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*Full Length Research Paper*

# Reliability assessment of WRPC gas turbine power station

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**The reliability indices of the turbines were analyzed based on a six-year failure database. Such reliability indices as failure rate ($\lambda$), repair rate ($\mu$) and mean time to repair ($\zeta$) have been estimated. The analyses showed that gas turbine 1 (GT1) has maximum failure rate ($\lambda_{max}$) of once in 100 h in 2007 with system availability ($\Psi$) of 0.333 and minimum failure rate ($\lambda_{min}$) of once in 1000 h in 2005 with $\Psi$ of 0.983. While for gas turbine 2 (GT2), $\lambda_{max}$ of once 100 h was obtained in 2007 with $\Psi$ of 0.333 and $\lambda_{min}$ of once in 1000 h in 2008 with $\Psi$ of 0.0869. It was also showed that GT1 has a maximum repair rate ($\mu_{max}$) of once in 1.45 h in 2005 with $\Psi$ of 0.983 and minimum repair rate ($\mu_{min}$) of once in 21.28 h in 2006 with $\Psi$ of 0.513. In the other hand, GT2 has $\mu_{max}$ of once in 1.44 h in 2008 with $\Psi$ of 0.869 and $\mu_{min}$ of once in 35.7 h in 2006 with $\Psi$ of 0.513. GT1 has maximum mean time to repair ($\zeta_{max}$) of 2133 h in 2006 with $\Psi$ of 0.595 and minimum mean time to repair ($\zeta_{min}$) of 72.5 h in 2005 with $\Psi$ of 0.714. Similarly, GT2 has $\zeta_{max}$ of 3552 h in 2006 with $\Psi$ of 0.595 and $\zeta_{min}$ of 144 h in 2008 with $\Psi$ of 0.984. For the period under study, GT1 has $\Psi_{min}$ of 0.333 in the year 2007 and $\Psi_{max}$ of 0.983 in 2005 while GT2 has $\Psi_{min}$ of 0.595 in 2006 and $\Psi_{max}$ of 0.984 in 2008. Measures to improve the reliability ($R(t)$) indices of the plant have been suggested such as training and retraining of technical personnel on the major equipment being used.**

**Key words:** Warri Refining and Petrochemical Company (WRPC) gas turbines, reliability indices, maintainability.

## INTRODUCTION

Reliability analysis techniques have been gradually accepted as standard tools for the planning, design, operation and maintenance of electric power system. The function of an electric power system is to provide electricity to its customers efficiently and with a reasonable assurance of continuity and quality (Adegboye and Ekundayo, 2010; Billinton and Allen, 1992; Kucherov et al., 2005). The task of achieving economic efficiency is assigned to system operators or competitive markets, depending on the type of industry structure adopted. On

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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 (Wang et al., 2002; Wang and Billinton, 2003; Sikos and Klemeš, 2010). 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 analyzed separately (Gupta and Tewari, 2009a, b; Kuo and Zuo, 2003; Lakhoua, 2009). 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 (Barabady and Kumar, 2007; Caraza and Martha de Souza, 2009; Eti et al., 2007; Sukhwinder and Wadhwa, 2004).

Reliability of the generation system is divided into adequacy and security (Hooshmand et al., 2009; Valdma et al., 2007). System adequacy relates to the existence of sufficient generators within the system to satisfy the customer load demand or system operational constraints. System adequacy is associated with static conditions of the system and do not include system disturbances. System security on the other hand relates to the ability of the system to respond to disturbances arising within the system. Therefore, system security is associated with response of the system to whatever perturbation it is subjected to. In this study, the reliability evaluations will be focused on the generation system adequacy and will not take into consideration system security. In a generation system study, the total system generation is examined to determine its adequacy to meet the total system load requirement. This activity is usually termed " generating system adequacy assessment". The transmission system is ignored in generating system adequacy assessment and is treated as a load point (Valdma et al., 2007). The main reason of the generating system adequacy assessment is to estimate the generating capacity required to meet the system demand and to have excess capacity to cater for planned and forced outages events. A failure in a generating unit results in the unit being removed from service in order to be repaired or replaced, this event is known as outage. Such outages can compromise the ability of the system to supply the required load and affect system reliability.

An outage may or may not cause an interruption of service depending on the margins of generation provided. Outages also occur when the unit undergoes maintenance or other scheduled work necessary to keep it operating in good condition. A forced outage is an outage that results from emergency conditions, requiring that component be taken out of service immediately.

A scheduled or planned outage is an outage that results when a component is deliberately taken out of service, usually for purpose of preventive maintenence or repair. During the last decade, Nigeria has been restructuring her power sector, abondoning the former regulated monopolistic model which ruled the provision of electric energy during most part of this century (Obodeh and Isaac, 2011). The new "deregulated" structures are based on free market principles, favouring competition among private participants and new entrants into the power market such as independent power producers (IPPs) and national integrated power projects (NIPPs) and consumer choice. In this new environment, each generating company should provide its reliability and associated price to ensure customer satisfaction and personal preference. One such organisation that generate power for its use is Warri Refining and Petrochemical Company (WRPC). It is one of the subsidiaries of Nigeria National Petroleum Company (NNPC). Like many organisational setups involved in production, the scheduled working time contribute to the productive capacity of the company. It is important therefore to ensure that equipment usage is maximised to save time and money. Again, prodction managers are demanding strict guaranteed performance to meet production targets. Continuous power supply is necessary for the achievement of these targets. In Nigeria, power supply to many consumers has over the years been done by the Power Holding Company of Nigeria (PHCN) but this supply has always been unreliable, with its many power outages. Due to the unreliability of power supply from PHCN, WRPC management established a thermal power station. The station consists of: gas turbine (dual fuel system) with capacity of 60 MW hereby called gas turbine 1 (GT1); gas turbine (distillates fuel system) with capacity of 20 MW hereby called gas turbine 2 (GT2) and turbo generator (steam turbine) with capacity of 45 MW. The study herein covers GT1 and GT2.

The theoretical basis of deregulation in the electricity industry are not completely developed yet and the practical experience with electricity markets is still limited (Kucherov et al., 2005; Prisyazhniuk, 2008; Wang and Billinton, 2003). 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 econmic efficiency in order to improve plant utilization rates (Kucherov et al., 2005). 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. The aim of this study is to find ways to increase equipment reliability and extend the equipment's life through cost-effective maintenance using WRPC as a case study.

## MATERIALS AND METHODS

The records of failure frequency of installations, containing the description and analysis of the failure and other materials filed by the operation monitoring services constitute the basic source of information on the failure frequency and range of repairs of generating devices of the power units. The reliability was calculated considering a six year operational database. In processing the data, mean time between failure (m), mean time to repair ( $\zeta$ ), availability ( $\Psi$ ) and reliability ( $R(t)$ ) were obtained. Mean time between failure (m) is a measure of how long, on average, an equipment will perform as specified before an unplanned failure will occur.

$$m = \frac{1}{\lambda} \tag{1}$$

Where:

$\lambda =$ expected failure rate,

$$\lambda = \frac{\varphi_n}{\beta_t} \tag{2}$$

Where,

$\varphi_n =$ number of failure between maintenance.

$\beta_t =$ total operating time between maintenance.

Mean time to repair ( $\zeta$ ) is a measure of how long, on average, it will take to bring the equipment back to normal serviceability when it does fail.

$$\zeta = \frac{\psi_t}{\phi_n} \tag{3}$$

when,

$\psi_t =$ total outage hours per year.

$\phi_n =$ number of failure per year.

$$\zeta = \frac{1}{\mu} \tag{4}$$

Where,

$\mu =$ expected repair rate.

Availability ( $\Psi$ ) is a measure of the percentage of time that an equipment is capable of producing its end product at some specified acceptable level. In the case of a turbine in a power plant, availability is a measure of the fraction of time that it is generating the nominal power output.

$$\Psi = \frac{\mu}{\lambda + \mu} \tag{5}$$

or,

$$\Psi = \frac{1}{1 + \lambda\zeta} \tag{6}$$

Using equations (1) and (4) in equation (6), we have:

$$\Psi = \frac{m}{m + \zeta} \tag{7}$$

Reliability ( $R(t)$ ) is regarded as the ability of an equipment to perform its required function satisfactory under stated conditions during a given period of time (Ireson et al., 1996; Smith and Hinchcliffe, 2004). In order words, reliability is a probability that the equipment is operating without failure in the time period $t$.

$$R(t) = e^{-\frac{t}{m}} \tag{8}$$

Using equation (1) in equation (8), yields:

$$R(t) = e^{-\lambda t} \tag{9}$$

Where,

$t =$ specified period of failure-free operation.

**Table 1.** Reliability indices.

| Year parameter | 2004 | | 2005 | | 2006 | | 2007 | | 2008 | | 2009 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | GT1 | GT2 | GT1 | GT2 | GT1 | GT2 | GT1 | GT2 | GT1 | GT2 | GT1 | GT2 |
| Number of failures | 3 | 5 | 1 | 6 | 2 | 1 | 3 | 6 | 4 | 1 | 2 | 2 |
| Down time (hours) | 1553 | 3200 | 145 | 2508 | 4266 | 3552 | 5842 | 2947 | 1148 | 144 | 680 | 747 |
| $\zeta$ (h) | 517.67 | 640 | 72.5 | 418 | 2133 | 3552 | 1947.33 | 491.17 | 287 | 144 | 340 | 373.5 |
| M (h) | 2402.33 | 1112 | 4307.5 | 1042 | 2247 | 5208 | 972.67 | 968.83 | 1903 | 8616 | 4040 | 4006.5 |
| $\Psi$ | 0.823 | 0.635 | 0.983 | 0.714 | 0.513 | 0.595 | 0.333 | 0.664 | 0.869 | 0.984 | 0.922 | 0.915 |
| $R(t)$ | 0.498 | 0.007 | 0.368 | 0.003 | 0.135 | 0.368 | 0.497 | 0.025 | 0.183 | 0.368 | 0.135 | 0.135 |

## RESULTS AND DISCUSSION

Table 1 presents reliability indices for the turbines thermal generation units from 2004 to 2009. Most of the failures were related to high temperature in combustors or excessive vibration on the bearings. In the years 2004 and 2008, GT1 experienced more failures due to high temperature in the exhaust collector caused by combustor failure. In the year 2005, GT2 experienced six failures. Three of these failures were related to calibration problems of pressure gauges located at the exhaust collector and the other three were related to fuel filters premature cleaning due to premature clogging caused by poor natural gas quality. In the year 2004, the main problems with GT2 were related to the lubrication oil system, mainly the oil feeding pressure. These failures can be reduced if the maintenance procedure tasks involve periodical inspection and replacement of parts, that were subjected to very high temperature and located in the hot gas paths (combustion chamber and turbine). However, sensors were installed in the oil pump to allow the use of a monitoring system to check oil pump vibration and oil temperature and flow. But a bi-monthly oil analysis should be implemented in order to check for the presence of metallic particles in the fluid that could be an indication of possible bearings parts wear. The failure rate ($\lambda$) is a reasonable measure for durability of generating devices and indication for economical effectiveness of repairs. Effect of $\lambda$ on the system availability is revealed in Figure 1. $\lambda$ of GT1 peaked at 0.01 (once in 100 h) in 2007 with system availability ($\Psi$) of 0.333 and its lowest value of 0.001 (once in 1000 h) was attained in 2005 with $\Psi$ of 0.983. While for GT2, maximum value of 0.01 (once in 100 h) was obtained in 2007 with $\Psi$ of 0.333 and minimum value of 0.001 (once in 1000 h) in 2008 with $\Psi$ of 0.0869. The forthgoing observations show that increase in $\lambda$ results in decrease in $\Psi$. However, effective maintenance management is essential in reducing the adverse effect of equipment failure. This can be accomplished by accurately predicting the equipment failure such that appropriate actions can be planned and taken in order to minimize the impact of equipment failure to operation. Also continuous use of operating unit exhibiting partial failure should be discourage so as to avoid degradation or catastrophic failure.

The effect of repair rate ($\mu$) on $\Psi$ is depicted in Figure 2. It showed that GT1 has a maximum repair rate ($\mu_{max}$) of 0.690 (once in 1.45 h) in 2005 with $\Psi$ of 0.983 and minimum repair rate ($\mu_{min}$) of 0.047 (once in 21.28 h) in 2006 with $\Psi$ of 0.513. In the other hand, GT2 has $\mu_{max}$ of 0.694 (once in 1.44 h) in 2008 with $\Psi$ of 0.869 and $\mu_{min}$ of 0.028 (once in 35.7 h) in 2006 with $\Psi$ of 0.513. The aforementioned analyses show that $\Psi$ increases with increase in $\mu$. Figure 3 represents variation of mean time to repair ($\zeta$ )with year. GT1 has maximum mean time to repair ($\zeta_{max}$) of 2133 h in 2006 with $\Psi$ of 0.595 and minimum mean time to repair ($\zeta_{min}$) of 72.5 h

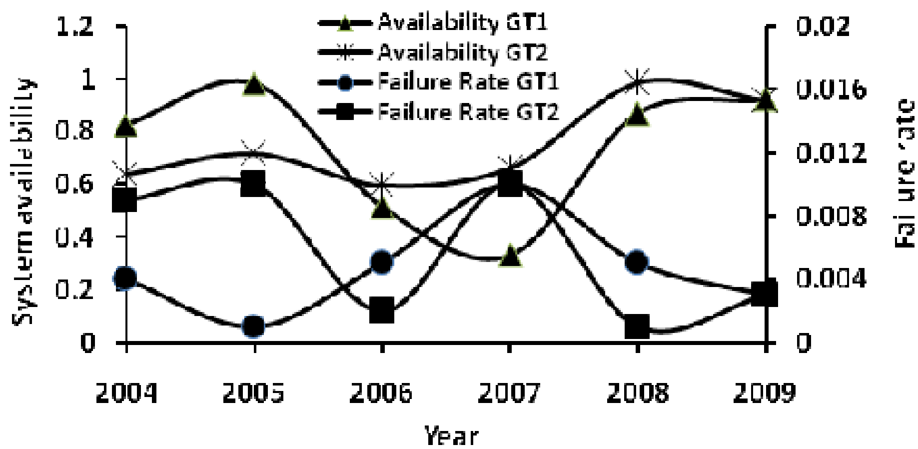


**Figure 1.** Effect of failure rate on system availability.

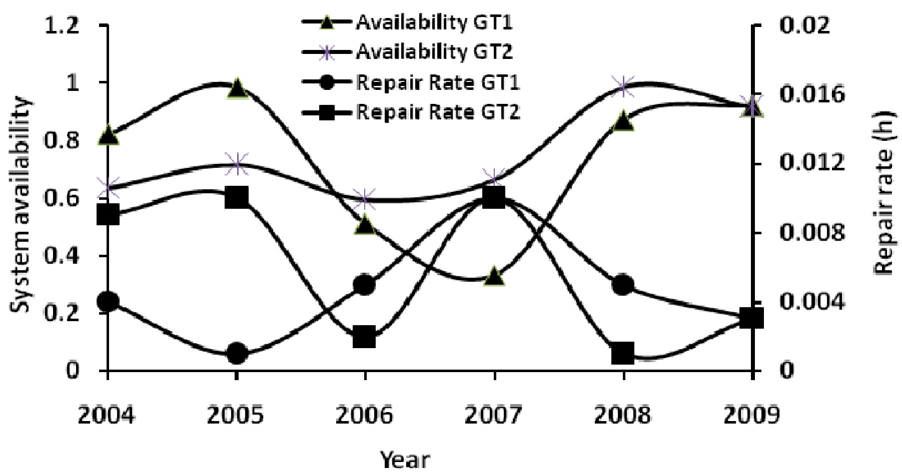


**Figure 2.** Effect of repair rate on system availability.

in 2005 with $\Psi$ of 0.714. Similarly, GT2 has $\zeta_{max}$ of 3552 h in 2006 with $\Psi$ of 0.595 and $\zeta_{min}$ of 144 h in 2008 with $\Psi$ of 0.984. From the forthgoing, it can be deduce that $\Psi$ decreases with increase in $\zeta$. The operational consequences of failure can be reduced by taking steps to shorten the downtime, most often by reducing the time to get hold of spare parts. The $\Psi$ over the period of study is shown in Figure 4. GT1 has $\Psi_{min}$ of 0.333 in the year 2007 and $\Psi_{max}$ of 0.983 in 2005 while GT2 has $\Psi_{min}$ of 0.595 in 2006 and $\Psi_{max}$ of 0.984 in 2008. From the analyses thus far, it is glaring that the measure of reliability $R(t)$ by extension $\Psi$ of the power plant is determined by indices such as $\lambda$, $\mu$ and $\zeta$. The $\Psi$ values for the gas turbine station are lower than the IEEE recommended standard of ASAI which is 0.999 (Bertling and Eriksson, 2005). Availability can be improved significantly by reviewing maintenance practices.

Planned maintenance is still essential but more and more, predictive maintenance is becoming the driver for planned outages. It has been reported that plant with availability of 50 to 60% gave 85% and above after it has been refurbished and maintained (Hooshmand et al., 2009).

## Conclusion

The analyses revealed that gas turbine 1 (GT1) has maximum failure rate ($\lambda_{max}$) of once in 100 h in 2007 with system availability ($\Psi$) of 0.333 and minimum failure

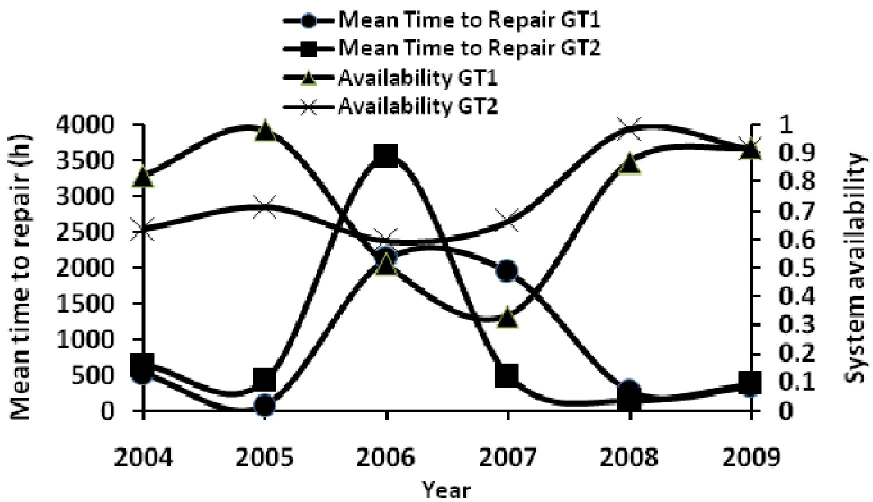


**Figure 3.** Effect of mean time to repair on system availability.

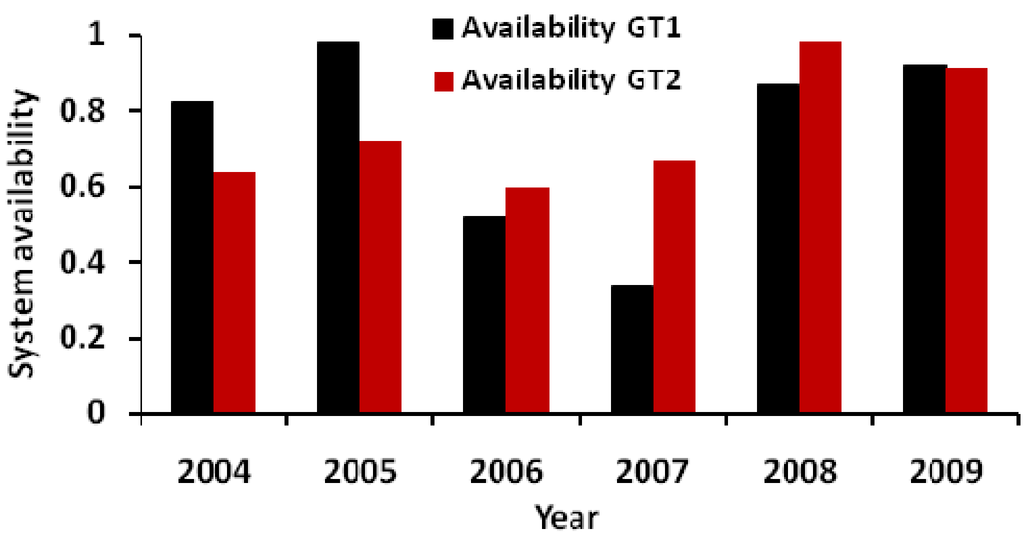


**Figure 4.** Variation of system availability with year.

rate ($\lambda_{min}$) of once in 1000 h in 2005 with $\Psi$ of 0.983. While for gas turbine 2 (GT2), $\lambda_{max}$ of once 100 h was obtained in 2007 with $\Psi$ of 0.333 and $\lambda_{min}$ of once in 1000 h in 2008 with $\Psi$ of 0.0869. Increase in $\lambda$ results in decrease in $\Psi$. Effective maintenance management is essential in reducing the adverse effect of equipment failure to operation. It was shown that GT1 has a maximum repair rate ($\mu_{max}$) of once in 1.45 h in 2005 with $\Psi$ of 0.983 and minimum repair rate ($\mu_{min}$) of once in 21.28 h in 2006 with $\Psi$ of 0.513. On the other hand, GT2 has $\mu_{max}$ of once in 1.44 h in 2008 with $\Psi$ of 0.869 and $\mu_{min}$ of once in 35.7 h in 2006 with $\Psi$ of 0.513. $\Psi$ increases with increase in $\mu$. GT1 has maximum mean time to repair ($\zeta_{max}$) of 2133 h in 2006 with $\Psi$ of 0.595 and minimum mean time to repair ($\zeta_{min}$) of 72.5 h in 2005 with $\Psi$ of 0.714. Similarly, GT2 has $\zeta_{max}$ of 3552 h in 2006 with $\Psi$ of 0.595 and $\zeta_{min}$ of 144 h in 2008 with $\Psi$ of 0.984. It is possible to reduce the operational consequences of failure by taking steps to shorten the downtime by reducing the time to get hold of spare parts. For the period under study, GT1 has $\Psi_{min}$ of 0.333 in the year 2007 and $\Psi_{max}$ of 0.983 in 2005 while GT2 has $\Psi_{min}$ of 0.595 in 2006 and $\Psi_{max}$ of 0.984 in 2008. The measure of ($R(t)$) of gas turbine station is determined by such indices as $\lambda$, $\mu$ and $\zeta$. Availability can be improved significantly by reviewing maintenance practices.

Planned or scheduled maintenance must be given more attention as directed by the unit manufacturer's operation and maintenance manual package, if the unit have to perform properly. In other words, routine preventive maintenance must be well planned and more regular. Measures to improve the ($R(t)$) indices of the plant have been suggested such as training and retraining of technical personnel on the major equipment being used. This will improve their skill and knowledge on the current information and communication technology (ICT) as well as improve their manpower quality.

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