# AVAILABILITY AND RELIABILITY ANALYSIS OF IBOM POWER PLANT

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**_ABSTRACT_**

*The availability and reliability of a gas power plant was investigated using mean time to failure and mean time to repair. These parameters seek to identify extent of time the power plant will be available to delivery electricity to consumers. Also, exponential probability distribution function was used to determine the expected duration of electricity generation by the power plant. The studied showed that the power plant has high mean time to repair indicating that the plant was unavailable for a long period. Also, the availability and reliability of the power plant were about 68 %. This is far below the IEEE recommended standard of 99 %. Finally, the probability weighted average for power generation was found to be 54.54 hours per month. This value is so small considering that we have an average of 720 hours in a month.*

***Keywords**: **Power Plant, Reliability, Availability, Electricity, Energy, Power Generation, Mean Time**.*

## 1. INTRODUCTION

Economic growth, population upsurge and industrialisation had led to an increase in the demand of electrical energy in Nigeria. There are several means of power generation, but currently gas turbine power plant remains the most efficient and viable means of power generation. Gas power plants are among the conventional methods of power generation. The gas turbine power plants can be sub-classified into simple cycle gas turbines, combined cycle gas turbine or gas-fired steam turbines depending on the cycle employed for the prime mover.
The gas turbine power plant is made up of the following main components: compressor, combustion chamber, gas turbine, alternator and starting motor. In a gas turbine power plant, air is used as a working fluid. The air is compressed by the compressor and is sent to the combustion chamber where heat is added to air, thus, raising its temperature. Heat is added to the compressed air either by burning fuel in the chamber or by the use of air heaters. The hot and high pressured air from the combustion chamber is then passed to the gas turbine where it expands and does the mechanical work. The gas turbine drives the alternator which converts mechanical energy into electrical energy.
According to the report of International Energy Outlook (IEO) 2010 (DoE, 2010) the world net electricity generation projection will increase by 87%, from 18.8 trillion kilowatt hours in 2007 to 25.0 trillion kilowatt hours in 2020 and 35.2 trillion kilowatt hours in 2035. Although the recession slowed the rate of growth in electricity demand in recent time, there are still substantial growths in demand of electricity. In general, in Organization for Economic Co-operation and Development (OECD) countries, where electricity markets are well established and consumption patterns are mature, the growth of electricity demand is slower than in non-OECD countries like Nigeria, where a large amount of potential demand remains unmet. According to that report, the total net generation in non-OECD countries increases by 3.3% per year on average, as compared with 1.1% per year in OECD nations.
Approximately 21% of the world's electricity production is based on natural gas. Gas power plant has outstanding prospects in Nigeria with about 187 trillion standard cubic feet of gas (Mustapha and Fagge, 2015). This quantity of gas reserve makes the establishment of gas power plant viable option for electricity generation. The electricity crisis facing the country brought about the need for establishment of gas power plants. So in the third quarter of 2001, Ibom Power Company commenced discussions with then Power Holding Company of Nigeria for the execution of a Power Purchase Agreement (PPA). Ibom Power Project was originally conceived as a 100 MW captive gas power plant which would be part of a crude oil refinery development. Subsequently, after discussions with the

Power Holding Company of Nigeria; the overall capacity was increased to 685 MW which was agreed be developed in two phases. In July 2002, Ministerial and Presidential approval for the PPA were obtained. On 6th August 2002, following negotiations lasting ten months, the first PPA was executed between Power Holding Company of Nigeria and Ibom Power Company. A Federal Government Support Agreement was also executed with the Federal Government of Nigeria on the same day.

Ibom Power Plant presently consist of two GE Frame 6B and one Frame 9E turbine generators installed in a simple cycle configuration, using the conventional open cycle gas turbine (OCGT) technology. These three gas turbines are: GTG 1(Model PG 6551B), GTG 2(Model PG 6561B), and GTG3 (Model PG 9171E) combined to give an installed capacity of 191 MW. The power plant is connected to the national grid via the 46 kilometres 132kV double circuit transmission line from Ikot Abasi to Eket. The associated substation in Ikot Abasi steps down the power to both 33kV and 11kV distribution lines for onward distribution to local industrial and private consumers. This line has the capacity of transmitting 200 MW of electric power and is enough to evacuate the power generated from the power plant.

## 2. MATERIALS AND METHODS

The data used in this work is secondary data. The information was collected from Ibom Power Plant. Ibom Power Plant Project started off as a captive power plant which was to be part of a 100,000 barrel per day export refinery. The project was designed as a public-private partnership between Akwa Ibom Industrial & Investment Promotion Council (AKIIPOC), the investment arm of the Akwa Ibom State Government. The objective of the company is to enhance power generation in Nigeria through the existing national grid and eventually provide uninterrupted power to consumers in Akwa Ibom State. Availability and reliability analysis were done to evaluate the performance of the plant which is a typical Independent Power Producer in Nigeria. Basic maintenance indices (MTBF and MTTR) were employed in the analysis.

In this work, Ibom Power Plant which is one of the Independent Power Producers (IPPs) will be studied. The plant gets its natural gas feedstock from Septa Energy's integrated gas receiving facility. The data for the analysis of the plant will be information contained in the Ibom Power Company monthly logbook. The period covered is between March 2010 to April 2015 being the period the company's data were provided.

### *2.1 Design Methodology and Analysis*

Reliability is the probability that a device will satisfactorily perform a specified function for a specified period of time under given operating conditions (Smith and Hinchcliffe, 2004). Reliability is represented by:

$$\mathrm{R(t)} = 1 - \mathrm{F(t)} \qquad (1)$$

Where: R(t) = Reliability at time t

F(t) = Failure probability at time t

However, gas turbine manufacturers, define reliability as probability of the plant not being out of service when the plant is needed. Balevic et al (2009) recommended a relation for reliability of a gas turbine as:

$$\mathrm{Reliability} = \left(1 - \frac{\mathrm{FOH}}{\mathrm{OH}}\right) \times 100 \qquad (2)$$

Where: FOH = Forced outage hours

OH = Operation hours

In the same vein, availability is the ability of a power plant to successfully perform its required function at a stated instant of time or over stated period of time (Duffuaa *et al.,* 1999). Oyedepo et al. (2014) proposed a method of obtaining the availability of power plant using record of failure and operational context of the plant as:

$$\mathrm{Availability} = \frac{\mathrm{MTBF}}{\mathrm{MTTR} + \mathrm{MTBF}} \qquad (3)$$

Where: MTBF = mean time between failures

MTTR = mean time to repair

According to the IEEE standard 762, availability measures are concerned with the function of time in which a power plant is capable of providing service and accounts for outage frequency and duration (IEEE, 2006).

Mean time between failures is the mean (average) of a distribution of product life time or life between successive failures. Literally, it is the average time from one failure to the next. This average time excludes the time spent waiting for repair, being repaired, being re-qualified, and other downing events such as inspections and preventive maintenance and so on; it is intended to measure only the time a system is available and operating. Mean Time between failures, as stated earlier is the average time between system failures of the entire sample population. It is calculated as the total time over the number of failures.

$$\mathrm{MTBF} = \frac{\text{Total up time}}{\text{Number of breakdowns}} \qquad (4)$$

Similarly, Mean Time to Repair is the expected time to recover a system from a failure. It is the average time required to fix a failed power plant and return it to production status. In other words, MTTR is the time needed to repair a failed plant. MTTR can be calculated by dividing the total time required for maintenance by the total number of repairs within a specific timeframe.

$$MTTR = \frac{Downtimes\ for\ repairs}{Number\ of\ repairs} \quad (5)$$

### 2.2 *Probability Distribution Theory*

In general terms, reliability is 'the ability of an entity to perform required function under given conditions for a given period of time'. In technical terms, reliability is measured by the probability that a system or a component will work without failure during a specified time interval under given operating conditions (Teixeira and Soares, 2012).Often the specified time interval or, alternatively, the mission duration is considered as a parameter t; and the probability P [T>t] that the random variable time to failure T; will be greater than t is given by the reliability function R (t); also referred to as the survival function,

$$R(t) = P[T > t] \quad (6)$$

The reliability function expresses the probability that the system operates without failure in a time period t; and therefore, since a system that does not fail for T ≤ t must fail at some T > t, then

$$R(t) = P[T > t] = 1 - F(t) = 1 - P[T \le t] \quad (7)$$

where F(t) is the cumulative distribution function (CDF) of the time to failure that gives the probability, P [T ≤ t] that the time to failure T will be equal or smaller than the specified time t; or in other words, the probability that the system will fail at a time less than or equal to t (Teixeira and Soares, 2012).

The cumulative distribution function F(t)and the reliability function R(t) are related to the probability distribution function f(t) of the time to failure by:

$$f(t) = \frac{d}{dt}F(t) \quad (8)$$

$$f(t) = -\frac{d}{dt}R(t) \quad (9)$$

Where f (t) describes how the failure probability is spread over time (Teixeira and Soares, 2012).

Fernando and Gilberto (2012) advocated the use of exponential distribution in reliability analysis of gas turbine. The exponential distribution is a particular case of a Weibull distribution with the shape parameter equal to one. Exponential distribution is use to model time to failure of power plant. If a range of variable t follows an exponential distribution then; the probability distribution function (pdf) will be

$$f(t) = \begin{cases} 0, & t < 0 \\ \lambda e^{-\lambda t}, & t \ge 0 \end{cases} \quad (10)$$

But the total area beneath probability distribution function is always equal to unity;

$$\int_0^\infty f(t)dt = \int_0^\infty \lambda e^{-\lambda t} dt \quad (11)$$

$$= \lambda e^{-\lambda t}\left(\frac{-1}{\lambda}\right)\Big|_0^\infty$$

$$= -\left[e^{-\lambda t}\Big|_0^\infty\right]$$

$$= -[0 - 1] = 1$$

$$\therefore \int_0^\infty f(t)dt = 1 \quad (12)$$

Therefore, the exponential f(x) is a valid probability distribution function.

The cumulative distribution function is the probability F(t) that P(X≤x)

$$F(t) = \begin{cases} 0, & if t < 0 \\ 1 - e^{\lambda t}, if\ t \ge 0 \end{cases} \quad (13)$$

The expectation of the function E (t) is given as

$$E(t) = \int_0^\infty t.f(t)dt = \int_0^\infty t.\lambda e^{-\lambda t}dt = \frac{1}{\lambda} \quad (14)$$

The second moment generating function gives the variance of the distribution, therefore we have

$$E(t^2) = \int_0^\infty t^2 \lambda e^{-\lambda t}dt = \frac{1}{\lambda^2} \quad (15)$$

It is important to note that λ is the rate parameter.

## 3. RESULTS AND DISCUSSION

The mean time between failures, mean time to repair, availability, reliability and expected time for electricity generation for Ibom Power Plant were presented. This will help in maintenance planning and schedule that will guarantee steady electricity generation.

The mean time between failure (MTBF) and mean time to repair (MTTR) for the power plant in 2010 are presented in Figure 1. The maximum value of MTBF was 35.32 hours in May 2010 and the minimum value of MTBF was 23.14 hours in December 2010; also the maximum value of MTTR was 30.01 hours in December 2010 and the minimum value of MTTR was 3.27 hours in September 2010. It was seen from Figure 7 that the plant was mostly available in September 2010 with availability of about 88%. Figure 2 showed the MTBF and MTTR for the power plant in 2011. The maximum and minimum MTBF were

46.35 hours and 22.53 hours in November 2011 and January 2011, respectively. The maximum and minimum MTTR were 58.47 hours and 1.17 hours in April 2011 and December 2011 respectively. Figure 7 showed that plant availability of 97% was obtained in November 2011 and December 2011.

Similarly, figure 3 presented the MTBF and MTTR for the plant in 2012 with September and April having the maximum values of MTBF and MTTR respectively. December 2012 and February 2012 have the minimum values of 33.35 hours and 1.23 hours respectively. The availability of the plant was 98% in February and March 2012 as presented in figure 7. The power plant was operational for only four months in 2013 as presented in figure 4; March 2013 has both maximum MTTR and minimum MTBF of 744 hours and 0 hour respectively; January 2013 has the maximum MTBF of 42.06 hours. Figure 5 showed that July 2014 has both the maximum MTBF and minimum MTTR of 744 hours and 0 hour respectively; whereas January 2014 has minimum MTBF of 12.83 hours and October 2014 has maximum MTTR of 108.58 hours; also figure 7 showed that July 2014 has availability of 100%. Finally, figure 6 presented MTBF and MTTR for 2015 with only four months covered. March 2015 has both maximum MTBF and MTTR; and January 2015 has both minimum MTBF and MTTR.

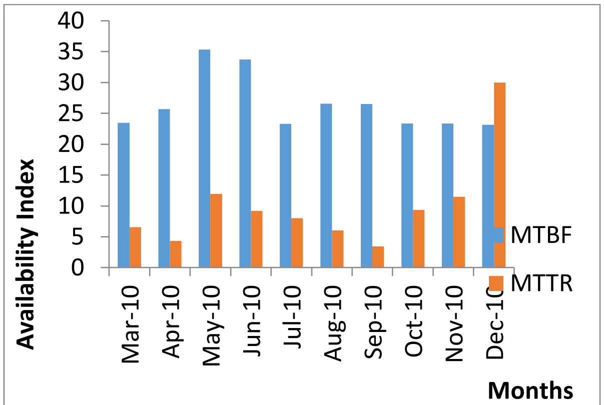


*Figure 1. Availability index for 2010*

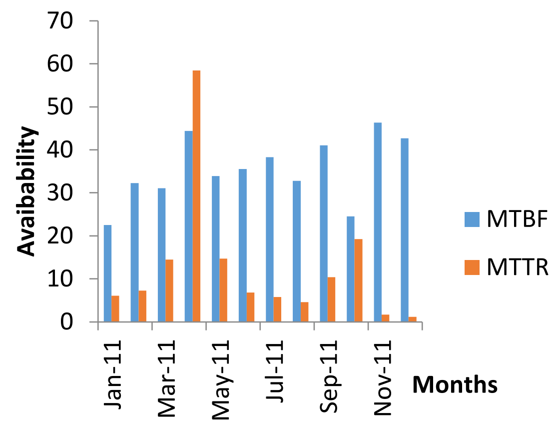


*Figure 2. Availability index for 2011*

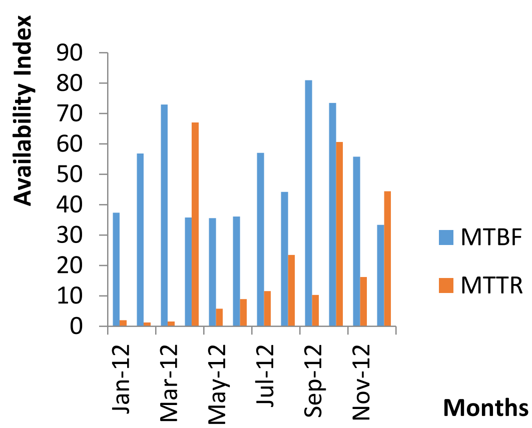


*Figure 3. Availability index for 2012*

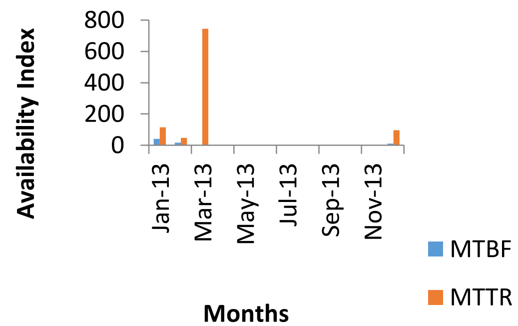


**Figure 4. Availability index for 2013**

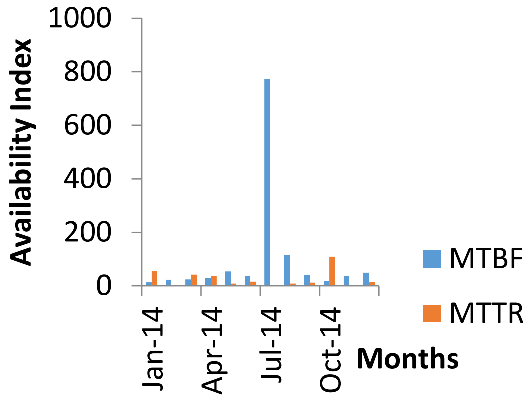


***Figure 5. Availability index for 2014***

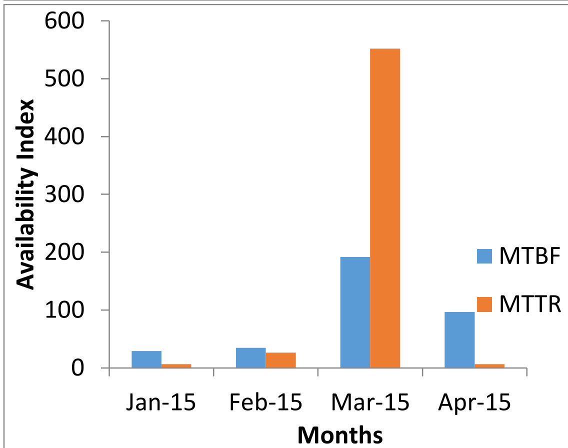


**Figure 6. Availability index for 2015**

MTBF is the mean (average) of a distribution of product life time or life between successive failures. This definition assumes that the power plant can be repaired and return back in operation after each failure. MTBF is expressed in hours. For power plants, it is commonly assumed that during the useful operation life period, the plants have constant failure rates, and part failure rates follow an exponential law of distribution. Therefore, MTBF is the average number of hours a power plant will operate without failure, power plant supposed to operate with maximum MTBF. Mean time between failures is a basic measure of a system's reliability. The higher the MTBF number, the higher the reliability of the plant.

Similarly, MTTR represents the average time required to repair a failed power plant, it implies that a very minimal MTTR is desired to ensure that plant is continuously available. The high values of MTTR in figures 1 – 6 are clear indication that the repair of the power plant takes longer time. The power plant will be unavailable during this repair period keeping the consumers without electricity supply. Mean Time to Repair is the expected time to recover a system from a failure. This may include the time it takes to diagnose the problem, the time it takes to get a repair technician onsite, and the time it takes to physically repair the system. Similar to MTBF, is represented in units of hours. As equation 4 shows, MTTR impacts availability and not reliability. The longer the MTTR, the worse off a system is. Simply put, if it takes longer to recover a system from a failure, the system is going to have a lower availability. As the MTBF goes up, availability goes up. As the MTTR goes up, availability goes down.

Figure 7 presented the monthly availability of Ibom power plant during the period under review. Availability is the probability that the power plant is operating under given condition at a given instant of time. From the figure, the availability is not stable and the power plant is not at all times available. This is unacceptable since gas turbines are designed to run continuously. Similarly, figure 8 showed the reliability of the power plant. The reliability and the availability of the Ibom power plant followed almost the same pattern as shown in figure 9. This conformed that reliability of a power plant depends on availability of the plant.

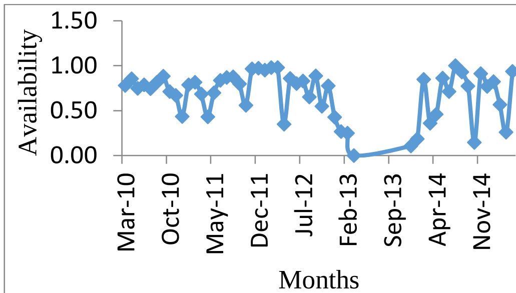


**Figure 7. Monthly Availability for the power plant**

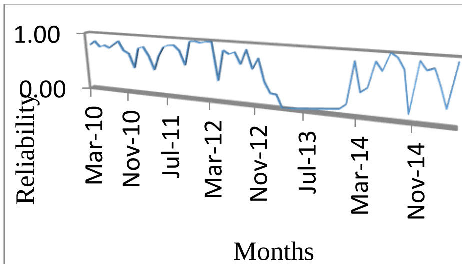


**Figure 8. Reliability of the power plant**

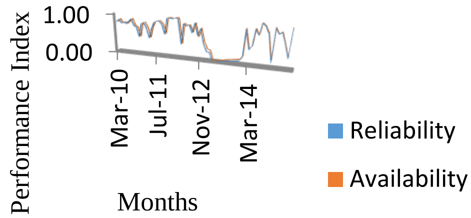


**Figure 9. Performance index for the power plant**

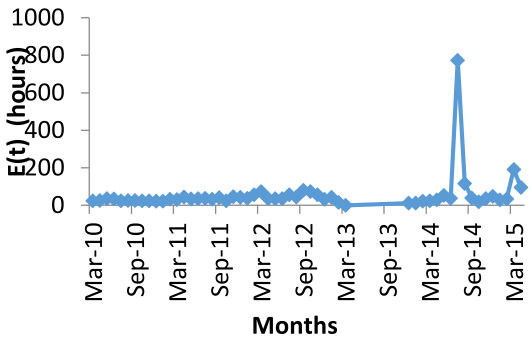


**Figure 10. Monthly electricity expectation**

The mean availability for the power plant was evaluated by dividing the sum of the availability of the power plant for all the by the total hours of the period considered and an average value of 68% was obtained. Similarly, the reliability of the power plant for the period under consideration was gotten as 68%. This is relatively very low when compared with IEEE recommended standard of 99%. Also according to Eti, *et al*. (2005) the availability and quality rate for the world's best power- stations are higher than 98%.

Figure 10 presented the monthly expected electricity generation from the Ibom power plant. July, 2014 had a value of 774hours being the maximum hours any plant can operate in a month. Every gas turbine power plant in Nigeria supposed to operate for maximum hours every month to ensure steady supply of electricity to consumers. Unfortunately, due to inadequate maintenance policy, the power plants operations are disrupted by forced outages. The weighted average power generation for Ibom power plant was found as 54.54 hours per month; this value is not quite very low. It is important for gas turbine plant operators to embark on structured maintenance programme that will eliminate forced outages. Onohaebi and Lawal (2010) defined maintenance as the combination of all technical and administrative actions with the intention of retaining an equipment in an operating state in order for it to perform its required functions. It can also be defined as any work undertaken in order to keep or restore a facility to any acceptable standard.

## 4. CONCLUSION

The availability of power plant is the ability of the power plant to deliver electricity to consumers when needed and the reliability of a power plant is the ability of the power plant to deliver electricity as specified. Therefore, availability is the probability that the power plant at a point in time will be operational and will be able to generate electricity and reliability is the probability that the power plant will operate over a specified time without failure. These two performance concepts point to the dependability of the power plant as high availability will entails that the plant will likely deliver electricity as specified.

The availability and reliability of Ibom power plant for the period under review were both 68%. This means that out of the total time considered, the plant was only available for 68% of the time. This value fall below the IEEE standard of 99%; indicating that the plant was not available for a long time. It is important to note that longer outage will lead to more electricity disruption. This incessant outage might be as a result of poor maintenance culture, adverse operating conditions, and inadequate supply of gas and instability of the national grid. Also, the average weighted duration was found to be 54.54 hours per month. It was observed that seasons of the year has no effect on the performance of gas power plant. In order to achieve better availability and reliability, fault avoidance through well plan online maintenance should be adopted by gas turbine power plant operators.

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