



## Improving Maintenance Strategy of a Natural Gas Powered Generator Using Reliability Technique: A Case Study

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### ABSTRACT

*The work seeks to improve the maintenance strategy of a natural gas powered generator using reliability techniques. In this study, the analysis was done in order to estimate generator reliability using failure data thus natural gas powered generator in Awoba flow station and gas plant are used as the case study to examine the maintenance strategy of the equipment. The operation time/running time, MTBF, downtime, failure rate, repair rate ( $\eta$ ) reliability, unreliability, availability and unavailability of the gas generator was determined using Monte Carlo reliability analysis Model. Thus the data regarding the generator operated in Awoba flow station industrial plant was collected from the maintenance department New cross energy for four (4) years period, before they were further analyzed. Based on the explanatory results the reliability and availability by failure modes and generator units are determined. The research showed that the failure rate of the generator increases from the first year 0.000570 to the fourth year 0.00136, also, the reliability of the generator decreases from the first year 30.81% to the second year 20.82%, then slightly increase from the third year 24.15% to the fourth year 25.14%. Thus, the availability of the generator is decreasing from the first year 0.9672 to the fourth year 0.8849. This research work recommends maintenance personnel should properly monitor the failure rates of the generator by adopting proper maintenance policies, it surely improve the efficiency of the generator and its working hours.*

**KEYWORDS:** Generator, Management, Failure rates, Reliability, Repair rates

### 1. INTRODUCTION

The contemporary business environment has raised the strategic importance of the maintenance function within organizations

which have significant investment in physical assets (Tsang, 2002). The performance and competitiveness of manufacturing and production companies is dependent on the reliability, availability and productivity of their production facilities (Muchiri *et al.*, 2011).

The maintenance function must achieve the organization's ultimate goal and translate business priorities into maintenance priorities. Maintenance expenditures can account for as much as 40% of the operational budget in many large-scale plant-based enterprises, therefore boosting maintenance efficacy is a viable technique for saving money (Eti *et al.*, 2006).

The oil and gas business is a competitive market that demands great plant efficiency, which translates to excellent equipment availability, reliability, and maintainability. Today's high expectations for equipment reliability and availability are so high that it necessitates optimizing maintenance operations (Calixto, 2012). The cost of maintenance is the third greatest cost in the oil and gas business, necessitating the optimization of this function (El-Jawhari & Collins, 2014). Maintenance strategies of natural gas-powered units is an important task in a power plant and plays major role in operation and planning of the system. This is in addition to order aspects of the plant as a functioning unit. So, the economic operation of an electric utility system requires the simultaneous solution of all aspects of the operation scheduling problem in the face of system complexity, different time-scales

involved, uncertainties of different order, and dimensionality of problems. Expected unserved energy (EUE) was used as reliability criteria for the generator maintenance scheduling (GMS) problem. In (Yare & Venayagamoorthy, 2010), For the GMS problem, the supply reserve margin was leveled, resulting in the lowest fuel costs possible during power system operation (Lindner, 2017). As a result, leveling the reserve margin is a typical solution for the GMS dilemma in order to meet the reliability requirement while also lowering fuel expenses. GMS problems are nonlinear, complicated problems involving a variety of variables such as resource characteristics and system requirements (Suresh & Kumarappan, 2013). Incorporating demand response (DR) into the GMS dilemma is particularly difficult. As a result, only a small amount of research has been done on GMS algorithms that incorporate DR programs. Market-based DR was explored in the GMS problem, and the impact of economic-based DR on the GMS problem was investigated (Mollahassani-pour *et al.*, 2015). However, in the GMS problem, a reliability-based DR has yet to be considered. DR based on reliability entails reducing demand during peak periods.

As a result, a curtailment request from the independent system operator triggers reliability-based demand response (ISO). In comparison to incentive-based demand react, reliability-based demand response's performance can be bolstered by significant penalties. Its capacity has the potential to influence the GMS problem's outcome by altering supply reserves for power system reliability across the scheduling period. In the GMS problem, it is critical to analyze the features of reliability-based DR, which differ from those of traditional generators, in order to efficiently maintain supply reserves in the power system.

Barabady (2005) recognized dependability as a critical aspect in the design and operation of engineering systems, describing it as a vital performance measurement yardstick for the entire system. The entire period during which a component is active has a significant impact on the component's and the system's reliability, according to the Reliability, Availability, and Maintainability (RAM) analysis.

Dewangan *et al.* (2014) investigated the reliability of turbines used in steam power plants using the failure mode and effect analysis.

The study focused on identifying, classifying, and improving critical components in the plant's operation for enhanced plant dependability by using prior failure records of each component and the overall failure effect of each component on the plant. Based on the manner of installation, the competency of the operations and maintenance team, the quality of steam generated, and fluctuating climatic circumstances, the research convincingly linked the dependability profile of any heavy-duty steam turbine to human variables along the chain. The study, on the other hand, failed to account for the impact that time has on equipment reliability.

Ogieva *et al.* (2015) conducted research at Egbin Power Station in Lagos to determine generator availability and unit performance. The plant's historical operational data was evaluated with MATLAB to determine the availability of the plant's units and overall availability. For future computations, a computer program was created based on the template employed in the analysis. However, generator availability alone is insufficient to judge a power plant's performance because it only considers the plant's total uptime and downtime, ignoring the number of failures and total effective generation during the available hours. In addition, certain inconsistencies in the data used during the

study period were noted, as some data were not available to the researchers thus limiting the scope of the study.

Adamu *et al.* (2015) study about evaluation of the reliability of Kainji power station, a hydroelectric power plant in Nigeria. 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).

The aim of this research is to use reliability techniques to improve the maintenance strategy of natural gas powered generator in Awoba flow station and gas plant. The specific objectives outlined were to: evaluate the meantime between failure and down time of the natural gas-powered generator; determine the failure rate of the natural gas-powered generator by applying reliability analysis; evaluate the reliability and unreliability of the selected natural gas-powered generator using reliability analysis; evaluate the availability and unavailability of the selected natural gas-powered generator using reliability analysis.

## 2. MATERIALS AND METHODS

### 2.1 Materials

There are many reliability techniques available for analyzing the failure of plant components and generators. For the one case study described herein, we have the Monte Carlo reliability models which can realistically assess plant and generator conditions when combined with cost, repair time and statistical events. Monte Carlo simulation model is very helpful for

considering approximate operating conditions in a plant including cost effectiveness to provide protection for short duration failures.

The data was obtained from the equipment availability report of the Awoba flow station and gas plant generators. The generator model is G3516 caterpillar Engine. The collected data was simulated using Microsoft Excel value-based analysis.

### 2.2 Methods

In carrying out this research, reliability techniques will be adopted (Parida, 2007). Data will be collected as stated below.

#### 2.2.1 Data Collection

Reliability assessment studies are mainly dependent on failure rates data. The more reliable and valid the data, the better the reliability can be assessed. In this research, the generator failure rates were extracted from the equipment availability report of a natural gas powered generator (OML 24) Awoba flow station, and gas plant. These data include the number of failure, stand by time (hour), Operational time running hour (hr/week), and down time. The data obtained included four years' study interval (SI) as well as the number of failures (NF) and the corrective time per failure (CTPE).

#### 2.2.2 Lambda and Mean-Time to Failure

Lambda ( $\lambda$ ) and mean time to failure (MTTF) was calculated using Equations (1) and (2), respectively. Mean time between failures yielded clear figures on the random failure behaviour of a particular component and ultimately it was essential for reliability calculations (Pedregal *et al.*, 2004).

$$\lambda = \frac{\text{number of failure}}{\text{number of unit tested} \times \text{duration of test}} \quad (1)$$

$$MTTF = \frac{1}{\lambda} \quad (2)$$

where

$\lambda$  = Failure rate

### 3.3. Analytical Procedure and Tools

Mathematical Language of Reliability: The following approaches will be used in resolving the analysis of generator components using reliability tools and techniques

- i. Start reliability improvement program with simple arithmetic and spreadsheets to quantify important cost and failure numbers.
- ii. Gaining momentum with good maintenance practices will improve team work using total productive maintenance program such as root cause analysis to efficiently solve problems.
- iii. The application on improvement of program by using statistics to quantify the results.
- iv. Application of Monte Carlo model to simulate generator engine components availability, reliability, maintainability, capability and life cycle costing for deciding reliability strategies.

### 3.4 Analytical Methods

The mathematical model for this research was established by considering four years study interval (SI) as well as the number of failures (NF) and the corrective time per failure (CTPE) (Pedregal *et al.*, 2004)

Mean Time between Failures (MTBF)

$$(MTBF) = \frac{\text{Operating time (OT)}}{\text{Number of failures (NF)}} \quad (3)$$

where

OT= Operating time (hour/year)

NF = Number of failure (year)

#### Total mean time between failures

Thus, Total failures per year is given as

$$TMTBF = \frac{\text{Annual hours per year}}{\text{Total failure per year}} \quad (4)$$

#### Failure Rate

The failure rate is given as thus,

$$FR = \frac{1}{MTBF} \quad (5)$$

#### Repair Time

The repair time is determined as

$$\text{Repair time} = \frac{\text{Down time}}{\text{Number of failure}} \quad (6)$$

#### Reliability Model

To determine the generator components reliability (GCR) the Equation used is expressed mathematically as (Pedregal *et al.*, 2004):

$$GCR = e^{-\lambda t} \quad (7)$$

#### Unreliability Model

To determine the generator components unreliability (GCR) we use the expressed (Yang & Hong, 2013):

$$BU = 1 - e^{\left(\frac{-t}{MTBF}\right)} \quad (8)$$

#### Availability Model

To determine the generator components availability (GCA) we have (Yang & Hong, 2013):

$$GCAV = \frac{\text{mean time between failure} - \text{lost time per year}}{\text{Lost time per year}} \quad (9)$$

where

GCAV = Generator component availability

### 3. RESULTS AND DISCUSSION

#### 3.1.1 Results of Mean Time Between Failure and Down Time for the Gas Generator- GZ-8201A

Given the operating data as presented in Table 1

**Table 1: Operating Data for the Generator**

Year	Failure equipment	No of failure	Stand by time (hour)	Operational time running hour(hr/week)	Down time
2017	GAS GENERATOR A - GZ-8201A	5	5676	2065	70
2018	GAS GENERATOR A - GZ-8201A	7	5986	1964	77
2019	GAS GENERATOR A - GZ-8201A	8	6521	1556	88
2020	GAS GENERATOR A - GZ-8201A	12	7679	1015	132

The total operating time is determined as

$$\text{Total operating time (4 years)} = 2065 + 1964 + 1556 + 1015 = 6600\text{hrs}$$

#### Mean Time between Failures (MTBF) for the GAS GENERATOR A - GZ-8201A

From Equations (3), the meantime between failure is determined as

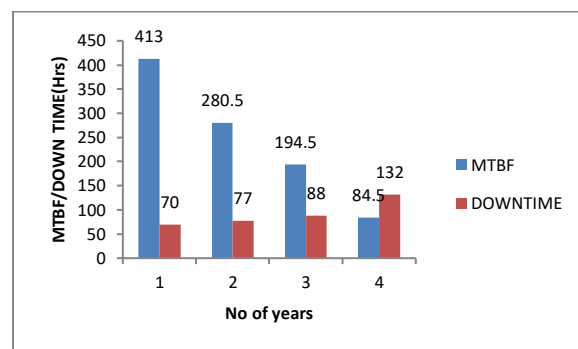
$$1^{\text{st}} \text{ year} = MTBF = \frac{2065}{5} = 413\text{hrs}$$

$$2^{\text{nd}} \text{ year} = MTBF = \frac{1964}{7} = 280.5\text{hrs}$$

$$3^{\text{rd}} \text{ year} = MTBF = \frac{1556}{8} = 194.5\text{hrs}$$

$$4^{\text{th}} \text{ year} = MTBF = \frac{1015}{12} = 84.5\text{hrs}$$

Figure 1 shows the evaluated mean time between failure and downtime from the data of the Gas Generator A - GZ-8201A using the Monte Carlo model of reliability analysis.



**Figure 1: Downtime and Mean Time Between Failure**

From the computational gas generator values, it was observed that there was a decline in the operating time from the 1st year to the 4th year, from 2065 hours to 1015 hours. Also decreasing yearly is the mean time between failures from 413 hours to 85.5 hours, while the down time (DT) increases from the 1st year to the 4th year from 70 hours to 132 hours. Consequently, from the investigation a bar chart was used to show the relationship between the number of years against the mean time between failure and downtime obtained. It was seen that when the down time of the gas generator is increasing the mean time between failure (MTBF) is decreasing. This shows that during production as the year increases, the number of failures for the gas generator will be steadily increasing, as observed from the 1st year (2017) until 4th year (2020). The breakdown of this gas generator affected the production capacity for these 4 years.

Therefore, proper maintenance strategy should be applied to the gas generator.

### 3.2 Results for Failure Rate of Gas Generator A - GZ-8201A

From Equations (5), the failure rate is determined as

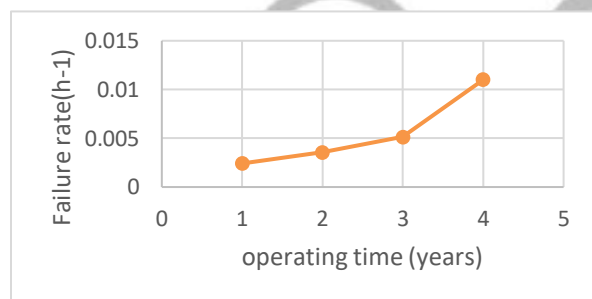
$$1^{\text{st}} \text{ year} = \text{Failure rate} = \frac{1}{413} = 0.00242$$

$$2^{\text{nd}} \text{ year} = \text{failure rate} = \frac{1}{280.5} = 0.00356$$

$$3^{\text{rd}} \text{ year} = \text{failure rate} = \frac{1}{194.5} = 0.00514$$

$$4^{\text{th}} \text{ year} = \text{failure rate} = \frac{1}{84.5} = 0.011$$

$$\begin{aligned} \text{Total failure for 4 years} &= \sum \text{failure rate/year} \\ &= 0.00242 + 0.00356 + 0.00514 + 0.011 = \\ &0.02212/\text{year} \end{aligned}$$



**Figure 2: Failure Rate Analysis for 4 years**

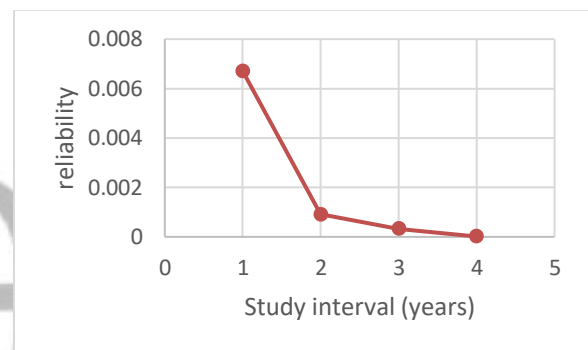
Figure 2 shows the evaluated failure rate of four years from the data of the Gas Generator A - GZ-8201A using the Monte Carlo model of reliability analysis.

Figure 2 shows the result of the failure rate of the generator using reliability analysis. From the figure, the failure rate of the generator of the first year is 0.00242, then it increases to the second year to 0.00356, then to the third year to 0.00514 and lastly to the fourth year to 0.011. From figure 4.2 it clearly seen that as the year is increasing the failure rate of the generator equipment is also increasing, which could be as a result of poor

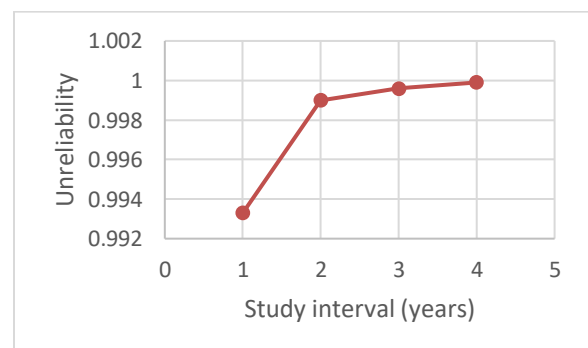
maintenance practices in the firm, which will result to poor performance of the equipment that will also cause high failure rate of the equipment. Therefore, proper maintenance strategy should be applied to the gas generator.

### 3.3 Results of Reliability and Unreliability of the Gas Generator A - GZ-8201A

Figures 3 and 4 shows the evaluated reliability and unreliability from the maintenance data of the gas generator A - GZ-8201A using the Monte Carlo model of reliability analysis.



**Figure 3: Reliability Against the Study Interval (4 years) for Gas Generator**



**Figure 4: Unreliability Against the Study Interval (4 years) for Gas Generator**

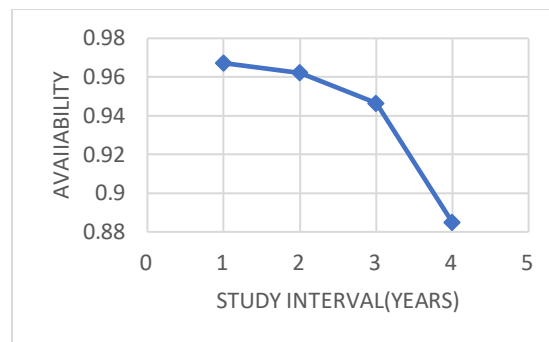
The analysis of the reliability and unreliability from Figures 4.3 and 4.4 generator of the gas generator as graphically represented shows that the reliability is decreasing gradually. This is detected as from between the 1st year 0.0067 (0.67%) and 2nd year, 0.00091 (0.091%), and there is a sharp decrease in reliability, and also, from the third year to the fourth year 0.00033(0.033%) to 0.000014(0.0014%). There was a shrill increase in the reliability curve and then it continued throughout the 4 year period. From Figure 3 it clearly seen that the reliability value is not up to 1%, which an indication that the generator is not satisfactory to be used.

The unreliability graph shows a reverse effect from the reliability graph as can be seen on Figure 4. it increases from the first year 0.9933 to the second year 0.9990, then decreases from the third year 0.9996 to the fourth year 0.9999. This shows that as the year increases, the gas generator became less reliable due to regular breakdown and improper maintenance strategies. Also, more attention should be given to less performers and proper maintenance strategies planned to enhance their reliability.

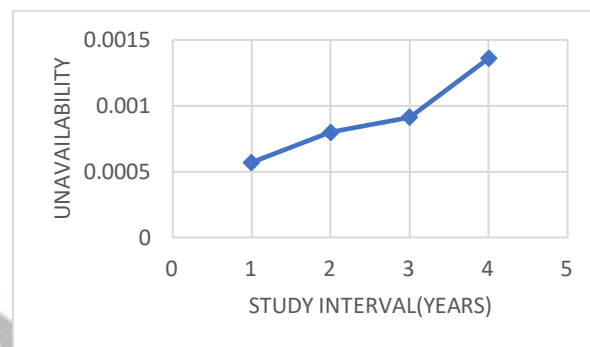
To improve the reliability of the generator preventive maintenance is needed for the equipment. Since the reliability of generator of different years was different, the maintenance time interval for different years will also be different.

### 3.4 Results Availability and Unavailability of the Gas Generator A - GZ-8201A

Figure 5 and 6 shows the evaluated availability and unavailability from the equipment availability report on the gas generator GZ-8201A using the Monte Carlo model of reliability analysis.



**Figure 5: Availability of the Gas Generator for a 4 Year Period**



**Figure 6: Unavailability of the Gas Generator for a 4 Years Period**

The analysis of the availability and unavailability from Figures 5 and 6 of the gas generator as graphically represented shows that the availability decreases gradually. This was detected from first year 0.9672 to the fourth year 0.8849. There was a sharp drop in the availability curve and then it continued throughout the 4-year period. The unavailability graph shows a reverse effect from the availability graph as can be seen in Figure 6. It increases from the first year 0.000570 to the fourth year 0.00136. This shows that as the year increases, the gas generator became less available due to regular breakdown and ineffective maintenance strategies.

## 4. CONCLUSION

From the objective one of this research work which is to evaluate the meantime between



failure and down time of the natural gas-powered generator in Awoba flow station and gas plant. it is seen that the mean time between failures (MTBF) decreased from the first year 413hrs to the fourth year 84.5hrs and down time increases as the year is increasing. This means that as the gas generator was operating for four years' period, without proper maintenance strategy, the generator was gradually deteriorating which will result to high cost of maintenance and loose of production objective one of this research was achieved.

From the objective two of this research work, which is to determine the failure rate of the natural gas-powered generator using reliability analysis, after my analysis it was seen that, as the operating year of the generator is increasing, the failure rate is also increasing, which is from the first year 0.00242 to the fourth year 0.011. This shows that the failure rate is high due to poor maintenance strategy.

The objective three of this research work is to evaluate the reliability and unreliability of the selected natural gas-powered generator using reliability analysis, which after analysis it was seen that, as the operating year of the gas-powered generator is increasing, its reliability is decreasing, from the first year 0.0067 to the fourth 0.000014, also the unreliability increased from the first year 0.9933 to the fourth year 0.9999. This shows that the generator reliability is reducing with time due to poor maintenance strategy. Objective three was achieved.

The objective four of this research is to evaluate the availability and unavailability of the selected natural gas-powered generator using reliability analysis, which after analysis it was seen that, as the operating year of the gas-powered generator is increasing, its availability is decreasing from the first year

0.9672 to the fourth year 0.8849, whereas the unavailability increases from the first year 0.0328 to the fourth year 0.1151. This shows that effective maintenance action is required.

From the objective five of this research which is to identify the existing maintenance strategy and suggest measures for improving the natural gas powered generator operation. It was observed that, there's no proper maintenance strategy in place. In fact, the company practice run to failure maintenance which have led to low availability of the generator from year 1 to 4 as we can see from the result of objective one to four. This investigation shows that, this gas generator either breakdown or fails during production after operating for several hours over a period of time running into years, if gas generator is not properly maintained or replaced, the tendency of influencing the production capacity negatively can occur. The Monte Carlo method was used for the successful evaluation of the reliability analysis of the gas generator. The Monte Carlo analysis was used to evaluate parameters such as the mean time between failure, failure rate, reliability, unreliability, availability and unavailability for generator. A loss of this equipment would lead to a loss of production which will have cost implications.

In evaluating the reliability of gas generator, some functional parameters such as the operating time, study interval, failure rate ( $\lambda$ ), downtime, meantime between failures (MTBF), repair rate ( $\eta$ ) reliability and unreliability were determined. It shows that the reliability of the gas generator was decreasing as the year increases giving rise to decreases, increase in failure rate, there is also a decrease in availability and increase in unavailability for the four years.

Based on the results obtained, there was a difference between the reliability values of estimation by failure rate. Hopefully, the



feasible results obtained from the analysis and the findings could be implemented to form a better maintenance strategy in terms of failure mitigation and inspection. Hence, the objective of the project has been achieved.

## 5. ACKNOWLEDGEMENTS

I would like to acknowledge the staff of the Department of Mechanical Engineering, Rivers State University, Nigeria for their technical support. Also, I appreciate Prof C.P Ukpaka, and Dr, Anthony Njoku my lovely husband for their supports. I say a very big thank you to all those who have in one way or another contributed to the success of this work.

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