

Maintenance Priority Evaluation of Turbine-Generator Components In A Sub-Critical Coal-Fired Power Plant

Hanumant P. Jagtap¹, Anand K. Bewoor², Ravinder Kumar^{3*}

¹Research Scholar, Zeal College of Engineering and Research, Narhe, Pune, 411041, Maharashtra, India
Email: jagtaphp@gmail.com

²Faculty, Department of Mechanical Engineering, Cummins College of Engineering for women, Pune, 411052, Maharashtra, India
Email: dranandbewoor@gmail.com

³Faculty, Department of Mechanical Engineering, Lovely Professional University, Phagwara, 144411, Punjab, India,

Email: ravinder.22218@lpu.co.in

*corresponding author: ravinder.22218@lpu.co.in

Abstract

Performance evaluation of the turbine-generator subsystem in a sub-critical power plant is presented. The major selected systems considered for the study are turbine governing, turbine lubrication, generator oil system, generator gas system, and generator excitation system. The availability simulation model is developed and solved using Laplace transformation techniques which are reported in this study. The transition diagram of the proposed model represented several states with full working capacity, reduced capacity, and failed state. The Markov based results revealed that the turbine lubrication and generator excitation subsystems are affected the system availability at most. Therefore these critical subsystems are on higher priority from a maintenance perspective.

Keywords: Availability analysis, performance evaluation, Markov Approach, Thermal power plant

1. INTRODUCTION

Availability is an important measure of system performance under defined working conditions. The incorrect maintenance work, erroneous operation, and improper design leads to random failures of thermal power plant (TPP). The defective system can be brought into operational state in shorter period. The criticality of the component/equipment/subsystem is associated with the effect of its failures on system performance. The higher the criticality level, the greater resources are used by maintenance

activity to keep the plant in operation. Therefore it is essential to examine the performance of TPP. The majorly used qualitative and quantitative methods by earlier researchers for investigating the system performance are; fault tree analysis (FTA) [1], failure mode effect analysis (FMEA)[2], functional analysis (FA) [3], reliability block diagram (RBD) [4] Markov approach [5], Monte Carlo simulation [6]. Furthermore, some studies are reported by earlier researchers related to the performance analysis of subsystems of TPP using the Markov approach and prioritized the critical equipment as per the criticality level. The subsystems of TPP includes flue gas and air system [7], steam generation system [8], turbine subsystem [9], boiler subsystem [10], furnace draft air cycle [11], water circulation system [12], coal handling unit [13]. The relevant published literature revealed that earlier researchers are continuously attempting to investigate reliability based maintenance scheduling of systems used in several process enterprises such as TPP. With the objective to enhance plant availability, the optimized availability parameters can be used to decide/modify existing maintenance schedule. It is observed that, previous studies were restricted to develop and analyze the theoretical models, but rarely few of them have tried to solve in a realistic environment. Moreover, a need of systematic approach for performance analysis of subsystems in case of TPP systems can be clearly sensed. An attempt is made to bridge the identified research gap. The present work reports, the performance evaluation of the turbine-generator (TG) system's maintenance schedule of TPP using Markov approach.

2. SYSTEM DESCRIPTION

The turbine generator system (TGS) of TPP has five subsystems in operation viz. a) Turbine Governing 'A', b) Turbine Lubrication 'B,' c) Generator oil system (cooling) 'C,' d) Generator gas system 'D,' e) Generator excitation system 'E.' The turbine governing and generator gas system have no standby available, hence its unavailability leads TG system failure. The failure of any component of turbine lubrication, generator oil system (cooling) and generator excitations system leads to run the TGS system at reduced capacity. The past failure data for the last eighteen years of the TG system was collected and categorized as the time between failure (TBF) and time to repair (TTR).

2.1 Assumptions

- a) The failure rate, repair rate of each subsystem is constant and statically independent.
- b) The repaired subsystem is like new.

c) The capacity of standby unit are same.

2.2. Performance evaluation of the turbine-generator system of DTPP

The simulation model of a turbine-generator system (TGS) is developed on the basis Markov approach. The new mathematical expressions using the Laplace transform technique are derived. The availability matrix is formed to illustrate system performance. Figure 1 shows the transition diagram of TG system. It comprises 26 states ('0' to '25') out of which '0' state represent the subsystem working with full capacity. The states from '1' to '6' represented the subsystem working with reduced capacity and '7' to '25' represented subsystem in failed state. The probability-based differential equations are derived using the Laplace transformation technique with the transition diagram.

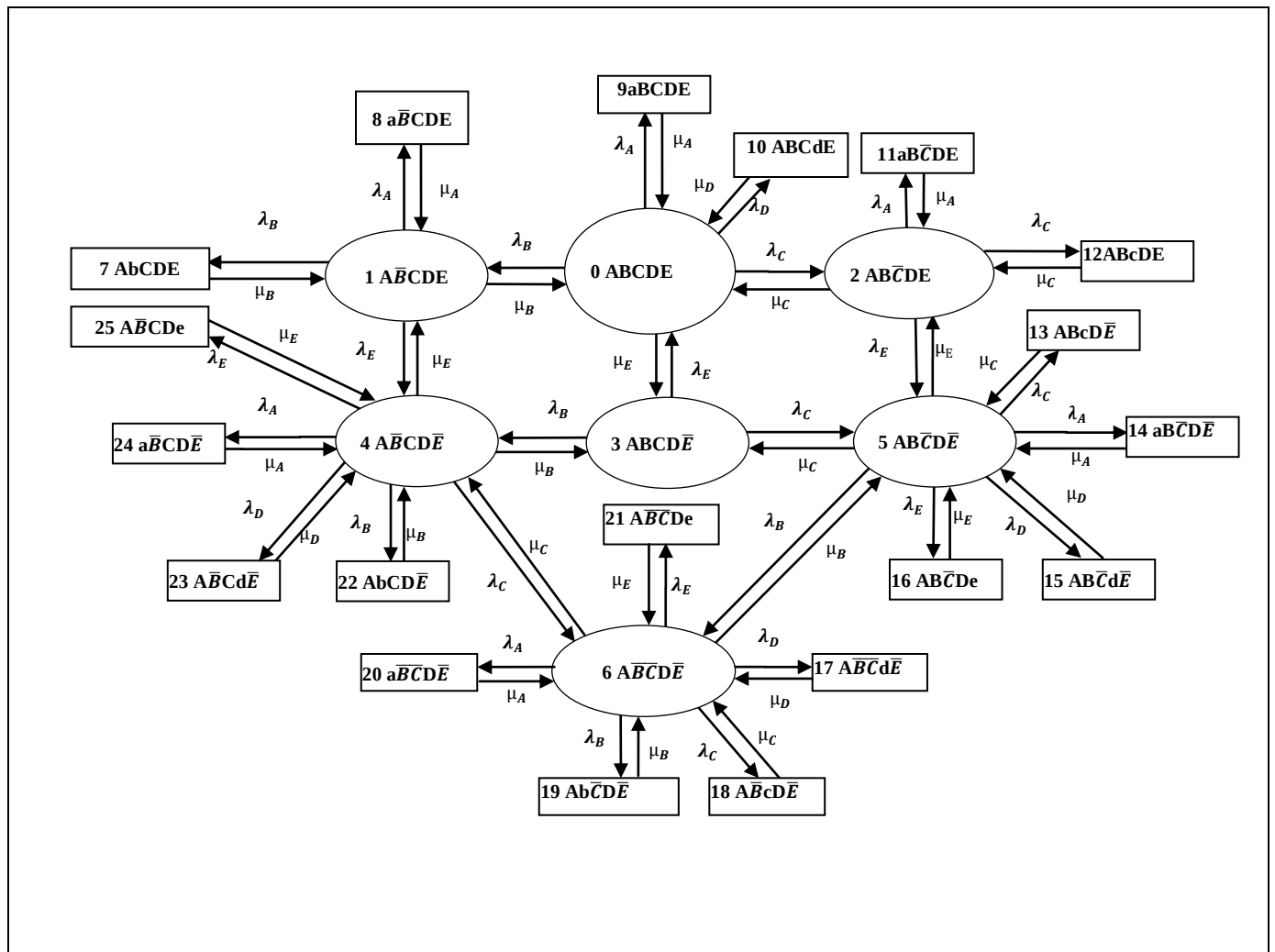


Fig. 1 Turbine-generator system transition diagram

At time $t = 0, P_i(t) = 1$ for $i = 0$ otherwise $P_i(t) = 0$, the system is analysed by providing $\frac{d}{dt} \rightarrow 0$ and $t \rightarrow \infty$. The equations are solved simultaneously, and the following values are obtained for all limiting probabilities state probability, which is as follows.

$$\begin{aligned} P_{1-6} &= L_{1-6} P_0, P_7 = K_B P_1, P_8 = K_A P_1, P_9 = K_A P_0, P_{10} = K_D P_0, P_{11} = K_A P_2, P_{12} = K_C P_2, P_{13} = K_C P_5, P_{14} = K_A P_5, \\ P_{15} &= K_D P_5, P_{16} = K_E P_5, P_{17} = K_D P_6, P_{18} = K_C P_6, P_{19} = K_B P_6, P_{20} = K_A P_6, P_{21} = K_E P_6, P_{22} = K_B P_4, P_{23} = K_D P_4, \\ P_{24} &= K_A P_4, P_{25} = K_E P_4 \end{aligned}$$

Where

$$K_A = \frac{\lambda_A}{\mu_B}, K_B = \frac{\lambda_B}{\mu_B}, K_C = \frac{\lambda_C}{\mu_C}, K_D = \frac{\lambda_D}{\mu_D}, K_E = \frac{\lambda_E}{\mu_E}$$

Using the matrix method of equations for solving the equation, we get $\sum_{i=0}^{26} P_i = 1$

$$P_0 = \left[1 + \sum_{i=1}^6 L_i + K_B L_1 + K_A L_1 + K_A + K_D + K_A L_2 + K_C L_2 + K_C L_5 + K_A L_5 + K_D L_5 + K_E L_5 + K_D L_6 + K_C L_6 + K_B L_6 + K_A L_6 + K_E L_6 + K_B L_4 + K_D L_4 + K_A L_4 + K_E L_4 \right]^{-1} \quad (1)$$

The steady state availability based simulation model for the TGS system of DTPP formed with the summation of all working probability states

$$A_V = [P_0 + P_1 + P_2 + P_3 + P_4 + P_5 + P_6] \quad (2)$$

$$A_V = [1 + L_1 + L_2 + L_3 + L_4 + L_5 + L_6] P_0 \quad (3)$$

2.3. Result and Discussion for Markov based analysis

Effect of failure as well as repair rate of TGS was analyzed for performance evaluation and availability analysis. The various state probabilities have been cited in the transition diagram and used for developing the availability matrix. The evaluated availability levels of TGS are tabulated from Table 1 to Table 5. Moreover, Figure 2 to Figure 6 represented the result of the failure rate and repair rate of the equipment on the overall availability of the TG system.

Table 1 Availability Matrix for Turbine governing system

λ_1 μ_1	0.0000430	0.0000453	0.0000596	0.0000740	0.0000883	Constant values
0.001907	0.9745	0.9734	0.9664	0.9595	0.9527	$\lambda_2=0.000052, \mu_2=0.013445$ $\lambda_3=0.000098, \mu_3=0.013181$ $\lambda_4=0.000045, \mu_4=0.012090$ $\lambda_5=0.000045, \mu_5=0.005742$
0.002007	0.9756	0.9745	0.9679	0.9612	0.9547	
0.002642	0.9805	0.9797	0.9745	0.9694	0.9644	
0.003278	0.9835	0.9828	0.9787	0.9745	0.9704	
0.003913	0.9856	0.985	0.9815	0.978	0.9745	

Table 2 Availability Matrix for Turbine lubrication system

λ_2	0.0000490	0.0000515	0.0000679	0.0000842	0.0001005	Constant values
μ_2						
0.012773	0.9745	0.9745	0.9744	0.9744	0.9744	$\lambda_2=0.000052$, $\mu_2=0.013445$ $\lambda_3=0.000098$, $\mu_3=0.013181$ $\lambda_4=0.000045$, $\mu_4=0.012090$ $\lambda_5=0.000045$, $\mu_5=0.005742$
0.013445	0.9745	0.9745	0.9745	0.9745	0.9744	
0.017703	0.9745	0.9745	0.9745	0.9745	0.9745	
0.021961	0.9746	0.9746	0.9745	0.9745	0.9745	
0.026218	0.9746	0.9746	0.9746	0.9746	0.9745	

Table 3 Availability Matrix for Generator oil system

λ_3	0.0000935	0.0000984	0.0001296	0.0001607	0.0001919	Constant values
μ_2						
0.012522	0.9745	0.9745	0.9745	0.9744	0.9744	$\lambda_1=0.000045$, $\mu_1=0.002007$ $\lambda_2=0.000052$, $\mu_2=0.013445$ $\lambda_4=0.000045$, $\mu_4=0.012090$ $\lambda_5=0.000045$, $\mu_5=0.005742$
0.013181	0.9745	0.9745	0.9745	0.9744	0.9744	
0.017355	0.9745	0.9745	0.9745	0.9745	0.9745	
0.021529	0.9745	0.9745	0.9745	0.9745	0.9745	
0.025703	0.9745	0.9745	0.9745	0.9745	0.9745	

Table 4 Availability Matrix for Generator gas system

λ_4	0.0000430	0.0000453	0.0000596	0.0000740	0.0000883	Constant values
μ_4						
0.011485	0.9745	0.9743	0.9732	0.972	0.9709	$\lambda_1=0.000045$, $\mu_1=0.002007$ $\lambda_2=0.000052$, $\mu_2=0.013445$ $\lambda_3=0.000098$, $\mu_3=0.013181$ $\lambda_5=0.000045$, $\mu_5=0.005742$
0.01209	0.9747	0.9745	0.9734	0.9723	0.9712	
0.015918	0.9755	0.9754	0.9745	0.9737	0.9728	
0.019747	0.976	0.9759	0.9752	0.9745	0.9738	
0.023575	0.9763	0.9762	0.9757	0.9751	0.9745	

Table 5 Availability Matrix for Generator excitation system

λ_5	0.0000430	0.0000453	0.0000596	0.0000740	0.0000883	Constant values
μ_5						
0.005455	0.9745	0.9744	0.9744	0.9744	0.9744	$\lambda_1=0.000045$, $\mu_1=0.002007$ $\lambda_2=0.000052$, $\mu_2=0.013445$ $\lambda_3=0.000098$, $\mu_3=0.013181$ $\lambda_4=0.000045$, $\mu_4=0.012090$
0.005742	0.9745	0.9745	0.9744	0.9744	0.9744	
0.007561	0.9745	0.9745	0.9745	0.9744	0.9744	
0.009379	0.9746	0.9745	0.9745	0.9745	0.9745	
0.011198	0.9746	0.9746	0.9745	0.9745	0.9745	

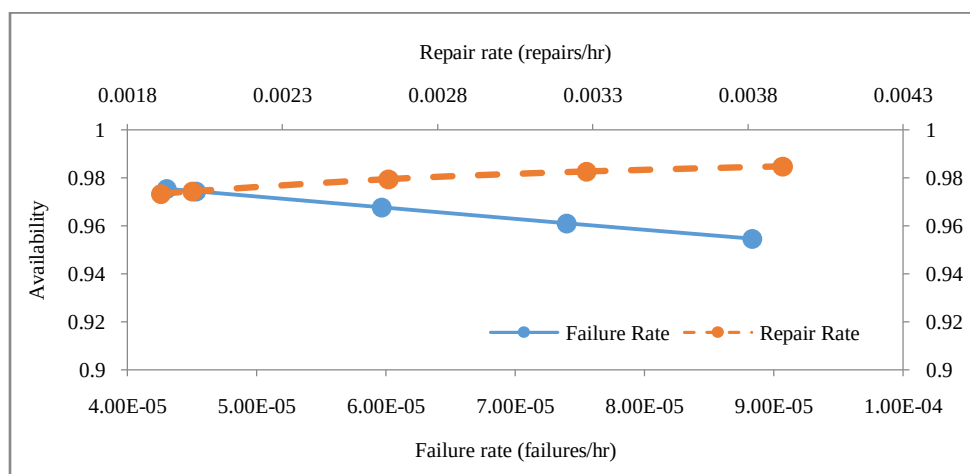


Figure 2 Availability of turbine governing subsystem

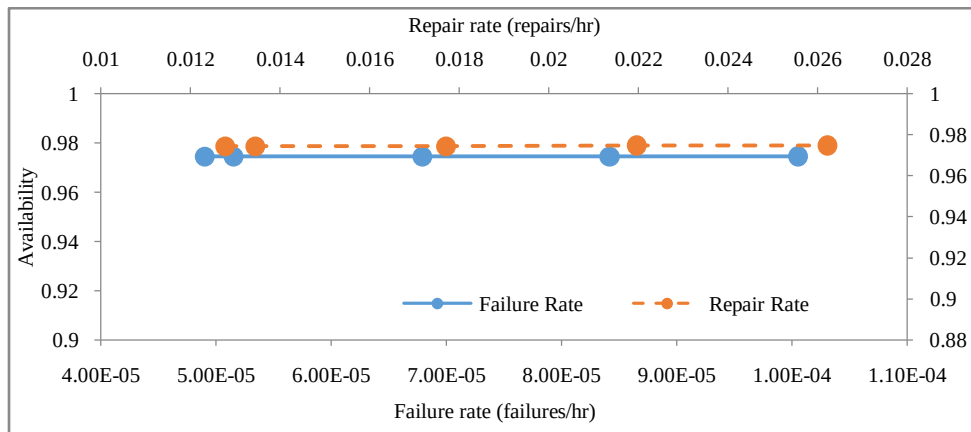


Figure 3 Availability of turbine lubrication subsystem

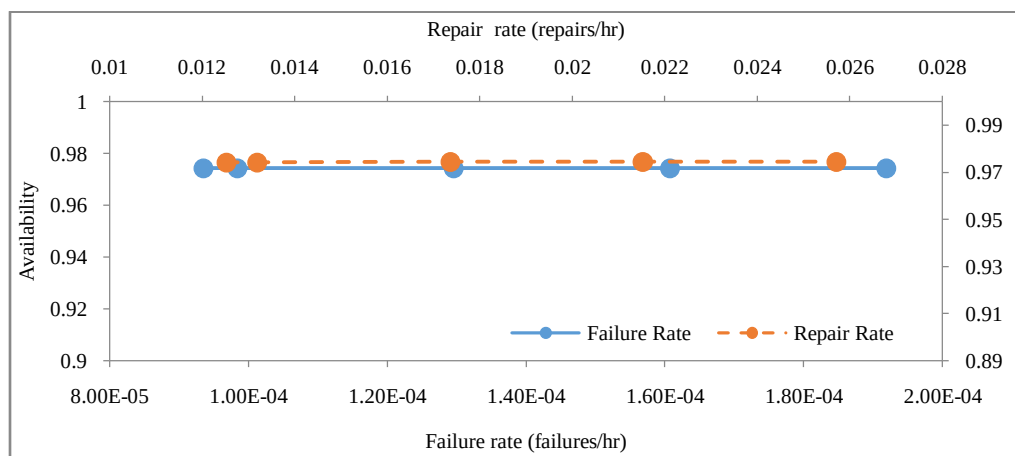


Figure 4 Availability of generator oil subsystem

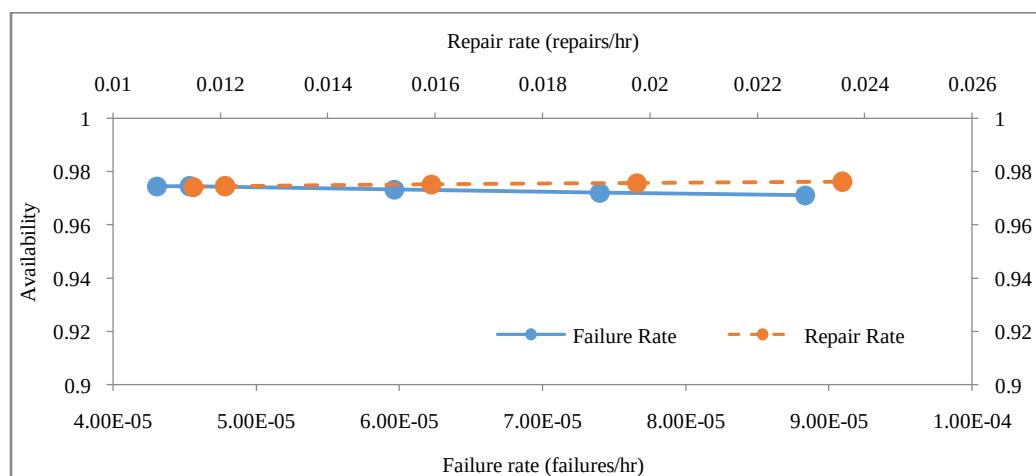


Figure 5 Availability of generator gas subsystem

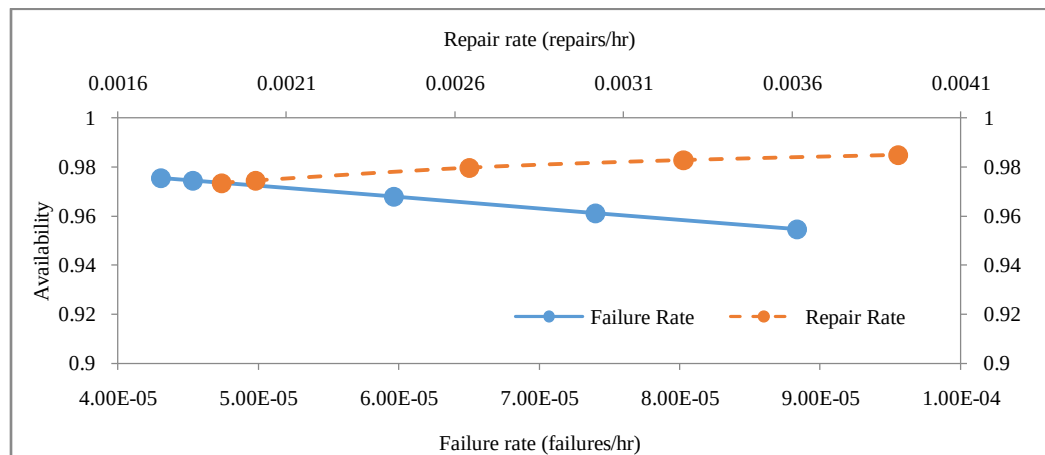


Figure 6 Availability of generator excitation subsystem

- i) Table 1 and Figure 2 reveals that for ' λ ' of turbine governing increased from '0.0000430 (failures/hr) to 0.0000883 (failures/hr), the system availability decreased by 2.09 % and for ' μ ' increased from 0.001907 (repairs/hr) to 0.003913 (repairs/hr), the system availability increased by 1.16 %.
- ii) Table 2 and Figure 3 reveals that that for ' λ ' of turbine lubrication system increased from 0.0000490 (failures/hr) to 0.0001005 (failures/hr), the system availability decreased by 0.01% and for ' μ ' of the turbine lubrication system increased from 0.012773 (repairs/hr) to 0.026218 (repairs/hr), availability increased upto 0.01%.
- iii) Table 3 and Figure 4 indicates that for ' λ ' of generator oil system increased from 0.0000935 (failures/hr) to 0.0001919 (failures/hr), the system availability decreased by 0.01% and for ' μ ' of generator oil system increased from 0.012522 (repairs/hr) to 0.025703 (repairs/hr), the system availability is increased by about 0.01%.
- iv) Table 4 and Figure 5 reveals that for ' λ ' of generator gas system increased from 0.0000430 (failures/hr) to 0.0000883 (failures/hr), the system availability decreased by about 0.35% and for ' μ ' of generator gas system increased from 0.011485 (repairs/hr) to 0.023575 (repairs/hr), availability is increased by 0.19%.
- v) Table 5 and Figure 6 reveals that for ' λ ' of generator excitation system increased from 0.0000430 (failures/hr) to 0.0000883 (failures/hr), the system availability decreased by about 0.01% and for ' μ ' of the generator excitation system increased from 0.005455 (repairs/hr) to 0.011198 (repairs/hr), availability is increased about 0.01%.

The optimum values were obtained for maximum availability level for the possible combination of failure rate and repair rate of the TG system. The study results reflected that the failure of the governing turbine system and generator excitation system of TGS affected the system performance rapidly and decreased overall system availability. Therefore, the turbine governing system and generator excitation system of Unit 1 are identified as most critical equipment of TG system with a failure rate of 0.0000453 (failures/hr) and 0.0000453 (failures/hr) respectively.

Table 6 Optimum values TG subsystem parameters

Equipment	Failure Rate (λ_i) (failures/hr)	Repair Rate (μ_i) (repairs/hr)	Decrease in Av. due to (λ_i)	Increase in Av. due to (μ_i)
Turbine Governing	0.0000453	0.0020069	2.09%	1.16%
Turbine Lubrication	0.0000515	0.0134454	0.01%	0.01%
Generator Oil system	0.0000984	0.0131810	0.01%	0.01%
Generator Gas system	0.0000453	0.0120898	0.35%	0.19%
Generator Excitation system	0.0000453	0.0057424	0.01%	0.01%

The following order for maintenance priority of TG system is decided based on criticality level obtained by Markov approach.

- 1) Turbine governing,
- 2) Generator gas system,
- 3) Turbine lubrication,
- 4) Generator oil system,
- 5) Generator excitation system.

The brainstorming sessions with domain expert at DTPP concluded that the proposed approach and similar results would help to schedule maintenance activity as per the criticality level of the turbine-generator system. The identified critical equipment and similar maintenance priority would take the lead in maintenance planning and allocating the overall availability of the plant.

4. CONCLUSION

The present paper highlighted the application of Markov approach for estimating the availability based performance of TG subsystem of TPP. The Markov approach based availability equations have been obtained, and the effects of failure as well as repair rate on overall system availability are studied. The study recommended the maintenance priority of subsystems of the TG system as per the criticality level obtained by Markov approach.

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