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Reliability Evaluation of Thermal Power Stations: A Case Study of a Power Station in Southern Nigeria

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Abstract

Nigeria's power generation sector faces persistent reliability challenges arising from frequent equipment failures, poor maintenance practices, and aging infrastructure. Thermal power plants, which supply the majority of Nigeria's electricity, continue to operate below international reliability benchmarks, leading to reduced efficiency and unstable power delivery. This study evaluated the reliability performance of Power Station located in the southern region of Nigeria, to quantify its operational dependability and identify major causes of unreliability. Five years of operational data (2017–2021) covering energy generation, fuel consumption, and outage records were analyzed using probabilistic reliability indices, including Mean Time to Failure (MTTF), Failure Rate (λ), Capacity Factor, and Thermal Efficiency. The analysis revealed that plant reliability fluctuated between 41.77% and 74.24%, with an average value consistently below the international standard of 90%. The highest reliability was recorded in February 2018 (74.24%), corresponding to improved maintenance activity, while the lowest occurred in February 2020 (41.77%), coinciding with increased downtime and equipment faults. The mean annual capacity factor ranged from 36.9% to 73.9%, and thermal efficiency values remained below optimal levels, indicating significant operational losses. These results highlight that reliability is largely influenced by maintenance consistency, equipment age, and operational planning. The study recommends adopting predictive and condition-based maintenance strategies, upgrading aging units, and improving operational scheduling to enhance system dependability.

Keywords: Thermal power station; Reliability evaluation; Mean time to failure; Capacity factor; Power Systems

1. Introduction

For a reliability evaluation of a thermal power station in the South region of Nigeria, it is important to recognize that plant reliability is still heavily constrained by practical, on-ground issues particularly frequent equipment breakdowns, weak maintenance culture, and aging infrastructure which reduce availability and worsen forced outages in gas-dominated generation portfolios (Shopeju & Oyedepo, 2021; Efenedo & Edegbo, 2023).

At the same time, reliability assessment is no longer only an "engineering performance" issue; it also sits within the wider energy-security and transition context. Evidence from Nigerian-focused sustainability synthesis shows that effective energy transition pathways require integrated, context-specific policy frameworks and stronger institutional coordination because fragmented approaches can weaken resilience and ultimately affect system performance and socioeconomic stability (Obuseh et al., 2025).

Operationally, sustaining reliability also depends on better planning and dispatch decisions that reflect actual demand conditions and uncertainty. Recent Nigerian power-system studies show that improving short-term load forecasting and operational planning can support more stable scheduling and resource allocation, which indirectly strengthens reliability outcomes for generation and grid operations (Efenedo & Akalagbaro, 2012; Eyenubo et al., 2025).

Thermal power stations are intricate systems composed of boilers, turbines, generators, and auxiliary units, whose combined performance determines total output efficiency. Failure in any of these components often triggers cascading outages that compromise overall plant reliability. Reliability, in this context, is defined as the probability that a system or component performs its intended function without failure under specified conditions (IEEE,1990). Metrics such as the Mean Time to Failure (MTTF), Mean Time to Repair (MTTR), Forced Outage Rate (FOR), and Availability Factor (AF) are traditionally used to quantify this performance. Yet, deterministic models that rely solely on fixed operating conditions have proven inadequate for capturing the stochastic and dynamic behavior of power system components (Shopeju & Oyedepo, 2021).

Consequently, researchers have increasingly adopted probabilistic and stochastic reliability models to improve predictive accuracy. Shopeju and Oyedepo (2021) demonstrated that probabilistic indices and Markov modeling better represent plant degradation and downtime variability than deterministic methods. Similarly, (Kumar 2024) employed Boolean Function Expansion and Mean Time to Failure analysis to enhance reliability prediction in thermal power plants, showing that integrating probabilistic and analytical techniques produces a more realistic estimation of system dependability.

Building on these foundations, Bassey and Odesola (2024) proposed the Combined Assessment Approach (CAA), which unifies reliability, availability, and exergy efficiency into a single evaluative metric. Their approach highlighted that traditional methods analyzing reliability or efficiency independently provide fragmented insights into plant health. The CAA framework, by contrast, integrates thermodynamic and reliability parameters, enabling comprehensive system evaluation and facilitating optimized maintenance scheduling, a method particularly applicable to Nigeria's thermal stations where both mechanical degradation and operational inefficiency are prevalent.

Predictive analytics has also been introduced into reliability evaluation. Dechgummarn et al. (2023) developed a Weibull + polynomial regression model that captures seasonal and operational effects on failure rates, resulting in a predictive metric known as the Total Factor Deterioration Index (TFDI). This model supports pre-emptive maintenance planning and reliability forecasting across the system life cycle, transforming reliability evaluation from a reactive to a proactive discipline.

Component-level studies reinforce these insights. Sunitha et al. (2025) examined the Reliability, Availability, and Maintainability (RAM) of a thermal boiler system and found that mechanical wear, corrosion, and maintenance delays significantly reduce reliability. They recommended condition-based maintenance and scheduling optimization. Similarly, Okeke et al. (2024) assessed power transformer reliability using statistical models and emphasized that transformer health is central to sustaining network reliability across generation and transmission systems.

Within Nigeria, reliability research has largely concentrated on distribution infrastructure rather than generation units. Eyenubo and Ebisine (2022) analyzed loaded distribution transformers under the Benin Electricity Distribution Company network, identifying overloading and insulation breakdown as key causes of failure and advocating for power-quality-based monitoring to ensure dependability. Extending this work, Eyenubo et al. (2025) conducted a quantitative reliability assessment of the Oria-Abraka 33/11 kV substation in Delta State using Fault Tree Analysis and power-flow modeling. Their findings revealed excessive restoration times and transformer overloading, and they proposed predictive maintenance and smart-grid integration as key strategies for improving reliability at the substation level.

Despite these advances, generation-level reliability assessments in Nigeria remain limited. Considering that thermal plants contribute over 80 percent of the nation's installed generation capacity (Shopeju & Oyedepo, 2021), their dependability is central to achieving sustainable power supply. Existing studies emphasize distribution-side reliability, leaving a gap in comprehensive generation analysis that accounts for plant-specific operational conditions, fuel variability, and maintenance frequency.

Accordingly, this study evaluates the reliability of a thermal power station in the southern region of Nigeria using probabilistic reliability indices and performance-based modeling. By integrating insights from previous works, this research contributes a holistic framework that links reliability modeling with operational data for improved generation planning.

2. Materials and Methods

2.1 Description of the Study Power Station

This study was carried out on a gas-fired thermal power station located at Eruemukohwarien-Ughelli, Delta State, Nigeria (5.541314°N, 5.915909°E). The station is made up of multiple generating units grouped under Delta III and Delta IV, with an overall installed (nameplate) capacity reported as 972MWh. Delta III comprises several gas turbine units (GT-6 to GT-14), each rated at 25 MW and connected to 81 MVA transformers, while Delta IV comprises higher-capacity units (GT-15 to GT-20) with unit ratings ranging from 100–115 MW and transformer ratings of 120–150 MVA. The station configuration and unit ratings were obtained from the operational records, and sample entries for Delta III and Delta IV. Tables 1 and Table 2 show the sample logbooks obtained for these two units respectively.

Table 1: Sample of the logbook for Delta III

Generating Unit	Rated Power (MW)	Transformer Rating (MVA)
GT-6	25	81
GT-7	25	81
GT-8	25	81
GT-9	25	81
GT-10	25	81
GT-11	25	81
GT-12	25	81
GT-13	25	81
GT-14	25	81

Table 2: Sample of the logbook for Delta IV

Generating Unit	Rated Power (MW)	Transformer Rating (MVA)
GT-15	115	150
GT-16	100	120
GT-17	100	120
GT-18	100	120
GT-19	100	120
GT-20	100	120

2.2 Data Collection and Sources

The data used for the reliability and performance evaluation were obtained from the Operations Department of the power station and covered a five-year operating period (2017–2021). Records were extracted primarily from the operational logbooks for Delta III and Delta IV, which document the station's daily/monthly operation, generation outputs, disruptions, and unit status. The dataset captured core operational variables needed for reliability assessment, including energy generated, fuel usage, unit trip events, outage durations, and the documented reasons for outages. In addition, installed capacity and available capacity records were collected to support capacity-based indices and to distinguish between nameplate capability and what was technically available for dispatch during the study period. For transparency and traceability, sample logbook structures used in extraction are shown in Table 1 and Table 2, while the compiled monthly/annual summaries used in analysis are presented in Tables 3-5.

2.3 Performance and Reliability Parameters

The analysis was based on a set of performance and reliability parameters extracted from the station's operational records. The key output variable was total energy generated (MWh), compiled monthly and annually across the five-year period to describe the station's delivered electrical energy. Fuel input was captured through gas consumption (SCF), which was further processed into mass of fuel consumed (kg) to enable consistent fuel-to-output evaluation over time, with the compiled fuel mass values presented in Table 3. Reliability-related events were characterized using unit trip records and outage information, including the frequency of trips, outage durations, and the documented causes of the outages, since these disruptions directly affect unit availability and generation continuity. In addition, installed capacity and available capacity (MW) were used to represent the station's maximum rated capability and the portion actually available for operation over each period. Finally, the study considered total power loss (MWh) as an indicator of lost generation attributable to interruptions, constraints, and inefficiencies, with the compiled loss values presented in Table 5, while the corresponding generated energy values are shown in Table 4.

2.4 Reliability and Performance Evaluation Methods

Reliability and performance evaluation was conducted by organizing the extracted operational data by year (2017–2021) and computing standard indices that relate actual generation to plant capability and operational interruptions. A primary measure used was the Capacity Factor (CF), which indicates the extent to which the station utilized its installed capacity to produce electrical energy over a given period. Capacity factor was determined as the ratio of total energy generated to the theoretical maximum energy that could have been produced if the plant operated continuously at its nameplate rating, expressed as:

$$Cf = \frac{E_{gen}}{C_n x\ 24hrs + 365days} \quad (1)$$

where Cn is the nameplate capacity of the plant in MW, and Egen is the total energy generated in MWh over the period considered. Beyond capacity utilization, reliability matrices were developed by analyzing the operational log data to quantify how unit trips and outage events shaped station performance over time. This involved evaluating outage durations and outage causes alongside the generation record, and relating these disruption patterns to observed changes in yearly output and total power loss. Fuel consumption data (gas usage and derived fuel mass) were also assessed together with generated energy to support an input-output perspective of operational effectiveness across the study years, while annual power loss records provided an additional basis for interpreting the magnitude of unrealized generation associated with station interruptions and constraints.

Table 4: Total Power Generated (MWh) by the Power Station from 2017-2021

Year	2017	2018	2019	2020	2021
Jan	166940	335672	237143	189720	239001
Feb	227567	334826	199041	167349	197423
Mar	218345	346128	222328	205052	229369
Apr	202818	335624	219694	251003	228756
May	240369	314397	253317	264339	229786
Jun	269073	337506	241771	248356	250709
Jul	288778	291659	263585	249064	288188
Aug	289403	279453	265571	221823	255136
Sep	290352	216968	230715	204711	219849
Oct	254430	249320	210051	211009	199690
Nov	320435	300957	193268	236265	229765
Dec	334249	286690	207712	281162	184786

Table 5: Total Power Loss (MWh) from 2017-2021 at the Power Station

Year	2017	2018	2019	2020	2021
Jan	285040	116308	214837	214837	212979
Feb	180673	73414	209199	209199	210817
Mar	233635	105852	229652	229652	222611
Apr	234582	101776	217706	217706	208644
May	211611	137583	198663	198663	222194
Jun	168327	99894	195629	195629	186691
Jul	163202	160321	188395	188395	163792
Aug	162577	172527	186409	186409	196844
Sep	147048	220432	206685	206685	217551
Oct	197550	202660	241929	241929	252290
Nov	116965	136443	244132	244132	20765
Dec	117731	165290	244268	244268	267194

Table 3: Mass of Fuel Consumed (Kg) from 2017-2021 at the Power Station

Year	2017	2018	2019	2020	2021
Jan	2172336197.16	4094067583.35	2770014628.69	2060970964.00	2679484788.38
Feb	27814216697.26	4202234409.65	2371238100.66	2077484658.00	2321530151.85
Mar	2695500029.40	4600239832.84	2788070670.06	2435359556.32	2821315517.45
Apr	2552065112.27	4437065732.08	2832474093.83	2753953434.71	2492308448.12
May	2850205175.50	4463410013.78	3098683851.99	3033136380.24	2540040806.79
Jun	3168338249.03	4316670763.75	2932826634.16	2990333483.43	2340209448.44
Jul	3534012595.88	4177926779.60	3184502721.96	3044424534.01	2604606572.17
Aug	3581294219.59	4117727187.97	3297914032.23	2798497516.16	2701240717.45
Sep	3731215716.95	3224291886.95	2851088858.70	2677978880.30	2094661402.54
Oct	3247469367.12	3513671087.85	2790793945.68	2829786794.20	2230299410.92
Nov	3714729066.91	3509929402.89	2133514805.00	2890328395.42	1845193669.23
Dec	4039193311.94	3283368545.59	2324864401.00	2331299356.02	1366488746.45

3. Results and Discussion

3.1 Analysis of Annual Metrics

To address the study objective of evaluating the reliability and operational performance of the Ughelli thermal power station (Delta State) over the period 2017–2021, Table 6 summarizes the annual operating ranges (minimum–maximum values) of key indicators, including total energy generated, plant reliability, capacity factor, lost power, fuel consumption, thermal efficiency, failure rate, and mean time to failure (MTTF). These indicators collectively show how consistently the plant converted installed capacity into usable electricity, how frequently it failed, and the magnitude of energy lost due to outages and operational constraints.

Table 6 reveals a plant that was operational but persistently underperforming relative to what would be expected from a well-maintained, mature thermal generation facility. First, the total power generated shows that peak monthly outputs were highest in 2018 (maximum value of 346,128 MWh), while other years recorded lower peaks (e.g., 263,585 MWh in 2019 and 281,162 MWh in 2020). This variability implies that the station's generation capability was not stable year-to-year, which is a direct reliability concern because a reliable base-load thermal plant should show more consistent dispatch readiness and output performance. A key implication for the South-region grid is that fluctuating generation from a major thermal station can worsen supply volatility, reduce reserve margins, and increase dependence on load shedding or alternative generation.

The plant reliability remained far below the 90% benchmark stated in the study across all five years, with annual ranges roughly between the low 40s and mid-70s. This is not a minor deviation; it indicates a plant environment where forced outages, prolonged downtimes, and recurrent trips were a dominant operational feature rather than an occasional event. The capacity factor shows the same structural challenge: although 2018 attained a maximum of about 82%, the other years show lower peaks and wide spreads, indicating that the station did not sustain high utilization consistently across months and years. The lost power (MWh) is consistently high, with maximum annual losses above 240,000 MWh in several years. This strengthens the reliability interpretation: large losses of this scale typically reflect forced outages, prolonged repairs, partial deratings, and operational unavailability. These losses have both technical and economic meaning: technically, they indicate lower system adequacy; economically, they translate into lost revenue, higher cost of energy, and reduced ability to meet industrial and domestic load reliably. The failure rate and MTTF values jointly confirm an unstable reliability environment. Higher failure rates coincide with lower MTTF, showing that unit interruptions were not rare events but frequent enough to reduce the average operating time between failures. Finally, the thermal efficiency values reported in Table 6 show very small numerical magnitudes, but the key interpretive point for this Results section is the variation over time rather than the absolute magnitude. The year-to-year and month-to-month spread suggests that the plant's conversion effectiveness fluctuated, which is typical where units operate at partial loads, experience unstable combustion conditions, or face operational constraints that reduce efficient dispatch. This supports your broader objective on performance evaluation: reliability problems and dispatch instability often propagate into efficiency instability.

Table 7 compares the reliability and utilization performance of the Ughelli thermal power station with closely related Nigerian case studies. The comparison shows that Ughelli's plant reliability remained well below international expectations (roughly 41.77–74.24% across 2017–2021) and its capacity factor was highly variable (36.93–82.01%), a pattern consistent with national evidence of constrained generation due to unit unavailability and operational limitations, as reflected by the wide unit-level availability/reliability spreads reported for Egbin and the low overall reliability and capacity factor reported using the Nigerian Plant case

Table 7: Comparison of reliability and utilization outcomes with similar Nigerian studies

Metric	Present study	Egbin, 2005–2009 (Oyedepo & Fagbenle, 2011)	Nigeria plant case (Kolawole et al., 2019)
Plant reliability /availability level	2017 44.25–70.45; 2018 49.27–74.24; 2019 46.63–63.01; 2020 41.77–59.37; 2021 44.26–57.06	Unit 1 59.11–91.76%; Unit 2 64.02–94.53%; Unit 3 28.79–91.57%; Unit 4 80.31–92.76%; Unit 5 73.38–87.76%; Unit 6 out of service 2–3 years	Overall reliability: 55.73%; Unit reliabilities: 0.00%, 82.39%, 8.25%, 18.60%, 45.98%, 83.41% (Units 1–6)
Capacity factor / utilization	2017 36.93–73.95; 2018 49.60–82.01; 2019 44.18–58.75; 2020 39.57–62.20; 2021 40.88–63.76	Not reported	Capacity factor: 35%

3.2 Plant Reliability Trends

To meet the study objective of examining reliability behavior over time, Figures 1–5 present the monthly trend of plant reliability for each year from 2017 to 2021, extracted from the annual reliability ranges in Table 6. These figures show not only whether reliability was high or low, but also whether reliability improved steadily, fluctuated seasonally, or declined patterns that are essential for linking reliability outcomes to maintenance practice and operational strategy.

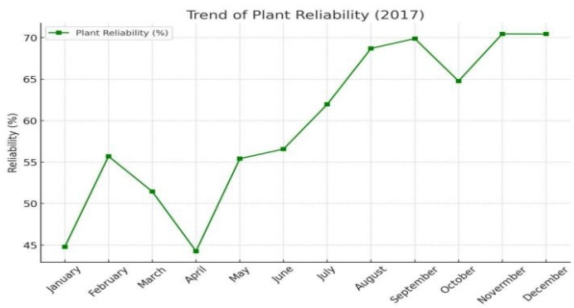

Figure 1: Trend of Plant Reliability (2017)

Table 6: Analysis of Annual Metrics (2017–2021)

		2017	2018	2019	2020	2021
Total Power Generated (MWH)	In	166940	216968	193268	167349	184786
	Ax	334249	346128	263585	281162	288188
Plant Reliability (%)	In	44.25	49.27	46.63	41.77	44.26
	Ax	70.45	74.24	63.01	59.37	57.06
Capacity Factor (%)	Min	36.93	49.6	44.18	39.57	40.88
	Max	73.95	82.01	58.75	62.2	63.76
Lost Power (MWH)	Min	116965	73414	186409	170818	163792
	Max	285040	220432	244268	262260	267194
Mass of Fuel Consumed (SCF)	Min	2172336197	3224291887	2133514805	2060970964	1366488746
	Max	4039193312	4600239833	3297914032	3044424534	2701240717
Thermal Efficiency (%)	Min	1.57204E-06	1.34745E-06	1.97352E-06	2.04381E-06	2.29472E-06
	Max	2.85342E-06	1.93392E-06	2.73124E-06	2.77926E-06	4.53614E-06
Failure Rate	Min	0.0056	0.0062	0.000785	0.0015	0.0033
	Max	0.095	0.0199	0.0138	0.0152	0.026
MTTF (Hours)	Min	43	50	73	66	39
	Max	178	160	272	657.2	121
Installed Capacity (MW)		972	972	972	972	972
Plant Reliability (Int. Range %)		90 and above	90 and above	90 and above	90 and above	90 and above
Capacity Factor (Int. Range %)		80 and above	80 and above	80 and above	80 and above	80 and above
Thermal Efficiency (Int. Range %)		40 - 50	40 – 50	40 – 50	40 - 50	40 – 50

In Figure 1, reliability fluctuates between a low value around 44.25% and a peak around 70.45%. The implication is that even when the station achieved relatively better months, it could not sustain those gains consistently through the year. This type of fluctuation is typical of plants where corrective maintenance dominates over predictive/preventive strategies, so performance temporarily improves after repairs but drops again when new failures occur.

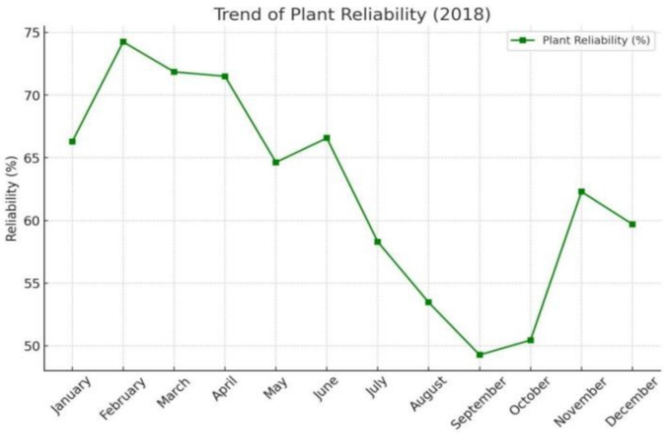

Figure 2: Trend of Plant Reliability (2018)

Figure 2 shows the strongest year among the five, with reliability reaching about 74.24% at peak and maintaining a higher minimum than several other years. Practically, this suggests that operational conditions such as better unit availability, more effective maintenance execution, or fewer severe failures were relatively improved in 2018. However, even this "best year" remained below the benchmark stated in the study, indicating that the plant still operated under reliability limitations.

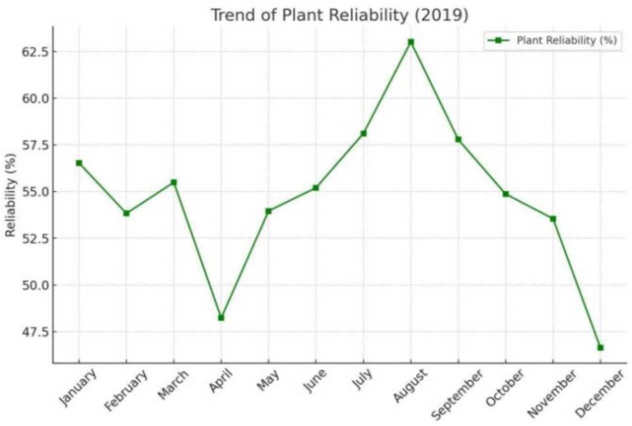

Figure 3: Trend of Plant Reliability (2019)

In Figure 3, the reliability peak drops compared with 2018 and the year ends at a lower minimum. This pattern implies that the station experienced either increased failure incidence, longer repair durations, or more frequent unit deratings.

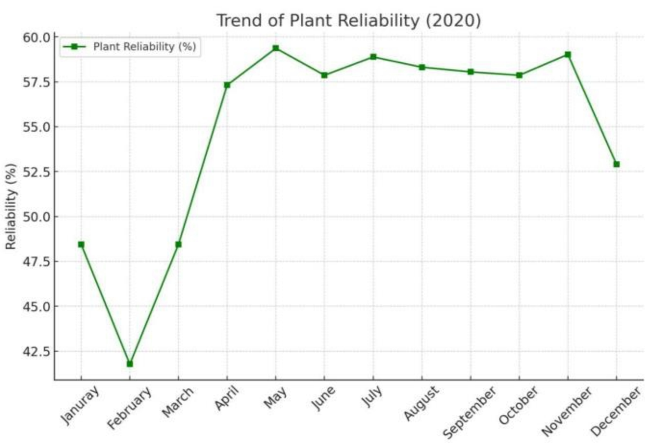

Figure 4: Trend of Plant Reliability (2020)

Figure 4 shows the worst minimum reliability (41.77%) across the entire study period. From a reliability-engineering standpoint, this reflects a year in which forced outages and/or prolonged downtimes were more severe. The implication is significant: when reliability drops into this range, the plant becomes less dependable as a grid-supporting asset, forcing the system operator to rely on load shedding, alternative generation, or reduced supply quality.

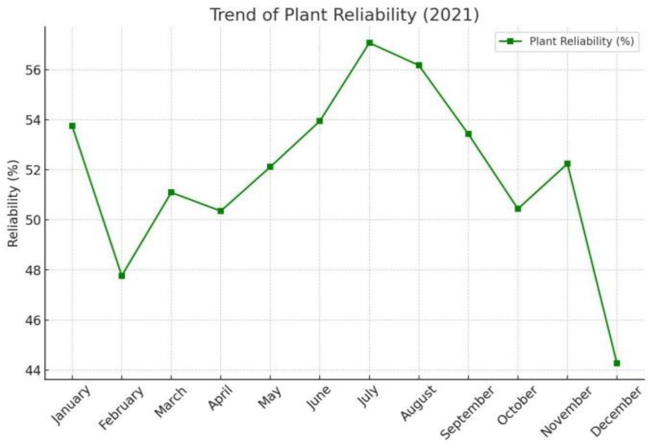

Figure 5: Trend of Plant Reliability (2021)

In Figure 5, reliability improves compared with the worst period in 2020 but still remains capped below 60% at peak in your annual range. This indicates that while some recovery may have occurred, the plant did not achieve a sustained improvement trajectory.

Taken together, the Figures 1–5 show that reliability improvement was not progressive or sustained across the five years; rather, the plant exhibited year-specific fluctuations and a persistent ceiling well below the benchmark stated in the study. This directly supports your study objective on reliability evaluation: the plant's performance challenge is systemic and requires interventions that reduce failure frequency (lower failure rate), shorten repair time (improve MTTF/MTTR dynamics), and improve dispatch availability.

4. Conclusion

While there were periods of good performance, the overall reliability of Ughelli Power Station remains below what is needed for dependable grid support. The findings show that, although there were some improvements in power generation across the study period, persistent challenges related to reliability and aging infrastructure continued to hinder the station's overall performance. The reliability of the power station averaged 56.64% for the period under review, which is significantly below the typical global benchmark of 85–95%, indicating frequent breakdowns and recurring system failures. The main issues identified include aging equipment, inadequate maintenance practices, technical inefficiencies, and suboptimal operational strategies. These factors contribute to repeated outages, increased downtime, higher power losses, and reduced energy supply to the national grid thereby limiting the station's ability to meet demand consistently. To improve performance, the plant requires better and more structured maintenance schedules, a more consistent year-round operational strategy, targeted workforce training, adoption of advanced energy management systems (EMS), and phased upgrades or rehabilitation of critical aging components.

Implementing these measures would enhance operational stability, reduce avoidable losses, and improve reliability and availability. Ultimately, by investing in appropriate technologies and a stronger operational plan, Ughelli Power Station can improve its reliability, reduce power losses, and contribute more effectively to meeting Nigeria's growing electricity demand and strengthening the national grid.

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