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Reliability Evaluation of Hydro-Electric Power Stations in Nigeria.
(A case Study of Kainji Units 1G7 & IG8 and Shiroro Units 411G1 & 411G2)

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Abstract

This research paper aims at evaluating the reliability performance of two units each from Shiroro and Kainji hydro electric power stations of Nigeria. The result of this study is intends to provide the basis for planning generation expansion of hydro electric power stations in Nigeria. Herein reliability evaluation based on the Frequency and Duration (F & D) approach is adopted. A set of reliability parameters which quantify generating unit reliability, are computed for each unit using the annual outage durations for the period of the study (2005-2009). The system failure probability (unavailability), frequency of system failure (F_F), and the mean duration of system failure (T_F) for each unit were obtained and fully discussed. The reliability of the individual unit was also computed for the period of study. The study generally shows that the generating units at Kainji Hydro Power Stations have not been adequately maintained, leading to frequent and delayed forced outage. This indicates unreliable performance of the individual units and the entire stations as compared with Shiroro Hydro Power Station.

Introduction

Reliability has been defined as the probability that a system or device performs its function adequately for the period of time under specified operating conditions (Endrenyi1978). This definition is distinct from its qualitative general meaning as it applied to engineering devices. It revolves around four major determinants viz, probability (uncertainty) of the device, adequate performance, operating conditions and specified period of time. The high rate of electricity demand requires stable and continuous supply of electrical power to consumers. However, the electrical power supply in our country has been erratic and unreliable. Therefore the operational performance of the overall power system of our nation should be improved.

Generating stations form an important and integral part of the overall power system and their reliability is dependent on the reliability of the overall electricity supply. Reliability of a generating station is a function of the reliability of the constituent generating units. Accurate estimates of generating unit reliability are needed for generating capacity planning in order to improve criteria for future designs and operations. Reliability assessment of a generating system is fundamentally concerned with predicting if the system can meet its load demands adequately for the period of time intended.

Valdma *et al.* (2007), studied the reliability of electric power generation in power systems with thermal and wind power plants. This study evaluated the principles of reliability of electric power generation at wind power plants treated as a non-stationary stochastic process. Subsequently the probability, uncertain probability and fuzzy probability models of reliability and their applications to the analysis of electric power generation reliability were introduced. Allan *et al.* (1988), presented various philosophical aspects concerning power system reliability and, in particular, adequacy and the concept of hierarchical levels in reliability evaluation. Their works provided a framework on which the discussions within the power industry and with external groups can be ideally based. The paper also briefly commented on the various methods that can be used to assess reliability. In one of the latest works on the reliability of power systems, Adler (1980), presented the mathematical methods and their underlying principles for calculating the probability of outages of generating equipment. Equations were developed for various types of generating units while formulae were also presented for the probabilities of multiple full outages as well as combination of full and partial outages. In a related work, Wang (1967), presented a method of calculating the probability of outages of a generating unit from recorded outage data.

However, in this paper, the reliability concept applicable to generation aspect of power systems is reviewed to enable us have basis for evaluating the case studies. Two units each from Kainji and Shiroro Hydro power stations are considered as the case studies, and the comparative study of the stations is highlighted. Furthermore, this work shows the reliability evaluation with a view to improve the generation and other system performance by applying probability theories, using Frequency and Duration approach and statistical analysis. The results obtained include the basic reliability indices, which gives an overview of the general reliability performance and the long-term predictive indices that can assist in long-term system planning.

Reliability Concepts And Markov Processes

Modern reliability evaluation techniques are used in a wide range of applications. These can be applied to large scale systems or systems in which failure can result in severe social consequences or to other products which individually have little socio-economic effect when they fail. It is therefore imperative that all reliability engineers should have some awareness of the basic concepts associated with a particular application and also to the mathematical modeling or Markov techniques.

Generation System Reliability

Generation system reliability concentrates on the performance of the generators where fuel is converted to electricity before entering the transmission system. Generators are subjected to forced outages or reduction in available capacity, which can affect the system reliability and hence must be evaluated. System reliability is commonly interpreted as the probability of that system staying in the operating state, performing its intended purpose adequately for a period of time without failures under required conditions (Endrenyi 1978).

Generation System Reliability Indices

A general approach to an electric power generating system reliability assessment is to determine one or a number of its reliability indices. A reliability index is defined as a quantity that measures and quantifies some aspects of system reliability performance (Rausand 2004). A number of indices have been introduced in reliability studies over the past years to assist reliability evaluations and predictions. Reliability indices are extremely useful as it quantifies the reliability of the system, hence making the assessment more meaningful. They are used to assess the reliability performance of a generation system against some predetermined criteria of reliability standards. However, the reliability index employed in this study is Frequency and Duration approach.

Frequency and Duration (F&D) Method

This method produces a set of useful reliability indices when the frequency of interruption over a specified period is of interest. The frequency and duration method is based on Markov theory but requires some more information regarding the system than the calculation of the Generation Capacity Outage Table. The method also gives the average frequency and duration of interruptions as the title indicates. The method needs input data like failure rate and repair time of the components. A state-space approach is applied to the sets of units present in the system in the reliability evaluation using the F&D method. This method also adopts the transition rate parameters λ and μ of generating units. This means that each possible combination of units in up or down states defines a capacity state of the system, which is then classified according to their available capacity, the relevant state probabilities and of course their transition states (Rausand 2004). The following formulas are used in Frequency and Duration approach;

$$pA = 0 \qquad (1)$$

System availability,

$$A_s = \sum_{j \in B} P_j = P_1 + P_2 + P_3 = 1 - q_1 q_2 \qquad (2)$$

System Unavailability,

$$1 - A_s = \prod_{i=1}^{n} q_i = \prod_{i=1}^{n} \frac{\lambda_i}{\lambda_i + \mu_i} \qquad (3)$$

Frequency of system failure, $f_f = (1 - A_s).\sum_{i=1}^{n} \mu_i.$ (4)

Mean duration of a system failure,

$$T_f = \frac{1}{\sum_{i=1}^{n} \mu_i} \qquad (5)$$

Mathematical Modeling

The first step towards the development of a mathematical model for the discrete state, continuous time processes is to construct the system's state space diagram. A state space diagram is a representation of all possible states in which the system can reside with all relevant transition rates between states inserted. (Biggerstaff 1969). Figure 2.0 shows the state space diagram of case study 1(Shiroro Units 411G1 and 411G2).

Case Study 1 (Shiroro Units)

Considering the reliability indices for Shiroro units 411G1 and 411G2 from the year 2005 to 2009

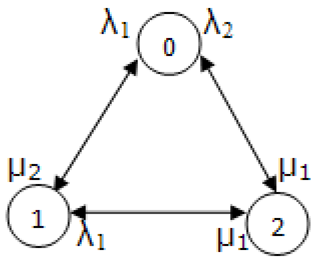

Figure 1.0: State-Space Diagram for Shiroro Units 411G1 and 411G2

The state-transition intensity matrix is given by;

$$A=\begin{bmatrix} -(\mu_1+\mu_2) & \mu_2 & \mu_1 \\ \lambda_1 & -(\lambda_1+\mu_2) & \mu_2 \\ \mu_2 & \lambda_1 & -(\lambda_1+\lambda_2) \end{bmatrix} \quad (6)$$

Equation (1) becomes

$$-(\mu_1+\mu_2)P_0+\lambda_1 P_1+\lambda_2 P_2=0 \quad (7)$$

$$\mu_2 P_0-(\lambda_1+\mu_2)P_1+\lambda_1 P_2=0 \quad (8)$$

$$\mu_1 P_0+\mu_2 P_1-(\lambda_1+\lambda_2)P_2=0 \quad (9)$$

Omitting equation (7) and replacing it with $P_0+P_1+P_2=1$, the solution of the steady state probabilities are:

$$P_0=\frac{(\lambda_1+\lambda_2)(\lambda_1+\mu_2)-\lambda_1\mu_2}{D},$$

$$P_1=\frac{\lambda_1\mu_1+\mu_2(\lambda_1+\lambda_2)}{D},$$

$$P_2=\frac{\mu_2^2\ +\mu_1(\lambda_1+\mu_2)}{D} \quad (10)$$

where

$$D=(\lambda_1+\lambda_2)(\lambda_1+2\mu_2)+2\lambda_1\mu_1+\mu_2(\mu_1-\lambda_1)+\mu_2^2$$

The steady- state probabilities for the years, 2005, 2006, 2007, 2008 and 2009 are presented in Table 1.0.

The system availability, the system unavailability, the frequency of system failure and the mean duration of system failure of each year under study is obtained from equations (2), (3), (4) and (5) respectively. This is presented in Table 2.0.

The overall Capacity Outage Probability Table (COPT) for the entire Shiroro units under the period of study (2005-2009) can be obtained from the failure rate and repair rate.

Hence, the overall system availability is:

$$A_s=\sum_{j\in B}P_j=P_1+P_2=0.9860$$

while the overall system unavailability

is $\overline{A_s}=(1-A_s)=\sum_{j\in F}P_j=P_0=0.0140.$

the frequency of system failure is

$$f_f=(1-A_s).\sum_{i=1}^{n}\mu_i=2.3786\times10^{-3}$$

and the mean duration of system failure

$$T_f=\frac{1}{\sum_{i=1}^{n}\mu_i}=5.888\,hours$$

CASE STUDY 2 (KAINJI UNITS)

Following the same procedure for case study 1 above, the steady state probabilities for case study 2 is presented in Table 4.0.

Hence, the overall system availability is

$$A_s=\sum_{j\in B}P_j=P_1+P_2=0.4619$$

while the overall system unavailability

is $\overline{A_s}=(1-A_s)=\sum_{j\in F}P_j=P_0=0.5381.$

the frequency of system failure is

$$f_f=(1-A_s).\sum_{i=1}^{n}\mu_i=13.5\times10^{-3}$$

and the mean duration of system failure

$$T_f = \frac{1}{\sum_{i=1}^{n} \mu_i} = 39.84 hours$$

Discussion of Results

Generally, typical values for Forced Outage Rates (FOR) tend to range between 0.3% and 29% which depends on factors such as unit type, size and age of the plant. Low values of forced outage rates are considered more reliable than thermal units. Judging from the average reliability indices of Kainji units for the period of study (see Figure 3.0), was observed that both units considered in the station performed below expectation due to high Forced Outage Rate which constantly occurred as a result of faults on the system. Hence the overall system availability for Kainji units was 0.4619, while the system unavailability was 0.5381 (see Table 6.0) which was more when compare with Shiroro units (Table 3.0). The frequency of system failure and mean duration of failure for these units are 13.5 x 10^{-3} and 39.84 hours respectively. This is as a result of lack of proper maintenance. It is quite obvious that there were prolonged Forced Outage Rate of Kainji units which occurred from time to time, giving rise to very high unit force outage rates and this invariably implied unreliable performance of the units. Also, the mean time to failure (MTTF) for the Kainji units within the years considered was too low leading its unreliable performance. Low MTTF implies that there will be frequent outages and hence overall poor system performance. According to the study, year by year assessment shows that the performance of the Kainji units was best in 2007(see Table 4.0), but even then the performance was quite below expectation.

Conclusion

The frequent outages (forced and scheduled) greatly affected the reliability of the stations, particularly Kainji. The main result of our analysis here, when compared with the corresponding results in Shiroro units, indicates that Kainji units has so far performed below expectation. Several conclusions were drawn from the case studies regarding the Hydro Electric power stations reliability in Nigeria. Looking at the case study 1 (Shiroro Hydro Electric power Station), the system is adequate to meet the load demand due to high availability of the constituent units. However, the level of adequacy decreases with increase in Forced Outage Rate (FOR) as seen in year 2005 (see Table 2.0). In case study 2 (Kainji Hydro Electric Power Station), it was noted that system was not adequate to meet the load demand due to frequent and delayed forced outage.

Table 1.0: Capacity Outage Probability Table (COPT) for Shiroro Units

Year	State No.	Capacity (MW)	Steady-State Probabilities	Average hour in state per year
2005	2	300	0.6830	5983.08
	1	150	0.2603	2280.23
	0	0	0.0567	496.69
2006	2	300	0.9800	8584.8
	1	150	0.0131	114.76
	0	0	0.0069	60.44
2007	2	300	0.9743	8534.87
	1	150	0.0204	178.704
	0	0	0.0053	46.428
2008	2	300	0.9825	8606.70
	1	150	0.0143	125.268
	0	0	0.0032	28.032
2009	2	300	0.9770	8558.52
	1	150	0.0209	183.084
	0	0	0.0021	18.396

Note: State 0 = State when both units are not operational
State 1 = State when only of the units is operational
State 2 = State when both units are operational

Table 2.0: System Availability and Unavailability for Shiroro Units

Year	System Availability	System Unavailability	Frequency of System Failure	Mean Duration of System Failure (hours)
2005	0.9433	0.0567	3.4077×10^{-3}	16.638
2006	0.9931	0.0069	3.6391×10^{-3}	1.8960
2007	0.9947	0.0053	2.1905×10^{-3}	2.4195
2008	0.9968	0.0032	1.7330×10^{-3}	1.8460
2009	0.9979	0.0021	9.0762×10^{-4}	2.3137

Table 3.0: Average Capacity Outage Probability Table (COPT) for Shiroro Units (2005-2009)

State	Capacity (MW)	Steady-State Probabilities	Average hour in state per year
2	300	0.8865	7765.74
1	150	0.0995	871.62
0	0	0.0140	122.46

Table 4.0: Capacity Outage Probability Table (COPT) for Kainji Units

Year	State No.	Capacity(MW)	Steady-State Probabilities	Average hour in state per year
2005	2	160	0.7502	6571.752
	1	80	0.1922	1683.672
	0	0	0.0576	504.576
2006	2	160	0.1253	1097.628
	1	80	0.2563	2245.188
	0	0	0.6184	5417.184
2007	2	160	0.9736	8526.736
	1	80	0.0179	156.804
	0	0	0.0085	74.46
2008	2	160	0.9326	8169.576
	1	80	0.0383	335.508
	0	0	0.0291	254.916
2009	2	160	0.0000	0.0000
	1	80	0.9721	8515.598
	0	0	0.0279	244.56

Table 5.0: System Availability and Unavailability for Kainji Units

Year	System Availability	System Unavailability	Frequency of System Failure	Mean Duration of System Failure (hours)
2005	0.9424	0.0576	4.1242×10^{-3}	13.966
2006	0.3816	0.6184	3.2770×10^{-2}	18.868
2007	0.9915	0.0085	3.6730×10^{-3}	2.3140
2008	0.9709	0.0291	5.6800×10^{-3}	5.1220
2009	0.9721	0.0279	6.414×10^{-3}	4.3497

Table 6.0: Average Capacity Outage Probability Table (COPT) for Kainji Units (2005-2009)

State	Capacity (MW)	Steady-State Probabilities	Average hour in state per year
2	160	0.1854	1624.104
1	80	0.2765	2422.14
0	0	0.5381	4713.756

3.0 Results

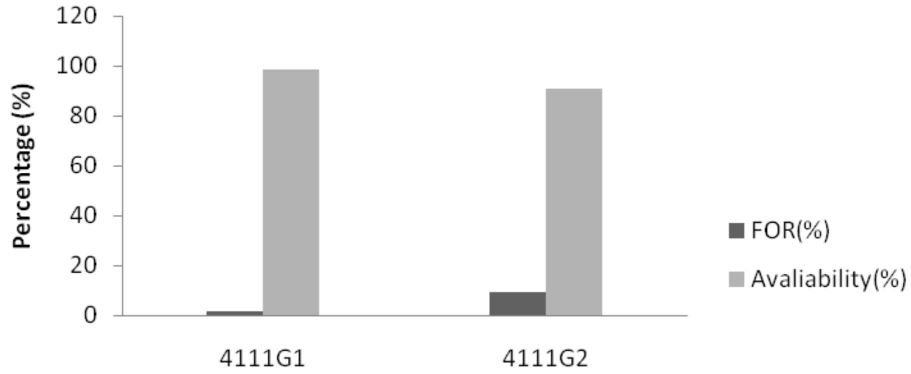

Fig. 1.0: Relationship between Forced Outage Rate (FOR) and Availability of Shiroro Units for Average Capacity Probability (2005-2009)

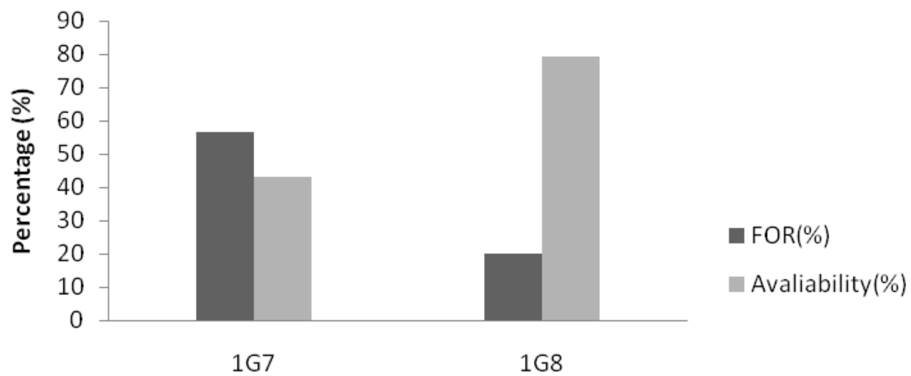

Fig. 2.0: Relationship between Forced Outage Reate (FOR) and Availability of Kainji Units for Average Capacity Probability (2005-2009)

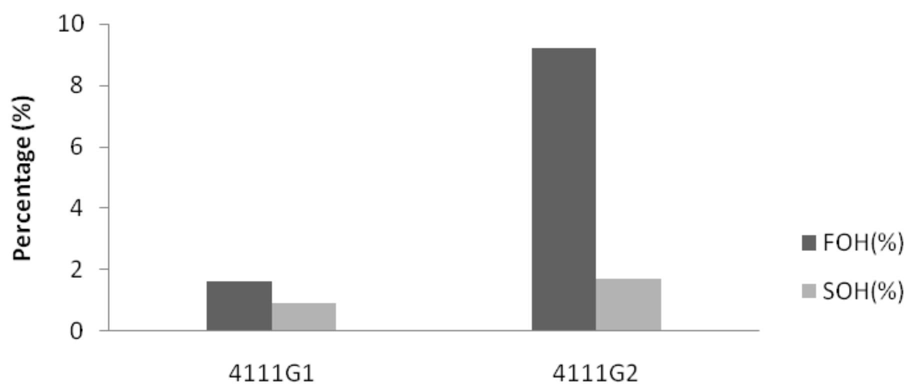

Fig. 3.0: Variation between Forced Outage Hour (FOH) and Schedule Outage Hour (SOH) of Shroro Units (2005-2009)

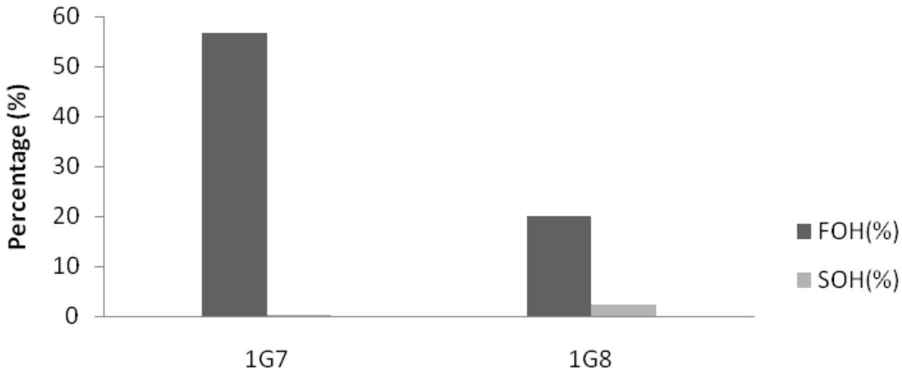

Fig. 4.0: Variation between Forced Outage Hour (FOH) and Schedule Outage Hour (SOH) of Kainji Units (2005-2009)

Reference

Allan R. N.and R. Billinton, (1988) "Concepts of power system reliability evaluation", International Journal of Electrical Power and Energy Systems, Vol. 10. pp 139-141.

Rausand M and Hoyland A (2004) "System Reliability Theory: Models Statstical Method and Application" John Wesley and Sons Inc. 2nd Edition, Canada.

Valdma, M, Keel. M, Tammoja. H and Kilk. K (2007) "Reliability of electric power generation in power systems with thermal and wind power plants", Oil Shale, Vol. 24. pp 197-208.

Wang, L.(1967) "Unit Forced Outage Rate Estimation from Recorded Outage Data", IEEE Transactions on Power Apparatus and Systems, Vol. 99, pp. 1467-1479.

Adler, H.A, (1980) "Principles and Method of Calculation of Probability of Loss of Generating Capacity", IEEE Transactions on Power Apparatus and Systems, Vol. 86, pp. 11.

Endrenyi, J. (1978) Reliability Modelling in Electric Power Systems, John Wiley and Sons, 589pp.

Anonymous, (2009) Kainji Hydro Power Station Generating Units' Outages Report. National Electric Power Authority, Kainji.

Anonymous, (2009) Shiroro Hydro Power Station Generating Units' Outages Report. National Electric Power Authority, Shiroro.

Biggerstaff, B.E. and Jackson, T.M, (1969) "The Markov Process as a Means of Determining Generating Unit State Probabilities for use in Spinning Reserve Applications", IEEE Transactions on Power Apparatus and Systems, Vol. 88, pp. 423-430.

Jimoh, A. A and Adegboye, B. A, (1995) "A Study of the Reliability Performance of Kainji Hydro Electric Power Station using the Frequency and Duration Method", African Journal of Science and Technology (AJST), Nairobi, Kenya, Series A, Vol. 11, No.1, pp. 23-33.

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Benabou, Roland (1994) "Education, Income Distribution, and Growth: The Local Connection". NBER working paper number 4798

Berglas, E. (1976) "Distribution of tastes and skills and the provision of local public goods". Journal of Public Economics Vol. 6, No.2, pp.409-423.

Edgeworth, F.Y. (1881) Mathematical Psychics, Kegan Paul: London.

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Appendix: At the end of the paper

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