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Performance Analysis of a High Pressure Boiler with Two Low Pressure Boilers: A Cold Standby System

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ABSTRACT

Boiler is an important component of a power plant system. The present paper deals with the performance analysis of a high pressure boiler with two low pressure boilers which is a cold standby unit operating in a power plant system. The system comprises of one main high pressure boiler, two low pressure cold standby boilers, one PA fan, one FD fan and one ID fan. The cold standby unit consists of two low pressure boilers and their capacity to bring out job is equivalent to that of one main high pressure boiler. Both low pressure boilers start their function simultaneously whenever failure occurs in the main boiler. There is single repairman available to do the job. The repair is done instantaneous. System effectiveness measures are evaluated and the profit analysis using Semi Markov process and Regenerative point technique is done for the system in this paper. Graphical study has also been done for the system.

KEYWORDS: Standby systems; Semi Markov process; Regenerative point technique.

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INTRODUCTION:

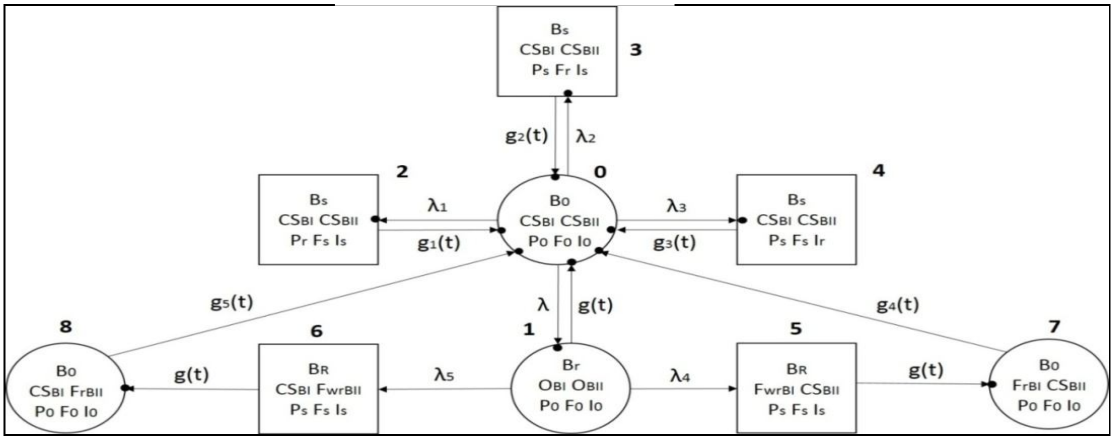
A boiler is a device which is used to bring out steam by applying heat energy to water. Therefore, boiler plays a significant role in the working of power plant system. Standby components serve as a crucial base of any system to increase its reliability and efficiency. The study of standby systems has been extensively done by researchers[1-7] in the field of reliability engineering. Reliability modelling of a 3-unit (induced draft fan) cold standby system working at full/reduced capacity is being studied by Bhatia *et. al*[4]. In it, they have studied a system comprising induced draft (ID) fans fitted in boilers used in thermal power plants. In the present study, the performance of a high pressure boiler with its cold standby unit along with three fans is being studied.

The system comprises of one main high pressure boiler, a cold standby unit which consists of two low pressure boilers, one PA (Primary Air) fan, one FD (Force Draught) fan and one ID (Induced Draft) fan. The cold standby unit which involves two low pressure boilers function together for the capacity of one main boiler, i.e. whenever failure occurs in the main boiler, both low pressure boilers start their operation together in order to make the system function properly. Fans are an important part of the boiler, so therefore their functioning and failure plays a crucial role in system's operation. A single repairman is available for the repair of any of the component of the system. The repair is done on First-cum-First-serve basis. The system fails completely if any of the fans come across failure or any of the low pressure boilers fail in presence of main boiler's failure. System effectiveness measures such as MTSF (Mean time to system failure), Availability, Busy period of repairman, Profit etc have been computed using Semi Markov process and Regenerative point technique. Various graphs have also been plotted for the present study.

MODEL DESCRIPTION:

A state transition diagram in fig. 1 shows various transitions of the system. The epochs of entry into states 0, 1, 7 and 8 are regenerative points and thus these are regenerative states. The states 2, 3, 4, 5 and 6 are failed states.

Fig. 1: Transition Diagram



Operating State Failed State

NOTATIONS:

λ	Constant failure rate of main boiler
$\lambda_1/\lambda_2/\lambda_3$	Constant failure rate of PA/FD/ID fan
λ_4/λ_5	Constant failure rate of cold standby low pressure boiler (Unit 1/2)
$g(t)/G(t)$	pdf/ cdf of repair time for main boiler
$g_1(t)/G_1(t)$	pdf/ cdf of repair time for PA fan
$g_2(t)/G_2(t)$	pdf/ cdf of repair time for FD fan
$g_3(t)/G_3(t)$	pdf/ cdf of repair time for ID fan
$g_4(t)/G_4(t)$	pdf/ cdf of repair time for low pressure boiler (Unit 1)
$g_5(t)/G_5(t)$	pdf/ cdf of repair time for low pressure boiler (Unit 2)
$B_0/P_0/F_0/I_0$	Main Boiler/ PA/ FD/ ID fan is in operative state
O_{BI}/O_{BII}	Cold standby low pressure boiler 1/2 is in operative state
CS_{BI}/CS_{BII}	Low pressure boiler 1/2 is in cold standby state
$B_r/P_r/F_r/I_r$	Main Boiler/ PA/ FD/ ID fan is under repair respectively
$B_S/P_S/F_S/I_S$	Main Boiler/ PA/ FD/ ID fan in switched off state

B_R Boiler is under repair from the previous state

F_{rBI}/F_{rBII} Cold standby low pressure boiler 1/2 is under repair

F_{wrBI}/F_{wrBII} Cold standby low pressure boiler 1/2 is waiting for repair

TRANSITION PROBABILITIES:

The non-zero elements p_{ij}, are obtained as under:

$$p_{01} = \frac{\lambda}{\lambda + \lambda_1 + \lambda_2 + \lambda_3} \qquad p_{02} = \frac{\lambda_1}{\lambda + \lambda_1 + \lambda_2 + \lambda_3}$$

$$p_{03} = \frac{\lambda_2}{\lambda + \lambda_1 + \lambda_2 + \lambda_3} \qquad p_{04} = \frac{\lambda_3}{\lambda + \lambda_1 + \lambda_2 + \lambda_3}$$

$$p_{10} = g^*(\lambda_4 + \lambda_5) \qquad p_{15} = \frac{\lambda_4[1 - g^*(\lambda_4 + \lambda_5)]}{\lambda_4 + \lambda_5} = p_{17}^{(5)}$$

$$p_{16} = \frac{\lambda_5[1 - g^*(\lambda_4 + \lambda_5)]}{\lambda_4 + \lambda_5} = p_{18}^{(6)} \qquad p_{20} = g_1^*(0)$$

$$p_{30} = g_2^*(0) \qquad p_{40} = g_3^*(0)$$

$$p_{57} = g^*(0) = p_{68} \qquad p_{70} = g_4^*(0)$$

$$p_{80} = g_5^*(0)$$

By these transition probabilities, it can be verified that

$$p_{01} + p_{02} + p_{03} + p_{04} = 1$$

$$p_{10} + p_{15} + p_{16} = 1 \qquad p_{10} + p_{17}^{(5)} + p_{18}^{(6)} = 1$$

$$p_{20} = p_{30} = p_{40} = p_{57} = p_{68} = p_{70} = p_{80} = 1$$

The unconditional mean time taken by the system to transit for any regenerative state j, when it is counted from epoch of entrance into that state i, is mathematically stated as –

$$m_{ij} = \int_0^\infty t dQ_{ij}(t) = -q_{ij}^{*'}(0), \text{Thus} -$$

$$m_{01} + m_{02} + m_{03} + m_{04} = \mu_0$$

$$m_{10} + m_{15} + m_{16} = \mu_1 \qquad m_{10} + m_{17}^{(5)} + m_{18}^{(6)} = m$$

$$m_{20} = f_1 \qquad m_{30} = f_2$$

$$m_{40} = f_3 \qquad m_{70} = m_1$$

$$m_{80} = m_2$$

where,

$$m = \int_0^\infty \overline{G}(t)dt \qquad f_1 = \int_0^\infty \overline{G}_1(t)dt$$

$$f_2 = \int_0^\infty \overline{G}_2(t)dt \qquad f_3 = \int_0^\infty \overline{G}_3(t)dt$$

$$m_1 = \int_0^\infty \overline{G}_4(t)dt \qquad m_2 = \int_0^\infty \overline{G}_5(t)dt$$

The mean sojourn time in the regenerative state i (μ_i) is defined as the time of stay in that state before transition to any other state, then we have -

$$\mu_0 = \frac{1}{\lambda + \lambda_1 + \lambda_2 + \lambda_3} \qquad \mu_1 = \frac{1 - g^*(\lambda_4 + \lambda_5)}{\lambda_4 + \lambda_5}$$

$$\mu_2 = g_1^*(0) \qquad \mu_3 = g_2^*(0)$$

$$\mu_4 = g_3^*(0) \qquad \mu_5 = g^*(0) = \mu_6$$

$$\mu_7 = g_4^*(0) \qquad \mu_8 = g_5^*(0)$$

MEAN TIME TO SYSTEM FAILURE:

The mean time to system failure when the system starts from the state 0, is

$$T_0 = \frac{N}{D}$$

Where

$$N = \mu_0 + \mu_1 p_{01}$$

$$D = 1 - p_{01} p_{10}$$

EXPECTED UP-TIME OF THE SYSTEM:

The steady state availability of the system is given by:

$$A_0 = \frac{N_1}{D_1}$$

Where

$$N_1 = M_0 + p_{01}[M_1 + M_7 p_{17}^{(5)} + M_8 p_{18}^{(6)}]$$

$$D_1 = \mu_0 + p_{01}[m + m_1 p_{17}^{(5)} + m_2 p_{18}^{(6)}] + f_1 p_{02} + f_2 p_{03} + f_3 p_{04}$$

BUSY PERIOD OF A REPAIRMAN:

The steady state busy period of the system is given by:

$$B_R = \frac{N_2}{D_1}$$

Where

$$N_2 = p_{01}[W_1 + W_7 p_{17}^{(5)} + W_8 p_{18}^{(6)}] + W_2 p_{02} + W_3 p_{03} + W_4 p_{04}$$

And D_1 is already specified.

EXPECTED NO. OF VISITS OF REPAIRMAN:

The steady state expected no. of visits of the repairman is given by:

$$V_R = \frac{N_4}{D_1}$$

Where

$$N_4 = p_{01} + p_{02} + p_{03} + p_{04} = 1$$

And D_1 is already specified.

PROFIT ANALYSIS:

The expected profit incurred of the system is:

$$P = C_0 A_0 - C_1 B_R - C_2 V_R$$

C_0 = Revenue per unit up time of the system

C_1 = Cost per unit up time for which the repairman is busy in repair

C_2 = Cost per visit of the repairman

GRAPHICAL INTERPRETATION AND CONCLUSION:

For graphical analysis following particular cases are considered:

$$g(t) = \beta e^{-\beta t} \qquad g_1(t) = p e^{-pt}$$

$$g_2(t) = f e^{-ft} \qquad g_1(t) = i e^{-it}$$

$$g_4(t) = \beta_1 e^{-\beta_1 t} \qquad g_5(t) = \beta_2 e^{-\beta_2 t}$$

$$p_{01} = \frac{\lambda}{\lambda + \lambda_1 + \lambda_2 + \lambda_3} \qquad p_{02} = \frac{\lambda_1}{\lambda + \lambda_1 + \lambda_2 + \lambda_3}$$

$$p_{03} = \frac{\lambda_2}{\lambda + \lambda_1 + \lambda_2 + \lambda_3} \qquad p_{04} = \frac{\lambda_3}{\lambda + \lambda_1 + \lambda_2 + \lambda_3}$$

$$p_{10} = \frac{\beta}{\lambda_4 + \lambda_5 + \beta} \qquad p_{15} = \frac{\lambda_4}{\lambda_4 + \lambda_5 + \beta} = p_{17}^{(5)}$$

$$p_{16} = \frac{\lambda_5}{\lambda_4 + \lambda_5 + \beta} = p_{18}^{(6)}$$

$$\mu_0 = \frac{1}{\lambda + \lambda_1 + \lambda_2 + \lambda_3} \qquad \mu_1 = \frac{1}{\lambda_4 + \lambda_5 + \beta}$$

$$m = \frac{1}{\beta} \qquad f_1 = \frac{1}{p}$$

$$f_2 = \frac{1}{f} \qquad f_3 = \frac{1}{i}$$

$$m_1 = \frac{1}{\beta_1} \qquad m_2 = \frac{1}{\beta_2}$$

Various Graphs have been plotted to study the model and are given as under with their analysis:

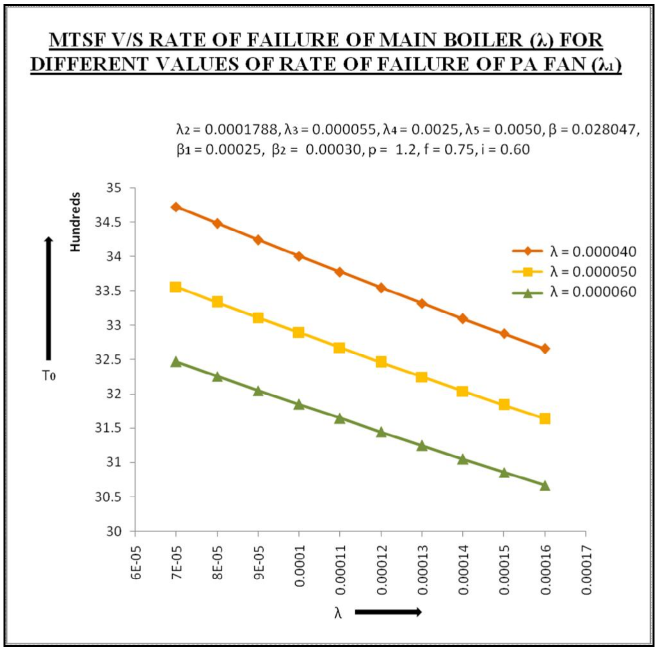


Fig. 2

The behaviour of MTSF w.r.t. failure rate of main high pressure boiler (λ) for different values of rate of failure of PA fan (λ_1) is shown by Fig. 2. It is analyzed that MTSF decreases with the increase in the values of the failure rate of main boiler (λ). MTSF also decreases as failure rate of PA fan (λ_1) increases.

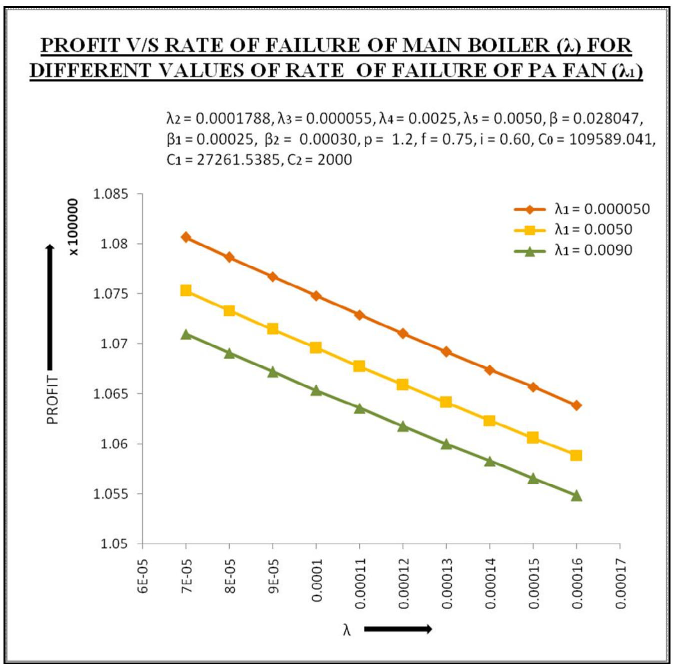


Fig. 3

Fig. 3 interprets the behaviour of profit w.r.t. to failure rate of main boiler (λ) for different values of failure rate of PA fan (λ_1). As the values of failure rate of main boiler (λ) increases, the profit decreases. Also, the profit decreases as failure rate of PA fan (λ_1) increases.

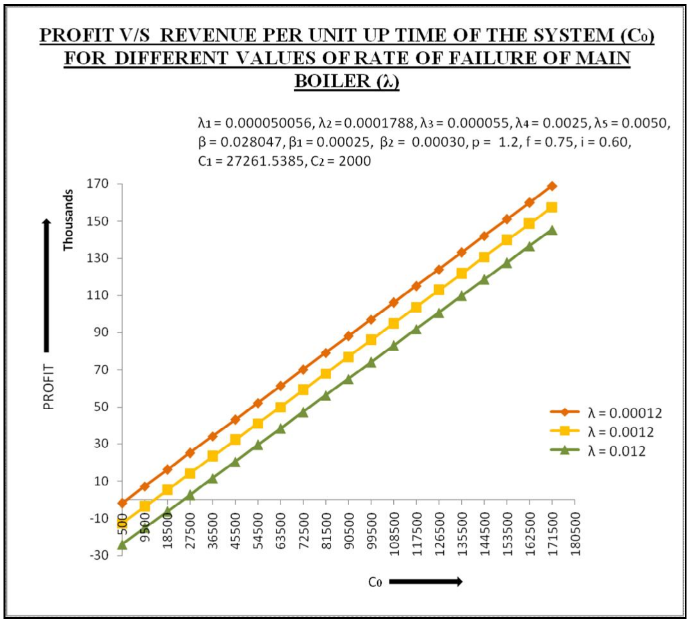


Fig. 4

Fig. 4 depicts the behaviour of the profit w.r.t. revenue per unit uptime of the system (C_0) for different values of rate of failure of main boiler (λ). It can be interpreted that the profit increases with increase in the values of C_0. Following conclusions can be drawn from the graph:

1. For α = 0.00012, profit is > or = or < according as C_0 > or = or < 2363, i.e. the revenue per unit uptime of the system in such a way so as to give C_0 not less than 2363 to get positive profit.

2. For α = 0.0012, profit is > or = or < according as C_0 > or = or < 13301 , i.e. the revenue per unit uptime of the system in such a way so as to give C_0 not less than 13301 to get positive profit.

3. For α = 0.012, profit is > or = or < according as C_0 > or = or < 24874, i.e., i.e. the revenue per unit uptime of the system in such a way so as to give C_0 not less than 24874 to get positive profit.

REFERENCES:

1. Kumar and Agarwal M., “A Review of standby redundant systems”, *IEEE transactions on reliability* 1980, *29*(4), 290-294.
2. Gupta R. and Goel R., “Profit analysis of a two-unit cold standby system with abnormal weather condition”, *Microelectronics and Reliability*, 1991, *31*(1), 1-5.
3. Parashar B. and Taneja G., “Reliability and profit evaluation of a PLC hot standby system based on a master-slave concept and two types of repair facilities”, *IEEE Transactions on Reliability* 2007, *56 (3)*, 534-539.

4. Bhatia P.K., Naithani A., Parashar B. and Taneja G., "Reliability modelling of a 3-unit (induced draft fan) cold standby system working at full/reduced capacity", *International Journal of Mathematical Archive*, 2012, *3(10)*, 3737-3744.
5. Yusuf and Hussaini N., "Evaluation of reliability and availability characteristics of 2-out of -3 standby system under a perfect repair condition", *American Journal of Mathematics and Statistics*, 2012, *2(5)*, 114-119.
6. El-Damcese M.A., Shama M.S., "Reliability and availability analysis of a 2-state repairable system with two types of failure", *Eng. Math. Lett.*, 2014, 2.
7. Sharma U., Sharma G., "Evaluation of a system for reliability and profit where stand by units functions to accommodate the required demand", *International Journal of Mathematics Trends and Technology*, 2017, 49(3), 178-182.