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Availability and Reliability Evaluation of Warri Refining and Petrochemical Company Gas Turbine Power Plant

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Abstract

Reliability and availability are key issues for the implementation of future sustainable power systems, hence, the need to carryout a reliability and availability studies of a power plant. This paper studies the availability and reliability of Warri Refining and Petrochemical Company (WRPC) Gas Turbine Power Plants. The reliability indices of the turbine plants such as failure rate, repair rate, mean time between failure and mean time to repair were used in the analysis based on a four year data collected from power station log book . Results obtained from the study showed that the average plant availability was 0.971, average reliability was 0.7898 and capacity utilization was 22.09% for WRPC Gas Turbine Power Plant. Thus, WRPC Gas Turbine Power Plants were found to posses a high reliability and availability factor values due to an effective maintenance structure employed by the management, but has a low capacity utilization, which revealed that low power was generated throughout the period of the study.

Key words: Availability, Reliability, Gas Turbine, Evaluation, Capacity utilization, Failure

1.0 Introduction

The access to reliable and stable supply of electricity is a major challenge for both the urban and rural dwellers in Nigeria. The challenge, however, is more significant in rural area where only about 10% of the population have access to electricity[1]. Gas turbines have established an important role in solve power generation problem in Nigeria because they are used in most current power project in the country [2]. The gas turbine based power is a multiple component repairable aging system. With increase in accumulation of operating hours by the power plant, the performance and reliability of the plant is degraded over time. The output rate of a gas turbine power plant can be adjusted to ensure the optimal response to the dynamic demand, by manipulating operating conditions such as load mode, fuel type and power augmentation. This flexibility makes modeling of the power plant performance, availability and reliability more cumbersome [3]. Proactive maintenance works are therefore required to mitigate the degradation of the plant, which restore the performance and reliability of the plant.

Reliability analysis techniques have been gradually accepted as standard tools for the planning, design, operation and maintenance of electric power systems [4]. The function of an electric power system is to provide electricity to its customers efficiently and with a reasonable assurance of continuity and quality [5-7]. The task of achieving economic efficiency is assigned to system operators or competitive markets, depending on the type of industry structure adopted. On the other hand, the quality of the service is evaluated by the extent to which the supply of electricity is available to customers at a usable voltage and frequency. The reliability of power supply is, therefore, related to the probability of providing customers with continuous service and with a voltage and frequency within prescribed ranges around the nominal values [8-10].

The availability of a complex system, such as a gas turbine, is strongly associated with its parts reliability and maintenance policy. Availability of a power plant depended on the type of fuel, the design of the plant and how is operated. Reliability is the ability of an item to perform a required function, under given environmental and operational conditions and a stated period of time. Maintenance of power plants is aimed at extending the life and reducing the risk of breakdown of plant. However, the ultimate consideration should be at minimum cost for maximum plant availability. A power plant is labelled to be effective, reliable, available and efficient when it continues to perform its intended capabilities and function [11].

In order to improve maintenance efficiency and to reduce maintenance costs, Eti et al. [12] proposed the use of reliability and maintainability concepts to define an availability index expressed by the ratio of the mean time to failure to the sum of the

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mean time to failure plus the mean time to repair. Most of the maintenance tasks of gas turbine power plant equipment are based on manufacturer's recommendations. Those recommendations are not always based on real experience data. Many manufacturers get very little feedback from users of their equipment after the guarantee period is over. Fear of product liability claims may also influence the manufactures' recommendations. In a large enterprise, such as a power plant, keeping asset reliability and availability, and reducing costs related to asset maintenance, repair, and ultimate replacement area the top of management concerns. In response to these concerns, the Reliability Cantered Maintenance (RCM)concept was developed. RCM has been formally defined by Moubray[13] as "a process used to determine what must be done to ensure that any physical asset continues to do whatever its users want it to do in its present operating context".

A modern power system is complex, highly integrated and very large. Fortunately, the system can be divided into appropriately subsystems or functional areas that can be analysed separately [14-16]. These functional areas are generation, transmission and distribution. Reliability studies are carried out individually and in combinations of the three areas. This work is limited to the evaluation of the generation reliability. Generation system reliability focuses on the reliability of generators in the whole electric power system where electric power is produced from the conversion process of primary energy (fuel) to electricity before transmission. The generation system is an important aspect of electricity supply chain and it is crucial that enough electricity is generated at every moment to meet demand. Generating units will occasionally fail to operate and the system operator has to make sure that enough reserve is available to be operated when this situation arises [12, 17-19].

In effect, the restructuring processes have brought about new problems and many open questions, especially regarding the introduction of competitive or market-based mechanisms and their effect on the reliability of power supply. However, it is becoming increasingly necessary to guarantee plant reliability and economic efficiency in order to improve plant utilization rates [7]. The increasing electricity demand, the increasingly competitive environment and the recent deregulation of Nigeria's electricity supply sector are resulting in increased competition among the IPPs. To survive, suppliers must reduce maintenance costs, prioritize maintenance actions and raise reliability in other to increase power plant availability.

Most power plants in Nigeria experience frequent shutdowns and breakdownsdue to inadequate maintenance practices adopted by the operators which eventually lead to unavailability of power supply. It is the need to improve on the performance of the power plants and increase electric power generation that give rise to the investigation of their maintenance practice, availability and reliability regularly [20]. Obodeh and Esabunor[21] had carried out a previous study on WRPC Gas Power plant, which reported a good availability value for the 2005 - 2010. Their paper was salient on capacity utilization, which is a necessary data that reveals the amount of power generated compared to installed power at the available period considered. For continuous monitoring and improvement needed as stated by [7, 21], therefore, the WRPC GasPower Plantneed to be evaluated.The aim of this paper is to evaluate the availability and reliability of WRPC Gas Turbine Power Plant.

2.0 Methodology

3.0 Data Collection

For the purpose of this work, data collected from the monthly log book of Warri Refining and Petrochemical Company Gas Turbine Control Room[22] were used to analyse maintenance, reliability and availability of the two functional units of the gas turbine plant, namely, GT1 and GT2

4.0 General Plant Description

WRPC Thermal Power Plant is situated at Ekpan town, Delta state in south-south region; the thermal power plant consist of 3 Gas Turbine Generators(GTGs) and 3 Steam Turbo-generators (STGs) which has a design potential to generate 125MW of electrical power for the Company. The three gas turbine units have a potential to produce 80MW of electrical power altogether with GT1 and GT2 generating 30MW electrical power each with 55 tonnes/hr waste heat boilers at maximum temperature of 530^{o}C and GT3 generating 20MW located in the petrochemical facilities. GT1 and GT2 Gas turbine units are run together on active synchronisation with each other in case one of the units is unable to power the company the other unit automatically starts up in order to meet the power consumption of the company, while GT3 is kept on standby. These three turbine generators start by raising temperature gradually and they are shut down by lowering temperature gradually.

The 3 Steam Turbo-generators (STGs) have a potential to generate 45MW of electrical power altogether with ST1 and ST2 generating 15MW each extraction/condensing and ST3 generating 15MW condensing. In the course of this study, GT1 and GT2 were considered for the reliability and availability assessment, because the other units werenot function as the time of this study.

5.0 Maintenance Guides of WRPC Gas Turbine Plant

To ensure constant and sustainable power supply it is paramount that continuous maintenance practices are carried out on the thermal power plant by maintenance operators either preventive or corrective measures. Maintenance also ensures better reliability and availability of power plants which also leads to the longevity of the plant.

WRPC Gas Power Plant units operate on a control system known as Speedtronics Mark VI. The Speedtronics Mark VI control system indicates fault by triggering off the alarm system. The alarm can either be critical or noncritical depending on the gravity. Another system called Automatic Voltage Regulator (AVR)/Exciter system though obsolete is also used for equipment and also to regulate voltage automatically in the plant.

The gas turbine generators could have physical damages in the critical situation; hence preventive measures are put in place to check damages to the units. In the course of trying to fix damages in the plant unit, the unit is shutdown or trip off at the level determined, if the fault requires Shutdown of the affected unit of plant. Shut down of the affected unit is necessary for better and convenient maintenance practices. Before shut down permission is sought by the unit head from the general manager, which can take some period of time to be granted. After obtaining permission to shutdown, the unit is isolated and technicians proceed to diagnose the fault. If the diagnose is correct, action is taken to clear the fault. However if it is wrong, the troubleshooting process is repeated thereby increasing downtime and availability of the unit.

Apart from deliberate shutdown of unit to enable proper maintenance practices as one of the reasons of increasing downtime and unavailability, the unit can also automatically tripped or shut down by itself due to unrepaired faults or lack of insufficient supply of gases from Nigeria Gas Company (NGC)thereby also increasing downtime and unit unavailability including its reliability in the long run.

In the company so far, effort is always made to ensure proper and continuous maintenance practices on power plant to enable the plant meet up to electric power supply services and to aid continuous production activities in the Company to other firms or consumers. One of the challenges to proper maintenance practices is the lack of availability of spare parts or resources which can increase unit downtime and unavailability. For example GT3 has been awaiting major overhauling since 11th of September 2007 due to lack of resources.

6.0 Reliability Appraisal

In appraising the reliability of a system, certain factors like mean time between failures and constant failure rates are first defined.

Mean Time Between Failures (MTBF) expressedin [20] as

$$\text{MTBF} = \frac{\text{A} \quad \text{F} \quad \text{i h}}{\text{N} \quad \text{o f}} \qquad \textbf{(1)}$$

Constant failure rate (λ) of a piece of equipment is the inverse of its mean time between failures as indicated in [20] as.

$$\text{Constant failure rate}, \lambda = \frac{1}{\text{M}} \qquad \textbf{(2)}$$

Reliability is a measure of the probability of successful performance of a system over a period of time [23], which is expressed as

$$\text{Reliability}, \qquad R\,(t) = \exp\frac{-t}{M} = \exp(-\lambda\ ) \qquad \textbf{(3)}$$

where t = non-available time (hrs) and λ =failure rate

7.0 Availability Appraisal

Availability (Ψ) is a fundamental measure of reliability. It can be calculated based on downtime that an interruption occurred and the frequency of interruptions for a specific period of time [24]. Availability can also be defined as the probability of a component to be in a working state or not.

Ψ is expressed as

$$\Psi = \frac{W}{W+D} \qquad \textbf{(4)}$$

where W is the number of hours the unit is in working condition

D is the number of hours when the unit is down

Availability can be defined in terms of Mean-Time-Between-Failures (MTBF) and Mean-Time-To-Repair (MTTR). The formula for MTTR expressed in [24] as

$$\text{MTTR} = \tau = \frac{\text{T} \quad \text{o} \quad \text{ti}}{\text{N} \quad \text{o f}} = \frac{1}{\mu} \qquad \textbf{(5)}$$

Where, τ=duration of outage and μ=repair rate

According to Iresun[25] based on Equations (2), (4) and (5), availability (Ψ) is expressed as

$$\Psi = \frac{\text{M}}{\text{M} \quad + \text{M}} = \frac{1}{1+\lambda\tau} = \frac{\text{U}}{\text{U} \quad -\text{D}} \qquad \textbf{(6)}$$

8.0 Results and Discussion

9.0 Gas Turbine Operating Data

Table 1 shows summaries of the data collected from the WRPC Gas Power Plant control room during the period under study, (January 2010 – December 2013). This analysis excludes gas turbine unit GT3 as it was out of service for a substantial duration of the period from January 2010 – December 2013.

Table 1: Summary of yearly data collected from WRPC Gas Power Plant

Year	Electrical Power Generated (MWH)			Running Hours (hrs)		Non Available Hours (hrs)		Number of Failures	
	GT1	GT2	Total	GT1	GT2	GT1	GT2	GT1	GT2
2010	62252.4	56546.9	118799.3	8748	7766	36	1018	0	0
2011	56606.92	64685.66	121292.6	8339	8688	144	0	3	0
2012	53199.41	48441.23	101640.6	8239	6977	125	48	4	4
2013	61095.28	62005.67	123101	8386	8243	310	130	4	2
Total	233154	231679.5	464833.5	33712	31674	615	1196	11	6

Table 2: Reliability and Availability Results for the Different Units on Yearly Basis

Year	Gas Turbine Units	Available Period in Running Hours	Non Available Period in Hours Due to Spares and Faults	Number of Defects/Failures Causes	MTBF (hrs)	MTTR (hrs)	1/MTTR	Reliability	Availability
2010	GT1	8748	36	0	0	0	0	1	0.9959
	GT2	7766	1018	0	0	0	0	1	0.8841
2011	GT1	8339	144	3	2779.67	140.33	0.0003598	0.8594	0.9519
	GT2	8688	0	0	0	0	0	1	0.9918
2012	GT1	8239	125	4	2059.75	136.25	0.0004855	0.7675	0.9380
	GT2	6977	48	4	1744.25	451.75	0.0005733	0.3549	0.7943
2013	GT1	8386	310	4	2096.50	93.50	0.0004770	0.8366	0.9573
	GT2	8243	130	2	4121.50	258.50	0.0002426	0.8821	0.9410

Table 3: Reliability and Availability Results for the Different Units for the Years

Gas Turbine Units	Available Period in Running Hours	Non Available Period in Hours Due to Spares and Faults	Number of Defects/Failures Causes	MTBF (hrs)	MTTR (hrs)	1/MTTR	Reliability	Availability
GT1	33712	615	11	3064.73	55.91	0.0003263	0.8182	0.9821
GT2	26314	1196	6	4386.67	199.33	0.0002280	0.7613	0.9565

10.0 Capacity Utilization of WRPC Gas Turbine Power Plant

Capacity utilization (CU) is the ratio of power generated by the generation plant to the installed plant capacity [20]. The study of this plant covered a period of 48 months. When the two gas turbine units are available and in service for the period under study, the maximum energy that can be generated is 30MW × 1461 days × 24hours = 1,051,920MWH for each of the two units.

This implies that in a scenario of maximum availability over the period of investigation, each gas turbine unit would generate 1,051,920MWH. But in reality, the turbine units would be unable to generate this amount of power due to downtime and failure stoppages.

It is expressed as

Capacity Utilization, $$CU = \frac{APG}{EPG} \quad (7)$$

Where APG = Actual Power Generated in MWH

EPG = Expected Power Generated in MWH

The capacity utilization of the gas turbine units can be analysed using data from Table1 and applying Equation (7). Their results are presented in Table 4.

Table 4: Capacity Utilization of Each Gas Turbine Unit

Gas Turbine Unit	Expected Power Generated(MWH)	Actual Power Generated (MWH)	Capacity Utilization
GT1	1,051,920	233,154.01	0.2216
GT2	1,051,920	231,679.50	0.2202
WRPC power plant	2,103,840	464,833.51	0.2209

11.0 Discussion

Table 2 shows details of the reliability of the individual gas turbines, GT1 has a maximum reliability value of 1 in 2010 and a minimum reliability value of 0.7675 in 2012. GT2 attained maximum reliability value of 1 in 2010 and 2011, while it had a minimum value of 0.3545 in 2012. The data from Table 3 shows that the average reliability of the two gas turbine units is 0.7898.

The availability of the individual turbine units shown in Table 2 varies from 0.7943 - 0.9959. This variation in the availability of the gas turbines arises due to the period the individual units were shutdown in order to carry out major maintenance works, low pressure of supplied gas, gas unavailability and system failure. The average availability of the two gas turbine units was determined from Table 3 to be 0.971. This is a little bit lower than the availability of 0.998 for optimally operated gas turbines. The availability values obtained in the work was found to be better than 0.333 – 0.984 obtainedin [21]. This reflected that maintenance practice has improved in the power plant. Table 4 indicates the capacity utilization for the two gas turbine units, namely GT1 and GT2. GT1 has the highest CU of 0.2216 while GT2 has the least CU of 0.2202. The average value of the plant capacity utilization using the power ratings of the two units is 0.2209 or 22.09%. The low capacity utilization reflected the under utilization of the plant, because low power was generated during this period.

12.0 Conclusion

The data collected from WRPC Gas Turbine Power Plant were used to evaluate the availability, reliability and capacity utilization of GT1 and GT2 units.From 2010 to 2013, the company has only encountered very few shutdowns on the gas turbine units which resulted to very low downtime hours and very high running hours. Its high values of availability and reliability obtained showed that the power plant has a reliable and good maintenance structure. The low capacity utilizationrevealed that low amount ofelectrical energy was generated during theperiod ofstudy. The need to boost capacity utilization by generating more energy in the power plant is required. It will be necessaryto encourage training and retrainingof technical personnel assigned to the major equipment/units in operation to increase their technical knowhow on the equipment and to further guarantee optimum reliability and availability.

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