

Kainji Hydro Power Station Generator Availability and Unit Performance Studies

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Abstract – This paper presents investigation on availability carried out on eight hydro-unit generators at Kainji Hydro-Power Station in Nigeria.

The availability investigation 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 also were necessary available sources. This investigation used the NERC/ 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 model all the eight (8) generating units available in the station. The result was used to evaluate performance indices 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. Specific guidelines for higher flexibility in operations through quality assurance procedures and maintenance for the power station was recommended from results output summaries in relation to peerpower stationunits for sustainable power availability. Result shows reduction in plant availability is caused by increased number and duration of forced and maintenance outages as well as prolonged maintenance periods. The causes and durations of forced outages and unscheduled maintenances were identified through the study of outage causes. The investigations ensured quantified comparative analysis for planned and unplanned outages by using results to estimate unit generators' performance. Possible use of a historic failure database to identify critical components for improvement of generating unit availability is demonstrated. The availability and performances results generated by stations values for a period of seven years were: 1G5 = 89%; 1G6= 89.99%; 1G7 =85.24%; 1G8 = 87.45%; 1G9= 86.50%; 1G10 = 29.71%; 1G11 = 29.71%; 1G12 = 29.71% while the overall station units' availability is 88.35%. Although the energy availability level in Nigeria 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.

Keywords – Availability, Generators, Maintenance, Performance, Reliability etc.

I. INTRODUCTION

In Nigeria today, little seems to be known about the theoretical 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 [2]. The new order is requiring new and more appropriate measures that link technical performance with financial results.

The facilitator 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 [2]. 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. In recent past, Nigeria has been referred to as a 'Nation that has Covenant with Darkness' by the Tell Magazine July 27, 2009 [21].

They were not far from the truth as a country with a population of over 140 million people had only 1500MW of electricity to share at that time. This was put at 15.58kW per individual per annum by the Central Intelligence Agency, (CIA 2007 fact book) [20]. That is about 1500MW total generation. Nigeria ranks abysmally low compared to other countries of Africa, as presented by the CIA Factbook [21].

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 [3]. 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 regard to whether or not the unit is required to generate [3]. 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.

The new "deregulated" (horizontal) structure in Nigeria is practically based on market principles, favoring 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, [12]. When fully established, this 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. Following these rationales, the traditional technical measures will become inadequate. 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 [20]:

- 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 hydro turbine unit, is basically associated with its parts reliability and maintenance policy. 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 consistently and rigorously 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 operation of a generating unit requires a coordinated operation of hundreds of individual components [5]. 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. Generally, according to NERC/ IEEE std 762, loss of generation has been distinguished to be caused by problems within and outside plant management control.

In a deregulated system, competition is indispensable. 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 [2].

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 [10].

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 [5].

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 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 [6]. The last sentence seems to be the ‘catch-word’ of the current deregulation exercise. 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 [6].

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 considering the relevance.

III. 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 [23].

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 in this paper, Availability, Reliability and Productivity indices and parameters were evaluated to justify study objectives [24].

IV. AVAILABILITY CALCULATIONS

Availability calculations are used to estimate the availability of components or systems that is repaired after

a failure. A power plant generator is an active component; 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 graph in Figure 1 shows a Component Repaired Immediately after Failure with consequent failures down time.

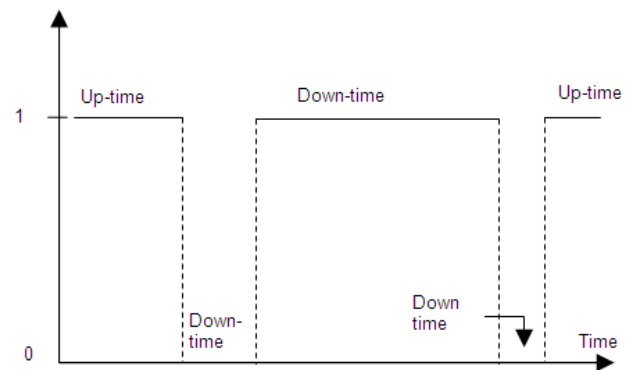


Fig.1. Graph Showing Component is Repaired Immediately after Failure

V. PLANT 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 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 [25]. Thus, statistical operational availability is considered here because of its relevance.

VI. AVAILABILITY AND RELATIONSHIP OF FUNCTIONAL ELEMENTS OF PLANT PERFORMANCE

If we consider the basic elements of plant performance, such as Reliability (Probability that the item will not fail) maintainability (the probability that the item is successfully restored after failure) then additional metric is required for the probability that that the component /system is operational at a given time, (i.e., has not failed or it is has been restored after failure). This metric is availability. This is the only performance criterion for repairable systems that accounts for both the reliability and maintainability properties of a component or system. According to the various formulas there are four time-dependent functional elements directly related to availability and reliability. These are service time (ST),

failure time (FT), maintenance time (MT) and idle time (IT) [25]. Productivity formula has amongst its elements, income and some cost-dependent functionality. All the income and cost-dependent functional elements are covered in the above four time-dependent functional elements.

VII. 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) [23].

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 [23]:

- 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.

VIII. 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 an “as good as new” condition [25].

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:

$$P(AB) = P(A) \cdot P(B)$$

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 [26]:

$$A(t) = P(X(t) = 1) \dots\dots\dots [1.0]$$

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:

$$A = \lim_{t \rightarrow \infty} A(t) \dots\dots\dots [1.1]$$

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 also been proposed. For $X(t) = 1$, if the system is up and at time $t = 0$, system is down [26].

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 [26]. 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 100Hrs/yr 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: $(8760-25)/8760 \times 100 = 99.71\%$ and a FOF and UCLF of $(25)/8760 \times 100 = 0.29\%$ 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:

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

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

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 and 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 as shown in Figure 2.

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:

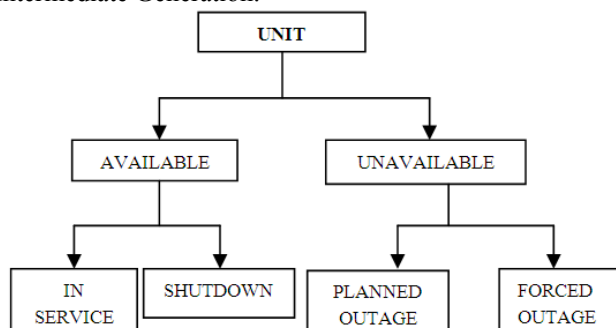


Fig.2. Simple Generation Unit States

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.

IX. ENERGY QUALITY AND AVAILABILITY

In a deregulated power structure, 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 [25].

X. 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 is the quantitative link between readiness objectives and supportability. 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” [24].

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 [24]. 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 [12]. In view of the forgoing, the operating requirements largely depend on reliability, maintainability and availability of the operating units of generators.

XI. MAINTENANCE COST ADVANTAGE

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.

XII. FUEL SAVINGS

According to GADS, the fuel savings that resulted from repairs or modifications accomplished during the overhaul for a particular plant is \$1 million in a year when compared with the time the company started its investigation on optimization of overhaul intervals. To be able manage this process, the availability engineer can handle this by using good standard review processes which includes, objective for improvement; technical definition of problem(s); careful analysis; Solution projection; results and process improvement.

All steps must be supported by facts. In this case, 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 can also be performed to identify all possible causes of events.

XIII. KAINJI HYDRO ELECTRIC POWER STATION HISTORICAL BACKGROUND

The submission of the two reports of survey in 1963 from Netherland Engineering Consultant (NEDECO) and Balfour Beatty Company Ltd, both by ECN and Federal Government led to the construction of Kainji and Jebba Hydro stations respectively.

The report recommended that the first dam be built at Kainji about 102 Kilometers up stream of Jebba. By 1962, Niger Dams Authority (NDA) was instituted by an act of parliament to oversee the proposed Hydro–Electric Station in Kainji. The construction work was contracted to IMPREGILO as major contractor. IMPREGILO is a consortium of three Italian companies: Impresit, Giriola and Lodigiani. Fund for the construction of the dam was

provided by the following governments and international organizations: Federal Government of Nigeria, Government of Netherlands, International Bank for Reconstruction and development, Institute Di CreditoPer le Imprese Di PublicaUtilita, U.K. Export credit Guarantee Department [11].

Construction work on Kainji Dam took off in 1964 and lasted for four years. By 1968, it was ready for commissioning with 4 sets of Kaplan turbines, Units 7, 8, 9 & 10 of 80MW each totaling 320MW. The station was officially commissioned in February 1969. In 1976, two additional sets of Kaplan turbine, Units 11 & 12 of 100MW each were installed, bringing the installed capacity of the station to 520MW. To further increase the installed capacity, two additional sets of fixed blade or base load machines were installed, Units 5 & 6 of 120MW each, making the total installed capacity of the station to be 760MW in 1978. For convenient hydrological operation, River Niger is divided into Upper Niger, Middle Niger and Lower Niger. Kainji Dam is located on the middle Niger. At this area, it is fed by many tributaries such as R. Malando, R. Danzaki and R. Sokoto/ Rima etc. Kainji reservoir experiences two dual flood regimes, i.e. Black and white floods. Back water effect of the reservoir can be felt as far back as Kawara Village after Yauri in Kebbi State. Measurement of rise and fall of Lake Elevation on daily basis is a hydrological priority. The station steps up voltage from 16kv to 330kV to the National grid. Electricity is transmitted from the transformer deck through 6 x 330kV lines to the switch yard. Each line at the switch yard has Sf6 breaker to break circuit when there is fault. Units 1, 2, 3, & 4 are open pits fervently awaiting the installations of additional four machines to beef up power generation [11].

XIV. TYPES OF GENERATION OPERATION

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.

However, 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. It is also a unit capability criterion.

XV. KAINJI 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 Kainji hydro-Power station rearranged, yielded the data used for MATLAB analysis. Some of the data are as presented below:

I. KAINJI DATA (2004-2010)

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%=====
%AH = input ('Enter Available Hours = ');
AH2004 = [0.00 4071.53 6556.17 4098.97 7543.31 7392.60 7079.08 1783.12];
AH2005 = [0.00 3882.77 5852.37 727.20 7026.53 6909.90 5281.13 4801.00];
AH2006 = [0.00 4585.35 5353.24 1554.00 3624.50 5972.25 6627.00 3815.63];
AH2007 = [0.00 4160.53 5308.23 7116.70 5350.58 6256.82 4895.53 3783.87];
AH2008 = [0.00 5536.72 261.00 6519.42 6571.12 4689.18 5824.02 5245.87];
AH2009 = [0.00 5152.26 0.00 6368.18 5749.81 5809.80 3503.08 5795.79];
AH2010 = [0.00 5011.86 0.00 5555.63 4910.83 3066.89 5846.13 5720.65];
AH_Kainji = [AH2004; AH2005; AH2006; AH2007; AH2008; AH2009; AH2010];
%=====
%PH = input ('Enter Period Hours = ');
PH2004 = [0.00 5837.35 6968.70 5998.10 7654.56 7597.10 7312.00 3123.00];
PH2005 = [0.00 4136.80 6104.20 3385.00 7498.90 7208.00 5691.00 4237.50];
PH2006 = [0.00 4776.85 6687.10 1564.00 4983.30 6292.50 6976.90 4571.20];
PH2007 = [0.00 5165.30 5424.10 7354.20 5665.21 6892.49 5323.76 4167.20];
PH2008 = [0.00 5765.40 1906.83 6845.22 7463.90 6873.70 6345.78 6004.80];
PH2009 = [0.00 5731.10 0.00 6753.00 6633.30 7487.90 3847.00 6732.90];
PH2010 = [0.00 5471.30 0.00 6230.00 5318.00 4295.10 6367.03 6829.60];
PH_Kainji = [PH2004; PH2005; PH2006; PH2007; PH2008; PH2009; PH2010];
%=====
%AG = input ('Enter Available Generation = ');
AG2004 = [0.00 671295.25 550527.30 467851.80 497546.40 417840.50 658080.00 281070.00];
AG2005 = [0.00 475732.00 488336.00 270800.00 487428.50 396440.00 557718.00 381375.00];
AG2006 = [0.00 535007.20 514906.70 123556.00 323914.50 440475.00 558152.00 388552.00];
AG2007 = [0.00 614670.70 417655.70 580981.80 368238.65 379086.95 521728.48 354212.00];
AG2008 = [0.00 680317.20 148732.74 540772.38 485153.50 446790.50 621886.73 540432.00];
AG2009 = [0.00 676269.80 0.00 533487.00 431164.50 524153.00 346230.00 605961.00];
AG2010 = [0.00 629199.50 0.00 467250.00 345670.00 214755.00 604867.85 614664.00];
AG_Kainji = [AG2004; AG2005; AG2006; AG2007; AG2008; AG2009; AG2010];
%=====
%MG = input ('Enter Maximum Generation = ');
MG2004 = [1051200.00 1051200.00 700800.00 700800.00 700800.00 700800.00 876000.00 876000.00];
MG2005 = [1051200.00 1051200.00 700800.00 700800.00 700800.00 700800.00 876000.00 876000.00];
MG2006 = [1051200.00 1051200.00 700800.00 700800.00 700800.00 700800.00 876000.00 876000.00];
MG2007 = [1051200.00 1051200.00 700800.00 700800.00 700800.00 700800.00 876000.00 876000.00];
MG2008 = [1051200.00 1051200.00 700800.00 700800.00 700800.00 700800.00 876000.00 876000.00];
MG2009 = [1051200.00 1051200.00 700800.00 700800.00 700800.00 700800.00 876000.00 876000.00];
MG2010 = [1051200.00 1051200.00 700800.00 700800.00 700800.00 700800.00 876000.00 876000.00];
MG_Kainji = [MG2004; MG2005; MG2006; MG2007; MG2008; MG2009; MG2010];
%=====
ESDH_Kainji = zeros (7, 8);
%=====
RSH_Kainji = zeros (7, 8);
%=====
EFPOH_Kainji = zeros (7, 8);
%=====
%EUNDH = input ('Enter EUNDH = ');
EUNDH2004 = [0.00 168.08 82.46 103.52 1726.05 3297.46 763.73 123.99];
EUNDH2005 = [0.00 168.55 0.00 0.00 1616.91 3124.98 106.42 352.45];
EUNDH2006 = [0.00 289.06 207.43 19.20 828.29 807.38 1650.52 470.50];
EUNDH2007 = [0.00 34.22 200.11 76.95 1220.98 2800.23 99.28 616.45];
EUNDH2008 = [0.00 80.29 2.65 81.54 1460.82 1080.49 107.42 478.34];
EUNDH2009 = [0.00 216.72 0.00 83.63 941.67 344.82 640.39 843.76];
EUNDH2010 = [0.00 215.05 0.00 355.91 633.56 1799.17 279.35 616.29];
EUNDH_Kainji = [EUNDH2004; EUNDH2005; EUNDH2006; EUNDH2007; EUNDH2008; EUNDH2009; EUNDH2010];
%=====
%FOH = input ('Enter Forced Outage Hours = ');
FOH2004 = [8760.00 1664.68 375.97 1895.42 81.78 148.18 203.35 1155.23];
FOH2005 = [8760.00 244.13 212.19 3618.38 452.45 207.20 296.30 4423.43];
FOH2006 = [8760 181.33 1282.96 7507.27 599.10 223.45 330.80 728.20];
FOH2007 = [8760 905.00 86.32 112.63 227.68 533.23 331.68 380.07];
FOH2008 = [8760 184.00 405.82 316.70 683.07 2035.92 509.43 300.40];
FOH2009 = [8760 428.68 8760.00 312.62 797.89 1032.65 300.54 724.21];
FOH2010 = [8760.00 397.97 8760.00 671.85 271.20 1128.37 404.08 1049.61];
FOH_Kainji = [FOH2004; FOH2005; FOH2006; FOH2007; FOH2008; FOH2009; FOH2010];

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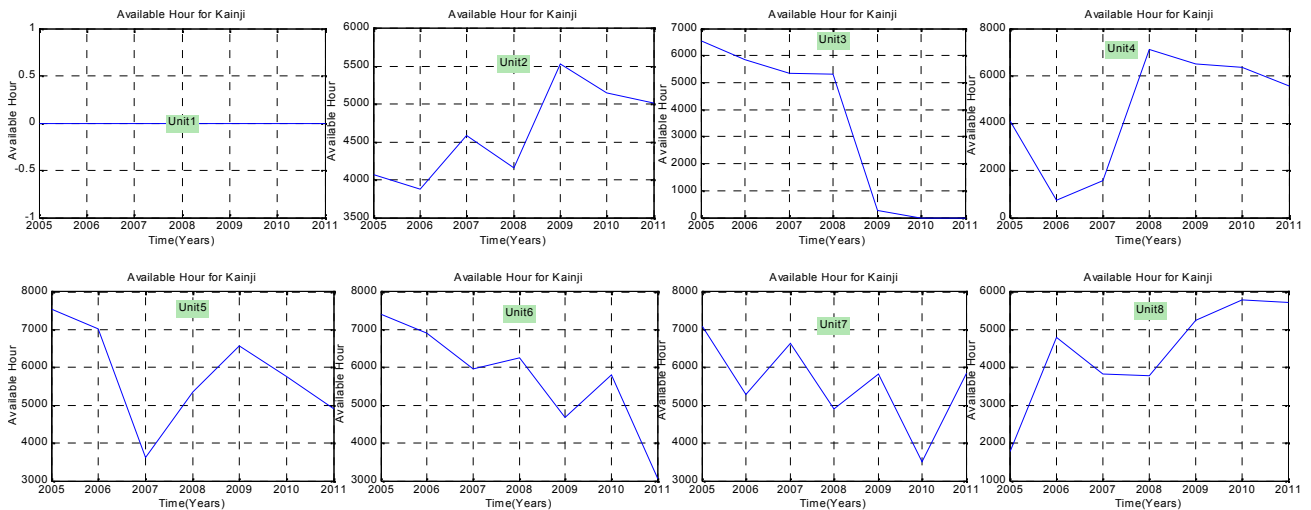
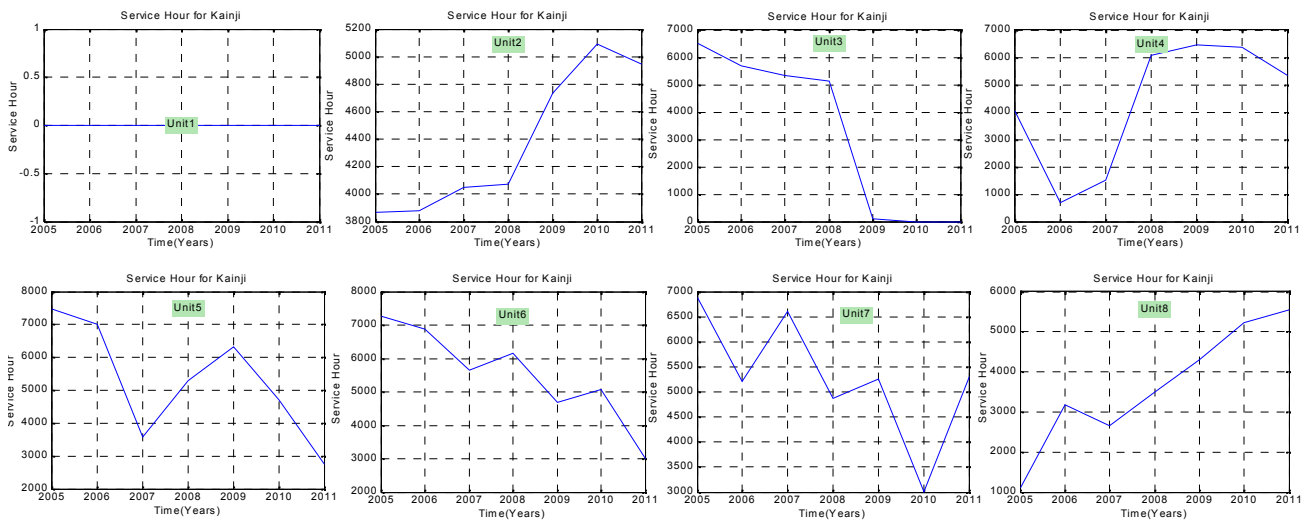
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=====
%SH = input ('Enter Service Hours = ');
SH2004 = [0.00 3865.82 6514.37 4037.21 7479.57 7254.42 6873.59 1115.89];
SH2005 = [0.00 3876.54 5698.92 689.18 7006.60 6874.96 5214.71 3172.07];
SH2006 = [0.00 4046.85 5323.92 1516.77 3589.25 5651.63 6602.06 2666.15];
SH2007 = [0.00 4072.50 5136.24 6078.95 5290.89 6160.51 4864.64 3493.22];
SH2008 = [0.00 4737.23 103.17 6441.96 6330.20 4682.14 5263.37 4305.07];
SH2009 = [0.00 5092.92 0.00 6356.05 4708.35 5068.91 3009.86 5231.30];
SH2010 = [0.00 4946.07 0.00 5338.61 2745.43 2998.62 5307.56 5546.61];
SH_Kainji = [SH2004; SH2005; SH2006; SH2007; SH2008; SH2009; SH2010];
=====
%SS = input ('Enter Starting Successes = ');
SS2004 = [0 45 50 44 50 45 42 18];
SS2005 = [0 37 36 16 46 21 14 15];
SS2006 = [0 27 64 42 47 55 55 35];
SS2007 = [0 27 64 42 47 55 55 35];
SS2008 = [0 30 5 72 89 70 57 34];
SS2009 = [0 46 0 75 73 143 40 61];
SS2010 = [0 32 0 77 51 52 80 70];
SS_Kainji = [SS2004; SS2005; SS2006; SS2007; SS2008; SS2009; SS2010];
=====
%SA = input ('Enter Start Attempts = ');
SA2004 = [0 47 54 45 50 48 45 24];
SA2005 = [0 39 41 16 49 28 19 24];
SA2006 = [0 29 67 42 50 59 56 35];
SA2007 = [0 35 40 41 55 78 46 12];
SA2008 = [0 31 5 72 91 72 58 34];
SA2009 = [0 47 0 76 75 147 47 62];
SA2010 = [0 32 0 80 52 53 83 72];
SA_Kainji = [SA2004; SA2005; SA2006; SA2007; SA2008; SA2009; SA2010];
=====
%POH = input ('Enter Planned Outage Hours = ');
POH2004 = [0.00 101.13 36.57 3.72 29.47 56.32 29.57 184.65];
POH2005 = [0.00 9.90 39.63 1898.03 19.92 90.90 113.57 22.23];
POH2006 = [0.00 10.17 50.90 391.32 759.70 96.80 19.10 27.37];
POH2007 = [0.00 99.77 29.55 124.87 86.95 102.43 96.55 3.27];
POH2008 = [0.00 44.68 0.00 9.10 209.72 148.60 12.33 458.53];
POH2009 = [0.00 150.16 0.00 72.20 85.60 645.45 43.38 212.90];
POH2010 = [0.00 61.47 0.00 2.52 135.97 99.85 116.82 59.33];
POH_Kainji = [POH2004; POH2005; POH2006; POH2007; POH2008; POH2009; POH2010];
=====
%MWH = input ('Enter Megawatt Hour Produced = ');
MWH2004 = [0.00 444569.00 514635.00 314902.00 486172.00 398993.00 618623.00 100430.00];
MWH2005 = [0.00 445802.00 455913.60 55134.00 455429.00 378123.00 511041.75 285486.00];
MWH2006 = [0.00 453247.00 409941.58 119825.10 233301.00 395614.00 528165.15 226622.65];
MWH2007 = [0.00 484628.00 395490.30 480237.00 343908.00 338828.00 476734.40 296924.00];
MWH2008 = [0.00 558993.00 8047.00 508915.00 411463.00 304339.00 515810.00 387456.00];
MWH2009 = [0.00 600964.00 0.00 502128.00 306043.00 354824.00 270887.00 470817.00];
MWH2010 = [0.00 568798.00 0.00 400396.00 178453.00 149931.00 504218.00 499195.00];
MWH_Kainji = [MWH2004; MWH2005; MWH2006; MWH2007; MWH2008; MWH2009; MWH2010];
=====
%NPC = input ('Enter Nameplate Capacity = ');
NPC2004 = [120 120 80 80 80 80 100 100];
NPC2005 = [120 120 80 80 80 80 100 100];
NPC2006 = [120 120 80 80 80 80 100 100];
NPC2007 = [120 120 80 80 80 80 100 100];
NPC2008 = [120 120 80 80 80 80 100 100];
NPC2009 = [120 120 80 80 80 80 100 100];
NPC2010 = [120 120 80 80 80 80 100 100];
NPC_Kainji = [NPC2004; NPC2005; NPC2006; NPC2007; NPC2008; NPC2009; NPC2010];
=====
%FON = input ('Enter Forced Outage Number = ');
FON2004 = [0 28 57 44 38 39 43 36];
FON2005 = [0 30 42 14 36 42 44 29];
FON2006 = [0 32 79 33 42 48 51 37];
FON2007 = [0 31 24 31 40 40 31 14];
FON2008 = [0 28 5 71 80 54 56 29];
FON2009 = [0 38 0 70 62 96 32 50];
FON2010 = [0 30 0 77 38 40 75 67];
FON_Kainji = [FON2004; FON2005; FON2006; FON2007; FON2008; FON2009; FON2010];
=====
%RUNCAP = input ('Enter Running Capacity = ');
RC2004 = [0 115 79 78 65 55 90 90];
RC2005 = [0 115 80 80 65 55 98 90];
RC2006 = [0 112 77 79 65 70 80 85];
RC2007 = [0 119 77 79 65 55 98 85];

```

```

RC2008 = [0 118 78 79 65 65 98 90];
RC2009 = [0 118 78 79 65 70 90 90];
RC2010 = [0 115 0 75 65 50 95 90];
RC_Kainji = [RC2004; RC2005; RC2006; RC2007; RC2008; RC2009; RC2010];
%=====
%FAILEDSTART = input ('Enter Failed Starts = ');
FS2004 = [0 2 4 1 5 3 3 6];
FS2005 = [0 2 4 1 5 7 6 12];
FS2006 = [0 2 3 0 3 4 1 0];
FS2007 = [0 2 2 1 5 7 0 1];
FS2008 = [0 1 0 0 2 2 1 0];
FS2009 = [0 1 0 1 2 2 0 1];
FS2010 = [0 0 0 3 1 1 3 2];
FS_Kainji = [FS2004; FS2005; FS2006; FS2007; FS2008; FS2009; FS2010];
%=====
    
```



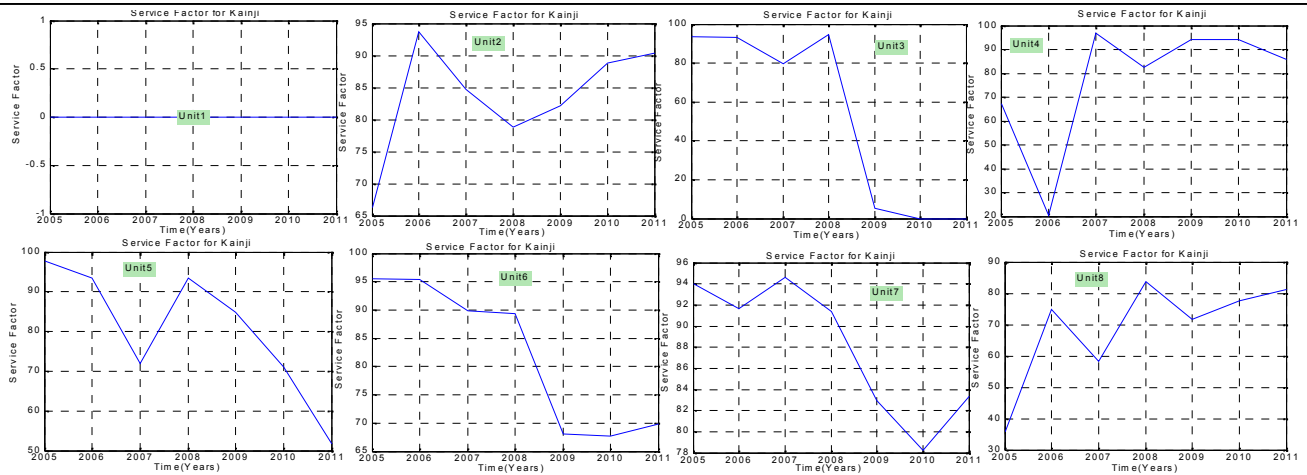


Fig.3. Kainji Service Factor for 2005-2011

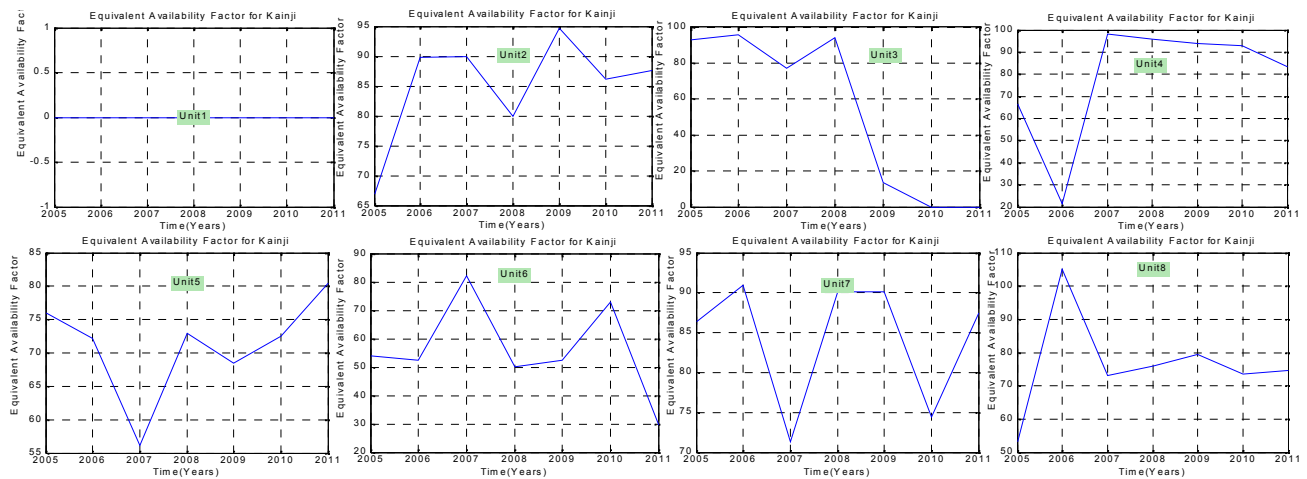


Fig. 4. Kainji Equivalent Availability Factor for 2005-2011

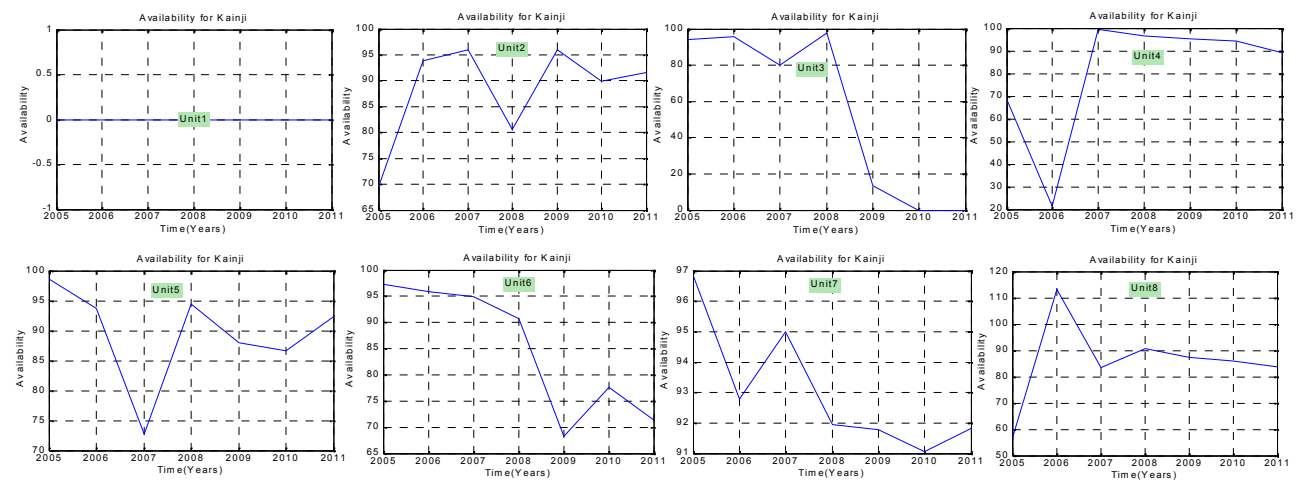


Fig.5. Kainji Availability for 2005-2011

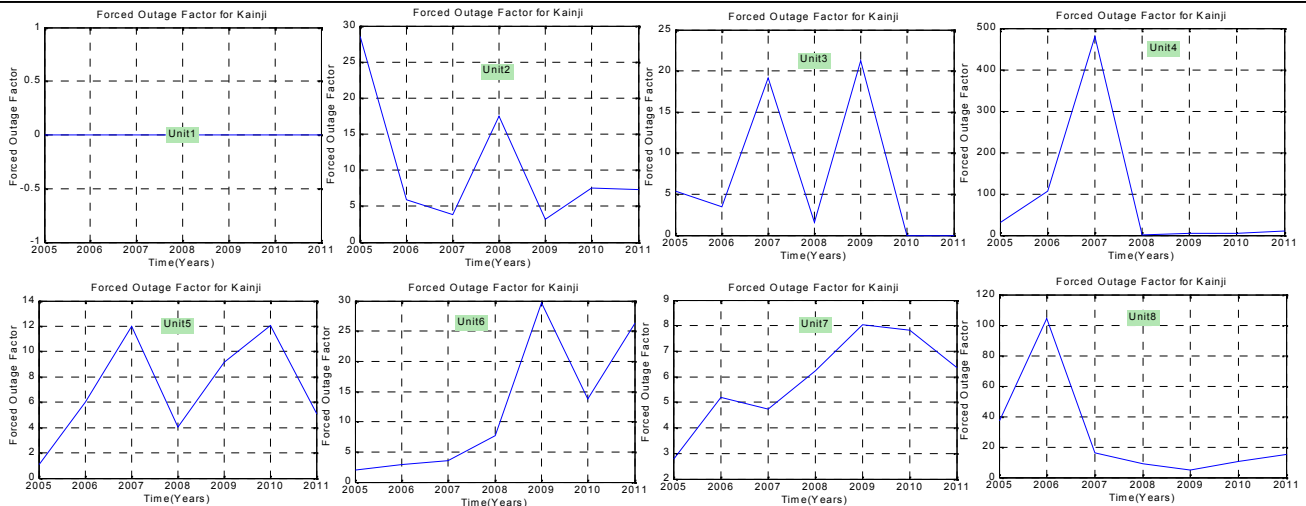


Fig.6. Kanji Forced Outage Rate for 2005-2011

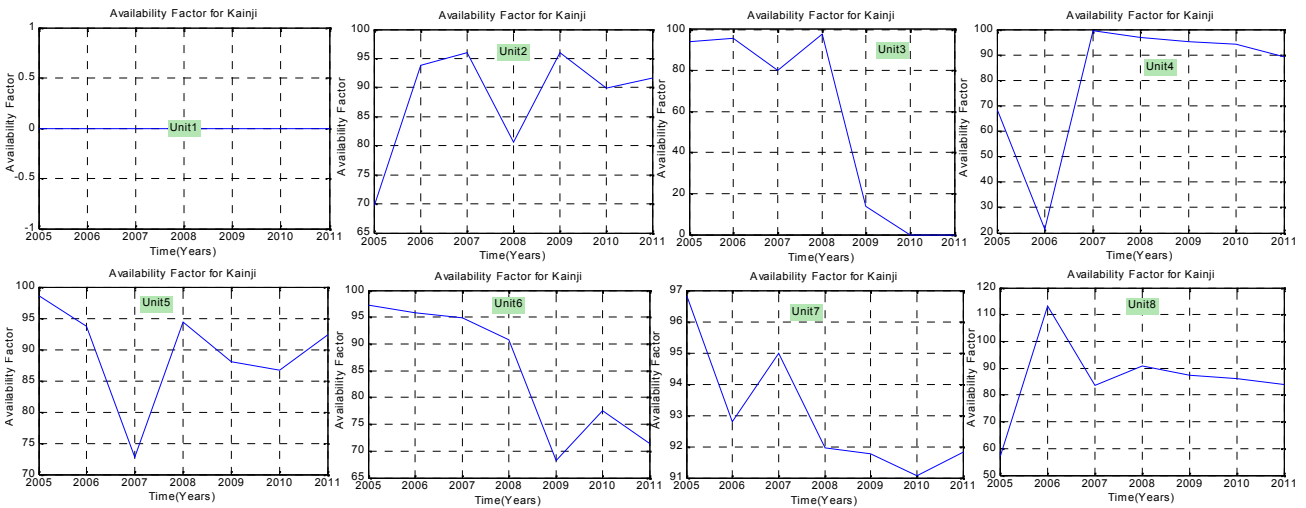


Fig.7. Kanji Availability Factor for 2005-2011

XVI. DETAILED SUMMARY OF KAINJI OUTPUT DATA AND THEIR AVERAGES

Table 1: Kainji Availability from 2005-2011

Years	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit12	Units Sum	Station Unit Ave.								
2004	0	69.7496	94.0802	68.3378	98.5466	97.3082	96.8146	57.0964	581.9334	83.13								
2005	0	93.8593	95.8745	21.483	93.7008	95.8643	92.7979	113.298	606.8777	86.70								
2006	0	95.9911	80.0532	99.3606	72.7329	94.9106	94.9849	83.4711	621.5044	88.79								
2007	0	80.5477	97.8638	96.7706	94.4463	90.7774	91.9562	90.8013	643.1633	91.88								
2008	0	96.0336	13.6876	95.2405	88.0387	68.2192	91.7778	87.3613	540.3587	77.19								
2009	0	89.9	0	94.3015	86.681	77.5892	91.06	86.0816	525.6133	75.09								
2010	0	91.6027	0	89.1754	92.3436	71.4044	91.8188	83.7626	520.1075	74.30								
Summation of Individual Unit for Eight year Span									Units Sum	Station Unit Ave.								
									0	617.68	381.559	564.6694	626.49	596.0733	651.210	601.8722		
									0.00	88.24	54.51	80.67	89.50	85.15	93.03	85.98	577.08	96.18

Table 2: Kanji AvailabilityFactor from 2005-2011

Years	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit12	Units Sum	Station Unit Ave.
2004	0	69.7496	94.0802	68.3378	98.5466	97.3082	96.8146	57.0964	581.933	83.13
2005	0	93.8593	95.8745	21.483	93.7008	95.8643	92.7979	113.298	606.878	86.70
2006	0	95.9911	80.0532	99.3606	72.7329	94.9106	94.9849	83.4711	621.504	88.79
2007	0	80.5477	97.8638	96.7706	94.4463	90.7774	91.9562	90.8013	643.163	91.88
2008	0	96.0336	13.6876	95.2405	88.0387	68.2192	91.7778	87.3613	540.359	77.19
2009	0	89.9	0	94.3015	86.681	77.5892	91.06	86.0816	525.613	75.09

2010	0	91.6027	0	89.1754	92.3436	71.4044	91.8188	83.7626	520.108	74.30
Summation of Individual Unit for Eight year Span									Units Sum	Station Unit Ave.
	0	617.684	381.5593	564.669	626.489	596.073	651.210	601.872		
	0.00	88.24	54.51	80.67	89.50	85.15	93.03	85.98	577.08	96.18

Table 3: Kainji Equivalent Availability Factor from 2005-2011

Years	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit12	Units Sum	Station Unit Ave.
2004	0	89.9398	76.9513	98.133	56.1116	82.0798	71.328	73.1784	547.7219	78.25
2005	0	89.7849	95.8745	21.483	72.1388	52.51	90.928	104.981	527.6997	75.39
2006	0	66.8702	92.897	66.6119	75.9973	53.904	86.3697	53.1262	495.7763	70.83
2007	0	79.8852	94.1745	95.7242	72.894	50.1501	90.0914	76.0084	558.9278	79.85
2008	0	94.641	13.5487	94.0493	68.4669	52.5	90.0851	79.3953	492.6863	70.38
2009	0	86.1185	0	93.0631	72.4849	72.9841	74.4136	73.5497	472.6139	67.52
2010	0	87.6722	0	83.4626	80.43	29.5155	87.4313	74.7388	443.2504	63.32
Summation of Individual Unit for Eight year Span									Units Sum	Station Unit Ave.
	0	594.912	373.446	552.5271	498.524	393.644	590.6471	534.977		
	0.00	84.99	53.35	78.93	71.22	56.23	84.38	76.43	505.53	84.25

Table 4: Kanji Forced Outage Factor from 2005-2011

Years	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit12	Units Sum	Station Unit Ave.
2004	0	28.5177	5.3951	31.6003	1.0684	1.9505	2.781	36.991	108.304	15.47
2005	0	5.9014	3.4761	106.895	6.0336	2.8746	5.2065	104.388	234.774	33.54
2006	0	3.796	19.1856	480.005	12.0222	3.5511	4.7414	15.9302	539.231	77.03
2007	0	17.5208	1.5914	1.5315	4.0189	7.7364	6.2302	9.1205	47.7497	6.82
2008	0	3.1915	21.2824	4.6266	9.1516	29.619	8.0279	5.0027	80.9017	11.56
2009	0	7.4799	0	4.6293	12.0286	13.7909	7.8123	10.7563	56.4973	8.07
2010	0	7.2738	0	10.7841	5.0997	26.2711	6.3464	15.3685	71.1436	10.16
Summation of Individual Unit for Eight year Span									Units Sum	Station Unit Ave.
	0	73.6811	50.9306	640.071	49.423	85.7936	41.1457	197.557		
	0.00	10.53	7.28	91.44	7.06	12.26	5.88	28.22	162.66	27.11

Table 5: Kanji Service Factor from 2005-2011

Years	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit12	Units Sum	Station Unit Ave.
2004	0	82.1665	5.4106	94.1089	84.8109	68.1167	82.9428	71.6938	489.2502	69.89
2005	0	78.8434	94.6929	82.6596	93.3927	89.38	91.376	83.8266	614.1712	87.74
2006	0	84.718	79.6148	96.9802	72.0256	89.8153	94.6274	58.3249	576.1062	82.30
2007	0	93.7087	93.3606	20.3598	93.435	95.3796	91.6308	74.8571	562.7316	80.39
2008	0	66.2256	93.4804	67.3081	97.7139	95.4893	94.0042	35.7313	549.9528	78.56
2009	0	88.8646	0	94.1219	70.9805	67.6947	78.2391	77.6976	477.5984	68.23
2010	0	90.4003	0	85.692	51.6252	69.8149	83.3601	81.2143	462.1068	66.02
Summation of Individual Unit for Eight year Span									Units Sum	Station Unit Ave.
	0	584.927	366.559	541.2305	563.984	575.6905	616.180	483.35		
	0.00	83.56	52.37	77.32	80.57	82.24	88.03	69.05	533.13	88.86

Table 6: Kanji Starting Reliability from 2005-2011

Years	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit12	Units Sum	Station Unit Ave.
2004	0	95.7447	92.5926	97.7778	100	93.75	93.3333	75	648.198	92.60
2005	0	94.8718	87.8049	100	93.8776	75	73.6842	62.5	587.739	83.96
2006	0	93.1034	95.5224	100	94	93.2203	98.2143	0	574.06	82.01
2007	0	77.1429	160	102.439	85.4545	70.5128	119.565	291.667	906.781	129.54
2008	0	96.7742	100	100	97.8022	97.2222	98.2759	0	590.075	84.30
2009	0	97.8723	0	98.6842	97.3333	97.2789	85.1064	98.3871	574.662	82.09
2010	0	100	0	96.25	98.0769	98.1132	96.3855	97.2222	586.048	83.72
Summation of Individual Unit for Eight year Span									Units Sum	Station Unit Ave.
	0	655.509	535.9199	695.151	666.545	625.097	664.565	624.776		
	0.00	93.64	76.56	99.31	95.22	89.30	94.94	89.25	638.22	91.17

Table 7: Kanji Planned Outage Factor from 2005-2011

Years	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit12	Units Sum	Station Unit Ave.
2004	0	1.7325	0.5248	0.062	0.385	0.7413	0.4044	5.9126	9.7626	1.39
2005	0	0.2393	0.6492	56.0718	0.2656	1.2611	1.9956	0.5246	61.0072	8.72
2006	0	0.2129	0.7612	25.0205	15.2449	1.5383	0.2738	0.5987	43.6503	6.24

2007	0	1.9315	0.5448	1.6979	1.5348	1.4861	1.8136	0.0785	9.0872	1.30							
2008	0	0.775	0	0.1329	2.8098	2.1619	0.1943	7.6361	13.71	1.96							
2009	0	2.6201	0	1.0692	1.2905	8.6199	1.1276	3.1621	17.8894	2.56							
2010	0	1.1235	0	0.0404	2.5568	2.3247	1.8348	0.8687	8.7489	1.25							
Summation of Individual Unit for Eight year Span									Units Sum	Station Unit Ave.							
0									8.6348	2.48	84.0947	24.0874	18.1333	7.6441	18.7813		
0.00									1.23	0.35	12.01	3.44	2.59	1.09	2.68	23.41	3.90

Table 8: Kanji Capacity Factor from 2005-2011

Years	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit12	Units Sum	Station Unit Ave.							
2004	0	0.6347	0.9231	0.6563	0.7939	0.6565	0.846	0.3216	4.8321	0.69							
2005	0	0.898	0.9336	0.2036	0.7592	0.6557	0.898	0.6737	5.0218	0.72							
2006	0	0.7907	0.7663	0.9577	0.5852	0.7859	0.757	0.4958	5.1386	0.73							
2007	0	0.7819	0.9114	0.8163	0.7588	0.6145	0.8955	0.7125	5.4909	0.78							
2008	0	0.808	0.0528	0.9293	0.6891	0.5534	0.8128	0.6452	4.4906	0.64							
2009	0	0.8738	0	0.9295	0.5767	0.5923	0.7042	0.6993	4.3758	0.63							
2010	0	0.8663	0	0.8034	0.4195	0.4363	0.7919	0.7309	4.0483	0.58							
Summation of Individual Unit for Eight year Span									Units Sum	Station Unit Ave.							
0									5.6534	3.5872	5.2961	4.5824	4.2946	5.7054	4.279		
0.00									0.81	0.51	0.76	0.65	0.61	0.82	0.61	4.77	0.80

Table 9: Kanji Forced Outage Rate from 2005-2011

Years	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit12	Units Sum	Station Unit Ave.							
2004	0	30.1	5.4565	31.9491	1.0816	2.0017	2.8734	50.8661	124.3284	17.76							
2005	0	5.9245	3.5897	84.0007	6.0658	2.9257	5.3765	58.2375	166.1204	23.73							
2006	0	4.2886	19.4185	83.1919	14.304	3.8034	4.7715	21.4533	151.2312	21.60							
2007	0	18.1818	1.6528	1.8191	4.1257	7.9661	6.383	9.8126	49.9411	7.13							
2008	0	3.7389	79.7304	4.6858	9.7397	30.3052	8.8247	6.5227	143.5474	20.51							
2009	0	7.7637	100	4.6879	14.4907	16.9244	9.0787	12.1603	165.1057	23.59							
2010	0	7.447	100	11.178	8.9902	27.3412	7.0747	15.9123	177.9434	25.42							
Summation of Individual Unit for Eight year Span									Units Sum	Station Unit Ave.							
0									77.4445	309.848	221.5125	58.7977	91.2677	44.3825	174.9648		
0.00									11.06	44.26	31.64	8.40	13.04	6.34	24.99	139.75	23.29

Table 10: Kainji (Partial Forced outage)Fp from 2005-2011

Years	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit12	Units Sum	Station Unit Ave.							
2004	0	0.9495	0.9936	0.9849	0.9916	0.9813	0.971	0.6258	6.4977	0.93							
2005	0	0.9984	0.9738	0.9477	0.9972	0.9949	0.9874	0.6607	6.5601	0.94							
2006	0	0.8826	0.9945	0.976	0.9903	0.9463	0.9962	0.6987	6.4846	0.93							
2007	0	0.9788	0.9676	0.8542	0.9888	0.9846	0.9937	0.9232	6.6909	0.96							
2008	0	0.8556	0.3953	0.9881	0.9633	0.9985	0.9037	0.8207	5.9252	0.85							
2009	0	0.9885	0	0.9981	0.8189	0.8725	0.8592	0.9026	5.4398	0.78							
2010	0	0.9869	0	0.9609	0.5591	0.9777	0.9079	0.9696	5.3621	0.77							
Summation of Individual Unit for Eight year Span									Units Sum	Station Unit Ave.							
0									6.6403	4.3248	6.7099	6.3092	6.7558	6.6191	5.6013		
0.00									0.95	0.62	0.96	0.90	0.97	0.95	0.80	6.14	0.88

Table 11: Kainji (Full Forced Outage Factor) Ff from 2005-2011

Years	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit12	Units Sum	Station Unit Ave.							
2004	0	0	0	0	0	0	0	0	0	0.00							
2005	0	0	0	0	0	0	0	0	0	0.00							
2006	0	0	0	0	0	0	0	0	0	0.00							
2007	0	0	0	0	0	0	0	0	0	0.00							
2008	0	0	0	0	0	0	0	0	0	0.00							
2009	0	0	0	0	0	0	0	0	0	0.00							
2010	0	0	0	0	0	0	0	0	0	0.00							
Summation of Individual Unit for Eight year Span									Units Sum	Station Unit Ave.							
0									0	0	0	0	0	0	0		
0.00									0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 12: Kainji EFORD from 2005-2011

Years	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit12	Units Sum	Station Unit Ave.
2004	0	0	0	0	0	0	0	0	0	0.00
2005	0	0	0	0	0	0	0	0	0	0.00
2006	0	0	0	0	0	0	0	0	0	0.00
2007	0	0	0	0	0	0	0	0	0	0.00
2008	0	0	0	0	0	0	0	0	0	0.00
2009	0	0	0	0	0	0	0	0	0	0.00
2010	0	0	0	0	0	0	0	0	0	0.00
Summation of Individual Unit for Eight year Span									Units Sum	Station Unit Ave.
0									0	0.00
0.00									0.00	0.00

Table 13: Kanji Maintenance Outage Factor from 2005-2011

Years	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit12	Units Sum	Station Unit Ave.
2004	0	7.9134	0	0	0	0	0	0	7.9134	1.13
2005	0	0	0	0	0	0	0	0	0	0.00
2006	0	89.9844	0	0	56.4439	0	1.8203	50.2358	198.4844	28.35
2007	0	0	0	0	24.5873	0	0	5.6981	30.2854	4.33
2008	0	56.4115	307.071	0	0	0	23.4836	22.688	409.654	58.52
2009	0	44.116	0	0	21.9307	0	109.5576	17.495	193.0993	27.59
2010	0	42.8514	0	12.8411	0	38.799	0	2.9284	97.4199	13.92
Summation of Individual Unit for Eight year Span									Units Sum	Station Unit Ave.
0									241.277	307.071
0.00									34.47	43.87

XVII. THE AVERAGES OVERALL SUMMARY OF TOTAL OF ALL PARAMETERS AND INDICES FOR KAINJI POWER STATION

Table 14: Overall summary of Averages of Kainji Power Station Indices and Parameters

Generator Parameters Analysed	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Unit 11	Unit 12	Station Sum	Averages
Availability for 2004-2011	0.00	88.24	54.51	80.67	89.50	85.15	93.03	85.98	577.08	72.13
Availability Factor for 2004-2011	0.00	88.24	54.51	80.67	89.50	85.15	93.03	85.98	577.08	72.13
Equivalent Availability for 2004-2011	0.00	84.99	53.35	78.93	71.22	56.23	84.38	76.43	505.53	63.19
Forced Outage Factor for 2004-2011	0.00	10.53	7.28	91.44	7.06	12.26	5.88	28.22	162.66	20.33
Service Factor for 2004-2011	0.00	83.56	52.37	77.32	80.57	82.24	88.03	69.05	533.13	66.64
Starting Reliability for 2004 -2011	0.00	93.64	76.56	99.31	95.22	89.30	94.94	89.25	638.22	79.78
Planned Outage Factor for 2004 -2011	0.00	1.23	0.35	12.01	3.44	2.59	1.09	2.68	23.41	2.93
Capacity Factor for 2004 -2011	0.00	0.81	0.51	0.76	0.65	0.61	0.82	0.61	4.77	0.60
Forced Outage Rate for 2004-2011	0.00	11.06	44.26	31.64	8.40	13.04	6.34	24.99	139.75	17.47
Partial Forced Outage, Pf for 2004-2011	0.00	0.95	0.62	0.96	0.90	0.97	0.95	0.80	6.14	0.77
Full Forced Outage for 2004-2011	0	0	0	0	0	0	0	0	0	0.00
Equiv. Forced Outage Rate Dd 2004-2011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maintenance Factor for 2004-2011	0.00	34.47	43.87	1.83	14.71	5.54	19.27	14.15	133.84	16.73

XVIII. KAINJI HYDRO POWER STATION MAJOR CAUSES OF OUTAGE AND UNAVAILABILITY SUMMARISED FROM OUTAGE DATA RECORDS

The major interpretations for various graphical presentations which includes description and causes of various major outages (Which includes seasonal changes, Planned outage, Maintenance Outage, Forced outage) of the Eight (8) generating units within the period of investigation are as listed below. Such Graphical movements as seen are: Increase, Decrease and Plateau

etc. some of these events are repetitive and were summarized. 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). Section 4.8.12 explains the entire characteristics based on the operational records collected from the power station. Majorly, this section complements the outage reasons given by the National Center, NCC amongst some of the reasons for the outages are as detailed below.

Some of the major events are damaged Turbine Pit occasioned by governor failure as well as turbine runaway which led to the damage of the unit 1G5. It is currently undergoing rehabilitation by the World Bank, under the World Bank assisted programme. Joint Monthly Inspection, Generator serious haunting (continuous load deflection from zero to 65MW), Tripping on Master G1& G2 and rotor earth fault, 40x and Auxiliary timer, Separation for back feed to Shiroro Generation Station, Over current voltage control trouble, high water leakages from the throat ring, Shut down for frequency regulation by NCC order, contamination of the main bearing oil, high water level in the turbine pit due to submersible pumps failures, upper guide high temperature, emergency shutdown due to loss of control, Shut down for Jebba lake level regulation, governor oil duplex filter trouble, under-water inspection of by divers, system disturbance, replacement of burnt dash pot solenoid, Tripping on Circuit breaker lockout and MCB trip.

Tripped on reverse power, serious oil leakage from thrust bearing sump, governor oil pumps failures, sheared guide vane arm gear pin, topping up intake gate 'A' oil sump, draining of the exciter tube accumulated with oil. Tripped on start block subs I & II and field breaker abnormal close, faulty return motion cable, Governor oil pumps failure, Restricted earth fault relay, transferring of unit auxiliary load from 'B' side to 'A' side of the station services system, smoking Blue phase Current Transformer, Shut down to deaden 330KV reserve bus for the purpose of isolating 1x205 330KV breaker on lock out, burnt exciter slip ring bolt and nuts, MMS fixing of sheared Head-cover stuffing box bolts, air coolers trouble, Intake gate leakage fault, Tripped on stator winding temperature phase 1 high alarm, 16kV breaker fault, current limitation 404 amps trip, under impedance, governor system proportional valve washing, thrust bearing heat exchangers high temperature, draining of its exciter tube oil, head cover pump failure, head cover sump high water level, operation on SS17 and 11kV/415V transformer, high thrust bearing temperature 83.5°C, stator earth fault trip, and EMS replacement of punctured stator coils, SSB Transformer connection to the 16kV Network, decoupling of isolator 7A3b permanent links for a work permit on SSB, Draining of accumulated oil in the runner tube, lower guide bearing temperature high (77 °C).

Others are Exciter housing troubles, Oil leakage from thrust /lower guide bearing sump due to misaligned shaft, field breaker abnormal closing, relay operation, Station Islanding, Burnt 16KV breaker closing coil, generator differential and stator earth fault under impedance start block subs 1 & 2, over excitation due to high system voltage trouble, distance protection relays trip, defective AC/DC converter, Transformer protection RET 316 relay, stator winding temperature sensors/transducers trouble, 16kv breaker failure, over-voltage yellow and blue phases, exciter slip ring and commutator carbon brushes replacement and etc.

XIX. KAINJI POWER STATION RESULTS DISCUSSION

Kainji Hydro Power Plant 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 (previous section).

The inferences drawn here, are from a combination of the graphical output result trend and the output results presented in tables above. The Availability of the units peaked at various times of the years as seen in the Tables. 1G6 peaked at 96.03% in 2008, 1G7 peaked at 97.86% in 2007, 1G8 peaked at 99.36% in 2006, 1G9 peaked at 98.55% in 2004, 1G10 peaked at 97.31% in 2004, 1G11 peaked at 96.81% in 2004, and 1G12 peaked at 90.80% in 2007. In the year 2006 1G8 had the highest yearly availability of 99.36%. The year 2007 recorded the highest station average availability of 91.88% while the Station's average for the period under review is 96.18%. Unit 1G5 recorded a low of 0.0% availability throughout the period under review due to damaged stator winding and turbine pit and has not come back as at the time of this writing.

Each of the units had their lowest availability values as thus: 1G5 had 0.0% all through the years as said earlier, 1G6 had 69.75% in 2004, 1G7 and 1G10 had a low of 13.69% and 68.22% respectively in 2008, 1G8 had a low of 21.48% in 2005, 1G9 has 72.73% in 2006, 1G11 had 91.06% in 2009, and 1G12 had a low of 57.10% in 2004 respectively.

Besides availability, the Equivalent Availability Factor which indicates that both full forced outage and deratings which has characterized the entire units has been considered in the evaluations and also shows that availability is limited majorly by these forced outages and many operational issues. The graphical results also followed the same trend as seen from the graphical result in the above section.

XX. FINDINGS

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. Generally, although some of the units showed strengths in some years, the trend of availability fluctuated greatly within the period of investigation this affected the average availability and on the average, could not get to the expected benchmark within the seven year span of investigation. The differences in the values obtained can be associated to the operational profiles of the various units and majorities are also non-operational. From the output results tables, equivalent availability values were almost the same with availability values. In reality (i.e. when output data is correctly reported), both differ greatly with about 20% variability. Again, full factor and EFORD which forms good measurement indices (particularly outages during

demand) recorded zeros throughout the years. This is as result of incoherent data recording system in place. There were identifiable areas of data manipulations in the outage records during the data arrangements against the different parameters. This might obviously have contributed to the high values obtained which are different from the realities.

On the overall, there is a trend in availability and other indices and parameters because they fluctuated greatly within the period of investigation and on the average, could not reach up to the expectations. When we reconcile these results output values to the parameters and indices definitions and implications on generators [10], 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 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 hours for base loads) [3].

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 [8]. Equivalent availability considers the lost capacity effects of partial equipment deratings and reports those effects as Equivalent Unavailable Hours [8].

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% [8]. 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:

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. but these were not the case in the study results.

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 justified by using the

Richwine model of Electricity Generation Standards to analyses the subject of availability using the illustration below.

XXI. SUMMARY OF ALL AVAILABILITY AND PERFORMANCE PARAMETERS AND INDICES FOR KAINJI HYDRO POWER STATION

1 through 9 of 14

Measurement Indices	Availability	Availability Factor	Equivalent Availability Factor	Forced Outage Factor	Service Factor	Starting Reliability	Planned Outage Factor
Indices Averages	74.30	63.32	74.30	10.16	66.02	83.72	1.25

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Capacity Factor	Forced Outage Rate	Partial Forced Outage, Fp	Full Forced Outage Factor, Ff	EFORD	Maintenance Outage Factor
0.58	25.42	0.77	0.00	0.00	13.92

For instance, assuming total installed power capacity in the Plant (station) within this period under review as 760MW. On the basis that we consider the total installed capacity of 760MW. 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.

The assumption of 15% 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.

For instance, assuming total installed power capacity in the power station within this period under review as 760MW. On the basis that we consider the total installed capacity of 760MW. 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 8.94MW 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 7.6MW 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 8.94MW at 85% availability (7.6/0.85). 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 15%, then the total equivalent capacity represented by this availability improvement would be 134MW.

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

$$\Rightarrow 760\text{MW} \times \frac{1}{100} = 7.6\text{MW}$$

Then if we consider a realistic availability goal of 85% of the above 7.6MW,

$$\text{Then, we have: } \frac{7.6}{0.85} \cong 8.94\text{MW}$$

But at 15% achievable & Sustainable Availability for these hydro -units; Will give $8.94 \times 15 = 134\text{MW}$;

The total equivalent capacity represented by this availability will be
= 134MW

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 Kainji and energy sector at large.

XXII. CONCLUSION

The inherent energy availability of power generation units in Kainji Hydro 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 and more detailed parameters 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 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.

RECOMMENDATIONS

1. Government through NERC should set up generating plant examining board. The board members should comprise select of the best-qualified and most respected individuals in their respective fields (Plant Engineering Design, Plant Management, Operations, Maintenance, etc.) from amongst 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 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, 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 & etc.
 5. Over the years, it has been observed according to researches, that in many production organizations the non-availability of spare parts, as and when required for repairs, contributes to as much as 50% of the total down time.
 6. Also, the cost of spare parts is more than 50% of the total maintenance cost in the industry. It is a paradox to note that sometimes why the maintenance department of a company is complaining of the non-availability of the spare parts to meet their requirement and the finance department is also facing the problem of increasing locked up capital in spare parts inventory. This amply signifies the vital importance of spare parts management in any power station.
 7. There should be pre-fixed meeting day for plant manager and senior executives in station to review all outages were each department is required to explain each outage event and to state, the root cause of the problem, the immediate 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.
 8. Load growth should be monitored locally from the station based on subsequent demand rates and frequency. This will help regulate incidences of system collapses.
 9. The new owners of the plant (Generation) must now come out with a tested and trusted blue print in system operations that must be flexible in implementations in the Nigeria circumstance to guarantee availability of electricity supply to consumers in the country.
 10. 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.
 11. 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.
 12. 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:
 - Set realistic, achievable goals
 - Identify best areas for potential improvement
 - Give advance warning of threats
 - Trade knowledge and experience with peers
 - Quantify and manage performance risks
 - Create increased awareness of the potential for and the value of increased plant performance
 13. 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.
 14. 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.
 15. 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.
 16. Management should endeavor to adhere to international best practice and standards in staff recruitment and rewards.
 17. Adequate structure should be put in place to monitor load growth nationwide.
 18. Preferred common trainings and good incentives should be given to the entire industry staff in the power industry.
 19. The empty penstock awaiting installation of new machines should be implemented urgently rather building new capacities from the beginning.
 20. Overhaul and extensive maintenances is recommended for all the units, particularly those above 25-years of operations or those above the operating numbers of running hours and megawatts generation specified for overhaul.
 21. Another feasibility study is required for the evaluation of the water volume in the dam to enable us have understanding whether the remaining penstocks in the station can be installed with new generators. This will enable us have knowledge of the capacity it can power together with the existing ones.

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