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Optimization Strategies for Reducing Power Losses in Thermal Power Stations: A Case Study of a Major Power Station in Ughelli

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ABSTRACT: Thermal power plants in Nigeria face significant challenges due to persistent power losses, undermining efficiency, economic growth, and environmental sustainability. This study investigates operational inefficiencies at a major thermal power station in Ughelli, Delta State, using five years of data (2017–2021). Analytical tools employed include reliability indices, thermal efficiency calculations, capacity factor evaluation, and international benchmarking. Results revealed that outdated equipment, poor maintenance, and lack of predictive diagnostics were key contributors to power losses. Reliability indices showed an average below 80%, falling short of the 90% global benchmark, with monthly reliability ranging from 41.77% to 74.24%. Capacity factors fluctuated widely, from 36.94% to 82.02%, indicating underutilization of available capacity. Thermal efficiency remained critically low, between 0.000002% and 0.000003%, highlighting severe energy waste. The study recommends adopting predictive maintenance using machine learning and statistical models, modernizing aging infrastructure, and improving operational management. Comparative analysis emphasizes the need for alignment with international best practices to enhance plant reliability and sustainability. Implementing these strategies can significantly reduce losses, boost performance, and help meet Nigeria's growing energy demands more efficiently.

KEYWORDS: Capacity Factor, Operational Efficiency, Power Losses, Reliability Indices, Thermal Efficiency

1.0 INTRODUCTION

Power generation is critically important for industrial and economic growth, and the efficiency and reliability of power stations significantly influence energy availability [1]. However, Nigeria's energy sector has been encountering substantial challenges, particularly in thermal power plants, which experience considerable power losses [2]. These losses adversely affect not only the stability of the energy grid but also economic progress, as Nigeria consistently faces higher power demands than supply capabilities. For example, in 2013, Nigeria had a generation capacity of approximately 10,400 MW, but only around 6,000 MW was accessible to end-users, highlighting the significant shortfall in energy provision [3].

Further compounding these issues are reliability problems within local substations, such as the Oria Abraka 33/11 kV power substation in Delta State, Nigeria. Analysis conducted at this substation from 2017 to 2022 reveals persistently low power availability, with significant outage durations severely impacting local economic and industrial activities. The highest monthly power availability recorded was in January 2020, with an average of only 6.68 hours of supply per day [4].

The major power station under study in Ughelli, Delta State, exemplifies these issues, facing persistent power losses despite considerable investment efforts aimed at improving reliability and efficiency [5]. The station's inefficiencies primarily stem from outdated equipment, inadequate maintenance practices, and poor operational planning [6]. Additionally, enhancing power quality through technologies such as Voltage Source Converter-based High Voltage Direct Current (VSC-HVDC) transmission can significantly contribute to improving transient stability and managing reactive power, thereby minimizing power losses and stabilizing power flow [7].

Furthermore, effective monitoring and real-time analysis of operational parameters, including voltage, current, frequency, and power factor, are essential for optimizing transformer reliability and mitigating power losses. Employing precise measurement equipment like the Power Analyzer PCE-PA 8000 aids in identifying and addressing anomalies proactively, thus improving overall equipment management and reducing energy losses [8].

The integration of advanced power system configurations, such as those incorporating solid oxide fuel cells, gas turbines, steam cycles, and organic Rankine cycles, along with carbon capture technologies, also presents significant opportunities for reducing environmental impact and enhancing overall efficiency. Systems employing these integrations have shown reduced CO_2 emissions and improved energy utilization, demonstrating their potential to significantly enhance power plant performance and sustainability [9].

This study aims to identify the root causes of power losses at the major thermal power station in Ughelli and propose viable strategies to enhance operational efficiency. By analyzing operational data from 2017 to 2021 and comparing performance against international standards, the study will highlight areas for improvement and suggest practical interventions. The overarching objective is to provide targeted solutions that not only reduce power losses and operational costs but also improve the reliability and environmental sustainability of Nigeria's energy sector [10].

[1] Energy scarcity is a big issue all around the world, especially in countries that rely heavily on fossil fuels for power. They looked at the KOSPO power plant and found out that a lot of energy was being wasted because of old equipment and inefficient power generation processes. Their study suggested solutions to fix these problems, but it didn't compare the plant's reliability to international standards, which would have helped to measure how well the plant was actually doing. This is important for Ughelli Power Station, because comparing its performance with global standards could help find ways to make it work better.

[11] compared coal-fired and gas-fired power plants. They found that gas-fired plants work more efficiently, with 33.4% efficiency compared to coal plants' 29.1%. This shows how important it is to focus on energy efficiency, especially when thinking about reliability in power plants. The same could apply to Ughelli Power Station, because if its energy efficiency was better, the plant's overall performance could improve.

[12] talks about how Nigeria's population growth and new technology have led to an increase in demand for electricity. But even with all this growth, Nigeria's power system still faces reliability problems, with frequent power cuts and outages. This is a big issue at Ughelli Power Station too, where the plant often struggles to provide enough power. Airoboman's study suggests that reliability needs to improve, but doesn't explore solutions like energy storage that might help solve some of these problems, something that could really help Transcorp Power Station.

[2] used something called Weibull reliability analysis to look at the Afam Thermal Power Plant's reliability. They found that if the plant optimized its overhaul schedules and reduced failure rates, it could improve reliability a lot. This shows that predictive maintenance is important because it can help predict when something will break before it causes a problem. Transcorp Power Station could benefit from using similar strategies to predict when equipment will fail and fix problems before they lead to major power losses.

[13] reviewed how using probability methods could improve the reliability of Nigerian thermal power plants. They found that the plants are often underused because of failures and poor maintenance. They suggested using modern tools like machine learning to predict when the plants might fail, but they didn't actually apply these tools in their study. This idea could help Ughelli Power Station, as using new technology to predict problems can make the plant more reliable and reduce downtime.

[14] built a model using probability tools to measure how reliable thermal power plants are. Their study showed that reliability is really important for keeping power plants working efficiently. But they didn't talk about how focusing on reliability could impact the economy or society, which is something important when we think about the bigger picture of making plants more reliable.

[16] argued that maintaining high reliability in power systems is key for a country's economic growth. They compared two types of maintenance models deterministic and probabilistic and found that probabilistic models work better at increasing reliability. But their study didn't really consider the social or environmental effects, which is also important when evaluating power plants' performance. Ughelli Power Station could definitely use a probabilistic maintenance model to improve its reliability, but it also needs to think about the environmental effects, such as emissions from burning fuel, which can be reduced by making the plant more efficient.

The studies reviewed show that there's a lot of research about improving the reliability of power plants, but there's still a need for more focused strategies. Many of the studies didn't compare local plants to global standards, or didn't look at how plants impact the environment. This study aims to fill that gap by looking at the Ughelli Power Station and suggesting improvements based on modern tools like predictive maintenance, updated infrastructure, and better management. By focusing on these strategies, Ughelli Power Station can reduce power losses, improve its performance, and contribute to the energy sector in Nigeria.

2. MATERIALS AND METHODS

2.1 Study Area

The research was conducted at a major power generation facility located in Ughelli, Delta State, Nigeria. This facility comprises four divisions, namely Delta I, Delta II, Delta III, and Delta IV, collectively capable of generating up to 972 MWh. The primary aim of this research was to assess the operational effectiveness and efficiency of the facility, focusing on critical metrics such as reliability, capacity factor, and thermal efficiency.

2.2 Data Collection

Operational data spanning five years, from 2017 to 2021, were collected from the operations department of the facility. These data included energy generation measured in megawatt-hours (MWh), gas consumption recorded in Standard Cubic Feet (SCF), unit trip records, load factor, and installed versus available capacities (MW). Specific unit details, including transformer and generator capacities for divisions Delta III and Delta IV, were also documented and analyzed to ensure a thorough evaluation of the plant's operational performance.

2.3 Statistical Analysis Tools

The study utilized two comprehensive statistical tools, Python and SPSS, to enhance the robustness and accuracy of the findings. Python was chosen for its flexibility and advanced analytical capabilities. Libraries such as Pandas for data manipulation, NumPy for numerical computations, and Matplotlib and Seaborn for data visualization were employed. Python allowed detailed analyses and visual representation of trends in power generation, failure rates, and efficiency measures. SPSS complemented Python by providing validation through its advanced statistical analyses. It was specifically used to calculate critical reliability indices including Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), Failure Rate, and interruption indices such as System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Customer Average Interruption Duration Index (CAIDI).

2.4 Reliability Metrics

Operational data from the five-year period (2017-2021) were analyzed to calculate reliability metrics. One of the key performance indicators examined was the Capacity Factor, representing the ratio of actual energy output to the theoretical maximum output achievable by the plant. This provided insights into operational efficiency relative to the plant's maximum potential.

Gas consumption was carefully recorded monthly and annually in Standard Cubic Feet (SCF), allowing for detailed analysis of fuel usage efficiency. In parallel, total energy generation and power losses were evaluated on both yearly and monthly bases, enabling the identification of periods with optimal performance and significant losses.

Thermal efficiency, a dimensionless indicator, was calculated to measure how effectively the plant converted thermal energy from gas into electricity. Given inherent limitations common to thermal engines, this efficiency metric was critically assessed to identify operational constraints and potential areas for enhancement.

2.5 Performance Analysis

Plant availability was assessed by calculating the ratio of Mean Time Between Failures (MTBF) to the sum of MTBF and Mean Time To Repair (MTTR). This metric indicated the plant’s operational preparedness and efficiency in managing downtimes. Plant reliability was evaluated based on the failure rate and operational duration, reflecting the effectiveness of maintenance management and the consistency of plant performance.

Additionally, the failure rate (λ) and Mean Time to Failure (MTTF) were computed to comprehensively analyze reliability. These calculations provided deeper insights into operational performance, facilitating informed decision-making on maintenance procedures and strategies to improve overall system reliability.

3. RESULTS & DISCUSSION

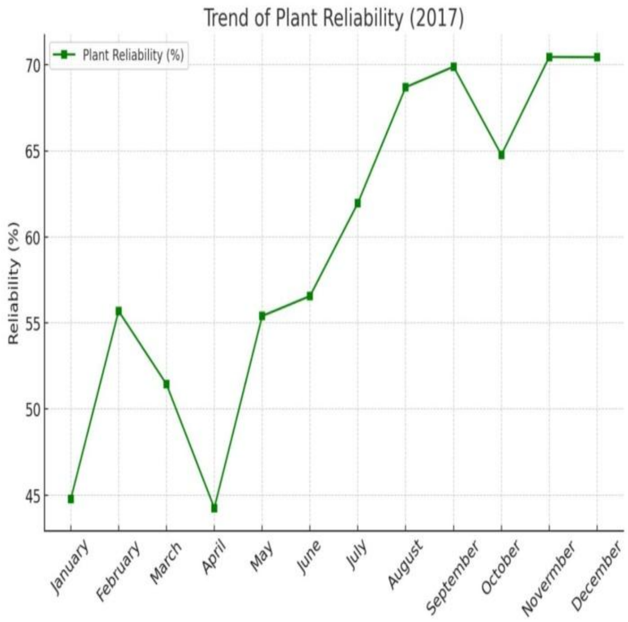
The result from this study shows how major power Station performed over five years (2017-2021). It gives us an idea of how reliable the plant was, how much power it lost, and how well it worked overall. The study looked at key things like the plant’s reliability, how well it used its capacity, how much energy it wasted, and how often it broke down.

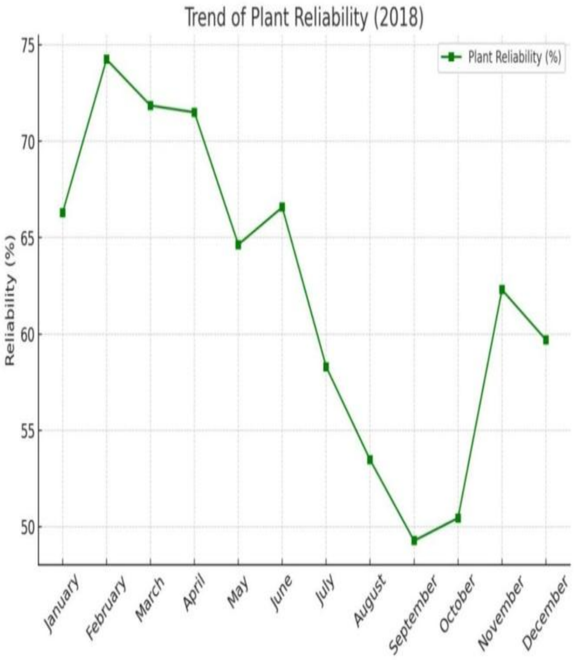
3.1 Reliability Trend

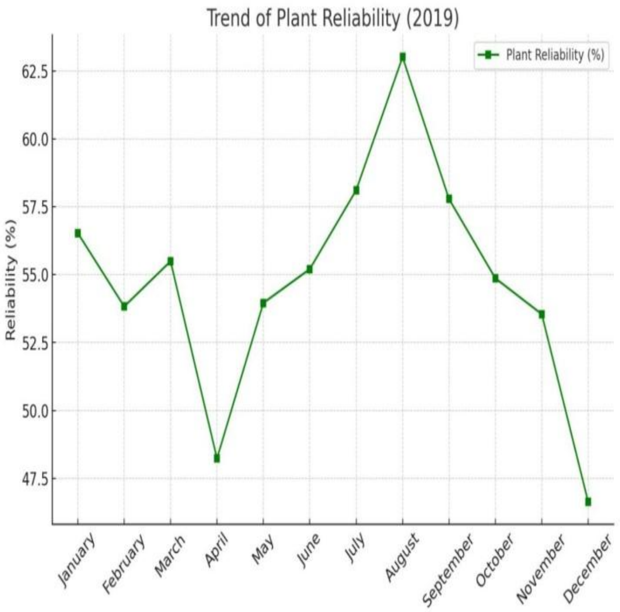
The reliability performance of the power station across the five-year period (2017–2021) shown in Figure 1 exhibited notable fluctuations, indicating persistent operational instability. In 2017, reliability values ranged from 44.25% in April to 70.45% in November, with an annual average of 49.51%. This performance falls significantly below the international benchmark for thermal power plants, which typically ranges between 85% and 95% reliability (IEA, 2021).

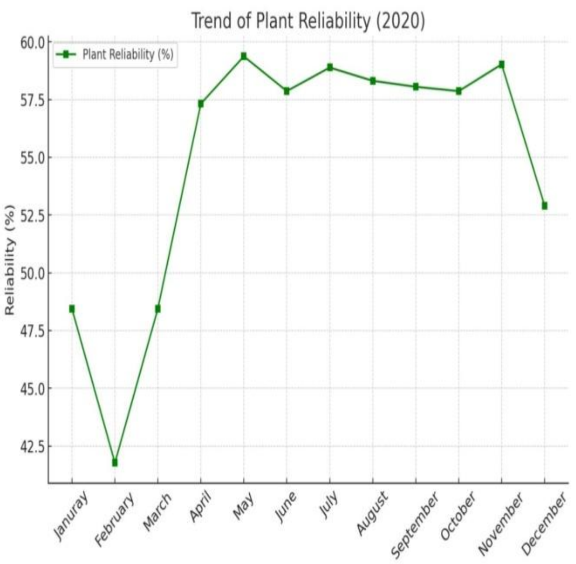
In subsequent years, marginal improvements were observed. February 2018 recorded the highest monthly reliability (74.24%) during that year, suggesting the possible effect of short-term maintenance interventions. However, this improvement was not sustained consistently. Reliability dropped sharply in February 2020 to a low of 41.77%, and again in December 2021 to 44.26%, pointing to unresolved systemic challenges related to equipment aging and inadequate preventive maintenance strategies.

The data suggest that although isolated improvements occurred, the facility struggled to maintain a reliable output over time. This highlights a critical need for structured reliability-centered maintenance (RCM) and strategic investment in infrastructure modernization.









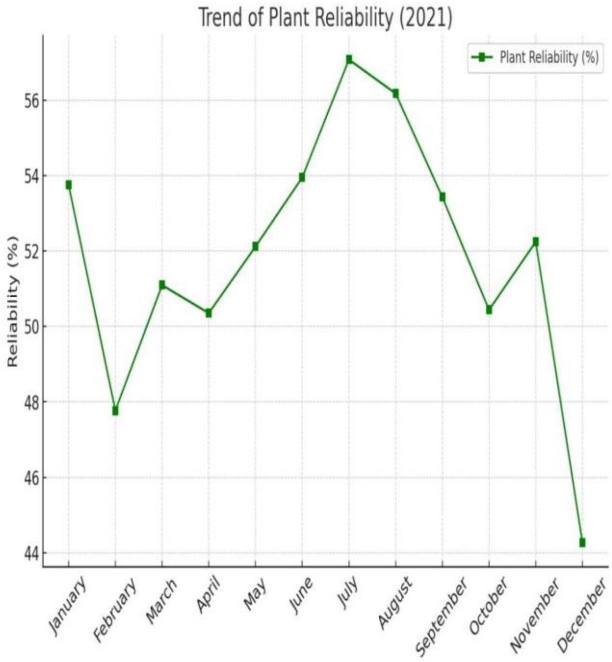


Fig 1. Trend of Plant Reliability from 2017-2021

3.2 Capacity Factor

The capacity factor of the power station in Figure 2 reflects the extent to which the plant utilized its installed capacity over time, exhibited both progress and inconsistency during the study period. In 2017, the capacity factor was relatively low, ranging from 36.94% in January to a peak of 55.74% in February, with an annual average of 48.11%. These values indicate that the plant operated below optimal capacity for most of the year, resulting in underutilization of available generation assets.

A significant improvement was observed in 2018, where the average capacity factor rose to 75.03%, with a monthly peak of 82.02% in February. This upward shift suggests that there may have been improvements in operational scheduling, equipment availability, or load demand matching. However, despite this progress, capacity factor values remained volatile in subsequent years, with periods of decline pointing to recurring operational inefficiencies.

By 2021, the capacity factor had shown signs of stabilization but still did not consistently meet the expected threshold for efficient thermal plant operation, typically above 80% (World Bank, 2022). These results emphasize the importance of sustained equipment maintenance, demand forecasting, and load optimization strategies to maximize plant output.

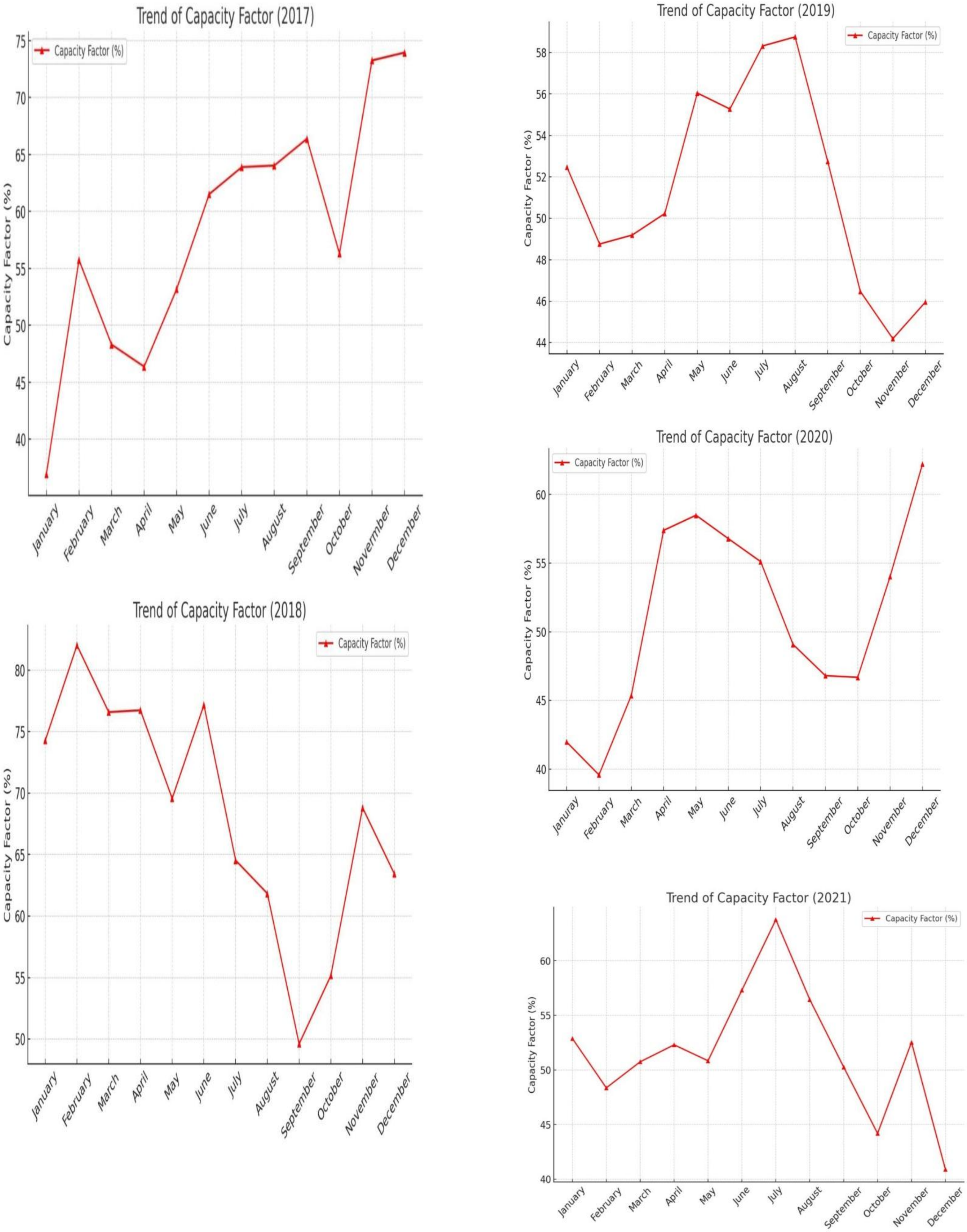


Fig 2. Trend of Capacity Factor from 2017-2021

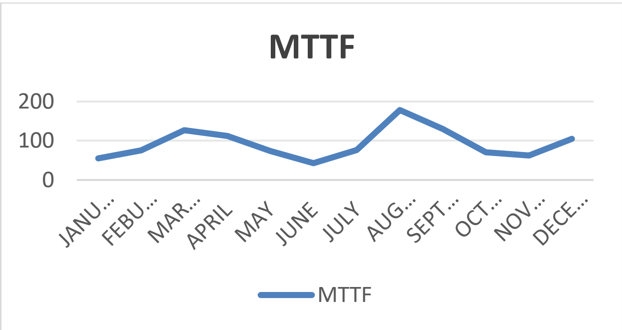
3.3. Failure rate and Mean Time to Failure (MTTF)

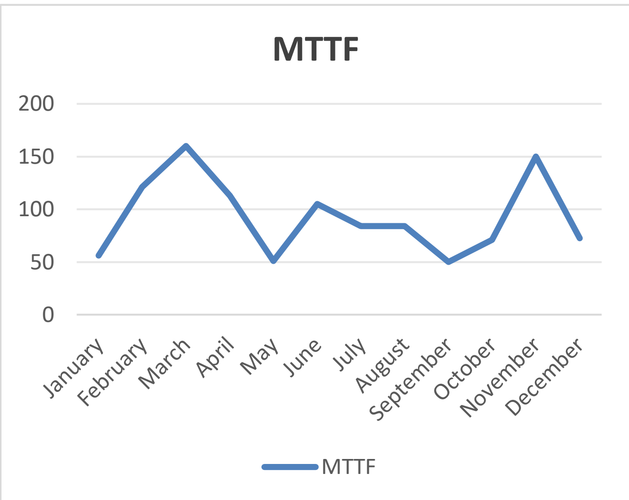
The failure rate and Mean Time to Failure (MTTF) shown in Figure 3 are essential indicators of plant reliability and equipment durability. Over the five-year observation period, these metrics revealed significant inconsistencies in system performance, pointing to recurring operational challenges.

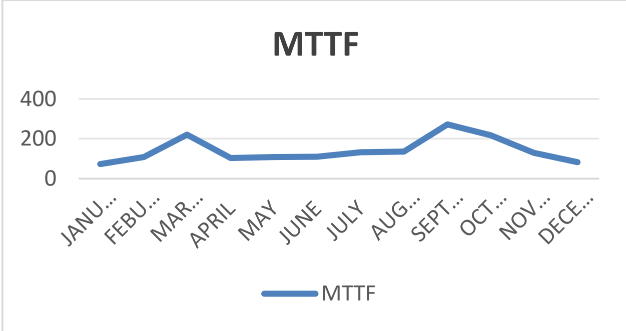
In 2017, failure rates were particularly high, with December recording a peak rate of 0.095 failures per operational hour. Such a high failure frequency suggests that critical components were either nearing the end of their lifecycle or not maintained according to preventive maintenance schedules. This corresponded with a low MTTF of just 55 hours in January 2017, indicating that on average, components failed roughly every two days.

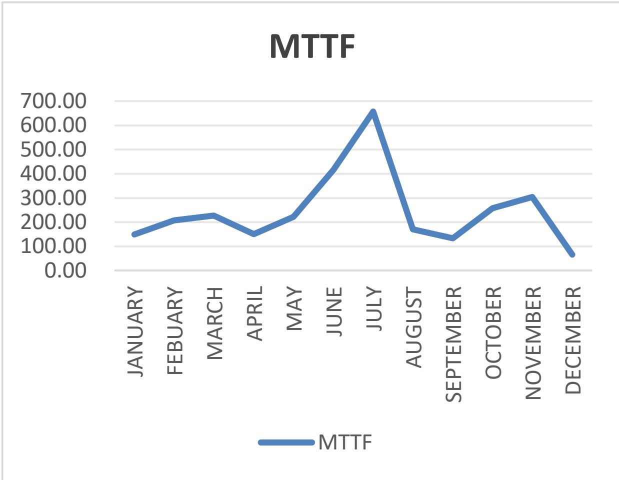
While 2019 witnessed notable improvement especially in March (MTTF = 228 hours) and August (MTTF = 470 hours) these gains were not sustained. By 2021, the performance declined again, with February reporting the worst MTTF of 39 hours, signaling a return to instability. This drop may reflect lapses in predictive maintenance, inadequate spare part inventory, or increased operational stress on aging equipment.

These fluctuations in failure rate and MTTF strongly suggest that maintenance strategies were reactive rather than proactive. To achieve long-term performance stability, the plant must shift toward reliability-centered maintenance (RCM) and predictive analytics using real-time monitoring systems. This would help reduce unexpected breakdowns and extend the operational lifespan of critical equipment.









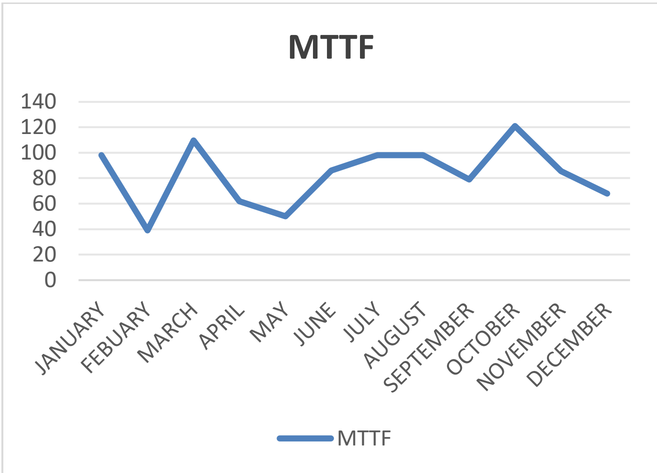


Fig 3. Trend of Mean Time to Failure From 2017 – 2021

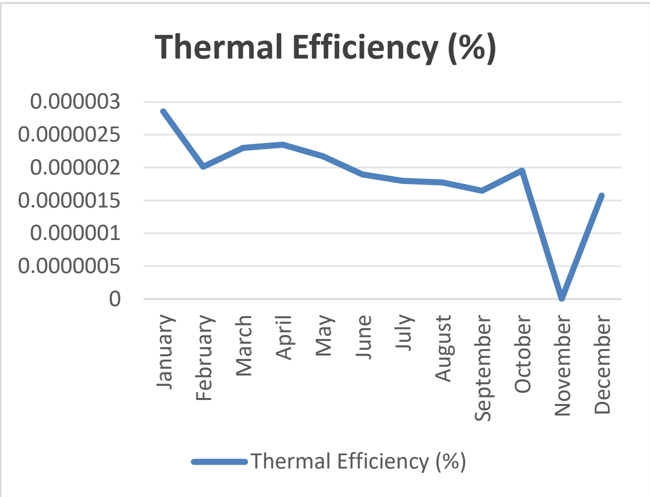
3.4 Thermal Efficency

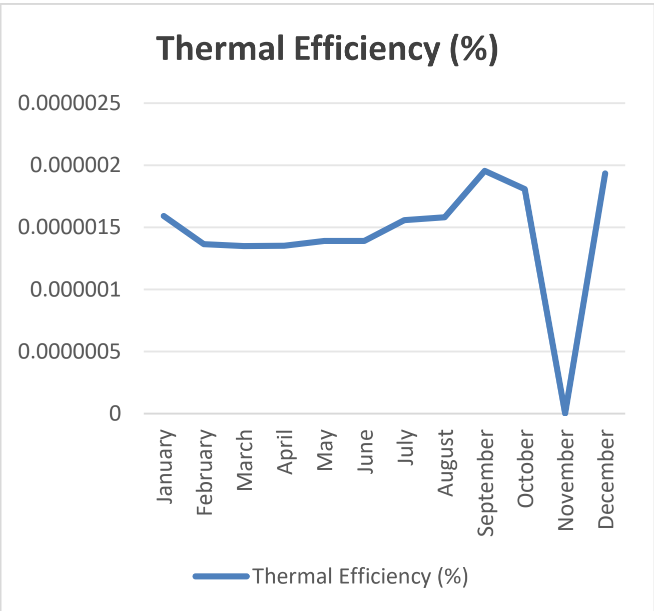
The thermal efficiency of the power station in Figure 4 measures how effectively the plant converts fuel energy (gas) into useful electrical energy, remained remarkably low throughout the five-year period. Across all the years observed, thermal efficiency values were persistently below standard performance expectations for thermal power plants, which typically range from 30% to 40% under optimal conditions (IEA, 2022).

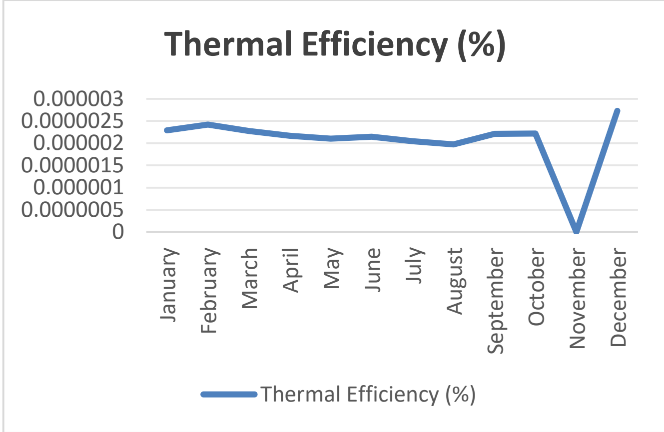
In 2021, thermal efficiency values fluctuated between 0.000002% and 0.000003%, a level that is virtually negligible. These figures suggest that a substantial portion of the fuel energy input was either lost as waste heat or consumed by internal processes, such as driving compressors and auxiliary equipment. The consistently high heat rates further confirmed this inefficiency, implying a poor energy conversion process and an outdated or poorly optimized thermal system.

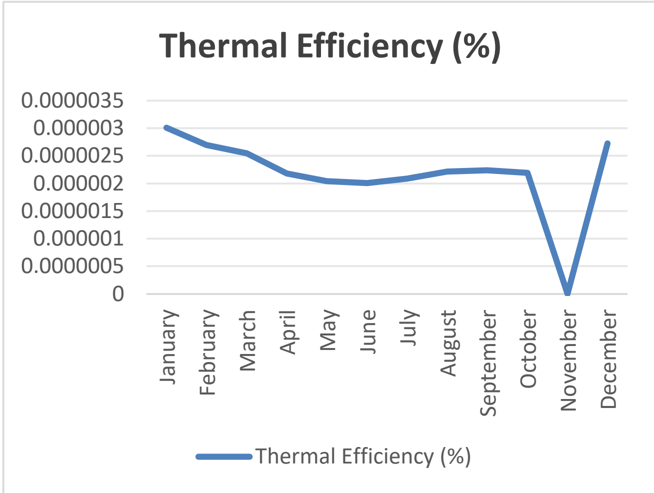
Despite variations in gas consumption and energy output from year to year, thermal efficiency showed no meaningful improvement. This stagnation implies that operational changes alone such as adjusting plant loading or scheduling were insufficient to impact core thermodynamic performance. To enhance thermal efficiency, significant technological upgrades are required, such as installing more modern turbines, implementing waste heat recovery systems, and adopting combined-cycle technologies.

Unless such long-term infrastructure investments and energy recovery strategies are adopted, the plant will continue to experience poor fuel-to-energy conversion, resulting in economic losses and environmental concerns due to excessive fuel consumption









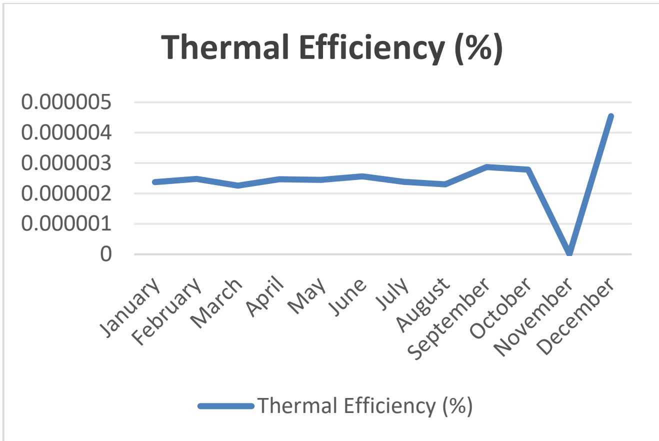


Fig 4. Trend of thermal efficiency From 2017 – 2021

4. CONCLUSION

This study evaluated the operational performance of a thermal power generation facility over a five-year period (2017–2021), with emphasis on key metrics such as reliability, capacity factor, failure rate, mean time to failure (MTTF), and thermal efficiency. The findings reveal a persistent pattern of underperformance when benchmarked against international standards.

The plant exhibited fluctuating reliability levels, with annual averages consistently below the expected 85–95% range. Although capacity utilization showed signs of improvement in some years particularly in 2018 these gains were not sustained, indicating systemic inefficiencies in scheduling, demand forecasting, and maintenance. Power losses, though slightly reduced by 2021, remained significantly above the recommended global threshold of 10%, emphasizing the need for better energy management and infrastructure upgrades.

Furthermore, the failure rate trends and low MTTF values point to a predominantly reactive maintenance culture, resulting in frequent breakdowns and reduced equipment lifespan. The thermal efficiency remained critically low throughout the study period, with negligible improvement despite variations in fuel input and energy output. This signals an urgent requirement for advanced technological interventions such as combined-cycle systems, waste heat recovery, and real-time monitoring for energy optimization.

In summary, the performance challenges observed in the facility are rooted in aging infrastructure, limited modernization, and insufficient reliability-focused strategies. To reverse these trends, the adoption of reliability-centered maintenance (RCM), investment in modern technologies, and implementation of predictive analytics are recommended to ensure long-term efficiency, cost-effectiveness, and sustainability.

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