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Reliability & Availability Evaluation of Turbo generators using Markov Approach of a Thermal Power Plant

Ch.Sai Amulya[1], Dr.M.Srinivasa Rao[2]

[1]M.Tech Student, Department of Mechanical Engineering, GMRIT, Rajam, Srikakulam, India.

[2]Professor, Department of Mechanical Engineering, GMRIT, Rajam, Srikakulam, India.

ABSTRACT

The Reliability of a power plant depends on the reliability of its various components and their operations. Reliability is the probability of systems to perform required functions for a desired period of time without failure in specified environments, whereas Availability represents the probability that the system is operable when required without undergoing a repair action. A Thermal Power Plant consists of a complex network of units. Failures of different components ultimately lead to the turn off of the units, which causes significant loss of availability of the units. In this paper a thermal power plant is analyzed by taking the failure and repair rates of various components like turbo generators for evaluating the reliability and availability using Markov approach. For this purpose a Thermal power plant in Visakhapatnam Steel Plant.

Keywords: Reliability, Availability, Thermal Power Plant, Markov approach

1. INTRODUCTION

The reliability prediction of manufacturing systems is becoming increasingly significant because of factors such as cost, risk of hazard, competition, demand, and usage of new technology. High reliability level is desirable to diminish the overall costs of production and risk of hazards of large, complex and sophisticated systems such as a thermal power plant. Steel industry is a power intensive industry and requires uninterrupted power supply. This requires a reliable confined power source which can supply power to all important loads of the plant all the time for safe and smooth operation of the steel plant. Any partial outage of the system due to breakdown, shutdown or other reasons, results in the short fall of power which is making the plant unreliable in operation.

Gupta et al. [1] stated that it is necessary to maintain the thermal power plant to provide reliable and uninterrupted electrical supply for a long time. Buzacott et.al.,[2] explained that reliability block diagrams of a system of independent units could be reduced to find the reliability of a non-maintained system, reduced to find the availability of the repairable system, MTBF and availability of the individual units. John et.al., [3] found the usage of the Markov approach for calculating the failure time measures such as availability, mean cycle time, and mean time to first failure to analyze repairable and also discussed various special techniques such as lumping states or decomposing the system into independent subsystems can simplify the analysis considerably for a large system.Papazoglou et.al., [4] used a Markov-chain model and the numerical difficulties associated with large transition-probability matrices were reduced by a systematic ordering of the system states and also described a technique for the systematic merging of processes corresponding to systems exhibiting symmetries.Papadopoulos et.al., [5] described the concept of frequency of failures during the useful life period was programmed by mathematical reliability model. It starts from the basic configuration component failure-rate data and uses the tie-set approach to carry out the reliability analysis of the system. Allan et.al., [6] presented an approach for determining the effect of terminal station failures on station-originated outages and the results used to assess the reliability of the terminal stations themselves and as input data to a composite system reliability evaluation technique.

Soeth et.al., [7] discussed about Reliability of generator system by using Markov models. Variations outage postponability distributions and their impact on unit indices were also investigated.Majeed et.al., [8] introduced a Markov reliability model for Dokan hydro power station by studying the operational data of this station for period of five years. The availability and reliability of individual units and for the power plant were evaluated by taking into account different case studies. Sahu et.al., [9] evaluated the Markov models which are used to obtain unit reliability and availability from the operational data of Pathri Power Stations (India). The most important reliability indices are found namely failure rate (λ), repair rate (μ), MTTR, MTBF, MTTF through data collection and analysis. Failure rate, repair rate of all the states were found from the classified data. Dash et.al., [10] computed Reliability and availability of the individual generating units of Balimela Hydro Electric Power Station were evaluated and analyzed by using a Markov model and also this paper determined the reliability 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) .

From the above literature survey, it is identified that the Thermal Power Plant consists of complex network of units. There occur failures at different components of the units this ultimately leads to the turn off of the units, this causes considerable loss of availability of the units. If we consider the outages of the units which affect the availability of the plant and the reasons behind it, the availability of the units can be improved. To mitigate these limitations, in this paper Markov approach is used to evaluate the reliability and availability of thermal systems as follows. In this work Visakhapatnam Steel Plant has been taken as a case study.

The main objective of of this paper is to evaluate the MTTR, MTTF, failure rate, repair rate and the probabilities of the various defined failure states of turbo generators in thermal power plant of the Visakhapatnam Steel plant. For this computation a Two state Markov model is used. There by reliability and availability of the individual units over a period of five years of Turbo generators is analysed.

2. METHODOLOGY

In this work the failure and repair rates of five turbo generators are collected from maintenance log books of the thermal power plant. All possible states of these turbo generators are considered and modelled by using Markov approach as described below.

A Markov chain is a process that undergoes transitions from one state to another on a state space. The probability distribution of the next state merely depends on the current state and not on the series of events that preceded it. This specific kind of “memorylessness” is called Markov property. Markov chains have many applications of real-world processes. An assumption is made that a repaired unit is as good as new in performance, for a definite period.

The state transition diagram using Markov model has been constructed by considering thirteen states of each turbo generator as shown in Figure 1:

A brief description of the thirteen states is mentioned below:

- State 1: Planned/ scheduled outage – preventive maintenance before the occurrence of failure
- State 2: Lube oil system fault – occurs when there is a starvation of oil
- State 3: Jacking oil system fault – occurs when there is insufficient oil for lifting the shaft
- State 4: Governor System fault – takes feedback of all problems from all the systems
- State 5: Control valve fault – occurs when control valve positions may be in extreme positions
- State 6: Vibration fault – occurs when there is misalignment in the system
- State 7: HP steam temperature, low – occurs when the temperature is below 440oC
- State 8: HP steam pressure low – occurs when pressure becomes below 85 kg/cm2

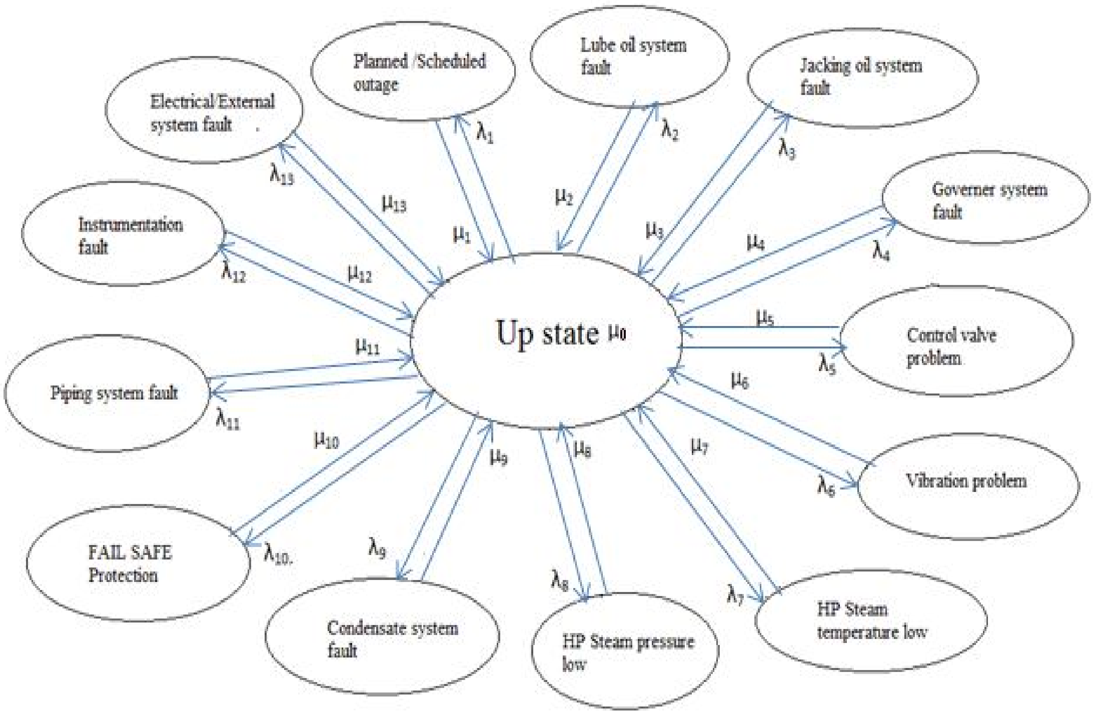

Figure 1 State transition diagram of Turbo Generators

State 9: Condensate system fault / vacuum low– occurs when improper condensation takes place or condenser vacuum is very low
State 10: FAIL SAFE protection – machine trips automatically for the safety of the machine
State 11: Piping system fault – occurs when leakages in a piping system
State 12: Instrumentation fault – occurs when there is a malfunction of probes or spurious problems
State 13: Generator fault/Electrical system /External fault – occurs when there is an earth fault/ frequency problems/ reverse power

3. DATA COLLECTION

The required data of turbo generators were collected over a period of five years from maintenance log books. The sample data of TG 4 (2015-16) is shown below in Table 1. This one year data used for calculation of reliability, availability and other parameters as a model calculation has been presented in this paper. By following the similar procedure, the total reliability, availability and other parameters for all five years have been calculated for all turbo generators as described below.

Modelling approach:

The objective of this work is to find out the state probabilities of each turbo generator to evaluate its reliability and availability. For this purpose the following procedural steps have been carried out.
The objective is to find the probability of the system being in each state as a function of time.

Let us define,
Pi (t) Probability of finding a generator in state ‘i’
Where ‘i’ = 0 (upstate)
= 1 (downsate)
λ- Transition rate (failure rate) from state 0 to state1.
μ- Transition rate (repair rate) from state 1 to state 0.
$1/\lambda$ -Average time a generator stays in upstate.
$1/\mu$ -Average time a generator stays in down state.

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From the above state transition a diagram every time two states only been considered that is from upstate to downstate (any of the fault condition). By using Markov process we can derive the state equations and the probabilities of the states can be derived.

By using Markov process we can derive the state equations and the probabilities of all the states as described below. State equation for one state is shown below:

For steady state solution

$$\lim_{t\to\infty}\frac{dP_i(t)}{dt}=0$$

$$-\lambda_1 P_0(t)+\mu_1 P_1(t)=0$$

$$\lambda_1 P_0(t)=\mu_1 P_1(t)$$

$$P_1(t)=\frac{\lambda_1}{\mu_1}P_0(t)$$

Similarly, by solving for other states, the following are the values of all state probabilities are shown below

$$\frac{dP_1(t)}{dt}=-\lambda_1 P_0(t)+\mu_1 P_1(t)$$

$$\frac{dP_2(t)}{dt}=-\lambda_2 P_0(t)+\mu_2 P_2(t)$$

$$\frac{dP_3(t)}{dt}=-\lambda_3 P_0(t)+\mu_3 P_3(t)$$

$$\frac{dP_4(t)}{dt}=-\lambda_4 P_0(t)+\mu_4 P_4(t)$$

...

$$\frac{dP_5(t)}{dt}=-\lambda_5 P_0(t)+\mu_5 P_5(t)$$

$$\frac{dP_6(t)}{dt}=-\lambda_6 P_0(t)+\mu_6 P_6(t)$$

$$\frac{dP_7(t)}{dt}=-\lambda_7 P_0(t)+\mu_7 P_7(t)$$

$$\frac{dP_8(t)}{dt}=-\lambda_8 P_0(t)+\mu_8 P_8(t)$$

$$\frac{dP_9(t)}{dt}=-\lambda_9 P_0(t)+\mu_9 P_9(t)$$

$$\frac{dP_{10}(t)}{dt}=-\lambda_{10} P_0(t)+\mu_{10} P_{10}(t)$$

$$\frac{dP_{11}(t)}{dt}=-\lambda_{11} P_0(t)+\mu_{11} P_{11}(t)$$

$$\frac{dP_{12}(t)}{dt}=-\lambda_{12} P_0(t)+\mu_{12} P_{12}(t)$$

$$\frac{dP_{13}(t)}{dt}=-\lambda_{13} P_0(t)+\mu_{13} P_{13}(t)$$

Substitute equations (2) to (14) in equation (1)

$$P_0(t)+P_1(t)+P_2(t)+P_3(t)+P_4(t)+P_5(t)+P_6(t)+P_7(t)+P_8(t)+P_9(t)+P_{10}(t)+P_{11}(t)+P_{12}(t)+P_{13}(t)=1$$

As per the model calculation shown above for state probability $P_1(t)$, the remaining state probabilities have been derived and incorporated as shown in Table 2

Table 1: Failure data of TG-4 for the year 2015-2016

S	From(hrs)	To (hrs)	Duration(hrs)	Remarks	State No.
1	28.09.15(5:35)	28.09.15(14:15)	8:40	Planned/Scheduled outage	1
2	01.09.15(15:50)	03.09.15(14:00)	46:10:00	Planned/Scheduled outage	1
3	30:04:16(3:55)	30:04:16(7:50)	4:00	Governor system fault	4
4	26.04.16(4:15)	26.04.16(8:35)	4:20	Lube oil system fault	2
5	24.04.16(4:05)	24.04.16(10:00)	6:00	Lube oil system fault	2
6	10.04.16(4:20)	10.04.16(9:00)	4:40	Lube oil system fault	2
7	31.03.16(14:30)	31.03.16(18:20)	3:40	External electrical system fault	13
8	29.01.16(7:45)	15.02.16(22:00)	398:15:00	Generator Fault	13
9	6.11.15(10:20)	7.11.15(11:00)	0:40	Piping system fault	11
10	29.08.15(10:20)	29.08.15(11:45)	1:20	External electrical system fault	13
11	14.07.15(10:30)	18.07.15(10:40)	96:10:00	External electrical system fault	13
12	21.06.15(6:30)	24.06.15(13:45)	79:15:00	External electrical system fault	13
13	19.06.15(17:40)	20.06.15(18:35)	23:05	External electrical system fault	13

Table 2: State Probabilities

State No.	State Probabilities	
0	$\mu_1\mu_2\mu_3\mu_4\mu_5\mu_6\mu_7\mu_8\mu_9\mu_{10}\mu_{11}\mu_{12}\mu_{13}$	d_0/D
1	$\lambda_1\mu_2\mu_3\mu_4\mu_5\mu_6\mu_7\mu_8\mu_9\mu_{10}\mu_{11}\mu_{12}\mu_{13}$	d_1/D
2	$\mu_1\lambda_2\mu_3\mu_4\mu_5\mu_6\mu_7\mu_8\mu_9\mu_{10}\mu_{11}\mu_{12}\mu_{13}$	d_2/D
3	$\mu_1\mu_2\lambda_3\mu_4\mu_5\mu_6\mu_7\mu_8\mu_9\mu_{10}\mu_{11}\mu_{12}\mu_{13}$	d_3/D
4	$\mu_1\mu_2\mu_3\lambda_4\mu_5\mu_6\mu_7\mu_8\mu_9\mu_{10}\mu_{11}\mu_{12}\mu_{13}$	d_4/D
5	$\mu_1\mu_2\mu_3\mu_4\lambda_5\mu_6\mu_7\mu_8\mu_9\mu_{10}\mu_{11}\mu_{12}\mu_{13}$	d_5/D
6	$\mu_1\mu_2\mu_3\mu_4\mu_5\lambda_6\mu_7\mu_8\mu_9\mu_{10}\mu_{11}\mu_{12}\mu_{13}$	d_6/D
7	$\mu_1\mu_2\mu_3\mu_4\mu_5\mu_6\lambda_7\mu_8\mu_9\mu_{10}\mu_{11}\mu_{12}\mu_{13}$	d_7/D
8	$\mu_1\mu_2\mu_3\mu_4\mu_5\mu_6\mu_7\lambda_8\mu_9\mu_{10}\mu_{11}\mu_{12}\mu_{13}$	d_8/D
9	$\mu_1\mu_2\mu_3\mu_4\mu_5\mu_6\mu_7\mu_8\lambda_9\mu_{10}\mu_{11}\mu_{12}\mu_{13}$	d_9/D
10	$\mu_1\mu_2\mu_3\mu_4\mu_5\mu_6\mu_7\mu_8\mu_9\lambda_{10}\mu_{11}\mu_{12}\mu_{13}$	d_{10}/D
11	$\mu_1\mu_2\mu_3\mu_4\mu_5\mu_6\mu_7\mu_8\mu_9\mu_{10}\lambda_{11}\mu_{12}\mu_{13}$	d_{11}/D
12	$\mu_1\mu_2\mu_3\mu_4\mu_5\mu_6\mu_7\mu_8\mu_9\mu_{10}\mu_{11}\lambda_{12}\mu_{13}$	d_{12}/D
13	$\mu_1\mu_2\mu_3\mu_4\mu_5\mu_6\mu_7\mu_8\mu_9\mu_{10}\mu_{11}\mu_{12}\lambda_{13}$	d_{13}/D

$$D= d_0+d_1+ d_2+ d_3+ d_4+ d_5+ d_6+ d_7+ d_8+ d_9+ d_{10}+ d_{11}+ d_{12}+ d_{13}$$

Table 3: Sample calculations of Turbo Generator 4 for the year 2015-16

TG 4 Availability Evaluation During 2015-2016									
State No.	No. of Occu-rences (N)	Total down time (hrs)	Service hours	MTTR (hrs)	MTTF (hrs)	μ (repair rate)	λ (failure rate)	d	P
0								0.0001944	0.856
1	2	54:50:00	8705:00:00	27:25:00	4352:30:00	0.036	2.29E-04	1.24E-06	0.00544
2	3	15:00:00	8745:00:00	5:00:00	2915:00:00	0.2	3.43E-04	3.33E-07	0.00147
4	1	4:00:00	8756:00:00	4:00:00	8756:00:00	0.25	1.14E-04	8.86E-08	3.90E-04
6	1	0:30:00	8759:30:00	0:30:00	8759:30:00	2	1.14E-04	7.39E-09	3.25E-05
11	1	0:40:00	8758:30:00	0:40:00	8758:30:00	1.5	1.14E-04	1.48E-08	6.50E-05
13	9	247:05:00	8513:05:00	27:27:13	945:53:53	0.036	1.15E-03	3.11E-05	0.137
		321:25:00							

4. Mathematical Calculations

The Probability of each unit being in upstate is given as $P_0(t) = d_0/D$ The availability and reliabilities of turbo generators are computed based on the state probabilities. Calculations for Turbo Generator-4(2015-16) for state 1 is shown below in Table 3.

Model calculation for Turbo Generator 4 for state 1:

Total down Time = Σ (down time due to individual failure states) = 321:25:00 hrs
No. of Outage occurrences in a specified time interval = N = 2
Service hours (SH) = 8760 - Total down Time =8760:00:00-321:25:00 = 8705:00:00 hrs
Mean Time to Failure (MTTF) = SH/ N =8705:00:00/ 2 = 4352:30:00 hrs
Mean Time to Repair (MTTR) = Total down Time / N = 54:50:00/ 2 = 27:25:00 hrs
Failure Rate (λ) = 1 / MTTF = 1/4352:30:00 = 0.000229
Repair Rate (μ) = 1 / MTTR = 1/27:25:00 = 0.036
Availability (A) = $\mu / (\lambda + \mu) = (d_0+d_1)/\Sigma D = P_0+P_1 = 0.856+0.00544$ = 0.861
Reliability (R) = $d_0/\Sigma D = P_0$ = 0.856

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5. Results and discussions

From the above calculations as performed in the previous section the following results have been obtained as shown in the following figures.

Reliability and Availability of five turbo generators for five years data are shown from Figure 2 to Figure 6:

Turbogenerator 1:

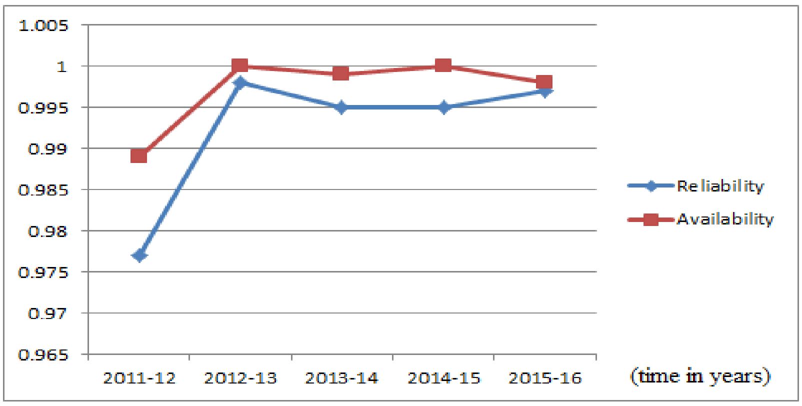

Figure 2 Reliability and Availability of TG 1

The probabilities of states (0,1,2,3,9,10,11,12,13) obtained from the above analysis are 0.889, 0.000102, 0.0291, 0.00584, 0.00253, 0.00024, 0.00102, 0.000798, 0.0713 of TG 1 during 2011-16. Reliability is less during 2011-12 due to the generator fault, lube oil system fault, external electrical system fault, condensate system fault and Instrumentation system fault.

Turbogenerator 2:

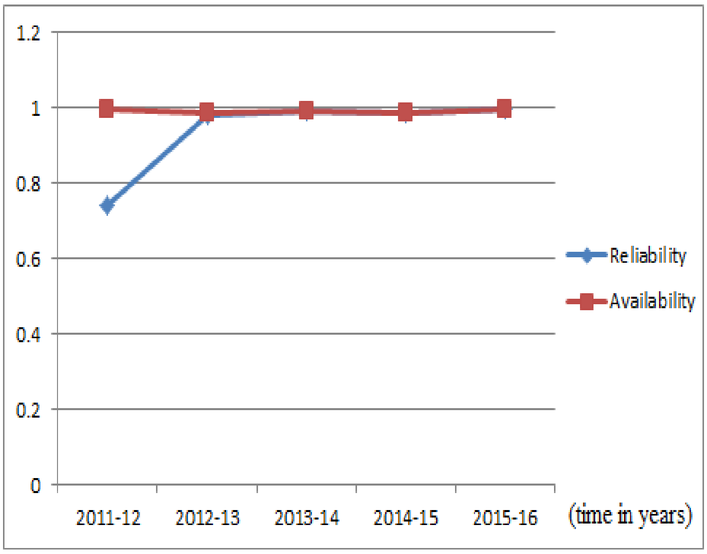

Figure 3 Reliability and Availability of TG 2

The probabilities of states (0,1,2,4,5,6,9,11,12,13) obtained from the above analysis are 0.798, 0.00249, 0.151, 0.00323, 0.0111, 0.00606, 0.0135, 0.00949, 0.000243, 0.0104 of TG 2 during 2011-16. Reliability is less during 2013-14 reliability due to jacking oil fault, lube oil system fault, piping system fault, generator fault, external electrical system fault and mechanical system fault.

Turbogenerator 3:

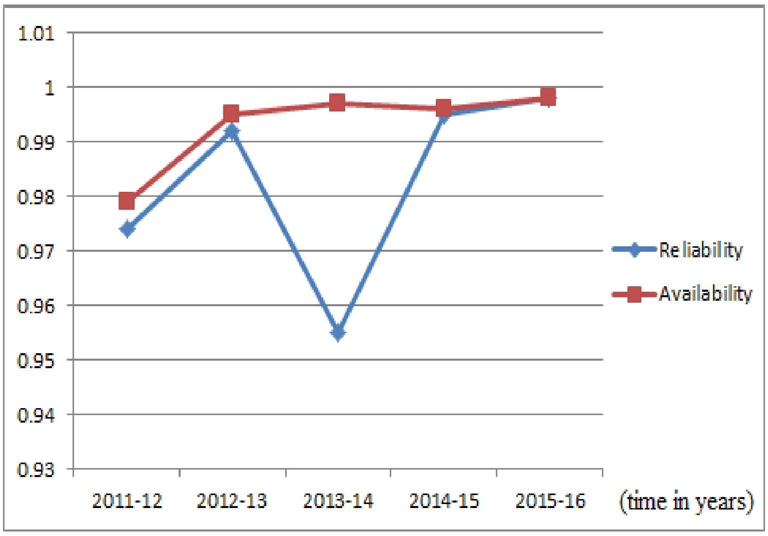

Figure 4 Reliability and Availability of TG 3

The probabilities of states (0,1,2,6,7,9,10,11,13) obtained from the above analysis are 0.732, 0.00237, 0.00237, 0.00854, 0.000118, 0.0341, 0.000886, 0.000167, 0.158 of TG 3 during 2011-16. Reliability is less during 2013-14 reliability due to generator fault, external electrical system fault and mechanical system fault.

Turbogenerator 4:

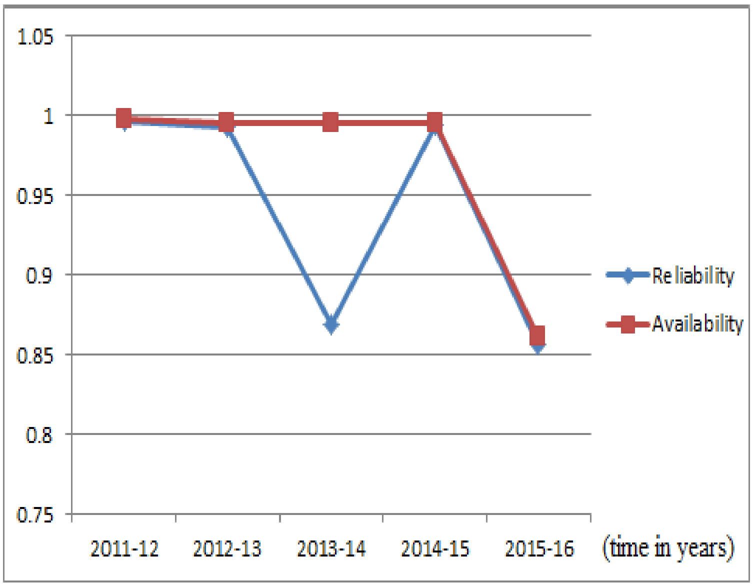

Figure 5 Reliability and Availability of TG 4

The probabilities of states (0,1,2,4,6,9,11,12,13) obtained from the above analysis are 0.975, 0.0109, 0.000104, 0.0000311, 0.000275, 0.000275, 0.0000519, 0.000335, 0.0132 of TG 4 during 2011-16 . Reliability is less during 2013-14 due to lube oil system fault, governor system fault, vibration fault, piping system fault, generator fault and external electrical faults.

Turbogenerator 5:

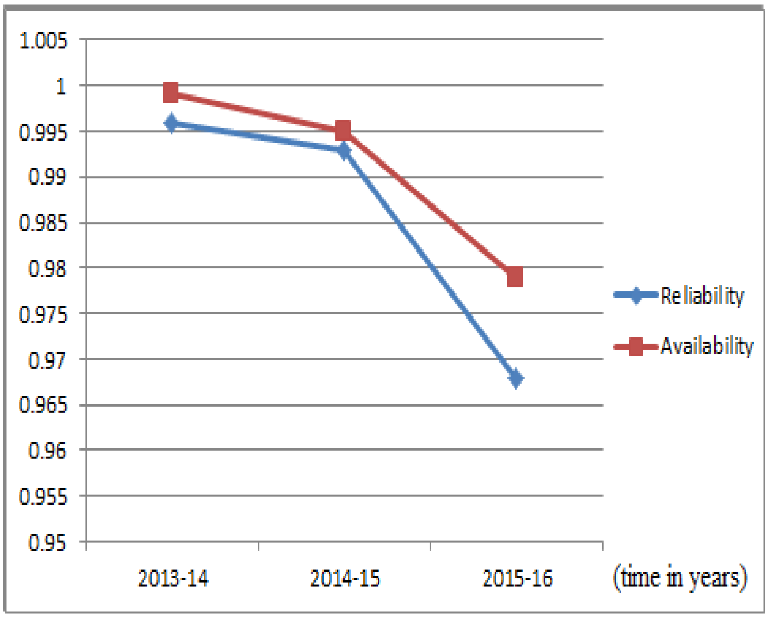

Figure 6 Reliability and Availability of TG 5

The probabilities of states (0,1,2,6,7,11,12,13) obtained from the above analysis are 0.5098, 0.00795, 0.00078, 0.0419, 0.00070, 0.0107, 0.00034, 0.4276 of TG 5 during 2013-16 . Reliability is less during 2015-16 due to HP steam temp. low, Piping system fault, Lube oil system fault, Excitation system fault, and External electrical system fault

6. CONCLUSION

In this paper a thermal power plant is analyzed by taking the failure and repair rates of various components like turbo generators for evaluating the reliability and availability using a state Markov approach. For this purpose a Thermal power plant in Visakhapatnam Steel Plant is taken as a case study and the required data over the period of five years was collected. All the states were analysed and their probabilities were calculated through a mathematical modelling to calculate the reliability and availability of turbo generators. The obtained results are analysed graphically and incorporated in tables. The specific benefits that can be realized from this study are an Increase in long term availability, decrease in post overhaul failures and also appreciable annual savings per unit. This type of analysis is very cost effective for thermal power plants. The present work is very much useful for the managers, supervisors, to optimize their maintenance activities in the process industries.

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