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Coal–fired Power Plant Boiler Unit Decision Support System

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Abstract

The present paper discusses decision support system for boiler unit of a coal-fired thermal power plant. The boiler unit consists of five subsystems arranged in series and parallel based configurations. The decision support system for boiler unit has been developed with the help of mathematical formulation based on Markov Birth-Death process using probabilistic approach. For this purpose, first differential equations have been generated. These equations are then solved using normalizing condition so as to determine the steady state availability of boiler unit. After that decision matrices are developed which provide the various availability levels for different combinations of failure and repair rates for all subsystems. The model developed helps in the operations and quantitative management of various maintenance decisions and actions. The results of this paper are therefore beneficial in deciding the relative repair priorities of various subsystems of boiler unit.

Keywords: Decision Support System, Transition diagram, Probabilistic approach, Availability matrices, Quantitative Management

1. Introduction

Manufacturing processes involve a continuous flow of raw materials through a series of sequential operations, which transform the raw materials into the final products. Industries producing products like paper, chemical and sugar etc. during manufacturing have such continuous operations. The goal of high productivity supplemented with minimum standby units, storage capacity, production losses and minimum cost of failure is difficult to achieve in these industries. So the importance of high system reliability and availability has been realized and this can be achieved by quantitative management methods using various concepts of Industrial Engineering and Operation Research. The quantitative analysis performed for system availability and reliability gives the factual knowledge in the form of failure and repair parameters of various equipments/subsystems. Practically various systems/subsystems are subjected to random failures due to poor design, lack of operative skills and wrong manufacturing techniques etc. causing heavy production losses. The failed systems can be brought back to the working state in minimum down time through effective maintenance planning and control. The factory operating conditions and repair strategic plans play important role in maintaining the system failure free for maximum duration. This can be accomplished only through quantitative analysis of each working subsystem of the plant concerned. The system performance can be quantified in terms of the availability if the real system is modeled mathematically and analyzed in actual operating conditions. The mechanical systems have attracted the attention of several researchers in the area of reliability theory. Kumar et.al. [1, 2] discussed about feeding systems in the sugar industry and paper industry. Kumar and Singh [3] analyzed the Availability of a washing system in paper industry. Singh and Pandey [4, 5] reported reliability analysis of mechanical systems in Fertilizer and Sugar industry. Kiureghian and Ditlevson [6] analyzed the availability, reliability and downtime of system with repairable components. Rajiv Khanduja et. al [7] reported the availability analysis of the bleaching system of a paper plant. Kumar et.al.[8] discussed the performance evaluation and availability analysis of ammonia synthesis unit of a fertilizer plant using probabilistic approach. Tewari et.al. [9] analyzed the performance evaluation and optimization for urea crystallization system in a fertilizer plant using Genetic Algorithm. Khanduja et.al. [10] developed the decision support system and performance model of a digesting system of a paper plant using a probabilistic approach. Deepika Garg et.al. [11] developed the mathematical model of a cattle feed plant using a birth-death Markov Process. The differential equations have been solved for the steady-state. The system performance has also been studied. Sanjeev et al. [12] discussed about simulation and modeling of urea decomposition system in a fertilizer plant. Gupta et al. [13] discussed reliability and availability analysis of boiler unit of a steam thermal power plant. Jorn Vatn et al. [14] discussed the optimization of maintenance interval using classical cost benefit analysis approach in Norwegian railways.

2. System description

2.1 The Boiler system consists of five sub-systems**:**

Furnace, denoted by A, failure of which results into failure of system.

Boiler-drum, denoted by B, having single unit, failure of which results into system failure.

Economizer, denoted by C, failure of which results into system failure.

Super-heater, denoted by D, having single unit, failure of which results into system failure.

Re-heater, denoted by E, having single unit.

2.2 Assumptions and Notations

1. Failure and repair rates for each subsystem are constant and statistically independent.
2. Not more than one failure occurs at a time.
3. A repaired unit is as good as new, performance wise.
4. The standby units are of the same nature and capacity as the active units.

The notations associated with the transition diagram are as follows:

1. A, B, C, D, E: Subsystems in good operating state
2. a, b, c, d, e: Indicates the failed state of A, B, C, D, E.
4. λ_i : Mean constant failure rates from states A, B, C, D, E to the states a, b, c, d, e.
5. μ_i : Mean constant repair rates from states a, b, c, d, e to the states A, B, C, D, E.
6. $P_i(t)$: Probability that at time 't' the system is in ith state.
7. ': Derivatives w.r.t.'t'

2.3 Mathematical Analysis of the System

Probability consideration gives following differential equations (Eq. 1 – Eq. 6) associated with the Transition Diagram (Figure 1).

$$P_0'(t)+(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5)P_0(t)=\mu_1P_1(t)+\mu_2P_2(t)+\mu_3P_3(t)+\mu_4P_4(t)+\mu_5P_5(t) \quad (1)$$

$$P_1'(t)+\mu_1P_1(t)=\lambda_1P_0(t) \quad (2)$$

$$P_2'(t)+\mu_2P_2(t)=\lambda_2P_0(t) \quad (3)$$

$$P_3'(t)+\mu_3P_3(t)=\lambda_3P_0(t) \quad (4)$$

$$P_4'(t)+\mu_4P_4(t)=\lambda_4P_0(t) \quad (5)$$

$$P_5'(t)+\mu_5P_5(t)=\lambda_5P_0(t) \quad (6)$$

Initial conditions at time t = 0 are

$P_i(t) = 1$ for i = 0 and 0 for $i \neq 0$

2.4 Steady State Availability

The long run or steady state availability of the System is obtained by putting d/dt→ 0 as t→0, into all differential equations (1) to (6).

$$(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5)P_0 = \mu_1 P_1 + \mu_2 P_2 + \mu_3 P_3 + \mu_4 P_4 + \mu_5 P_5 \quad (7)$$

$$\mu_1 P_1 = \lambda_1 P_0 \quad (8)$$

$$\mu_2 P_2 = \lambda_2 P_0 \quad (9)$$

$$\mu_3 P_3 = \lambda_3 P_0 \quad (10)$$

$$\mu_4 P_4 = \lambda_4 P_0 \quad (11)$$

$$\mu_5 P_5 = \lambda_5 P_0 \quad (12)$$

Solving the above equations, we get:

Let us assume,

$$P_1 = K_1 P_0,\ P_2 = K_2 P_0,\ P_3 = K_3 P_0,\ P_4 = K_4 P_0,\ P_5 = K_5 P_0$$

Where, $K_1 = \lambda_1/\mu_1$, $K_2 = \lambda_2/\mu_2$, $K_3 = \lambda_3/\mu_3$, $K_4 = \lambda_4/\mu_4$, $K_5 = \lambda_5/\mu_5$

Now using normalizing conditions i.e. sum of all the probabilities is equal to one, we get:

$$\sum_{i=0}^{5} P_i = 1 \text{ i.e } P_0 = [1 + K_1 + K_2 + K_3 + K_4 + K_5]^{-1}$$

Now, the steady state availability of the system may be obtained as the summation of all the working state probabilities, i.e.

$$A_V = P_0$$

3. Performance analysis

The failure and repair rates of various subsystems of Boiler system are taken from the maintenance history sheet of thermal power plant. The decision support system deals with the quantitative analysis of all the factors viz. courses of action and states of nature, which influence the maintenance decisions associated with the Boiler system. The decision matrices are developed to determine the various availability levels for different combinations of failures and repair rates. Table 1, 2, 3, 4, 5 represent the decision matrices for various subsystems of Boiler system. Accordingly, maintenance decisions can be made for various subsystems keeping in view the repair criticality and we may select the best possible combinations of failure and repair rates.

4. Results and discussion

Tables 1 to 5 show the effect of failure and repair rates of Furnace, Boiler-drum, Economizer, Super-heater, & Re-heater on the steady state availability of the Boiler system. **Table 1** reveals the effect of failure and repair rates of Furnace subsystem on the availability of the system. It is observed that for some known values of failure / repair rates of Boiler-drum, Economizer, Super-heater, & Re-heater (λ_2=0.0008, μ_2=0.008, λ_3=0.04, μ_3=0.05, λ_4=0.00010, μ_4=0.014, λ_5=0.0020, μ_5=0.014), as the failure rates of Furnace increases from 0.0006 to 0.001 the availability decreases by about 1.06%. Similarly as repair rates of furnace increases from 0.02 to 0.10, the availability increases by about 1.33%.

Table 2 reveals the effect of failure and repair rates of Boiler-drum on the availability of the System. It is observed that for some known values of failure / repair rates of Furnace, Economizer, Super-heater, & Re-heater (λ_1=0.0006, μ_1=0.02, λ_3=0.04, μ_3=0.05, λ_4=0.00010, μ_4=0.014, λ_5=0.0020, μ_5=0.014), as the failure rates of Boiler-drum increases from 0.0008 to 0.0016, the availability decreases by about 5.03%. Similarly as repair rates of Boiler-drum increases from 0.008 to 0.016, the availability increases by about 2.81%.

Table 3 reveals the effect of failure and repair rates of Economizer on the availability of the System. It is observed that for some known values of failure / repair rates of Furnace, Boiler-drum, Super-heater, & Re-heater (λ_1=0.0006, μ_1=0.02, λ_2=0.0008, μ_2=0.008, λ_4=0.00010, μ_4=0.014, λ_5=0.0020, μ_5=0.014), as the failure rates of economizer increases from 0.004 to 0.01, the availability decreases by about 5.96%. Similarly as repair rates of economizer increases from 0.05 to 0.2, the availability increases by about 3.40%.

Table 4 reveals the effect of failure and repair rates of Super-heater on the availability of the System. It is observed that for some known values of failure / repair rates of Furnace, Boiler-drum, Economizer, & Re-heater (λ_1=0.0006, μ_1=0.02, λ_2=0.0008, μ_2=0.008, λ_3=0.04, μ_3=0.05, λ_5=0.0020, μ_5=0.014), as the failure rates of Super-heater increases from 0.00010 to 0.00030, the availability decreases by about 0.76%. Similarly as repair rates of Super-heater increases from 0.014 to 0.026, the availability increases by about 0.18%.

Table 5 reveals the effect of failure and repair rates of Re-heater on the availability of the System. It is observed that for some known values of failure / repair rates of Furnace, Boiler-drum, Economizer, & Super-heater (λ_1=0.0006, μ_1=0.02, λ_2=0.0008, μ_2=0.008, λ_3=0.04, μ_3=0.05, λ_4=0.00010, μ_4=0.014), as the failure rates of Re-heater increases from 0.0020 to 0.0080, the availability decreases by about 17.6%. Similarly as repair rates of Re-heater increases from 0.014 to 0.050, the availability increases by about 6.02%.

5. Conclusion

The Decision Support System for Boiler system has been developed with the help of mathematical modeling using probabilistic approach. The decision matrices are also developed. These matrices facilitate the maintenance decisions to be made at critical points where repair priority should be given to some particular subsystem of Boiler system. Decision matrix as given in table 5 clearly indicates that the Re-heater is most critical subsystem as far as maintenance aspect is concerned. So, Re-heater should be given top priority as the effect of its failure and repair rates on the unit availability is much higher than that of other sub-systems. Therefore, on the basis of repair rates, the maintenance priority should be given as per following order:

1. Re-heater
2. Economizer
3. Boiler-drum
4. Super-heater
5. Furnace

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Table 1: Effect of Failure and Repair Rates of Furnace on Availability

μ_1 \ λ_1	0.0006	0.0007	0.0008	0.0009	0.001	Constant values
0.02	0.7352	0.7326	0.7299	0.7272	0.7246	λ_2=0.0008, μ_2=0.008, λ_3=0.04, μ_3=0.05, λ_4=0.00010, μ_4=0.014, λ_5=0.0020, μ_5=0.014
0.04	0.7434	0.7421	0.7407	0.7393	0.7380	
0.06	0.7462	0.7453	0.7444	0.7434	0.7425	
0.08	0.7476	0.7469	0.7462	0.7455	0.7448	
0.10	0.7485	0.7479	0.7473	0.7468	0.7462	

Table 2: Effect of Failure and Repair Rates of Boiler drum on Availability

μ_2 \ λ_2	0.0008	0.0010	0.0012	0.0015	0.0016	Constant values
0.008	0.7352	0.7220	0.7092	0.6968	0.6849	λ_1=0.0006, μ_1=0.02, λ_3=0.04, μ_3=0.05, λ_4=0.00010, μ_4=0.014, λ_5=0.0020, μ_5=0.014
0.010	0.7462	0.7352	0.7246	0.7142	0.7042	
0.012	0.7537	0.7444	0.7352	0.7263	0.7177	
0.014	0.7592	0.7510	0.7430	0.7352	0.7276	
0.016	0.7633	0.7561	0.7490	0.7421	0.7352	

Table 3: Effect of Failure and Repair Rates of Economizer on Availability

μ_3 \ λ_3	0.004	0.0055	0.0070	0.0085	0.01	Constant values
0.05	0.7352	0.7194	0.7042	0.6896	0.6756	λ_1=0.0006, μ_1=0.02, λ_2=0.0008, μ_2=0.008, λ_4=0.00010, μ_4=0.014, λ_5=0.0020, μ_5=0.014
0.087	0.7541	0.7444	0.7350	0.7258	0.7168	
0.125	0.7621	0.7552	0.7485	0.7418	0.7352	
0.162	0.7664	0.7610	0.7557	0.7504	0.7453	
0.2	0.7692	0.7648	0.7604	0.7561	0.7518	

Table 4: Effect of Failure and Repair Rates of Super-heater on Availability

μ_4 \ λ_4	0.00010	0.00015	0.00020	0.00025	0.00030	Constant values
0.014	0.7352	0.7333	0.7314	0.7306	0.7276	λ_1=0.0006, μ_1=0.02, λ_2=0.0008, μ_2=0.008, λ_3=0.04, μ_3=0.05, λ_5=0.0020, μ_5=0.014
0.017	0.7359	0.7343	0.7328	0.7312	0.7296	
0.020	0.7364	0.7351	0.7337	0.7324	0.7310	
0.023	0.7368	0.7356	0.7344	0.7332	0.7321	
0.026	0.7370	0.7360	0.7349	0.7339	0.7329	

Table 5: Effect of Failure and Repair Rates of Re-heater on Availability

μ_5 \ λ_5	0.0020	0.0035	0.0050	0.0065	0.0080	Constant values
0.014	0.7352	0.6815	0.6352	0.5872	0.5591	λ_1=0.0006, μ_1=0.02, λ_2=0.0008, μ_2=0.008, λ_3=0.04, μ_3=0.05, λ_4=0.00010, μ_4=0.014
0.023	0.7668	0.7302	0.6970	0.6667	0.6389	
0.032	0.7814	0.7538	0.7281	0.7040	0.6815	
0.041	0.7899	0.7677	0.7467	0.7269	0.7080	
0.050	0.7954	0.7769	0.7592	0.7423	0.7261	

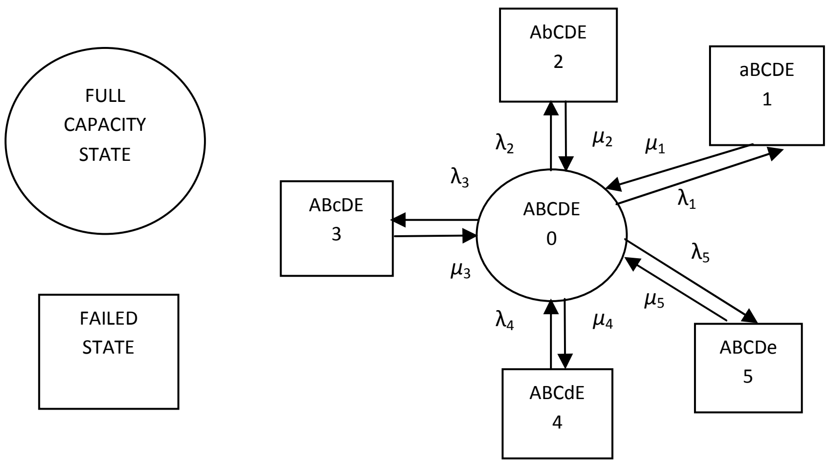

Figure 1: Transition Diagram of BOILER System.