THERMAL POWER STATIONS' RELIABILITY EVALUATION IN A HYDROTHERMAL SYSTEM

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ABSTRACT
A quantitative tool for the evaluation of thermal power stations reliability in a hydrothermal system is presented. A reliable power station is one which would supply the required power within its installed capacity at any time within the specified voltage and frequency limits. Required for this evaluation are the station's installed capacity and available generation. A reliability index for making this evaluation is highlighted. The effectiveness of this approach is demonstrated using a sample power system, National Electric Power Authority's (NEPA) system and the reliability evaluated. The results obtained are presented and discussed.

1. INTRODUCTION

Among the various energy resources: Fossil fuel (thermal power); falling water (hydro power); atomic nucleus (nuclear power); sun (solar power); wind (wind power) and the rest, thermal power and hydro power have been in the forefront in the generation of electricity in both developed and developing countries. In Britain for example, the power stations there are predominantly thermal. In Nigeria, electric power generation dates back to 1896 with the advent of the first thermal station in Ijora Lagos [i]. Subsequently more thermal stations were built with the result that at present there are six thermal and three hydro stations. The first hydro station, Kanji station, was established in 1968. Of these stations, thermal stations constitute about 70% of the total installed capacity.

In Nigeria for economic dispatch, hydro stations are mainly used for base load supply while thermal stations are used for peak load supply. Generation at peak load level therefore depends on the reliability of the thermal stations. The peak load period may be local (daily peak load period) or global (annual peak load period). In Nigeria, the local peak load occurs either between 0600 and 0900 hours or between 1800 and 2200 hours. The global peak load usually occurs between March and April (the hottest period in the year).

A close observation of the frequent 'blackouts' experienced in Nigeria, which may be as a result of load shedding predicated on generation outages, shows that the frequency is higher within the peak load periods (local and global). It is, therefore, imperative to investigate the reliability of the thermal power stations mainly used during this period, which also constitute a major percentage of NEPA system.

In recent times, generation reliability/adequacy study has received widespread interest [2,3,4,5,6]. In generation/adequacy study, the use of deterministic reliability indices in terms of generating reserve capacity is now considered obsolete [6]. Probabilistic indices such as Loss- of-Load Probability/Expectation (LOLP/E) are used. These are the convolution of the generation (supply) model and the load (demand) model. They are the global reliability indices for generation reliability studies. Forced Outage Rates (FORs) of the generating units and their unit capacities are the basic inputs to the programmes that compute them. In a mixed (hydrothermal) system, for sectoral cum comparative reliability study, these indices are inadequate since it is almost impossible to have separate load models for hydro and thermal stations in a mixed system. Reliability index such as availability factor is therefore used.

In this paper a framework for the evaluation of reliability of thermal power stations in a hydrothermal system using this index is presented.

2. THE CONCEPT OF RELIABILITY

The reliability of a system is said to be high if it performs its function without failure and low otherwise. For analysis, a numerical value or measure of this concept is necessary. To this end, Endrenyi [8] defines reliability as the probability of a system performing its function adequately for the period of time intended under the operating conditions specified. A lot of reliability indices evolved from the above definition, for assessing systems reliability/adequacy. As noted previously, probabilistic approach (indices) are more favoured than deterministic indices which are being abandoned. The popular probabilistic indices are now reviewed:

i) LOLP: This describes the probability of the system load exceeding the available generation under the assumption that the peak load of each day lasts all day. It is expressed in units of day/year.

ii) LOLE: This describes the expected number of days in a year when loss of load occur. This does not assume that the failure lasts all day. The unit is also in day/year.

In practice, the major difference between the two is that in LOLP calculation, daily peak loads are used whereas in LOLE calculation, hourly peak loads are used. There are other primary indices. These are also reviewed.

i) Mean Time Between Failure (MTBF): This may be measured by testing the system for a total period T, during which N faults occur. Each fault is repaired and the system put back on test. The repair time is excluded from the total test time T. The index MTBF is then given by:

$$MTBF = \frac{T}{N}(Hours) \quad (1)$$

This index is subject to sampling errors, since the system is observed for only a sample of its total life. Deduction from the result should allow for this error. Thus other things being equal, the system with the greatest MTBF is considered the most reliable.

Frequency of Failure/Railure Rate (F): This the number of faults per unit time. For Idealised system with constant failure rate for much of its working life, the failure rate is the reciprocal of the MTBF.

$$i.e. F = \frac{1}{MTBF}(faults/Hour) \quad (2)$$

In all the above indices, the time needed to effect repairs on faulty components / units has not been considered. This is a very great deficiency, since there may be situations where short repair time is more desirable than high MTBF. Hence a better measure of reliability which considers repair time is needed.

iii) Availability: This is the up the time ratio of the system. It is calculated by splitting all the time in a given period into two categories namely:

a) Up Time, U: when the machine is in working order.

b) Down Time, D: during which the machine is faulty or being repaired.

The total period of observation is then U + D and availability or Up time ratio becomes:

$$A \frac{U}{U+D} \quad (3)$$

and unavailability:

$$\bar{A} + \frac{U}{U+D} \quad (4)$$

For systems in which the component failure rate is constant (i.e. systems operating within their normal life period) the availability may be given by:

$$A = \frac{MTBF}{MTBF+MTTR} \quad (5)$$

$$\text{And } \bar{A} = \frac{MTTR}{MTBF+MTTR} \quad (6)$$

where MTTR is Mean Time To Repair A further expression for the availability may be obtained in terms of the failure rate (F) and repair rate (R) as:

$$A = \frac{1/F}{1/F+1/R} = \frac{R}{R+F} \quad (7)$$

And

$$\bar{A} = \frac{1/R}{1/F+1/R} = \frac{R}{R+F} \quad (8)$$

However, in generating system, unit unavailability is obtained by a traditional method known as the Forced Outage Rate (FOR) [8]. This index is defined as the ratio of the Forced Outage Hours (FOH) to the sum of the Forced Outage Hours and the In-Service Hours (ISH).

$$i.e. FOR = \frac{FOH}{FOH+ISH} \quad (9)$$

Further still, deficiency exists in all the enumerated indices since none models partial outages, Endrenyi in [8] made a good attempt by introducing a modified FOR called

Equivalent Forced Outage Rate (EFOR), that takes partial alternative method that models both partial and full outages by looking at the outputs of the units directly, instead of the time of the units is proposed. The resulting index is availability factor discussed in the next section. Some of these primary indices are inputs for the calculation of the global indices. The choice of a particular index depends on the problem at hand and also on the data available.

2.1 AVAILABILITY FACTOR

Due to the constrained nature of the sectoral reliability study in a mixed system, a reliability index called Availability Factor (AF) is used. This is defined as the ratio of the Available Capacity CAC) to the Installed Capacity (IC) of a generating station.

$$i.e. AF = \frac{AC}{IC} \quad (10)$$

This index is adequate because the available generating capacity may be less than the installed generating capacity by capacity on outage of generating units on fault or maintenance. It does not discriminate between available capacities from derated units and healthy units. It therefore models both the partial and full outages of the generating units in the stations.

i. Inadequate supply of fuel to the stations.
ii. Faulty components/equipment.
iii. Lack of spare parts for maintenance and repairs.
iv. Shortage of qualified personnel to render required and timely maintenance.

This index therefore gives a measure of the probability of a station performing its intended function.

3. EVALUATION OF RELIABILITY INDEX

In reliability evaluation, reliability indices could be assessed on either absolute or relative form. In the absolute use of an index, there should be a standard stated for the index in advance for the purpose of passing or failing. In the relative use of an index, a comparison is made, using the index, for different systems. In this paper, a relative use of the index, availability factor, for the thermal and hydro stations is made.

3.1 Computation availability factor

Data for the analysis consisting of the installed and available generating capacities for the power stations in the NEPA system were collected for the years 1984 through 1990 from NEPA. Table 1 shows the availability factors of the NEPA generating stations on monthly basis for the years 1984 through 1990. For ease of analysis these are averaged into annual data shown in Table 2. This table is used to generate plots shown in Figures 1 and 2.

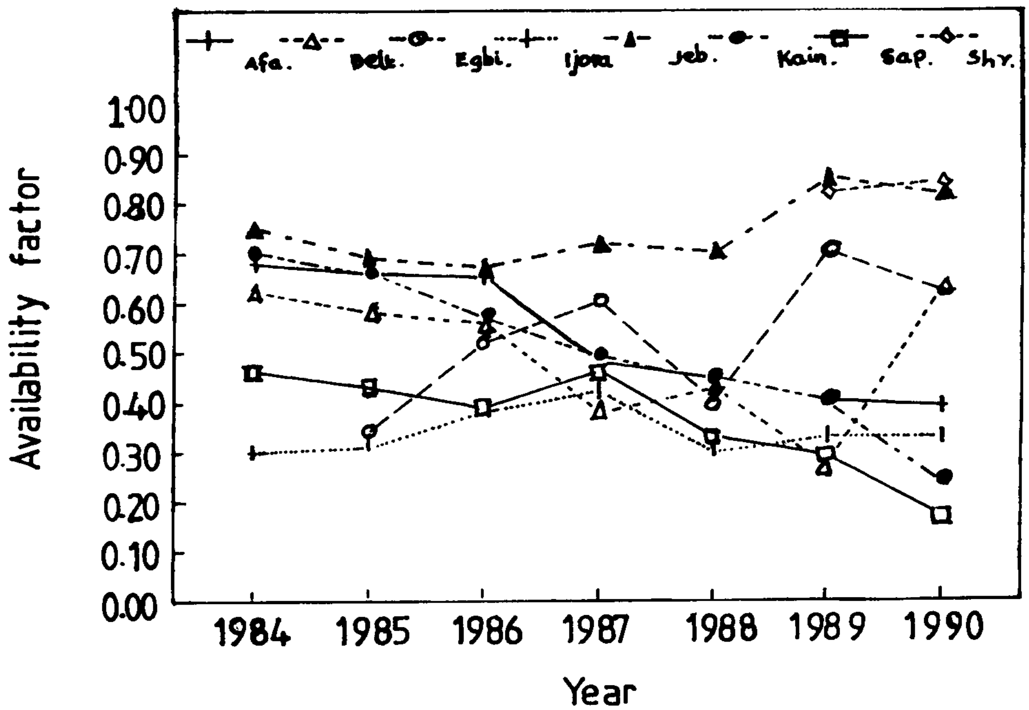

Fig. 1 Availability factors of NEPA power stations minus Oji for 1984 through 1990

TABLE 1 - AVAILABILITY FACTORS OF NEPA GENERATING STATIONS.

1984	Afam	Delta	Egbin	Ijora	Jebba	Kainji	Oji	Sapele	Shiroro
Jan.	0.78	0.62	*	0.30	0.76	0.63	0.11	0.50	*
Feb.	0.72	0.62	*	0.30	0.74	0.62	0.11	0.52	*
Mar.	0.68	0.60	*	0.31	0.75	0.68	0.11	0.44	*
Apr.	0.70	0.64	*	0.31	0.76	0.78	0.11	0.42	*
May	0.66	0.62	*	0.31	0.68	0.80	0.10	0.45	*
Jun.	0.55	0.65	*	0.31	0.69	0.70	0.10	0.46	*
Jul.	0.58	0.60	*	0.32	0.70	0.59	0.10	0.47	*
Aug.	0.64	0.64	*	0.32	0.73	0.70	0.10	0.41	*
Sep.	0.65	0.58	*	0.30	0.78	0.58	0.12	0.43	*
Oct.	0.70	0.60	*	0.29	0.80	0.88	0.12	0.49	*
Nov.	0.76	0.68	*	0.29	0.82	0.63	0.12	0.50	*
Dec.	0.74	0.60	*	0.29	0.81	0.85	0.12	0.48	*
Aver.	0.68	0.62	*	0.30	0.75	0.70	0.11	0.46	*

1985	Afam	Delta	Egbin	Ijora	Jebba	Kainji	Oji	Sapele	Shiroro
Jan.	0.68	0.48	*	0.32	0.68	0.64	0.05	0.42	*
Feb.	0.65	0.57	*	0.32	0.69	0.69	0.05	0.41	*
Mar.	0.64	0.54	*	0.31	0.68	0.68	0.05	0.40	*
Apr.	0.69	0.62	*	0.31	0.67	0.70	0.05	0.44	*
May	0.62	0.64	*	0.31	0.72	0.72	0.04	0.43	*
Jun.	0.59	0.61	*	0.31	0.70	0.65	0.04	0.43	*
Jul.	0.59	0.56	0.27	0.30	0.66	0.62	0.06	0.48	*
Aug.	0.61	0.53	0.30	0.30	0.64	0.70	0.06	0.39	*
Sep.	0.64	0.63	0.32	0.30	0.68	0.59	0.06	0.38	*
Oct.	0.68	0.52	0.36	0.32	0.73	0.61	0.05	0.45	*
Nov.	0.70	0.60	0.38	0.32	0.65	0.64	0.05	0.46	*
Dec.	0.72	0.57	0.42	0.32	0.72	0.68	0.05	0.42	*
Aver.	0.66	0.58	0.34	0.31	0.69	0.66	0.05	0.43	*

1986									
Jan.	0.66	0.53	0.49	0.33	0.70	0.57	0.11	0.44	*
Feb.	0.62	0.45	0.52	0.35	0.73	0.52	0.11	0.42	*
Mar.	0.64	0.51	0.48	0.35	0.68	0.55	0.10	0.40	*
Apr.	0.67	0.58	0.53	0.38	0.62	0.58	0.10	0.38	*
May	0.60	0.54	0.38	0.38	0.68	0.60	0.10	0.37	*
Jun.	0.64	0.64	0.50	0.37	0.72	0.63	0.10	0.33	*
Jul.	0.66	0.58	0.51	0.39	0.75	0.54	0.10	0.32	*
Aug.	0.61	0.49	0.50	0.40	0.70	0.48	0.10	0.40	*
Sep.	0.65	0.59	0.56	0.40	0.66	0.52	0.10	0.43	*
Oct.	0.60	0.59	0.58	0.40	0.63	0.58	0.11	0.39	*
Nov.	0.70	0.60	0.60	0.38	0.61	0.60	0.11	0.42	*
Dec.	0.68	0.52	0.61	0.38	0.62	0.71	0.11	0.41	*
Aver.	0.65	0.56	0.52	0.38	0.67	0.57	0.10	0.39	*

1987									
Jan.	0.47	0.40	0.68	0.40	0.63	0.40	0.06	0.48	*
Feb.	0.46	0.38	0.66	0.40	0.68	0.47	0.06	0.44	*
Mar.	0.52	0.37	0.64	0.42	0.76	0.49	0.06	0.36	*
Apr.	0.50	0.44	0.53	0.42	0.70	0.35	0.05	0.47	*
May	0.48	0.36	0.65	0.42	0.70	0.38	0.05	0.38	*
Jun.	0.47	0.42	0.59	0.43	0.78	0.33	0.05	0.53	*
Jul.	0.44	0.33	0.73	0.43	0.69	0.37	0.06	0.53	*
Aug.	0.46	0.32	0.75	0.43	0.86	0.33	0.06	0.60	*
Sep.	0.53	0.34	0.67	0.42	0.85	0.36	0.06	0.52	*
Oct.	0.45	0.35	0.49	0.42	0.63	0.50	0.06	0.38	*
Nov.	0.49	0.40	0.34	0.43	0.69	0.57	0.06	0.39	*
Dec.	0.48	0.41	0.52	0.43	0.68	0.55	0.06	0.40	*
Aver.	0.48	0.38	0.60	0.42	0.72	0.49	0.06	0.46	*

1988									
Jan.	0.43	0.38	0.40	0.30	0.62	0.40	0.04	0.37	*
Feb.	0.47	0.39	0.49	0.30	0.63	0.46	0.04	0.30	*
Mar.	0.45	0.47	0.38	0.30	0.78	0.57	0.04	0.32	*
Apr.	0.47	0.37	0.57	0.30	0.68	0.31	0.07	0.27	*
May	0.48	0.36	0.37	0.30	0.70	0.51	0.07	0.29	*
Jun.	0.49	0.48	0.33	0.30	0.70	0.45	0.07	0.36	*
Jul.	0.46	0.48	0.33	0.30	0.80	0.39	0.07	0.36	*
Aug.	0.45	0.41	0.35	0.31	0.59	0.38	0.04	0.32	*
Sep.	0.41	0.37	0.36	0.31	0.58	0.49	0.04	0.34	*
Oct.	0.39	0.37	0.55	0.30	0.63	0.44	0.04	0.30	*
Nov.	0.43	0.39	0.47	0.30	0.85	0.52	0.04	0.34	*
Dec.	0.43	0.39	0.50	0.30	0.88	0.51	0.04	0.42	*
Aver.	0.45	0.43	0.49	0.30	0.70	0.45	0.05	0.33	*
1989									
Jan.	0.43	0.38	0.57	0.33	0.92	0.48	0.04	0.28	*
Feb.	0.39	0.36	0.67	0.33	0.78	0.42	0.04	0.25	*
Mar.	0.48	0.38	0.67	0.33	0.75	0.56	0.04	0.30	*
Apr.	0.42	0.30	0.72	0.33	0.66	0.42	0.07	0.27	*
May	0.41	0.30	0.59	0.33	0.86	0.51	0.07	0.24	*
Jun.	0.38	0.29	0.69	0.33	0.80	0.45	0.07	0.39	*
Jul.	0.41	0.26	0.70	0.33	0.83	0.45	0.07	0.32	0.78
Aug.	0.36	0.21	0.69	0.32	0.55	0.37	0.07	0.33	0.79
Sep.	0.39	0.25	0.97	0.32	0.75	0.35	0.07	0.29	0.82
Oct.	0.39	0.23	0.66	0.32	0.78	0.31	0.04	0.24	0.82
Nov.	0.35	0.26	0.86	0.33	0.73	0.24	0.04	0.26	0.85
Dec.	0.33	0.27	0.57	0.33	0.69	0.26	0.04	0.25	0.86
Aver.	0.40	0.27	0.70	0.33	0.85	0.40	0.06	0.29	0.82
1990									
Jan.	0.36	0.76	0.70	0.33	0.98	0.26	0.04	0.20	0.76
Feb.	0.39	0.55	0.68	0.33	0.95	0.25	0.04	0.19	0.74
Mar.	0.38	0.37	0.66	0.33	0.85	0.26	0.04	0.21	0.67
Apr.	0.44	0.33	0.55	0.33	0.84	0.26	0.04	0.20	0.96
May	0.43	0.58	0.67	0.33	0.86	0.23	0.04	0.23	0.78
Jun.	0.34	0.65	0.60	0.32	0.95	0.22	0.04	0.23	0.73
Jul.	0.32	0.38	0.75	0.32	0.85	0.20	0.04	0.17	0.81
Aug.	0.35	0.52	0.76	0.33	0.78	0.21	0.07	0.10	0.98
Sep.	0.42	0.41	0.67	0.33	0.87	0.21	0.07	0.13	0.86
Oct.	0.42	0.49	0.48	0.33	0.87	0.21	0.07	0.13	0.92
Nov.	0.40	0.58	0.33	0.33	0.89	0.26	0.04	0.12	0.98
Dec.	0.37	0.45	0.55	0.33	0.96	0.26	0.04	0.13	0.86
Aver.	0.45	0.43	0.49	0.30	0.70	0.45	0.05	0.33	0.84

Note: *denotes data not available because the station was not yet established.

TABLE 2 - ANNUAL AVAILABILITY FACTORS OF NEPA GENERATING STATIONS

	1984	1985	1986	1987	1988	1989	1990
Afam	0.68	0.66	0.65	0.48	0.45	0.40	0.39
Delta	0.62	0.58	0.56	0.38	0.43	0.27	0.63
Egbin	*	0.34	0.52	0.60	0.40	0.70	0.62
Ijora	0.30	0.31	0.38	0.42	0.30	0.33	0.33
Jebba	0.75	0.69	0.67	0.72	0.70	0.85	0.82
Kainji	0.70	0.66	0.57	0.49	0.45	0.40	0.24
Sapele	0.46	0.43	0.39	0.46	0.33	0.29	0.17
Oji	0.11	0.05	0.10	0.06	0.05	0.06	0.05
Shiroro	*	*	*	*	*	*	*

Note: *denotes data not available because the station was not yet established.

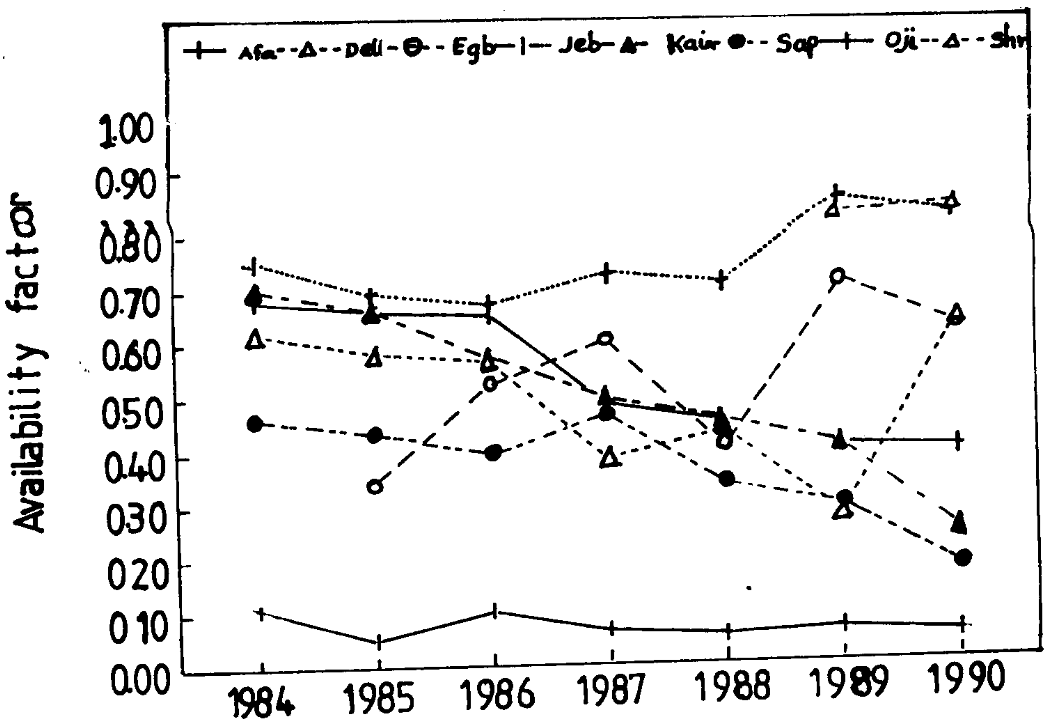

Fig. 2 Availability factors of NEPA power stations minus Ijora for 1984-1990

4 RESULT AND DISCUSSION

From Figs. 1 and 2, it is observed that all the thermal stations operated well below the hydro stations in terms of reliability, with the exception of Kainji hydro station, during the period under consideration. Kainji showed high reliability in 1984 and 1985 only within the period under investigation.

Amongst the thermal power stations, between 1984 and 1986 only Afam and Delta stations showed appreciable figures of reliability. The others; Sapele, Ijora and Oji Stations operated below average. Between 1989 and 1990, Delta and Egbin thermal stations showed very high reliability. Obviously, this must be due to the recent boost given to these two stations in terms of newly commissioned units. Oji thermal station greatly affected by spare parts problem, generally remains the least in terms of reliability.

5 CONCLUSION

The central objective of every power utility company in these days of modern power utilisation is to achieve a very high degree of reliability (assurance against widespread outages and subsequent blackout). To perform reliably well, it should have reliable generating Stations and units. This paper has presented a framework for the reliability evaluation of the thermal power stations in a hydrothermal system.

A cursory look at Figs. 1 and 2 showed that generally, thermal power stations in Nigeria have relatively low reliability. These thermal stations are the premier power stations. They presumably had high reliability figures when they were newly installed. The low reliability value is therefore mainly as a result of lack of spare parts for repair of the broken down units. Insufficient supply of fuel has been reported as one of the factors responsible for plant's unavailability. It is therefore suggested that obsolete units in these old thermal stations should be replaced and adequate supply of fuel to these stations enforced. A long term decision for Nigeria should be to convert all oil fired thermal stations into gas fired stations and leave oil alone for other competing demands since Nigeria has abundant natural gas.

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