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# *Enhancing Reliability Through Strategic Maintenance Schedule of Power Generating Units*

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## *Abstract*

*Key factors influencing steam turbine unit reliability are provided in this study, along with mitigation techniques and optimization tactics to increase unit reliability for the period between 2021 to 2023. Articles covering the application of various maintenance strategies were researched, and it was discovered that each strategy has its own distinct ideas, guiding principles, methods, and difficulties for actual industrial use. Mixed method design, also called explanatory sequential, which incorporated both qualitative and quantitative approach, was used in this study to identify contributing factors arising during the execution of maintenance projects that resulted in the unreliability of steam turbine units in operation by interviewing members of the maintenance execution team. The article ends with important suggestions for further study by outlining maintenance optimization techniques that would improve the operational units' reliability. It can be concluded that the age of the steam turbine units has a major effect on selecting a suitable maintenance strategy that will ensure reliability of units in operation.*

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## Introduction

The innovation of electricity in the 19th century created a paradigm shift which is still evident today through the 4th industrial revolution [1]. The global demand for electricity is rapidly increasing and requires uninterrupted supply. Nguea and Kaguendo highlighted electricity as one of the fundamental aspects of modern life because it powers businesses, homes, educational and health facilities, businesses, facilitate transportation, communication and connectivity [2]. Several researchers have explored the maintenance of steam turbines, but little research on the reliability of steam turbine units in operation has been explored.

As a result, there are complex literatures on steam turbine maintenance strategies, but they do not address the direct impact of poor maintenance on steam turbine efficiency which affects reliability. Sabri et al in their study, investigated reliability of steam turbine critical components and mentioned probabilistic or deterministic approach as technique used to determine the system reliability [3]. Probabilistic analysis focuses on the operational performance of maintenance. The Weibull probability distribution is a commonly employed method for evaluating the reliability of steam turbine systems. The deterministic approach to system reliability analysis deals with how and why a system fails, as well as how it can be designed to prevent such failures from occurring or reoccurring. This entails analyzing past field failure reports, comprehending the scientific theory underlying the failure and determining the extent and function of maintenance policies.

Power plants are in charge of creating electricity that will be transmitted and delivered to consumers. Since the demand for reliable electricity is constantly growing, power plants and their component parts must always be accessible and reliable. The South African coal-fired power plants produce more than 70% of the nation's electricity; therefore, it becomes critical to increase the power plant steam turbine units' reliability by preventing unplanned breakdowns that cause power outages [4]. There could be serious societal repercussions from a power outage if the power plants are not properly maintained and consistently running/operating [5]. Power plant steam turbine units are maintained at set interval periods as guided by the original equipment manufacturer (OEM). The purpose of maintenance is to increase the equipment's lifespan or, at the very least, postpone the next issue that would need a costly repair [6]. Common causes of steam turbine unreliability are the failure of turbine blades, generator, bearings and corrosion pipelines, sensors, governor, steam sealing leakage, rotor vibration and rotor imbalance [7].

## Objectives

The objective of this study was to find the reasons why steam turbine units in coal-fired power stations continue to operate unreliably despite undergoing routine maintenance, to establish maintenance strategies that will ensure reliability of these units, and to improve the reliability of ageing steam turbine components. Reliability of operating units will result in fewer unplanned malfunctions, guaranteeing a steady supply of electricity and ultimately avoiding loadshedding. Thus, the study aims to answer the following research questions; (1) Why are steam turbines unreliable in operation even when scheduled maintenances are performed? and (2) How can maintenance strategies be optimized to ensure reliability of energy generating steam turbines including ageing steam turbines components?

## Literature Review

There are several methods available for maintenance to address problems and increase equipment reliability. Ameeri et al in their study about maintenance strategies' effective and ineffective effects on electric power plants attest that choosing the right maintenance plan is essential to guaranteeing that all machinery and equipment run smoothly to enhance overall plant reliability and availability [8]. In recent years, maintenance has become a significant burden for companies. As a result, contemporary businesses are looking for methods to improve maintenance at a higher degree through the use of various strategies [9].

Maintenance strategies employed on various energy generating plants may differ in terms of approach. Maintenance methods used as recommended by the manufacturers at predetermined intervals are discussed as follows; Corrective maintenance is done to return an asset to its pre-damaged state [10]. Reliability and availability may be impacted by the employment of corrective maintenance strategies on steam turbine units, in which a component is replaced or fixed after

failing [11]. The definition of preventive maintenance, also known as routine maintenance, is "an equipment maintenance strategy based on replacing, or restoring, an asset at a fixed interval regardless of its condition," so preventive maintenance jobs include planned restoration and replacement activities [12].

The condition-based maintenance (CBM) approach keeps track of an asset's real state to determine what maintenance is required. Only when certain signs indicate declining performance or impending failure should maintenance be carried out [13]. The equipment's working state, which can be determined by a number of monitoring measures like vibration, temperature, lubricating oil, pollutants, and noise levels are used in CBM to track the equipment's lifespan (age).

CBM is driven by the fact that 99 percent of equipment failures are preceded by certain conditions, signals, or indications that a failure is imminent. As a result, CBM is required for improved equipment health monitoring, reduced life cycle costs and preventing catastrophic failures, etc. [14]. Using real-time circumstances, predictive maintenance (PdM) is a data-driven method to maintenance that forecasts when equipment will require maintenance [12]. Predictive maintenance is also viewed as a more sophisticated version of CBM that uses a variety of process metrics obtained from online sensors to identify whether the equipment is approaching failure or departing from stable operating conditions [10].

Reliability-Centered Maintenance (RCM) aims to optimize maintenance procedures by identifying the potentially vital functions of a system, piece of equipment, or asset. The most important assets are those that frequently fail or that, in the event of a failure, have some hazardous implications. Although it is almost impossible to stop every failure, it is possible to create a maintenance strategy that might stop some of them. RCM's main goal is to control the effects of failures rather than necessarily stop them [15].

## Methods

Mixed method design, also called explanatory sequential, which incorporated both qualitative and quantitative approach was used in this study. A case study research approach was used to establish maintenance strategies that will ensure reliability of steam turbine units when in service by finding out why steam turbine units are unreliable in operation even when scheduled maintenances are performed. A secondary data collection method was employed to gather quantitative data from steam turbine operating manuals to validate the unreliability of units in operation, despite maintenance activities. Semi-structured interviews were used in this study to gather qualitative data through in-person and telephone interviews. Participants from ten different coal-fired power plants provided new study data through these interviews. Open-ended interview questions were used to ask participants about the factors that contribute to the operational unreliability of steam turbine units and the strategies used to mitigate those factors.

A case study has been considered to optimise maintenance strategies performed during maintenance of steam turbine units in a coal-fired power station of the main South African power supplier. The power utility has 14 coal-fired power stations with each power station having six steam turbine units (Table 1). Every year, the power utility develops a maintenance schedule that indicates steam turbine units that will undergo maintenance/repairs as guided by original equipment manufacturer.

**Table 1:** Power Stations and Unit Count

| No. | Power Station | Unit Count |
|---|---|---|
| 1 | Arnot | 6 |
| 2 | Camden | 6 |
| 3 | Duvha | 6 |
| 4 | Grootvlei | 6 |
| 5 | Hendrina | 6 |
| 6 | Kendal | 6 |
| 7 | Kriel | 6 |
| 8 | Kusile | 4 |
| 9 | Lethabo | 6 |
| 10 | Matla | 6 |
| 11 | Majuba | 6 |
| 12 | Matimba | 6 |
| 13 | Medupi | 4 |
| 14 | Tutuka | 6 |

## Data Collection

In order to validate the unreliability of units in operation

even though maintenance activities were performed, quantitative data was gathered from 10 steam turbine operating manuals using the secondary data gathering approach. After the completion of a unit maintenance, an operating manual is written and stored for record keeping. From each operating manual the unit maintenance description, operating history, and OEM maintenance guidelines data were extracted and analysed. The data were collected from 10 coal-fired power stations over a period of three years (2021-2023) during which load shedding in South Africa was in force. The data from each operating manual were classified in the form required for analysis (i.e., power station lifespan, unit accumulated running hours and availability factor.)

Semi-structured interviews were used as an instrument to collect new research qualitative data from 10 participants using open ended interview questions to gather information from the participants' experiences, difficulties, annoyances, and viewpoints regarding unreliability of energy generating units. The questions included the background of the study, factors contributing to the unreliability of units and optimization strategies. Participants were interviewed one-on-one at their place of employment in a suitable office. The interview session was noted down, recorded, and shared with the participant for verification. The interviewee's perspective in relation to the research and interview questions was analysed through values coding. Subsequently, the outcomes were classified to align with the data nodes for analysis, recommendations, and conclusions.

## Results and Discussion

### Numerical Results

From the interview sessions conducted, participants' common viewpoints regarding the causes of unreliability of steam turbine units were captured.

The research participants: service engineer, technicians, OEM engineers, project managers and senior engineers who are directly involved with maintenance of steam turbine units noted the following factors as causes of unreliability of steam turbine units in operation: spares scarcity, shortage of maintenance skills, illicit activities, ageing units, poor operation of units in service, lack of training and mentoring, Lack of inter-departmental collaboration, poor leadership skills, poor quality control, lack of planning, outdated technology, and interference from senior management.

The qualitative data presented the causes of unreliability of units and optimization strategies as outlined by research participants. The qualitative research results of the study showed that the following factors contribute to steam turbines' unreliability in operation, even when planned maintenance is carried out: a shortage of spare parts when maintenance is due, a shortage of maintenance skills from resources, illicit activities, aging units, poor operation of units in service, a lack of training and mentoring, a lack of interdepartmental collaboration, poor leadership skills, poor quality control, a lack of planning, outdated technology, and interference from senior management.

The study explored maintenance strategies that will enhance the reliability of the steam turbine units when in service. The research participants who are directly involved with maintenance of steam turbine units noted the causes of unreliability of steam turbine units and mitigation factors. The noted common causes of the unreliability of steam turbines were categorised into three as turbine maintenance and equipment, power plant management and personnel skills and development. The spares scarcity is caused by the unavailability of appropriate spare parts when maintenance is supposed to take place, the ageing units where their operational dependability is impacted by age, and outdated technology which is evident when units are serviced using antiquated maintenance technology. Reliability may be impacted, leading to unanticipated failures. The identified factors are due to the lack of proper planning for a maintenance project, lack of accountability from project coordinators who begin projects without necessary equipment, the use of older equipment which frequently breaks down, operating units which have a lifespan of over 40 years and maintenance tasks carried out using techniques that were created over 40 years ago. To alleviate this issue, strategic spares must be procured, units repaired with reliable spares, spares availability guaranteed before beginning a maintenance project, interval periods between maintenance projects reduced, and cutting-edge repair and inspection techniques applied to keep up with emerging technologies and ensure that technically inclined personnel are involved with every process during maintenance activities.

The manner in which a power plant is managed impacts the plant's reliability [16]. Poor leadership skills, lack of inter-departmental collaboration, poor quality control, lack of planning, illicit activities, and interference from senior management were identified as the core indicators to poor power plant management. These indicators were influenced by various departments who lacked dedication and a sense of urgency when working autonomously to perform maintenance tasks. Some departments had conflicting mandates because they had diverse interests during maintenance projects, while others operated in silos with unclear directives. Therefore, not all departments knew the urgency of the maintenance project. It is vital for superiors to have good leadership skills to ensure that the team performs effectively to achieve the objectives of the projects because the lack of project management skills and project managers who do not take note of the past experiences or optimize the project schedule will cause the plant to have skilled individuals working under a manager who does not understand their function.

For a project to be deemed successful, it must meet its objectives, and the quality of the job done should be satisfactory, but some project managers to an extent tend to compromise quality over committed project end date. Where quality is overlooked in the race of time, starting a maintenance project without having a detailed project schedule will cause project delays because planning was not done correctly, as per the project lifecycle methodology, which requires following the best practice project management planning process. In some cases, senior management make critical decisions regarding maintenance and operation of steam turbine units while they are not technically minded when it comes to steam turbine units, like prioritizing project end date over raised technical issues and deciding, based on energy demand as opposed to maintenance philosophy and machine health.

Suggested methods to address the issues include: the involvement of technically capable personnel in every maintenance project or activity, encouraging departments to work as a team where project managers mainly focus on the administrative aspect of the project and expediting things that technical team requires, which excludes them from making technical decisions. This will ensure that departments have clear mandates. Leaders must adopt the lead-by-example style by upholding high standards and relevant leadership skills for their key positions, have skilled maintenance resources who will enforce high quality standard during maintenance execution so that the planned maintenance process covers the pre stage of the project execution phase and post project phase. Readiness planning should be done 12 months before the start of the project. Senior management needs to practice a concept of "balcony and the dance floor" allowing only the engineering team to make critical engineering decisions [11].

Much emphasis has been put on improving power plant management and equipment, but little on personnel development, and this has been highlighted as one of the causes of unreliability of steam turbine units. When the maintenance team lack maintenance skills or display poor maintenance skills, they will affect the reliability of the steam turbine unit due to their lack of turbine maintenance knowledge and due to their low skill accuracy; they will have poor turbine operation skills when the units are in service, and therefore, they are likely to operate the unit outside the OEM guidelines, which will lead to unexpected failures.

To empower and develop maintenance personnel, power plant management must work on ways to upskill personnel to improve their efficiency, ensure that maintenance human resources have the right technical qualifications, relevant experience of more than five years, and with traceable good track record, encourage operators to undergo OEM awareness and refresher training so that they will be able to provide OEM training and have mentorship programs for critical maintenance personnel under their management to maintain the reliability and effectiveness of the steam turbine units.

With 4th industrial revolution being the talk of town lately it is important to understand the impact of energy policies, since the application of energy policies in maintenance of energy generating units is a new trend in the industry 4.0 era [17]. Incorporating some energy policies in the maintenance of steam turbine units can lead to maintenance cost reduction. With reduced cost of maintenance, strategies can be optimized to ensure reliability of energy generating units to ensure uninterrupted supply of power to all consumers.

In this era of 4th industrial revolution, the world is advocating zero emissions energy policies [18]. As noted, fossil fuels are used in generating steam to operate steam turbines which is opposing the objective of the energy policy.

## Graphical Results

Each power station's lifespan as of 2023, which covers the research period, is presented in Figure 1, together with total unexcepted failures or breakdowns each station encountered. Since the functioning steam turbine units have varying lifespans, the data shows that the unit lifespan can have an impact on its reliability as most aged units failed frequently.

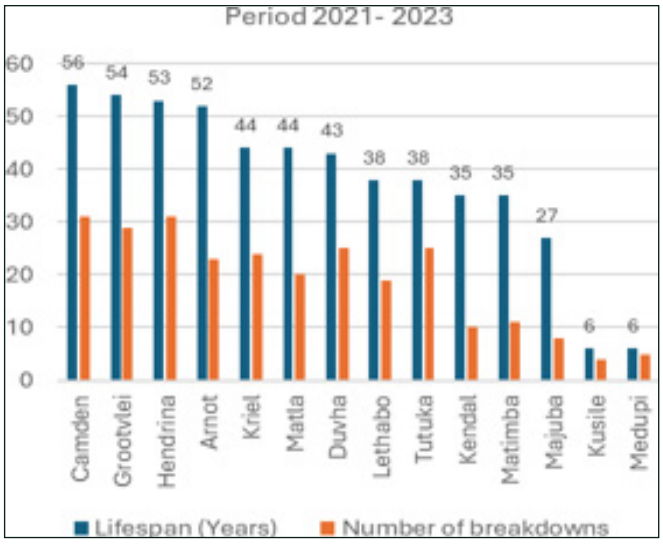



**Figure 1**: Lifespan & Breakdowns

**Figure 2** illustrates the difference between the OEM expected running hours following repair or maintenance and the actual running hours accrued prior to the units' unaccepted failure. According to OEM requirements, the Hendrina unit 1, Kriel unit 3, Kusile unit 2, Duvha unit 1, and Medupi unit 2 should have operated for 80,000 hours before they failed. The data analysis reveals that the units' premature failures prevented them from reaching the desired outcome. Identical to the other units they likewise fell short of their predetermined goal.

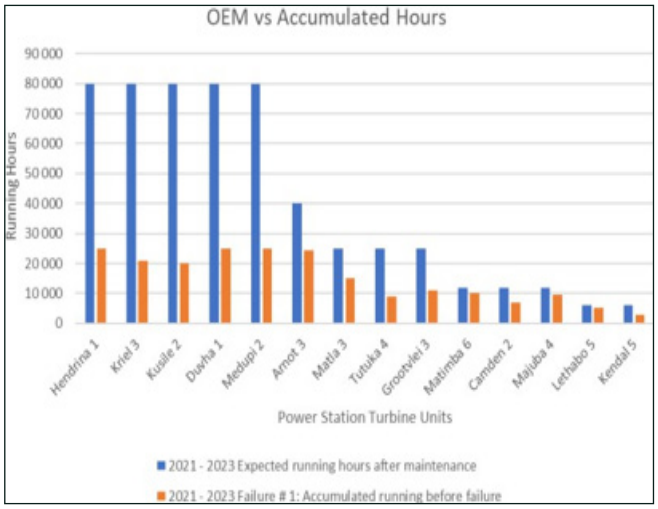



**Figure 2:** OEM vs Accumulated Hours Chart

**Figure 3** shows the number of units that are maintained or repaired annually, the units that failed too soon after maintenance, the total number of units that are still in operation or that can provide energy because some units failed too soon after being repaired, and the availability factor, which shows the percentage of steam turbine units that are in operation.

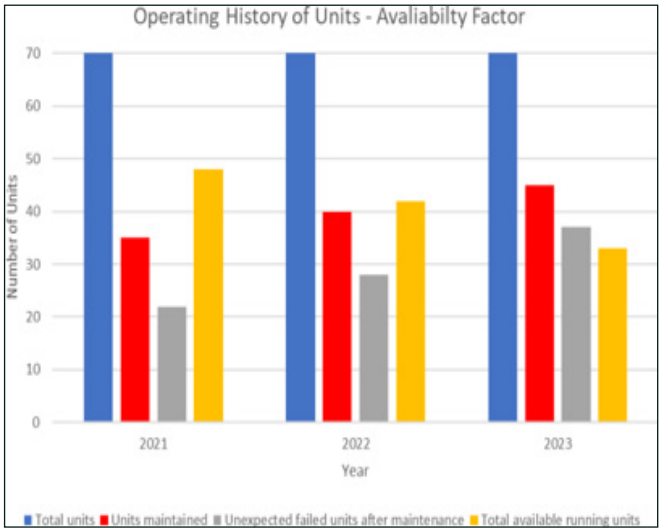



**Figure 3:** Steam Turbine Units Operating History Chart

In order to understand the performance, capability, and limitations of the steam turbine units, a power station's availability factor is essential. Between 60% and 90% is the acceptable availability factor for a power plant [15].

The availability factor was calculated using equation (1) below:

$$Af = \frac{Ru}{(Ru+Fu)} \qquad (1)$$

Af: Availability Factor
Ru: Repaired units
Fu: Failed units

From 2021 to 2023, the availability factor declined, according to the data in Figure 4. Unexpected unit failures are probably the reason for the availability factor's gradual drop over time.

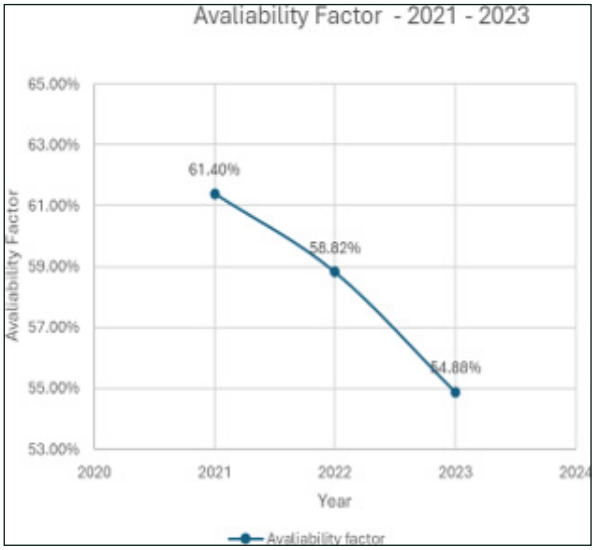



**Figure 4:** Power Plant Availability Factor Chart

The quantitative data gathered from the power utility steam turbine operating manuals such as the unit maintenance description, operating history, and OEM maintenance guidelines showed that the lifespan and operating hours are factors that cause the unreliability of units in operation and ultimately affect the power plant availability factor.

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A power plant's total performance is impacted by the longevity of its steam turbine units [19]. Although power plants are supposed to last 40 years, 50% of the power plants under study were in operation for longer than that, necessitating OEM-recommended maintenance on the steam-generating turbine components. This demonstrates how the longevity of the steam turbine units and power station affect the dependability of the electrical supply. After maintenance, some of the turbine units are meant to function for 80,000 hours, but they experienced break down before they reached that amount.

The collected data between the period of 2021 and 2023 across various power stations showed that all units failed to reach the expected running hours provided by the OEM. The failure of steam turbine units to reach the expected running hours also affects the availability factor of the power station. As it is noted in figure 4, during the period between 2021 and 2023, the availability factor was low and below the set acceptable target range of 60% to 90%. Therefore, the unreliability of units which leads to interruption of electricity supply can be curbed by ensuring that steam turbine units are able to reach the expected running hours after being maintained.

## Proposed Improvements

Maintenance projects are seen as complex projects which require proper planning in time to ensure successful completion. For improvement, planning process for scheduled maintenance should start with a project contract preparation and planning phase 24 months before the start of the project. The major stakeholders involved should be the project managers and engineers. The project managers will take the lead in terms of managing the planning process, arranging meetings and gathering required information from respective role players. A month before the start of the project, the mobilisation phase should commence, which involves the finalisation of the required human resources and verification of their qualifications.

Steam turbine units consist of various components with different functions that ensure the turbine system operates as a whole and effectively. To further improve the efficiency of the turbine unit in operation, every turbine component should be maintained with a maintenance strategy that suits that specific component based on the component characteristics. Elements of corrective and preventative maintenance strategies should be integrated since different types of maintenance strategies where derived from the principle of corrective and preventative maintenance strategies [20]. Doing the integration process during maintenance of steam turbine units will ensure reliability of the whole turbine system in operation. The power utility should invest in training and development of all parties involved during

the maintenance of steam turbine units, using the OEM to provide the required training. In addition, during execution of maintenance projects, the OEM should provide a technical field advisor (TFA) to physically work with the maintenance team so as to guide the team and to facilitate the skills transfer process. The benefit of providing OEM training will equip the maintenance human resources with knowledge of detailed OEM standards and procedures related to the maintenance activities of steam turbine units, so they can perform tasks accurately.

## Validation

The calibre of participants, the use of different instruments for data collection, and the validation of the results from one level of data collection and analysis to another ensured the validity of the research results. In accordance with the triangulation principle, additional data collection instruments included information gathered from participant interviews, data analysis from the steam turbine maintenance operating manuals database, and correlations with OEM maintenance interval guidelines [21,22].

## Conclusion

The study's goal was to develop maintenance plans that would guarantee steam turbine reliability while they are operating. This stemmed from the fact that, despite ongoing maintenance being performed on the steam turbines in accordance with the maintenance schedule, malfunctions continue to occur. The objectives of the study were to identify the causes of steam turbine units' unreliability in operation, even when planned maintenance is carried out, and to develop maintenance strategies that will increase the reliability of aging steam turbine units. Utilizing a quantitative research methodology, information from operating manuals was gathered to establish whether the units are reliable or unreliable in operation. To find out why steam turbines are unreliable in operation even when scheduled maintenance is carried out, the qualitative method employed semi-structured interviews to collect information from those who are directly involved in steam turbine unit maintenance.

Interviewing maintenance staff who work on steam turbine unit maintenance helped to achieve the study's goals. By supplying elements that contribute to the unreliability of units even when maintenance is conducted, the participants contributed their knowledge and experiences about steam turbine units. In order to confirm the unreliability of units in operation by presenting the technical facts, the study also collected operational histories of steam turbine units from operating manuals. Unit unreliability can be reduced by optimizing certain factors and putting solutions into practice. Additionally, a plant-based maintenance approach was developed to address the age-related unreliability of units.

According to the study, current maintenance practices have an impact on the steady supply of electricity. However, by incorporating the mitigation strategies suggested by the participants will guarantee the steam turbine units' operational reliability and a steady supply of electricity by preventing unplanned unit failures. Although the power utility contains nuclear, hydro, wind, and gas energy generating units, only coal-fired power plants were taken into consideration for the study. Thus, the information from nuclear, hydro, wind, and gas power plants were not collected, meaning the factors that participants indicated as contributing to the unreliability of units are not the only ones.

While the energy policy is advocating for decarbonization, it is important to note that optimization of steam turbine maintenance strategies will lead to efficient operation and reliability of units and achieve acceptable emissions levels.

When steam turbine units are operating, their dependability is essential since the nation will gain from preventing loadshedding. Without loadshedding, educational institutions, the agricultural sector, domestic and international travel, the tourism industry, small businesses, health care providers, and many other essential services would all operate smoothly without interruptions from the erratic supply of electricity. Ordinary South Africans would also be able to carry out their daily social activities without any problems. In the long run, preventing load shedding is crucial. For future studies on the same subject should include factors contributing to the unreliability of units from nuclear, hydro, wind and gas power station to determine whether factors identified in coal-fired plants are synonymous to them.

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