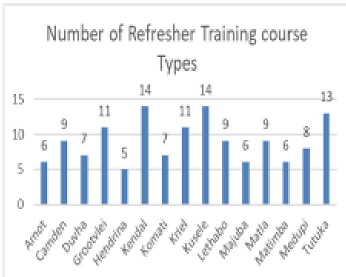
Operating Training Courses and Number of Attendees

Eskom

Operating Employee's M18-18.2					
Power Station	Number of Refresher Training course Types	Number of Attendees	Number of Formal Training course Types	Number of Attendes	Total number of Attendes
Arnot	6	102	41	258	360
Camden	9	384	55	261	645
Duvha	7	109	60	833	942
Grootvlei	11	1056	33	158	1214
Hendrina	5	2421	38	206	2627
Kendal	14	286	49	429	715
Komati	7	74	46	263	337
Kriel	11	1373	58	290	1663
Kusele	14	2286	61	510	2796
Lethabo	9	735	62	434	1169
Majuba	6	309	40	258	567
Matla	9	251	34	225	476
Matimba	6	4303	39	374	4677
Medupi	8	2432	50	450	2882
Tutuka	13	739	29	330	1069

Note: The course type references a number of courses scheduled under a specific heading such as legislative Training.





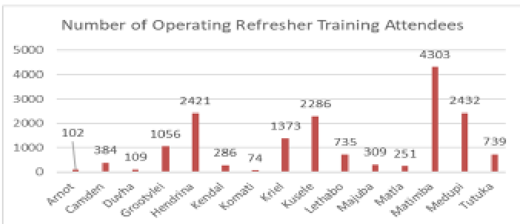


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Figure 281: Operating training courses and number of attendees [58]

[58] Eskom – file ”VGB Operating Training Questions.pptx”

7.5 General Findings and Way Forward

This section sums up the general findings of the KWS team, based on the meetings attended and the interviews conducted at the individual power plants.

Manager level:

Leadership development: Development of leaders at power plants needs to be reviewed. There is a lack of strong leadership at numerous power plants. Leadership reviews needs to be carried out in all areas of the plants, in order to gain a clear picture and to identify the most appropriate solutions and decide the best way forward.

Individual Development Plans are in many cases seen as a paper exercise. In general, older employees do not take these plans seriously. Work pressure, caused by plant issues, means that little or no time is available for training and development and that training is often interrupted by the need to address urgent plant issues. Performance contracts are often not taken seriously. Bonuses used to be available as an incentive for managers but, for some years now, no bonuses have been paid due to shortage of funds.

Outsourcing: The fact that Eskom currently outsources most of the maintenance work needs to be reviewed. Contractor competencies are compromised due to the frequent changing of contractors on expiry of contracts.

Procurement: The purchasing process and requirements are very bureaucratic and are extremely long-winded. The Eskom process addresses government legislation in terms of equitable purchasing. It is also an area that is prone to misuse and corruption. The red tape and long lead times lead to huge frustration and certainly have a negative impact on motivation and morale among the staff, as well as on the performance of the plant. This probably leads to an acceptance of the status quo. Staff just accept that purchases take an excessively long time and just live with it. This whole process negatively affects the productivity and efficiency of the staff. It also leads to extended outages.

Work attitude: Another factor affecting the performance of staff is the lack of accountability and consequences.

Staff performance interviews: Due to the constant stream of operational issues at the plants, managers and supervisors tend not to hold formal performance review meetings with team members. Also, the fact that no performance bonuses have been paid in recent years, due to shortage of funds, means that performance contracts have become little more than a formality. Therefore, some managers feel that employees lack the motivation to perform well.

Competencies: Overall, staff competencies are deemed to be reasonable. However, it should be borne in mind that knowledge and competency are one thing, but their application in practice is another matter completely. Clear objectives, appropriate performance agreements or contracts, feedback, strong managerial guidance and leadership, a good work life balance and suitable real development are all essential competencies. However, they are not given adequate attention at present.

HR processes: The procedures and systems for addressing various matters seem to be very good. They comprise many plant-related matters, human resources and commercial aspects. However, in some areas, the processes overrule common sense. The risk is that some of the processes become a paper exercise and that reliance on them is too heavy.

Moral: At several plants, the operating and commissioning managers said that the maintenance and repairs carried out during planned and forced outages were all too often insufficient, leading to delays in returning the plants to service. Some of the reasons for this situation include insufficient competencies, insufficient motivation and care, low morale, insufficient quality control, lack of guidance and monitoring and, also, inadequate availability of spares. Poor coal quality at many plants is also a major cause of poor performance. The impact of this on staff morale and staff attitudes needs to be further investigated and remedial action taken.

Local communities: A very significant human resource challenge exists at various plants because of the demands placed on them by the local communities. The communities expect the plants to offer maximum employment to local workforce.

The **outage department** operates as an independent department parallel to operations and maintenance. Hence, responsibilities for the core tasks of the power plant are not concentrated in one accountable department – this set-up paves the way for inefficiencies and blame shifting.

<u>Non-manager level:</u>

Work attitude: Control room operators (unit controllers)/shift supervisors often tend to not be particularly involved in the process and tend to wait for instructions. For example, the unit controller and shift supervisor often wait for decisions or observations from the remote monitoring and diagnostic centre before acting themselves.

Theoretical basic knowledge is available, but a proper understanding of the procedures is missing. As a result, it is difficult for some employees to react appropriately to malfunctioning or to critical operating situations.

New C&I systems, in particular, offer a multitude of options for process analysis, but they are hardly used at all in the power plants. During the site visits, it was noticeable that the overall attitude with regards to managing power plant processes is reactive rather than proactive. This is also the case in the control rooms, where very few trends are available or predefined on the DCS.

Work culture: Overall, identification of staff members with the task in hand and their understanding of the importance of these tasks for the overall power plant process is underdeveloped.

Many operational decisions are thus left to management, blocking resources there and slowing down processes.

7.5.1 Recommendations

General:

Detailed assessment at each power plant: A detailed internal assessment on the job should be conducted in each power plant to monitor and evaluate the potential of each position. Individual support, possible promotion (e.g. unit controller to shift supervisor) and individually-tailored training plans can be developed subsequently.

Implementation of new operating philosophy: The operating staff should use all tools the DCS system offers (e.g. trends, plant displays, alarm sequence display) to be able to react preventively before a trip occurs. This can easily be trained in simulator trainings, as can the handling of the DCS system.

Recruitment of trainers and train-the-trainer courses: Based on the detailed assessment mentioned above, possible candidates to be a trainer or instructor, who have shown their potential, can easily be identified and encouraged to join a train-the-trainer course. This course content should cover basic training for trainers up to high level technical, operational and simulator training.

Role of Eskom Academy of Learning (EAL): An independent examination committee, which conducts examinations for standardised trainings (e.g. operator / shift supervisor / maintenance technician) should be formed at EAL. EAL should also act as a certifier for the standardised contents of these training courses. Furthermore, EAL can also conduct trainings at headquarters, with the benefit that the trainees can concentrate on the training sessions instead of being called back to their work. These centralised trainings have the advantage that every power plant can send one or two participants.

Manger level:

Leadership: There is a broad need, across many of the plants, for training to develop stronger and more effective leadership skills. This needs to include the practical day-to-day requirements of leadership, as well as actions focussed on the longer term. The same applies to managerial competencies.

Structures generally seem to be top-heavy with very low reporting ratios. Communication between managers and subordinates should be optimised to improve the exchange of information and to enable better performance of the plant.

Eskom has developed a work ethic model detailing the expected work ethic, integrity and clear accountability. Perhaps individuals need to be trained on such requirements and to individually commit to the required behaviour. For this purpose, head office created a cultural transformation model: 1:1:6:10 Desired Culture Model (DCM). It is currently little known in the plants and is therefore not applied. It possibly needs to be simplified and/or made a common goal.

*Organisational culture: **1:1:6:10** is the cultural transformation model.*

> ***1:1:6:10** ratio:*
> ***1** Purpose: powering growth sustainably*
> ***1** "To be" culture: high performance culture*
> ***6** cornerstones. accountability, operational excellence, people prioritisation, financial prudency, value driven culture, customer centricity*
> ***10** key levers of organisational culture:*
> *Empowerment, governance and ethics, teamwork, engagement, wellness, technology, change agility, celebration, leadership*

Morale: Personal performance contract management and recognition, regular performance reviews and feedback need to be carried out to a high standard. Performance bonuses should be implemented for employees who performing well. The results of such a process include more motivated employees and more encouragement. It should also result in clearer objectives and expectations.

Moral support for over-worked staff is needed.

Competencies: In general, the competencies at the plants seem to be at a reasonable level. As mentioned above (see 7.1.2), regular training that is suited to the needs of the various departments is needed to improve performance. A sound plan needs to be developed.

Training assets: Some of the corporate training departments should be dedicated to supporting the development and enhancement of competencies of power plant employees. In addition to this, a contract could be put in place to carry out a detailed assessment and review of plant training plans, individual training plans and training courses and interventions that are currently available. The training departments then need to ensure that suitable interventions and programmes are available to address all the training gaps and needs. The Eskom Academy of Learning (EAL) is the obvious choice to do this, so they should be supported to take on this task, as they are very ready and willing to be re-empowered.

External staff: The competencies of contracted staff probably also need improvement, but this is going to be challenging. A robust methodology to assess contractor competencies is required. It is not good enough to check if the contractors comply with the formal qualification requirements. A more robust way of ensuring contractors have the required competencies and quality control of these is required.

However, the practice of outsourcing most of the maintenance should be critically reviewed. There are numerous factors to consider, but this is worth a thorough review.

Dwell time: Many of Eskom's power plants are located in rural areas. The cost of living can be significantly higher than in urban regions. In addition to this, there are other challenges such as unrest which result in a migration of skilled workers. A concept that outlines measures to attract qualified personnel to work in the power plants needs to be developed – some ideas for incentives are already presented in this report.

Operator pipeline: A suitable operator pipeline needs to be in place at all plants.

Competencies: Leadership competencies are, in general, not at the required level. There used to be suitable leadership development programmes in place and something similar needs to be established again. Possibly, some extra staff will have to be appointed, as an interim measure while training and development take place. The poor performance of the plants and the extremely heavy workload caused by the many plant issues have a negative impact on various human resource aspects. These include:

- Low morale and motivation
- Long working hours, poor work-life balance
- Managers needing to be too hands-on.
- Too much overtime required.
- Interruption of training due to staff being required to attend to plant issues.
- Inadequate refresher training for operation staff

Non-manager level:

Operator training by means of simulator instruction needs to be improved. There are insufficient experienced instructors for a start. Most of the operating training simulators are not in good condition and many are not maintained adequately. Adequate funding should be made available for upgrading, maintaining or, where necessary, replacement. The simulators need to reflect all plant modifications so that accurate simulation can be provided.

Furthermore, the following actions should be taken:

- Introduce new operator philosophies
- Implement operation philosophies in simulator training
- Introduce anticipatory action as an operation philosophy
- Strengthen willingness to make decisions (acceptance etc.)
- Promote a sense of responsibility (assign tasks and areas of responsibility based on results)
- Involve trade unions in technical/organisational processes to prevent blocking of improvement measures.
- Implement a new way of working to motivate the staff and use the technical background of level of staff (more *Bottom Up Culture*)
- Increase the priority given to operator training in coal-fired plants, so that it is at the same level as Koeberg nuclear power plant.

7.5.2 Outlook

As shown in Figure 2, Eskom HR has outlined the necessary measures for further development.

Talent & Skills, Training and Development — Eskom

Technical Training	Functional Training	Management and Leadership Development	Digital Training
• Emerging highly specialized technical learning solutions to address current and emergent technical needs in innovative facilitated, 'laboratory' and on the job settings • Build specialised technical capability in terms of new technologies such as Smart Generation, Smart Grids, Renewable Energy, E-Mobility and other leading technologies • Establishing new learning methodologies such as coaching laboratories aimed at enhancing technical competency	• Ensuring competitive and regulatory complaint learning solutions in the service of functional skills excellence, through cutting edge learning solutions • Build functional expertise to close the related competency gaps and strengthen future knowledge, skill and ability within Eskom. • Providing world class learning solutions through best practices and continuous improvement • Co-create customised functional related learning and development solutions with key stakeholders • Provide competitive and regulatory compliant learning solutions in the service of functional skills	• Address critical processes, management and leadership skills gaps across the leadership pipeline (supervisors, middle managers, senior and general managers. • build leadership capacity to effectively execute the Eskom strategy now and into the future • Develop managers on core management competencies and Eskom specific programmes. • Deliver customised learning solutions for sustainable leadership effectiveness	• Discover and implement digital platforms for learning on the go, learning anytime and anywhere, and is learner centric • Introduce and implement new digital learning platforms and solutions e.g.. learning mobile application, micro learning • Improve delivery and administration of learning in a digital era e.g.. digital learner feedback, digital logbook • Drive digital learning awareness throughout the business • Implement digital learning tools and practices to improve learning solution productivity and efficiency

Figure 282: Training concepts of Eskom's HR
Source: Eskom[59]

The next step is to implement and monitor these measures. Since coal-fired power plants are a key source of South Africa's electricity supply, there needs to be more emphasis on providing targeted training to address skills shortages at the plants.

The measures should also be accepted and implemented at plant level. During the interviews at the plants, it became clear that the actual situation on site is at odds with HR's perception. In a next step, this discrepancy needs to be addressed because the plants already know what they want to happen and what they need in order to become more effective.

[59] Source: Eskom: "HUMAN RESOURCES PRIORITIES FEB 2023.pptx

8 Proposal for Follow-up Actions

Follow-up activities are mentioned at various places in the report. This chapter provides an overview of the proposed activities at a glance:

A) **Installation of an Expert Team outside Eskom:** The vgbe team recommends engaging an interim team of external experts which reports directly to National Treasury (NT). This expert team should support the power plants in managing the turnaround. Member(s) of the expert team should be permanently based at each site, to follow up key risk areas and intervene if required. The assignment should be limited to a defined period, e.g. 1.5 to 2 years.

B) **Review of Eskom's investment plans for the coal fleet:** In order to improve the technical status of the power plants and in order to ensure their environmental compatibility, several Capex projects will be needed. The vgbe team recommends that the existing Eskom plans for further investment in the coal fleet be reviewed by an independent third party. This review could also be placed within the remit of the external expert team (A).

C) **Development of a new organisational structure for the coal fleet:** The vgbe team recommends separating the coal fleet from the rest of the Generation Division. This is to ensure sole focus on the revitalisation of the power plants and to facilitate the application of fast-track decision procedures. A new managerial and organisational structure is needed, as well as the development of a new business model that also considers concessions and privatisation as options.

D) **Analysis and forensic review of accounting methods and the way money is used:** The assessment of the maintenance budgets for the period 2013 to 2027 showed that they are well above the international benchmark. Hence, the money spent by Eskom should have been sufficient to execute proper maintenance and to keep the power plants in a good condition. In view of the low EAF, this has obviously not been the case. Therefore, further investigation is needed, to assess the gap between the budget, the money spent and the actual technical status of the power plants.

E) **Lifetime-extension study for Arnot, Camden, Grootvlei, Hendrina and Matla power plants:** In view of the electricity crisis, a further extension of power plant lifetimes is an option. The Arnot, Camden, Grootvlei and Hendrina power plants are all approaching their planned shut-down dates, starting in 2024. Matla is due to be retired in 2034 but may have to run for longer, as well. In order to assess whether longer lifespans are an option, a feasibility study needs to be carried out. This study should comprise a detailed assessment of all critical power plant components. The operational profile and inspection report, as well as documentation about refurbishment and repair measures, need to be investigated for each component. There may even be a need for specific material tests. All this information is essential, in order to be able to make qualified decisions about the remaining lifespans of the stations. Based on these results, it will be possible to estimate the potential costs associated with extending their lifespans. It should be noted that Eskom has carried out such studies in the past, to extend the life of these power stations and to grant concessions to operate beyond normal inspection intervals. This historical data should be provided for the assessment.

F) **Continuous improvement through international exchange of best practices:** In order to ensure the continuous improvement of operational and maintenance practices in the Generation fleet, the engagement of Eskom expert staff and management on platforms which promote the exchange of international best practices needs to be intensified, e.g. through regular participation in the activities of international technical associations like vgbe energy.

G) **Know-how transfer in unbundling electricity markets:** The spin-off of Eskom's Transmission Division is an essential step and a major challenge. The assessment and evaluation of experiences and lesson learnt in electricity markets that have already been unbundled could add value to the process – especially in view of the design of the regulatory framework. This framework should facilitate stable operation of the grid system and outline an appropriate remuneration scheme. Furthermore, the introduction of tariffs for the operation of the transmission system and related services should be considered in such a study.

9 Appendices

9.1 Useful vgbe Standards

Standard No.	Title	Abstract
S-008-00-2020-11-EN ISBN 978-3-96284-232-1 (eBook)	Recommendations for managing functional safety in steam boiler plants and systems of the water/steam cycle	The standard addresses both operators of thermal power plants and manufacturers and is intended as an aid in applying the standards on functional safety. standards on functional safety. It was developed on the basis of EN 61508.
S-010-T-00;2011-12.EN ISBN 978-3-86875-671-5 (eBook)	Feed Water, Boiler Water and Steam Quality for Power Plants/Industrial Plants	This standard supports operators of water-steam cycles in power plants in selecting and judging suitable water regimes with respect to a safe and economically sound operation for a long period of time. It describes requirements for feed water, boiler water and steam of water-steam cycles in once-through and drum boilers and all pressure ranges.
S-015-2011-EN ISBN 978-3-86875-660-9 (eBook)	Type, Operation and Maintenance of Flue Gas Desulphurisation Plants (FGD)	This standard provides detailed information for the O&M of FGD in large combustion plants. The recommendations and technical information is based on decades of operational experience.
S-036-00-2017-04-EN ISBN 978-3-86875-996-9 (eBook)	Preservation of Steam and Gas Turbo-Generator Sets	The standard covers all aspects of preservation: it provides operators, manufacturers and planners with a basic framework on how and to what extent the steam turbines, gas turbines and generators are to be treated.
S-042-00-2018-01-EN ISBN 978-3-96284-029-7 (eBook)	Chemical Feeding and Feed Systems for Water/Steam Circuits	This standards supplements the standards S-010-T-00;2011-12.EN and S-006-00-2012-09-EN and contains recommendations for the correct location, design and instrumentation as well as operation and maintenance of chemical feed equipment in the water/steam cycle.
S-103-00-2020-02-EN ISBN 978-3-96284-198-0 (eBook, English)	Monitoring, limiting and protection devices on steam turbine plants	This standard is addressed to manufacturers, service providers and operators of steam turbine plants and is intended in particular to assist operators in equipping their steam turbine plants.
S-115-00-2016-01-EN	Recommendations for the Inspection	The standard outlines strategies and criteria used for optimal scheduling of turbine inspections and for

Standard No.	Title	Abstract
ISBN 978-3-86875-909-9 (eBook)	and Overhaul of Steam Turbines	minimizing the time required for the implementation of inspections and overhauls.
S-116-00-2016-04-EN ISBN 978-3-86875-913-6 (eBook)	Preservation of Power Plants	The standard describes proven concepts for the preservation of power plants in order to avoid of damage caused during standstills.
S-130-00-2017-07-EN ISBN 978-3-96284-004-5 (eBook)	Acceptance test measurements and operational monitoring of water-cooled surface condensers	The standard explains the physical parameters and conditional equations of a water-cooled turbine condenser. How to perform condenser performance test measurements and operational monitoring of condenser condition during normal operation is described. The standard includes a programme for the determination and assessment of the heat transfer coefficient under actual operating conditions.
S-131-00-2017-07-EN ISBN 978-3-96284-008-2 (eBook)	Acceptance Test Measurements and Operation Monitoring of Air-Cooled Condensers under Vacuum	The standard explains the physical parameters and conditional equations of air-cooled condensers. How to perform condenser performance test measurements and operational monitoring of condenser performance during normal operation is described.
S-165-00-2014-07-EN ISBN 978-3-86875-825-2 (eBook)	Recommendations for the improvement of H_2 safety at hydrogen-cooled generators	The standard provides information for designing, constructing, modernising/refurbishing and operating hydrogen-cooled generators in power plants.
S-166-00-2014-02-EN ISBN 978-3-86875-779-8 (eBook)	Quality Assurance in the Manufacture of Generators	This standard supports operators of generators to assure the quality of the generator and its auxiliary systems and components during the manufacturing phase.
S-455-00-2022-12-EN 978-3-96284-299-4 (eBook)	Cooling Water Systems and Cooling Water Treatment	This new standard explains the essential aspects of cooling water chemistry and cooling water treatment, describes operational problems like fouling, scaling and corrosion and how to solve them.
VGB-R 106e (Copper Alloys) VGB-R 113e (Stainless steels) VGB-R 114e (Titanium)	Tubes for Condensers and other Heat Exchangers for the Operation of Steam Turbine Plants	These guidelines are intended to provide detailed information for the selection of the right tube material, for the contract with the tube manufacturer and for the quality assurance for the manufacturing and delivering process. Guidelines for the installation

Standard No.	Title	Abstract
		and for operation are given to prevent faults, damage and corrosion including photos illustrating typical problems.
VGB-S-609-00-2016-03-EN	Application, design and quality assurance criteria for the use of fibre-reinforced plastics in power plant construction	The standard reflects the current European standardisation especially to vessels and piping. It should be regarded as a complementary recommendation specifically for power plants. Accordingly, typical components, actions/stresses, material requirements and tests are presented along with design and calculation information.
VGB-S-610-00-2019-10-EN	Structural Design of Cooling Towers	This standard includes information on the structural design, calculation, engineering and construction of cooling towers.

9.2 Transmission Interview Documentation

A lot of information and data was analysed in the course of the Opera project. There are some – more detailed – findings that are not included in the main part of the report. However, the vgbe team considers these aspects as important too. Therefore, the interview documentation is presented in this chapter.

9.2.1 Interview with Grid Planning and Development Business Unit

Date: 11 April 2023

Place: Eskom Megawatt Park

Participants:

1.	Manswet Banka	Dornier
2.	Pieter Janse van Rensburg	Dornier
3.	Thomas von Schieszl	Dornier
4.	Jacob Machinijke	Eskom
5.	Ronald Marais	Eskom
6.	Prince Moyo	Eskom
7.	Leslie Naidoo	Eskom

Agenda:

1. Opening and introduction
2. Presentation on the structure of the Grid Planning and Development Business Unit of Eskom Transmission
3. Comments on the Development Plan for Eskom Transmission's Grid

Results:

1. Opening and introduction:

   The teams introduced themselves to their counterparts.

2. Presentation on the structure of the Grid Planning and Development Business Unit of Eskom Transmission:

- About 110 people work at the department.
- There is one transmission grid and many distribution grids.
- The transmission voltage levels are:
  - 220 kV
  - 275 kV
  - 400 kV

- 533 kV (DC)
- 765 kV
- Exceptionally 132 kV

− Within the Business Unit the following main areas are defined and dealt with:
  - Customer services, grid connection and access
  - Long-term load forecast and research
  - Long-term strategic grid plans studies
  - 10 years grid planning (TDP)
  - Land development (Land and Rights)
  - Project development (PDD)
− Eskom Transmission’s customers are distributors, large industry customers, IPPs, Eskom Generation.
− The Land Development is important for lines development since acquiring the land or land servitude is a long-time process, 6 – 10 years.

3. Presentation on the Development Plan for Eskom Transmission’s Grid (TDP):

− 10 years moving window is used for the process:
  - 3 years in the future – review of the projects under constructions
  - 3–6 years in the future – business cases for the projects
  - 7–10 years in the future – speculations about the projects
− Integrated Resource Plan (IRP) is the basis for planning, but it ends in 2030 and beside that not all projects are progressing according to the plan.
− The integration of the growing number of renewables creates the urgent need for the grid development and it is the biggest driver for that.
− The demand does not change significantly over time. The observed changes relate to building new data centres, they are however geographically located close to the old load centres. Additionally, an increase of power consumption for Green Hydrogen is anticipated but it is uncertain.
− In the IRP 70% of power consist of wind and photovoltaic energy.
− The Generation Connection Capacity Assessment (GCCA) is done regularly.
− For the modelling of the system several software is used:
  - PowerFactory
  - PSSE
  - Python
− In the grid models, the voltage levels below 132 kV are not modelled in detail (only mapped as grid equivalent).
− The operation department uses planned models with real operation points to test the planning.
− There is good correlation between potential of renewables and interests.
− Load is forecast to increase by 10 GW, but ca. 50 GW need to be connected.
− Only 20% of load is located in the south but most of the renewables will be there.

- 765 kV lines should be expanded because the renewables should be connected along these lines. The 400 kV network should become a collective network for the renewables to connect them to the 765 kV level.
- Current tariffs for transmission are not cost reflective. It is not a drawback for Eskom Transmission as long as it stays bundled but after unbundling it will not be sufficient for secure operation.
- If the transmission does not receive a proper budget for investments, it is not possible to connect 90% of potential for the renewables.
- 40 to 45% of the transmission network was built in last 15 years.
- It should be noted that the grid must be ready before the renewables in order to encourage the renewables investments. The risk of the investment in renewables is rather low since the weather patterns are rather constant and favouring renewables.
- Transmission system is crucial for the development of the economy of South Africa.

Conclusions

- Long term planning transmission development plan (TDP)
  - The TDP is an expedient and useful tool to carry out network planning according to demand.
  - The annual update of the TDP allows for a quick readjustment of the network development to changing requirements.
  - The TDP sets out the guidelines for action for the medium and long-term expansion of the network and indicates the financial resources required.
  - In practical implementation, there is a discrepancy between the planned measures and their timely implementation.
- Securing the necessary servitudes could provide a strategic advantage to expedite the Transmission build programme.
- Relationships with customers are managed through network planning.
- Network planning is carried out using state of the art power system planning tools (PSSE / Power Factory).
- The future connection of planned renewable energy generation projects has been identified as a major challenge. Grid expansion planning is being oriented towards these requirements, even though little has currently happened in grid expansion and RES project development.
- Project development: Network expansion projects are developed in the department, prepared for implementation and monitored during realization so that planned measures are also implemented as expected.

9.2.2 Interview with Asset Management Business Unit

Date: 11 April 2023

Place: Eskom Megawatt Park

Participants:

1.	Manswet Banka	Dornier
2.	Pieter Janse van Rensburg	Dornier
3.	Thomas von Schieszl	Dornier
4.	Prince Moyo	Eskom
5.	Atha Scott	Eskom
6.	Victor Shikoana	Eskom

Agenda:

1. Opening and introduction
2. Presentation on the structure of the Asset Management Business Unit of Eskom Transmission
3. Presentation of the strategy for the asset management

Results:

1. Opening and introduction:

   The teams introduced themselves to their s.

2. Presentation on the structure of the Asset Management Business Unit of Eskom Transmission:

- The department was established in 2020. 126 people work at the department, it is planned to increase this number to about 300 by 2025.
- Within the department the following main areas are defined and dealt with:
  - Substation Equipment and Diagnostics
  - Asset Strategy
  - Asset Investment Planning
  - Contracts, Resources & Performance
  - Servitude and Land Management
  - Grid Modernisation
  - Program Management
- Contracts, Resources and Performance is a new department of high importance because increasing number of issues will be outsourced.

- In the Grid Modernization the development and research roadmap is prepared.
- Program Management deals with the coordination of the implementation of TDP and acts as a Project Management Office.
- The Business Unit is working towards ISO 55000 certification.
- Eskom Transmission as a whole is working on unbundling, the regulatory authority is involved in this process.
- CAPEX consideration:
    - CAPEX is planned in a 15-year period but there are also 30-year projections. The 5-year plan is very similar to TDP. Further years differentiate much more because Eskom as a whole, cuts the budget for Transmission, Distribution, Generation.
    - The budget for financial year 2024 (started April 2023) was R 74 billion.
- OPEX consideration:
    - Overall OPEX is about R 900 – 1000 million.
    - The OPEX budget was never exceeded, but mostly only used up to approximately 90%.

3. Presentation of the strategy for the asset management:

    - The age of the asset spans over a wide range of years. Some of the equipment is not manufactured any more. Spare parts are taken from the decommissioned equipment. It is one of the tasks to secure the spare parts.
    - The maintenance is based on the assessment of the actual condition of the asset. The condition of the devices is assessed before exchange. The importance of the asset is taken as an additional criterium.
    - Ca. 30 classes of asset are defined, for which Asset Health Reports are generated.
    - The results of the health reports define the asset's "End of Life".
    - It is assessed if conditions are reversable or not.
    - The asset management is compliant with ISO 55001.
    - This Business Unit developed Asset Management Policy.
    - Normal Useful Life indicator was developed for financial auditors, but no asset is replaced due to age only.
    - The load shedding has impact on the circuit breakers because of the mechanical stress. Distribution operators use the transmission breakers not the distribution breakers.

Conclusions

- Asset strategy ensures maximum utilisation of the possible operating time of the equipment used.
- Regardless of the asset strategy currently in use, modernisation should be pushed forward and corresponding financial resources planned in the next few years in order to avoid critical conditions:
    - Old equipment in use can fail in large quantities once it reaches a certain age

    - Spare parts are no longer available in sufficient quantities or are no longer procurable
    - Maintenance costs for obsolete technology increase exorbitantly and can no longer be implemented economically.
- The strategy of replacing equipment after the end of life should be combined with useful life indicators.
- The permanent switching for load shedding led to increased wear of the circuit breakers used for this purpose. Circuit breaker failure will thus become more likely in the future and can lead to critical situations in the grid.
    - Upstream switches must become active - large-scale shutdowns in the event of grid faults
    - N-1 criterion can be endangered
    - Grid stability can be endangered

9.2.3 Interview with Group Executive

Date: 11 April 2023

Place: Eskom Megawatt Park

Participants:

1.	Manswet Banka	Dornier
2.	Pieter Janse van Rensburg	Dornier
3.	Thomas von Schieszl	Dornier
4.	Segomoco Scheepers	Eskom

Agenda:

1. Opening and introduction
2. Introduction of Dornier Group
3. Discussion

Results:

1. Opening and introduction:

   The teams introduced themselves to their counterparts.

2. Introduction of Dornier Group:
   - Dornier Group company profile was introduced.
   - Goal of the audit was explained.

3. Discussion:

- Power plants and generation are causing most of the problems of the power system nowadays.
- Generation tends to dominate Eskom. Attention of National Treasury and other stakeholders should be attracted to transmission as well.
- The investments in transmission will need to increase, the costs reduction will be counterproductive.
- There were not enough investments but since about three years a positive change has been observed. The investments must be made for expansion but also for renewing of the equipment.
- There are several urgent issues at the same time:
    - unbundling process,
    - increasing number of renewables,
    - aging of the asset.
- The grid stability becomes a problem due to lack of ancillary services from the power plants. In the future it may become even worse when the coal power plants will be decommissioned.
- Salaries have not been adjusted for five years. It should be improved as soon as possible.

Conclusions

- Budgets for modernization are required, in the next few years, otherwise there is a risk that critical network infrastructure will not meet the requirements for system stability and supply reliability (see asset management).
- The unsatisfactory situation of permanent load shedding results from the unavailability of sufficient generation capacities which is necessary for stable grid operation.
- The transmission system is responsible for stable grid operation, not for providing sufficient power plant capacities.
- The change process in the energy industry requires a clear regulatory framework:
    - unbundling process – tariffs for the services of the TSO
    - increasing number of renewables – budgets for grid extension, infeed tariffs for the RES and financing model of the tariffs
    - aging of the asset – budgets for modernization
- Securing highly qualified staff through
    - competitive salary
    - recruitment of young good skilled employees
    - transfer of knowledge to new employees

9.2.4 Interview with System Operator Business Unit

Date: 13 April 2023

Place: Eskom Simmerpan

Participants:

1.	Manswet Banka	Dornier
2.	Pieter Janse van Rensburg	Dornier
3.	Thomas von Schieszl	Dornier
4.	Paul Davel	Eskom
5.	Isabel Fick	Eskom
6.	Nico Kleynhans	Eskom

Agenda:

1. Opening and introduction
2. Presentation of the structure and tasks of the Grid Control Business Unit of Eskom Transmission
3. Visit in the National Control Centre

Results:

1. Opening and introduction:

   The teams introduced themselves to their counterparts.

2. Presentation on the structure of the Grid Control Business Unit of Eskom Transmission:

- The root cause of the current state is the bad state of power plants.
- Grid code compliance office for South Africa recertificates power plants every six years.
- There is a grid code in South Africa which is issued by NERSA.
- Recently a grid code for battery storage was developed.
- The operating reserves are not enough.
- Until now the highest load shedding stage was 6, each stage represents 5% of load which equates to approximately 1 000 MW.
- This business unit performs system studies and also stress studies.
- They are responsible for metering from transmission perspective.
- They own an isolated telecommunication network only for power system purposes. The network is built of a combination of different technologies.
- Asset ownership is split *between* Generation, Transmission and Distribution.
- There is a back-up for the National Control Centre, which takes care of local control during normal operation.
- There are six local control centres, performing mainly local control but some parts of transmission as well.
- There are only main and back-up telecommunication control centres. There are no local control centres for telecommunication.
- Grid Control Business Units identify as most important in the current situation:

  - Availability of power plants.
  - Ancillary services and reserves.
  - Appropriate tariffs are required for demand response and other ancillary services. It should be addressed by NERSA. It will be costlier to buy Ancillary Services on the market.
  - SCADA and telecommunication system should be renewed and is already budgeted for 2024. It should be guaranteed that this money is available.
- New lines are all built with fibre optics.
- The telecommunication network is exclusive for Eskom use and the operational system (OT).
- Transmission established its own facilities management area that has to be properly resourced since most of the existing resources were allocated to Distribution during the decentralization of this function.
- It is important to be able to perform small projects regarding facility management locally. Nowadays this is challenging due to lack of staff and parts locally.
- A national blackout is a low probability due to controlled load shedding as well as a number of built in barriers. Emergency plans are in place and regular testing and certification is done.
- Diesel consumption is constrained due to budget constraints and logistics.
- Because of logistics the dispatch is not always done according to merit order but considering current fuel availability at the power plants.
- For the grid restoration after black-out a bottom-up approach is planned. Regular trainings are scheduled and performed.
- The black-out would be not only Eskom’s but the country’s event. Eskom’s plans say that the system should be restored within 6 to 14 days.
- For the purpose of training a grid simulator is available.
- (N-1)-Criterium is not fulfilled everywhere nowadays but they are working on that. This is not proceeding according to the original plan because of budget shortage and other priorities like connection of renewables.
- Forecast department for loads:
  - Start 18 months ahead
  - Generator bids come automatically, every hour for a day
  - About 1 000 MW reserve
  - Intraday but 7-days window, they decide about load shedding,
  - Load shedding is treated as the last measure,
  - Generation have to update their capacities if they changed,
- There is no balancing market, the market is simulated,
- Frequency control: Automatic Generator Control is running but most of the generators are running 100% anyway.
- The primary and secondary power is paid but it does not reflect the real costs.
- In the next two years about 400 MW battery storage should be connected to the grid but there should be market created for their usage.

- SCADA records are kept of all system events. Documentation of switching is done manually (book-logs) at substation sites.
- Switching is done manually on-site because of the regulatory requirements of visual inspections of disconnection.
- SCADA:
    - Status of 98% of asset in available in National Control Centre.
    - In the local control centres and below the status is lower.
    - There is a combination of different technologies in SCADA and substations:
        - Very dependent on the situation of a substation.
        - There are RTUs at each substation, which concentrate information and exchange it with SCADA.
- PMUs are being rolled out in the transmission system.
- Fault statistics:
    - 40–50 interruptions/year
    - 1–2 system minutes was rather maximal values
    - There is a field fire risk indicator/prediction.
    - Every fault occurred on the system is analysed.
- Import/Export:
    - Eskom Transmission is a member of South Africa Power Pool
    - Some market for primary energy
- The maintenance programs of power plants were scheduled for summer but now all other maintenance is cancelled.
- Last night there was 18 GW of unplanned unavailable power (in comparison to 44 GW system). It is unacceptable but in winter the load shedding will most probably exceed stage 6.
- The employee age profile is very unfavourable at Eskom. The recruitment was stopped several years ago because of the budget cuts and until today there is no new young staff.
- The external recruitment is very cumbersome, it takes at least one year between the vacancy is stated and the external advertisement, and it is only on the Eskom's website.
- People are being trained at Eskom but due to HR policy it is very difficult to hire them after the training is completed.

3. Visit in the National Control Centre:

- No photos allowed because it is a national key point.
- Control room standard of nineties but a little bit outdated nevertheless in good condition.
- 4 shifts per week each 12 hours.
  - 2 actives
  - 1 stand by
  - 1 training

Conclusions

- Grid control is stressed by permanent load management.
- Grid control is well organized.
- All staff in grid control are permanently in training for operation and troubleshooting / trouble management.
- Remote control is possible for almost all switching devices. The switching operations are instructed by the Control Centre, but carried out by the staff on-site. Potential for efficiency improvement with transition to remote control by the Control Centre in the future.

9.2.5 Interview with Grids Operation and Maintenance Business Unit

Date: 13 April 2023

Place: Eskom Simmerpan

Participants:

1.	Manswet Banka	Dornier
2.	Pieter Janse van Rensburg	Dornier
3.	Thomas von Schieszl	Dornier
4.	Mbulelo Kibido	Eskom
5.	Regional Grid Managers	Eskom

Agenda:

1. Opening and introduction
2. Presentation of the structure and tasks of the Grids Business Unit of Eskom Transmission
3. Discussion

Results:

1. Opening and introduction:

   The teams introduced themselves to their counterparts.

2. Presentation on the structure of the Grids Business Unit of Eskom Transmission:

- About 1 330 employees.
- 7 regional grids: 6 AC grids cover provinces and 1 HVDC grid.
- HVDC connection to Mozambique.
- South Africa used to export energy to neighbouring countries.
- Target of the line fault is ≤ 2,1/100 km.
- Maintenance is constrained by system operation, load shedding. Normal maintenance schedule cannot be held because of power shortage and need of 100% system availability for supply.
- There is an index for monitoring “happiness” of the employees at work.
- There is a risk management system.
- The Business Unit hires ten helicopter pilots to inspect the lines and schedule the maintenance.
- Sufficient budget is always secured for this Business Unit.
- Emerging issues:
    - System constraints and load shedding impact the availability for maintenance.
    - Spares non-availability – there are some older protection schemes with limited availability of spare parts.
    - Local power transformer manufacturers – local manufacturers of especially 400/132 kV Transformers have problems with delivering spare parts of required quality.
    - Procurement delays – very long process of establishing new contracts, mainly due to policy of local inclusivity and local content.
    - Vegetation management – changed weather pattern in last few years causes faster growth of plants and therefore difficulties with trimming.
    - Security – there are many problems with theft of steel from the overhead lines tower and with break-ins to the substations.
- It is difficult to retain the staff. Many trained personnel leaves Eskom to work in other western countries.
- From the human resources perspective, continuation of leadership is important in the current situation, so that staff can see that the leaders are not running away, when problems arise.

3. Discussion:

    - Condition of the buildings is not good because Eskom has centralized property management, and Eskom’s real estate workers were far away from some of the locations. Now it is being changed, regional grids get budgets for this type of activities. It also goes along with the localization of contracts.
    - There is a refurbishment program for mechanical relays going on. In Gauteng the ration of mechanical relays is the highest.

Conclusions

- Maintenance is well organized and, with the exception of special tasks (protective relays, circuit breakers, etc.), is largely carried out by substation staff. Special tasks are executed by skilled internal maintenance teams per region.
- The strategic guidelines for maintenance are set by asset management. Compliance with these guidelines is monitored by asset management. (see asset management).
- The unsatisfactory situation of permanent load shedding has a negative impact on the execution of maintenance.
- Securing highly qualified staff important for the quality of maintenance and should be supported by
    - competitive salary
    - recruitment of young good skilled employees
    - transfer of knowledge to new employees

9.2.6 Interview with Finance Department

Date: 13 April 2023

Place: Eskom Simmerpan

Participants:

1.	Manswet Banka	Dornier
2.	Pieter Janse van Rensburg	Dornier
3.	Thomas von Schieszl	Dornier
4.	Ragini Ramkumar	Eskom

Agenda:

1. Opening and introduction
2. Presentation of the structure and tasks of the Finance Department of Eskom Transmission and discussion

Results:

1. Opening and introduction:

   The teams introduced themselves to their counterparts.

2. Presentation on the structure and tasks of the Finance Department of Eskom Transmission and discussion:

   - About 139 employees, including 10 managers.
   - Head finance department is above the transmission finance department.
   - The main tasks of the finance department are:

    - Financial Reporting and Compliance
    - Process Control and Assurance
    - Management Accounting
    - Project Accounting
- The payments and salaries are done centrally.
- There are regional teams dedicated to reporting of provincial grids.
- The finance department supports all the transmission departments but also distribution and corporate when necessary.
- Real estate, human resources are centralized to great extent, but the finance department has also employees dedicated for these topics.
- Southern African Development Community (SADC) cooperate for import and export.
- Most of the revenue is collected by Distribution, Transmission does not do any billing. It will be changed after unbundling. The tariffs for transmission are under development and are discussed with NESRA.

Conclusions

- The transmission system is currently financially managed as a cost centre.
- Until the transmission system is established as an independent company, a tariff structure must be created. The tariff structure is currently being prepared.

9.2.7 Conclusion Meeting with Management

Date: 18 April 2023

Place: online meeting

Participants:

1.	Manswet Banka	Dornier
2.	Thomas von Schieszl	Dornier
3.	Isabel Fick	Eskom
4.	Jacob Machinijke	Eskom
5.	Leonardo Pittorino	Eskom
6.	Nico Kleynhans	Eskom
7.	Prince Moyo	Eskom
8.	Ragini Ramkumar	Eskom
9.	Segomoco Scheppers	Eskom
10.	Jeffrey Quvane	National Treasury

Agenda:

1. Opening
2. Dornier's presentation of the first observations and results after on-site activities
3. Discussion

Results:

1. <u>Opening:</u>

Thomas von Schieszl welcomed the participants and shortly explained the meeting agenda.

2. <u>Dornier's presentation of the first observations and results after site visits:</u>

Thomas von Schieszl presented the first summary of the on-site activities. He explained the methodology that Dornier followed. The data required for the assessment comes from the sources including questionnaires, interviews with Eskom Transmission management and site visits. The first findings are based on the consideration of them all.

First observations made based on the received information focused on the age structure of the equipment as well as the structure of the transmission grid itself and installed capacities in comparison to the load.

The topics and the most important messages of the following interviews with the Eskom Transmission managers were summarized:

- Managing Director Transmission – Mr. Segomoco Scheppers
- Asset Management Manager – Mr. Prince Moyo
- Financial Transmission Manager – Mrs. Ragini Ramkumar
- Grid Planning and Development – Mr. Jacob Machinijke
- National Control Centre – Mrs. Isabel Fick
- Operation and Maintenance – Mr. Mbulelo Kibido

The overview of the site visits in the following plants was given:

- Substation Minerva
- Substation Craighall
- Substation Eiger
- HVDC Substation Apollo
- HVAC Substation Apollo
- Substation Thuso
- Section of the line of Apollo-Thuso (tower 13)
- National Control Centre

The observations made during visiting the plants concentrated around aging but well-maintained equipment.

The presentation was concluded. Among other things it was indicated that although the equipment is partially very old it is well-maintained. The current unsatisfactory situation in the energy sector results from the insufficient availability of the power plants, the way of operation the transmission system is not a reason for this.

Among other things it was recommended to intensify the modernization programs, while the budgets must be available. The process of unbundling and separating Eskom Transmission as independent TSO should be continued. The grid will require further expansions and after unbundling the budget should be guaranteed based on proper cost-based tariffs.

Thomas von Schieszl thanked the Eskom Transmission team for the excellent cooperation during the on-site activities.

3. Discussion:

   - Jeffrey Quvane expressed satisfaction that the first findings of the audit are in line with the work currently ongoing by Eskom Transmission.
   - Prince Moyo claimed that the tariffs which are currently being designed could be provided to Dornier.
   - Jacob Machinijke supported the idea of provision of the tariffs design to Dornier. He added that the transporting of the power from the south to the load centres has to be reflected in the prices. He also indicated that Eskom Transmission teams were often afraid to start the construction works without having gathered all the permissions from respective offices and landowners, which could lead to very long times of implementation of the construction projects. The idea would be that the National Treasury should support the risks of starting earlier.
   - Isabell Fick indicated that there were six Local Control Centres.
   - Ragini Ramkumar had no further comments.
   - Segomoco Scheppers corrected that the ISO 55000 standard is not awarded yet, but Eskom Transmission is working towards it (Prince Moyo confirmed this statement). He also corrected the statement that only during the last three years were enough budget for the maintenance. According to Mr. Scheppers, the budget for the maintenance was always sufficient, but in the last three years the investment budget was the one which also increased to the sufficient size. He also emphasized that the tariffs were very important.
   - Jeffrey Quvane had no more comments to the presented content but anticipated possible contacting Dornier for assistance in the implementation of the recommendations after the report is done.
   - Nico Kleynhans closed the meeting.

9.2.8 Interview with CSIR Representatives

Date: 13 June 2023

Place: online meeting

Participants:

1.	Monique Le Roux	CSIR
2.	Manswet Banka	Dornier
3.	Pieter Janse van Rensburg	Dornier
4.	Thomas von Schieszl	Dornier
5.	Jeffrey Quvane	National Treasury
6.	Mark Newby	vgbe

CSIR = Council of Scientific and Industrial Research

Agenda:

1. Opening
2. Dornier's presentation of the first observations and recommendations for Eskom
3. Discussion

Results:

1. Opening:

Pieter Janse van Rensburg welcomed the participants and shortly explained the meeting agenda. The purpose of the meeting was to ask for opinion of a local expert.

2. Dornier's presentation of the observations and recommendations for Eskom:

Thomas von Schieszl presented the first summary and recommendations for Eskom after analysis done until date.

3. Discussion:

- Monique Le Roux stated that the Integrated Resource Plan (IRP) which was used for preparation of the TDP was still the version from 2019 and the assumptions made there were questionable in terms of not considering the grid constraints.
- Participants agreed that for the proper planning Eskom Transmission needs a validated basis, which is up to date.
- Monique Le Roux expects wider studies on selection of the best generation mix for South Africa.
- Participants agreed that the training and proper wages are crucial to keep the qualified staff and that the situation in this regard might be in Distribution worse than in Transmission.

Pieter Janse van Rensburg closed the meeting.

9.3 Assessment of other Inspected Substations

The assessment results of the various grid facilities are presented in this chapter.

9.3.1 Substation Craighall

Brief description of the substation

- GIS 275 kV double busbar (2x overhead line bays; 6x transformer bays (3 of Eskom, 3 of local DSO), 2x cross coupling bays and 2x lengthwise coupling bay in both busbars, all bays equipped with circuit breakers, see Figure 9-1).
- GIS 88 kV double busbar (13x overhead line bays; 3x transformer bays, 2x cross coupling bays and 2x lengthwise coupling bay in both busbars, all bays equipped with circuit breakers, see Figure 9-1).
- 3 power transformers 275/88 kV 315 MVA.
- Year of commissioning 1978, extension of section B in 2008.
- 3 auxiliary transformers 22/0,4 kV connected to the tertiary winding of each power transformer.
- On-site inspection on 12 April 2023.

The summarised assessment extract is attached in the appendix Assessment Matrix of Evaluated Transmission Assets. The substation condition details are described below.

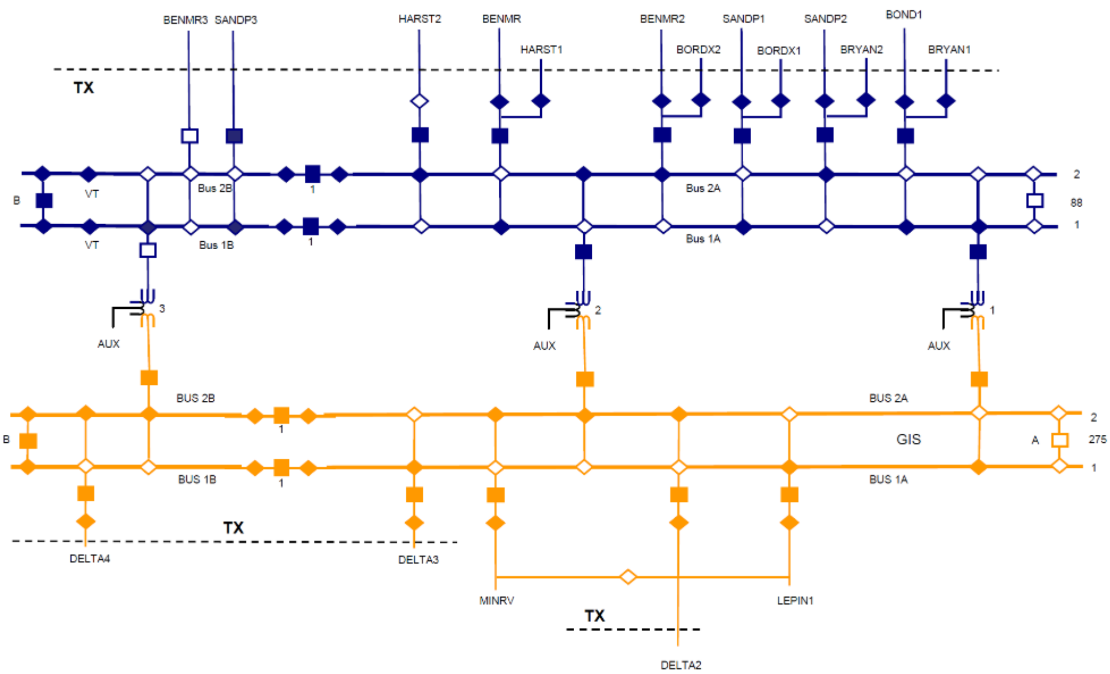

Figure 9-1: Single line diagram substation Craighall

Switchgears

Activity class of GIS classification 1,4 – Age-related wear and tear outside especially in section A 275 and 88 kV due to the operation age, only visual inspection from outside and random inspection of the displays for monitoring the switching devices, no urgent measures required (see Figure 9-2).

- 275 kV SF_6 GIS general condition section A AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- 275 kV SF_6 GIS general condition section B AC classification 1 – Age-related wear and tear, refurbishment measures are not necessary.
- 88 kV SF_6 GIS general condition section A AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- 88 kV SF_6 GIS general condition section B AC classification 1 – Age-related wear and tear, refurbishment measures are not necessary.
- Steel constructions AC classification 1 – Age-related wear and tear, refurbishment measures are not necessary.

Due to its age, the GIS of section A in 275 and 88 kV has small wear and tear on the outside. According to information from the substation's operating staff, all switchgear bays are well maintained and fully functional despite its high operating age. Modernisation measures can be required for the older parts of the GIS may be in the medium term (see Figure 9-3).

Figure 9-2: 275 kV GIS substation Craighall

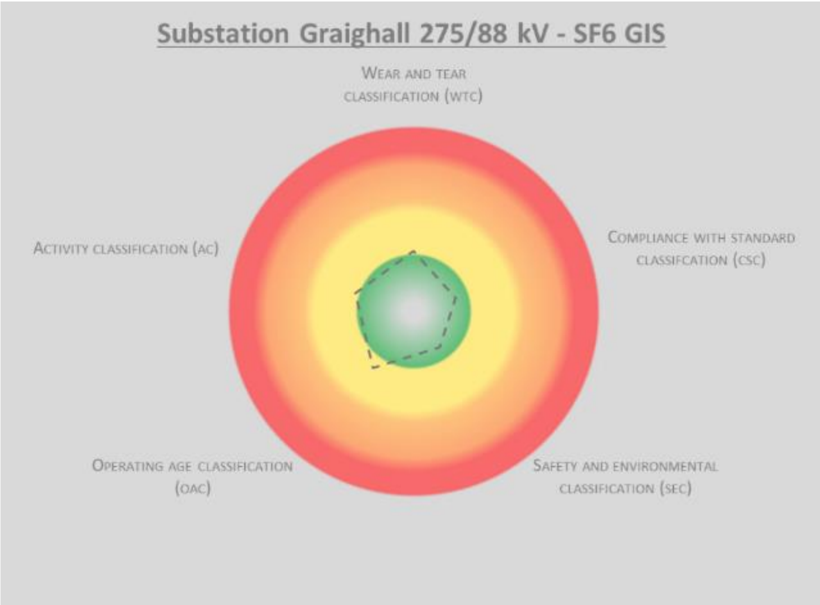

Figure 9-3: Evaluation graphic 275 and 88 kV GIS substation Craighall

Power Transformers

Activity class of Power Transformers (in operation since 1977 TRFR 1 and 2, since 2010 TRFR 3) classification 1,78 – Age-related wear and tear. Transformer 1 has poor value of gas-in-oil analysis and must be observed. If the value continues to deteriorate, replacement/repair may have to be considered (see Figure 9-4)

- General impression of inspection AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Gas in oil analysis (all three transformers last test of 30.12.2022, TRFR1 D poor, TRFR 2 B good, TRFR 3 A very good) AC classification 2 – Age-related wear and tear, monitoring of Gas in oil analysis results of TRFR 1.
- Bushings AC classification 1 – Age-related wear and tear, refurbishment measures are not necessary.
- Tank AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Oil leakage AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Fire protection walls AC classification 1 – Age-related wear and tear, refurbishment measures are not necessary.
- Groundings randomly inspected AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Steel construction, radiators etc. AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Basement, oil leakage sump AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.

No refurbishment measures are currently required for the transformers. The poor gas-in-oil analysis results of the transformer 1 must be monitored. Cleanliness and maintenance condition are excellent (see Figure 9-5).

Figure 9-4: Power Transformer substation Craighall

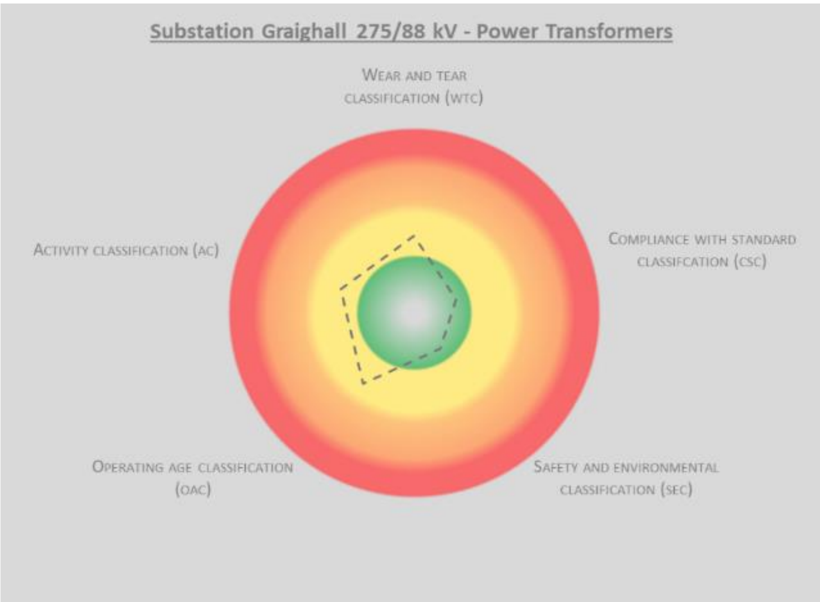

Figure 9-5: Evaluation graphic Power Transformer substation Craighall

Operation Building

Activity class of the operation building classification 1,43 – Wear and tear due to age, no immediate measures necessary but the weathering below the roof should be investigated and could result in refurbishment measures (see Figure 9-6).

- Outside general impression of inspection AC classification 2 – Wear and tear due to age, no immediate measures necessary.
- Roof visual inspection from the ground AC classification 2 – Wear and tear due to age, no immediate measures necessary.
- Walls AC classification 2 – Wear and tear due to age, no immediate measures necessary.
- Basement AC classification 1 – condition without findings.
- Surface AC classification 2 – Wear and tear due to age, no immediate measures necessary.
- Waterproofing visual inspection AC classification 1 – condition without findings.
- Lightning protection visual inspection from the ground AC classification 1 – condition without findings.
- Inside general impression of inspection AC classification 2 – Wear and tear due to age, no immediate measures necessary.
- Emergency exits, place for exit AC classification 1 – condition without findings.
- Ventilation AC classification 1 – condition without findings.
- Illumination AC classification 1 – condition without findings.
- Cleanness AC classification 1 – condition without findings.

Despite its many years of use, the operation building is good condition. Cleanliness and maintenance condition are excellent (see Figure 9-7).

Figure 9-6: Operation Building substation Craighall

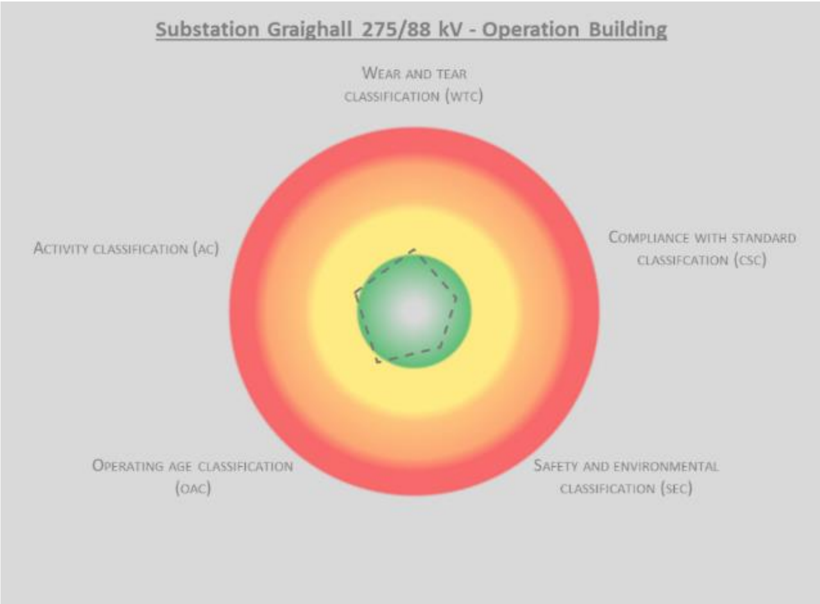

Figure 9-7: Evaluation graphic Operation Building substation Craighall

Secondary Technology

Activity class of Secondary Technology classification 2,0 – only a few switch panels have already been renovated in terms of secondary technology. The majority is still equipped with old electromechanical protection technology. This is no longer state of the art and should be replaced in the medium term (see Figure 9-8).

- SCADA Connection to Control Centre available AC classification 2 – Partly modernised, further modernisation required in short or medium term.
- Protection relays are only a few digital AC classification 2 – Only a few relays replaced, further modernisation required in the short or medium term.

A high percentage of the secondary technology is still electromechanical. The devices of the secondary technology are to be replaced by modern digital equipment in short or medium term. Cleanliness and maintenance condition are excellent (see Figure 9-9).

Figure 9-8: Example protection panel substation Craighall

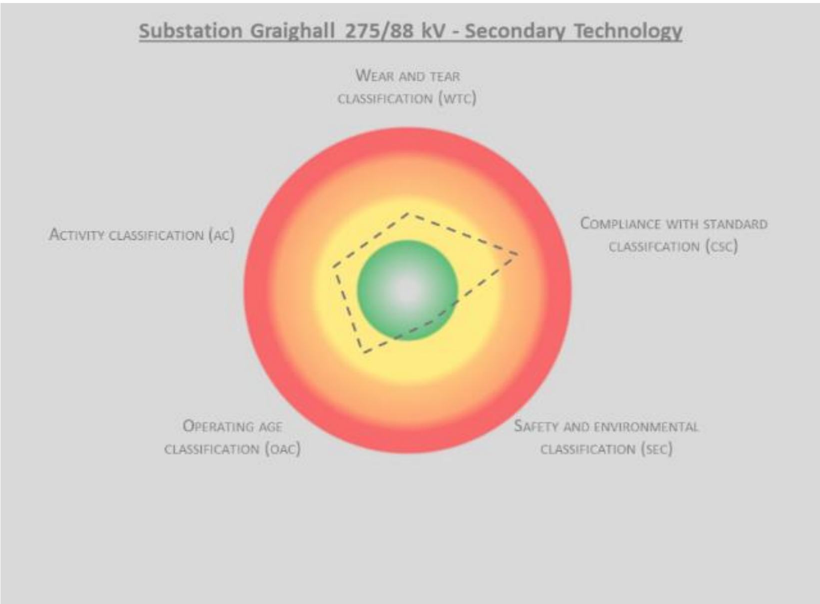

Figure 9-9: Evaluation graphic Secondary Technology substation Craighall

AC/DC systems

Activity class of AC/DC systems classification 2,0 – Age-related wear and tear (see Figure 9-10).

- AC system including auxiliary transformers and AC-distribution AC classification 2 – Age-related wear and tear, no immediate measures required.
- DC-distribution AC classification 2 – Age-related wear and tear, no immediate measures required.

- AC/DC converters AC classification 2 – Age-related wear and tear, no immediate measures required.

The AC/DC systems are old but in good condition for their operation age. Cleanliness and maintenance condition are excellent (see Figure 9-11).

Figure 9-10: AC/DC converter substation Craighall

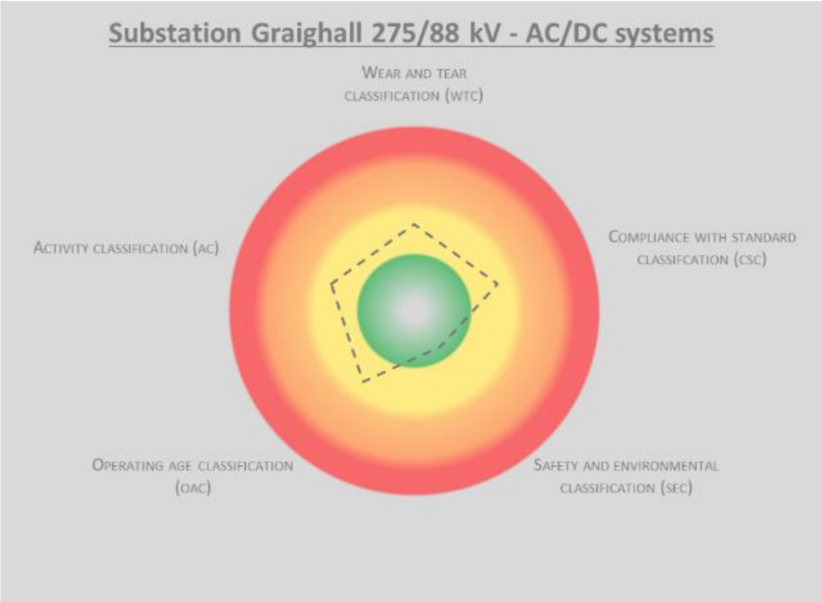

Figure 9-11: Evaluation graphic AC/DC systems substation Craighall

Battery systems

Activity class of Battery systems classification 1 – condition without findings, no measures necessary (see Figure 9-12).

- 220 V Batteries AC classification 1 – condition without findings.
- 50 V Batteries AC classification 1 – condition without findings.

The battery systems were renewed cyclically during operation. The current status corresponds to the state of the art. Cleanliness and maintenance condition are excellent (see Figure 9-13).

Figure 9-12: Battery systems substation Craighall

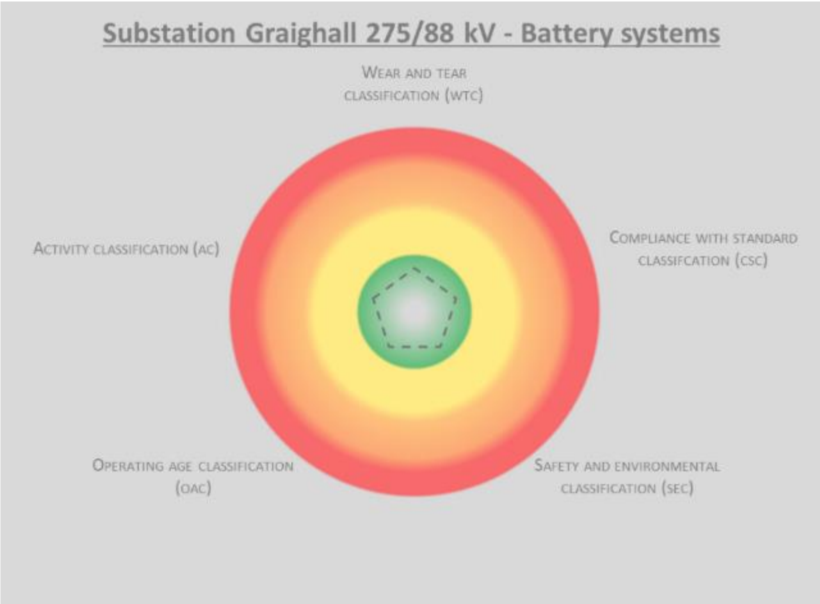

Figure 9-13: Evaluation graphic Battery systems substation Craighall

Streets/Footpaths/Fences

Activity class of streets, footpaths and fences classification 1,0 – Age-related wear and tear, but in a very good state of maintenance (see Figure 9-14).

- General condition AC classification 1 – Age-related wear and tear, no measures required.
- Fences and security AC classification 1 – Age-related wear and tear, no measures required.
- Dimensioning AC classification 1 – Age-related wear and tear, no measures required.

The streets, footpaths and fences are in good condition. No measures are required. Cleanliness and maintenance condition are excellent (see Figure 9-15).

Figure 9-14: Street and fences substation Craighall

Figure 9-15: Evaluation graphic Streets/Footpaths/Fences substation Craighall

Summary substation Craighall

The Craighall substation was commissioned in 1978 (see Figure 9-16). The GIS of the substation was extended by several switchgear bays in 2008. With this expansion, several modernization measures were implemented. However, the majority of the secondary technology is at the level of the 1978 commissioning. Due to the excellent maintenance condition of all components of the substation, it is fully functional and available with a high degree of reliability despite its high operating age. In line with the general modernization strategy for the transmission system, the Craighall substation should also be modernized in the medium term. The activity class was assessed at 1.52 (see Figure 9-17).

Figure 9-16: 88 kV GIS substation Craighall

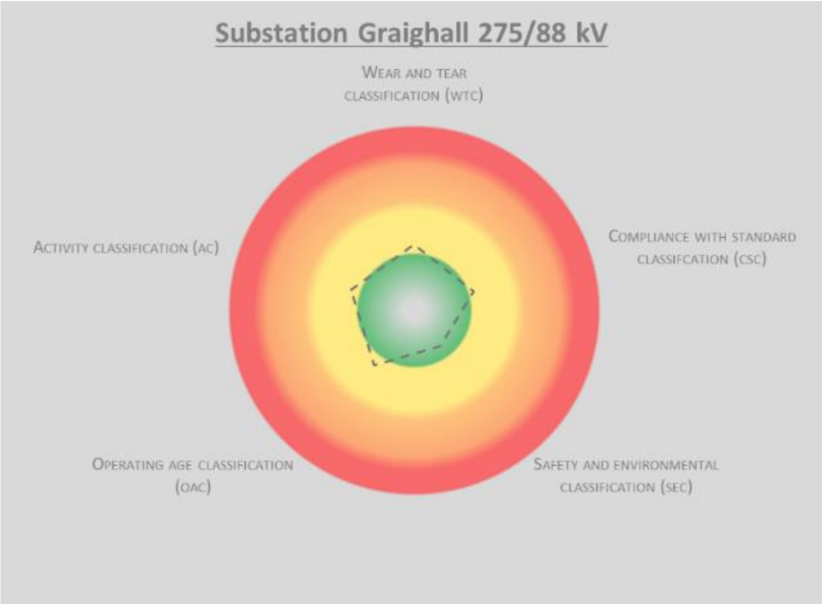

Figure 9-17: Evaluation graphic total substation Craighall

9.3.2 Substation Eiger

Brief description of the substation

- Air insulated switchgear 275 kV double busbar (5x overhead line bays; 3x transformer bays, 1x cross coupling bays, all bays equipped with circuit breakers, see Figure 9-18).
- Air insulated switchgear 88 kV switchgear double busbar (8x overhead line bays; 3x transformer bays, 3x transformer bays 88/33 kV for direct connection of costumer, 2x cross coupling bays and 1x lengthwise coupling bay in busbar 1, 3x capacitor banks, all bays equipped with circuit breakers, Figure 9-18).
- 4 power transformers 275/88 kV 315 MVA.
- 3 auxiliary transformers 22/0,4 kV 315 kVA connected to the tertiary winding of the power transformers 1, 2 and 3.
- Year of commissioning 1973.
- On-site inspection on 12th of April 2023.

The summarised assessment extract is attached in the appendix Assessment Matrix of Evaluated Transmission Assets. The substation condition details are described below.

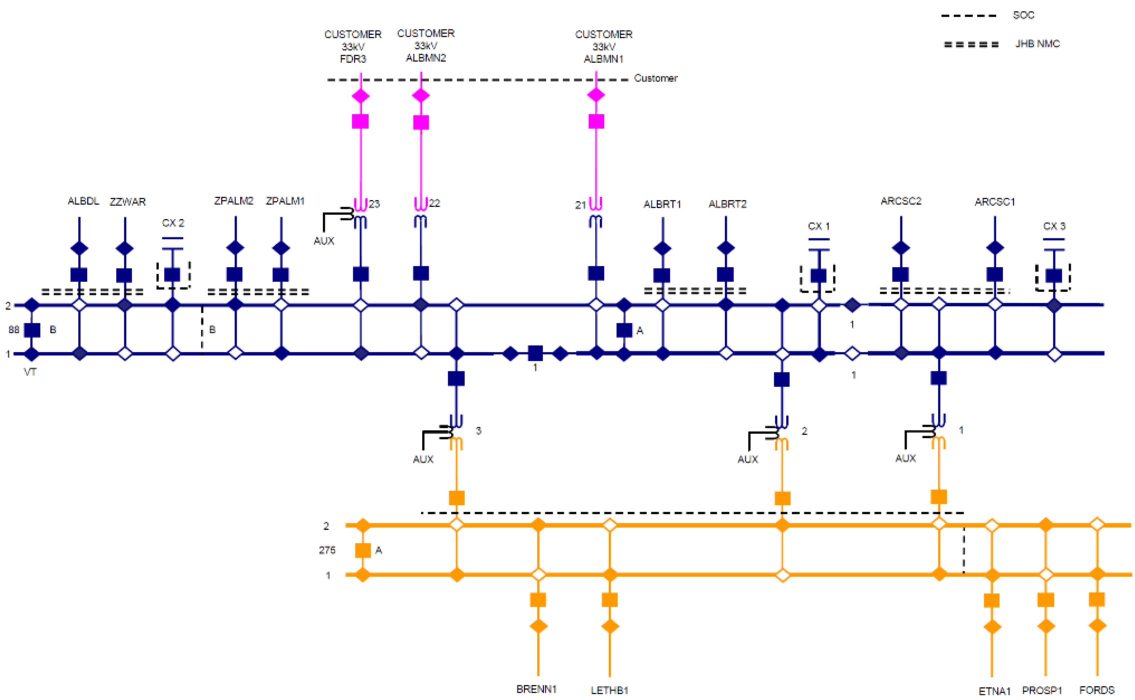

Figure 9-18: Single line diagram substation Eiger

Switchgears

Activity class of switchgears classification 2.43 – Age-related wear and tear, little rust on steel structures, a few equipment items have been partially replaced by new equipment, no urgent measures required at the moment, but failures of equipment are to be expected due to age, a plan for modernisation should be developed and implemented in the near future (see Figure 9-19)

- Most circuit breakers are old, only few are replaced by SF_6-circuit-breakers AC classification 3 – Old low-oil circuit breakers should be replaced in the near future.
- Most disconnectors are old, only few are replaced by new one's AC classification 3 – Old disconnectors should be replaced in the near future.
- Most instrument transformers are old, only few are replaced AC classification 3 – Old instrument transformers should be replaced in the near future.
- Conductor ropes are corroded due to age. AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Steel construction slight signs of rust AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Basements with some wear and tear AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Groundings visually inspected at random, visual signs of wear AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.

Due to operation age of 50 years, the switchgear shows wear and tear. Few major components of the switchgear were replaced by new equipment. Due to the good maintenance of the switchgear, it is fully functional despite its high operating age. Further modernisation measures are to be carried out in the near future. Much of the equipment appears to have reached the end of its service life and should be replaced as part of a basic modernisation plan for the substation (see Figure 9-20).

Figure 9-19: 88 kV switchgear substation Eiger

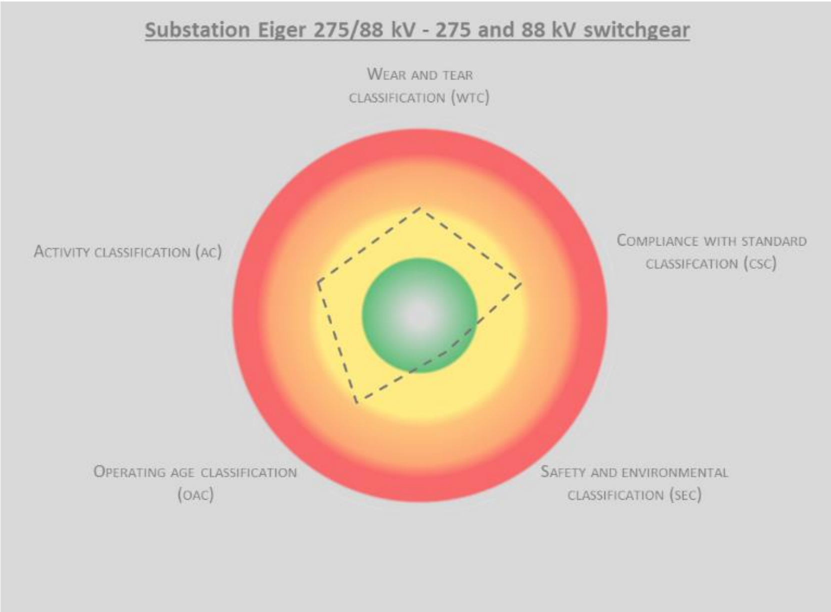

Figure 9-20: Evaluation graphic 275 and 88 kV switchgear substation Eiger

Power Transformers

Activity class of Power Transformers (in operation between 1986 and 2013) classification 1,56 – Age-related wear and tear. The power transformers were replaced in the past (1986, 1997 and 2013). The last gas in oil analysis results were very good for all three transformers (see Figure 9-21)

- General impression of inspection AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Gas in oil analysis (all three transformers last test of 07.09.2022, all results A very good) AC classification 1 – condition without findings.
- Bushings AC classification 1 – Age-related wear and tear, refurbishment measures are not necessary.
- Tank AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Oil leakage AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Fire protection walls AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Groundings randomly inspected AC classification 1 – Age-related wear and tear, refurbishment measures are not necessary.
- Steel construction, radiators etc. AC classification 2 – Age-related wear and tear, refurbishment measures are not necessary.
- Basement, oil leakage sump AC classification 1 – Age-related wear and tear, refurbishment measures are not necessary.

No refurbishment measures are currently required for the transformers. Cleanliness and maintenance condition are excellent (see Figure 9-22).

Figure 9-21: Power Transformer 3 substation Eiger

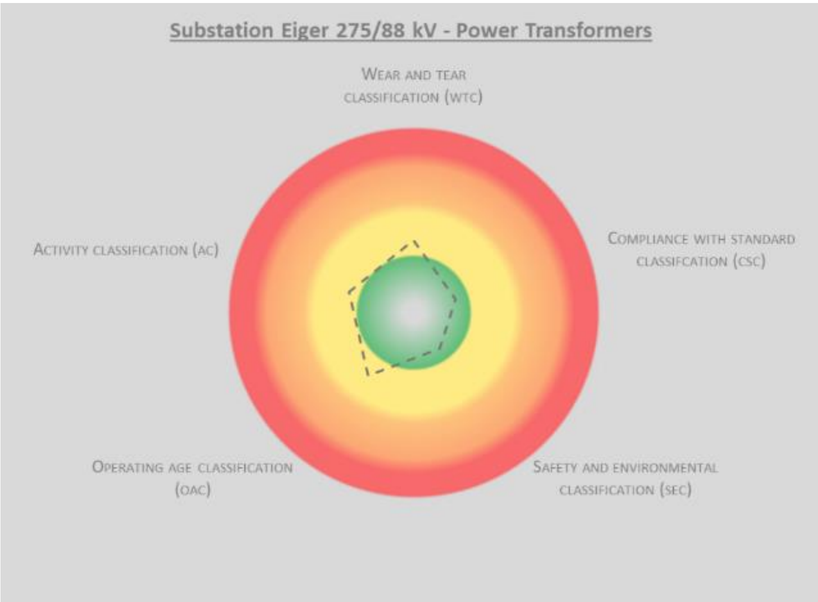

Figure 9-22: Evaluation graphic Power Transformers substation Eiger

Operation Building

Activity class of the operation building classification 1,93 – Wear and tear due to age, no immediate measures necessary but the defective gutter should be repaired quickly. It should be assessed if further rehabilitation measures are required (see Figure 9-23).

- Outside general impression of inspection AC classification 3 – Wear and tear due to age, defect rain gutter shall be repaired quickly.

- Roof visual inspection from the ground AC classification 3 – Wear and tear due to age, Wear and tear due to age, defect rain gutter shall be repaired quickly.
- Walls AC classification 2 – Wear and tear due to age, no immediate measures necessary.
- Basement AC classification 2 – condition without findings.
- Surface AC classification 2 – Wear and tear due to age, no immediate measures necessary.
- Waterproofing visual inspection AC classification 3 – Wear and tear due to age, defect rain gutter shall be repaired quickly.
- Lightning protection visual inspection from the ground AC classification 2 – condition without findings.
- Inside general impression of inspection AC classification 2 – Wear and tear due to age, no immediate measures necessary.
- Emergency exits, place for exit AC classification 1 – condition without findings.
- Ventilation AC classification 1 – condition without findings.
- Illumination AC classification 1 – condition without findings.
- Cleanness AC classification 1 – condition without findings.

Despite its many years of use, the operation building is general in good condition. The repair of the gutter should be done in the short term. At the same time, the water tightness of the roof should be checked and, if necessary, further renovation work should be carried out. Cleanliness and maintenance condition are excellent (see Figure 9-24).

Figure 9-23: Operation Building substation Eiger, small defects of the roof observed

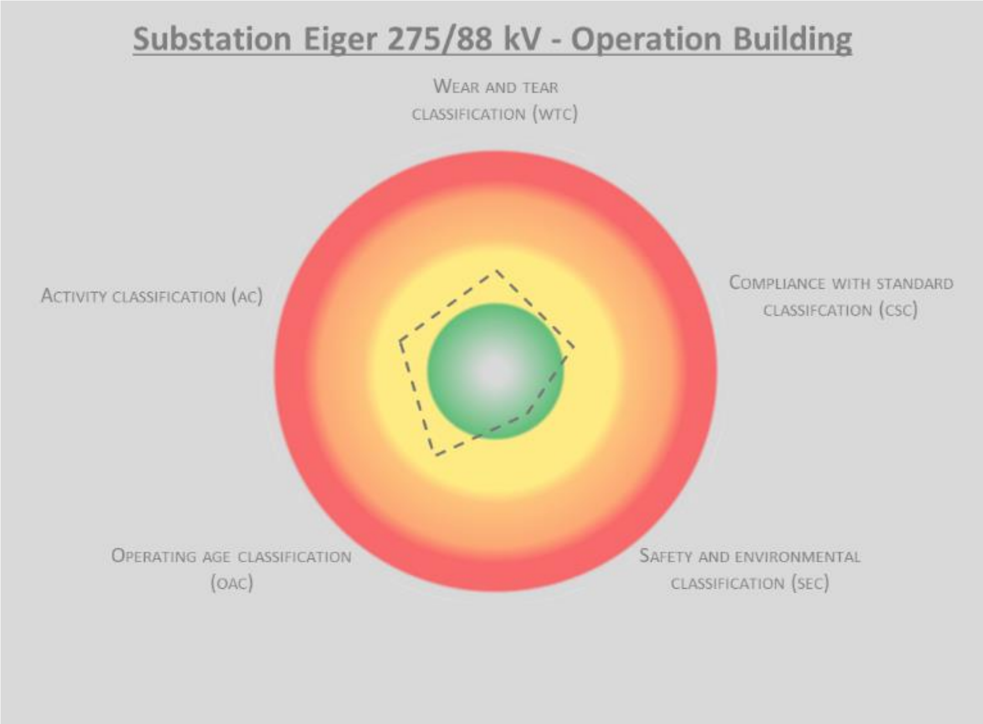

Figure 9-24: Evaluation graphic of Operation Building substation Eiger

Secondary Technology

Activity class of Secondary Technology classification 3,0 – only few switch panels have already been renovated in terms of secondary technology. The majority is still equipped with old electromechanical protection technology. This is no longer state of the art and should be replaced in the medium term (see Figure 9-25).

- SCADA Connection to Control Centre available AC classification 3 – Only a few are modernised, further modernisation required in short or medium term.
- Protection relays are only a few digital AC classification 3 – Only a few relays are replaced, further modernisation required in the short or medium term.

A high percentage of the secondary technology is still electromechanical. Only the busbar protection of 275 and 88 kV switchgear is digital technology. The electromechanical devices of the secondary technology are to be replaced by modern digital equipment in short or medium term. Cleanliness and maintenance condition are excellent (see Figure 9-26).

Figure 9-25: Example of control and protection panel substation Eiger

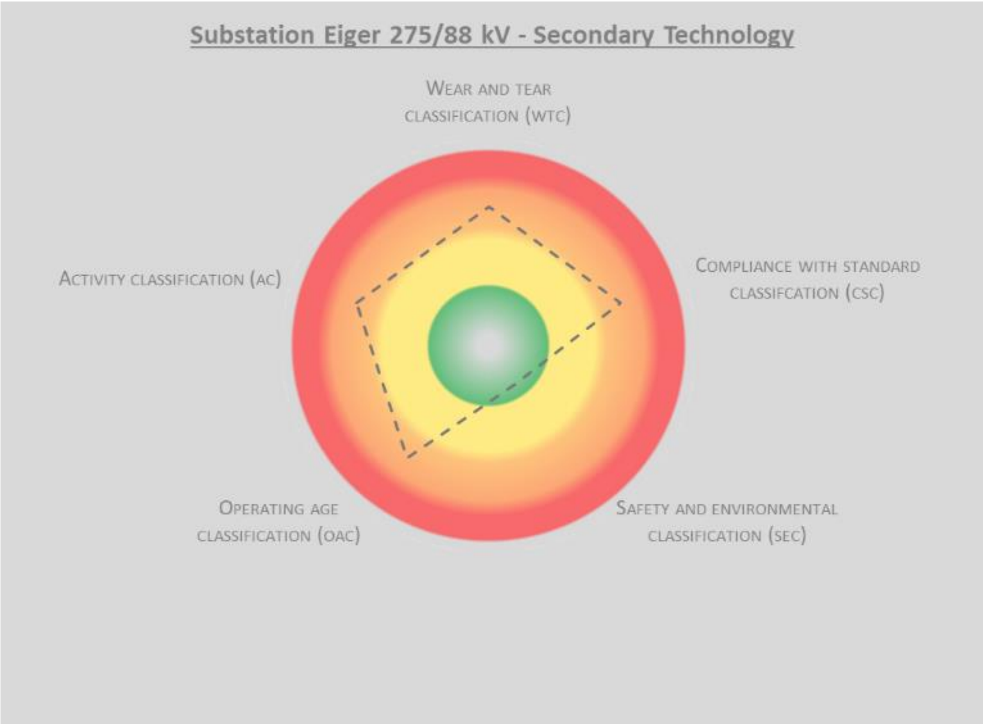

Figure 9-26: Evaluation graphic Secondary Technology substation Eiger

AC/DC systems

Activity class of AC/DC systems classification 2,0 – Age-related wear and tear (see Figure 9-27).

- AC system including auxiliary transformers and AC-distribution AC classification 2 – Age-related wear and tear, no immediate measures required.
- DC-distribution AC classification 2 – Age-related wear and tear, no immediate measures required.
- AC/DC converters AC classification 2 – Age-related wear and tear, no immediate measures required.

The AC/DC systems are old but in good condition for their operation age. Cleanliness and maintenance condition are excellent (see Figure 9-28).

Figure 9-27: AC/DC converter substation Eiger

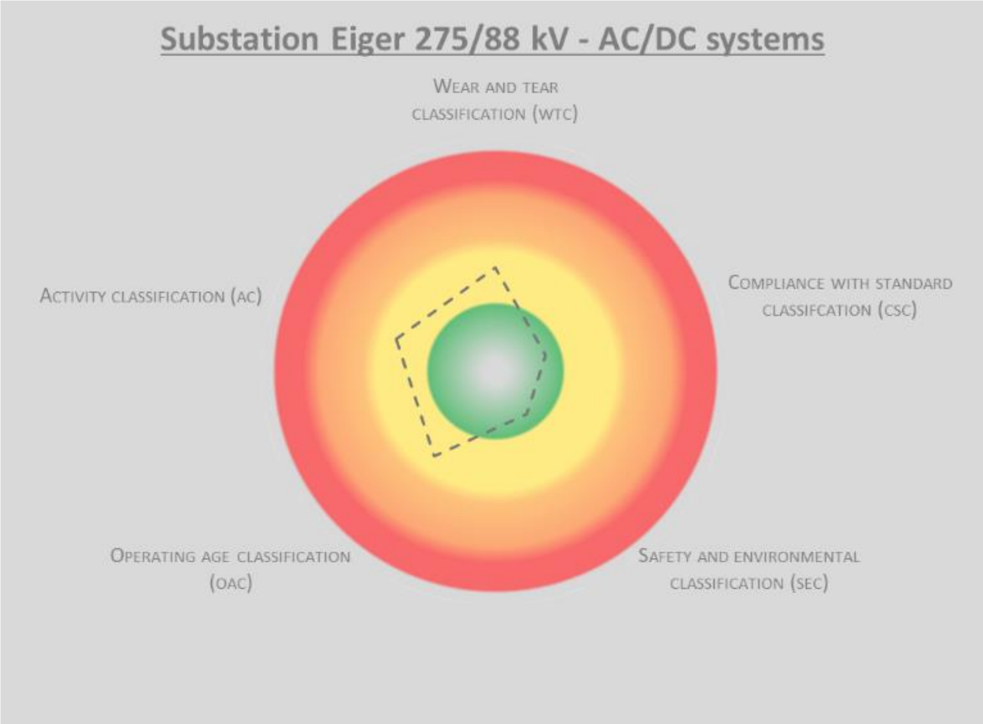

Figure 9-28: Evaluation graphic AC/DC systems substation Eiger

Battery systems

Activity class of Battery systems classification 1 – condition without findings, no measures necessary (see Figure 9-29).

- 220 V Batteries AC classification 1 – condition without findings.
- 50 V Batteries AC classification 1 – condition without findings.

The battery systems were renewed cyclically during operation. The current status corresponds to the state of the art. Cleanliness and maintenance condition are excellent (see Figure 9-30).

Figure 9-29: 50 V Battery substation Eiger

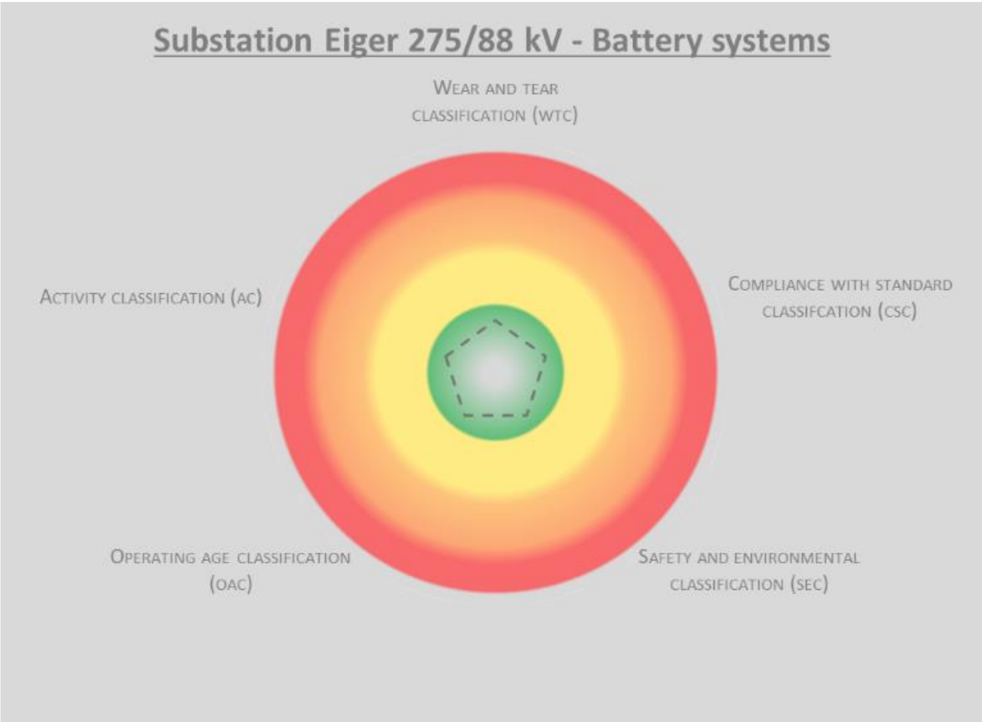

Figure 9-30: Evaluation graphic Battery systems substation Eiger

Streets/Footpaths/Fences

Activity class of streets, footpaths and fences classification 1,67 – Age-related wear and tear, but in a very good state of maintenance (see Figure 9-31).

- General condition AC classification 2 – Age-related wear and tear, no measures required.
- Fences and security AC classification 2 – Age-related wear and tear, no measures required.
- Dimensioning AC classification 1 – Age-related wear and tear, no measures required.

The streets, footpaths and fences are in good condition. No measures are required. Cleanliness and maintenance condition are excellent (see Figure 9-32).

Figure 9-31: Street and fences substation Eiger

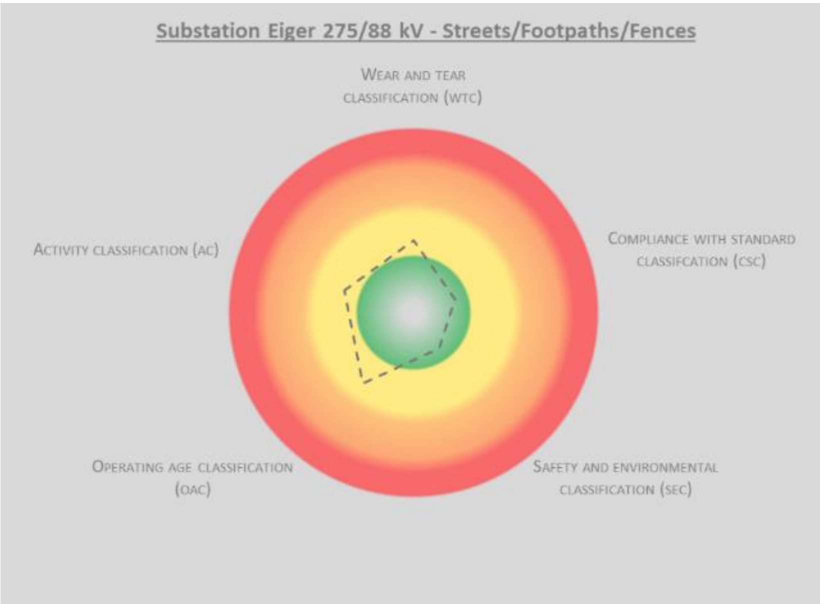

Figure 9-32: Evaluation graphic Streets/Footpaths/Fences substation Eiger

Cable ducts

Activity class of cable ducts classification 2 – Age-related wear and tear, but in a very good state of maintenance (see Figure 9-33).

- Ducts AC classification 2 – Age-related wear and tear, no measures required.
- Covers AC classification 2 – Age-related wear and tear, no measures required.
- General condition, weathering AC classification 2 – Age-related wear and tear, no measures required.

The cable ducts are in good condition. No measures are required. Cleanliness and maintenance condition are excellent (see Figure 9-34).

Figure 9-33: Example of Cable duct substation Eiger

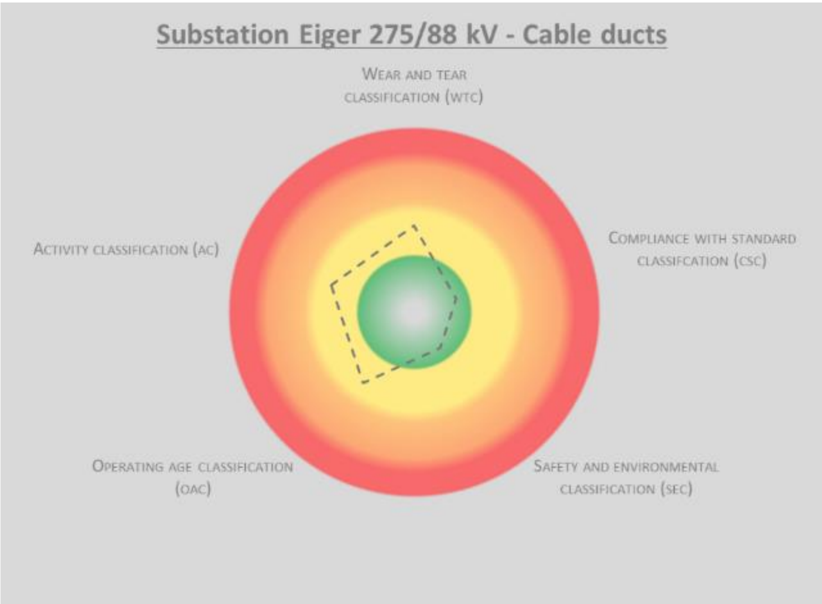

Figure 9-34: Evaluation graphic Cable ducts substation Eiger

Summary substation Eiger

The Eiger substation was commissioned in 1973. During the years of operation, essential components such as all 3 power transformers, some circuit breakers, a few instrument transformers and disconnectors were gradually replaced. A general modernization measure was not carried out until now. A refurbishment project for the substation has been announced for the near future. Despite 50 years of operation, the substation is in relatively good condition (see for example Figure 9-35). This is due to the permanent renewal of worn components and excellent maintenance of all substation components. Accordingly, the substation can continue to operate safely for few years if the current strategy is continued by replacing worn parts and intensively maintaining all components. However, the already planned fundamental modernization measure for the substation should be carried out in the near future, as many of the components in operation have reached the end of their service life due to wear and tear and age.

The total evaluation results in an AC 1,95 for substation Eiger (see Figure 9-36).

Figure 9-35: 88 kV switchgear substation Eiger

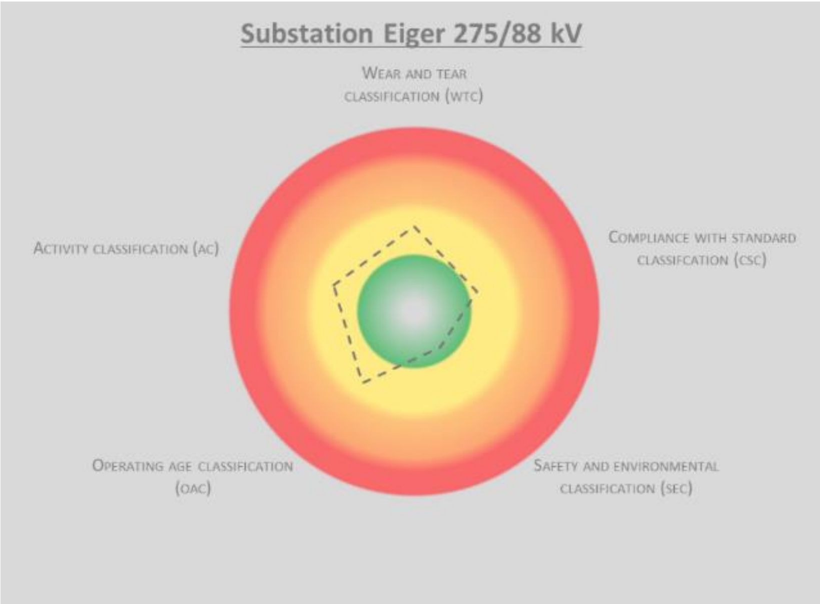

Figure 9-36: Evaluation graphic total substation Eiger

9.3.3 Apollo Converter Station 530 kV DC/275 kV AC

Brief description of the Converter Station

- 2 AC/DC converter 533 kV
  - Operation mode +533 kV to ground one pole and one pole -533 kV to ground
  - 4 converter per pole in line (converter cascade), each converter 133 kV
  - Connection of each converter via transformer bank – 3x 107/275 kV 90,8 MVA.
- Air insulated switchgear 275 kV double busbar (2x connection bays to Apollo AC; 8x transformer bays (connection to converter), 1x cross coupling bay, 2x filter bays 2 capacitor bays, all bays equipped with circuit breakers, see Figure 9-37).
- 2x capacitor bank 275 kV 150 Mvar.
- 2x filter bank (harmonic 5, 7, 11, 13 and high pass) 275 kV 200 Mvar.
- Year of commissioning 1977 – 1979.
- Last intensive refurbishment activity 2013 – 2014.
- On-site inspection on 14th of April 2023.

The summarised assessment extract is attached in the appendix Assessment Matrix of Evaluated Transmission Assets. The substation condition details are described below.

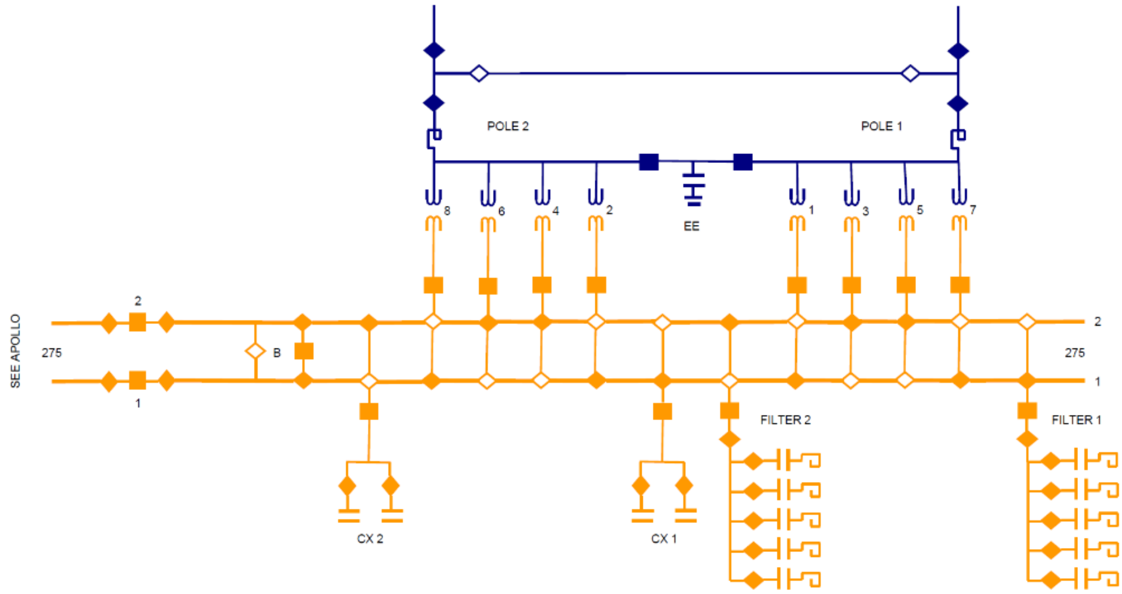

Figure 9-37: Single line diagram Apollo Converter Station

Switchgear

Activity class of converter bank and 275 kV switchgear classification 1,47 – small Wear and tear, no measures required (see Figure 9-38 and Figure 9-39).

Converter bank

- Converter AC classification 1 – condition without findings.
- Insulators AC classification 1 – condition without findings.
- Bushings AC classification 1 – condition without findings.
- Conductor ropes AC classification 1 – condition without findings.
- Steel constructions AC classification 1 – condition without findings.
- Basements AC classification 1 – condition without findings.
- Groundings randomly inspected AC classification 1 – condition without findings.

275 kV switchgear

- Circuit breakers – small wear and tear, no measures required.
- Disconnectors – small wear and tear, no measures required.
- Instrument transformers – small wear and tear, no measures required.
- Conductor ropes – small wear and tear, no measures required.
- Harmonic filters and capacitors – small wear and tear, no measures required.
- Steel constructions – small wear and tear, no measures required.
- Basements – small wear and tear, no measures required.
- Grounding – small wear and tear, no measures required.

All major components were replaced with new ones and the structural infrastructure was renovated from the ground up during the upgrading of the converter bank and the 275 kV switchgear, which was carried out in 2013 to 2014. Cleanliness and maintenance condition are excellent (see Figure 9-40).

Figure 9-38: Converter Bank Apollo Converter station 530 kV DC/275 kV AC

Figure 9-39: 275 kV switchgear Apollo Converter station 530 kV DC/275 kV AC

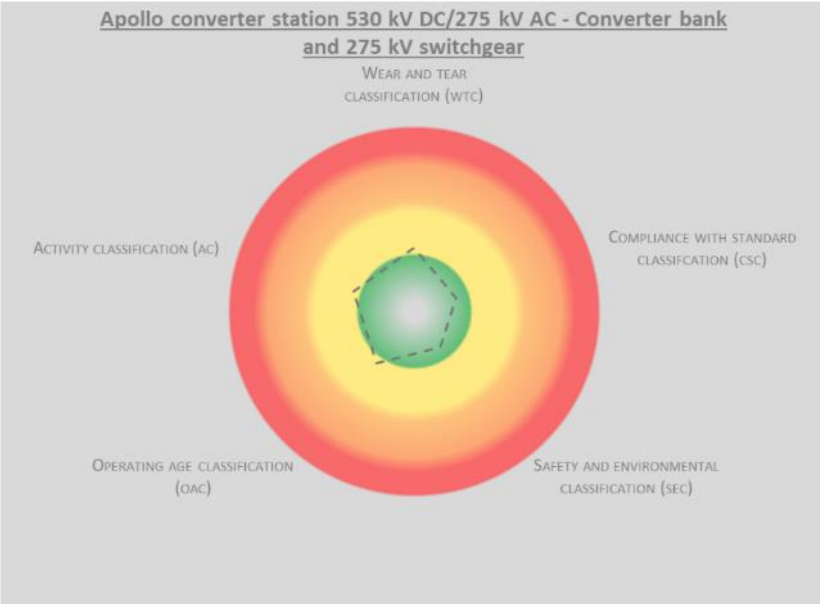

Figure 9-40: Evaluation graphic Converter bank and 275 kV switchgear Apollo Converter Station 530 kV DC/275 kV AC

Power Transformers

Activity class of Power Transformers classification 2 – The commissioning years of the 24 transformers used vary from 1977 to 2023. The tests of the gas-in-oil analyses also range from A very good, to E very poor. These results tend to deteriorate with the age of the transformers, but there are also some newer transformers with very poor test results. The transformers with class E test results must be monitored and replaced at short notice if possible (see Table 1). The majority of the transformers are in good overall condition (see Figure 9-41).

- General impression of inspection AC classification 2 – small wear and tear, no measures required.
- Gas in oil analysis (both transformers last test of 19.12.2022, A very good) AC classification 2 – small wear and tear, transformers in Bridge 1, 2 and 3 with classification E shall be monitored intensively.
- Bushings AC classification 2 – small wear and tear, no measures required.
- Tank AC classification 2 – small wear and tear, no measures required.
- Oil leakage AC classification 2 – small wear and tear, no measures required.
- Fire protection walls AC classification 2 – small wear and tear, no measures required.
- Groundings randomly inspected AC classification 2 – small wear and tear, no measures required.
- Steel construction, radiators etc. AC classification 2 – small wear and tear, no measures required.

- Basement, oil leakage sump AC classification 2 – small wear and tear, no measures required.

Transformer	Year	last Test	classification oil test
Apollo CS DC Pole No1 Bridge No1 107kV - 275kV Trfr B-Ph	2008	25.10.2022	B
Apollo CS DC Pole No1 Bridge No1 107kV - 275kV Trfr R-Ph	2008	25.10.2022	C
Apollo CS DC Pole No1 Bridge No1 107kV - 275kV Trfr W-Ph	2006	25.10.2022	E
Apollo CS DC Pole No1 Bridge No3 107kV - 275kV Trfr B-Ph	2015	25.10.2022	B
Apollo CS DC Pole No1 Bridge No3 107kV - 275kV Trfr R-Ph	1977	25.10.2022	E
Apollo CS DC Pole No1 Bridge No3 107kV - 275kV Trfr W-Ph	1977	25.10.2022	E
Apollo CS DC Pole No1 Bridge No5 107kV - 275kV Trfr B-Ph	2023	13.03.2023	A
Apollo CS DC Pole No1 Bridge No5 107kV - 275kV Trfr R-Ph	2023	13.03.2023	A
Apollo CS DC Pole No1 Bridge No5 107kV - 275kV Trfr W-Ph	2023	13.03.2023	A
Apollo CS DC Pole No1 Bridge No7 107kV - 275kV Trfr B-Ph	1979	19.12.2022	B
Apollo CS DC Pole No1 Bridge No7 107kV - 275kV Trfr R-Ph	1998	19.12.2022	C
Apollo CS DC Pole No1 Bridge No7 107kV - 275kV Trfr W-Ph	1979	19.12.2022	B
Apollo CS DC Pole No2 Bridge No2 107kV - 275kV Trfr B-Ph	2008	19.12.2022	E
Apollo CS DC Pole No2 Bridge No2 107kV - 275kV Trfr R-Ph	2008	19.12.2022	C
Apollo CS DC Pole No2 Bridge No2 107kV - 275kV Trfr W-Ph	1977	19.12.2022	B
Apollo CS DC Pole No2 Bridge No4 107kV - 275kV Trfr B-Ph	1977	11.10.2022	B
Apollo CS DC Pole No2 Bridge No4 107kV - 275kV Trfr R-Ph	2000	11.10.2022	A
Apollo CS DC Pole No2 Bridge No4 107kV - 275kV Trfr W-Ph	1977	11.10.2022	C
Apollo CS DC Pole No2 Bridge No6 107kV - 275kV Trfr B-Ph	2014	30.11.2022	A
Apollo CS DC Pole No2 Bridge No6 107kV - 275kV Trfr R-Ph	2014	30.11.2022	A
Apollo CS DC Pole No2 Bridge No6 107kV - 275kV Trfr W-Ph	2014	30.11.2022	A
Apollo CS DC Pole No2 Bridge No8 107kV - 275kV Trfr B-Ph	2017	30.11.2022	A
Apollo CS DC Pole No2 Bridge No8 107kV - 275kV Trfr R-Ph	2017	30.11.2022	A
Apollo CS DC Pole No2 Bridge No8 107kV - 275kV Trfr W-Ph	2017	30.11.2022	A

Table 1: List of transformers with last oil test result Apollo Converter Station 530 kV DC/275 kV AC

The majority of the transformers are in good overall condition. The maintenance condition is very good. The 4 transformers with very poor oil analysis values are to be monitored (see Figure 9-42).

Figure 9-41 Transformers Apollo Converter Station 530 kV DC/275 kV AC

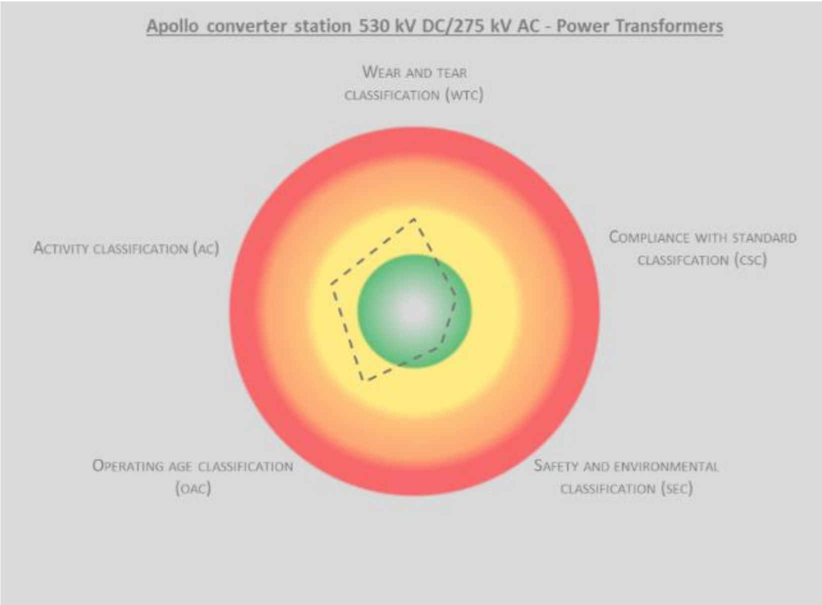

Figure 9-42: Evaluation graphic transformers Apollo Converter Station 530 kV DC/275 kV AC

Operation Building

Activity class of the operation building classification 1,36 – Slight wear due to age, condition without findings, no measures necessary.

- Outside general impression of inspection AC classification 2 – Slight wear due to age, condition without findings.

- Roof visual inspection from the ground AC classification 2 – Slight wear due to age, condition without findings.
- Walls AC classification 2 – Slight wear due to age, condition without findings.
- Basement AC classification 1 – condition without findings.
- Surface AC classification 2 – Slight wear due to age, condition without findings.
- Waterproofing visual inspection AC classification 1 – condition without findings.
- Lightning protection visual inspection from the ground AC classification 1 – condition without findings.
- Inside general impression of inspection AC classification 1 – condition without findings.
- Emergency exits, place for exit AC classification 1 – condition without findings.
- Ventilation AC classification 1 – condition without findings.
- Illumination AC classification 1 – condition without findings.
- Cleanness AC classification 1 – condition without findings.

Despite its many years of use, the operation building is in excellent condition. Cleanliness and maintenance condition are excellent (see Figure 9-43).

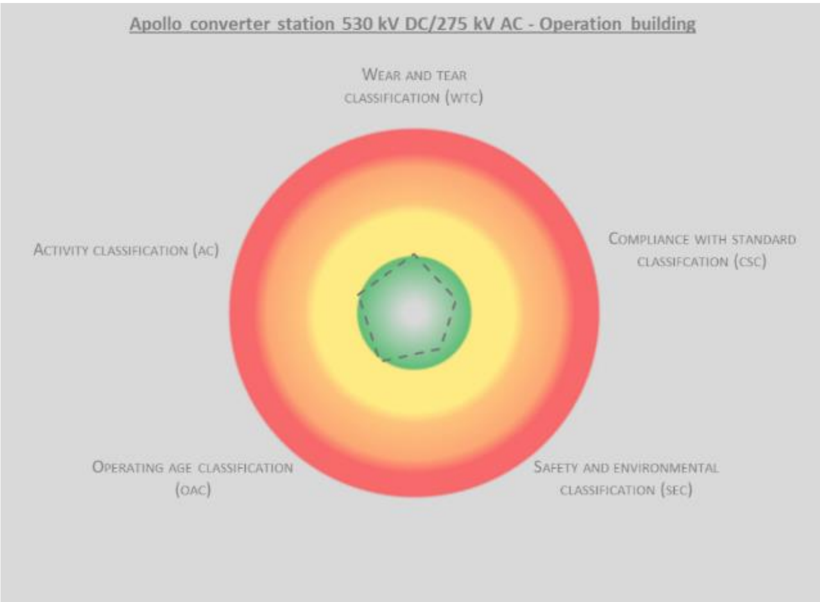

Figure 9-43: Evaluation graphic Operation Building Apollo Converter Station 530 kV DC/275 kV AC

Secondary Technology

Activity class of Secondary Technology classification 1,5 – The equipment and software used to control and monitor the converter bank are outdated but fulfil all functions. Most of the protection technology has been modernised, no measures necessary (see Figure 9-44).

- SCADA outdated equipment and software AC classification 2 – modernization recommended, no immediate measures required.

− Protection relays are modernized AC classification 1 – condition without findings.

The outdated equipment and software for the control and monitoring of the converter bank should be replaced in the medium term with state-of-the-art technology. (see Figure 9-45).

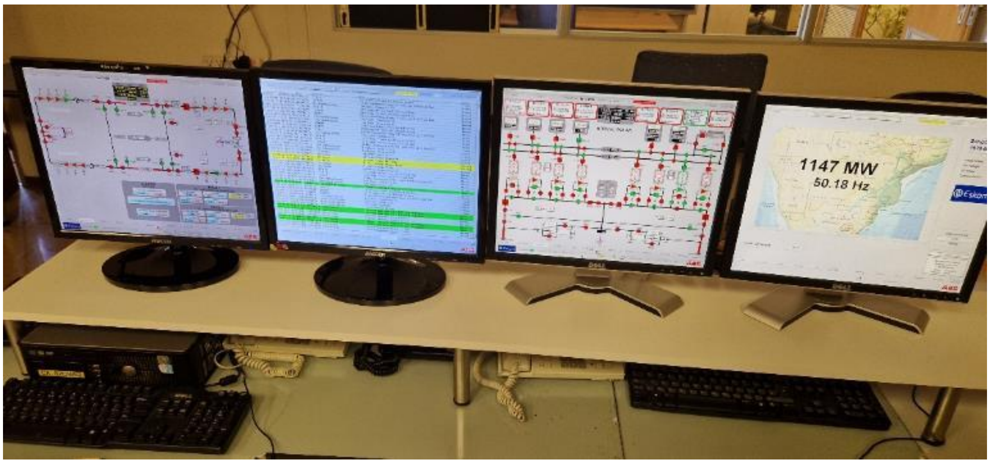

Figure 9-44: Control desk Apollo Converter Station 530 kV DC/275 kV AC

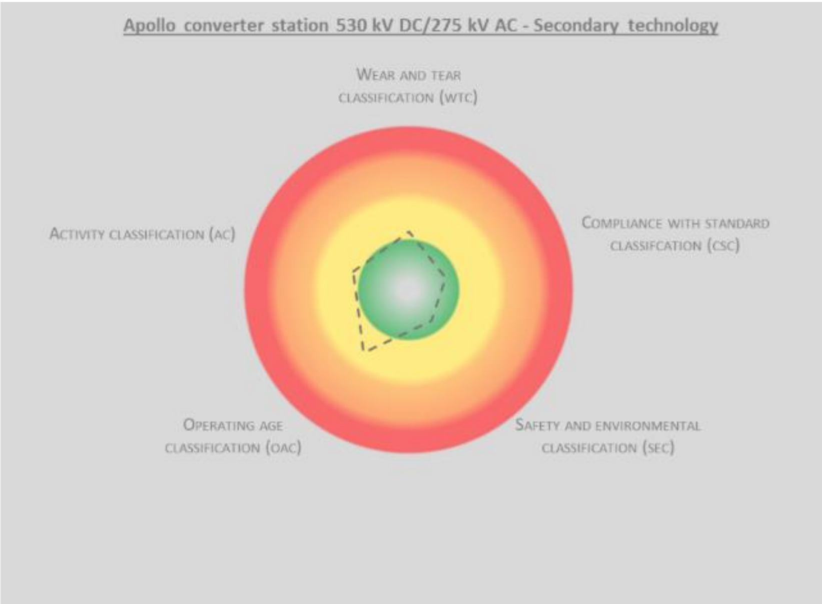

Figure 9-45: Evaluation graphic Secondary Technology Apollo Converter Station 530 kV DC/275 kV AC

AC/DC systems

Activity class of AC/DC systems classification 1 – condition without findings, no measures necessary.

- AC system including auxiliary transformers and AC-distribution AC classification 1 – condition without findings.
- DC-distribution AC classification 1 – condition without findings.
- AC/DC converters AC classification 1 – condition without findings.

The AC/DC system was modernized in the past. Cleanliness and maintenance condition are excellent (see Figure 9-46).

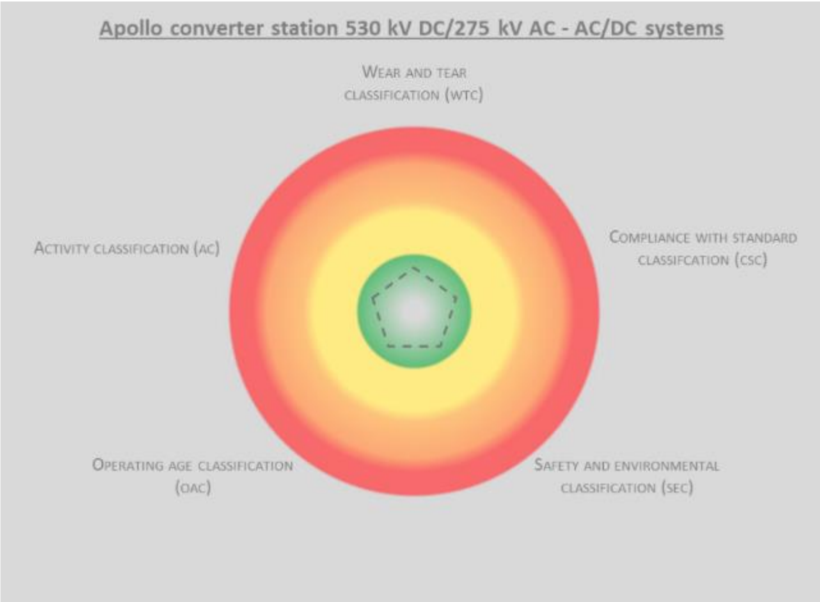

Figure 9-46: Evaluation graphic of AC/DC systems Apollo Converter Station 530 kV DC/275 kV AC

Battery systems

Activity class of Battery systems classification 1 – condition without findings, no measures necessary.

- 220 V Batteries AC classification 1 – condition without findings.
- 50 V AC classification 1 – condition without findings.

The Battery systems are in good condition. Cleanliness and maintenance condition are excellent (see Figure 9-47).

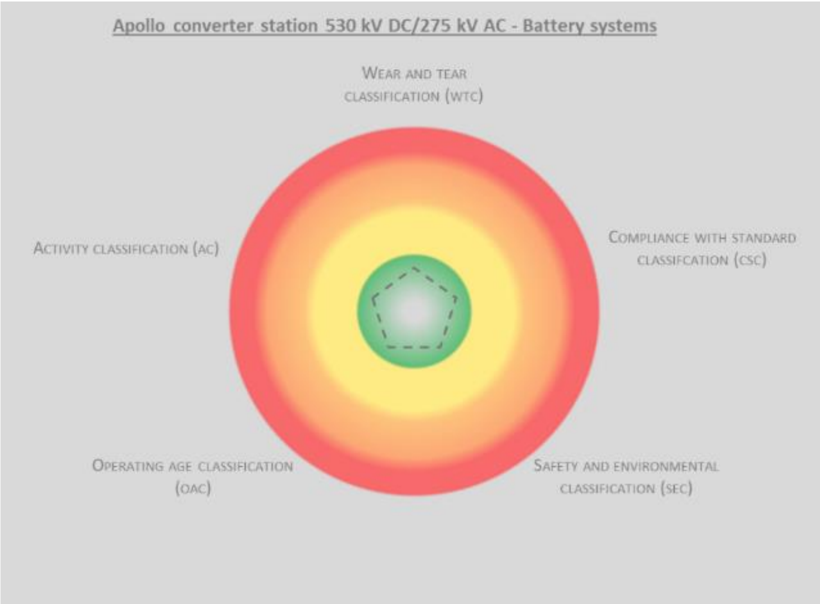

Figure 9-47: Evaluation graphic Battery systems Apollo Converter Station 530 kV DC/275 kV AC

Streets/Footpaths/Fences

Activity class of streets, footpaths and fences classification 1,67 – small wear and tear, no measures required (see Figure 9-48).

- General condition AC classification 2 – small wear and tear, no measures required.
- Fences and security AC classification 2 – small wear and tear, no measures required.
- Dimensioning AC classification 1 – small wear and tear, no measures required.

The streets, footpaths and fences have small wear and tear due to age, no measures required. Cleanliness and maintenance condition are excellent (see Figure 9-49).

Figure 9-48: Street and fences Apollo Converter Station 530 kV DC/275 kV AC

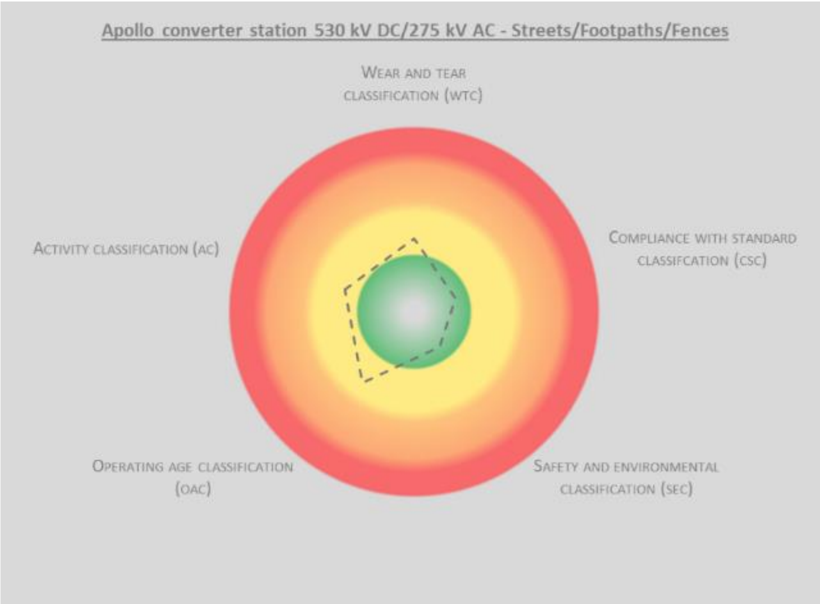

Figure 9-49: Evaluation graphic Streets/Footpaths/Fences Apollo Converter Station 530 kV DC/275 kV AC

Cable ducts

Activity class of cable ducts classification 2 – Age-related wear and tear, but in a very good state of maintenance (see Figure 9-50).

- Ducts AC classification 2 – Age-related wear and tear, no measures required.
- Covers AC classification 2 – Age-related wear and tear, no measures required.
- General condition, weathering AC classification 2 – Age-related wear and tear, no measures required.

The cable ducts are in good condition. No measures are required. Cleanliness and maintenance condition are excellent (see Figure 9-51).

Figure 9-50: Cable ducts Apollo Converter Station 530 kV DC/275 kV AC

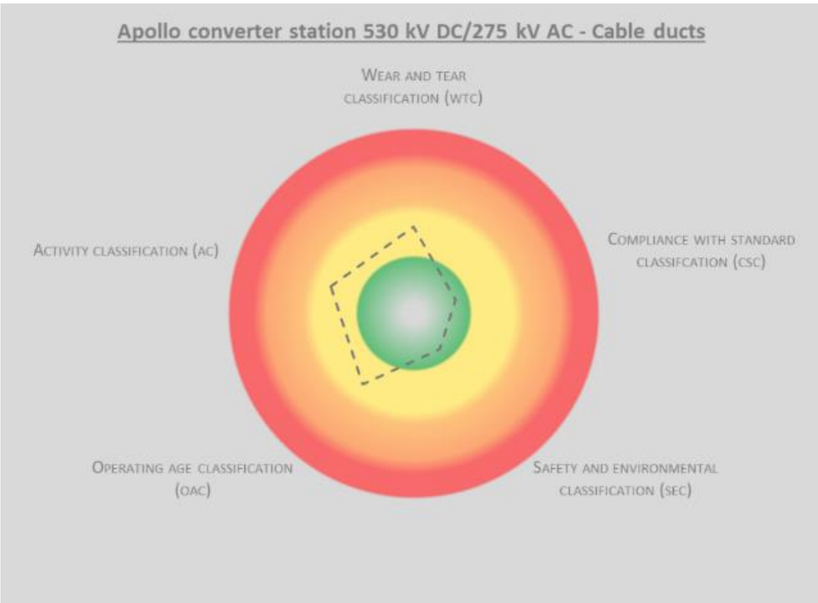

Figure 9-51: Evaluation graphic Cable ducts Apollo Converter Station 530 kV DC/275 kV AC

Summary substation Apollo Converter Station 530 kV DC/275 kV AC

The Apollo Converter Station 530 kV DC/275 kV AC was modernized between 2013 and 2014 (see Figure 9-52). The essential devices (circuit breakers, instrument transformers, disconnectors) were renewed during the modernization. Due to the excellent maintenance the condition of all components of the converter station, it is fully functional and available with a high degree of reliability despite its high operating age. The activity class was assessed at 1.5 (see Figure 9-53).

Figure 9-52: 275 kV switchgear Apollo Converter Station 530 kV DC/275 kV AC

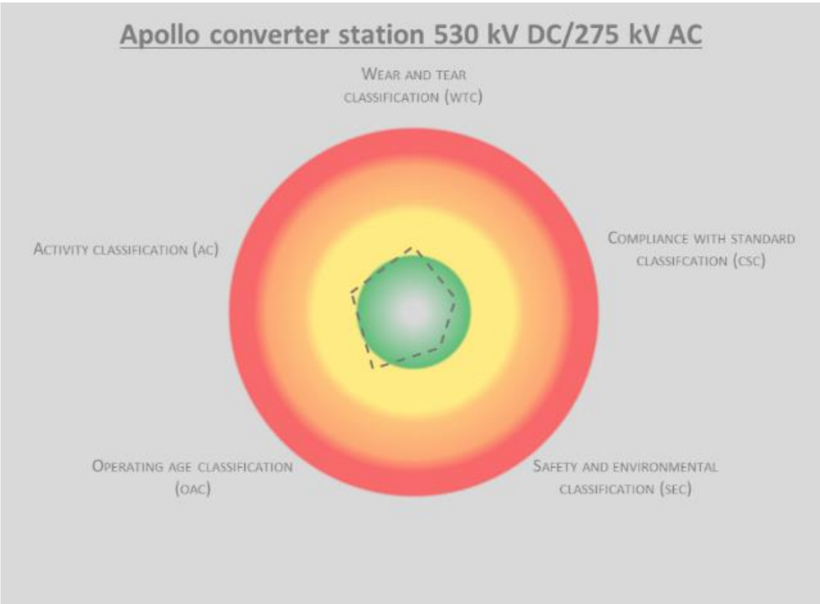

Figure 9-53: Evaluation graphic total Apollo Converter Station 530 kV DC/275 kV AC

9.3.4 Substation Apollo AC

Brief description of the substation

- Air insulated switchgear 400 kV double busbar plus bypass per section not connected (5x line bays, 3x transformer bays, 2x cross coupling bays and 1x lengthwise coupling bay in busbar 1, all bays equipped with circuit breakers, see Figure 9-54).
- Air insulated switchgear 275 kV double busbar (2x connections to Apollo DC – described in Apollo DC, 5x line bays, 3x transformer bays, 1x cross coupling bay and 1x lengthwise coupling bay in busbar 2, all bays equipped with circuit breakers, see Figure 9-54).
- Year of commissioning 1970.
- Last intensive refurbishment activity 2017.
- On-site inspection on 14th of April 2023.

The summarised assessment extract is attached in the appendix Assessment Matrix of Evaluated Transmission Assets. The substation condition details are described below.

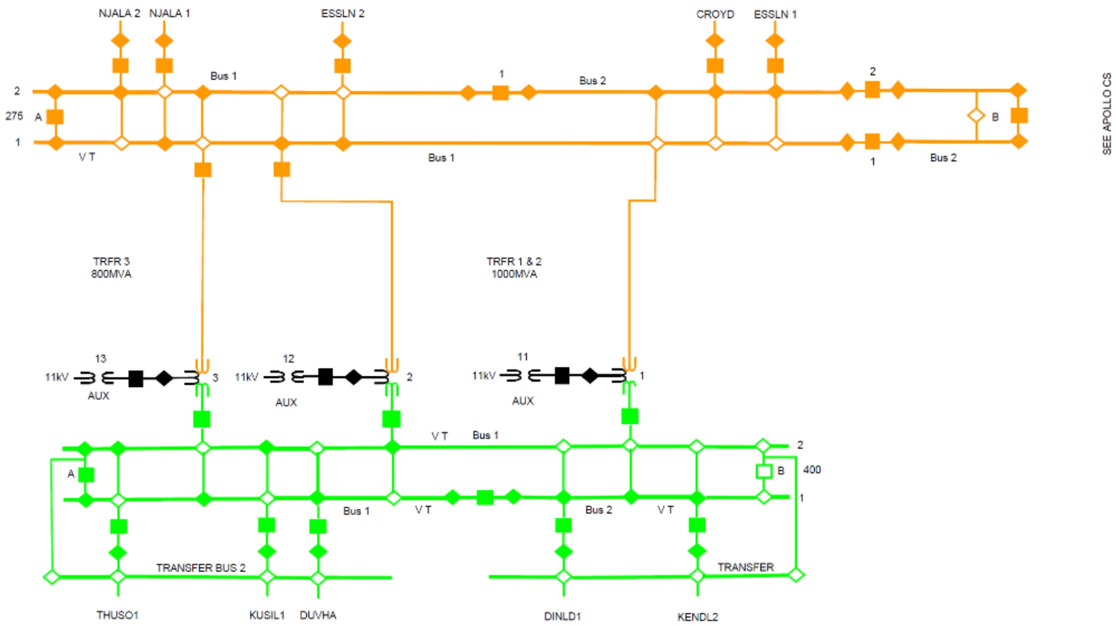

Figure 9-54: Single line diagram substation Apollo 400/275 kV

Switchgear

Activity class of switchgears classification 1,5 – The main devices (circuit breakers, instrument transformers, disconnectors) were renewed during the modernisation in 2013, with a few exceptions in the 275 kV switchgear. Age-related wear and tear, no measures required (see Figure 9-55)

- New 6 SF_6-circuit-breakers AC classification 400 kV 1, 275 kV 2 – few low oil circuit breakers in 275 kV still in operation, replacement recommended in medium term.

- All disconnectors AC classification 1 – condition without findings.
- All instrument transformers AC classification 1 – condition without findings.
- Conductor ropes AC classification 1 – Age-related wear and tear, no measures required.
- Steel construction AC classification 2 – Age-related wear and tear, no measures required.
- Basements AC classification 2 – Age-related wear and tear, no measures required.
- Groundings randomly inspected AC classification 2 – Age-related wear and tear, no measures required.

The 400 and 275 kV switchgears are in very good condition, as many devices were renewed in 2013. Both switchgears have been thoroughly overhauled and very good maintenance and servicing has been carried out to date. Cleanliness and maintenance condition are excellent (see Figure 9-56).

Figure 9-55: Modernized 400 kV switchgear substation Apollo 400/275 kV

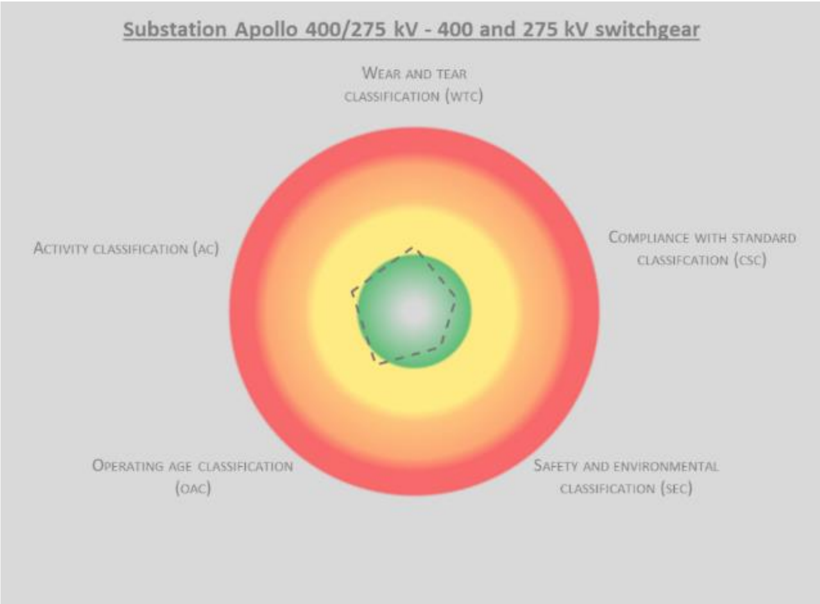

Figure 9-56: Evaluation graphic switchgears substation Apollo 400/275 kV

Power Transformers

Activity class of Power Transformers (in operation since TRFR 1 2017, TRFR 2 2015, TRFR 3 1989) classification 1,11 – The two newer transformer banks have a classification A very good of the last gas to oil analysis test values except for pole 1 of transformer 1. This has only a classification C fair test value, as does transformer 3, which has been in operation for over 30 years. No immediate action is required, but the gas in oil analysis test values should be monitored for deterioration (see Figure 9-57).

- General impression of inspection AC classification 1 – condition without findings.
- Gas in oil analysis (all transformers last test of 19.12.2022, A very good) AC classification 1 – condition without findings.
- Bushings AC classification 1 – condition without findings.
- Tank AC classification 1 – condition without findings.
- Oil leakage AC classification 1 – condition without findings.
- Fire protection walls AC classification 1 – condition without findings.
- Groundings randomly inspected AC classification 1 – condition without findings.
- Steel construction, radiators etc. AC classification 1 – condition without findings.
- Basement, oil leakage sump AC classification 1 – condition without findings.

The two new power transformers 1 and 2 are in good condition. The older power transformer 3 has age-related wear and tear but no immediate measures are required. The gas in oil analysis test values of the transformers with last test classification C should be monitored for deterioration. Cleanliness and maintenance condition are excellent (see Figure 9-58).

Figure 9-57 Power Transformer pole substation Apollo 400/275 kV

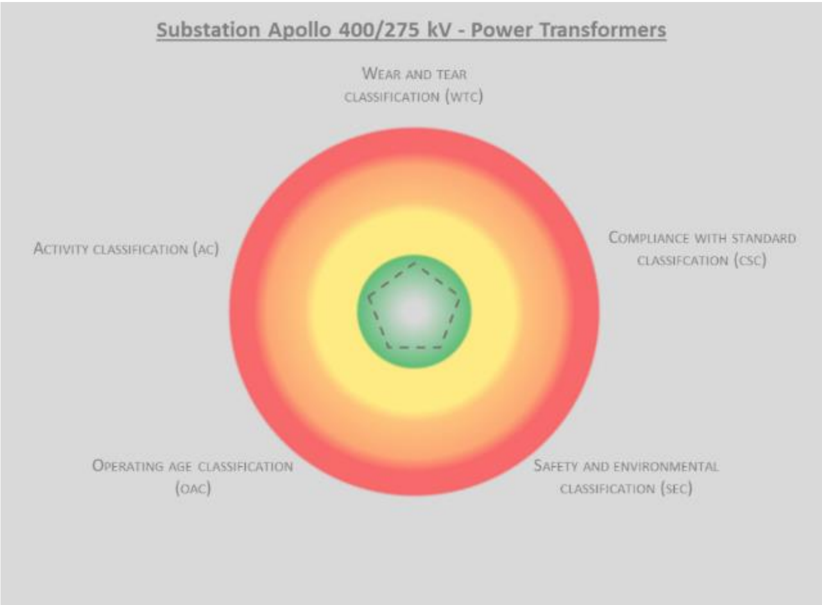

Figure 9-58: Evaluation graphic Power Transformer substation Apollo 400/275 kV

Operation Building

Activity class of the operation building classification 1,07 – Age-related wear and tear, no measures required (see Figure 9-59).

- Outside general impression of inspection AC classification 2 – Age-related wear and tear, no measures required.
- Roof visual inspection from the ground AC classification 1 – Age-related wear and tear, no measures required.

- Walls AC classification 1 – Age-related wear and tear, no measures required.
- Basement AC classification 1 – Age-related wear and tear, no measures required.
- Surface AC classification 1 – Age-related wear and tear, no measures required.
- Waterproofing visual inspection AC classification 1 – Age-related wear and tear, no measures required.
- Lightning protection visual inspection from the ground AC classification 1 – Age-related wear and tear, no measures required Inside general impression of inspection AC classification 1 – Age-related wear and tear, no measures required.
- Emergency exits, place for exit AC classification 1 – Age-related wear and tear, no measures required.
- Ventilation AC classification 1 – Age-related wear and tear, no measures required.
- Illumination AC classification 1 – Age-related wear and tear, no measures required.
- Cleanness AC classification 1 – Age-related wear and tear, no measures required.

Despite its many years of use, the operation building is in excellent condition. Cleanliness and maintenance condition are excellent (see Figure 9-60).

Figure 9-59: Operation Building substation Apollo 400/275 kV

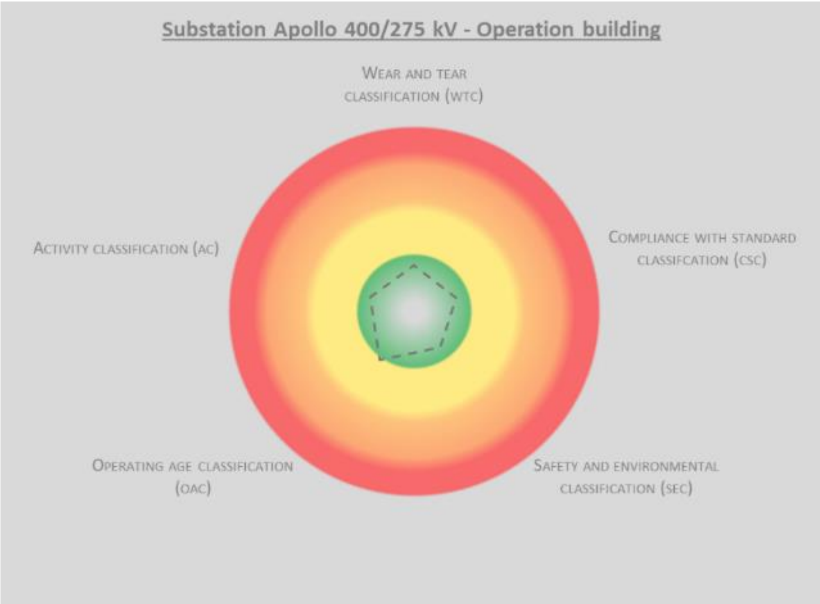

Figure 9-60: Evaluation graphic Operation Building substation Apollo 400/275 kV

Secondary Technology

Activity class of Secondary Technology classification 1,5 – Most of the SCADA components were renewed. The protection technology has been partially modernised but a high percentage are still electromechanical technology, nevertheless no immediate measures are necessary (see Figure 9-61).

- SCADA connection is available AC classification 1 – modernization activities implemented, no immediate measures required.
- Protection relays are modernized only partly AC classification 2 – further modernization activities recommended at least in medium time, no immediate measures are necessary.

Further modernization activities for secondary technology is recommended in the medium term to keep the substation available for remote control (see Figure 9-62).

Figure 9-61: Outdated secondary technology substation Apollo 400/275 kV

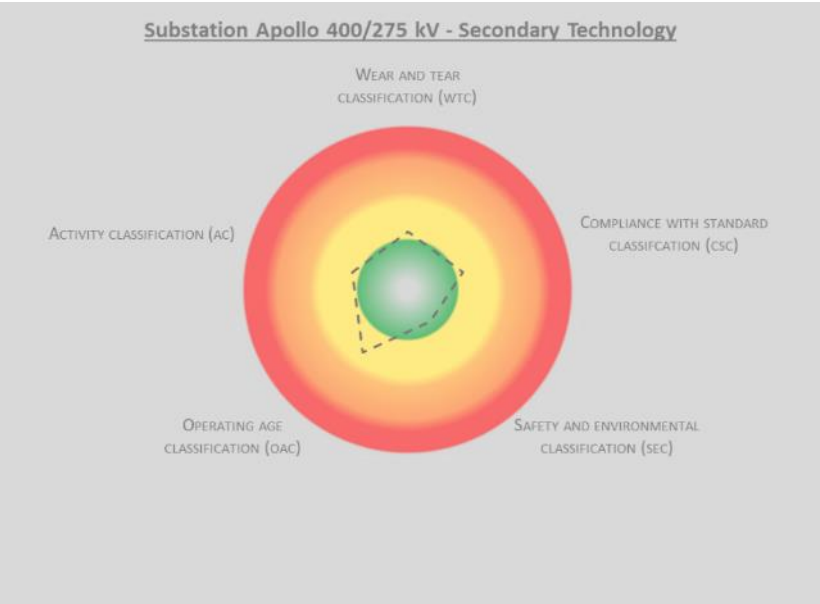

Figure 9-62: Evaluation graphic secondary technology substation Apollo 400/275 kV

AC/DC systems

Activity class of AC/DC systems classification 1,33 – Age-related wear and tear, no measures required, auxiliary transformers were replaced in 2016, 2021 and 2022 (see Figure 9-63).

- AC system including auxiliary transformers and AC-distribution AC classification 1 – condition without findings.
- DC-distribution AC classification 2 – Age-related wear and tear, no measures required.
- AC/DC converters AC classification 1 – Age-related wear and tear, no measures required.

The AC/DC systems were partly modernized. The auxiliary transformers were renewed in the last years. Cleanliness and maintenance condition are excellent (see Figure 9-64).

Figure 9-63: Part of auxiliary system substation Apollo 400/275 kV

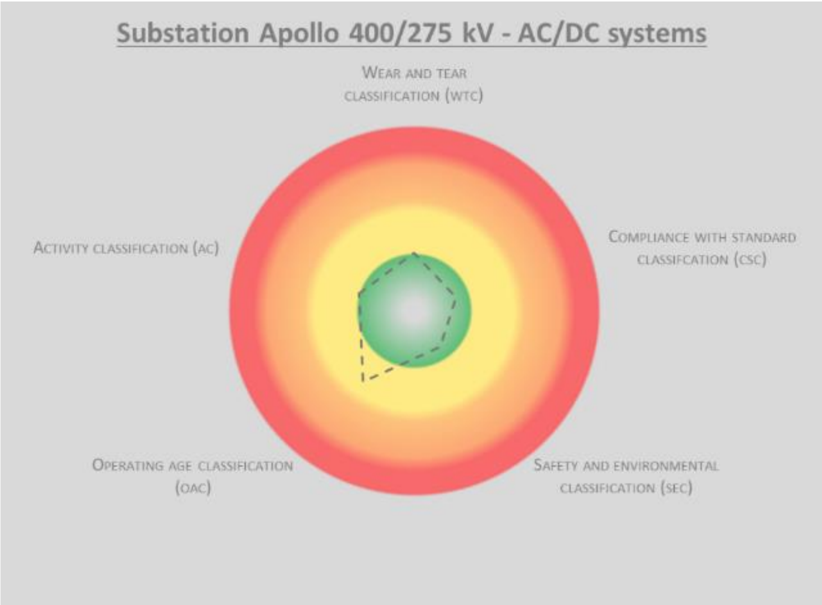

Figure 9-64: Evaluation graphic AC/DC systems substation Apollo 400/275 kV

Battery systems

Activity class of Battery systems classification 1 – condition without findings, no measures necessary (see Figure 9-65).

- 220 V Batteries AC classification 1 – condition without findings.
- 50 V AC classification 1 – condition without findings.

The Battery systems correspond to the condition that it was commissioned less than 10 years ago and is according to the current state of technology. Cleanliness and maintenance condition are excellent (see Figure 9-66).

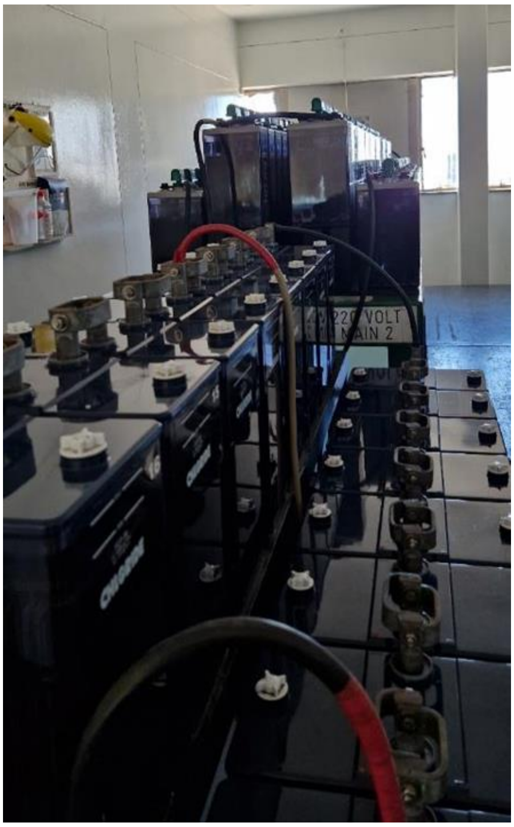

Figure 9-65: Battery system substation Apollo 400/275 kV

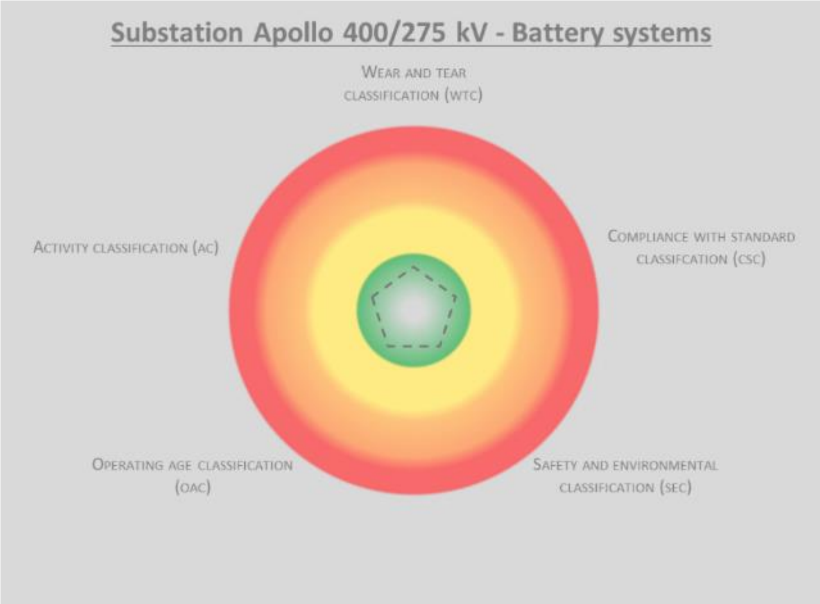

Figure 9-66: Evaluation graphic Battery systems substation Apollo 400/275 kV

Streets/Footpaths/Fences

Activity class of streets, footpaths and fences classification 1 – small wear and tear, no measures required (see Figure 9-67).

- General condition AC classification 1 – small wear and tear, no measures required.
- Fences and security AC classification 1 – small wear and tear, no measures required.
- Dimensioning AC classification 1 – small wear and tear, no measures required.

The streets, footpaths and fences have small wear and tear due to age, no measures required. Cleanliness and maintenance condition are excellent (see Figure 9-68).

Figure 9-67: Street and fences substation Apollo 400/275 kV

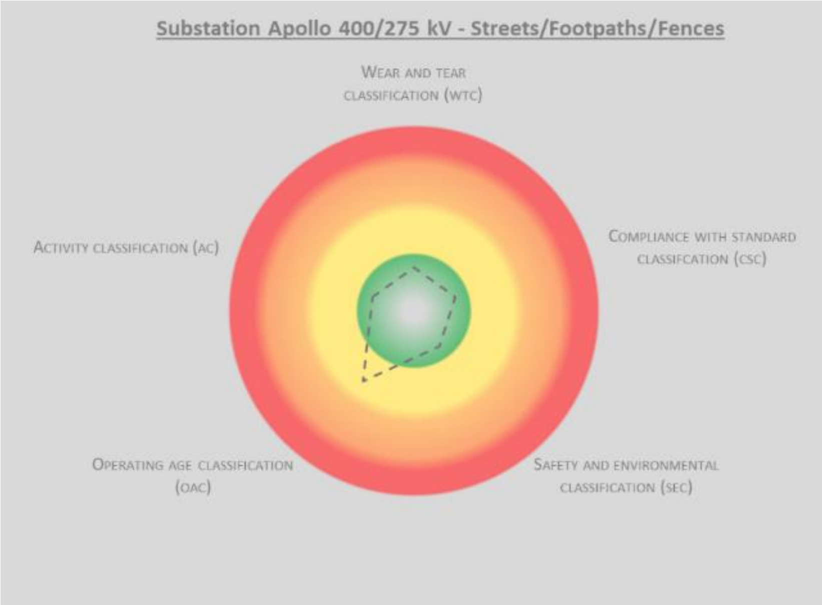

Figure 9-68: Evaluation graphic Streets/Footpaths/Fences substation Apollo 400/245 kV

Cable ducts

Activity class of cable ducts classification 2 – Age-related wear and tear, but in a very good state of maintenance (see Figure 9-69).

- Ducts AC classification 2 – Age-related wear and tear, no measures required.
- Covers AC classification 2 – Age-related wear and tear, no measures required.
- General condition, weathering AC classification 2 – Age-related wear and tear, no measures required.

The cable ducts are in good condition. No measures are required. Cleanliness and maintenance condition are excellent (see Figure 9-70).

Figure 9-69: Cable duct substation Apollo 400/275 kV

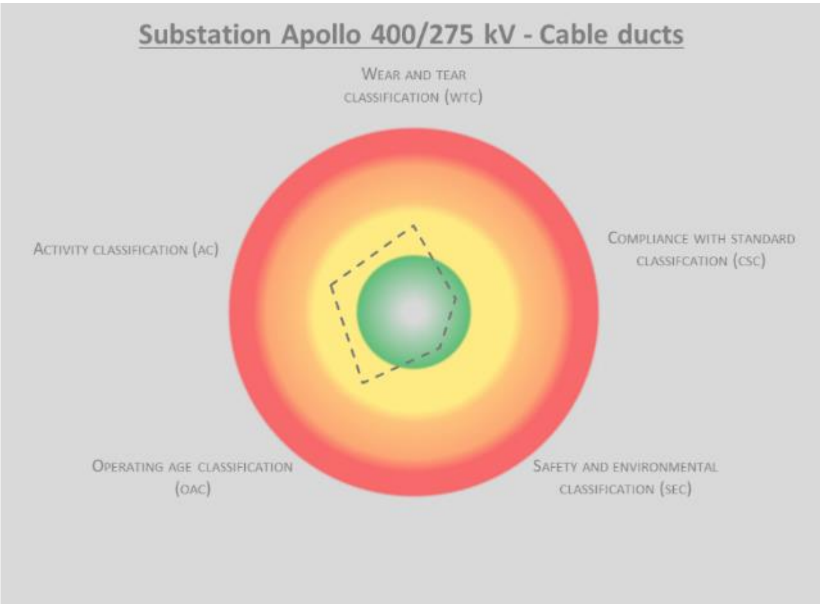

Figure 9-70: Evaluation graphic substation Apollo 400/275 kV

Summary substation Apollo 400/275 kV

The Apollo 400/275 kV AC substation was modernized in 2017 (see Figure 9-71). The essential devices (circuit breakers, instrument transformers, disconnectors) were renewed during the modernization. Due to the excellent maintenance condition of all components of the converter station, it is fully functional and available with a high degree of reliability despite its high operating age. The activity class was assessed at 1.31 (see Figure 9-72).

Figure 9-71: Modernized 275 kV switchgear substation Apollo 400/275 kV

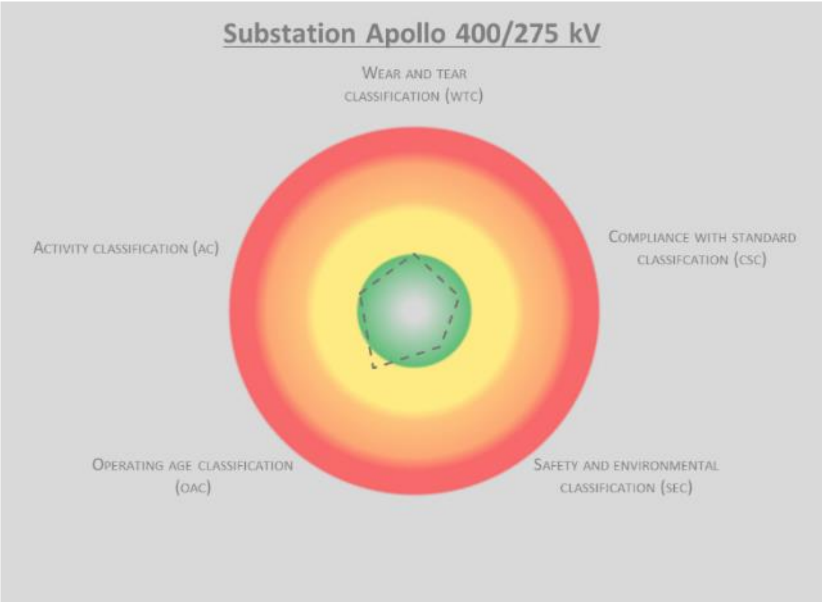

Figure 9-72: Evaluation graphic total substation Apollo 400/275 kV

9.3.5 Substation Thuso

Brief description of the substation

- Air insulated switchgear 400 kV double busbar plus bypass busbar (2x overhead line bays; 2x transformer bays, 1x coupling bay, all bays equipped with circuit breakers, see Figure 9-73).
- 2 power transformers 400/132 kV, 250 MVA each.

- 132 kV transformer circuit breaker owned by Eskom, feeding into 132 kV switchgear of the local distribution network.
- Year of commissioning 2014.
- 2 auxiliary transformers 22/0,4 kV, 315 kVA connected to the tertiary winding of the two power transformers.
- On-site inspection on 14th of April 2023.

The summarised assessment extract is attached in the appendix Assessment Matrix of Evaluated Transmission Assets. The substation condition details are described below.

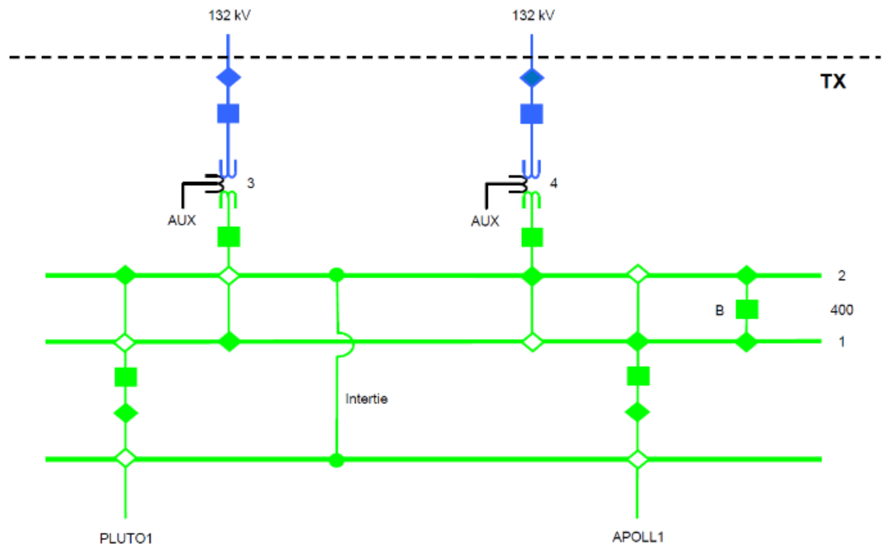

Figure 9-73: Single line diagram substation Thuso

Switchgear

Activity class of 400-kV-switchgear classification 1 – condition without findings, no measures necessary (see Figure 9-74)

- All 6 SF_6-circuit-breakers AC classification 1 – condition without findings.
- All disconnectors AC classification 1 – condition without findings.
- All instrument transformers AC classification 1 – condition without findings.
- Conductor ropes are only used for short connections, mainly tubular rails are used for the busbars and equipment connections. AC classification 1 – condition without findings.
- Steel construction AC classification 1 – condition without findings.
- Basements AC classification 1 – condition without findings.
- Groundings randomly inspected AC classification 1 – condition without findings.

The entire switchgear corresponds to the condition that it was commissioned less than 10 years ago. Cleanliness and maintenance condition are excellent (see Figure 9-75).

Figure 9-74: 400-kV-switchgear of substation Thuso

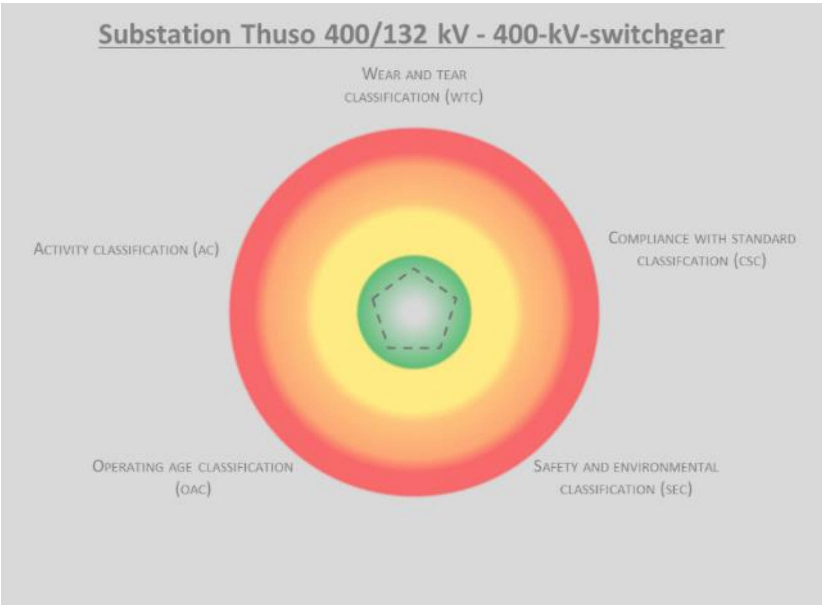

Figure 9-75: Evaluation graphic 400-kV-switchgear substation Thuso

Power Transformers

Activity class of Power Transformers (in operation since 2015) classification 1 – condition without findings, no measures necessary (see Figure 9-76).

- General impression of inspection AC classification 1 – condition without findings.
- Gas in oil analysis (both transformers last test of 19.12.2022, A very good) AC classification 1 – condition without findings.
- Bushings AC classification 1 – condition without findings.
- Tank AC classification 1 – condition without findings.
- Oil leakage AC classification 1 – condition without findings.
- Fire protection walls AC classification 1 – condition without findings.
- Groundings randomly inspected AC classification 1 – condition without findings.

- Steel construction, radiators etc. AC classification 1 – condition without findings.
- Basement, oil leakage sump AC classification 1 – condition without findings.

The two power transformers correspond to the condition that it was commissioned less than ten years ago. Cleanliness and maintenance condition are excellent (see Figure 9-77).

Figure 9-76: Power Transformer 4 of substation Thuso

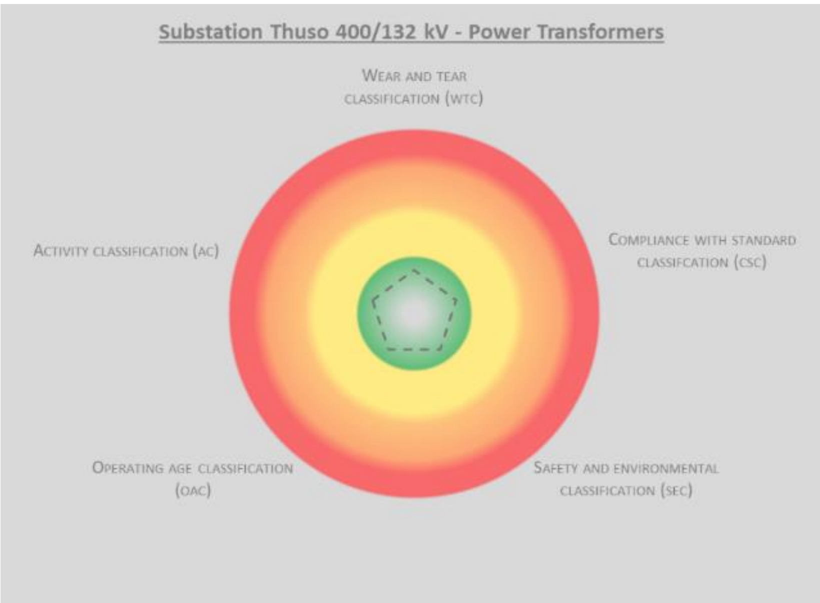

Figure 9-77: Evaluation graphic of Power Transformers of substation Thuso

Operation Building

Activity class of the operation building classification 1 – condition without findings, no measures necessary (see Figure 9-78)

- Outside general impression of inspection AC classification 1 – condition without findings.
- Roof visual inspection from the ground AC classification 1 – condition without findings
- Walls AC classification 1 – condition without findings.
- Basement AC classification 1 – condition without findings.
- Surface AC classification 1 – condition without findings.
- Waterproofing visual inspection AC classification 1 – condition without findings.
- Lightning protection visual inspection from the ground AC classification 1 – condition without findings.
- Inside general impression of inspection AC classification 1 – condition without findings.
- Emergency exits, place for exit AC classification 1 – condition without findings.
- Ventilation AC classification 1 – condition without findings.
- Illumination AC classification 1 – condition without findings.
- Cleanness AC classification 1 – condition without findings.

The operation building corresponds to the condition that it was commissioned less than ten years ago. Cleanliness and maintenance condition are excellent (see Figure 9-79).

Figure 9-78: Operation Building of substation Thuso

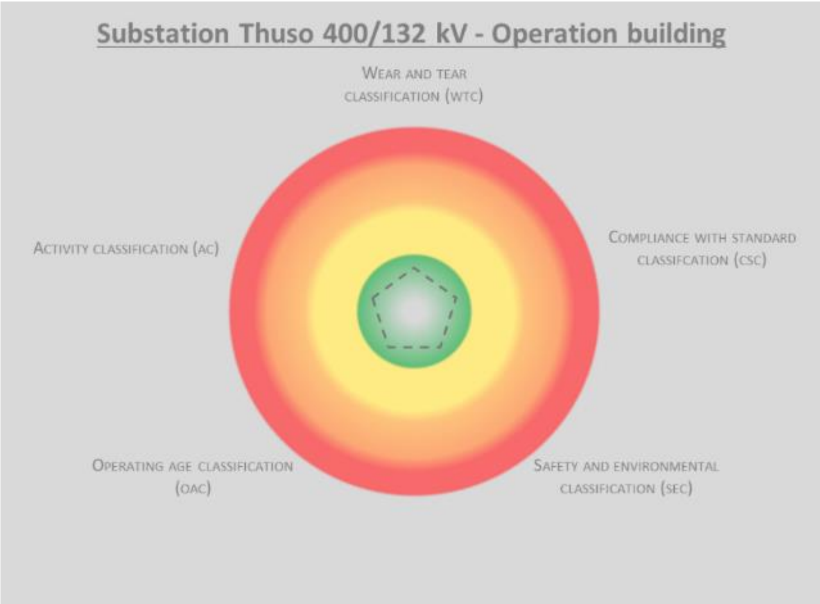

Figure 9-79: Evaluation graphic of Operation Building of substation Thuso

Secondary Technology

Activity class of Secondary Technology classification 1 – condition without findings, no measures necessary (see Figure 9-80)

- SCADA according to the current state of the art AC classification 1 – condition without findings.
- Protection relays are all digital, according to the current state of technology AC classification 1 – condition without findings.
- Control room and equipment AC classification 1 – condition without findings.

The secondary technology corresponds to the condition that it was commissioned less than ten years ago, and is according to the current state of technology. Cleanliness and maintenance condition are excellent (see Figure 9-81).

Figure 9-80 Example of a protection cabinet in substation Thuso

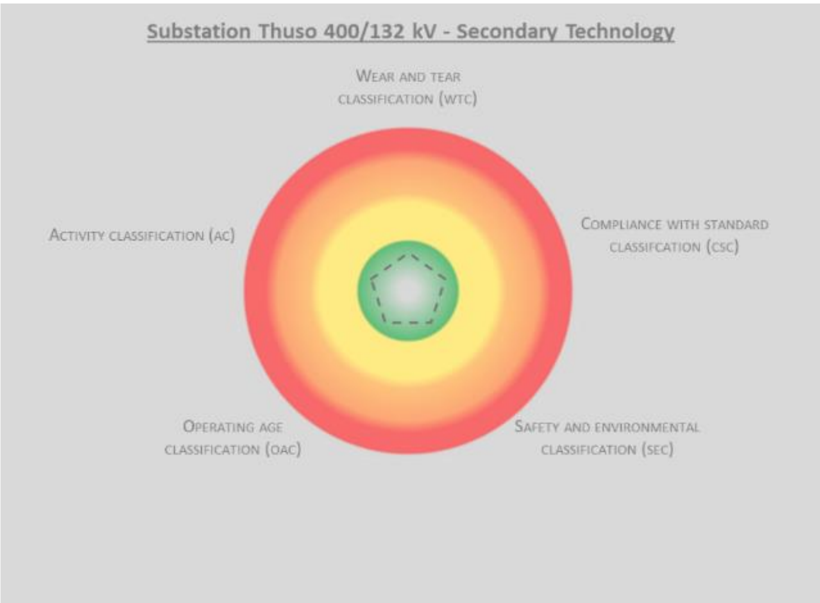

Figure 9-81: Evaluation graphic of Secondary Technology in substation Thuso

AC/DC systems

Activity class of AC/DC systems classification 1 – condition without findings, no measures necessary (see Figure 9-82).

- AC system including auxiliary transformers and AC-distribution AC classification 1 – condition without findings.
- DC-distribution AC classification 1 – condition without findings.
- AC/DC converters AC classification 1 – condition without findings.

The AC/DC systems correspond to the condition that it was commissioned less than ten years ago and is according to the current state of technology. Cleanliness and maintenance condition are excellent (see Figure 9-83).

Figure 9-82: Auxiliary transformer as example of one component of the AC/DC system

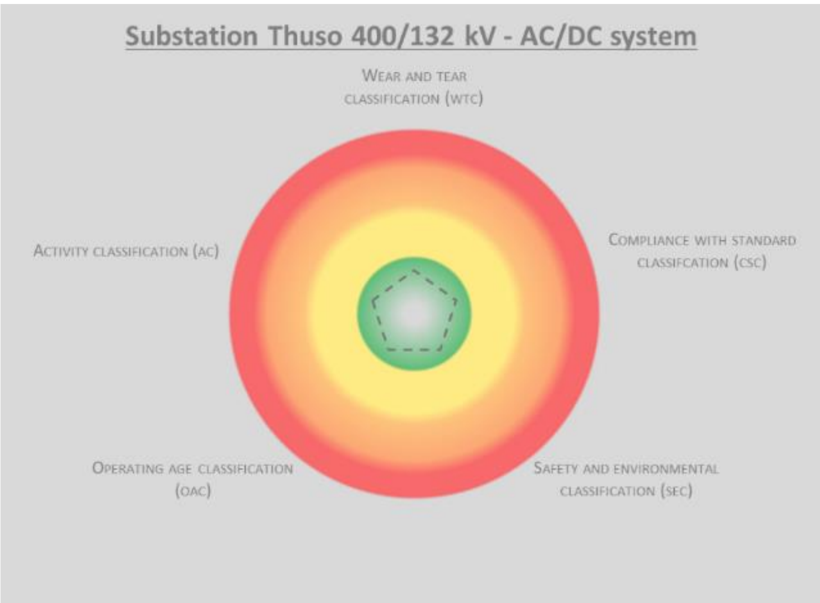

Figure 9-83: Evaluation graphic of AC/DC systems of substation Thuso

Battery systems

Activity class of Battery systems classification 1 – condition without findings, no measures necessary (see Figure 9-84).

- 220 V Batteries AC classification 1 – condition without findings.
- 50 V AC classification 1 – condition without findings.

The Battery systems correspond to the condition that it was commissioned less than ten years ago and is according to the current state of technology. Cleanliness and maintenance condition are excellent (see Figure 9-85).

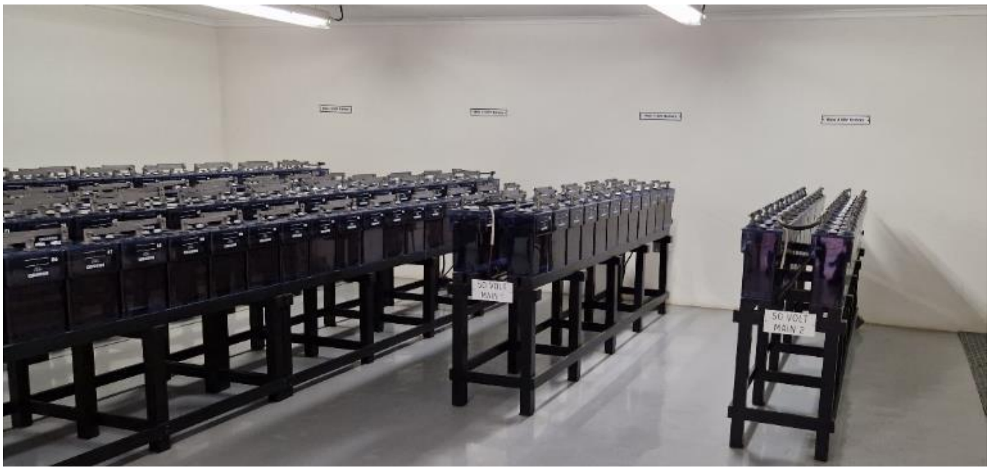

Figure 9-84: Battery room of substation Thuso

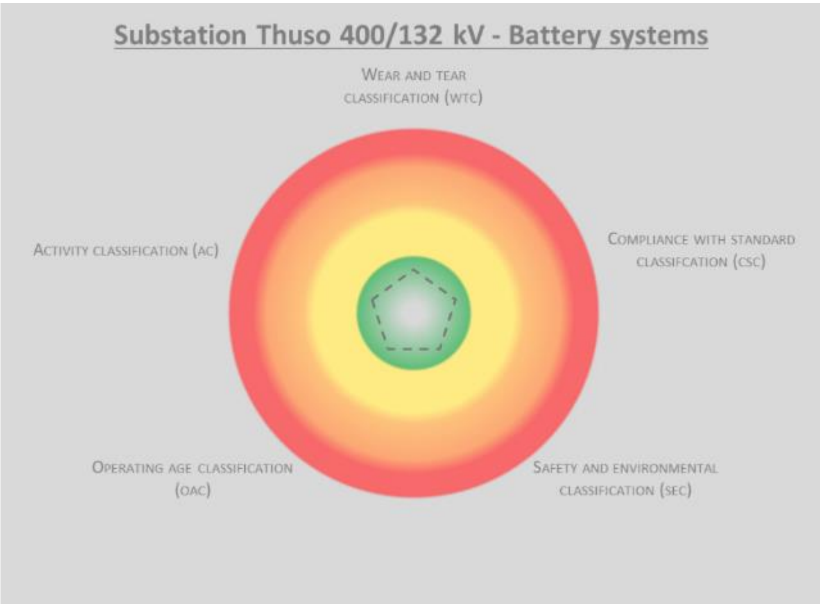

Figure 9-85: Evaluation graphic of Battery systems

Streets/Footpaths/Fences

Activity class of streets, footpaths and fences classification 1 – condition without findings, no measures necessary (see Figure 9-86).

- General condition AC classification 1 – condition without findings.
- Fences and security AC classification 1 – condition without findings.
- Dimensioning AC classification 1 – condition without findings.

The streets, footpaths and fences correspond to the condition that it was commissioned less than ten years ago and is according to the current state of technology. Cleanliness and maintenance condition are excellent (see Figure 9-87).

Figure 9-86: Transportation street and fence of substation Thuso

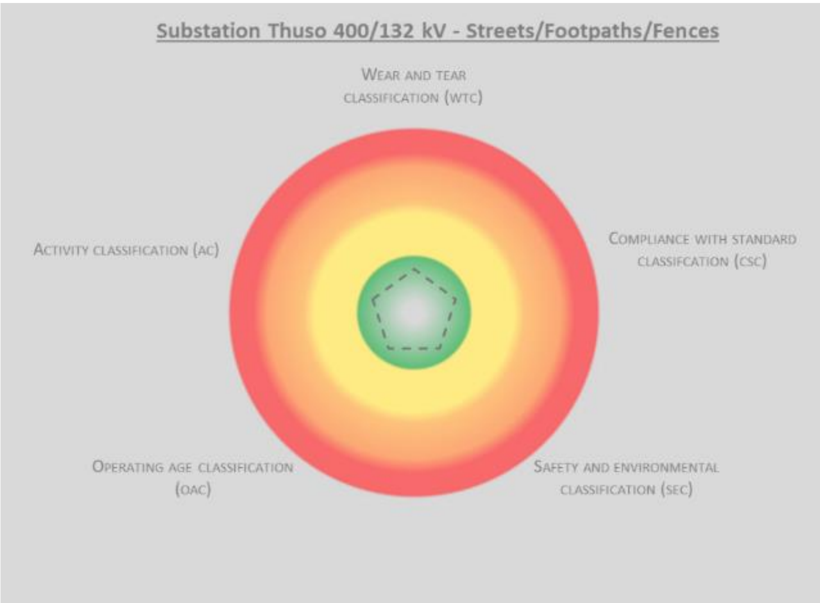

Figure 9-87: Evaluation graphic of streets, footpaths and fences in substation Thuso

Cable ducts

Activity class of cable ducts classification 1 – condition without findings, no measures necessary (see Figure 9-88).

- Ducts AC classification 1 – condition without findings.
- Covers AC classification 1 – condition without findings.
- General condition, weathering AC classification 1 – condition without findings.

The cable ducts correspond to the condition that it was commissioned less than ten years ago and is according to the current state of technology. Cleanliness and maintenance condition are excellent (see Figure 9-89).

Figure 9-88: Cable duct in substation Thuso

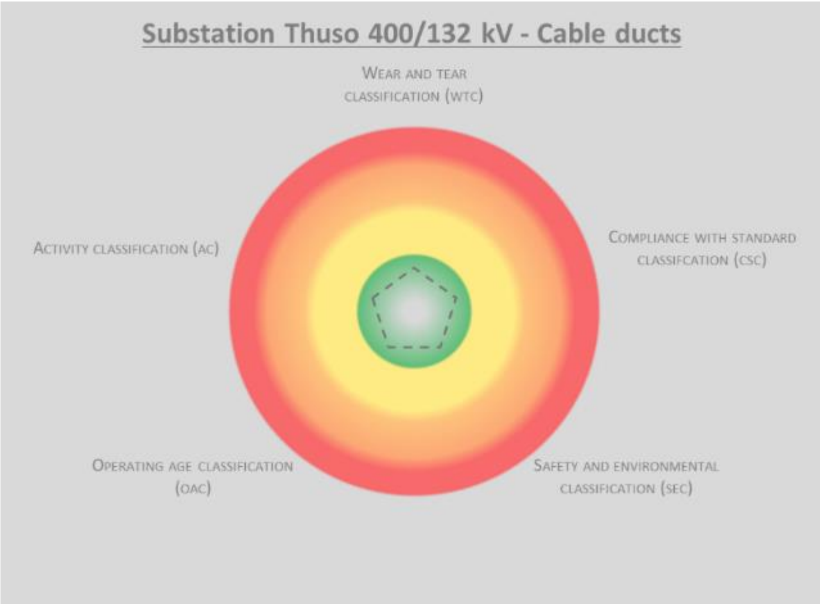

Figure 9-89: Evaluation graphic of cable ducts in substation Thuso

Summary substation Thuso

The Thuso substation was commissioned in 2014. No noticeable wear and tear have been observed on any of the plant components as a result of operation to date (see Figure 9-90). This corresponds to the relatively short period of operation of the substation, but also results from the good maintenance and servicing by the substation staff. Accordingly, no activities are necessary to improve the condition and all assessment classes were classified as 1 (see Figure 9-91, AC 1).

Figure 9-90: Substation Thuso

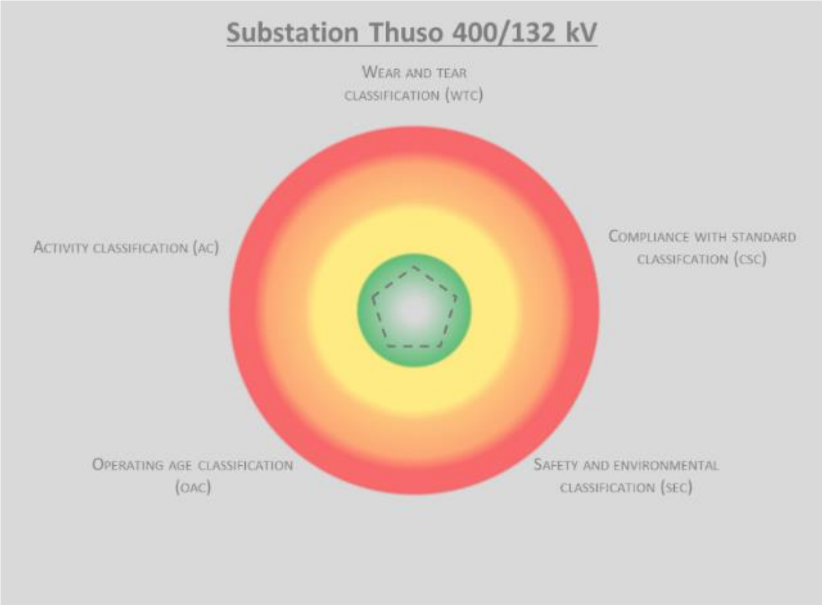

Figure 9-91: Evaluation graphic total substation Thuso

9.4 Assessment Matrices of Evaluated Transmission Assets

The assessment matrices of the various grid facilities are presented in this chapter.

Assessment Matrix Substation Minerva

Substation Minerva 400/275 kV			Classifications				Activity classification
			WTC	CSC	SEC	OAC	AC
		Grade	1,47	1,06	1	1,65	1,45
		range of values	1-4	1-4	1 - 2 - 4	1-4	1-4
Main equipment (incl. Basement & steel construction							
1		**High voltage switchgear 400 and 275 kV**	**1,86**	**1**	**1**	**1,86**	**1,86**
		400 kV switchgear					
		Circuit breakers	2	1	1	2	2
		Disconnectors	2	1	1	2	2
		Instrument transformers	2	1	1	2	2
		Conductor ropes	1	1	1	1	1
		Steel constructions	2	1	1	2	2
		Basements	2	1	1	2	2
		Grounding	2	1	1	2	2
		275 kV switchgear					
		Circuit breakers	2	1	1	2	2
		Disconnectors	2	1	1	2	2
		Instrument transformers	2	1	1	2	2
		Conductor ropes	1	1	1	1	1
		Steel constructions	2	1	1	2	2
		Basements	2	1	1	2	2
		Grounding	2	1	1	2	2
2		**Power Transformers**	**1,56**	**1**	**1**	**1,44**	**1,44**
	1	General	2	1	1	2	2
		Gas in oil analysis last result	3	1	1	2	2
		Bushings	1	1	1	1	1
		Tank	2	1	1	2	2
		Oil leakage	2	1	1	2	2
		Fire protection walls	1	1	1	1	1
		Grounding	1	1	1	1	1
		Steel construction, radiators etc.	1	1	1	1	1
		Basement, oil leakage sump	1	1	1	1	1
3		**Operation building**	**1,15**	**1**	**1**	**1,21**	**1,14**
	1	Outside general		1	1	2	1
		Roof	1	1	1	1	1
		Walls	1	1	1	1	1
		Basement	1	1	1	1	1
		Surface	2	1	1	2	2
		Waterproofing	1	1	1	1	1
		Lightning protection	1	1	1	1	1
		Optical impression	2	1	1	2	2
	2	Inside general	1	1	1	1	1
		Water, wetness	1	1	1	1	1
		Emergency exits, place for exit	1	1	1	1	1
		Ventilation	1	1	1	1	1
		Illumination	1	1	1	1	1
		Cleanness	1	1	1	1	1
Additional components							
4		***Secondary Technology***	**1,5**	**1,5**	**1**	**2**	**1,5**
	1	SCADA, Control equipment	*1*	*1*	*1*	*2*	1
	2	Protection	*2*	*2*	*1*	*2*	2
5		**AC/DC systems**	**1,33**	**1**	**1**	**2**	**1,33**
	1	AC system	1	1	1	2	1
	2	DC system	2	1	1	2	2
	3	AC/DC converters	1	1	1	2	1
6		**Battery systems**	**1**	**1**	**1**	**1**	**1**
	1	Batteries 220 V	1	1	1	1	1
	2	Batteries 50 V	1	1	1	1	1
8		**Streets/Footpaths**	**1,33**	**1**	**1**	**1,67**	**1,33**
	1	General condition	2	1	1	2	2
	2	Fences/Security	1	1	1	1	1
	3	Dimensioning	1	1	1	2	1
9		**Cable ducts**	**2**	**1**	**1**	**2**	**2**
	1	Ducts	2	1	1	2	2
		Covers	2	1	1	2	2
		General condition, weathering	2	1	1	2	2

in co-operation with

Assessment Matrix Substation Craighall

Substation Graighall 275/88 kV			Classifications				Activity classification
			WTC	CSC	SEC	OAC	AC
		Grade	1,52	1,43	1	1,56	1,52
		range of values	1-4	1-4	1 - 2 - 4	1-4	1-4
Main equipment (incl. Basement & steel construction							
1		**High voltage 275 kV and 88 kV switchgear - double busbar (SF_6 GIS)**	**1,40**	**1**	**1**	**1,60**	**1,40**
		275 kV SF6 GIS general condition section A	2	1	1	2	2
		275 kV SF6 GIS general condition section B	1	1	1	1	1
		88 kV SF6 GIS general condition section A	2	1	1	2	2
		88 kV SF6 GIS general condition section B	1	1	1	1	1
		Steel constructions	1	1	1	2	1
2		**Power Transformers**	**1,78**	**1**	**1**	**1,89**	**1,78**
	1	General	2	1	1	2	2
		Gas in oil analysis last result	2	1	1	2	2
		Bushings	1	1	1	1	1
		Tank	2	1	1	2	2
		Oil leakage	2	1	1	2	2
		Fire protection walls	1	1	1	2	1
		Grounding	2	1	1	2	2
		Steel construction, radiators etc.	2	1	1	2	2
		Basement, oil leakage sump	2	1	1	2	2
3		**Operation Building**	**1,43**	**1**	**1**	**1,43**	**1,43**
	1	Outside general	2	1	1	2	2
		Roof	2	1	1	2	2
		Walls	2	1	1	2	2
		Basement	1	1	1	1	1
		Surface	2	1	1	2	2
		Waterproofing	1	1	1	1	1
		Lightning protection	1	1	1	1	1
		Optical impression	2	1	1	2	2
	2	Inside general	2	1	1	2	2
		Water, wetness	1	1	1	1	1
		Emergency exits, place for exit	1	1	1	1	1
		Ventilation	1	1	1	1	1
		Illumination	1	1	1	1	1
		Cleanness	1	1	1	1	1
Additional components							
4		***Secondary Technology***	**2**	**3**	**1**	**2**	**2**
	1	SCADA, Protection, Control equipment	*2*	*3*	*1*	*2*	2
	2	Protection	*2*	*3*	*1*	*2*	2
5		**AC-/DC systems**	**2**	**2**	**1**	**2**	**2**
	1	AC system	2	2	1	2	2
	2	DC system	2	2	1	2	2
	3	AC/DC converters	2	2	1	2	2
6		**Battery systems**	**1**	**1**	**1**	**1**	**1**
	1	Batteries 220 V	1	1	1	1	1
	2	Batteries 50 V	1	1	1	1	1
8		**Streets/Footpaths**	**1**	**1**	**1**	**1**	**1**
	1	General condition	1	1	1	1	1
	2	Fences/Security	1	1	1	1	1
	3	Dimensioning	1	1	1	1	1

in co-operation with

Assessment Matrix Substation Eiger

		Substation Eiger 275/88 kV	Classifications				Activity classification
			WTC	CSC	SEC	OAC	AC
		Grade	1,96	1,5	1	2,03	1,95
		range of values	1-4	1-4	1 - 2 - 4	1-4	1-4
		Main equipment (incl. Basement & steel construction					
1		**High voltage switchgear 275 and 88 kV**	**2,43**	**2,43**	**1**	**2,43**	**2,43**
		275 kV switchgear					
		Circuit breakers	3	3	1	3	3
		Disconnectors	3	3	1	3	3
		Instrument transformers	3	3	1	3	3
		Conductor ropes	2	2	1	2	2
		Steel constructions	2	2	1	2	2
		Basements	2	2	1	2	2
		Grounding	2	2	1	2	2
		88 kV switchgear					
		Circuit breakers	3	3	1	3	3
		Disconnectors	3	3	1	3	3
		Instrument transformers	3	3	1	3	3
		Conductor ropes	2	2	1	2	2
		Steel constructions	2	2	1	2	2
		Basements	2	2	1	2	2
		Grounding	2	2	1	2	2
2		**Power Transformers**	**1,67**	**1**	**1**	**1,78**	**1,56**
	1	General	2	1	1	2	2
		Gas in oil analysis last result	1	1	1	1	1
		Bushings	1	1	1	2	1
		Tank	2	1	1	2	2
		Oil leakage	2	1	1	2	2
		Fire protection walls	2	1	1	2	2
		Grounding	1	1	1	2	1
		Steel construction, radiators etc.	2	1	1	2	2
		Basement, oil leakage sump	2	1	1	1	1
3		**Operation building**	**1,93**	**1,57**	**1**	**2**	**1,93**
	1	Outside general	3	3	1	3	3
		Roof	3	3	1	3	3
		Walls	2	1	1	2	2
		Basement	2	1	1	2	2
		Surface	2	1	1	2	2
		Waterproofing	3	3	1	3	3
		Lightning protection	2	1	1	2	2
		Optical impression	3	3	1	3	3
	2	Inside general	2	1	1	2	2
		Water, wetness	1	1	1	2	1
		Emergency exits, place for exit	1	1	1	1	1
		Ventilation	1	1	1	1	1
		Illumination	1	1	1	1	1
		Cleanness	1	1	1	1	1
		Additional components					
4		***Secondary Technology***	**3**	**3**	**1**	**3**	**3**
	1	SCADA, Protection, Control equipment	*3*	*3*	*1*	*3*	3
	2	Protection	*3*	*3*	*1*	*3*	3
5		**AC-/DC systems**	**2**	**1**	**1**	**2**	**2**
	1	AC system	2	1	1	2	2
	2	DC system	2	1	1	2	2
	3	AC/DC converters	2	1	1	2	2
6		**Battery systems**	**1**	**1**	**1**	**1**	**1**
	1	Batteries 220 V	1	1	1	1	1
	2	Batteries 50 V	1	1	1	1	1
8		**Streets/Footpaths/Fences**	**1,67**	**1**	**1**	**2**	**1,67**
	1	General condition	2	1	1	2	2
	2	Fences/Security	2	1	1	2	2
	3	Dimensioning	1	1	1	2	1
9		**Cable ducts**	**2**	**1**	**1**	**2**	**2**
	1	Ducts	2	1	1	2	2
		Covers	2	1	1	2	2
		General condition, weathering	2	1	1	2	2

in co-operation with

Assessment Matrix Substation Apollo DC

		Apollo converter station 530 kV DC/275 kV AC	Classifications				Activity classification
			WTC	CSC	SEC	OAC	AC
		Grade	1,51	1	1	1,6	1,5
		range of values	1-4	1-4	1 - 2 - 4	1-4	1-4
		Main equipment (incl. Basement & steel construction					
1		**High voltage converter bank and 275 kV switchgear**	**1,47**	**1**	**1**	**1,47**	**1,47**
		Converter bank					
		Converter	1	1	1	1	1
		Insulators	1	1	1	1	1
		Bushings	1	1	1	1	1
		Conductor ropes	1	1	1	1	1
		Steel constructions	1	1	1	1	1
		Basements	1	1	1	1	1
		Grounding	1	1	1	1	1
		275 kV AC switchgear					
		Circuit breakers	2	1	1	2	2
		Disconnectors	2	1	1	2	2
		Instrument transformers	2	1	1	2	2
		Conductor ropes	1	1	1	1	1
		Harmonic filters and capacitors	2	1	1	2	2
		Steel constructions	2	1	1	2	2
		Basements	2	1	1	2	2
		Grounding	2	1	1	2	2
2		**Power Transformers**	**2,11**	**1**	**1**	**2**	**2**
	1	General	2	1	1	2	2
		Gas in oil analysis last result	3	1	1	2	2
		Bushings	2	1	1	2	2
		Tank	2	1	1	2	2
		Oil leakage	2	1	1	2	2
		Fire protection walls	2	1	1	2	2
		Grounding	2	1	1	2	2
		Steel construction, radiators etc.	2	1	1	2	2
		Basement, oil leakage sump	2	1	1	2	2
3		**Operation Building**	**1,36**	**1**	**1**	**1,36**	**1,36**
	1	Outside general	2	1	1	2	2
		Roof	2	1	1	2	2
		Walls	2	1	1	2	2
		Basement	1	1	1	1	1
		Surface	2	1	1	2	2
		Waterproofing	1	1	1	1	1
		Lightning protection	1	1	1	1	1
		Optical impression	2	1	1	2	2
	2	Inside general	1	1	1	1	1
		Water, wetness	1	1	1	1	1
		Emergency exits, place for exit	1	1	1	1	1
		Ventilation	1	1	1	1	1
		Illumination	1	1	1	1	1
		Cleanness	1	1	1	1	1
		Additional components					
4		***Secondary Technology***	**1,5**	**1**	**1**	**2**	**1,5**
	1	SCADA, Protection, Control equipment	*2*	*1*	*1*	*2*	2
	2	Protection	*1*	*1*	*1*	*2*	1
5		**AC/DC systems**	**1**	**1**	**1**	**1**	**1**
	1	AC system	1	1	1	1	1
	2	DC system	1	1	1	1	1
	3	AC/DC concerters	1	1	1	1	1
6		**Battery systems**	**1**	**1**	**1**	**1**	**1**
	1	Batteries 220 V	1	1	1	1	1
	2	Batteries 50 V	1	1	1	1	1
8		**Streets/Footpaths**	**1,67**	**1**	**1**	**2**	**1,67**
	1	General condition	2	1	1	2	2
	2	Fences/security	2	1	1	2	2
	2	Dimensioning	1	1	1	2	1
9		**Cable ducts**	**2**	**1**	**1**	**2**	**2**
	1	Ducts	2	1	1	2	2
		Covers	2	1	1	2	2
		General condition, weathering	2	1	1	2	2

in co-operation with

Assessment Matrix Substation Apollo AC

Substation Apollo 400/275 kV			Classifications				Activity classification
			WTC	**CSC**	**SEC**	**OAC**	**AC**
		Grade	**1,31**	**1,08**	**1**	**1,61**	**1,31**
		range of values	1-4	1-4	1 - 2 - 4	1-4	1-4
Main equipment (incl. Basement & steel construction							
1		**High voltage switchgear 400 and 275 kV**	**1,5**	**1**	**1**	**1,5**	**1,5**
		400 kV switchgear					
		Circuit breakers	1	1	1	1	1
		Disconnectors	1	1	1	1	1
		Instrument transformers	1	1	1	1	1
		Conductor ropes	1	1	1	1	1
		Steel constructions	2	1	1	2	2
		Basements	2	1	1	2	2
		Groundings	2	1	1	2	2
		275 kV switchgear					
		Circuit breakers	2	1	1	2	2
		Disconnectors	1	1	1	1	1
		Instrument transformers	1	1	1	1	1
		Conductor ropes	1	1	1	1	1
		Steel constructions	2	1	1	2	2
		Basements	2	1	1	2	2
		Groundings	2	1	1	2	2
2		**Power Transformers**	**1,11**	**1,11**	**1**	**1**	**1,11**
	1	General	1	1	1	1	1
		Gas in oil analysis last result	2	2	1	1	2
		Bushings	1	1	1	1	1
		Tank	1	1	1	1	1
		Oil leakage	1	1	1	1	1
		Fire protection walls	1	1	1	1	1
		Groundings	1	1	1	1	1
		Steel construction, radiators etc.	1	1	1	1	1
		Basement, oil leakage sump	1	1	1	1	1
3		**Operation Building**	**1,07**	**1**	**1**	**1,36**	**1,07**
	1	Outside general	2	1	1	2	2
		Roof	1	1	1	2	1
		Walls	1	1	1	2	1
		Basement	1	1	1	1	1
		Surface	1	1	1	2	1
		Waterproofing	1	1	1	1	1
		Lightning protection	1	1	1	1	1
		Optical impression	1	1	1	2	1
	2	Inside general	1	1	1	1	1
		Water, wetness	1	1	1	1	1
		Emergency exits, place for exit	1	1	1	1	1
		Ventilation	1	1	1	1	1
		Illumination	1	1	1	1	1
		Cleanness	1	1	1	1	1
Additional components							
4		***Secondary Technology***	**1,5**	**1,5**	**1**	**2**	**1,5**
	1	SCADA, Protection, Control equipment	*1*	*1*	*1*	*2*	1
	2	Protection	*2*	*2*	*1*	*2*	2
5		**AC-/DC systems**	**1,33**	**1**	**1**	**2**	**1,33**
	1	AC system	1	1	1	2	1
	2	DC system	2	1	1	2	2
	3	AC/DC concerters	1	1	1	2	1
6		**Battery systems**	**1**	**1**	**1**	**1**	**1**
	1	Batteries 220 V	1	1	1	1	1
	2	Batteries 50 V	1	1	1	1	1
8		**Streets/Footpaths/Fences**	**1**	**1**	**1**	**2**	**1**
	1	General condition	1	1	1	2	1
		Fences/Security	1	1	1	2	1
	2	Dimensioning	1	1	1	2	1
9		**Cable ducts**	**2**	**1**	**1**	**2**	**2**
	1	Ducts	2	1	1	2	2
		Covers	2	1	1	2	2
		General condition, weathering	2	1	1	2	2

Assessment Matrix Substation Thuso

		Substation Thuso 400/132 kV	Classifications				Activity classification
			WTC	CSC	SEC	OAC	AC
		Grade	1	1	1	1	1
		range of values	1-4	1-4	1 - 2 - 4	1-4	1-4
		Main equipment (incl. Basement & steel construction					
1		**High voltage 400 kV switchgear - double busbar + bypass**	**1**	**1**	**1**	**1**	**1**
		Circuit breakers	1	1	1	1	1
		Disconnectors	1	1	1	1	1
		Instrument transformers	1	1	1	1	1
		Conductor ropes	1	1	1	1	1
		Steel constructions	1	1	1	1	1
		Basements	1	1	1	1	1
		Grounding	1	1	1	1	1
2		**Power Transformers**	**1**	**1**	**1**	**1**	**1**
	1	General	1	1	1	1	1
		Gas in oil analysis last result	1	1	1	1	1
		Bushings	1	1	1	1	1
		Tank	1	1	1	1	1
		Oil leakage	1	1	1	1	1
		Fire protection walls	1	1	1	1	1
		Grounding	1	1	1	1	1
		Steel construction, radiators etc.	1	1	1	1	1
		Basement, oil leakage sump	1	1	1	1	1
3		**Operation building**	**1**	**1**	**1**	**1**	**1**
	1	Outside general	1	1	1	1	1
		Roof	1	1	1	1	1
		Walls	1	1	1	1	1
		Basement	1	1	1	1	1
		Surface	1	1	1	1	1
		Waterproofing	1	1	1	1	1
		Lightning protection	1	1	1	1	1
		Optical impression	1	1	1	1	1
	2	Inside general	1	1	1	1	1
		Water, wetness	1	1	1	1	1
		Emergency exits, place for exit	1	1	1	1	1
		Ventilation	1	1	1	1	1
		Illumination	1	1	1	1	1
		Cleanness	1	1	1	1	1
		Additional components					
4		***Secondary Technology***	**1**	**1**	**1**	**1**	**1**
	1	SCADA, Control equipment	*1*	*1*	*1*	*1*	1
	2	Protection	*1*	*1*	*1*	*1*	1
5		**AC/DC system**	**1**	**1**	**1**	**1**	**1**
	1	AC system	1	1	1	1	1
	2	DC system	1	1	1	1	1
	3	AC/DC converters	1	1	1	1	1
6		**Battery systems**	**1**	**1**	**1**	**1**	**1**
	1	Batteries 220 V	1	1	1	1	1
	2	Batteries 50 V	1	1	1	1	1
8		**Streets/Footpaths/Fences**	**1**	**1**	**1**	**1**	**1**
	1	General condition	1	1	1	1	1
	2	Fences/Security	1	1	1	1	1
	3	Dimensioning	1	1	1	1	1
9		**Cable ducts**	**1**	**1**	**1**	**1**	**1**
	1	Ducts	1	1	1	1	1
		Covers	1	1	1	1	1
		General condition, weathering	1	1	1	1	1

Assessment Matrix OHL Section

Overhead Line Tower 1APO/THU013			Classifications			Activity classification
		WTC	CSC	SEC	OAC	AC
	Grade	1,5	1	1	1,5	1,5
	range of values	1-4	1-4	1 - 2 - 4	1-4	1-4
Main equipment (incl. Basement & steel construction						
1	**Tower**	**2,00**	**1**	**1**	**2,00**	**2,00**
	Basements	2	1	1	2	2
	Steel construction	2	1	1	2	2
	Coating	2	1	1	2	2
	Groundings	2	1	1	2	2
2	**Security**	**2**	**1**	**1**	**2**	**2**
1	Prevention of unauthorised climb up	2	1	1	2	2
	Prevention of vandalism	2	1	1	2	2
3	**Insulation chains**	**1**	**1**	**1**	**1**	**1**
1	General condition	1	1	1	1	1
	Cleanness	1	1	1	1	1
	Glass cups condition	1	1	1	1	1
Additional components						
4	***Marking***	**1**	**1**	**1**	**1**	**1**
1	Label condition	*1*	*1*	*1*	*1*	1
2	Name of line	*1*	*1*	*1*	*1*	1
3	Number of tower	*1*	*1*	*1*	*1*	1