Effect Of Switch-Over Devices on Availability of a Steam Generating System in A Thermal Power Plant

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Abstract:
Purpose: Suggests a method to compute availability of the main part i.e. Steam- generation part of a Thermal Power Plant by taking into consideration the reapir/ failure rates of switch-over devices. This part contains gas classifier, crushing mills and boilers as its subsystems.
Design/ Methodology/ Approach:. Assuming constant failure and repair rates, transition diagram of the system is drawn and problem is formulated using Markov Method. The governing difference equations are solved recursively for a steady state.
Findings: System is analyzed for long run availability followed by illustration, table and graph.
Originality / Value: It will help in increasing overall performance of Thermal Power Plant.

Keywords: Reliability, Availability, Markov Method.

Paper Type: Research Paper.

1. Introduction:

Competition is the life blood of our present day industrial civilization. This fact is apparent everywhere ranging from user of smallest domestic appliance to those responsible for the management of largest industrial concerns, technological projects or process industries. Today with increasing use of highly complex systems, increasing automation, the importance of obtaining highly reliable system has been recognized. A brief look back to the historical beginning of a systematic approach to the reliability problem is revealing. In the expansion of the aircraft industry after First World War, the fact that an engine might fail was partially instrumented to the development of multi-engine aircraft. This led, in 1930, to the concept of reliability. Since mid 1950, much work had been done on reliability analysis. Availability is the combination of two elements : reliability and maintainability. This means that poor reliability can be offset by improved maintainability. To improve the reliability of the system the concept of redundancy was introduced. Weiss (1956) studied a redundant system which operates repetitively and obtained various results. The priority concept of queueing theory in reliability problems has been introduced by Jaiswal (1968). Reliability is a particular case of availability in which no maintenance activity is practiced. Before going in detail, one must have some idea about Markov process . It is based on the assumption that only the last state occupied by the process is relevant in determining the future behavior. This assumption is very strong . If we turn to a process which is no longer strictly Markovian but retain enough of Markovian properties to deserve the name of Semi

Markov Process in which transition from one state to another is governed by the transition probabilities of a Markov process but the time spent in each state, before a transition occurs , is a random variable depending upon the last transition made. Thus, at transition instants, the semi Markov process behaves just like a Markov process. Singh (1980) considered the Semi-Markov process generated by the system with imperfect switch over devices. Gupta *et al.*(2005) studied the numerical analysis of reliability and availability of the serial processes in butter-oil processing plant. Sarhan (2006) studied the reliability equivalences of a series system consisting of n Independent and Non-identical components. . Bansal and Goel (2016) studied the availability analysis of poultry , cattle and fish feed plant by taking various probability considerations. Ram and Nagiya (2017) discussed the gas turbine power plant performance evaluation under key failures by assuming the different types of component failure by using supplementary variable techniques, Laplace transformation and Markov process. Bala (2018) gave an idea about patents. Ghamry *et al (2022) a*vailability and reliability analysis of a k-Out-of-n Warm Standby System with common-cause failure and fuzzy failure and repair rates by assuming that the failure time of each operating unit or warm standby unit follows Weibull distribution with two fuzzy parameters and the repair time of any failed unit follows exponential distribution with one fuzzy parameter. Each fuzzy parameter is represented by triangular membership function estimated from statistical data taken from random samples of each unit. Bala K. (2022) discussed about impact of covid-19. Saini et al. (2023) studied the availability and performance analysis of primary treatment unit of sewage plant by introducing the concept of redundancy and constant failure rates. It has been observed that reliability and availability of a system in different industries have been discussed so far. This has motivated me to consider the case of thermal power plant.

In this paper, a method to compute availability of Steam- generation part of a Thermal Power Planti is proposed by assuming constant failure and repair rates. Transition diagram of the system is drawn and problem is formulated using Markov Method. The governing differential equations are solved recursively for a steady state. System is analyzed for long run availability followed by illustration, table and graph.

This paper is organized in five sections. The present is introductory section . Section 2 consists of brief description about system and assumptions and notations. Mathematical formulation is done in section 3. Section 4. gives numerical illustrations. In last section results are analyzed.

2. System, Notations and assumptions

The steam generating system in a thermal power plant consists of three subsystems A, B, D and two switch over devices S_1, S_2.**Subsystem A** (Gas Classifier) provides air to furnace. It consists of components in series. Failure of any component in it causes the complete failure of A and hence the complete failure of the plant. **Subsystem B** (Crushing Mills) from where powdered form of the coil is sent to boiler furnace with the help of compressed air consisting of two units in operating state and one in cold standby mode each composed of several components in series. The subsystem B is further supported by a fuel subsystem B_F . If two units of subsystem B fail, then fuel system runs the system. It is assumed that fuel subsystem B_F never fails because it is used only when both the main units fail. As soon as the unit of B are repaired it is switched in and the full subsystem B_F is switched out.

Steam is generated in **Subsystem D** (Boilers). It is composed of several components in parallel. Failure of a unit(s) in D reduces the working capacity of D and hence the efficiency of the plant. It is assumed that subsystem D never fails completely.

Switch-over device S_1 is imperfect. Whenever the unit of subsystem B fails, it is switched out and standby unit if available is switched in by S_1 successfully with **probability u.** Failure of S_1, when online unit has already failed causes the complete failure of the system.

Switch-over device S_2 is imperfect. Whenever two units fail in subsystem B, the fuel subsystem B_F is switched in by Switch-over device S_2 successfully with **probability v.** Failure of S_2 when on line unit(s) as in subsystem B has already failed causes complete failure of the system.

Most of researchers have work in the field of reliability for different techniques.

Assumptions and Notations:

1.Failures and repairs are S-independent.

2. Separate repair facilities are available for each subsystem and switch over devices.

3.Upon failure, if all repair facilities are busy, the failed unit joins the end of the queue of respective non- operating units.

4. A repaired unit is as good as new and after repair it is immediately reconnected to the system.

5. Nothing can fail when the system is in failed state.

6. System comes in field state if the switch(es) cannot detect and disconnect a failed unit.

7.Switchover is instantaneous.

8. The repair of a failed unit starts at once.

9. The failure and repair rates of all units are constant.

A, B, D denote that subsystems are in full operating state.

B_S denotes that subsystem B is working on standby unit.

B_F denotes that subsystem B is working on fuel system when all units in system B have failed.

B_F' denotes that subsystem B is working on fuel system when one unit in subsystem B is still in good state.

$\bar{D}$ denotes that subsystem D is working in reduced-state.

a denotes that system is in failed state.

b_1, b_2, b_3 denote that one, two and three units in subsystem B are in failed state.

α_1 denotes the failure rate of sub-system A from good to failed state.

α_2 denotes the transition rate of the one unit as a system be from good to failed state.

α_3 denotes the transition rate of two units of subsystem B from good to failed state.

α_4 denotes the failure rate of subsystem D from good to reduce state D.

β_1 denotes the constant transition rate of the subsystem A from failed state to good state.

β_2 denotes the constant transitions rate of subsystem B from failed state b_1 to good state.

β_3 denotes the constant transition rate of subsystem B from their failed state to good state.

β_4 denotes the constant transition rate of subsystem D from reduced state to good state.

β_5 , β_6 denotes the respective mean constant repair rates of switch-over devices S_1, S_2 from failed states to good states.

u, v denotes the respective probabilities of successful working of switches S_1, S_2 for each failure event.

$\bar{u}$ = 1-u , $\bar{v}$ =1-v

P_n is the probability that the system is in n^{th} state at the time t, ($1 \leq n \leq 22$)

$P_n = \lim_{t\to\infty} P_n(t)$

dash ($'$) denotes the derivative with respect to time t.

Following the above assumptions and notations , the block diagram and transition diagram of the system as shown in the figure 1 and 2respectively.

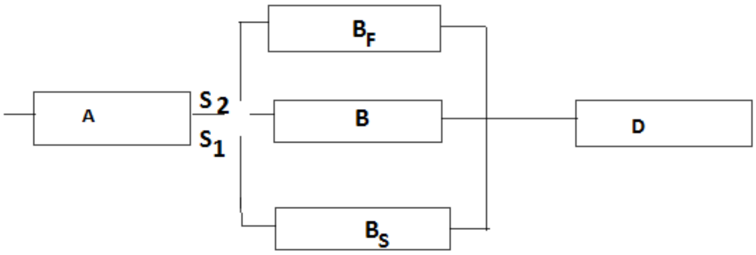


Fig. 1. Block Diagram of the System

3. Mathematical formulation :

Probability considerations give the following differential equations associated with transition diagram of the system:

$$P_1'(t) + (u\,\alpha_2 + \bar{u}\,\alpha_2 + \bar{v}\,\alpha_3 + v\,\alpha_3 + \alpha_4 + \alpha_1)\,P_1(t) = u\,\beta_2\,P_2(t) + v\,\beta_3\,P_4(t) + \beta_4\,P_5(t) + \beta_1\,P_{15}(t) \qquad (1)$$

$$P_2'(t) + (u\,\beta_2 + v\,\alpha_2 + \bar{v}\,\alpha_2 + v\,\alpha_3 + \bar{v}\,\alpha_3 + \alpha_4 + \alpha_1)\,P_2(t) = u\,\alpha_2\,P_1(t) + v\,\beta_3\,P_3(t) + v\,\beta_2\,P_4(t) + \beta_4\,P_6(t) + \beta_5\,P_{10}(t) + \beta_1\,P_{16}(t) \qquad (2)$$

$$P_3'(t) + (v\,\beta_3 + \alpha_4 + \alpha_1)\,P_3(t) = v\,\alpha_3\,P_2(t) + \beta_4\,P_7(t) + \beta_6\,P_9(t) + \beta_1\,P_{17}(t) \qquad (3)$$

$$P_4'(t) + (v\,\beta_3 + v\,\beta_2 + \alpha_4 + \alpha_1)\,P_4(t) = v\,\alpha_3\,P_1(t) + v\,\alpha_2 P_2(t) + \beta_4\,P_8(t) + \beta_6\,P_{11}(t) + \beta_1\,P_{18}(t) \qquad (4)$$

$$P_5'(t) + (u\,\alpha_2 + \bar{u}\,\alpha_2 + \bar{v}\alpha_3 + v\,\alpha_3 + \beta_4 + \alpha_1)\,P_5(t) = \alpha_4\,P_1(t) + u\,\beta_2\,P_6(t) + v\,\beta_3\,P_8(t) + \beta_1 P_{19}(t) \qquad (5)$$

$$P_6'(t) + (u\,\beta_2 + \bar{v}\,\alpha_2 + v\alpha_3 + \bar{v}\alpha_3 + v\alpha_3 + \alpha_1 + \beta_4)\,P_6(t) = \alpha_4\,P_2(t) + u\,\alpha_2\,P_5(t) + v\,\beta_3\,P_7(t) + v\beta_2\,P_8(t) + \beta_5\,P_{14}(t) + \beta_1\,P_{20}(t) \qquad (6)$$

$$P_7'(t) + (\beta_4 + v\,\beta_3 + \alpha_1)\,P_7(t) = \alpha_4\,P_3(t) + v\,\alpha_3 P_6(t) + \beta_6\,P_{13}(t) + \beta_1\,P_{21}(t) \qquad (7)$$

$$P_8'(t) + (v\,\beta_3 + v\,\beta_2 + \beta_4 + \alpha_1)\,P_8(t) = \alpha_4\,P_4(t) + v\,\alpha_3 P_5(t) + v\,\alpha_2 P_6(t) + \beta_6\,P_{12}(t) + \beta_1\,P_{22}(t) \qquad (8)$$

$$\beta_6\,P_{9+i}(t) = \bar{v}\alpha_3\,P_{2+i}(t) \;\; ;\; i = 0, 4 \qquad (9)$$

$$\beta_5 P_{10+i}(t) = \bar{u}\alpha_2\,P_{1+i}(t) \;\; ;\; i = 0, 4 \qquad (10)$$

$$\beta_6 P_{11}(t) = \bar{v}\alpha_3\,P_1(t) + \bar{v}\alpha_2\,P_2(t) \qquad (11)$$

$$\beta_6 P_{12}(t) = \bar{v}\alpha_3\,P_5(t) + \bar{v}\alpha_2\,P_6(t) \qquad (12)$$

$$\beta_1\,P_{14+i}(t) = \alpha_1\,P_i(t)\;;\; 1 \le i \le 8 \qquad (13)$$

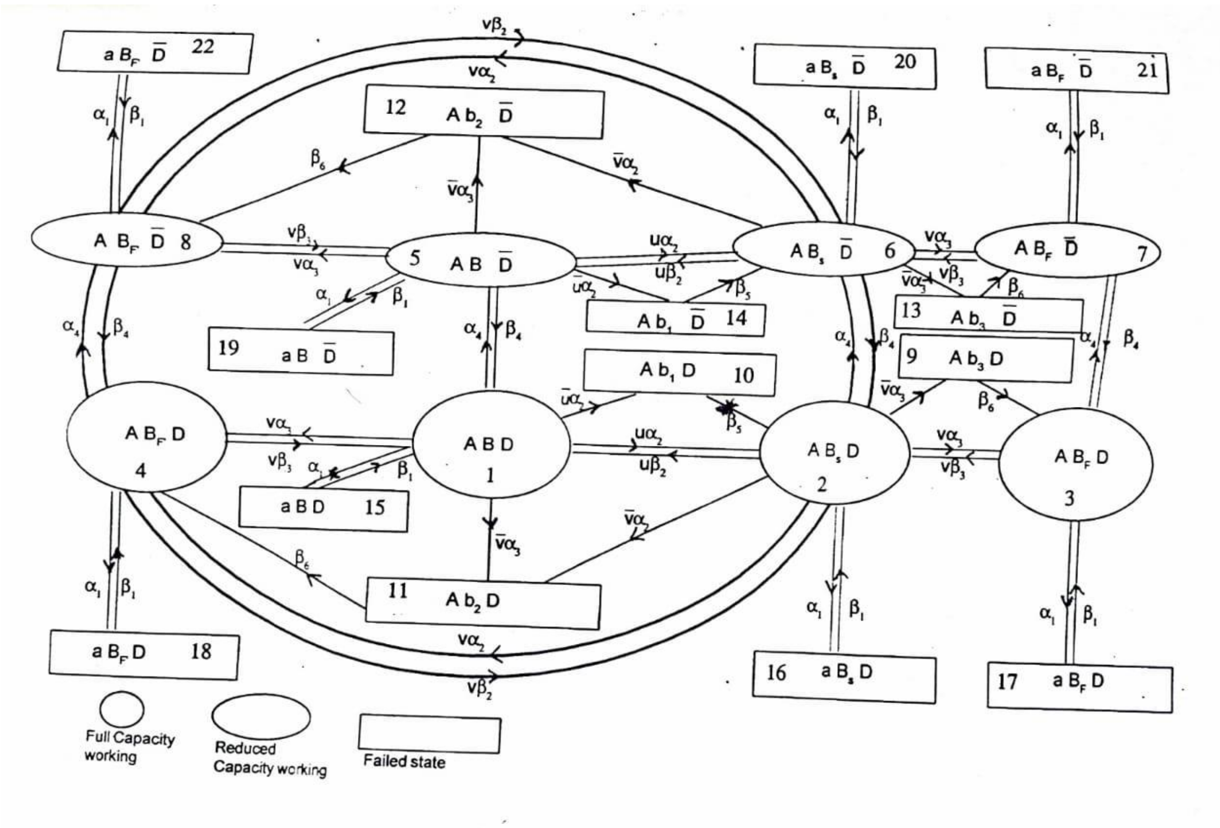


Fig. 2. Transition diagram of the System

With initial conditions

P_1 (0)=1 and 0 otherwise.

Since management is generally interested in long run availability of the system, the system is required to run satisfactorily for a long time.

As t → ∞, $\frac{dP}{dt} \to 0$

Putting $\frac{dP}{dt} \to 0$ in equations (1) to (13) and solving recursively , we get the steady state probabilities as

$p_n = r_n\, p_1$; $1 \leq n \leq 22$ (14)

Using the normalizing condition $\sum_{n=1}^{n=22} p_n = 1$,

p_1 may be obtained and is evaluated as

$p_1 = [\sum_{i=1}^{i=22} r_i]^{-1}$

The steady state availability (A_v) of the system is given by

$A_v = \sum_{n=1}^{n=8} p_n = [\sum_{n=1}^{n=8} r_n][\sum_{n=1}^{n=8} r_n]^{-1}$ (15)

Where $k_1 = \beta_4 + v\,\beta_3$, $k_2 = k_1 + v\,\beta_2$,

$l_1 = k_1\,[(\alpha_2 + \alpha_3 + u\,\beta_2 + \beta_4)\,k_2 - \alpha_2 v\beta_2] - v\,\beta_3\,\alpha_2\,k_2$,

$l_2 = k_1\,k_2\,\alpha_4$,

$l_3 = k_2 v\alpha_4\,\beta_4$,

$l_4 = k_1 v\beta_2\alpha_4$,

$l_5 = k_1\,(k_2\alpha_2 + v\,\beta_2\alpha_3$,

$m_1 = k_2 l_1\,\alpha_4$,

$m_2 = (k_2 u\beta_2 + v\,\beta_3\,\alpha_2)\,l_2$,

$m_3 = m_2 l_3\,(l_2)^{-1}$,

$m_4 = m_2 l_4 (l_2)^{-1} + v b_3 \alpha_4 l_1,$
$m_5 = l_1 [(\alpha_2 + \alpha_3 + \beta_4) k_2 - v \beta_3 \alpha_3] - l_5 (k_2 u \beta_2 + v \beta_3 \alpha_2),$
$m_6 = [(\alpha_2 + \alpha_4 + \alpha_3 + u \beta_2) l_1 - \beta_4 l_2] m_5 - \beta_4 l_5 m_2 ,$
$m_7 = m_5 l_1 \alpha_2 + \beta_4 l_5 m_1 ,$
$m_8 = (v \beta_3 l_1 + \beta_4 l_3) m_5 - \beta_4 l_5 m_3,$
$m_9 = (v \beta_2 l_1 + \beta_4 l_4) m_5 + \beta_4 l_5 m_4,$
$n_1 = m_5 \alpha_3 l_1 k_2 + (l_1 \alpha_3 + \alpha_2 l_5) m_1 \beta_4,$
$n_2 = m_5 \alpha_2 (l_1 k_2 + \beta_4 l_2) + (l_1 \alpha_3 + \alpha_2 l_5) m_2 \beta_4,$
$n_3 = \beta_4 [m_5 \alpha_2 l_3 k_2 + (l_1 \alpha_3 + \alpha_2 l_5) m_3],$
$n_4 = m_5 [l_1 k_2 (\alpha_4 + v \beta_2 + v \beta_3) - \alpha_4 \beta_4 l_1 - \alpha_2 \beta_4 l_4] - (l_1 \alpha_3 + \alpha_2 l_5) m_4 \beta_4,$
$n_5 = m_5 l_1 [k_1 (\alpha_4 + v \beta_3) - \alpha_4 \beta_4] - \alpha_3 \beta_4 (m_5 l_3 + m_3 l_5),$
$n_6 = m_1 l_5 \alpha_3 \beta_4 ,$
$n_7 = m_5 \alpha_3 (l_1 k_1 + \beta_4 l_2) + l_5 m_1 \alpha_3 \beta_4,$
$n_8 = \alpha_3 \beta_4 (l_4 m_5 + l_5 m_4),$
$n_9 = n_4 n_5 - n_8 n_3,$
$n_{10} = m_8 n_4 + m_9 n_3,$
$n_{11} = n_4 n_6 + n_8 n_1,$
$n_{12} = m_6 n_4 - m_9 n_2,$
$n_{13} = n_4 n_7 + n_8 n_2,$
$r_1 = 1,$
$r_2 = [(n_4 m_7 + m_9 n_1) n_9 + n_{10} n_{11}][n_9 n_{12} - n_{13} n_{10}]^{-1} ,$
$r_3 = [(n_{11} + n_{13} r_2) (n_9)^{-1},$
$r_4 = [(n_1 + n_2 r_2 + n_3 r_3) (n_4)^{-1},$
$r_5 = [(m_1 + m_2 r_2 + m_3 r_3 + m_4 r_4) (m_5)^{-1},$
$r_6 = [(l_2 r_2 + l_3 r_3 + l_4 r_4 + l_5 r_5) (l_1)^{-1},$
$r_7 = (\alpha_3 r_3 + \alpha_3 r_6) k_2^{-1} ,$
$r_8 = (\alpha_4 r_4 + \alpha_3 r_5 + \alpha_2 r_6) k_1^{-1} ,$
$r_9 = r_2 \bar{v} \alpha_3 \beta_6^{-1},$
$r_{10} = \bar{u} \alpha_2 \beta_5^{-1},$
$r_{11} = \bar{v} (\alpha_2 r_2 + \alpha_3) \beta_6^{-1},$
$r_{12} = \bar{v} (\alpha_2 r_6 + \alpha_3 r_5) \beta_6^{-1},$
$r_{13} = \bar{v} \alpha_3 r_6 \beta_6^{-1},$
$r_{14} = \bar{u} \alpha_2 r_5 \beta_5^{-1},$
$r_{15} = \alpha_1 \beta_1^{-1},$
$r_{14+i} = r_{15} r_i \quad ; \; 2 \le i \le 8$

4. Numerical illustrations:

To study the effect of switch –over device over the availability, we evaluate availability of the system by taking **u = v = 0.9**, $\alpha_1 = \alpha_2 = 0.02$, $\alpha_4 = 0.01$, $\alpha_3 = 0.001$,
$\beta_2 = \beta_4 = 0.2, \beta_1 = 0.3, \beta_3 = 0.15$

The Availability Table is given below:

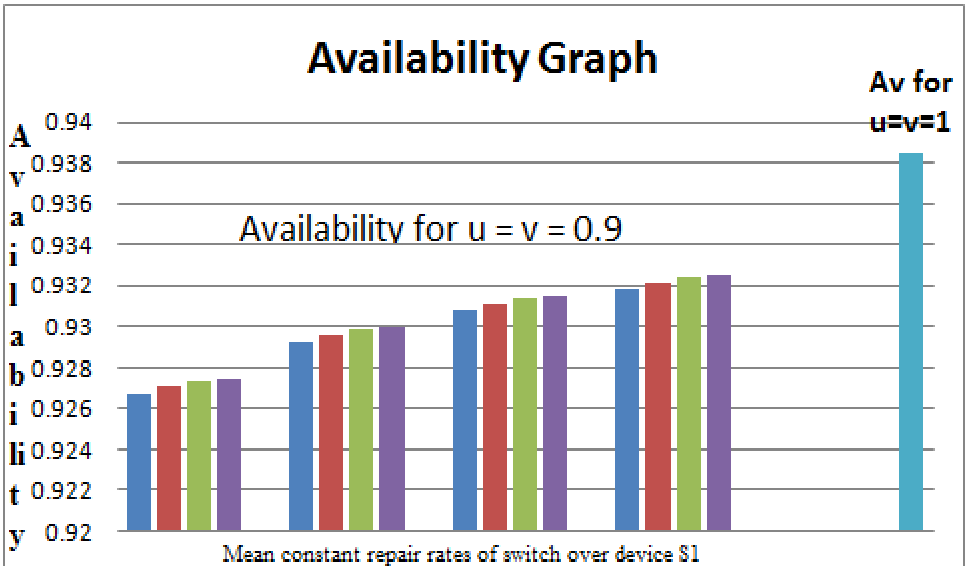
β_6 \ β_5	0.15	0.20	0.25	0.30
0.15	0.92671533	0.929253191	0.930782538	0.93180489
0.20	0.92709225	0.92963207	0.93116266	0.93218585
0.25	0.92731848	0.92985955	0.93139089	0.93241458
0.30	0.92746937	0.93001127	0.93154310	0.93257265

Perfect Switch-over Devices:

When the switch-over device is perfect, the results are obtained by taking **u = v = 1** in the forgoing analysis. By taking $\alpha_1 = \alpha_2 = 0.02$, $\alpha_4 = 0.01$, $\alpha_3 = 0.001$,

$\beta_2 = \beta_4 = 0.2, \beta_1 = 0.3, \beta_3 = 0.15$

Availability of the system is evaluated to be 0.938493205.



5.Analysis of results:

Study of above Availability table and graph reveals that β_5 increases the availability of the system more effectively than β_6. Although we should try to keep the switches good, availability for perfect switch-over devices can be calculated by taking u=v=1. Athough, the repair of the switch S_1 , requires more care than the switch S_2 . Similar comparative tables and graphs can be prepared by taking repair/failure rates for various components. As controlling the failure of subsystems/units is more difficult than controlling the repair. Table for repair rates provides good information about the effectiveness of the system components.

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