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Availability Assessment of Steam and Gas Turbine Units of a Thermal Power Station Using Markovian Approach

Christian Emeka Okafor[1*], Augustine A. Atikpakpa[2] and Ugochukwu Chuka Okonkwo[1]

[1]Department of Mechanical Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.
[2]Department of Mechanical Engineering, Delta State Polytechnic, Otefe – Oghara, Delta State, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author CEO designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author AAA managed the analyses of the study. Author UCO managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of this study is to assess the availability of steam and gas turbine units of a thermal power station using Markovian Approach.
Place and Duration of Study: Operational data from 2003 to 2012 were collected from a thermal power station in Nigeria. These raw data represents records of plant generation capabilities as well as other inherent daily conditions that will enhance the success of this study.
Methodology: Relevant indices such as Repair Rate (μ), Failure Rate (λ), Mean Time to Repair (MTTR), Mean Time to Failure (MTTF) and Mean Time Between Failures (MTBF) was determined for each of these states. For each state, state probability are also calculated through repair rate and failure rate of the corresponding state.

**Corresponding author: Email: ce.okafor@unizik.edu.ng;*

Results: The repair rate for ST01, ST02 and ST06 in terms of assessment in the period studied is high, particularly ST01 and ST06. But for 2008 and 2011, ST02 was completely unavailable. the station availability figures of ST01 for the year 2003 is 0.929 and its failure rate (λ) is 0.0478 in 83.7 hrs; repair rate was 0.64 and failure rate (λ_{max}) for ST06 is 0.1396 in 2007 while the repair rate is 0.7862 in 72.5 hrs. For the year 2007, ST02 (λ_{min}) has failure rate of 0.05308 in 113 hrs while, ST02, GT01, GT02 in ∞hrs is nil (completely unavailable) between year 2008 to 2011; ST06 has failure rate (λ) of 0.1163 in 52 hrs in 2006 while the repair rate was 0.1806. Effects of leakages along the lines is most paramount in the entire unit with ST01and ST06 most affected 762hrs and 2568 respectively.

Conclusion: For the thermal power station to be reliable, the failure rate of equipment must be reduced to the barest minimum. Repair rate for assessment must be high to guarantee plant efficiencies.

Keywords: Availability; assessment; turbine; Markovian; failure; model.

1. INTRODUCTION

In reliability theory and reliability engineering, the term availability is the degree to which a system, subsystem or equipment is in a specified operable and committable state at the start of a mission, when the mission is called for at an unknown, i.e. a random, time [1]. Simply put, availability is the proportion of time a system is in a functioning condition. This is often described as a mission capable rate. Mathematically, this is expressed as 100% minus unavailability. Availability therefore is the ratio of (a) the total time a functional unit is capable of being used during a given interval to (b) the length of the interval. The definition of reliability is usually applicable to a particular kind of performance, where a device is successful if it has not failed during its intended time of service. However, the possibility of repairs after failures and of continued service after repairs is not considered. Availability therefore is an index of reliability. The availability of a repairable device is defined as the proportion of time, in the long run, that is in or ready for service [2,3].

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 operation of a generating unit requires a coordinated operation of hundreds of individual components [4]. 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 power station. Still, some might cause immediate or total shutdown of the unit if they fail. The failure rates of all the gas and steam turbines in a power station contribute to the overall unavailability of the station [5].

According to Sulaiman [6], energy is one of the major building blocks of modern society, it is needed to produce/manufacture goods and services from natural resources and to provide many of the services we have come to take for granted. Economic development and improved standard of living are complex processes that share a common denominator, the availability of an adequate and reliable supply of energy [6]. Due to the fact that availability of electricity is one of the main key to national growth, a maintenance policy must be concretely strategized to regulate it. Maintenance costs have risen steadily over recent years in proportion to total investment. Simultaneously, the growth of mechanization and automation means that reliability and availability have become key issues in the Nigerian power-industry [7,6].

The availability of a complex system, such as a turbine (gas and steam), is associated with its parts reliability and maintenance policy [5]. 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 [8,5].

Availability measures are concerned with the fraction of time a unit is capable of providing service. Most power plants use the index proposed by IEEE std. 762 (1987) to define availability. That index represents the percentage of a given period of time, expressed in hours, that the unit is in service [9]. A reduction in availability is caused by planned maintenance and unplanned maintenance actions. Eti et al. [7]

and Carazas and Marthade-Souza [9] proposed the use of reliability and maintainability concepts to define an availability index expressed by the ratio of the mean time to failure (MTTF) to the sum of the mean time to failure plus the mean time to repair. Sahu and Barve [3] carried out reliability and availability evaluation of PATHRI & CHILLA hydro power station (India) by using Markov Model. Carazas and Marthade-Souza [9] presented a method for reliability and availability evaluation of gas turbines installed in an electric power station. Dash and Das [10] carried out availability assessment of individual generating units of Balimela hydro electric power station using Markovian approach. Deepak, Tri and Mahesh [11] undertook reliability and availability evaluation of Sunkoshi Hydro power station Nepal, during the period of FY 2009/10 to FY 2013/14. Gupta, Tewari and Sharma [12] carried out reliability and availability analysis of the ash handling unit of a steam thermal power plant.

Pokorádi [13] carried out availability assessment based on stochastic maintenance process modeling. The paper demonstrated the possibilities of the use of Markov matrix in case of stationary maintenance processes. Qadeer, et al. [14] proposed a unique risk matrix and methodology to determine the critical equipment with direct impact on the availability, reliability and safety of the process using Markov method. Kharchenko et al. [15] undertook availability assessment of computer systems described by stiff markov chains. Loganathan et al. [16] evaluated the availability of manufacturing systems using Semi-Markov model. The developed models are solved using an analytical solution method to obtain steady-state probabilities of their states and hence, the system steady-state availability. Hua et al. [17] assessed the of reactor trip system based on Markov model, the paper shows that Markov chain is an effective method to be applied to the availability assessment of digital instrumentation and control systems of nuclear power plants. Evangelos and Evangelos and Agapios [18] assessed the availability of diesel generator system of a ship, the paper aims to show the advantages of Markov modelling in maritime risk assessment compared to conventional techniques. Lakehal et al. [19] carried out an assessment of electric power based on switch reliability modelling with dynamic bayesian networks, a case study of electrical distribution networks. Kim et al. [20] carried out availability analysis of subsea blowout preventer using Markov model considering demand rate. Dawid et al. [21] reviewed Markov models for maintenance optimization in the context of offshore wind. Sagayaraj et al. [22] presented Markov models in system reliability with applications, also, they determine the system availability for few systems and the same technique can be used to find the Availability of any mixed configuration system involving series and parallel configuration. Tewari and Kumar [23] studied the availability analysis of milling system of a rice milling plant using probabilistic approach, The subsystems under study are special purpose machines. Kumar et al. [24] carried out mathematical modeling and availability Analysis of Packaging Section in a Paint Industry.

HajibashI and Ebrahimi [25] applied markovian approach to reliability modeling of a wind farm. Jakiul et al. [26] analysed the availability of an LNG processing plant using the Markov process and found that Markov process provides an easier way to measure the performance of the process facility, their study also revealed that the maintenance interval has a major influence in the availability of a process facility as well as in maintaining target availability. Loganathan, Girish and Gandhi [27] evaluated Availability of manufacturing systems using Semi-Markov model. The developed models are solved using an analytical solution method to obtain steady-state probabilities of their states and hence, the system steady-state availability. Peter [28] applied Markov state model of the two-state behaviour of water, with the help of a Markov State Model (MSM), two-state behaviour was resolved for two computer models of water in a temperature range from 255 K to room temperature (295 K). Tzioiutzias et al. [29] carried out Markov modeling of the availability of a wind turbine utilizing failures and real weather data using Markov chains, they developed a model describing the availability of a wind turbine considering the wind intensity and the operational condition or the downtime of a wind turbine. Smriti et al. [30] examined the optimal availability analysis of brake drum manufacturing system by using Markov approach. Hsu et al. [31] analyzed reliability based on nonhomogeneous continuous-time Markov modeling with application to repairable pumps of a power plant, an optimal solution in consideration of the life cycle cost under a certain availability constraint was found through the model.

In general, the Nigerian power generation capability has nosedived to an abysmal level, particularly at the generation stations due to unavailability occasioned by many factors. Unplanned downtime has resulted in lost electricity-generation and requires resources to be diverted to get the system running again, i.e., lower profitability occurred. This has affected many sectors of the economy with the commercial sector being the most affected. The rising demand of this commodity from generating power stations cannot be over emphasized. The need to assess the availability of these stations to ascertain if they are economically viable is therefore necessary. The aim of this study therefore is to carry out carry out availability evaluation of steam and gas turbines system components using two state and three state Markov models.

2. MATERIALS AND METHODS

Data were obtained from a thermal power station in Nigeria. These raw data were extracted from the operation department, which represents records of plant generation capabilities as well as other inherent daily conditions that will enhance the success of this study. To evaluate the availability of the individual turbine units of the thermal station, the operational data from 2003 to 2012 were collected and analyzed by using Markov model. From the collected data and based on the type of faults faced by each unit, different states are defined as Markov states. Then relevant indices such as Repair Rate (μ), Failure Rate (λ), Mean Time to Repair (MTTR), Mean Time to Failure (MTTF) and Mean Time between Failures (MTBF) was determined for each of these states following the procedures of Sahu and Barve [3]. The state probabilities for each of these states are also calculated. Thus reliability and availability are determined subsequently as per their definitions in [3]. The developments of availability model basis on simple probabilistic considerations are below.

- The differential Markov equations have been formulated with related transition diagram.
- These equations are equating first order derivative to zero for a steady state condition i.e. P_1, P_2, P_3, P_4, P_5, P_6, P_7, and P_8.
- The obtained steady state probabilities are further solved using normalizing condition. Then find availability and unavailability of each the unit.

To model turbine units, the states was broadly classified into up-state and down-state as shown in Fig. 1 in line with the report of Majeed and Sadiq [32].

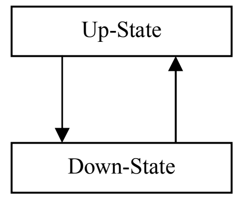

Fig. 1. Two-state Markov model [32]

Subhasish and Devadutta [33] reported that a unit is said to be in up-state if it is either in or ready for service. The system transits from up-state to down-state due to forced or scheduled outages. Forced outage means the shutdown of a generating unit for emergency reasons or a condition in which the generating equipment is unavailable for load due to unanticipated breakdown. Scheduled outage means the shutdown of a generating unit for inspection or maintenance, in accordance with an advance schedule. To carry out Markov model for the turbine units it is assumed that the failure and repair rates of turbines are exponentially distributed [34,11]. There is no transition between the scheduled and forced outages. The unit after repairs is immediately returning to up-state. From this, a developed Markov model is given as follows known as three state Markov model [32] as shown in Fig. 2.

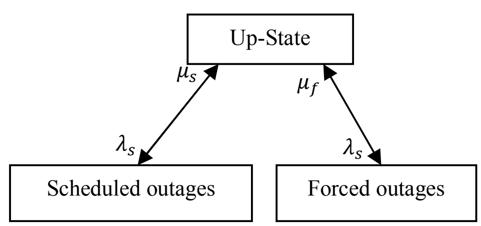

Fig. 2. Three-state Markov model [32]

The probability that the equipment is in the operating state after time interval dt i.e. at time $(t + dt)$ is given by $P_0(t + dt)$ = [(Probability of being in operating state at time t) and (Probability of not failing between $t + dt$)] + [(Probability of being failed states at time t) and (Probability of being repaired between t and $t + dt$)]. Probabilities of failure between t and dt are $\lambda_i dt$ and the probabilities of not failing are$(1 - \lambda_i dt)$. Similarly, the probabilities of repair are $\mu_i dt$. Using the addition and multiplication rule for probabilities gives

$$P_0(t+dt) = P_0(t)[(1-\lambda_1 dt) + (1-\lambda_2 dt) + (1-\lambda_3 dt) + (1-\lambda_4 dt) + (1-\lambda_5 dt) + (1-\lambda_6 dt) + (1-\lambda_7 dt) + (1-\lambda_8 dt)] + \mu_1 dt P_1(t) + \mu_2 dt P_2(t) + \mu_3 dt P_3(t) + \mu_4 dt P_4(t) + \mu_5 dt P_5(t) + \mu_6 dt P_6\,(t) + \mu_7 dt P_7(t) + \mu_8 dt P_8(t). \quad (1)$$

Now rearranging we get,

$$P_0(t+dt) = -P_0(t) \times (\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8) + \mu_1 P_1(t) + \mu_2 P_2\,(t) + \mu_3 P_3(t) + \mu_4 P_4(t) + \mu_5 P_5(t) + \mu_6 P_6(t) + \mu_7 P_7(t) + \mu_8 P_8(t) \quad (2)$$

$$P_0(t+dt) = \sum \mu_i P_i(t) - P_0(t) \sum \lambda_i \quad (3)$$

Equating first order derivative to zero for a steady state and taking $P_i(t) = P_i$ for i = 0, 1, 2…8. Then these equations will take the following forms

$$P_0\,(\lambda_1 + \lambda_2 + \lambda_3 + + \lambda_5 + \lambda_6 + \lambda_7 + \lambda_8) = \mu_1 P_1 + \mu_2 P_2 + \mu_3 P_3 + \mu_4 P_4 + \mu_5 P_5 + \mu_6 P_6 \quad (4)$$

$P_1\mu_1 = P_0\lambda_1$; $P_2\mu_2 = P_0\lambda_2$; $P_3\mu_3 = P_0\lambda_3$; $P_4\mu_4=P_0\lambda_4$; $P_5\mu_5=P_0\lambda_5$; $P_6\mu_6=P_0\lambda_6$; $P_7\mu_7=P_0\lambda_7$; $P_8\mu_8 = P_0\lambda_8$

Using normalizing condition, we get

$$P_0+P_1+P_2+P_3+P_4+P_5+P_6+P_7+P_8 = 1 \quad (5)$$

Substituting value of P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8, the steady state availability of the various components is found as

$$P_0 = \left(\frac{1}{1+\sum \mu_i \lambda_i}\right) = \left(\frac{1}{1+D}\right) \quad (6)$$

Where $D = \sum \mu_i \lambda_i$

And unavailability of other subsystem is found as

$P_1 = (\lambda_1/\mu_1)$ 1/ (1+D); $P_2 = (\lambda_2/\mu_2)$ 1/ (1+D); $P_3 = (\lambda_3/\mu_3)$ 1/ (1+D); $P_4 = (\lambda_4/\mu_4)$ 1/ (1+D); $P_5 = (\lambda_5/\mu_5)$ 1/ (1+D); $P_6 = (\lambda_6/\mu_6)$ 1/ (1+D); $P_7 = (\lambda_7/\mu_7)$ 1/ (1+D); $P_8 = (\lambda_8/\mu_8)$ 1/ (1+D)

2.1 Markov Model for the Thermal Station

For the ease of study, events of thermal unit and its down states are classified as in Fig. 3 into: (1) Field Breaker (2) Boiler Feed Pump (3) Gear Defect & Hood Diaphragm (4) Water Pump (5) Economizer Inlet non Return Valve (6) Leakages (7) Scheduled Outage (Planned maintenance) (8) Dirty Air filter (9) Gas Supply.

It is assumed that there are no transition between the scheduled and force outages and also that the unit after repairing is immediately returning to up state.

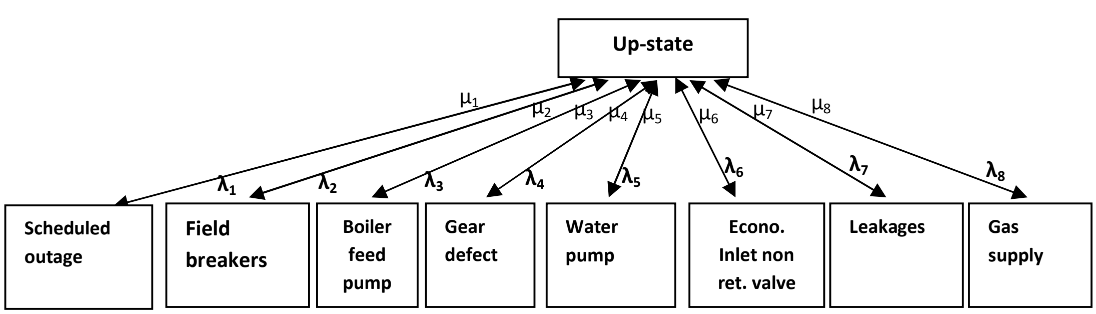

Fig. 3. Proposed thermal station model

Table 1. State probability value & frequency of encountering states

State number	State probability		Rate of departure	Frequency of state
0	$\mu_1\mu_2\mu_3\mu_4\mu_5\mu_6\mu_7\mu_8/D$	d_0/D	$\lambda_1+\lambda_2+\cdots+\lambda_8$	$(\lambda_1+\lambda_2+\cdots+\lambda_8)d_0/D$
1	$\lambda_1\mu_2\mu_3\mu_4\mu_5\mu_6\mu_7\mu_8/D$	d_1/D	μ_1	$\mu_1 d_1/D$
2	$\mu_1\lambda_2\mu_3\mu_4\mu_5\mu_6\mu_7\mu_8/D$	d_2/D	μ_2	$\mu_2 d_2/D$
3	$\mu_1\mu_2\lambda_3\mu_4\mu_5\mu_6\mu_7\mu_8/D$	d_3/D	μ_3	$\mu_3 d_3/D$
4	$\mu_1\mu_2\mu_3\lambda_4\mu_5\mu_6\mu_7\mu_8/D$	d_4/D	μ_4	$\mu_4 d_4/D$
5	$\mu_1\mu_2\mu_3\mu_4\lambda_5\mu_6\mu_7\mu_8/D$	d_5/D	μ_5	$\mu_5 d_5/D$
6	$\mu_1\mu_2\mu_3\mu_4\mu_5\lambda_6\mu_7\mu_8/D$	d_6/D	μ_6	$\mu_6 d_6/D$
7	$\mu_1\mu_2\mu_3\mu_4\mu_5\mu_6\lambda_7\mu_8/D$	d_7/D	μ_7	$\mu_7 d_7/D$
8	$\mu_1\mu_2\mu_3\mu_4\mu_5\mu_6\mu_7\lambda_8/D$	d_8/D	μ_8	$\mu_8 d_8/D$

Where $D = d_0 + d_1 + d_2 + d_3 + d_4 + d_5 + d_6 + d_7 + d_8$

Total uptime is given as

$$\varphi_u = NT - \sum_{j=1}^{Nf} T\Delta_j \tag{7}$$

Mean failure rate (hour) is

$$\lambda = \frac{\Phi_n}{\beta_t} \tag{8}$$

Expected number of failure (Mean Time before Failure) is given as,

$$m = \frac{1}{\lambda} \tag{9}$$

Mean time to repair (MTTR) (hours) is given

$$\varsigma = \frac{\Psi_i}{\Phi_n} \tag{10}$$

Expected mean repair rate

$$\mu = \frac{1}{\varsigma} \tag{11}$$

Where

Φ_n= number of failures, β_t=total operating time between maintenance in the year, ψ_i = total outage hour per year, NT= total time for one year, m, can be expressed in terms of reliability

$$m = \int_{\circ}^{\infty} R_1(dt) \tag{12}$$

$$R_{(t)} = e^{-\lambda_t} \tag{13}$$

3. RESULTS AND DISCUSSION

3.1 Response of Two State Markov Model

Reliability is the probability of the unit without failure, state 0 and 1 are the two states that are without failure. Availability is the probability that the unit is in state 0, thus: Reliability, R= P_o +P_1 and availability (A) = P_0. Using the two state model analysis in analyzing those reliability data; the analysis was done on the entire factors that has impended generation and have caused interruption to the flow of power generation. This includes human, material and equipment in general. Base on this perception Fig 4-7 highlight its effects on availability and reliability on those units.

Reliability and availability of the turbines was assessed using two state models as shown in Table 2 and Figs. 4-5, the station availability figures of ST01 for the year 2003 is 0.929 and its failure rate (λ) is 0.049 in 83.7 hrs; repair rate was 0.64 and failure rate (λ_{max}) for ST06 is 0.1396 in 2007 while the repair rate is 0.7862 in 55.3 hrs. For the year 2007, ST02 (λ_{min}) has failure rate of 0.05308 in 116 hrs while, ST02, GT01, GT02 in ∞ *hrs is nil (completely u navailable)* between (2008-2011); ST06 has failure rate (λ) of 0.1163 in 52 hrs in 2006 while the repair rate was 0.1806.

3.2 Response of Three State Markov Model

Reliability analysis using three state model was carried out on some vital mechanical system in the turbines, and their failure rate was assessed as shown in Figs. 6-7. The reliability and availability for Steam Turbine 01, Steam Turbine

02, and Steam Turbine 06, Gas Turbine 01 and 02, presented in Tables 3-7 was therefore calculated using probability approach from the three state Markov models of equations 1-13. It is obvious that equipment and human inefficiency factors may have influenced these results.

Table 2a. Two state model result show complete results of analysis of reliability for 2003

Year	2003				
Units	**ST01**	**ST02**	**ST06**	**GT01**	**GT02**
MTBF (hrs)	2034	1584	1083.43	929.14	564
MTTR (hrs)	156	168	168	322.29	312
Availability	0..929	0..9043	0.8658	0.7418	0.6438
Unavailability	0.071	0.0957	0.1343	0.258	0.3562
Failure rate	0.049	0.063	0.0923	0.108	0.1773
Repair rate	0.64	0.595	0.5952	0.3103	0.3205
Reliability	0.0183	0.00674	0.000912	0.000912	0.0000454

Table 2b. Two state model result show complete results of analysis of reliability for 2004

Year	2004				
Units	**ST01**	**ST02**	**ST06**	**GT01**	**GT02**
MTBF (hrs)	2600	1128	2424	1281.6	267.69
MTTR (hrs)	320	3252	496	470.4	406.15
Availability	0.8903	0.2577	0.83	0.7316	0.397
Unavailability	0.1097	0.7423	0.17	0.2684	0.6028
Failure rate	0.0385	0.0887	0.0413	0.078	0.3736
Repair rate	0.3125	0.0308	0.2016	0.2026	0.2462
Reliability	0.0498	0.135	0.0498	0.000000121	0.00019

Table 2c. Two state model result show complete results of analysis of reliability for 2005

Year	2005				
Units	**ST01**	**ST02**	**ST06**	**GT01**	**GT02**
MTBF (hrs)	2094	1252.8	748.7	_	_
MTTR (hrs)	96	499.2	127.2	_	_
Availability	0.9561	0.7151	0.8548	_	_
Unavailability	0.0439	0.2845	0.1452	_	_
Failure rate	0.0478	0.0798	0.1336	_	_
Repair rate	1.042	0.2003	0.7862	_	_
Reliability	0.0183	0.00674	0.0000454	_	_

Table 2d. Two state model result show complete results of analysis of reliability for 2006

Year	2006				
Units	**ST01**	**ST02**	**ST06**	**GT01**	**GT02**
MTBF (hrs)	1413.4	777.222	906.333	_	_
MTTR (hrs)	338.6	196.111	553.667	_	_
Availability	0.8067	0.798	0.6083	_	_
Unavailability	0.1933	0.2019	0.3917	_	_
Failure rate	0.07075	0.129	0.1163	_	_
Repair rate	0.2953	0.5099	0.1806	_	_
Reliability	0.00674	0.000124	0.00248	_	_

Table 2e. Two state model result show complete results of analysis of reliability for 2007

Year	2007				
Units	**ST01**	**ST02**	**ST06**	**GT01**	**GT02**
MTBF (hrs)	1188	1884	715.2	_	4200
MTTR (hrs)	272	306	160.8	_	180
Availability	0.8136	0.86027	0.8165	_	0.9589
Unavailability	0.8136	0.1395	0.1835	_	0.0411
Failure rate	0.0842	0.05308	0.1398	_	0.0238
Repair rate	0.3676	0.3268	0.6219	_	0.5556
Reliability	0.00248	0.00212	0.0000454	_	0.1353

Table 2f. Two state model result show complete results of analysis of reliability for 2008

Year	2008				
Units	**ST01**	**ST02**	**ST06**	**GT01**	**GT02**
MTBF (hrs)	691.64	_	606	_	403.64
MTTR (hrs)	104.73	_	124	_	392.13
Availability	0.8685	_	0.8301	_	0.5069
Unavailability	0.1315	_	0.1699	_	0.4931
Failure rate	0.1446	_	0.1375	_	0.2477
Repair rate	0.9549	_	0.672	_	0.2546
Reliability	0.0000167	_	0.00000567	_	0.0000167

Table 2g. Two state model result show complete results of analysis of reliability for 2009

Year	2009				
Units	**ST01**	**ST02**	**ST06**	**GT01**	**GT02**
MTBF (hrs)	505.85	_	1284	_	715.2
MTTR (hrs)	168	_	176	_	160.8
Availability	0.7507	_	0.8795	_	0.8165
Unavailability	0.2493	_	0.1205	_	0.1835
Failure rate	0.1977	_	0.07788	_	0.1398
Repair rate	0.5952	_	0.5682	_	0.6219
Reliability	0.00000226	_	0.00248	_	0.0000454

Table 2h. Two state model result show complete results of analysis of reliability for 2010

Year	2010				
Units	**ST01**	**ST02**	**ST06**	**GT01**	**GT02**
MTBF (hrs)	2076	_	735	_	_
MTTR (hrs)	114	_	360	_	_
availability	0.9479	_	0.6712	_	_
unavailability	0.0521	_	0.3288	_	_
failure rate	0.0482	_	0.1361	_	_
repair rate	0.8772	_	0.2778	_	_
reliability	0.0183	_	0.00034	_	_

Table 2i. Two state model result show complete results of analysis of reliability for 2011

Year	2011				
Units	**ST01**	**ST02**	**ST06**	**GT01**	**GT02**
MTBF (hrs)	834.667	_	738.667	_	_
MTTR (hrs)	138.667	_	234.667	_	_
Availability	0.8576	_	0.7589	_	_
Unavailability	0.1424	_	0.2411	_	_
Failure rate	0.1198	_	0.1354	_	_
Repair rate	0.7212	_	0.4261	_	_
Reliability	0.00012	_	0.00012	_	_

Table 2j. Two state model result show complete results of analysis of reliability for 2012

Year	2012				
Units	**ST01**	**ST02**	**ST06**	**GT01**	**GT02**
MTBF (hrs)	667.64	1059.43	_	_	_
MTTR (hrs)	128.73	192	_	_	_
Availability	0.8383	0.8466	_	_	_
Unavailability	0.1617	0.1535	_	_	_
Failure rate	0.1498	0.0944	_	_	_
Repair rate	0.7768	0.5208	_	_	_
Reliability	0.0000167	0.000912	_	_	_

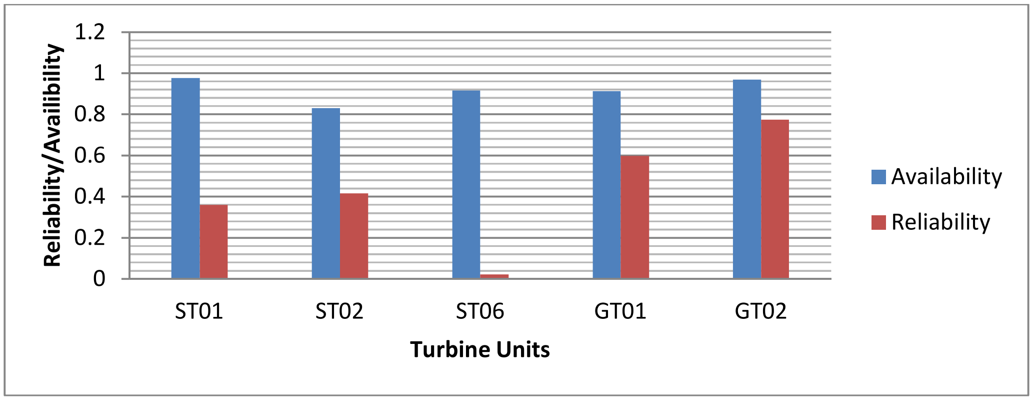

Fig. 4. Reliability and availability of turbines using two state models

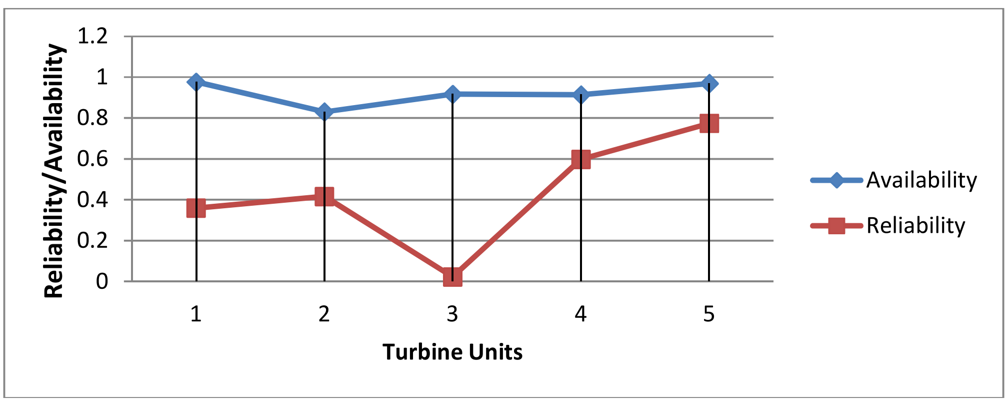

Fig. 5. Reliability and availability turbines using two state models

Station availability is gotten from the total sum of average availability figure of all the units which is 0.2477 divided by the total installed unit. Since the total installs capacity is 1020MW, 1% of this capacity is 10.20MW. Therefore, the station availability for ten years assessment is 24.77% of 1020 MW. That is 252.65MW which was the average capacity of power that is available. This is a sustainable & achievable station generation.

Figs. 8-11 compares the response of two state and three state response models, for the thermal power station to be reliable, the failure rate of equipment must be reduced to the barest minimum. Repair rate for assessment must be high to guarantee plant efficiencies. When there is equipment failure, there must be and immediate repair on the units for maximum plant performance. The repair rate for ST01, ST02 and ST06 in terms of assessment in the period studied is high, particularly ST01 and ST06. But for 2008 and 2011, ST02 was completely unavailable. More also, GT01, in eight years, the repair rate was at zero these unit was down (2005 to 2012). While ST06 and GT01, was shut down for one year; and ST02, five years.

Table 3. Failure rates, repair rates and state probability of ST01

				2003-2012					
State number	**Basic event**	**No. of occurrences**	**Total repair time (hrs)**	**MTTR (hrs)**	**MTBF hrs**	**MTTF hrs**	**Repair rate**	**Failure rate (λ)**	**State probability**
0									068550
1	Field breaker	2	504	252	4194	3942	0.003968	0.0002537	0.04828
2	Bioler Field pump	10	648	64.8	864	799.2	0.0154324	0.0001251	0.0055569
3	Gear Defect& Hood diaph	2	240	120	4320	4200	0.008333	0.0002315	0.01904
4	Water Pump	1	1	1	1	1	1	1	1
5	Econo. Inlet non Return Valve	1	120	120	8640	8520	0.008333	0.000117	0.009658
6	Leakages	7	792	113.14	1331.26	1218.1	0.00884	0.000821	0.009104
7	Dirty Air Filters	1	24	24	8640	8616	0.04167	0.000116	0.0019083
8	Gas Supplied	2	264	132	4386	4254	0.007576	0.0002351	0.02127

Reliability = $p_0 + p_1$ = 0.73378 Availability= p_0 = 0.68550

Table 4. Failure rates, repair rates and state probability of ST02

				2003-2012					
State number	**Basic event**	**No. of occurrences**	**Total repair time (hrs)**	**MTTR hrs**	**MTBF hrs**	**MTTF hrs**	**Repair rate**	**Failure rate (λ)**	**State probability**
0									
1	Field breaker	-	-	-	-	-	-	-	-
2	Bioler Field pump	3	336	168	2656	2824	0.00592	0.0003765	0.019586
3	Gear Defect& Hood diaph	1	957	957	6726	7683	0.001045	0.0001302	0.03837
4	Water Pump	4	936	234	1867.5	2101.5	0.00427	0.000476	0.034331
5	Econo. Inlet non Return Valve	1	336	336	7968	8304	0.002976	0.0001204	0.012460
6	Leakages	4	576	144	1980	2124	0.00694	0.000471	0.02090
7	Dirty Air Filters	-	-	-	-	-	-	-	-
8	Gas Supplied	1	24	24	5692	8616	0.000176	0.0001116	0.20298

Reliability = $p_0 + p_1$ = 0.30797 Availability= p_0 =0.30797

Table 5. Failure rates, repair rates and state probability of ST06

2003-2012									
State number	**Basic event**	**No. of occurrences**	**Total repair time (hrs)**	**MTTR hrs**	**MTBF hrs**	**MTTF hrs**	**Repair rate**	**Failure rate (λ)**	**State probability**
0									0.50519
1	Field breaker	-	-	-	-	-	-	-	-
2	Bioler Field pump	5	1488	2976	1370.88	1668.5	0.00336	0.000599	0.090063
3	Gear Defect& Hood diaph	4	528	132	1995	2127	0.007576	0.000470	0.031341
4	Water Pump	3	336	112	2730.7	2843	0.00893	0.000352	0.019913
5	Econo. Inlet non Return Valve	-	-	-	-	-	-	-	-
6	Leakages	14	2568	183.4	420.6	604.04	0.005453	0.00166	0.153790
7	Dirty Air Filters	4	1416	354	1717.5	2071.5	0.002825	0.000483	0.014637
8	Gas Supplied	2	120	60	4230	4290	0.01667	0.0002331	0.0070642

Reliability = $p_0 + p_1$ = 0.50519 Availability= p_0 =0.50519

Table 6. Failure rates, repair rates and state probability of GT01

2003-2012									
State number	**Basic event**	**No. of occurrences**	**Total repair time (hrs)**	**MTTR hrs**	**MTBF hrs**	**MTTF hrs**	**Repair rate**	**Failure rate (λ)**	**State probability**
0									0.74544
1	Field breaker	-	-	-	-	-	-	-	-
2	Bioler Field pump	-	-	-	-	-	-	-	-
3	Gear Defect& Hood diaph	-	-	-	-	-	-	-	-
4	Water Pump	-	-	-	-	-	-	-	-
5	Econo. Inlet non Return Valve	-	-	-	-	-	-	-	-
6	Leakages	-	-	-	-	-	-	-	-
7	Dirty Air Filters	9	3724	413.78	500.24	914.02	0.0024167	0.0010941	0.33748
8	Gas Supplied	-	-	-	-	-	-	-	-

Reliability = $p_0 + p_1$ = 0.74844 Availability= p_0 =0.74544

Table 7. Failure rates, repair rates and state probability of GT02

			2003-2012						
State number	**Basic event**	**No. of occurrences**	**Total repair time (hrs)**	**MTTR hrs**	**MTBF hrs**	**MTTF hrs**	**Repair rate**	**Failure rate (λ)**	**State probability**
0									0.66039
1	Field breaker	-	-	-	-	-	-	-	-
2	Bioler Field pump	-	-	-	-	-	-	-	-
3	Gear Defect& Hood diaph	-	-	-	-	-	-	-	-
4	Water Pump	-	-	-	-	-	-	-	-
5	Econo. Inlet non Return Valve	-	-	-	-	-	-	-	-
6	Leakages	1	96	96	8448	8544	0.01042	0.000117	0.0074151
7	Dirty Air Filters	2	3888	1944	1404	3348	0.0005144	0.0002987	0.38347
8	Gas Supplied	-	-	-	-	-	-	-	-

Reliability = $p_0 + p_1$ = 0.0.66039 Availability= p_0 =0.66039

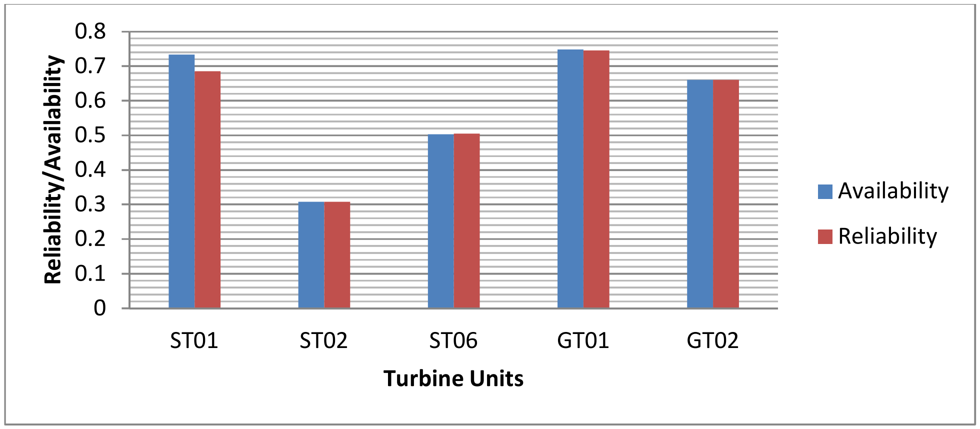

Fig. 6. Availability and reliability of turbines using three state models

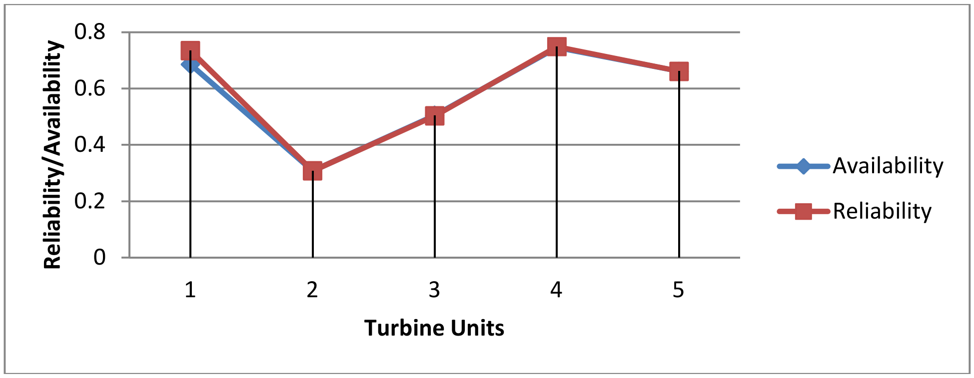

Fig. 7. Availability and reliability of turbines using three state models

The station availability for Steam turbine unit (ST02) is low between 2003 and 2012. For, in between 2008 to 2011 (MTBF) was nil. On this the period, ST02 was shut down due to high vibration noticed from the generator. For Gas turbine unit (GT01); (MTTR) was also nil between (2005 and 2012); reasons was that these unit was on planned outage as a result of dirty air intakes from the combustion chamber caused by dirty filters. GT02 was on complete outage for eight years due to fault from the generator transformer. The nil periods showed that the unit was on outage schedule; this outage was either planned or forced.

Reliability analysis using three state models was carried out on some vital mechanical system in the turbines, and their failure rate was assessed. Using the two state model analysis in analyzing those reliability data; the analysis was done on the entire factors that has impends generation and have caused interruption to the flow of power generation. This includes human, material and equipment in general. Base on this perception Figs. 4 – 11 highlight its effects on availability and reliability on those units. Availability is higher on the three state model curve reason because here fewer mechanical equipment is been considered. For the two state model this work is all inclusive i.e. the entire system. So in none shell using three state markov models only fewer failed equipment failure can be consider and when the parameters are too much the analysis becomes cumbersome because of the model analysis.

For this period, there was no power generation from the units. These two transition stage, Mean Time to Repair (MTTR) and Mean Time before Failure (MTBF) are the basic parameter that determine reliability of power station, reason because they determine the maximum or minimum hour of plant usage. For power station on this period, the station reliability assessment was low. The analysis also shows low generation capability and as such affect reliability. The period that some of the units where on planned outage; precisely the year 2008, the station generation were low, there was a slight increase of station reliability 2010. While the availability was 0.9479, this was due to in-house plant maintenance from the fund released by the then federal government for plant maintenance, this now dropped in 2012.

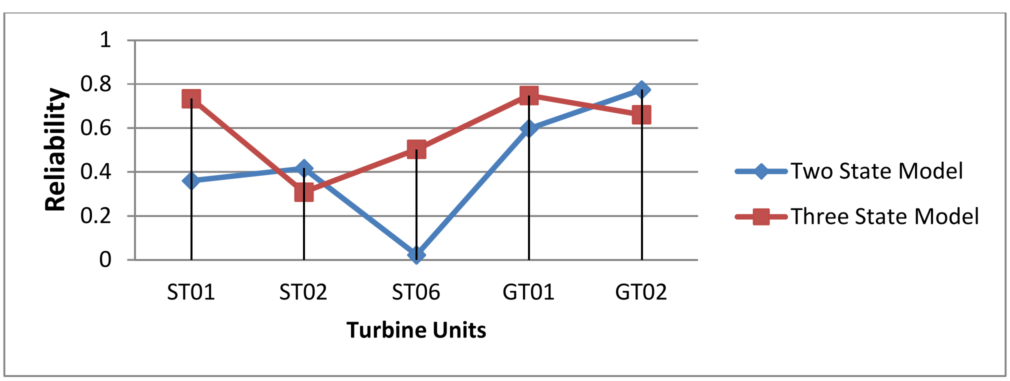

Fig. 8. Reliability of turbines for both models

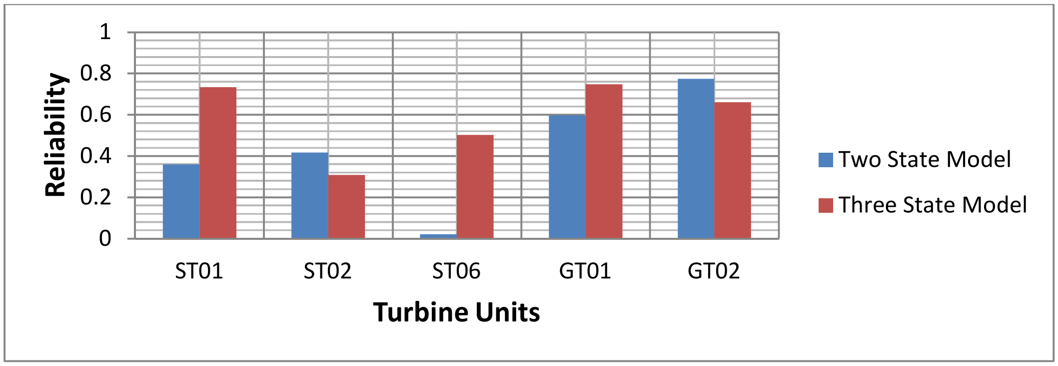

Fig. 9. Reliability of turbine using both models

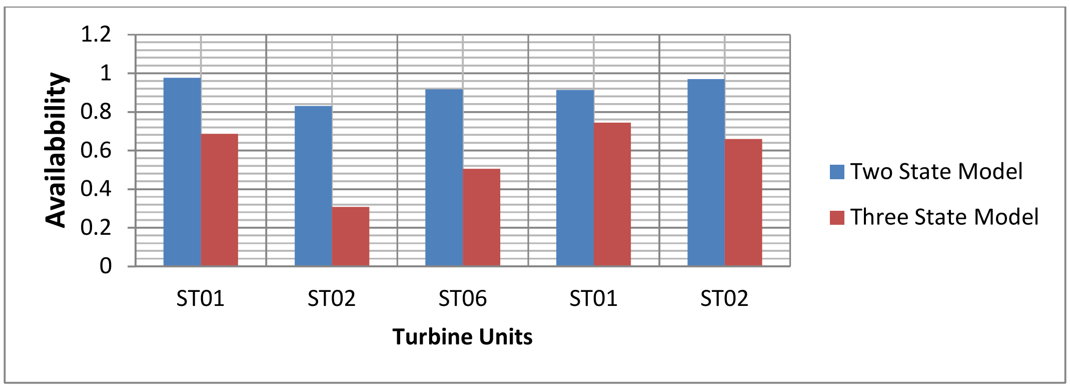

Fig. 10. Availability of turbines for both models

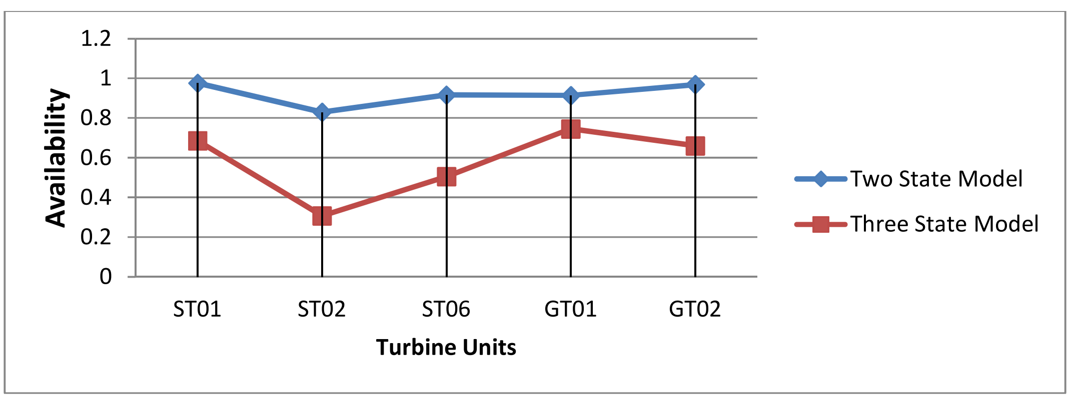

Fig. 11. Availability of Turbines for both models

4. CONCLUSION

Analysis using three state models was carried out on some vital mechanical system in the turbines, and their failure rate was determined. Using the two state model, these analysis was done on data generated from failure of some subsystem that have caused interruption to power generation. This includes human, material and equipment in general and the numbers hours this have affected power generation was also noted. Availability is higher on the three state model because fewer mechanical equipment is being considered. Unlike in the two state model where process of evaluation is direct, generally in the three state model both force and scheduled outages can easily be capture which make analysis to be elaborate.

Availability assessment of steam and gas turbine units of a thermal power station has been assessed using Markovian Approach. The availability analysis of the system is carried out to determine the effect of failure and repair rates of each subsystem on overall performance of system concerned. The failure rate and repair rate data where computed and from the result of analysis of operational data, maximum outage is seen to be scheduled in all units. Also the scheduled outage is greater in ST06. The scheduled outage which is in this study planned maintenance should suppose to be similar in all units but seem different in all the units. Effects of leakages along the lines is most paramount in all the unit with ST01 and ST06 most affected 762 hrs and 2568 respectively.

This study is beneficial to supervisors and managers as it optimize their maintenance activities, it is also helpful for them in taking decisions for appropriate maintenance policy in the process industries, this study therefore contributes to long term availability of the thermal plant, reduce the post overhaul failures and increases annual savings per unit. In general, for the thermal power station to be reliable, the failure rate of equipment must be reduced to the barest minimum. Repair rate for assessment must be high to guarantee plant efficiencies. When there is equipment failure, there must be an immediate repair on the units for maximum plant performance. Being more than 37 years old thermal power station, plant (equipment) and human in-efficiency both contribute to low performance of plant, which in result lower the reliability.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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