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Egbin power station generator availability and unit performance studies

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This paper presents investigation on availability carried out on six steam unit generators in Egbin Thermal-Power Station in Nigeria. The availability investigation covers from 2005 to 2011 and was done through an exhaustive collection of data from samples of operating facilities in the power station. Data was collected from plant user maintenance log, operation records and manufacturers' data were also sources of information. This investigation used the IEEE std 762 generator performance indices amongst other calculated key operational availability indices in the evaluations and analysis of the collected data. A software program was developed, 'Function Outage Parameters (OP)', using the outage frameworks of data collected from the station. The program was implemented in MATLAB 11.5b which provided user-friendly Graphical User Interfaces (GUI) and corresponding output results in numerical values in tables of values and graphs. The data was used to evaluate all the six generating units available in the station. The result was used to appraise a periodic availability assessment of all the generating units. The study has demonstrated that availability has a very major impact on power generation and plant economy. The investigations ensured quantified (computed) comparative analysis for planned and unplanned outages by using results to estimate unit generators" performance capacity credibility. The availability results generated by stations values were: ST01 = 89%; ST02= 89.99%; ST03 =85.24%; ST04 = 87.45%; ST05= 86.50%; ST06 = 29.71% while the overall availability is 88.35%. Result shows reduction in plant availability is caused by increased number and duration of forced outages. The causes and durations of forced outages and unscheduled maintenances were identified through the study of outage causes. The use of a historic failure database to identify critical components for improvement of generating unit availability is demonstrated. While Nigeria is practically hungry for power supply availability to support economic growth and provide basic modern energy services to her people though the energy level is still abysmally low, the facts presented herein are sufficient to exhibit the importance of power availability and unit performance measurement in enhancing the country energy revolution and development.

Key words: Availability, performance, generators, steam turbines, maintenance, reliability.

INTRODUCTION

As power supply availability becomes the current catchphrase in business, industry, and society at large in

Nigeria, energy researches on availability is indispensible. The increasing competition in the electricity sector has had significant implications for plant operations; it requires thinking in strategic and economic rather than purely technical terms (André et al., 2007).

The overall power scene in Nigeria indicates heavy shortages almost in all states of the federation. The situation may be aggravated in coming years as the demand is increasing and if the power industry does not keep pace with the increasing energy demand.

In recent past, Nigeria has been referred to as a ‘Nation that has Covenant with Darkness’ by the Tell Magazine July 27, 2009. They were not far from the truth as a country with a population of over 140 million people had only 1500 MW of electricity to share at that time. This was put at 15.58 kW per individual per annum by the Central Intelligence Agency (CIA) Factbook (2007). That is about 1500 MW total generation. However, people have diverse view about the root cause of the electricity problems. Nigeria ranks abysmally low compared to other countries of Africa, as shown in the CIA Factbook (Tell Magazine July 27, 2009). The challenges of energy production vary from nations to nations. However, electric energy is produced and delivered practically on real time and there is no convenient method to readily store it, hence, it is said that electricity is simply ubiquitous.

While rapidly growing economies like Nigeria is hungry for practically any power to support economic growth and provide basic energy services to her people, the industrialized nations of the world are focusing on ensuring secured electricity supplies at competitive prices also in an environmentally acceptable way.

In order to achieve this goal, compulsory availability data documentation is crucial. The traditional measures used in reliability evaluation are probabilistic and consequently, they do not provide exact predictions (Richwine, 2004). They only state averages of past events and chances of future ones by means of most frequent values and long-run averages (Fernando, 1999). These measures that are mostly "factors" (Equivalent Availability Factor (EAF), the Forced Outage Factor (FOF) and Unit Capability Factor (UCF) use as their denominator the entire time period being considered (typically one year and above) without regard to whether or not the unit is required to generate (Richwine, 2004). Commercial availability is a proper availability evaluation used as a source of information that can be complemented with other economic and policy considerations for decision making in planning, design and operations in the power industry. Operational availability is the quantitative link between readiness objectives and supportability. The new “deregulated” (horizontal) structure in Nigeria is practically based on market principles, favouring competitions amongst private participants and consumer choice.

Under deregulation, a competitive power production becomes standard operation procedure. The quality of power a company produces becomes the measure of its success (Killich, 2006). Under the deregulation setting, energy particularly power generation should be decided by its quality. This supports the customer view point which is summed up into two concepts: technical and economical. Technical concept is all indicated in availability and reliability indices. The economical concept is integrated in electrical energy price which is required to be in the lowest possible range. While the managerial concepts which are figured in the performance indices are: availability, reliability and productivity (Mahmoud et al., 2000).

When deregulation is fully established, it will require the utility, Independent Power Producer (IPP), National Integrated Power Producers (IPP) and other Power Producers (perhaps Industrial Power Producers, IND) to bid power competitively at current market rates. In this case, the power producer that operates at the lowest cost per kilowatt-hour will thrive in this challenging environment. As we progress under deregulation thus, the traditional technical measures will become inadequate. This will thrust utilities to add specifics in terms of measurements that provides and help build on their traditional economics. This requires high importance to be placed on power plant performance and availability indices to form groundwork for performance and benchmarking (Richwine, 2011).

Turbine units more than 25 years in operation face serious threats in view of their remaining lifetime. Even in case of proper operation and maintenance talk less, absence of proper operation and maintenance (Stein and Cohen, 2003). The ageing of power plants leads to higher production cost which presently faces the Nigerian Electricity Generation Industry, mainly due to the following according to Stein and Cohen (2003):

i. Duration, occasioned by deterioration of original performance level (output and efficiency) and
ii. Decline in availability occasioned by increased number and duration of forced outages.

The availability of a complex system such as a steam turbine unit, is basically associated with its parts reliability

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and maintenance policy. This may be enhanced by proper recording of failure rates and maintenance frequencies and etc. Timely and appropriate recording of these data could help in product improvement by manufacturers (insight on design improvement) and to identify critical components for improvement to enhance system reliability, availability and maintainability evaluations based on a historical failure/outage database.

This question however highlights the need for systems that will consistently and rigorously seek to classify outage events using the performance indicators to justify their progress. Consequently, availability performance indicator amongst others is indispensable.

Background

The operation of a generating unit requires a coordinated operation of hundreds of individual components (Casazza and Delea, 2003). Each component has a different level of importance to the overall operation of the operating single unit. Failure of some pieces of equipment particularly the auxiliaries might cause little or no impairment in the operation of a generating unit.

Still, some might cause immediate or total shutdown of the unit if they fail. The failure rates of all the various components of a generating unit contribute to the overall unavailability of the unit. The unavailability of a generating unit due to component failure is known as its 'forced outage rate'. Generally, according to NERC/IEEE std 762, loss of generation have been distinguished to be caused by problems within and outside plant management control such as substation failure, transmission operating/repair errors, acts of terrorism or war, acts of nature (lightning) whether inside or outside the plant boundary (NERC/IEEE std 762 2006).

In a deregulated environment, competition is indispensible. Still, some might cause immediate or total shutdown of the unit if they fail. This has brought about the need for efficient allocation and use of available energy resources and power generation assets; effective scheduling of plant activities, such as outages and maintenance; greater use of analytical tools to conduct/benefit evaluation of proposed activities are changing the industry mindset (André et al., 2007). In another development, various components of a generating unit must be removed from service on a regular basis for preventive maintenance or to completely replace component(s) before forced outage results. This is called maintenance outage and major maintenance would include turbine overhauls, generator rewinds and boiler turbines, for which complete shutdowns are required. In summary, any condition requiring repairs which can be postponed to a weekend is referred to as 'maintenance outage'. If the unit must be removed from service during week days for a component problem, this is usually referred to as forced outage (NERC/IEEE std 762).

Meanwhile, forced outages are events whose specific occurrence cannot be predicted but can be described by using probabilistic measures. Maintenance outages are event which can be scheduled in advance. This difference is important in making analyses of total generator requirements for a system. The major area of judgment and discretion involved in classifying availability data is that they are usually influenced by economic and reliability considerations. For this reason, compilation and analyses of data requires extensive judgment and experience (Casazza and Delea, 2003).

With the traditional technical measure being considered inadequate in the now, supposedly competitive Nigeria Electricity Supply Industry NESI, there is need to place high importance on power plant availability measurement as font for performance measurement and benchmarking. Commercial availability accurately reflects more, the present-day market place. It therefore remains critical that the Nigerian power industry generate more meaningful metrics to evaluate commercial availability as the need to maximize utility from limited financial resource is equally important on both regulated and competitive environment. In a broader way, benchmarking with gap analysis offers a valuable input to the cost reduction and performance improvement in power generation management. The global liberalization of the electricity market is forcing utilities to deliver electrical energy with high efficiency and at a competitive price (Chirikutsi, 2007). The last sentence seems to be the 'catch-word' of the current deregulation exercise. Failure of some pieces of equipment particularly the auxiliaries might cause little or no impairment in the operation of a generating unit.

The combination of industry averages and the variability of distribution of data basing on technologies, size, age and mode of operation of the peer group plants are also of importance to performance improvements (Chirikutsi, 2007).

In this paper, performance measurements are considered to be based on statistical technical availability (Operational (commercial) Availability) of electric generating unit based on time and energy. The operational availability is considered appropriate for the following reason:

Availability measurements

Before you can begin to control anything, 'system' simple engineering methodology demands that, we must first measure it. The same applies to availability; even more so given the cost of implementing highly available systems can double for just a fraction of percentage of availability. The key is obviously to minimize downtime, since as downtime approaches zero, availability approaches 100%. Not all downtime results from unexpected system outages, since it also includes scheduled maintenance. Downtime consists of two categories: planned and unplanned, while unplanned downtime is the result of an unexpected system failure, planned downtime is that from planned system maintenance such as upgrades and patch installs.

This study is meant to improve procedures for estimating performances of generating units and systems of generating units from operational and technical angle. Hence, it is useful to discuss purposes and uses of some of the specific generating unit performance indices. For example, the forced outage rate (FOR) is used widely in generation system reliability and probabilities production cost studies. Indices including FOR, availability factor (AF), and unavailability factor (UF), are time based indices and depend strictly on the cumulative time in specific plant unit. But here, availability, reliability and productivity indices and parameters were evaluated to justify study objectives. The IEEE std 762 [IEEE Power Engineering Society, 2006] was used for the definitions and formulas.

Impact of downtime

Not all systems have the same level of dependency on availability. Downtime in some systems may be painful, like in the case of power generation supply, but the impact may be localized so that only a small group of users are affected (Islanding in transmission and distribution).

More than ever before, now availability has become a critical design criteria in energy industry–this is not to say that availability has not been important, but the impact of downtime and exposure has become much greater in considerations in repairable system design and implementations, particularly under deregulated market structure. More so, the desire to stand head-high above other competitors has also given this criterion a boost. The reason for this is that, we now provide systems that interact directly with customers, and there is no insulation between the system problems and those customers (Like the prepaid meter, and recharge cards etc.). There is a wide range of the cost of downtime, so it is useful to categorize the impact of downtime into different categories. Many applications can be classified into the following groups:

a. Mission critical: If the application is down, then critical production processes and/or customers are affected in a way that has massive impact on its profitability.
b. Business critical: Downtime that is often not visible to customers, but does have a significant cost associated with it.
c. Task critical: The outage affects only a few users, or the impact is limited and the cost is insignificant.

A close study of the above applications informs that the more mission critical oriented our application, the more the focus on availability efficiency should be. Unfortunately, increases in availability do not come for free. It is often tempting to try to increase system availability by first spending money on the system. Hence, precedence must be adhered to.

Availability performance

Availability performance is the ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided. This ability depends on the combined aspects of reliability performance, maintainability performance and maintenance supportability (IEC 60050 (191-02-05)).

A power plant generator is an active component therefore in this case, everything is considered active. Such components will give an immediate feedback if there is a failure. Corrective maintenance is normally carried out shortly after a component has failed. The purpose is to bring the component back to a functional state as soon as possible. The component may be replaced or repaired. The calculation formulas assume that the repaired component will bring it to “as good as new” condition (Mahmoud et al., 2000).

All items are assumed operating unless failed. The exception would have been standby redundancy, but this scarcely exists in this power station because of high power supply demand.

The results in the analysis are based on two fundamental rules for combining probabilities:

1. If A and B are two independent events with probabilities P(A) and P(B) of occurring, then the probability P(AB) that both events will occur is the product:

$$P(AB) = P(A).P(B)$$

2. If two events A and B are mutually exclusive so that when one occurs the other cannot occur, the probability that either A or B will occur is:

$$P(AB) = P(A) + P(B)$$

This is used as a validation for fall calculations and computer simulations carried out.

In Javad (2005), like reliability, availability is considered a probability. If we considered a system which can be in one of two states, namely 'up (on)' and 'down (off)' as stated earlier. By 'up' it mean that the system is still functioning while by 'down' it mean that the system is not functioning; in this case it is being repaired or replaced, depending on whether the system is repairable or not.

Technically, availability performance is defined in four measures of: the availability function, limiting availability, the average availability function and limiting average availability. All of these measures are based on the function *X(t)*, which denotes the status of a repairable system at time *t*. The instant availability at time t (or point availability) is defined by (Javad, 2005):

$$A(t) = P(X(t) = 1) \quad (1)$$

This is the probability that the system is operational at time t. Because it is very difficult to obtain an explicit expression for A(t), other measures of availability have been proposed. One of these measures is the steady system availability (or steady-state availability or limiting availability) of a system, which is defined by:

$$A = Limit\ t \rightarrow \infty\ A(t) \quad (2)$$

This quantity is the probability that the system will be available after it has been run for a long time, and it is a very significant measure of the performance of a repairable system. Because it is very difficult to obtain an explicit expression for A(t), other measures of availability have also been proposed. For X(t) = 1, if the system is up and at time t = 0, system is down (Javad, 2005). The Equations (1) and (1) respectively, are used here only for the explanation of technical availability concept.

Any improvement in the unit's reliability and availability is associated with the requirement of additional effort through performance improvement. It is, therefore imperative to evolve techniques for reliability and availability allocation amongst various units of a system with minimum effort (Javad, 2005). However, some of these factors do not correctly describe the true state of the units.

For instance, if a peaking unit was required to generate 100 h/year but experienced forced outages during 25 of those demand hours (and no other outages over the 8760 h in the year), it would still have an EAF and UCF of: (8760-25)/8760 x 100 = 99.71% and a FOF and UCLF of (25)/8760 x 100 = 0.29% which are still relatively very high.

These numbers might look good on paper but the reality is that the unit could only produce 75% of the power required of it. So these factors do not correctly describe the unit's ability to produce its rated capacity when demanded.

Mathematically, Operational availability is defined:

$$\text{Mathematically, } A_o = \frac{Up\ Time}{Operating\ Time}$$

$$\text{Availability, } A_V = \frac{Available\ Hours}{Period\ Hours} \times \frac{100}{1}$$

Where, Available Hours = Period Hours – Forced Outage Hours – Scheduled Outage Hours.

It is the probability that an item will operate satisfactorily at a given point in time when used in an actual or realistic operating and support environment. It includes logistics time, ready time, and waiting or administrative downtime, and both preventive and corrective maintenance downtime. Other availability performance indices have been developed for accurate measures amongst which are equivalent availability etc.

The availability of a unit generator determines its performance credibility. The status of a generating unit is conveniently described as residing in one of several possible states. A hierarchical representation of these states is shown in Figure 1.

In any good electricity supply environment, power generation for an area must be simple (matrix) mix of three types of generations:

i. Based–Load Generation: This runs continuously to supply the minimum requirements of the area. This type has shock absorbing capabilities.
ii. Intermediate Generation: This runs to upgrade day time loads.
iii. Peaking Generation: This is started rapidly to meet the few peak hours on a peak day, or to provide immediate support for an area in the event of a contingency on the power system.

The last two fall within the range of frequency generators which are used for grid optimization. The two technical reasons for these categories are the ability of the generator to maneuver and the other, is its efficiency. A generator can maneuver if it can run at a wide range of output power levels, and change output power levels quickly.

Energy quality and availability

In a deregulated power structure, energy particularly power generation should be decided by its quality. This

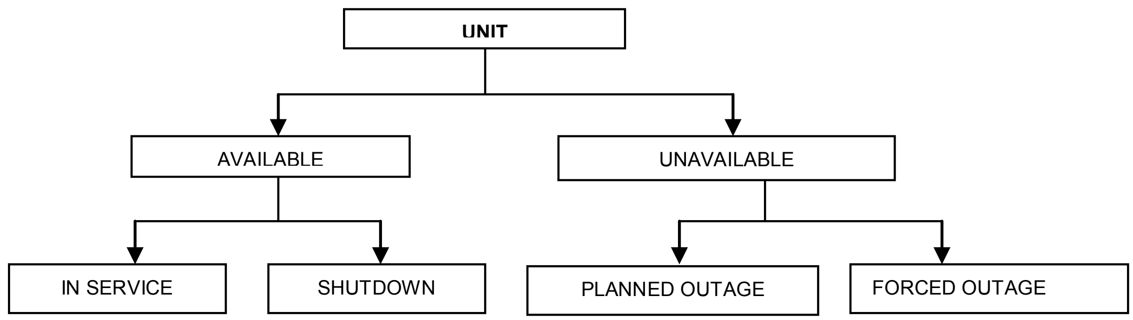


Figure 1. Simple generation unit states.

supports the customer view point which is summed up into two concepts: technical and economical. Technical concept is all indicated in availability and reliability indices. The economical concept is integrated in electrical energy price which is required to be in the lowest possible range. While the managerial concepts-which are figured in the performance indices-are: Availability, reliability and productivity (Mahmoud et al., 2000).

Generator performance measurement gains

A properly planned generator unit availability improvement program can go a long way to optimize overhaul intervals and many more. The cost advantage is immense and more so, there will be:

a. Long – term availability increase as a result of fewer overhauls on the generators,
b. Decrease in post–overhaul failures due to fewer overhauls performed on the system and subsequent overall improvement in availability,
c. Increased availability as result of specific repairs that will be made without overhaul required. Data monitoring helps to track increase in forced or maintenance outages and identifies components responsible.

Operational availability is the quantitative link between readiness objectives and supportability. Availability is a performance criterion for repairable systems that accounts for both the reliability and maintainability properties of a component or unit system.

It is defined as “a percentage measure of the degree to which machinery and equipment is in an operable and committable state at the point in time when it is needed”. It is the degree (expressed as a decimal between 0 and 1, or the per-unit) to which one can expect a piece of equipment system to work properly when it is required. Technical considerations also classify the characteristic non-maintained and maintained systems. The non-maintained systems either fulfill their missions (by surviving beyond expected time) or fail it (by perishing before the expected time is completed). In contrast, maintained systems can be repaired (maintained) e.g. a unit generator, and put back into operation (Romeu, 2010). Ultimately, the contractual parties to deregulation in the entire energy sector that is, generation transmission and distribution are focusing on unilateral objectives, which normally are different from each other, and trying to reach them separately (Killich, 2006). In view of the forgoing, the operating requirements largely depend on reliability, maintainability and availability of the operating units of generators.

Maintenance cost advantage gains

According to GADS (2007), when performance improvement is properly planned, it is estimated that the cost of a turbine overhaul for one unit will be $3 million, making the annual cost of an overhaul done on a three-year interval $1 million. Extending the interval to seven years ($60,000 equivalent hours), the cost is about $400,000 a year. Total annual savings will be $600,000 a year per unit (Kopman et al., 1995).

Fuel savings

According to GADS, the fuel savings that results from repairs or modifications accomplished during an overhaul of a plant investigated was $1 million in a year when compared with the time the company started its investigation on optimization of overhaul intervals. This means that, extensive upgrade of old generators particularly through the life extension programs can almost assumes new units status. This in effect increases availability due to fewer overhauls. Post–overhaul failures decreases because of fewer overhauls performed and consequently, leads to overall improvement in availability.

Table 1. Egbin power plant commissioning dates. (Source: Egbin Thermal Business Unit Power Station).

Unit code name	Unit commissioning dates/year	Order of commissioning
ST-1	11/5/1986	3rd
ST-2	11/11/1985	2nd
ST-3	11/5/1985	1st
ST-4	11/11/1986	4th
ST-5	11/5/1987	5th
ST-6	11/11/1987	6th

Plant equipment availability will also increase because specific repairs could be made without requiring overhauls (Kopman et al., 1995).

To be able to manage this process, the availability engineer can handle this by using six standard review processes which include reason for improvement; definition of problem; careful analysis; solution projection; results and process improvement (Kopman et al., 1995). All steps must be supported by facts. We can establish the need for improvements by stratifying the areas of concerns with respect to impact to generation loss. We can study the description of events to define problems. Root cause analysis is performed to identify all possible causes of events.

BRIEF DESCRIPTION OF EGBIN ELECTRIC THERMAL POWER BUSINESS UNIT

The decision to site a thermal power station in Lagos metropolis came up in 1982 by the Federal Government of Nigeria under President Shehu Shagari. The Egbin power plant is located at Igede, near Egbin Town of Ikorodu Local Government of Lagos State, Nigeria. The power station is located about 40 km North East of the City of Lagos. It is situated by the Lagoon around Igede village. Its situation by the Lagoon satisfies the logistic need as well as the water supply requirements of the steam power plant. The Egbin power station is a thermal (steam) power plant. It also utilizes chemical energy of natural gas fuel or LPFO/HPFO (Low pour fuel oil/ High pour fuel oil) through combustion processes in the boiler to generate high pressure and temperature steam to run a three stage steam turbine. This is directly coupled to the generator motor at rated speed of 3000 rpm capable of generating maximum power of 220MW.

The Egbin power station consist of 6 (six) installed units each having a capacity of generating 220MW at maximum continuous rating (MCR). The station has a total installed capacity of 1320MW, the boiler at a capacity of 705t/h are designed for dual firing of natural gas and low/high pour fuel oil (LPFO/HPFO) (Table 1).

MAJOR CAUSES OF OUTAGES UNAVAILABILITY SUMMARISED FROM FIELD OUTAGE DATA RECORDS

This section summarizes the major interpretations for the various graphical presentations which includes description and causes of various major outages (As per Planned outage, Maintenance Outage, Forced outage) of the six (6) generating units within the period of investigation of the power station.

For every increase, it is either steady rise, sharp rise, an upward, trend, or a boom (a dramatic rise) and for every decrease either a decline, steady fall, sharp drop, a lump (a dramatic fall), or a reduction. Plateau normally levels out, does not change (steady), remained stable or stayed constant (maintained the same level).

Some of the reasons for the pattern exhibited by the different units' graphs are summarized. Some of these events are yearly repetitive and were summarized. The events (generated from the outage report and operators' log) which brought about the unavailability of the Egbin plant Units as reflected in the output graphs are: Industrial action, inspections and annual routine maintenance (RAM), annual overhauls, low gas head pressure making all BFP's trip, under frequency/ABC power failure, shutdown on ATS/Governor problem, SH output safety valve, tube leakage of secondary super heater, high main steam temperature, 330KV Switchyard inter-trip alarm, shattered current transformer in the Switch Yard, ground relay trouble, serious steam leakages, burners valve closed trip, condenser cleaning problems, de-mineralized water crisis, boiler tube leakage, natural gas header trip, fire outbreak due to frequency disturbance, bearings problems, heater bypass load runback failure, extreme low instrument air pressure, partial loss of flame, loss of excitation, generator hydrogen level, exploded furnace, system surge, unit service transformer fault, stage negative phase sequence, lifting of drum safety valve, very low main tank oil level, ATS failure, broken carbon brushes holders, loss of burner B1, generator main seal oil pump failure, pigging exercise at National Gas Company (NGC), super-heater attemprator nozzle problem, generator rotor ground fault, Unit 6 was on forced outage due to furnace explosion and boiler tube leakage throughout the entire year 2006. Unit 6 was on forced outage due to furnace explosion and boiler tube leakage 2007 to 2011 in the years under review.

EGBIN DATA GENERATED FROM RAW FIELD DATA ARRANGED IN MATRIX FORM FOR ALL THE PARAMETERS ANALYSIS USING MATLAB SOFTWARE

The data in from the outage report from Egbin Power station rearranged, yielded the data used for MATLAB analysis as presented:

Some of the formulas amongst others inputted into the model program are listed as follow (IEEE Power Engineering Society, 2006)

Availability Factor – AF:
AF = (AH/PH) x 100 (%)
Forced Outage Rate – FOR:
FOR = (FOH/(FOH + SH)) x 100 (%)
Forced Outage Factor – FOF:
FOF = (FOH/PH) x 100 (%)
Service Factor – SF:
SF = (SH/PH) x 100 (%)

Planned Outage Factor – POF:
POH = (POH/PH) x 100 (%)
Where,
AH = Available Hours
PH = Period Hours
FOH = Forced Outage Hours
SH = Service Hours
POH = Planned Outage Hours

Egbine input data (from 2004 - 2011)

```
ESDH_Egbin = (ESDH2004;ESDH2005;ESDH2006;ESDH2007;ESDH2008;ESDH2009;ESDH2010;ESDH2011);
%========================================================
%FOH = input('Enter Forced Outage Hours = ');
FOH2004 = (215.67 127.25 480.32 238.52 308.43 204.23);
FOH2005 = (410.23 273.6 252.37 183.47 216.3 125.93);
FOH2006 = (384.07 207.63 1218.68 121.98 1194.77 0.00);
FOH2007 = (1501.02 1153.12 8230.56 757.43 1576.3 8760.00);
FOH2008 = (568.2 478.27 237.32 926.55 1137.82 8760.00);
FOH2009 = (460.57 474.49 1350.68 561.78 493.19 8760);
FOH2010 = (8.11 764.38 724 442.03 733.36 8760.00);
FOH2011 = (189.04 211.43 809.05 525.32 412.9 8760.00);
FOH_Egbin = (FOH2004;FOH2005;FOH2006;FOH2007;FOH2008;FOH2009;FOH2010;FOH2011);
%========================================================
%SH = input('Enter Service Hours = ');
SH2004 = (6535.39 6552.34 6789.34 7345.42 6360.75 7029.51);
SH2005 = (6654.76 7647.14 6947.38 7363.54 7270.58 7292.31);
SH2006 = (5845.43 6131.01 4712.19 4673.40 4960.67 941.52);
SH2007 = (3818.70 5636.87 436.32 4446.15 4747.05 0.00);
SH2008 = (5368.18 4669.41 1708.68 4971.34 5969.25 0.00);
SH2009 = (3450.37 4557.81 2563.45 3243.12 3662.06 0.00);
SH2010 = (330.79 6772.50 6709.79 7012.98 6022.14 0.00);
SH2011 = (7889.08 6479.23 6182.52 6694.26 6239.24 0.00);
SH_Egbin = (SH2004;SH2005;SH2006;SH2007;SH2008;SH2009;SH2010;SH2011);
%========================================================
%SS = input('Enter Starting Successes = ');
SS2004 = (25 28 35 32 22 19);
SS2005 = (44 44 41 24 32 30);
SS2006 = (33 35 32 21 37 2);
SS2007 = (41 41 0 30 41 0);
SS2008 = (32 33 13 34 38 0);
SS2009 = (35 30 38 36 28 0);
SS2010 = (4 45 49 63 42 0);
SS2011 = (24 19 31 36 29 0);
SS_Egbin = (SS2004;SS2005;SS2006;SS2007;SS2008;SS2009;SS2010;SS2011);
%========================================================
%SA = input('Enter Start Attempts = ');
SA2004 = (28 31 38 32 22 20);
SA2005 = (46 44 47 33 33 33);
SA2006 = (35 35 33 22 39 4);
SA2007 = (42 42 1 39 41 0);
SA2008 = (40 30 14 39 40 0);
SA2009 = (37 30 38 39 33 0);
SA2010 = (4 46 54 66 45 0);
SA2011 = (25 21 32 46 31 0);
SA_Egbin = (SA2004;SA2005;SA2006;SA2007;SA2008;SA2009;SA2010;SA2011);
%========================================================
%POH = input('Enter Planned Outage Hours = ');
POH2004 = (670.00 874.47 526.87 498.12 659.48 106.98);
POH2005 = (475.22 35.43 24.77 0.50 0.00 4.75);
POH2006 = (285.25 336.17 0 1006.07 185.68 0);
POH2007 = (304.85 191.8 0.00 845.73 38.02 0);
POH2008 = (148.08 273.25 0 501.83 141.62 0);
POH2009 = (253.63 0 397.72 294.55 155.18 0);
POH2010 = (0.00 208.35 0 243 378.69 0.00);
POH2011 = (1.93 171.5 701.88 192.21 166.67 0);
POH_Egbin = (POH2004;POH2005;POH2006;POH2007;POH2008;POH2009;POH2010;POH2011);
%========================================================
%MWH = input('Enter Megawatt Hour Produced = ');
MWH2004 = (1339755 1310468 1412183 1432356 1202182 1265311);
MWH2005 = (1364226 1529428 1458950 1435890 1381410 1422001);
MWH2006 = (1052177 919652 918877 925333 992133 195836);
MWH2007 = (706460 1014636 85083 880338 949410 0);
MWH2008 = (1052164 887188 324649 994267 1128188 0);
MWH2009 = (690074 865983 487056 648624 692130 0);
MWH2010 = (67811 1408680 1341958 1332467 1234539 0);
MWH2011 = (1617262 1347680 1236504 1271909 1279044 0);
MWH_Egbin = (MWH2004;MWH2005;MWH2006;MWH2007;MWH2008;MWH2009;MWH2010;MWH2011);
%======================================================
%NPC = input('Enter Nameplate Capacity = ');
NPC2004 = (220 220 220 220 220 220);
NPC2005 = (220 220 220 220 220 220);
NPC2006 = (220 220 220 220 220 220);
NPC2007 = (220 220 220 220 220 220);
NPC2008 = (220 220 220 220 220 220);
NPC2009 = (220 220 220 220 220 220);
NPC2010 = (220 220 220 220 220 220);
NPC2011 = (220 220 220 220 220 220);
NPC_Egbin = (NPC2004;NPC2005;NPC2006;NPC2007;NPC2008;NPC2009;NPC2010;NPC2011);
%======================================================
```

```
%RSH = input('Enter Reserve Shotdown Hours = ');
RSH2004 = (0 0 0 0 0 0);
RSH2005 = (0 0 0 0 0 0);
RSH2006 = (0 0 0 0 0 0);
RSH2007 = (0 0 0 0 0 0);
RSH2008 = (0 0 0 0 0 0);
RSH2009 = (0 0 0 0 0 0);
RSH2010 = (0 0 0 0 0 0);
RSH2011 = (0 0 0 0 0 0);
RSH_Egbin = (RSH2004;RSH2005;RSH2006;RSH2007;RSH2008;RSH2009;RSH2010;RSH2011);
%========================================================
%FON = input('Enter Forced Outage Number = ');
FON2004 = (34 27 42 36 18 30);
FON2005 = (45 44 39 22 31 23);
FON2006 = (32 20 34 16 38 2);
FON2007 = (38 39 1 34 39 0);
FON2008 = (35 25 12 34 39 0);
FON2009 = (33 29 34 37 30 0);
FON2010 = (5 45 54 65 40 0);
FON2011 = (25 21 32 46 31 0);
FON_Egbin = (FON2004;FON2005;FON2006;FON2007;FON2008;FON2009;FON2010;FON2011);
%========================================================
%FOH = input('Enter Full Forces Outage Hours = ');
FOH2004 = (215.67 127.25 480.32 238.52 308.43 204.23);
FOH2005 = (410.23 273.6 252.37 183.47 216.3 125.93);
FOH2006 = (384.07 207.63 1218.68 121.98 1194.77 0.00);
FOH2007 = (1501.02 1153.12 8230.56 757.43 1576.3 8760.00);
FOH2008 = (568.2 478.27 237.32 926.55 1137.82 8760.00);
FOH2009 = (460.57 474.49 1350.68 561.78 493.19 8760);
FOH2010 = (8.11 764.38 724 442.03 733.36 8760.00);
FOH2011 = (189.04 211.43 809.05 525.32 412.9 8760.00);
FOH_Egbin = (FOH2004;FOH2005;FOH2006;FOH2007;FOH2008;FOH2009;FOH2010;FOH2011);
%========================================================
%EPOH = input('Enter Equivalent Planned Outage Hours, EPOH = ');
EPOH2004 = (670.00 874.47 526.87 498.12 659.48 106.98);
EPOH2005 = (475.22 35.43 24.77 0.50 0.00 4.75);
EPOH2006 = (285.25 336.17 0 1006.07 185.68 0);
EPOH2007 = (304.85 191.8 0.00 845.73 38.02 0);
EPOH2008 = (148.08 273.25 0 501.83 141.62 0);
EPOH2009 = (253.63 0 397.72 294.55 155.18 0);
EPOH2010 = (0.00 208.35 0 243 378.69 0.00);
EPOH2011 = (1.93 171.5 701.88 192.21 166.67 0);
EPOH_Egbin = (EPOH2004;EPOH2005;EPOH2006;EPOH2007;EPOH2008;EPOH2009;EPOH2010;EPOH2011);
%========================================================
%MOH = input('Enter Full maintenance Outage Hours = ');
MOH2004 = [0.00 174.67 0.00 0.00 136.00 38.54];
MOH2005 = [201.93 480.85 490.93 24.00 398.00 0.00];
MOH2006 = [0 0 0 0 0 7960.52];
MOH2007 = [784.18 200 0 0 0 0];
MOH2008 = [0 254.8 6717.43 320.83 200.00 0];
MOH2009 = [1003.19 4.68 602.71 831.49 924.88 0];
MOH2010 = [316.29 100.39 0 0 0 0];
MOH2011 = [71.2 279.37 0 221.36 461.46 0];

MOH_Egbin = [MOH2004;MOH2005;MOH2006;MOH2007;MOH2008;MOH2009;MOH2010;MOH2011];(souce: NCC, 2011)
%========================================================
%RUNCAP = input('Enter Running Capacity = ');
RC2004 = (205 200 208 195 189 180);
RC2005 = (205 200 210 195 190 195);
RC2006 = (180 150 195 198 200 208);
RC2007 = (185 180 195 198 200 0.0);
RC2008 = (196 190 190 200 189 0.0);
RC2009 = (200 190 190 200 189 0.0);
RC2010 = (205 208 200 190 205 0.0);
RC2011 = (205 208 200 190 205 0.0);
RC_Egbin = (RC2004;RC2005;RC2006;RC2007;RC2008;RC2009;RC2010;RC2011);
%========================================================
%FAILEDSTART = input('Enter Failed Starts = ');
FS2004 = (3 3 3 0 0 1);
FS2005 = (2 0 6 9 1 3);
FS2006 = (2 0 1 1 2 2);
FS2007 = (1 1 1 9 0 0);
FS2008 = (2 3 1 5 2 0);
FS2009 = (2 0 0 3 5 0);
FS2010 = (0 1 5 3 3 0);
FS2011 = (1 2 1 10 2 0);
FS_Egbin = (FS2004;FS2005;FS2006;FS2007;FS2008;FS2009;FS2010;FS2011);
%========================================================
%NOOFSTOP = input('Enter No Of Stops = ');
NOS2004 = (28 31 38 32 22 20);
NOS2005 = (46 44 47 33 33 33);
NOS2006 = (35 35 33 22 39 4);
NOS2007 = (42 42 1 39 41 0);
NOS2008 = (40 30 14 39 40 0);
NOS2009 = (37 30 38 39 33 0);
NOS2010 = (5 46 53 65 45 0);
NOS2011 = (24 20 31 45 31 0);
NOS_Egbin = (NOS2004;NOS2005;NOS2006;NOS2007;NOS2008;NOS2009;NOS2010;NOS2011);
%========================================================
```

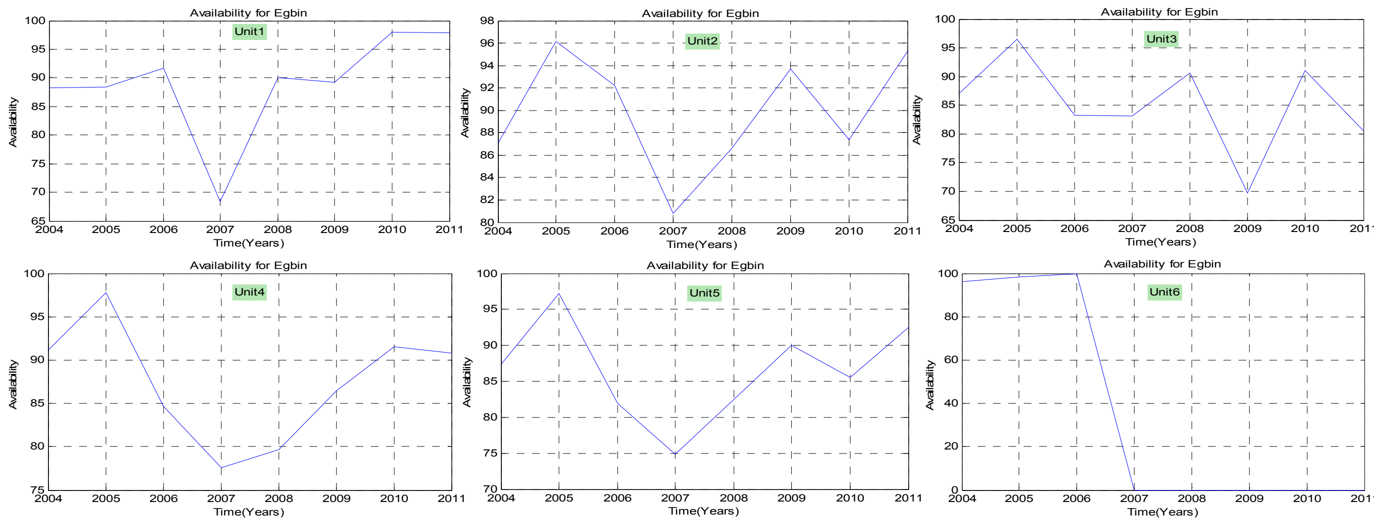
However, the analysis modeling output result shows some abnormally high availability values for some units which would not reflect the real situation. This may have been caused by frequent shutdowns and data manipulations; recording patterns which does not align with the IEEE std 762 reporting standards.

Parameters analysis

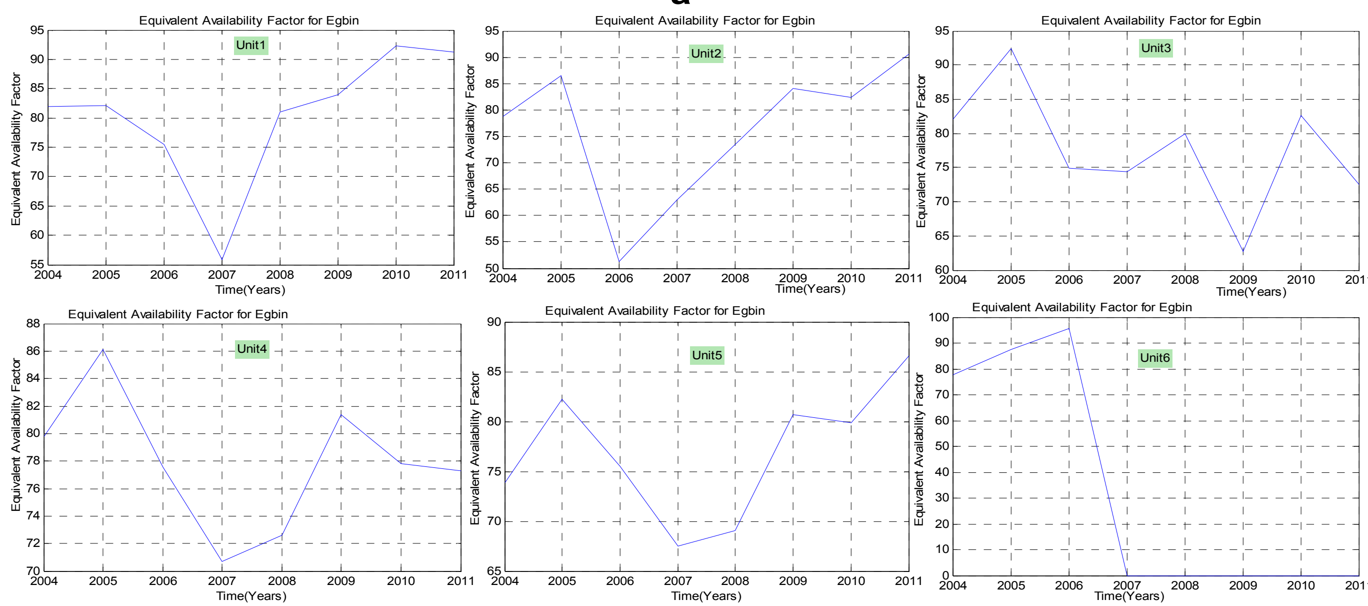
Data were generated for a total number of 22 parameters and indices from the data inputs entered. A corresponding numbers of graphs were also plotted after analysis by using MATLAB software. But only few out of the 22 parameters and indices are presented here. Some of the input data are also presented. The reasons for the graphical patterns are also presented as deduced from the outage report with reasons for major outages experienced within this period of seven years. They are presented before the final summary (Figure 2a-e).

Egbin output result data from MATLAB

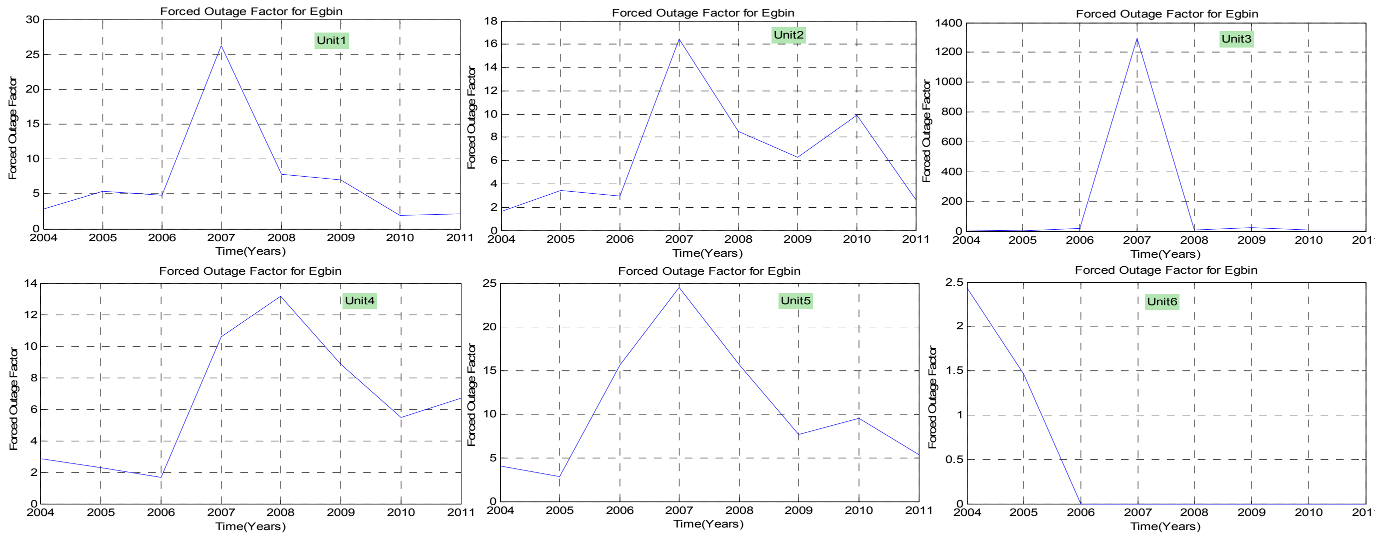
Using the above data as inputs for the software program written, the following output data results and graphs are generated as presented in this article.


Availability for Egbin
Unit1
Unit2
Unit3
Unit4
Unit5
Unit6
Availability
Time(Years)

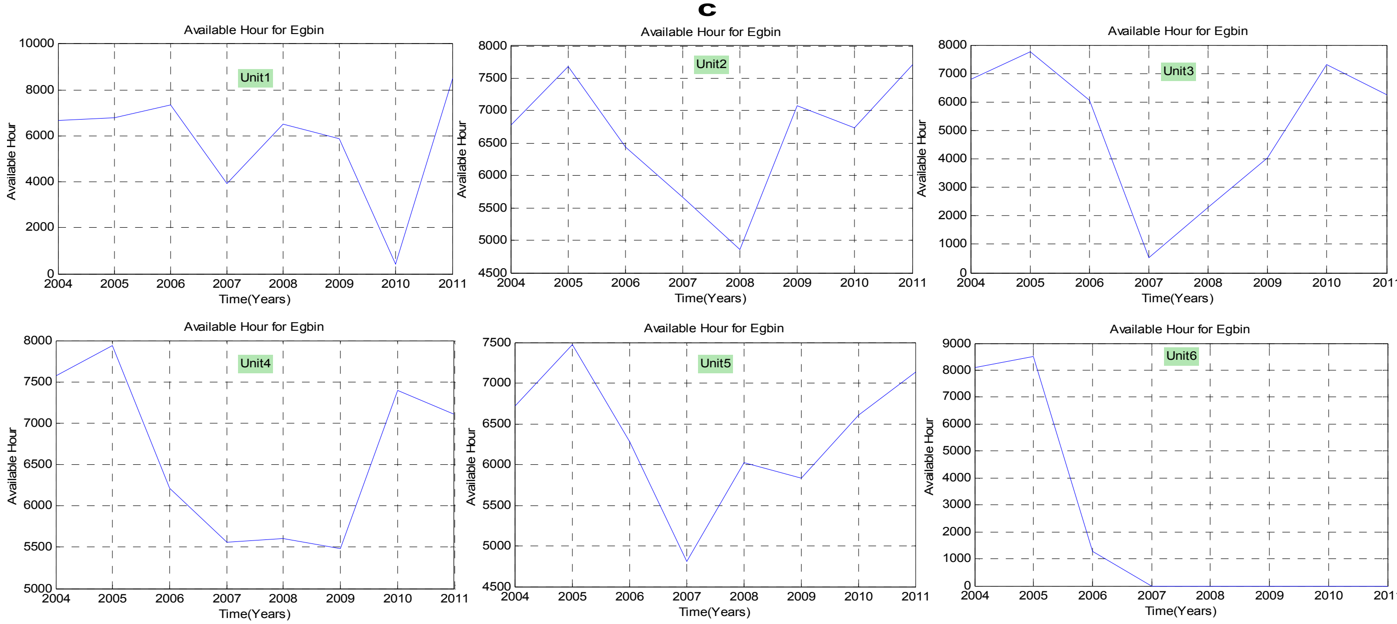
a


Equivalent Availability Factor for Egbin
Unit1
Unit2
Unit3
Unit4
Unit5
Unit6
Equivalent Availability Factor
Time(Years)

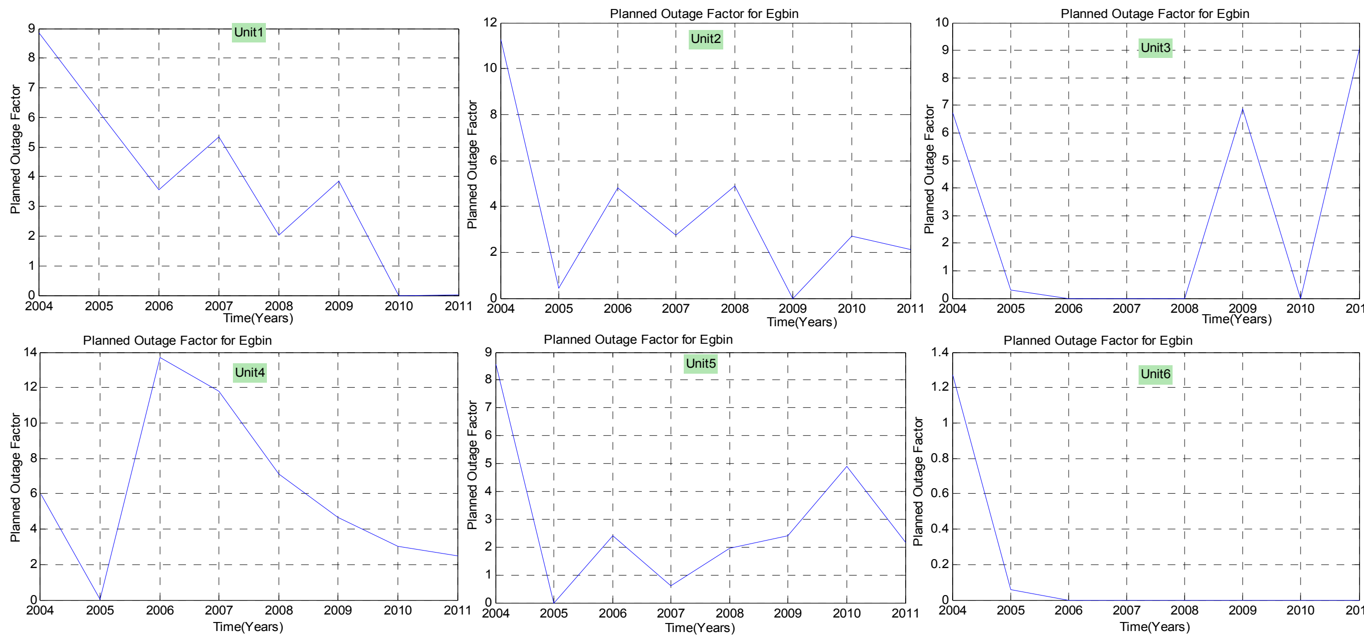
b


Forced Outage Factor for Egbin
Unit1
Unit2
Unit3
Unit4
Unit5
Unit6
Forced Outage Factor
Time(Years)

c


Available Hour for Egbin
Unit1
Unit2
Unit3
Unit4
Unit5
Unit6
Available Hour
Time(Years)

d



e

Figure 2a-e. Graphical outputs from analysis of data using MATLAB a. Egbin Availability for 2004 – 2011; b. Egbin Equivalent Availability for 2004 – 2011; c. Egbin Forced Outage Factor for 2004 – 2011; d. Egbin Available Hours for 2004 – 2011; e. Egbin Planned Outage Factor for 2004-2011.

Egbin output parameters result data op4(6)

Egbin availability from 2005-2011 =

88.2866	87.1148	87.1161	91.1398	87.4070	96.2982
88.4509	96.1323	96.5450	97.7360	97.1865	98.4844
91.6727	92.2084	83.2195	84.6210	81.9940	100.0000
68.4186	80.8300	83.1511	77.6002	74.8853	0
90.1052	86.5999	90.5897	79.6958	82.4783	0
89.1786	93.7098	69.7794	86.4976	89.9949	0
98.0677	87.3922	91.0024	91.5219	85.5928	0
97.8052	95.2711	80.5018	90.8272	92.4916	0

Egbin availability factor from 2005-2011 =

88.2866	87.1148	87.1161	91.1398	87.4070	96.2982
88.4509	96.1323	96.5450	97.7360	97.1865	98.4844
91.6727	92.2084	83.2195	84.6210	81.9940	100.0000
68.4186	80.8300	83.1511	77.6002	74.8853	0
90.1052	86.5999	90.5897	79.6958	82.4783	0
89.1786	93.7098	69.7794	86.4976	89.9949	0
98.0677	87.3922	91.0024	91.5219	85.5928	0
97.8052	95.2711	80.5018	90.8272	92.4916	0

Egbin equivalent availability factor from 2005-2011 =

81.9622	78.6865	82.1057	79.8130	73.8332	77.7170
82.0997	86.5614	92.4206	86.1182	82.2539	87.6416
75.5116	51.2137	74.9010	77.5416	75.5235	95.7546
55.7841	62.9753	74.3655	70.6976	67.5000	0
81.0247	73.4538	79.8920	72.6292	69.0699	0
83.9507	84.1697	62.7833	81.3840	80.7260	0
92.3018	82.3279	82.6638	77.8177	79.8841	0
91.1707	90.6550	72.5234	77.3147	86.5772	0

Egbin forced outage factor from 2005-2011 =

1.0e+003 *

0.0029	0.0016	0.0061	0.0029	0.0040	0.0024
0.0054	0.0034	0.0031	0.0023	0.0028	0.0015
0.0048	0.0030	0.0168	0.0017	0.0156	0
0.0263	0.0164	1.2926	0.0106	0.0245	0
0.0078	0.0085	0.0094	0.0132	0.0156	0
0.0070	0.0063	0.0233	0.0089	0.0076	0
0.0019	0.0099	0.0090	0.0055	0.0095	0
0.0022	0.0026	0.0104	0.0067	0.0053	0

Egbin service factor from 2005-2011 =

86.4337	84.2835	86.8486	88.3495	82.7559	83.6156
86.7995	95.7092	86.6106	90.6193	94.5728	84.5742
72.7252	87.8458	64.8841	63.7138	64.7047	73.5850
66.7821	80.3461	68.5262	62.1228	73.8520	0
74.1570	83.2585	67.7529	70.6668	81.7479	0
52.2791	60.4215	44.3085	51.1365	56.5098	0
78.8139	87.7802	83.3863	86.7940	78.0200	0
90.6704	80.0132	79.7840	85.5786	80.8300	0

Egbin starting reliability from 2005-2011 =

89.2857	90.3226	92.1053	100.0000	100.0000	95.0000
95.6522	100.0000	87.2340	72.7273	96.9697	90.9091
94.2857	100.0000	96.9697	95.4545	94.8718	50.0000
97.6190	97.6190	0	76.9231	100.0000	0
80.0000	110.0000	92.8571	87.1795	95.0000	0
94.5946	100.0000	100.0000	92.3077	84.8485	0
100.0000	97.8261	90.7407	95.4545	93.3333	0
96.0000	90.4762	96.8750	78.2609	93.5484	0

Egbin planned outage factor from 2005-2011 =

8.8611	11.2484	6.7397	5.9913	8.5801	1.2725
6.1984	0.4434	0.3088	0.0062	0	0.0551
3.5489	4.8167	0	13.7160	2.4219	0
5.3313	2.7339	0	11.8168	0.5915	0
2.0456	4.8722	0	7.1334	1.9395	0
3.8429	0	6.8745	4.6444	2.3946	0
0	2.7005	0	3.0074	4.9061	0
0.0222	2.1179	9.0576	2.4572	2.1592	0

Egbin capacity factor from 2005-2011 =

0.8054	0.7662	0.8211	0.7831	0.7109	0.6841
0.8088	0.8701	0.8267	0.8032	0.8168	0.7496
0.5950	0.5989	0.5751	0.5734	0.5882	0.6957
0.5616	0.6574	0.6074	0.5591	0.6714	0
0.6607	0.7191	0.5851	0.6424	0.7023	0
0.4753	0.5218	0.3827	0.4649	0.4855	0
0.7344	0.8299	0.7581	0.7496	0.7270	0
0.8449	0.7565	0.7253	0.7391	0.7532	0

Egbin forced outage rate from 2005-2011 =

3.1946	1.9051	6.6072	3.1451	4.6247	2.8233
5.8065	3.4542	3.5053	2.4310	2.8891	1.6976
6.1653	3.2756	20.5481	2.5437	19.4100	0
28.2161	16.9826	94.9657	14.5559	24.9282	100.0000
9.5715	9.2910	12.1953	15.7099	16.0097	100.0000
11.7765	9.4289	34.5078	14.7646	11.8691	100.0000
2.3930	10.1419	9.7393	5.9293	10.8557	100.0000
2.3401	3.1601	11.5718	7.2763	6.2070	100.0000

Egbin Fp from 2005-2011 =

0.9790	0.9675	0.9969	0.9694	0.9468	0.8683
0.9813	0.9956	0.8971	0.9272	0.9731	0.8588
0.7933	0.9527	0.7797	0.7529	0.7891	0.7358
0.9761	0.9940	0.8241	0.8005	0.9862	0
0.8230	0.9614	0.7479	0.8867	0.9911	0
0.5862	0.6448	0.6350	0.5912	0.6279	0
0.8037	1.0044	0.9163	0.9483	0.9115	0
0.9271	0.8398	0.9911	0.9422	0.8739	0

Egbin Ff from 2005-2011 =

0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

Egbin EFORD from 2005-2011 =

10.0367	12.9122	7.7364	6.5738	9.8163	1.3214
7.0077	0.4613	0.3198	0.0063	0	0.0559
3.8713	5.2237	0	16.2088	2.9538	0
7.7921	3.3822	0	15.2278	0.7899	0
2.2702	5.6261	0	8.9508	2.3515	0
4.3093	0	9.8517	5.3694	2.6608	0
0	3.0901	0	3.2860	5.7319	0
0.0227	2.2230	11.2514	2.7053	2.3345	0

Egbin maintenance outage factor from 2005-2011 =

0	2.2468	0	0	1.7694	0.4584
2.6338	6.0182	6.1203	0.2954	5.1770	0
0	0	0	0	0	622.1587
13.7139	2.8507	0	0	0	0
0	4.5432	266.3607	4.5605	2.7390	0
15.2001	0.0620	10.4177	13.1107	14.2720	0
75.3592	1.3012	0	0	0	0
0.8183	3.4500	0	2.8298	5.9783	0

SUMMARY

Egbin Power Plant had most of the failures related to incessant outages occasioned by both issues within plant management control and outside plant management control. Majority of the reasons within and without plant management control as shown in the outages reasons earlier. Availability of turbine unit generator as expressed earlier is the percent of time; the turbine is available to generate power in any given period at its acceptance load. This specifies that higher percent value means high availability of the plant units, while low indicates limitations in power generation capacity.

The results obtained are a combination of the graphical output trend and the results from the output summaries and averages above. From the results, the availability of the units peaked at various times of the years. ST01 peaked at 98.07% in 2010, while ST02, 03, 04, 05 and 06 peaked at 96.13, 96.55, 97.19 and 98.48%, respectively in 2005. The overall availability of the entire units averaged at 89.00%. ST01 has the highest availability in 2010. But the year 2007 had the lowest percent values for majority of the station units. Units ST01, ST02, ST04, and ST05 had their lowest values in 2007 as 68.42, 80.83, 77.60, and 74.89, respectively. ST06 went out on Furnace explosion in 2006 but had its lowest value at 0.0% but for the period it run, it had 96.30% as it's lowest, while ST03 decreased significantly between 2008 and 2009 to as low of about 69.78% availability. Equivalent availability factor which indicates that both full forced outages and deratings which has characterized the entire units has been considered in the evaluations and also shows that availability is limited majorly by outages which is also revealed in the same trend as seen from the graphical output result above (Tables 2 and 3).

FINDINGS

There is gross inconsistency in data presentation coupled with incoherent and non-uniform presentation of operational activities, particularly in data presentations. The failure rate which is a determinant of reliability and availability is a reasonable measure for stability of generating units and indication for economical effectiveness of repairs. On the overall, the trend of availability and other indices and parameters fluctuated greatly within the period of investigation and on the average, could not reach up to the expected benchmark within the seven years span owning to reasons given above for their unavailability.

When we reconcile these results output values to the parameters and indices definitions and implications on generators (NERC/IEEE std 762), it becomes clear that some of the units' generators performed below potentials. The high values of availability and other parameters were due to the fact that full and prorated partial forced outage hours are not accounted for. However, it is likely that the time to restore a unit to full capability would average more than five hours for a single generator during demand periods. It is much more probable that the total forced outage hours would be several times higher (some previous studies suggest that the average restoration time for a gas turbine forced outage is on the order of 24 h for base loads) (Richwine, 2004).

However, equivalent availability is another index considered very effective in this regards. It is another measurement which can be tracked based on outage reporting style; it has become increasingly popular in the new power performance measurement. This is not same with the traditional time-based availability measurement expressed above (GE Power systems, 2000). Equivalent availability considers the lost capacity effects of partial equipment deratings and reports those effects as equivalent unavailable hours (GE Power systems, 2000). For example, if a unit operated for 100 h with an equipment limitation at 80% of nominal rated capacity, it would be considered to have accrued 100 h x 20% derating = 20 equivalent derated hours. For operating hours of 100 h, the traditional (time-based) availability would show as 100%; but, the equivalent availability

Table 2. The averages of overall summary of all parameters (Total) and indices for Egbin Power Station (Source: Fergus (2015) Unpublished material: The Inherent Energy Crisis in Nigeria).

Generator parameter	Unit						Station sum	Averages
	1	2	3	4	5	6		
Availability for 2004-2011	89	89.91	85.24	87.45	86.5	25.71	463.81	77.3
Availability factor for 2004-2011	89	89.91	85.24	87.45	86.5	25.69	463.79	77.3
Equivalent availability for 2004-2011	80.48	76.26	77.71	77.91	76.92	32.64	421.91	70.32
Forced outage factor for 2004-2011	0.01	0.01	0.17	0.01	0.01	0	0.2	0.03
Service factor for 2004-2011	76.08	82.46	72.76	74.87	76.62	30.22	413.02	5.04
Starting reliability for 2004-2011	93.43	98.28	82.1	87.29	94.82	29.49	485.41	80.9
Planned outage factor for 2004-2011	3.73	3.62	2.87	6.1	2.87	0.17	19.36	3.23
Capacity factor for 2004-2011	0.69	0.71	0.66	0.66	0.68	0.27	3.67	0.61
Forced outage rate for 2004-2011	8.68	7.2	24.21	8.29	12.1	63.07	123.55	20.59
Partial forced outage, Pf for 2004-2011	0.86	0.92	0.85	0.85	0.89	0.31	4.67	0.78
Full forced outage for 2004-2011	0	0	0	0	0	0	0	0
Equiv. forced outage rate Dd 2004-2011	4.41	4.11	3.64	7.29	3.33	0.17	22.97	3.83
Maintenance factor for 2004-2011	13.47	1.99	2.64	35.32	3.97	78.17	135.56	22.59

Table 3. Summary of all availability and performance parameters for Egbin Power Stations (2005-2011). (Source: Fergus E.O. (2015) Unpublished material: The Inherent Energy Crisis in Nigeria).

Power station	Availability	Availability factor	Equivalent availability factor	Forced outage factor	Service factor	Starting reliability	Planned outage factor	Capacity factor	Forced outage rate	Partial forced outage, Fp	Full Forced outage factor, Ff	EFORD	Maintenance outage factor
Average stations values	88.35	88.34	80.36	0.04	78.67	92.46	3.69	0.70	23.53	0.89	0.00	4.37	25.82

would equal 100 available hours minus the 20 equivalent derated hours for a measure of 80% (GE Power systems, 2000). This parameter could however not be used because incomplete data recording style observed generally in this Power stations.

For a good and balanced power generation system, the availability requirements should be as follows:

i. The unit generator should be = 97% which means a maximum of 11 days in a given year period of unavailability for reason of unplanned repair or maintenance etc. The important components of the unit generator should have availability of 94% minimum.

ii. The fuel supply should have the availability of 99.5% etc, but these were not the case here.

iii. The evaluation of power plant performance should be one of the most important tasks at any power station. Without its availability records, the plant staff and stakeholders cannot determine ways to improve performance of the equipment and make the plant more profit-oriented for plant owners. The causes of unavailability must be thoroughly analysed to identify the areas for generators performance improvement.

This study can be said to have provided some corresponding levels of potential and cost-effective improvements from the use of performance parameters to improve unit availability. This can be justified by using the Richwine model of electricity generation standards to justify the subject of availability using this illustration: For instance, assuming total installed power capacity in the power station within this period under review as 1320MW. On the basis that we consider the total installed capacity of 1320MW. From study findings, most of the units have derated either due to spare supply shortage or due to ageing, and hence we consider this value for illustration only.

One percent improvement in availability that can be achieved and sustained is equivalent to approximately 15.53MW of new capacity at 85% availability. To arrive at that figure we calculate the Available Capacity as the product of the capacity times the availability. Therefore a 1% improvement in Availability would result in a 13.2MW increase in Available Capacity only if that capacity were 100% available. But for a more realistic availability goal we might chose 85% (considering the average of the running units' availability) so that the 7.6 MW at 100% availability would be equal to 15.53MW at 85% availability (13.2/0.85). However, it is also apparent that not all plants and sectors have equal opportunity to achieve the same levels of cost-effective availability improvement. Hence, if the total availability improvement that can be achieved and sustained is 14%, then the total equivalent capacity represented by this availability improvement would be 217.4MW.

The assumption of 14% is made based on the nature of data available and the performance of their peers in other parts of the world, and considering the unique set of conditions in some of these generators (base loads).

It should be noted, however, that this improvement will not happen overnight, but rather will be a process that will take place over several years. The time required for the performance improvement can be minimized by taking advantage of other company's experiences to 'get down the learning curve' as quickly as possible:

i.e.: at 1% improvement in availability;

$$\Rightarrow 1320MW \times \frac{1}{100} = 13.2MW$$

Then if we consider a realistic availability goal of 85% of the above 13.2MW,

Then, we have: $\frac{13.2}{0.85} = 15.53MW$

But at 14% achievable and sustainable availability for these steam turbine-units;

Will give 15.53 × 14 = 217.4MW;

The total equivalent capacity represented by this availability will be = 217.4MW.

Some basic questions with regards to information gathering, data sourcing, collation and analysis to evaluate the inherent energy crisis have been formulated into action statements used to remedial actions to fill some of the existing gaps in the Egbin and energy sector at large.

Thus, we can conclude here that this research analysis highlights significantly the amount of potential "equivalent energy producing capability increase" that can be cost-effectively achieved by improving the availability of existing electricity generating units in Egbin power station to optimum levels.

Some basic questions with regards to information gathering, data sourcing, collation and analysis to evaluate station availability in order to ameliorate the energy crisis in Nigeria have been formulated into action statements used to remedial actions to fill some of these existing gaps in the power plant management.

MANAGING THE FUTURE

The benefits of pooling data for performance and availability monitoring system henceforth depends – in addition to the current procedures described in this paper - on the commitment of power plant operators and the energy regulators to enhance them. The underlying goal is to encourage increased production and international participation.

Key factors influencing plant performance should be identified and analysed to allow a cost benefit analysis of any activity/programme before its implementation. Strong political will is needed to handle the implementation of deregulation policies.

To analyze plant availability performance, the energy losses/outages should be scrutinised to identify the causes of unplanned or forced energy losses and to reduce the planned energy losses. Reducing planned outages increases the number of operating hours, decreases the planned energy losses and therefore, increases the energy availability factor. Reducing unplanned outages leads to a safe and reliable operation, and also reduces energy losses and increases energy availability factor (Pierre et al., 2008).

Conclusion

The inherent energy availability of power generation units in Egbin power plant in Nigeria has been investigated. Some possible causes of unavailability have been identified. Ways to overcome the causes comparable to international peers have been presented. The results of analysis through the use of software have justifiably outlined the areas of weakness in the power units. The study has touched areas of availability likely to be encountered by power plants generation managers in other power stations in Nigeria.

The study is a lead study product especially in the area of conventional power plant units' availability management that satisfies international standards as well as foundation for further researches in the field of National power availability and performances analysis in Nigeria. Generally, the facts presented alone in the study are sufficient to exhibit the importance of power availability and performance measurement in enhancing the Nigeria's energy revolution and development.

This paper challenges the widespread practice of abuse in the use of relevant parameters and indices for the determination of generator performance improvements for a healthy electricity generation, profitability and sustainability in the plant and in Nigeria.

The analysis is self-contained and gives a useful practical introduction to standard availability performance evaluations and monitoring. The indices and parameters analysis are presented in most lucid and compact manner for proper understanding especially in data arrangement and tabulations. The process and techniques applied to achieve this goal are fully articulated. Results output presentations and analysis have been covered in the most logical manner from the IEEE power plant standard availability evaluations ideology. However, to design all-encompassing tables of indices and parameters for effective availability measurement more detailed than the NERC/IEEE std 762 typically put forward requires in-depth field experience for sustainable robust results. The introduction of reasonable key performance measures, such as some Availability Value Indicators (a measure of Commercial Availability) will enable the Power station to be one of the leaders in measuring the economic value of its generators in Nigeria. Some of these new indicators have prototyped and showed success in other countries energy industries. Hence, the research provides a comprehensive strategy for other power stations to follow, and appears to be a positive step towards achieving more satisfactory integration in the industry. The evolution of "data analysis" and statistics ensures other factors/ goals are set.

RECOMMENDATIONS

1. Government through NERC should set up generating plant examining board. The board members should comprise well selected best-qualified and most respected individuals in their respective fields (Plant Engineering Design, Plant Management, Operations, Maintenance, etc.) from amongst all of the operating power plants in the country. The board shall review annually the condition of each power plant and make recommendations to executive management and owners of plants concerning actions and expenditures required to achieve performance improvement. This will help local staff to gain knowledge and also help the plant owners to allocate resources equitably.
2. The power station should align in the development of very well enhanced equipment specific Operations and Maintenance (O & M) procedures programs.
3. The power station should embrace the use of powerful software for analyses of the various performance parameters and indices. The result will be beneficial in the exchange of information and monitoring of station units performance trend allowable for improvement of performance of power generating assets in the station and to improve the quality of life to its users.
4. In alignment with other typical industry players, there is need for optimum spare parts management. Spare parts management plays a very important role in the achievement of the desired power generation availability at optimum cost. This will remove the unique problems of controlling and managing spare parts such as element of uncertainty and unavailability.
5. There should be pre-fixed meeting day for plant manager and senior executives in the power station to review all outages where each department is required to explain each outage event and to state the root cause of the problem, the immediate short term solution applied and results in addition to the long term solution that would eliminate or minimize the problem. This will enable plant managers to offer their insights and perspectives to help find the best solution.
6. Load growth should be monitored locally from the station based on subsequent demand rates and frequency. This will help regulate incidences of system collapses.
7. The new owners of the plant (Generation) must now come out with a tested and trusted blueprint in system operations that must be flexible in implementations in the Nigeria environment to guarantee availability of electricity supply to consumers.
8. The plant staff should be fully involved in decision making when a considerable decision is to be made about the management of any power station particularly in the area of maintenances. After all, "The man that wears shoes knows where it pains/ hurts". This will improve performance and availability of the plant units and make the plant profit-oriented.
9. The economics of scale should apply when sitting Power Stations. In another way, the sitting of Power

stations should not be influenced politically or affected by ethnic sentiments. This guarantees adequate gas supply or other raw materials at the long run.

10. Generally, the regulatory authority should benchmark the unit generators in the power industry. The benchmarking philosophy will help Nigeria to achieve the following if properly implemented:

i. Set realistic, achievable goals,
ii. Identify best areas for potential improvement,
iii. Give advance warning of threats,
iv. Trade knowledge and experience with peers,
iv. Quantify and manage performance risks,
v. Create increased awareness of the potential for and the value of increased plant performance

11. There is need to set up a well-equipped effective efficiency department for data collection and analysis using the applicable KPIs and standards. The results of analysis and study will help to enable us have a good planning system in the station. The data collection and monitoring should align with the industry requirement to enable all the power plants harmonize reporting standard and procedure.

12. The issue of gas shortage or low gas pressure climaxed the unavailability of the various unit generators as deduced from system collapse records as well as reasons for outages summarized. A good fuel supply policy should be put in place. This will encourage consistent supply of raw material to the power stations.

13. The “best practices” in computer database should be developed for use by all Power industry’s’ staff. Nigeria must as a result of urgency align with the international community in providing the various generation parameters and performance data for the operation and regulation of the power industry.

14. The plant design organizations should henceforth provide increased engineering support to the operating plants staff particularly during design upgrade projects. This is very important in Nigeria as we seek to upgrade most of the old power plants either to increase availability or dependable capacity.

Conflict of Interest

The authors have not declared any conflict of interest.

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