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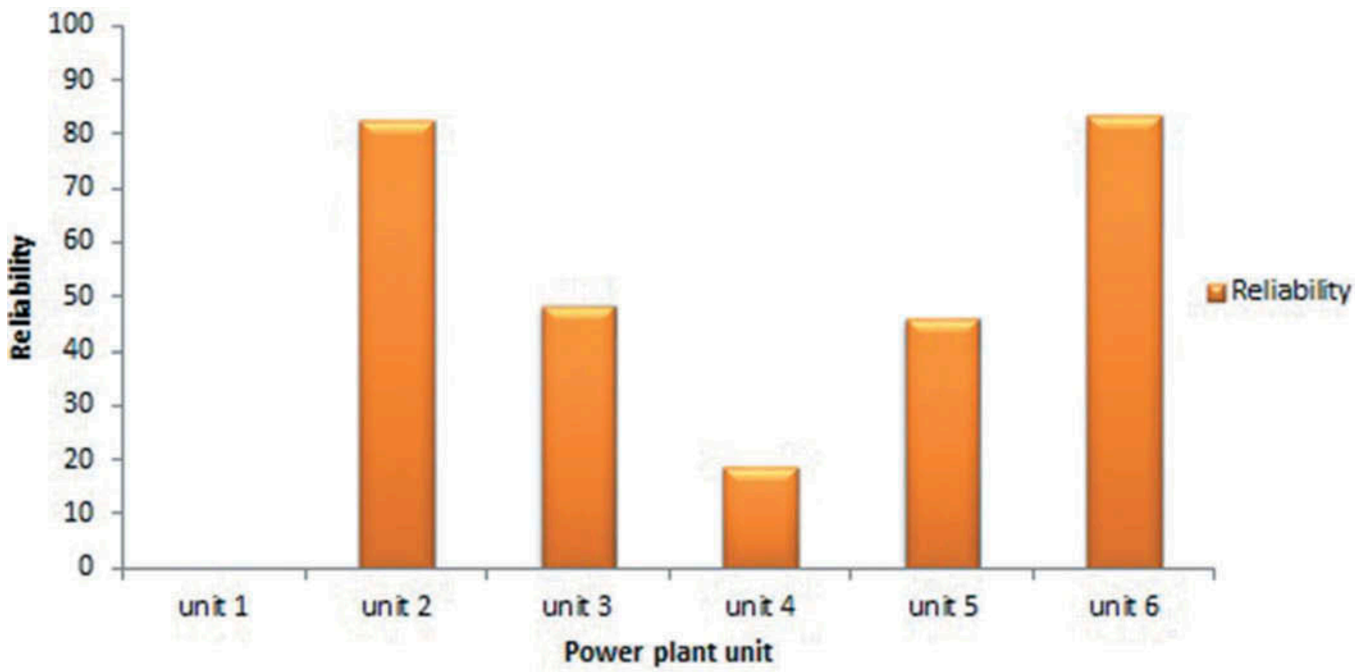


MECHANICAL ENGINEERING | RESEARCH ARTICLE

# Reliability and power loss analysis: A case study of a power plant in Nigeria

Adekunle Kolawole, Olayinka Oluwole Agboola, Peter Pelumi Ikubanni, Olakunle Ganiyu Raji and Christian Okechukwu Osueke

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# Reliability and power loss analysis: A case study of a power plant in Nigeria

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Additional information is available at the end of the article

**Abstract:** The consequence of electric power outage goes beyond the frustration experienced. Electric power outage could lead to injuries and sometimes deaths especially when it interferes with the elements of daily utility like the powered elevators in towers and life-saving equipment in the hospitals. In this study, an assessment of the reliability of a power generating plant was carried out to provide an opportunity to checkmate frequent fault occurrence and prolonged outages. Historical data were obtained from a generating plant in Nigeria. The data were used to evaluate the overall performance of the plant and its generating units. The results showed reliability results of the six units of the plant as 0.00%, 82.39%, 8.25%, 18.60%, 45.98% and 83.41% for units 1, 2, 3, 4, 5 and 6, respectively, while the overall reliability was 55.73%. The plant's availability and capacity factor were 50% and 35%, respectively. The generation loss analysis indicated that gas restriction, grid constraints and plant unavailability prevented the plant from running at maximum continuous ratings (MCR). It was recommended that to have an optimum

## ABOUT THE AUTHORS

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## PUBLIC INTEREST STATEMENT

The desire of every developing nation is to have a constant power supply but in reality, this dream is far from being realized due to so many factors. To ensure that the power supply is relatively stable, effort should be made to assess the reliability of the power system. One of the power plants assessed has six (6) generating units with the reliability of 0.00%, 82.39%, 8.25%, 18.6%, 45.98% and 83.41%, respectively. The overall reliability of the entire power is 55.73% which accounts for erratic power supply in Nigeria. Some of the identified factors responsible for low reliability are lack of effective maintenance culture, grid constraint, plant unavailability and gas restriction. To guaranty a reliable power supply in the country, major players in the power sector should not only pay attention to maintenance exercise but also conduct this kind of study on the power transmission and distribution.

operation of the entire system, further study should be extended to the transmission and distribution arms of the power system.

**Subjects: SPC/Reliability/Quality Control; Industrial Engineering & Manufacturing; Mechanical Engineering; Reliability & Risk Analysis; Engineering Management; Engineering Economics**

**Keywords: reliability; availability; performance evaluation; power loss; capacity factor**

## 1. Introduction

Among the many challenges being faced in many developing countries, like Nigeria, is the availability of reliable power supply. The three arms of power supply such as generation, transmission and distribution have contributed to this erratic power supply. However, the focal problem is generally inadequate power generation (Sambo, Garba, Zarma, & Gaji, 2010). There is a long persisting shortfall in power output of the nation. It is worthy of note that maintaining a steady and reliable power supply is important for the smooth running and development of any nation. The effect of epileptic power supply could lead to production losses due to damaged equipment, production downtime, severe injuries and even death (Awosope, 2014).

The major ways of generating electricity in Nigeria include thermal, hydro and gas turbine power plants. These are meant to complement one another for sustainable electricity for the populace. However, electricity utilization to the Nigerian users is not reliable and this can be attributed to some shortfalls in the power generation, transmission and distribution. The performance analysis such as reliability and power loss analysis for electricity generation in a gas power plant should be determined towards the actualization of the plant's energy efficiency.

Various researchers have given several definitions of reliability (Abdullahi, Akinsanmi, Muazu, & Jubril, 2007; Dhillon, 2006; Ireson & Coombs, 1998). Generally, the probability that a device, equipment or system will perform its function adequately, for the period of time intended, under the operating conditions intended can be termed reliability.

Barabady (2005) identified reliability as a key consideration during the design and operation of systems in engineering, naming it a key performance measurement yardstick of the overall system. Using the Reliability, Availability and Maintainability (RAM) analysis, it was discovered that the overall time during which a component is active greatly influences the reliability of the component as well as the whole system. Souza (2012) dealt with the probabilistic aspect of the operational performance of the power plant. The study employed a deterministic approach of reliability analysis of a system to deal with the understanding of how and why a system is unsuccessful, and how proper planning could be done to prevent such failure from re-happening. The work included analysis such as review of historical field failure reports, understanding scientific theory behind the failure, the role and degree of maintenance policies.

The reliability of turbines used in steam power plants using the failure mode and effect analysis was investigated by Dewangan, Kumar, and Banjare (2014). The study focused on using past failure records of each of the components and the overall failure effect of each component on the plant to identify, classify and improve important components in the operation of the plant, for improved reliability of the plant. The research conclusively linked the reliability profile of any heavy-duty steam turbine to the human factors along the chain, based on the method of installation, competence of the operations and maintenance team, quality of steam generated and variable environmental conditions.

However, the study failed to take cognizance of the attendant effect that time has on the reliability of equipment. Ogieva, Ike, and Anyaeji (2015) conducted a study to find the generator availability and unit performance study of Egbin power station, Lagos. Past operational data of the plant was analysed using MATLAB to evaluate the availability of the units of the plant and the overall availability. A computer program based on the template used in the analysis for subsequent computations was developed. However, generator availability alone is not enough to base the performance of a power plant on, as it measures only the total uptime and downtime of the plant, neglecting number of failures experienced and also the total effective generation during the available hours. Also, some inconsistencies were observed in the data used over the study period, as some data were not available to the researchers, thus limiting the scope of the study.

Evaluation of the reliability of Kainji power station, a hydro-electric power plant in Nigeria was carried out by Adamu, Adegboye, Bajoga, Ambafi, and Omokhafe (2012). The frequency and duration of outages (F and D) method of reliability computation were used for the analysis. Based on the result obtained, the station lacked appropriate and adequate maintenance practice, which was evident in the low reliability of the station. The frequency and duration approach used in the research is one of the most effective methods in generating capacity reliability evaluation, as explained by Prada (1999). Agbo (2007) compared the electricity being generated by Cuba, a country with about 11 million inhabitants, with what Nigeria generates with a population that is about 17 times higher. The study gave the amount of electricity being generated by both countries to be around 4000 megawatts of electricity.

According to the Nigerian Electricity Supply Industry (NESI), Nigeria has an installed generating capacity of 10,396 MW and an available capacity of 6,056 MW to supply power to over 170 million people living in the country (Presidential Task Force on Power [PTFP], 2015). This is considerably low, as it gives the per capita consumption for each individual at about 0.036kW. Efforts are being made to increase this, however, for the time being, it is logical to ensure that the few generation stations available are effectively operated to ensure efficient and optimal performance at all time.

Due to unavailability caused by many factors at the generation stations, power generation capability is gradually declining in Nigeria to a level that is abysmal. Plant unavailability, gas restriction, grid constraints and unplanned downtime had been the major causes of electricity-generation losses. These have resulted in lower profitability which has affected many sectors of the economy especially the commercial sectors. Power plant performance evaluation and reliable energy efficiency play important economic roles to the consumer. Hence, the increase in demand of electricity being generated from generating power stations cannot be overemphasized. It is important to investigate how reliable and available the power plant will be for effective and efficient power supply to its end-users. Therefore, this study investigates the reliability of the plant and performs the power loss assessment putting into consideration the power output, rate and duration of failures.

## 2. Methods and materials

### *2.1. Data acquisition*

Data on power generation and outages, as well as durations and reason(s) for the outage, of the plant were obtained for all the six units. These data were collected from the plant's daily operational log book and outage reports over a 12 months period, from October 2016 to September 2017 from the operations department. These data represent the records of plant capabilities which include other inherent daily conditions. The data for each unit were analysed separately, before that of the overall plant.

Quantitative approach, which uses both statistical and engineering methods, to appraise the power situation of the case study plant was adopted. This choice of approach is as a result of the far-reaching ability of the quantitative approach to effectively capture both the engineering and analytic aspects of power systems evaluation.

### *2.2. Unit performance analysis*

To appraise the overall performance of the case study power plant, the performance data obtained from the plant were analysed to evaluate some key performance indices, like availability, mean time to repair (MTTR), mean time between failure (MTBF) and capacity factor (CF).

Mathematically, availability can be obtained using Equation (1):

$$\text{Availability} = \frac{\text{System Uptime}}{\text{System Uptime} + \text{System Downtime}} \tag{1}$$

This can be well modified as Equation (2) which was used in obtaining the monthly, yearly and overall availability of the plant over the 12 months period.

$$\text{Availability} = \frac{\text{Supply Hours}}{\text{Supply Hours} + \text{Outage Hours}} \tag{2}$$

MTBF and MTTR values were obtained using Equations (3) and (4)

$$\text{MTBF} = \frac{\text{Total System Operating Hours}}{\text{Number of Failures}} \tag{3}$$

$$\text{MTTR} = \frac{\textit{Forced outage hour}}{\textit{Total number of failure}} \tag{4}$$

Equation (5) indicates the determination of capacity factor which was calculated for all the units and for the whole plant.

$$CF = \frac{\text{Total generation in the period}}{\text{Total periodic hours XMCR}}\text{X100\%} \tag{5}$$

### *2.3. Reliability indices*

Reliability indices are important according to Kececioglu (1995). The indices that were used in this study are given below;

#### *2.3.1. Failure rate*

Equation (6) gives the mathematical equation of failure rate which pertains to non-repairable systems while Equation (7) indicates the equation for the determination of failure rates for repairable systems.

$$\text{Failure Rate}, \lambda = \frac{\text{Fault Frequency}}{\text{Period of occurence}} \tag{6}$$

$$\text{Failure Rate}, \lambda = \frac{\text{Number of Times Failure Occurs}}{\text{Number of Unit} - \text{Hour of Operation}} \tag{7}$$

The unit of $\lambda$ $(N)$ is failures per unit-hour. A high value of failure rate indicates low reliability of the system.

#### *2.3.2. Maximum continuous rating (MCR) militating factors*

Investigation of the critical factors that prevented the plant from running at maximum capacity within the period was done. The total generation loss across all units in the plant was documented against the factor causing the loss for each month. Summation of all these losses was done to get the total loss for each militating factor in the plant for the 12-month period of investigation. The major factors that generally inhibit a steam power plant from running at maximum continuous ratings (MCR) are gas restriction, grid constraint and plant unavailability.

The outage frequency, forced outage hour, service hour, total energy generation and period hour were determined.

## 3. Results and discussion

### *3.1. Analysis of the operational data*

Table 1 shows the summary of operational data obtained from the operations department of the plant between the period of October 2016 and September 2017 for each of the units. These data involve the outage frequency, forced outage hour, service hour, total power generated and the period in an hour for running the engine.

### *3.2. Performance analysis of the units*

The most basic parameter/index used in reliability computation is the failure rate (λ) which is the number of failures (shutdown) per unit time. The number of failures is given as outage frequency (N) in Table 1. The maximum value was obtained for MTTR at unit 1 with a value of 730 hours and the minimum value obtained was at unit 6 with 25.71 hours value. The MTBF has the maximum value to be obtained at unit 6 at 201.09 hours while the minimum value was at unit 1. Moreover, unit 6 was found to have the highest value for availability, capacity factor and reliability, respectively, with value at 84.39%, 63.48% and 83.41%, respectively. From Tables 2–3, the overall MTTR, MTBF, availability, capacity factor and reliability were 219.34 hours, 118.77 hours, 49.87%, 34.67% and 55.73%, respectively.

A major determinant of reliability and availability of a plant is the failure rate which gives a reasonable measure of the stability of the plant units and indicates the economic effectiveness of repairs (Ogieva et al., 2015). Throughout the time of investigation in this study, availability, reliability and other parameters needed to be considered fluctuate and could not reach the required expected benchmark. This finds agreement with the work of Ogieva et al. (2015). Some of the units in the period of study had a good and balanced power generation system availability requirements such that is above 97%. Moreover, as stated by Ogieva et al. (2015), 94% minimum availability is required for the important components of the unit generator. Unit 6 met this requirement for most of the months under study while unit 1 could not meet up with this requirement as the availability value was 0% throughout the investigation period. Units 4 and 5 gave low responses to availability throughout the investigation period except in August when unit 4 was 97.5%. Also, unit 3 met up with the minimum requirement in December but failed in the other months. This implies that their plant requires more maintenance so that its performance can be improved.

### *3.3. Generation loss analysis*

An analysis of the total generation loss due to outages in the plant within the statistical year was investigated. The causes or nature of the outages were investigated and evaluated in order to determine the factors precluding the plant from running at a maximum continuous rating. Table 4 shows the generation loss analysis where the major factors that inhibited the plant from running at full capacity were analysed.

As stated, the analysis excluded unit 1 outage, as the unit was completely unavailable throughout the study period.

The total generation loss for the plant in the study period was 6,185,680 MWH. The three major generation losses obtained from the plant were due to gas restriction, grid constraints and plant unavailability. Except for September 2017, there were no generation losses due to gas restriction. This could be attributed to the constant and adequate supply of gas required to fire the plant. The amount of generation losses due to grid constraints and plant unavailability were very high. It would require much attention so as to reduce the high value and make energy generation more available to the end-users.

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Table 1. Summary of operation data for the units

| S/N | Month | Outage frequency (N) | | | | | | Forced outage Hour (h) | | | | | | Service hour (h) | | | | | | Total Generation (MWh) | | | | | | Period Hour (h) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 | |
| 1 | October | 1 | 7 | 5 | 2 | 10 | 4 | 1 | 189 | 261 | 744 | 228 | 129 | 0 | 555 | 483 | 0 | 516 | 615 | 0 | 100578 | 80739 | 0 | 86497 | 102340 | 744 |
| 2 | November | 1 | 5 | 7 | 1 | 2 | 3 | 1 | 68 | 294 | 720 | 642 | 218 | 0 | 652 | 426 | 0 | 78 | 502 | 0 | 107096 | 69239 | 0 | 8603 | 81193 | 720 |
| 3 | December | 1 | 1 | 5 | 1 | 1 | 4 | 1 | 6 | 44 | 744 | 744 | 8 | 0 | 738 | 700 | 0 | 0 | 736 | 0 | 117408 | 0 | 0 | 0 | 114867 | 744 |
| 4 | January | 1 | 11 | 2 | 1 | 9 | 11 | 1 | 326 | 615 | 744 | 626 | 114 | 0 | 418 | 129 | 0 | 118 | 630 | 0 | 74327 | 13703 | 0 | 13667 | 109299 | 744 |
| 5 | February | 1 | 4 | 4 | 1 | 11 | 6 | 1 | 237 | 653 | 672 | 389 | 21 | 0 | 435 | 19 | 0 | 283 | 651 | 0 | 67568 | 1370 | 0 | 32739 | 110104 | 672 |
| 6 | March | 1 | 8 | 5 | 1 | 10 | 6 | 1 | 21 | 585 | 744 | 381 | 266 | 0 | 723 | 159 | 0 | 363 | 478 | 0 | 121593 | 11153 | 0 | 48133 | 79961 | 744 |
| 7 | April | 1 | 3 | 4 | 1 | 2 | 4 | 1 | 343 | 420 | 720 | 605 | 18 | 0 | 377 | 300 | 0 | 115 | 702 | 0 | 60757 | 32084 | 0 | 16587 | 119754 | 720 |
| 8 | May | 1 | 5 | 4 | 1 | 5 | 4 | 1 | 25 | 195 | 744 | 446 | 250 | 0 | 719 | 549 | 0 | 298 | 494 | 0 | 110950 | 72046 | 0 | 25096 | 63900 | 744 |
| 9 | June | 1 | 5 | 5 | 1 | 1 | 4 | 1 | 14 | 279 | 720 | 720 | 7 | 0 | 706 | 441 | 0 | 0 | 713 | 0 | 112590 | 75408 | 0 | 0 | 145135 | 720 |
| 10 | July | 1 | 3 | 1 | 5 | 3 | 2 | 1 | 153 | 744 | 365 | 422 | 8 | 0 | 591 | 0 | 379 | 322 | 736 | 0 | 93139 | 0 | 71663 | 32685 | 144592 | 744 |
| 11 | August | 1 | 1 | 1 | 1 | 6 | 1 | 1 | 25 | 744 | 19 | 494 | 5 | 0 | 719 | 0 | 725 | 250 | 739 | 0 | 111144 | 0 | 127938 | 26995 | 109992 | 744 |
| 12 | September | 1 | 1 | 1 | 15 | 10 | 5 | 1 | 534 | 720 | 143 | 265 | 328 | 0 | 186 | 0 | 577 | 455 | 392 | 0 | 34079 | 0 | 101785 | 64971 | 40928 | 720 |

**Table 2. Failure rate, MTTR and MTBF analysis per month for the six units of the plant**

| S/N | Month | Failure rate (λ) | | | | | | MTTR | | | | | | MTBF | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | October | ∞ | 0.013 | 0.01 | ∞ | 0.019 | 0.007 | 744 | 27 | 52.2 | 372 | 22.8 | 32.25 | 0 | 79.286 | 96.6 | 0 | 51.6 | 153.75 |
| 2 | November | ∞ | 0.008 | 0.016 | ∞ | 0.026 | 0.006 | 720 | 13.6 | 42 | 720 | 321 | 72.67 | 0 | 130.4 | 60.86 | 0 | 39 | 167.33 |
| 3 | December | ∞ | 0.001 | 0.007 | ∞ | ∞ | 0.005 | 744 | 6 | 8.8 | 744 | 744 | 2 | 0 | 738 | 140 | 0 | 0 | 184 |
| 4 | January | ∞ | 0.026 | 0.016 | ∞ | 0.076 | 0.017 | 744 | 29.64 | 307.5 | 744 | 69.56 | 10.36 | 0 | 38 | 64.5 | 0 | 13.111 | 57.273 |
| 5 | February | ∞ | 0.009 | 0.211 | ∞ | 0.039 | 0.009 | 672 | 59.25 | 163.25 | 672 | 35.36 | 3.5 | 0 | 108.75 | 4.75 | 0 | 25.727 | 108.5 |
| 6 | March | ∞ | 0.011 | 0.031 | ∞ | 0.028 | 0.013 | 744 | 2.63 | 117 | 744 | 38.1 | 44.33 | 0 | 90.375 | 31.8 | 0 | 36.3 | 79.667 |
| 7 | April | ∞ | 0.008 | 0.013 | ∞ | 0.017 | 0.006 | 720 | 114.33 | 105 | 720 | 302.5 | 4.5 | 0 | 125.67 | 75 | 0 | 57.5 | 175.5 |
| 8 | May | ∞ | 0.007 | 0.007 | ∞ | 0.017 | 0.008 | 744 | 5 | 48.75 | 744 | 89.2 | 62.5 | 0 | 143.8 | 137.25 | 0 | 59.6 | 123.5 |
| 9 | June | ∞ | 0.007 | 0.011 | ∞ | ∞ | 0.006 | 720 | 2.8 | 55.8 | 720 | 720 | 1.75 | 0 | 141.2 | 88.2 | 0 | 0 | 178.25 |
| 10 | July | ∞ | 0.005 | ∞ | 0.013 | 0.009 | 0.003 | 744 | 51 | 744 | 73 | 140.67 | 4 | 0 | 197 | 0 | 75.8 | 107.33 | 368 |
| 11 | August | ∞ | 0.001 | ∞ | 0.001 | 0.024 | 0.001 | 744 | 25 | 744 | 19 | 82.33 | 5 | 0 | 719 | 0 | 725 | 41.667 | 739 |
| 12 | September | ∞ | 0.005 | ∞ | 0.026 | 0.022 | 0.013 | 720 | 534 | 720 | 9.53 | 26.5 | 65.6 | 0 | 186 | 0 | 38.47 | 45.5 | 78.4 |
| | Average | | | | | | | 730 | 72.5208 | 259.025 | 523 | 216.002 | 25.705 | 0 | 224.79 | 58.2467 | 69.939 | 39.7782 | 201.1 |

**Table 3. Availability, capacity factor and reliability analysis per month for the six units of the plant**

| S/N | Month | Availability | | | | | | Capacity Factor (CF) | | | | | | Reliability | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | October | 0 | 0.746 | 0.649 | 0 | 0.694 | 0.827 | 0 | 61.45 | 49.33 | 0 | 52.85 | 62.52 | 0 | 0.739 | 0.78 | 0 | 0.628 | 0.856 |
| 2 | November | 0 | 0.906 | 0.592 | 0 | 0.108 | 0.697 | 0 | 67.61 | 43.71 | 0 | 5.43 | 51.26 | 0 | 0.832 | 0.674 | 0 | 0.54 | 0.866 |
| 3 | December | 0 | 0.992 | 0.941 | 0 | 0 | 0.989 | 0 | 71.73 | 0 | 0 | 0 | 70.18 | 0 | 0.968 | 0.843 | 0 | 0 | 0.878 |
| 4 | January | 0 | 0.562 | 0.173 | 0 | 0.159 | 0.847 | 0 | 45.41 | 8.37 | 0 | 8.35 | 66.78 | 0 | 0.532 | 0.689 | 0 | 0.16 | 0.658 |
| 5 | February | 0 | 0.647 | 0.028 | 0 | 0.421 | 0.969 | 0 | 45.7 | 0.93 | 0 | 22.14 | 74.48 | 0 | 0.802 | 0.006 | 0 | 0.393 | 0.802 |
| 6 | March | 0 | 0.972 | 0.214 | 0 | 0.488 | 0.643 | 0 | 74.29 | 6.81 | 0 | 29.41 | 48.85 | 0 | 0.767 | 0.47 | 0 | 0.516 | 0.74 |
| 7 | April | 0 | 0.524 | 0.417 | 0 | 0.16 | 0.975 | 0 | 38.36 | 20.26 | 0 | 10.47 | 75.6 | 0 | 0.826 | 0.726 | 0 | 0.659 | 0.872 |
| 8 | May | 0 | 0.966 | 0.738 | 0 | 0.401 | 0.664 | 0 | 67.78 | 44.02 | 0 | 15.33 | 39.04 | 0 | 0.846 | 0.84 | 0 | 0.669 | 0.823 |
| 9 | June | 0 | 0.981 | 0.613 | 0 | 0 | 0.99 | 0 | 71.08 | 47.61 | 0 | 0 | 91.63 | 0 | 0.844 | 0.762 | 0 | 0 | 0.874 |
| 10 | July | 0 | 0.794 | 0 | 0.509 | 0.433 | 0.989 | 0 | 56.9 | 0 | 43.78 | 19.97 | 88.34 | 0 | 0.885 | 0 | 0.729 | 0.8 | 0.937 |
| 11 | August | 0 | 0.966 | 0 | 0.975 | 0.336 | 0.993 | 0 | 67.9 | 0 | 78.16 | 16.49 | 67.2 | 0 | 0.967 | 0 | 0.967 | 0.562 | 0.968 |
| 12 | September | 0 | 0.258 | 0 | 0.801 | 0.632 | 0.544 | 0 | 21.51 | 0 | 64.26 | 41.02 | 25.84 | 0 | 0.879 | 0 | 0.536 | 0.59 | 0.736 |
| | Average | 0 | 0.7762 | 0.3637 | 0.1904 | 0.3192 | 0.8439 | 0 | 57.477 | 18.42 | 15.517 | 18.455 | 63.4767 | 0 | 0.8239 | 0.4825 | 0.186 | 0.4598 | 0.8341 |

Figure 1. Overall MTTR and MTBF of the units.

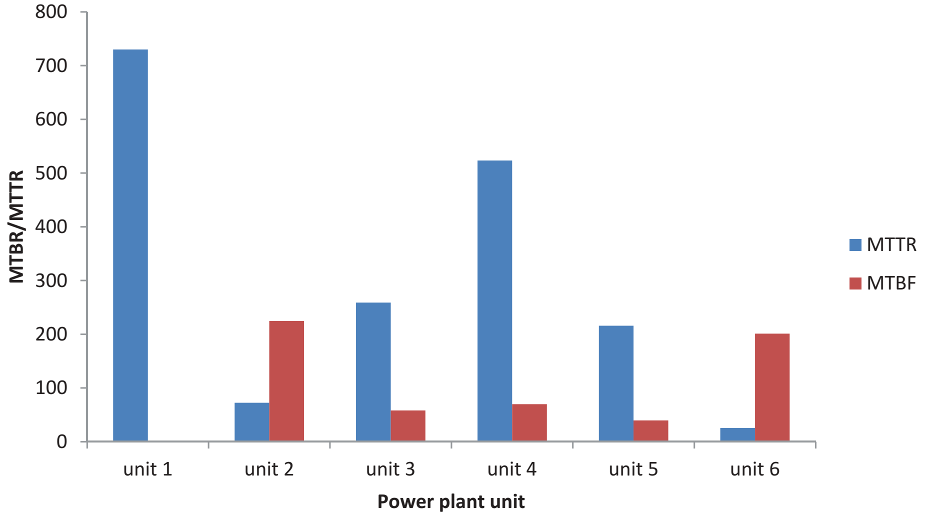
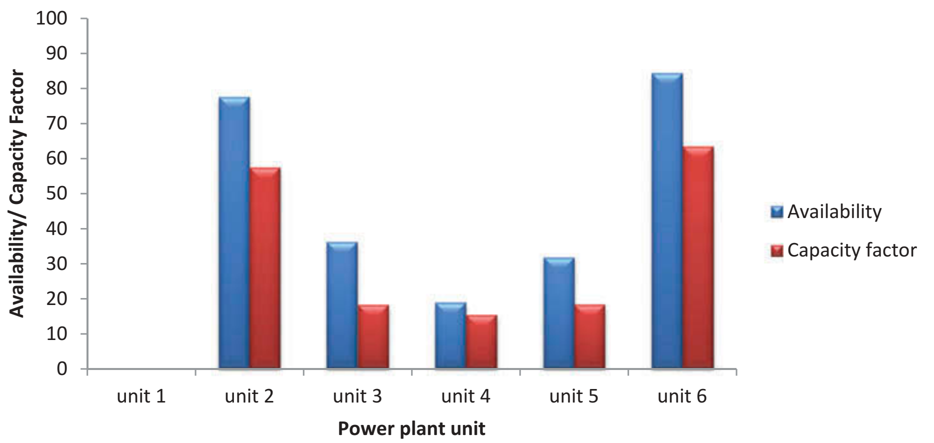



Figure 2. Overall availability and capacity factor of the units.

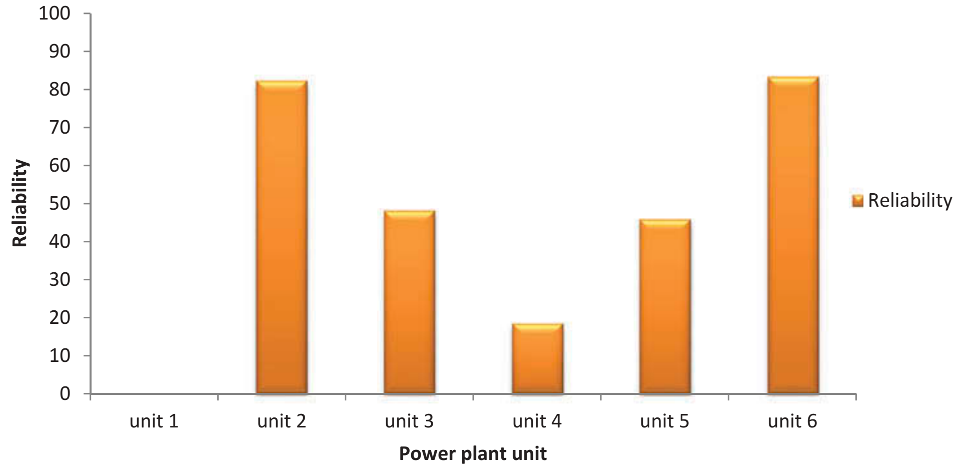



### *3.4. Overall plant's performance*

The plant is made up of six individual and identical units. The overall performance of the plant depends on the performances of each of these units. The overall failure and reliability indices analyses carried out on these units within the period of study were illustrated in Figures 1–3.

The unavailability of unit 1 makes it unreliable as shown in Figures 2 and Figure 3. From Figure 3, the unit with the highest reliability value was unit 6 at 83.41%, followed by unit 2 at 82.39%. In terms of availability and capacity factor, unit 6 also had the highest values, at 84.39% and 63.46%, respectively. More so, unit 2 had availability and capacity factor of 77.62% and 57.48%, respectively, as shown in Figure 2. The major factors responsible for these high values in reliability and availability were their high MTBFs and low MTTR. It was observed that their average MTBFs were above 200 hours. This implied that, on the average, these units worked for more than 8 days without experiencing a major failure. Also, their average MTTRs were between 1 and 3 days for major maintenance work after failure. This suggested that the lower the MTTR, the higher the uptime and ultimately the availability of a unit (Dhillon, 2006). However, these two units which gave the highest from this study were below the minimum requirement of availability value for a plant unit.

Figure 3. Overall reliability of the units.




The major reason for unit 6 to have obtained a high value of availability was due to a memorandum of understanding (MOU) that the plant should constantly supply power generated by Unit 6 primarily to a major commercial city in south-western Nigeria. This means that special attention was given to unit 6 so as to meet up with the signed MOU. However, unit 2 with no special attention also performed fairly well as availability value was close to that of unit 6. This study suggests that the plant operators should replicate the swift maintenance actions carried out on units 2 and 6 on others, especially unit 1 that was shut down throughout the period of study.

### *3.5. Generation loss analysis*

The total monthly generation loss in the plant, as well as the factors responsible for the loss was analysed. As explained earlier, the major factors preventing the steam power plant from running at maximum capacity were fuel/gas restriction, grid constraint and plant unavailability.

From Table 4, the total generation loss due to gas restriction was 2,162,336 MWH, grid constraint was 935,566 MWh and plant unavailability was 3,087,778 MWH. These bring the overall loss across the plant to be 6,185,680 MWH.

From the analysis, it can be seen that the highest contributing factor to the plant's inability to run at maximum continuous rating (MCR) within the statistical period was unavailability of the plant, at 62% of the total loss (Figure 4). This was caused by the poor and slow maintenance practice on the plant, especially in some units (units 1, 3, 4 and 5) having very high MTTR values.

Gas restriction caused 27% of the total generation loss. Gas restriction loss was due to low gas header pressure which could be caused by low gas production, vandalization of the pipeline or accident along the pipeline. Eleven per cent of the total generation loss was caused by grid constraint. The factors responsible for these range from grid collapse; total blackout; instruction from the national control centre (NCC) to reduce generation; outages caused by natural phenomena like wind or storm. If all these generation losses were removed or reduced, energy generation from the plant would be more available and reliable to the end-users.

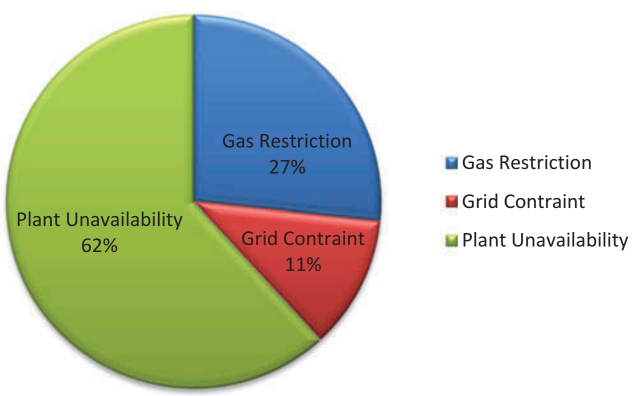
## 4. Conclusions

In this study, reliability and performance analysis of a power generating plant in Nigeria was analysed. Historical data obtained from the plant were used to appraise the overall performance of the plant and its generating units. Availability and capacity factor were also determined. The overall reliability was found to be 55.73% while the plant's availability and capacity factor were 50% and 35%, respectively. It was discovered that gas restriction, grid constraints and plant unavailability inhibited the plant from running at maximum continuous rating (MCR). To improve

**Table 4. Monthly generation loss**

| | | Gas Restriction (MWH) | Grid Constraints (MWH) | Plant Unavailability (MWH) |
|---|---|---|---|---|
| 1 | October, 2016 | 154,061 | 46,267 | 247,918 |
| 2 | November, 2016 | 264,415 | 23,044 | 238,410 |
| 3 | December, 2016 | 419,372 | 3,073 | 163,680 |
| 4 | January, 2017 | 310,598 | 18,482 | 278,324 |
| 5 | February, 2017 | 250,475 | 5,370 | 271,574 |
| 6 | March, 2017 | 255,896 | 5,546 | 296,116 |
| 7 | April, 2017 | 286,851 | 2,725 | 195,804 |
| 8 | May, 2017 | 200,930 | 106,726 | 238,752 |
| 9 | June, 2017 | 161 | 240,087 | 218,619 |
| 10 | July, 2017 | 6,577 | 139,701 | 320,043 |
| 11 | August, 2017 | 13,000 | 185,931 | 226,915 |
| 12 | September, 2017 | 0 | 158,614 | 391,623 |
| | **TOTAL** | 2,162,336 | 935,566 | 3,087,778 |
| **GRAND TOTAL** | | | | **6,185,680** |

**Figure 4. Factors responsible for power generation loss.**




on power supply to the end users, there is a need to ensure adequate gas supply, better maintenance and further examination of the transmission and distribution units of the power system.

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**References**

Abdullahi, M. I., Akinsanmi, O., Muazu, M. B., & Jubril, Y. (2007). Reliability assessment of an electronic system: A case study of a British Siren in Nigeria. *Assumption University Journal of Thailand*, *14*, 217–224.

Adamu, M. Z., Adegboye, B. A., Bajoga, B. G., Ambafi, J. G., & Omokhafe, J. T. (2012). Reliability evaluation of Kainji hydro-electric power station in Nigeria. *Journal of Energy Technologies and Policy*, *2*, 15–30.

Agbo, A. (2007). Ending the power nightmare. *Stud Tribes Tribals. Kamla-Raj*, *10*, 73–82.

Awosope, A. C. (2014). Nigeria electricity industry: Issues, challenges and solutions. *Public Lecture Series*, *3*, 5–9.
Barabady, J. (2005). *Improvement of system availability using reliability and maintainability analysis* (pp. 1–12). Luleå, Sweden: Luleå University of Technology.
Dewangan, D. N., Kumar, M. J., & Banjare, Y. P. (2014). Reliability investigation of steam turbine used in thermal power plant international. *Journal of Innovative Research in Science, Engineering and Technology (IJIRSET)*, *3*, 14915–14923.
Dhillon, B. S. (2006). *Maintainability, maintenance, and reliability for engineers* (1st ed., pp. 1–7). Boca Raton, FL: CRC Press, Taylor & Francis Group.
Ireson, W. G., & Coombs, C. F. (1998). *A handbook of reliability engineering and management*. New York, NY.
Kececioglu, D. (1995). *Maintainability, availability, & operational readiness engineering*. Upper Saddle River, NJ: Prentice Hall PTR.
Ogieva, F. E., Ike, A. S., & Anyaeji, C. A. (2015). Egbin Power station generator availability and unit performance study. *International Journal of Physical Sciences*, *10*(4), 155–172. doi:10.5897/IJPS2014.4226
Prada, J. F. (1999). The value of reliability In *Power systems; Pricing and operating reserves*. Massachusetts, MA: Energy Laboratory, Massachusetts Institute of Technology.
Presidential Task Force on Power (PTFP). (2015). “2014 year in review”. Annual report of the Presidential Task Force on Power (PTFP), Nigeria. Retrieved from http://www.springer.com/978-94-007-0634-7
Sambo, A. S., Garba, B., Zarma, I. H., & Gaji, M. M. (2010). Electricity generation and the present challenges in the Nigerian power sector. In *Energy commission of Nigeria* (pp. 1–10). Abuja-Nigeria. Retrieved from https://nairametrics.com/wp-content/uploads/2013/02/electricity-generation.pdf
Souza, G. F. M. (2012). *Thermal power plant performance analysis. Springer series in reliability engineering*. Springer-Verlag London Limited. Retrieved from https://link.springer.com/content/pdf/bfm%3A978-1-4471-2309-5%2F1.pdf