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Sapele Thermal Power Station Generator Availability and Units Performance Studies

By Engr. Ogieva F. E.[1], Engr. Dr. Ike S.A.[2], & Engr. Dr. Anyaeji C.A.[3]
Department of Electrical Electronic Engineering, Faculty of Engineering, University of Benin, Benin City- Edo State,(NIGERIA)

ABSTRACT:- This paper presents investigation on generator availability and performance studies on four gas and six steam turbine unit generators at Sapele 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 (FOP)', using the outage frameworks of data collected from the station. The program was implemented in MATLAB 11.5b. The data was used to evaluate six (6) out of the ten generating units available in the station because four of the units (mainly gas turbines) had been out of service before the start–to–end period of investigation. The result was used to appraise performance indices and parameters and a periodic availability assessment of all the installed generating units.

The study has demonstrated that availability has a very major impact on power generation and plant economy. The availability and performances results generated for a period of seven years were: ST01= 89%; ST02 = 89.99%; ST03 = 85.24%; ST04= 87.45%; ST05 = 86.50%; ST06 = 29.71%; while the overall station units' availability is 88.35%. The total power generation availability Sapele power station is 7%. Where ST-1 = 36.7%; ST-2 = 20.03%; ST-3 = 0.77%; ST-4 = 0.00%; ST-5 = 0.0%; and ST-6 = 14.54% respectively. Result shows reduction in plant availability is caused by increased number and duration of forced outages. The reasons and durations of forced outages and unscheduled maintenances were identified through the study of outage causes.

Keywords:- Availability, Performance, Steam turbines, Maintenance, Reliability.

I. INTRODUCTION

Presently, in Nigeria little seems to be known about the practical basis of deregulation in the electricity industry. This is because knowledge of it is still very limited. In this regards, the restructuring processes have brought about new problems and many open questions, especially regarding the introduction of competitive mechanisms and their effects on the availability of power supply. In dealing with these uncertainties, it is required that the electricity generation industry have some basic knowledge, no matter how little, about issues that could affect performances of power generation in order to enhance reliability and availability. 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,2007]. The new order is requiring new and more appropriate measures that link technical performance with financial results.

As power supply availability becomes the current catchphrase in business, industry, and society at large in Nigeria, energy researches on availability is indispensible.

The motivator for this new interest in reliability measures will be the evolving market-based business environment ushered in by the need of customers for lower electricity prices to help them meet the demands of the presumably competitive electricity market economy [André,2007]. Commercial Availability is one measure that has evolved to meet that need of the present power management and has been successfully adopted by numerous countries and companies around the world.

The challenges of energy production vary from nations to nations even when they are open to many choices as per type and regulation. While rapidly growing economy like Nigeria is hungry for practical supply of 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.

The Nigerian power generation capability has nosedived to an abysmal level, particularly at the generation stations due to unavailability occasioned by many factors.

The energy demand and supply projections in Nigeria made using two IEA Energy Modelling tools by the Energy Commission of Nigeria (ECN), to make both energy demand and supply projections in Nigeria based on four different scenarios reveals the dare need for energy improvements in Nigeria [Sambo et al, 2008]. According to the projections, Nigeria will need about 28GW in demand by year 2015 at a GDP of 7% and 30GW at GDP of 10% respectively [Sambo et al, 2008]. These will almost double by the year 2020.

In 2005, Nigeria with a population of over 140 million people had only 1500MW (1.5GW) of electricity to share. This was put at 15.58kW per individual per annum by the Central Intelligence Agency, CIA factbook (2007). That is about 1500MW total generation. Nigeria ranks abysmally low compared to other countries of Africa, as indicated in the CIA Factbook.

In order to achieve notable power generation capability, compulsory availability data documentation is crucial. The traditional measures used in reliability evaluation are probabilistic and, consequently they do not provide exact predictions [Richwine, 2003]. They only state averages of past events and chances of future ones by means of most frequent values and long-run averages. These measures that are mostly "factors" (EAF, FOF, UCF) use as their denominator the entire time period being considered (typically one year and above) without regards to whether or not the unit is required to generate [Richwine, 2003]. Commercial Availability is an index 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 generation industry. Thus, it is the quantitative link between readiness objectives and supportability [Romeu, 2010]

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]. When deregulation is fully established, this will require the utility, Independent Power Producer (IPP), National Integrated Power Producers (NIPP) and other Power Producers (perhaps Industrial Power Producers, IND) to bid power competitively at current market rates.

Under the deregulation setting, energy particularly power generation is 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

In this case, the power producer that operates at the lowest cost per kilowatt-hour will thrive in this challenging environment. Following these rationales, the traditional technical measures will become inadequate. This directly thrusts 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].

Hence, high importance is expected to be placed on power plant performance and availability statistics as a baseline for performance and benchmarking. For instance, according to Stein and Cohen (2003), Turbine units more than 25 years in operation face serious threats in view of their remaining lifetime. Even in case of proper operation & maintenance talk less, absence of proper operation & maintenances. The ageing of power plants units leads to higher production cost which presently faces the Nigerian Electricity Generation Industry, mainly due to the following:

- Deration, occasioned by Deterioration of original performance level (output & efficiency) and
- Decline in availability occasioned by increased number and duration of forced outages.

The availability of a complex system, such as a thermal unit (gas and steam), is associated with its parts reliability and maintenance policy [Fernando, 1999]. This may be enhanced by proper recording of failure rates and maintenance frequencies etc. Timely and appropriate recording of these data can help in product improvement by manufacturers (by giving insight on design Improvement) and to identify critical components for improvement to enhance system reliability, availability and maintainability based on a historical failure/ outage database.

This new scenario however highlights the need for systems that will rigorously andconsistently seek to classify outage events using the performance indicators to justify their progress. Consequently, availability performance indicator amongst others becomes indispensable.

II. BACKGROUND OF STUDY

The concept of a power plant is viewed in the light assembly of systems or subsystems to generate electricity, i.e., power with economy and requirements. 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'. Forced outages are not planned or maintenance outages. In practice, "forced outages" represent the risk that a unit's capacity will be affected by limitations beyond a generator's control. An outage (including full outage, partial outage or a failed start) is considered "forced" if the outage cannot reasonably be delayed beyond 48 hours.

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). 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, Force 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].

Generally, from according to IEEE std 762 (2006), loss of generation have been distinguished to be caused by problems within and outside plant management control.

In a deregulated system, competition is indispensible. This necessitates the need for efficient allocation and use of available energy resources and power generation assets; effective scheduling of plant activities, greater use of analytical tools to conduct/ benefit evaluation of proposed activities are changing the industry mindset [André,2007].

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 foundation for performance measurement and benchmarking. Commercial availability accurately reflects more, the present-day market place following the above rationale.

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 another 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 in Nigeria. 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 of generators [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 because it includes all experienced sources of downtime, such as administrative downtime, logistic downtime, etc.

2.1 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 [McDougall, 1999].

This study is meant to improve procedures for estimating performances of generating units and systems of generating units from technical and operational perspective. 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 [Romeu, 2010]. The IEEE std 762 [IEEE Power Engineering Society, 2006] was used for the definitions and formulas.

2.2 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) [McDougall, 1999].

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 [McDougall, 1999]:

- 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.
- Business Critical--Downtime that is often not visible to customers, but does have a significant cost associated with it.
- 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

2.3 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 hence, 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 an “as good as new” condition [Mahmoud, 2000].

In general, all items are assumed to be active. That is, operating unless failed. The exception is would have been standby redundancy, but scarcely exist in the station; this was handled by computer simulation, with output of simple analytical result given.

The results in this paper are based on two fundamental rules for combining probabilities:

a) 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:

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

b) 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 all calculations and computer simulations carried out.

In Javad (2005), like reliability, availability is considered a probability. He 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]:

$$A(t) = P(X(t) = 1) \qquad \text{[1.0]}$$

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:

$A = Limit\ t\to\infty\ A(t)$ ……………………………………………………………..………… [1.1]

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 been proposed. For X(t) =1, if the system is up at time t = 0, system is down [Javad, 2005].

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].

For instance, if a peaking unit was required to generate 100hours per year but experienced forced outages during 25 of those demand hours (and no other outages over the 8760 hours 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%.

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

2.4 Types of Generation Operations

In any good electricity supply environment, power generation for an area must be simple (matrix) mix of three types of generations. Based–Load Generation: This runs continuously to supply the minimum requirements of the area. This type has shock absorbing capabilities. Intermediate Generation: This runs to upgrade day time loads. 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. It is also a unit capability criterion.

2.5 System Availability

The new concept of Availability measurement 'Commercial Availability' or Operational Availability is a measure of the average availability over a period of time and it includes all experienced sources of downtime, such as operations, administrative downtime, logistic downtime, etc. 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. The operational availability is the availability that the customer actually experiences [Grigsby, L.L]. Thus, statistical operational availability is considered here because of its significance.

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 as shown below in Figure 1.

The operational availability is expressed as the ratio of the system uptime and total time.

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

Availability, $A == \frac{Available\ \ Hours}{Period\ \ Hours}\ x\,\frac{100}{1}$

Where Available hours = Period Hours – Forced Outage Hours – Scheduled Outage Hours

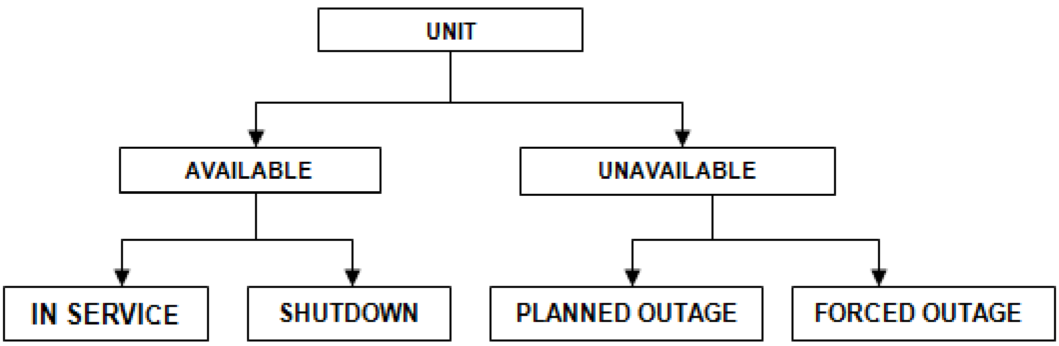


Figure 1: Simple Generation Unit States

2.6 Availability And 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:

- Long–term availability increase as a result of fewer overhauls on the Generators.
- Decrease in post–overhaul failures due to fewer overhauls performed on the system and subsequent overall improvement in Availability.
- 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 means the proportion of time a system is either operating, or is capable of operating, when used in a specific manner in a typical maintenance and supply environment. In summary, 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 also 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" [Romeu, 2010].

It is the degree (expressed as a decimal between 0 and 1, or the percentage equivalent) 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].

2.7 Maintenance Cost Advantage Gain

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 SE, 1995].

2.8 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. Plant equipment availability will also increase because specific repairs could be made without requiring overhauls [Kopman SE, 1995].

To be able manage this process, the availability engineer can handle this by using six standard review processes which includes, Reason for improvement; Definition of problem; careful analysis; Solution projection; Results and process improvement [Kopman SE, 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.

2.9 Sapele Thermal Electric Power Station Historical Background

Sapele Thermal Power Station (Business Unit) witnessed its birth in mid-year of 1978. It is located in the shores of the popular Benin River in Sapele in the defunct Ethiope Local Government Area of Bendel State, Nigeria, now Sapele Local Government Area of Delta State, Nigeria. The thermal station uses both steam and gas turbines. Sapele Thermal Power Station plants consist of six [6No.] 120MW Steam Turbine Unit [with total capacity of 720MW] and four [4No.] 75MW Gas Turbine Units [of total capacity of 300MW]. They were all commissioned in stages between September, 1978 and August, 1981.

The first unit [Steam turbine unit ST01] was commissioned on 12th September, 1978, while the last unit [gas turbine unit GT04] was commissioned on 22nd August, 1981; the total site installed capacity became 1020MW. However, when it was established less than 17 % of the installed capacity was available. Reasons were not given by the station, but assumedly raw materials such as gas could have been responsible.

Sapele power station became the most modern thermal power station in Nigeria, with one of the highest generation capacity and capability in August 1981.

2.10 Sapele Power Station Data Analysis

For Sapele Thermal Power Station, data collected covers the period of 2004 to 2011 in the power station. The data generated were relatively incomplete in some periods under investigation due to lack in plant availability and data report compliance. The data was arranged to suit the ANSI/ IEEE std 762 and also reduced to manageable sizes.

III. SAPELE POWER STATION RAW DATA OUTPUT PARAMETERS RESULTS

Sapele Availability from 2005-2011 =

90.1912	0	0	0	0	88.3229
86.7746	0	0	0	0	87.5342
92.9223	0	0	0	0	0
78.2024	69.8862	0	0	0	0
95.7424	95.0274	0	0	0	0
93.8252	98.7307	0	0	0	0
79.4911	99.1532	0	0	0	0
91.3666	98.6451	65.8249	0	0	0

Sapele Availability Factor from 2005-2011 =

90.1912	0	0	0	0	88.3229
86.7746	0	0	0	0	87.5342
92.9223	0	0	0	0	0
78.2024	69.8862	0	0	0	0
95.7424	95.0274	0	0	0	0
93.8252	98.7307	0	0	0	0
79.4911	99.1532	0	0	0	0
91.3666	98.6451	65.8249	0	0	0

Sapele Equivalent Availability Factor from 2005-2011 =

46.2105	0	0	0	0	59.1700
51.0645	0	0	0	0	65.1504
27.9787	0	0	0	0	0
39.9780	41.5569	0	0	0	0
57.4744	63.4667	0	0	0	0
51.0863	68.3862	0	0	0	0
48.0886	67.1935	0	0	0	0
47.0280	70.4625	49.0269	0	0	0

Sapele Forced Outage Factor from 2005-2011 =

8.2019	0	0	0	0	8.9690
12.2562	0	0	0	0	12.4658
4.6843	0	0	0	0	0
11.3077	28.6380	0	0	0	0
4.2576	2.5912	0	0	0	0
6.1748	1.2693	0	0	0	0
20.5089	0.8468	0	0	0	0
8.6334	1.3549	34.1751	0	0	0

Sapele Service Factor from 2005-2011 =

87.9615	0	0	0	0	87.4583
86.7244	0	0	0	0	85.0585
90.9213	0	0	0	0	0
76.4489	68.7995	0	0	0	0
92.9365	94.6819	0	0	0	0
85.4779	91.0345	0	0	0	0
76.2632	95.8794	0	0	0	0
88.6775	84.5477	63.8300	0	0	0

Sapele Starting Reliability from 2005-2011 =

85.7143	0	0	0	0	83.3333
87.1795	0	0	0	0	97.7778
100.0000	0	0	0	0	0
96.0784	91.6667	0	0	0	0
97.2603	77.5862	0	0	0	0
96.8750	95.4545	0	0	0	0
96.6667	98.9130	0	0	0	0
100.0000	98.4252	90.9091	0	0	0

Sapele Planned Outage Factor from 2005-2011 =

1.6068	0	0	0	0	2.7082
0.9692	0	0	0	0	0
2.3934	0	0	0	0	0
10.4900	1.4757	0	0	0	0
0	2.3813	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

Sapele Capacity Factor from 2005-2011 =

0.5864	0	0	0	0	0.6559
0.6143	0	0	0	0	0.6734
0.5304	0	0	0	0	0
0.5097	0.4873	0	0	0	0
0.6583	0.7101	0	0	0	0
0.5699	0.6828	0	0	0	0
0.5402	0.7191	0	0	0	0
0.5912	0.6341	0.5053	0	0	0

Sapele Forced Outage Rate from 2005-2011 =

8.5292	100.0000	100.0000	100.0000	100.0000	9.3013
12.3824	100.0000	100.0000	100.0000	100.0000	12.7822
4.8996	100.0000	100.0000	100.0000	100.0000	100.0000
12.8853	29.3912	100.0000	100.0000	100.0000	100.0000
4.3805	2.6639	100.0000	100.0000	100.0000	100.0000
6.7372	1.3751	100.0000	100.0000	100.0000	100.0000
21.1930	0.8755	100.0000	100.0000	100.0000	100.0000
8.8720	1.5773	34.8707	100.0000	100.0000	100.0000

Sapele Fp from 2005-2011 =

0.9753	0	0	0	0	0.9902
0.9994	0	0	0	0	0.9717
0.9785	0	0	0	0	0
0.9776	0.9845	0	0	0	0
0.9707	0.9964	0	0	0	0
0.9110	0.9220	0	0	0	0
0.9594	0.9670	0	0	0	0
0.9706	0.8571	0.9697	0	0	0

Sapele EFORD from 2005-2011 =

1.7816	0	0	0	0	3.0662
1.1170	0	0	0	0	0
2.5757	0	0	0	0	0
13.4139	2.1116	0	0	0	0
0	2.5060	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

Sapele Maintenance Outage Factor from 2005-2011 =

0	0	0	0	0	31.9072
0	0	0	0	0	3.5020
0	0	0	0	0	0
0	65.1193	0	0	0	0
53.5515	75.9559	0	0	0	0
88.5155	22.4325	0	0	0	0
60.0482	15.2735	0	0	0	0
20.4318	16.3366	5.8973	0	0	0

3.1 Sapele Graphical Analysis Output Result of Input Data From 2004 – 2011

Fig.2 [a – k]: Graphical Outputs from Analysis Using MATLAB
Fig. 2a: Sapele Service Hours for 2004-2011

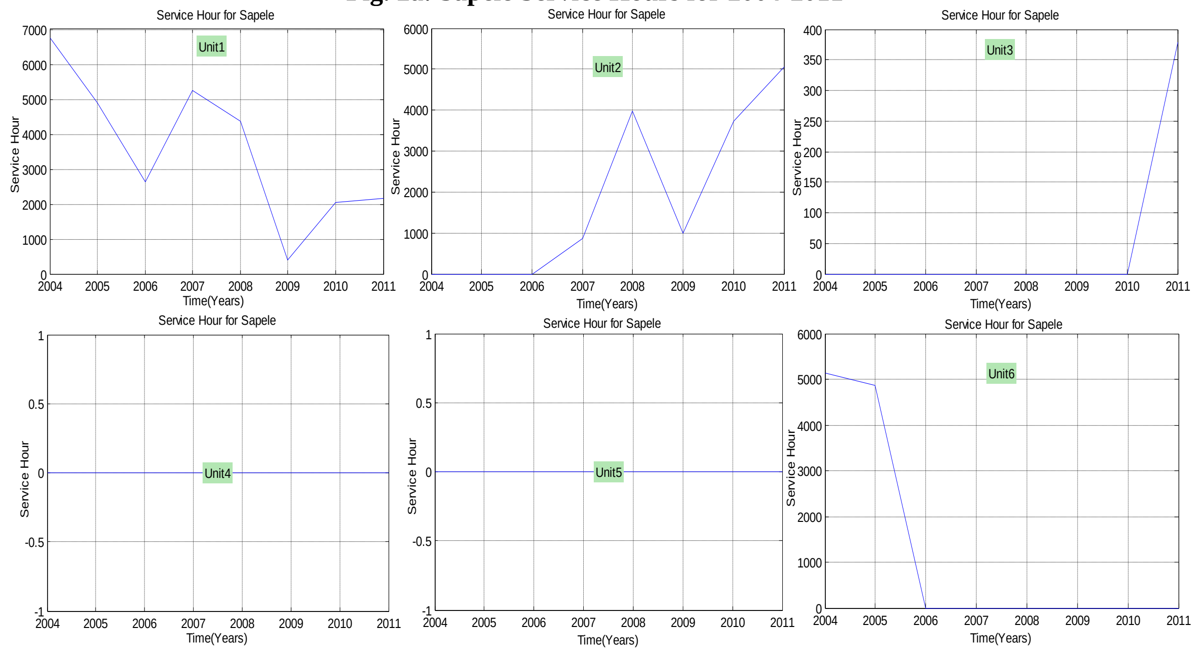


Fig. 2b: Sapele Availability for 2004 - 2011

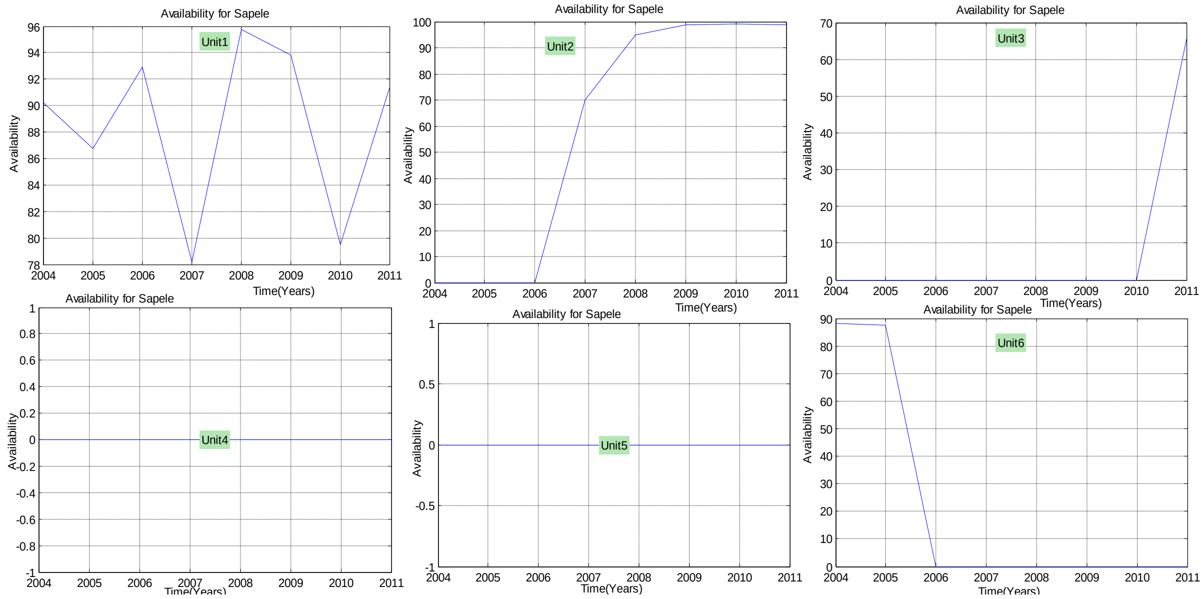


Fig. 2c: Sapele Equivalent Availability for 2004-2011

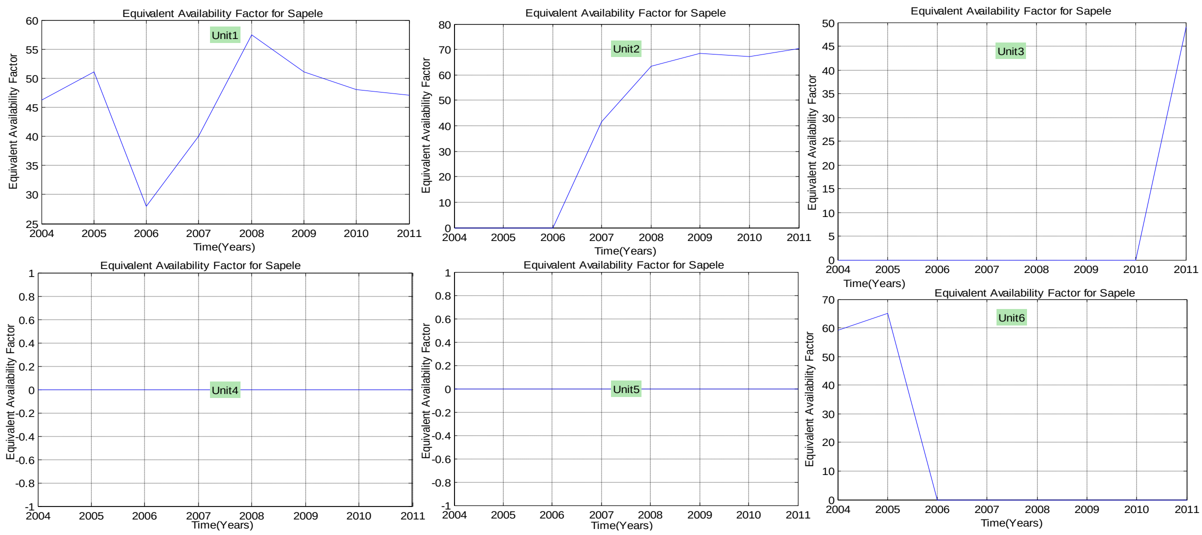


Fig. 2d: Sapele Forced Outage Rate for 2004-2011

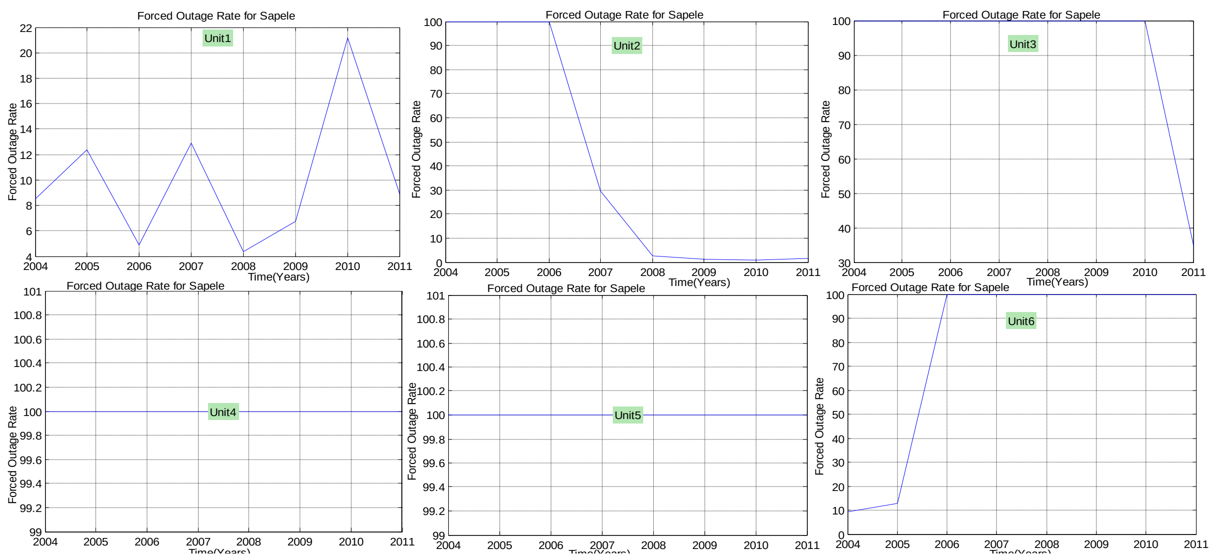
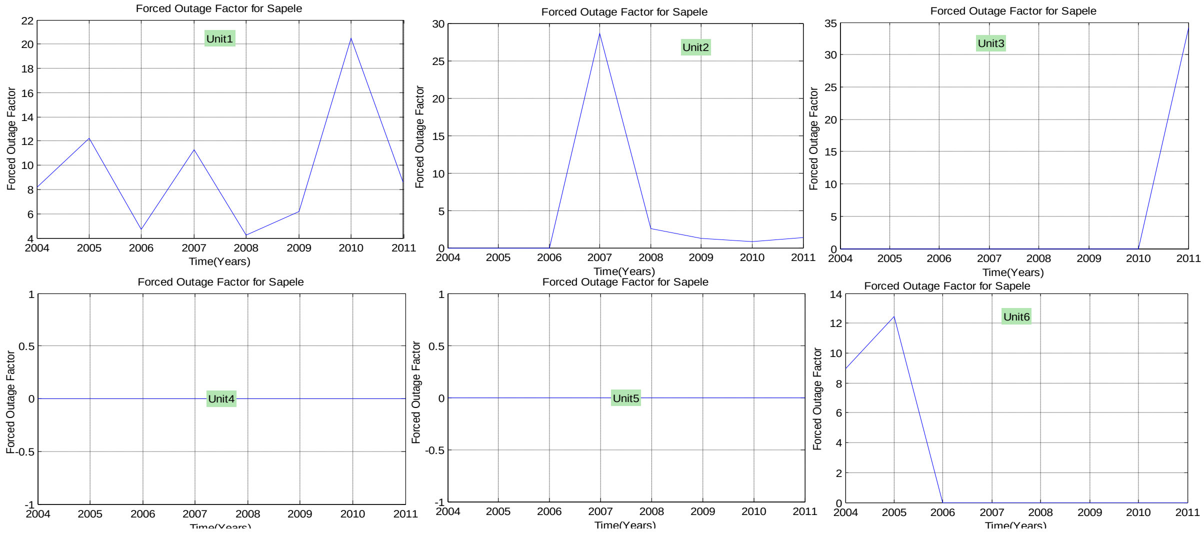


Fig. 2e: Sapele Forced Outage Factor for 2004-2011



3.2 Sapele Power Plant Major Causes of Outage & Unavailability from Outage Data Records

This section summarizes some of the reasons behind the patterns exhibited by the different units' graphs and the major interpretations for the various graphical presentations which includes description and causes of various major outages of the ten generating units (four evaluated) within the period of investigation for Sapele power station. Such Graphical movements as seen are, Increase, Decrease and Plateau etc. some of these events are repetitive for the different units and were summarized. In the graphs, 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). The data outputs and graphs explain the entire characteristics based on the operational records collected from the power station.

Majorly, this section compliments the outage reasons given by the station with the National Control Center, NCC amongst some of the reasons for the outages as detailed below.

For the Gas turbines, the units have been out of service due to the following: GT01 had damaged turbine blade since Sept 1998; GT02 has been forced-out on high compressor vibration problem since December 2003; GT03 has been out of service on forced outage due to generator transformer defective 26/4/90 huge amount of money is required to resume suspended rehabilitation; GT04 has been out on forced outage due to starting equipment failure and generator transformer fault since April 1990, huge amount of money is required to replace damaged generator.

While for the steam turbine units the events causing their outages are: Lack of gas supply, NGC low gas pressure, Routine maintenances, Generator cooling water leakage, False Control Oil pressure low alarm, Generator Differential trip, System Collapse, Differential Fault, Drum Level Problem, Loss of Burners, Generator Rotor earth fault, Poor Vacuum trouble, Low Instrumentation air pressure, Excitation trip fault alarm, HP Heater 5 Cascade to condenser flash box burst, Condensate extraction pump problem, Run delayed by Defective ignition gas pressure regulator, compressor belt fault, Generator air cooler inlet/outlet temperature high-booster pump coupling failure, logic problem, Serious warming up line leakage on BFPs, Burner Failure, Generator protection trip, Economizer inlet valve, burnt Power and Control cables, earth leakages on the Machine, difficulty in putting unit on barring, turbine shaft stiffness, load limiter problem, Unit Transformer on differential lockout, Generator cooling water leakage,

Thrust bearing filter flange oil leakage, turbine governor load limiter fault, Boiler Logic converter tripped, adjustment of labyrinth packing of turbine bearing 4, defective generator breaker, leakages on the D/A vent to condenser & BFP 1A warming up line leakage, Instrument Air Compartment 'D' LP cylinder vibration, Multiple amplifier oil Leakage, Control Oil pressure fault as 1A pump tripped, Throttle Valve D oil leakage, Burner failure, Final super heater outlet temperature alarm, Excitation fault, Loss of CW pumps A and B, AVR trip to manual, Auxiliaries fault, Excessive condensate in the fuel gas system, Transformer on Restricted Ground fault, defective helical spring, High Vibration trouble, Burner B2 Refectory failure repairs problem, Load Swinging, 330kV annunciation cubicle trouble, CT explosion on line S3B, Generator Breaker Leakage, speeder gear trouble, Boiler tube rupture, Negative phase sequences, Turbine thrust bearing oil leakage, Drum manhole and auxiliary steam tap off, FWR (25 - 100)% failure, ST06 did not come back from December 2005 till 2011 under the period of research review due to High Vibration checks.

Table 2: The Averages Overall Summary of Total of all Parameters and Indices for Sapele Power Station

GENERATOR PARAMETERS ANALYSED	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Station Sum	Averages
Availability for 2004-2011	88.56	57.68	8.23	0.00	0.00	21.98	176.46	29.41
Availability Factor for 2004-2011	88.56	57.68	8.23	0.00	0.00	21.98	176.46	29.41
Equivalent Availability for 2004-2011	46.11	38.88	6.13	0.00	0.00	15.54	106.67	17.78
Forced Outage Factor for 2004-2011	9.50	4.34	4.27	0.00	0.00	2.68	20.79	3.47
Service Factor for 2004-2011	85.68	54.37	7.98	0.00	0.00	21.56	169.59	28.26
Starting Reliability for 2004-2011	94.97	57.76	11.36	0.00	0.00	22.64	186.73	31.12
Planned Outage Factor for 2004-2011	1.93	0.48	0.00	0.00	0.00	0.34	2.75	0.46
Capacity Factor for 2004-2011	0.58	0.40	0.06	0.00	0.00	0.17	1.21	0.20
Forced Outage Rate for 2004-2011	9.98	41.99	91.86	0.00	0.00	77.76	221.59	55.40
Partial Forced Outage, Pf for 2004-2011	0.97	0.59	0.12	0.00	0.00	0.25	1.93	0.48
Full Forced Outage for 2004-2011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equiv. Forced Outage Rate Dd 2004-2011	2.36	0.58	0.00	0.00	0.00	0.38	3.32	0.83
Maintenance Factor for 2004-2011	27.82	24.39	0.74	0.00	0.00	4.43	57.37	14.34

IV. SAPELE POWER STATION RESULTS DISCUSSION

Sapele Power station has been confronted by both technical, logistics, administrative and environmental problems these have contributed to the serious unavailability due to forced outages of some of the units over the years. It has had most of its failures related to frequent outages occasioned by, both issues within plant management control and outside plant management control. Majority of the reasons within and without plant management control being are as given in the outage reasons (preceding chapters), such as industrial actions (see previous section). Sapele power station has ten (10) units but only six were considered because the gas turbine units GTs (1 to 4) have been on forced outage before the period considered for the study; so they are completely unavailable (100% unavailable). From the output results from tables presented above, ST01 peaked at 95.74% in 2008 with an average of 88.56%; although ST02 was not available for three years, its percent peak value stood at 99.15% in 2010 while the average percent value was 57.68%. ST03 hardly run throughout this period, except for only one year and stood at 65.82% as its percent value while ST04 and ST05 were not available for service within this period, and ST06 was in service for two years and has availability peaked at 88.32% in 2004 with an average of 21.98%.

Each of the Sapele power plant units had their lowest availability values as thus: ST01 has its low at 78.20% in 2007, while ST02 had its lowest availability for the years it available as 69.89% in 2007 although it was grounded at 0% for the first three years. However, it is difficult to judge on the trend of low availability for ST03 - ST06 because they were relatively all at low throughout the period under review. ST06 only run for two years and had its lowest availability as 87.53% in 2005. On the average, ST01 has the highest value of 88.56% from 2005-2011. Also, the station had its total station average of 44.11% in 2011. Meanwhile, GT01 to GT10 were all unavailable for reasons given above. The Equivalent Availability Factor which indicates that both full forced outage and deratings which characterized all the units has been considered also in the analysis (though a reliability criterion) shows that availability is limited majorly by the same within and outside plant management control events. The graphical results output also followed the same trend for other parameters and indices as seen from the graphical results in the preceding section.

V. FINDINGS

Generally, both the individual availability and the overall availability are low. Results also showed ST01 is the only unit that runs consistently from 2005 to 2011 although data reflects contrary. Total availability value here, is not satisfactory because it could not reach the acceptable availability requirements. From findings, the rosy start and the glorious years of Sapele power station began to decline when the units began to break down one after the other essentially due to management shortcomings in the provision of fund for procurement of necessary spare parts to effect the statutory inspection and maintenance of the Units as at when due. Whereas, major overhaul/ inspection should be carried out after every 25,000 operation hours or three operating years for Steam turbine unit and 16,000 operating hours or two operating years for Gas turbine units, all [Steam or gas turbine units] over-ran their statutory limits before any overhaul was carried out in them. Unit ST05 was first to go out of operation on account of unit transformer failure and extensive damage to the 3.3KV switch gear that occurred on 2nd March, 1986.

Although the unit was first commissioned on 24th April, 1980, it was never overhauled before it went out of operation, even though it had run for about 35,260 hours [as against recommended 25,000 hours]. Study reveals other units began to break down since then and they were not restored to service, to the extent that only two units, [ST01 and ST06] were available for operation between July, 2002 and last quarter of 2005, both of them generating Power at less than 60% installed capacity. One important advantage of Sapele unit turbines is that the units have intermediate sections in addition to Low–and High pressure sections in the internal combustion systems. In a nut shell, the generators have the ability to maneuver its efficiency and could change output power levels quickly. For this reason, recovery of some of the units may be considered unavoidable. In June-July 2009, no unit was running in Sapele thermal power station. This was due to unavailability of Gas supply by the Nigerian Gas Company, (NGC) occasioned by vandalism perpetrated by the restive erstwhile Niger-Delta militants on the national gas pipe line. Summary of the station's operations are shown below in table 3 and 4and they are quite revealing.

The study about Sapele power station whether under horizontal or vertical management structure shows that the power station will need to recover as much lost energy producing capability as possible from its existing generating facilities. In addition to that, the analysis carried out on the outage report data collected from the power station in relation to available capacity and the discussions with several on-hand plant maintenance engineers as well as the rising Nigerian load forecasts suggests same need for capacity recovery. This can be done using the two methods already put forward earlier, which is either through recovering lost capacity or improvement of availability of the capacity being enhanced. When we reconcile these result output values to the parameters and indices definitions and implications on generators (NERC/ IEEE std 762), it becomes clear that majority of the unit generators were obviously not available as and when required. However, for a good and balanced power generation system, the availability requirements should be as proposed as follows:

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.

The fuel supply should have the availability of 99.5% etc.

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 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 each 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 hours for base loads) [WEC, 2004].

However, Equivalent Availability is other indices considered very effective in this regards. Equivalent Availability 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 hours with an equipment limitation at 80% of nominal rated capacity, it would be considered to have accrued 100 Hours x 20% Derating = 20 equivalent derated hours. For operating hours of 100hrs the traditional (time-based) Availability would show as 100%; but, the Equivalent Availability 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.

The evaluation of power plant performance is 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 profit-oriented for plant owners. The causes of unavailability must be thoroughly analysed to identify the areas for generators performance improvement.

This study provides some corresponding levels of potential and cost-effective improvements from the use of performance parameters to improve unit availability. This can be buttressed by using the Richwine model of Electricity Generation Standards to analyse the subject of availability using the illustration below.The goals of the indicators used for this analysis will be a necessary end aimed at providing realistic expectations for this plant in the near term to ensure that they can be achieved without large investment requirements and dramatic rate shocks to the customers. Even though the primary focus here is on power plant reliability, availability, efficiency, other performance indicators were considered for completeness

The above Table 3 gives the total sum summary of the average values of various availability parameters for the six out of seven power stations investigated, where data was collected and analysed for different years span.

From the summary of the overall averages of all indices the following values for various parameters and Indices were found:

For instance, assuming total installed power capacity in the power station within this period under review as 1020MW. On the basis that we consider the total installed capacity of 1020MW. 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.1% improvement in Availability that can be achieved and sustained is equivalent to approximately 12.75 MW of new capacity at 80% availability.

Power Plants Parameters	Average Overall Availability,	Average Equivalent Forced Outage Rate Demand, EFORD	Average Maintenance Outage Factor, MOF	Average Overall Availability Factor, AF	Average Overall Equivalent Availability Factor, EAF	Average Overall Forced Outage Factor, FOF	Average Overall Service Factor, SF	Average Overall Starting Reliability, SR	Average Overall Planned Outage Factor, POF	Average Overall Capacity Factor, CF	Average Overall Forced Outage Rate, FOR	Average Partial Forced Outage Fp	Average Full Forced Outage Factor Ff
Average Station Values	**44.11**	**0.83**	**14.3**	**44.11**	**26.67**	**5.2**	**42.4**	**72.33**	**0.69**	**0.3**	**70.3**	**0**	**0**

Table 3: Summary of Averages of Availability and Performance Parameters and Indices for Sapele Thermal-power Station

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 10.20 MW increase in Available Capacity only if that capacity were 100% available. But for a more realistic availability goal we might chose 80% (considering the average of the running units' availability) so that the 10.2 MW at 100% availability would be equal to 12.75MW at 80% availability (10.2/0.80). 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 12%, then the total equivalent capacity represented by this availability improvement would be 153MW. The assumption of 12% is made based on the inconsistent nature of data available and the performance of their peers in other parts of the world, and considering the unique set of conditions in 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;
$\Longrightarrow$1020MW x $\frac{1}{100}$ = 10.20MW

Then if we consider a realistic availability goal of 80% of the above
10.20MW,
Then, we have: $\frac{10.20}{0.80}$ $\cong$12.75MW
But at 12% achievable & Sustainable Availability;
Will give 12.75 x 12 = 153MW;

The total equivalent capacity represented by this availability will be
= 153MW
By these dispositions, some basic questions with regards to information gathering, data sourcing, collation and analysis toevaluate the inherent energy crisis have been formulated into action statements used to remedial actions to fill some of the existing gaps in the Sapele power station and energy sector in general.

5.1 Summary of Study Findings

The findings of this work should inform further concern about the technical efficiency required to secure Sapele power generation system against the backdrop of present inherent power crisis in Nigeria.

1. From the graphical analysis, there is a trend in virtually all the indices used to evaluate the units.
2. The level of availability in the station cannot complement the expenditures on the plant overheads. For a station of 1020MW capacity giving less than 100MW, the expenditure will far exceed the station's income generated.
3. The power stations operations efficiency departments have utmost disregard for international power generation performance standards, hence crude Key Performance Indices (KPI) are still being used.
4. Incessant outages resulted in the non-availability of the power plants units across the country resulting in gross inadequacy in their results outputs. Forced outage numbers reveals these shortcomings.
5. The core performance elements (availability, efficiency, production costs, and unit flexibility) are not tightly coupled to business objectives amongst the power stations.
6. The outputs results of the major basic operational indices such as availability amongst others are not satisfactory.
7. There is gross inconsistency in data presentation coupled with incoherent and non-uniform presentation of operational activities, particularly in data usage.
8. Maintenance periods were usually overshot (i.e. prolonged maintenance periods) during maintenances. Spare parts unavailability usually prolonged the maintenance durations as well as overhauls.
9. There is a problem of acute derations amongst the entire unit generators in all the power plants in Nigeria, either due to ageing or lack of consistencies in maintenances resulting in natural fatigue.
10. Unavailability due to fuel supply and environmental necessities were increasingly interlinked and has adversely affected the energy generation efficiency and performance.
11. Crude methods of generator performance evaluation and computations are still being used in the station rather than using modern software and programs.
12. Obsolesce power equipment in the power stations is responsible for reduction of power generation index. As majority of the units are above twenty-five (25) years.

5.2 Contributions of study to knowledge

The research study contributes to knowledge in the Nigerian power industry in many ways not limited to the under-listed:

1. A computer software program that can handle large numbers of generating units was developed to compute the performance parameters and indices of generating units in the station.
2. A well-structured standard representation format comparable to international standards for coherent Generation Availability Data presentations and analysis amongst the power generation stations was developed.
3. The results of the study have shown that Nigeria can recover lost capacity generation across the power stations and improve dependable capacity.
4. The development of a cost-effective way to increase medium and long-term generating prospects and energy producing capabilities in Nigeria has been achieved.
5. The study has successfully created a high level of Performance Improvement awareness amongst the power generation management cadet in the station and Nigeria in general.

VI. CONCLUSION AND RECOMMENDATIONS

The inherent energy availability of power generation units in Sapele Thermal-power station 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 station. The study has touched areas of availability likely to be encountered by power plants generation managers in other stations in Nigeria.

As Nigeria welcome on board the new power deregulation policy, it becomes obvious the paper 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 work 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 supply, profitability and sustainability in the station and in Nigeria in general.

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 has 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 IEEE std 762 typical 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 industry. 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.

6.1 Study and Industry Based Recommendations

1. Sapele power station should try and regain the massive lost capacities amongst the individual units by adopting the best industry practices particularly the life extension program. This is necessary in view of the unit above 25-years of operations or those above the operating numbers of running hours and megawatts generation specified for overhaul
2. The Sapele 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 its users.
4. In alignment with other typical industry players, there is need for optimum spare parts management. This will remove the unique problems of controlling and managing spare parts such as element of uncertainty, unavailability, the problem of the number and variety of spare parts being too large making a close control more and more tedious, the tendency that from the stage of purchase of the spare equipment to the stage of the use of the spare parts as well as requisition spare parts are more in number than actually required leading to the accumulation of spare, and finally, the variability of the rate of consumption of different spare parts and etc.
5. Load growth should be monitored locally from the station based on subsequent demand rates and frequency. This will help regulate incidences of system collapses.
6. Sapele plant managers should come out with a tested and trusted blue print in system operations that must be flexible in implementations in the Nigeria contest to guarantee availability of electricity supply.
7. 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. This will improve performance and availability of the plant units and make the plant profit-oriented.
8. 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 guarantee adequate gas supply or other raw materials.
9. There is need to set up a well-equipped effective efficiency department for data collection and analysis using the applicable KPIs and standards. The data collection and monitoring should align with the industry requirement to enable all the power plants harmonize reporting standard and procedure for god planning.
10. The "best practices" in computer database should be developed for use by plant's staff.
11. The plant design Companies 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.
12. Management should endeavour to adhere to international best practice and standards in staff recruitment and rewards and preferred common trainings and good incentives should be given to the entire plant staff.

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