AVAILABILITY ANALYSIS FOR IDENTIFICATION OF CRITICAL FACTOR OF A THERMAL POWER PLANT

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Abstract

In the present stimulated business environment, power sector is playing a major role in the economic growth of India. During the last 20 years, the country had been facing a poor supply of energy and this supply-demand gap is increasing continuously. So, it is important for power plants to improve its power generation capacity drastically by reducing the failure rate. In the present paper, to analyze the causes of poor availability, thermal power plant has divided into six different systems and a system comprising of waste gases heating system has been considered. With the help of transition diagram, mathematical equations have been used to find out the availability. After analyzing, it was found that the value of availability is very low and boiler tube failure is one of the most critical factors for this low availability of system. Economizer zone has identified having long existence time of failures and frequency of occurrence is very high. So, minimizing the failure rate with the help of a proper maintenance schedule will result in decreasing the shutdown period of the plant and increasing the system availability.

Keywords: Thermal Power Plant; Performance Evaluation; Availability, Boiler; Tube Failure; Economizer

I. Introduction

In today's competitive world, it becomes necessary that thermal power plant will be available for long run without any failure. In India, total installed capacity of electricity generation is 3,30,354 MW while total thermal installed capacity is 2,20,456 MW i.e. 66.8% of the total installed capacity (refer table 1). The major contribution almost 59% in thermal installed capacity is coal fired thermal power plant. For continuous power production, boiler becomes the backbone of a thermal power plant. Boiler tube failure is one of the critical problems which are facing the thermal power plant and influence the rate of power generation. This loss of generation increases the operating cost of plant and significant amount of water is being waste. Availability analysis gives the necessary information about various parameters of the system.

Table 1: *Installed Capacity for Different Source of Fuel*

Fuel Used	Installed Capacity (MW)	% of Total
Total Thermal	**2,20,456**	**66.8 %**
Coal	1,94,433	58.9 %
Gas	25,185	7.6 %
Oil	838	0.3 %
Hydro	44,614	13.5 %
Nuclear	6,780	2.1 %
Renewable Energy Sources	58,303	17.7 %
Total	**3,30,354**	

II. Literature Review

From last decades, Complexity in the industries is increasing day by day, so many researchers using Markov Method for the performance evaluation of complex system in process industry.

Tsarouhas [1] computed the parameters on which the reliability of the machine of the ice cream plant is dependent. Dai et al. [2] presented as a model for a system which is centralized heterogeneously widely used in distributed system design. With the help of this model the reliability of the distributed service is find out to provide a best service in a distributed environment. Gupta et al [3] studied the critical components on which the reliability of the plant is mainly dependent and on the basis of these components, a Decision Support system for for minimizing the failure rate of the industry has been decided. Gupta [4] discussed the DSS and performance modelling for a subsystem of feed water in a system of thermal power plant by using performance Modelling and analysis. With the help of a transition diagram, differential equations are generated and then study state probabilities are applied to find out the performance level for the combination of different failure and repair rate of all the sub-system. Using Markov process and probability theory, Gupta [5, 8] found the availability and reliability of a system of a thermal power plant. The author found that the reliability or availability decreases with increasing failure rate while the availability improves with increasing the repair rate for different sub-systems. On the basis of this, author made a maintenance policy for all the subsystems of a thermal power plant. To evaluate the reliability parameter, Gupta [6] expressed the mathematical formulation and expression for mission reliability and availability of a complex polymer powder production system with more realistic and practical assumption. Swiderski et al. [7] discussed the models of semi-Markov and Markov as best conventional tools to evaluate the availability and reliability of each subsystem of the full system. Kumar [9] developed a mathematical model based on the Markov birth-death process and developed differential equations based on probabilistic approach and solved these equations recursively. Khanduja et al. [10-11] developed a system for performance evaluation with the help of mathematical formulation and this performance evaluation deals with quantitative analysis of all critical factors which affects the maintenance decision support system of a paper plant. Lai et al. [12] designed a Markov based model and derived the equations to obtain the steady-state availability by considering both software and hardware failures. Kumar et al. [13-15] studied the behavior of a thermal power plant to improve the performance by minimizing the failure rate so that all the systems in thermal power plant can be function effectively. Sabouhi [16] proposed reliability oriented analysis to drive the mathematical expression for the analysis of availability of the critical component of the plant so that an effective maintenance plan can be scheduled. Hassan et al. [17] purposed a stochastic model for liquefied natural gas plant using Markov analysis. Parkash and Tiwari [18-19] suggested a approach which can helps both engineers and managers to enhance the performability of the system by utilizing the best combination of failure and repair rates.

III. Availability Analysis of Waste Gases System of a Thermal Power Plant

The flow diagram of thermal power plant consisting of waste gases system (refer figure 1) shows that flue or waste gases from furnace flow upward and this waste heat is utilized in superheater, economizer and air preheater to raise the temperature of some extent of steam, feed water and air.

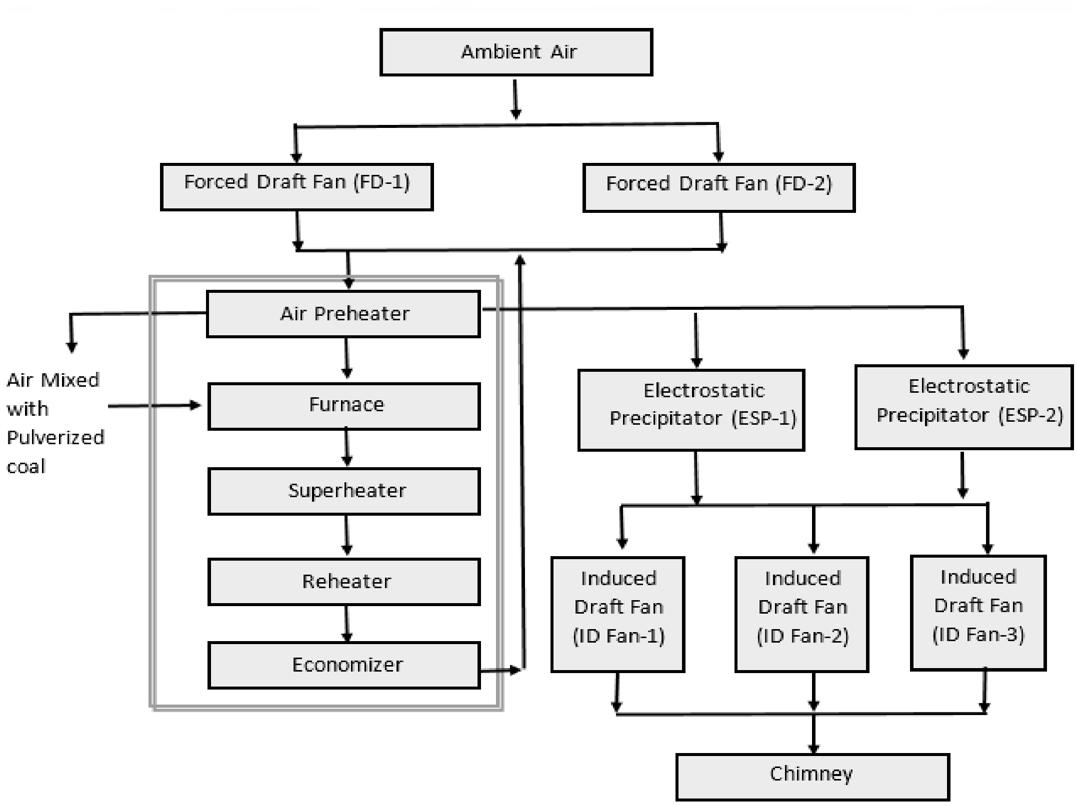

Figure 1: *Flow Diagram of Waste Gases Heating System*

To find the availability, this system is divided further in four different subsystems.
Subsystem A: it consists of furnace, superheater, economizer and air preheater andarranged in series to establish a single subsystem.
Subsystem B: It consists of two electrostatic precipitator (ESP) which makes a single subsystem.
Subsystem C: Two forced draught fans working in parallel consists a subsystem.
Subsystem D: Three induced draught fans (ID Fan) arranged in parallel, creating one subsystem.
The table 2 shows some notation which are used to construct the transition diagram as shown in figure 2.

Table 2: *Notation Used*

Full capacity States (without standby)	A_2,A_4,A_5,A_6
One unit of subsystem A1andA3 are in failed state and the system is working in full capacity with stand by unit.	$A_1^*$and A_3^*
Failed states	a_1,a_2,a_3,a_4,a_5,a_6
Reduced capacity states	A_4^I
Failure rates	α_i, i=1to6
Repair rates	β_i, i=1to6
System Working at Full Capacity	
System Working at Reduced Capacity	
System in Failed State	

I. Performance Modelling of Waste Gases System

The mathematical equations are derived using Chapman–Kolmogorov equation with the help of transition diagram.

$$P_0'(t)+\sum_{i=1}^{4}\lambda_i P_0(t)=\beta_1 P_{12}(t)+\beta_2 P_6(t)+\beta_3 P_3(t)+\beta_4 P_1(t) \quad (1)$$

$$P_1'(t)+\sum_{i=1}^{4}(\lambda_i+\beta_4)P_1(t)=\beta_1 P_{11}(t)+\beta_2 P_7(t)+\beta_3 P_4(t)+\beta_4 P_2(t)+\beta_4 P_0(t) \quad (2)$$

$$P_2'(t)+\sum_{i=1}^{4}(\lambda_i+\beta_4)P_2(t)=\beta_1 P_{10}(t)+\beta_2 P_8(t)+\beta_3 P_5(t)+\beta_4 P_9(t)+\beta_4 P_1(t) \quad (3)$$

$$P_3'(t)+\sum_{i=1}^{4}(\lambda_i+\beta_3)P_3(t)=\sum_{i=1}^{3}\beta_i P_{i-18}(t)+\lambda_3 P_0(t)+\beta_4 P_4(t) \quad (4)$$

$$P_4'(t)+\sum_{i=1}^{4}(\lambda_i+\beta_3+\beta_4)P_4(t)=\sum_{i=1}^{3}\beta_i P_{i-15}(t)+\lambda_{33} P_1(t)+\lambda_4 P_3(t)+\beta_4 P_5(t) \quad (5)$$

$$P_5'(t)+\sum_{i=1}^{4}(\lambda_i+\beta_4+\beta_3)P_5(t)=\sum_{i=1}^{4}\lambda_i P_{i-12}(t)+\lambda_4 P_4(t)+\lambda_3 P_2(t) \quad (6)$$

$$P_i'(t)+\beta_m P_i(t)=\lambda_m P_j(t) \quad (7)$$

When

$$m=1, then\, \mathrm{i}=12, \mathrm{j}=0; \mathrm{i}=11, \mathrm{j}=1, \mathrm{i}=10, \mathrm{j}=2; \mathrm{i}=13, \mathrm{j}=3; \mathrm{i}=16, \mathrm{j}=4; \mathrm{i}=19, \mathrm{j}=5;$$

$$m=2, then\, \mathrm{i}=6, \mathrm{j}=0; \mathrm{i}=7, \mathrm{j}=1; \mathrm{i}=8, \mathrm{j}=2; \mathrm{i}=14, \mathrm{j}=3; \mathrm{i}=17, \mathrm{j}=4; \mathrm{i}=20, \mathrm{j}=5$$

$$m=3, then\, \mathrm{i}=15, \mathrm{j}=3; \mathrm{i}=18, \mathrm{j}=4, \mathrm{i}=21, \mathrm{j}=5$$

$$m=4, then\, \mathrm{i}=9, \mathrm{j}=2; \mathrm{i}=22, \mathrm{j}=5$$

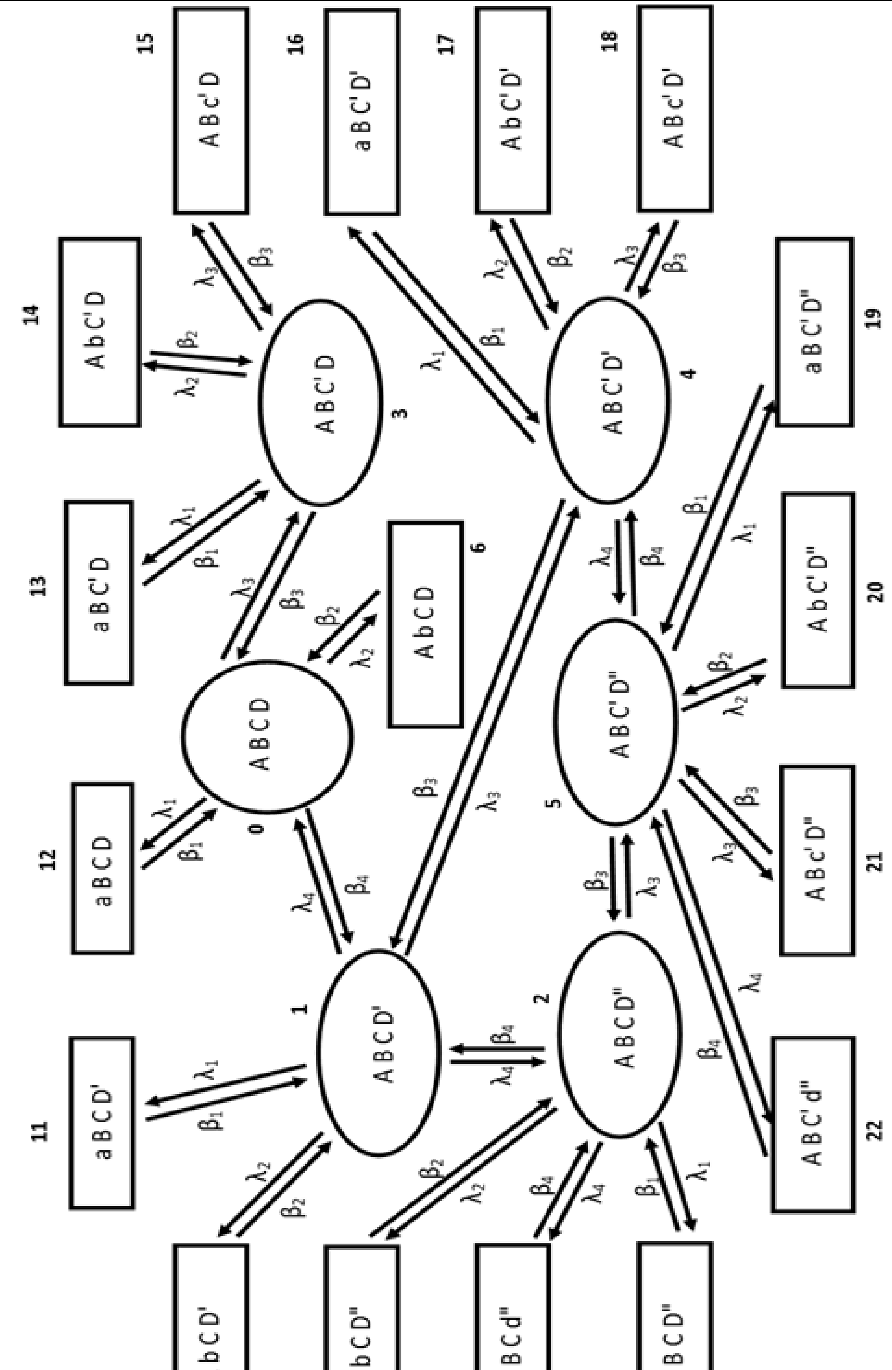

Figure 2: *Transition Diagram of Waste Gases Heating System*

IV. Steady State Availability of Waste Gases System

By putting derivatives = 0 as t→∞ in equations 1 to 7 and solved by recursive method, the following values obtained of all 23 states probabilities (P0 to P22) in terms of full working state probability i.e. P_0.

$$P_1 = C_{12}P_0 \qquad P_2 = C_{13}P_0 \qquad P_3 = C_{14}P_0 \qquad P_4 = C_{11}P_0$$

$P_5 = C_{15}P_0$ $\quad P_6 = \frac{\phi_2}{\lambda_2}P_0$ $\quad P_7 = \frac{\phi_2}{\lambda_2}C_{12}P_0$ $\quad P_8 = \frac{\phi_2}{\lambda_2}C_{13}P_0$

$P_9 = \frac{\phi_4}{\lambda_4}C_{13}P_0$ $\quad P_{10} = \frac{\phi_1}{\lambda_1}C_{13}P_0$ $\quad P_{11} = \frac{\phi_1}{\lambda_1}C_{12}P_0$ $\quad P_{12} = \frac{\phi_1}{\lambda_1}P_0$

$P_{13} = \frac{\phi_1}{\lambda_1}C_{14}P_0$ $\quad P_{14} = \frac{\phi_2}{\lambda_2}C_{14}P_0$ $\quad P_{15} = \frac{\phi_3}{\lambda_3}C_{14}P_0$ $\quad P_{16} = \frac{\phi_1}{\lambda_1}C_{11}P_0$

$P_{17} = \frac{\phi_2}{\lambda_2}C_{11}P_0$ $\quad P_{18} = \frac{\phi_3}{\lambda_3}C_{11}P_0$ $\quad P_{19} = \frac{\phi_1}{\lambda_1}C_{15}P_0$ $\quad P_{20} = \frac{\phi_2}{\lambda_2}C_{15}P_0$

$P_{21} = \frac{\phi_3}{\lambda_3}C_{15}P_0$ $\quad P_{22} = \frac{\phi_4}{\lambda_4}C_{15}P_0$

The probability of full working capacity, namely, P0 determined by using normalizing condition: i.e (sum of the probabilities of all working states, reduced capacity and failed states is equal to 1)

$\sum_{i=0}^{22} P_i = 1$, therefore

$$P_0 = \frac{1}{\left[(1 + C_{11} + C_{12} + C_{13} + C_{14} + C_{15})\left(1 + \left(\frac{\lambda_1}{\beta_1} + \frac{\lambda_2}{\beta_2}\right) + \frac{\lambda_3}{\beta_3}(C_{11} + C_{14} + C_{15}) + \frac{\lambda_4}{\beta_4}(C_{14} + C_{15})\right)\right]}$$

Where

$C_1 = \lambda_3 + \beta_4$ $\quad C_2 = \lambda_3 + \lambda_4 + \beta_4$ $\quad C_3 = \lambda_3 + \beta_4$

$C_4 = \lambda_4 + \beta_3$ $\quad C_5 = \lambda_4 + \beta_3 + \beta_4$ $\quad C_6 = \beta_3 + \beta_4$

$C_7 = \frac{\lambda_4\beta_3}{C_3C_6 - \lambda_3\beta_3}$ $\quad C_8 = \frac{\lambda_4 C_6}{C_3C_6 - \lambda_3\beta_3}$ $\quad C_9 = \frac{\lambda_3 + C_7\beta_4}{C_3 - \beta_4 C_8}$

$C_{10} = \frac{\lambda_4}{C_2 - \beta_4 C_8}$ $\quad C_{11} = \frac{C_3C_4 - \lambda_3\beta_3 - C_{10}C_4\beta_4}{\beta_3\beta_4 - C_9C_4\beta_4}$

$C_{12} = C_9C_{11} + C_{10}$ $\quad C_{13} = C_7C_{11} + C_8C_{12}$ $\quad C_{14} = \frac{C_{11}\beta_4 + \lambda_3}{C_4}$

$C_{15} = \frac{C_{13}\lambda_3 + C_{11}\lambda_4}{C_6}$

Hence

$$Av = P_0 + P_1 + P_2 + P_3 + P_4 + P_5$$

$$Av = P_0(1 + C_{11} + C_{12} + C_{13} + C_{14} + C_{15})$$

Table 3 shows the variation of system availability with different possible combination of failure and repair rates for waste gases heating system. System availability decreases (0.9402 - 0.7985) appreciably by 14.2 % with increasing the failure rate from 0.005 (once in 200 hrs) to 0.040 (once in 25 hrs). Similarly other values show the decreasing trend of availability. Correspondingly, repair rate also effect the value of availability, as repair rate increases from 0.10 (once in 10 hrs) to 0.50

(once in 2 hrs), the system availability increases (0.9784-0.9402) drastically by 3.82 %.

Table 3: *Availability Matrix for Waste Gases Heating System*

λ_1 ↓	β_1 →	0.1	0.2	0.3	0.4	0.5	Constant values
0.005		0.9402	0.9596	0.9676	0.9712	0.9784	$\lambda_2 = 0.010$, $\lambda_3 = 0.0033$, $\lambda_4 = 0.005$, $\beta_2 = 0.20$, $\beta_3 = 0.25$, $\beta_4 = 0.20$
0.0066		0.9298	0.9424	0.9639	0.9701	0.9731	
0.100		0.9192	0.9322	0.9412	0.9565	0.9698	
0.020		0.9085	0.9408	0.9533	0.9599	0.9653	
0.040		0.7985	0.9164	0.9398	0.9492	0.9619	

This table also shows that the failure rate influences the availability of the system. System availability can be improved by decreasing the failure rate. Maintenance data shows that boiler tube failure is one of the most critical reasons for low availability of waste gases heating system.

V. Results

The performance evaluation of waste gases heating system has been done with the help of simulation modeling. Table 3 showed the variation in the system performance with the variation in failure and repair rates of its different components. The various availability levels (Av.) for different combinations of failure and repair rates were also calculated and found that availability of system decreases appreciably as failure rate increases. To improve the availability of the system it becomes essential that reduces the significant causes of failure.

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