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An analytical study on reliability modeling and analysis of mechanical system of a thermal power plant

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Abstract: The aim of this study is to analyze the reliability modeling indices and to study the mechanical system of a thermal power plant. The reliability of a system, equipment and a product is very important aspect of quality for its consistence performance over its expected life span. In fact, uninterrupted service and hazard free operation is an essential requirement of large complex systems like electric power generation and distribution plants or communication network systems such as railways, airways etc. In these cases, a sudden failure of even a single component, assembly or system results in health hazard, accident or interruption in continuity of service. Thermal power plants provide electric power for domestic, commercial, industrial and agricultural use. Reliability problems may reduce generation of power resulting in load shedding and many other problems including loss of productive activities.

Keywords: reliability, modeling, thermal plant, power load.

1. Introduction

Thermal power plants provide electric power for domestic, commercial, industrial and agricultural use. Reliability problems may reduce generation of power resulting in load shedding and many other problems including loss of productive activities. Failure of any one system of an aircraft may result in forced landing or an accident. Sudden stoppage of Sub urban railway train due to fault in carriage system, interruption in the power supply or faulty track sets up a chain of events leading to disruption of services or accidents. The events such as the loss of space shuttles Columbia and challenger, the chemical spills at Bhopal, India and recent electricity outage in North America are prime examples of complex system failures. Thus, the reliability of complex systems has emerged as a thrust area because of happening of such disastrous events. The manufacturers are highly concerned about it. The manufacturers lose billions of dollars every year as a direct consequence of the unreliability of industrial plants viz cost of production. Cost of fixing or replacing equipment as a result of major forced failure and of course the loss of human life that cannot be measured in terms of money.

Similarly, sudden failure of a car brake system while it is running may cause serious accident. Causes which are true for the failure of power plants, aircrafts, railways etc. are also true for other products like washing machine, mixer grinder etc. Although the failure of such products may cause inconvenience on smaller scale. The problem of assuring and maintaining reliability has many responsible factors such as original equipment design, control of quality during manufacturing, acceptance inspection, field trials, life testing and design modifications. Therefore, deficiencies in design and manufacturing of such complex systems need to be detected by elaborate testing at the development stage and later corrected by a planned program of maintenance.

To compete with the global market and to achieve high production goals, the industrial system should remain operative (i.e. run failure free) for maximum possible duration. However, the practical situations are that these systems are subjected to random failures which may be due to poor design, wrong manufacturing technique, lack of operative skill and experience, complaint of intermediate components and equipments, poor maintenance policies adopted, power fluctuations, operation at overload/underload, delay in starting the maintenance, delay in getting the equipment behaviour information, organizational rigidity and complexity and many times human error also. The process industries comprise of large complex engineering system/sub systems, arranged in series, parallel or a combination of both. For efficient and economical operation of process plant, each system/sub system should run failure free for long duration under the existing operative factory conditions. Therefore, all the activities concerning the utilization of men, machine, material and supporting resources must be well

organized and coordinated to develop strategies for the optimal utilization. It increases production and hence profit of the industry concerned.
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From the literature available, it is found that no rigid system for maintenance can be applied universally to process industries to accommodate every situation. Therefore a suitable maintenance system must be designed and develop to suit the requirements of a particular process industry. A detailed behavior analysis and scientific maintenance planning helps the equipments/ systems be remain available for long run. In order to express the system availability in quantitative terms, it is necessary to develop mathematical models for the system/ sub systems and analyze their behavior to evaluate the performance in real operating conditions.

2. Literature Review

Dhillon (1977) discussed a A4 unit redundant system with common cause failure. Later on Singh (1989) calculated the reliability of a warm standby system with common cause failures. The important factor of critical human error, which causes complete failure of the system, was introduced by Dhillon and Misra (1984). Sharma et al. (1985) suggested a methodology for prevention of failure and repair policy for systems with common cause failures. Gupta and Kumar (1987) evaluated the availability and mean time to failure of a two-unit cold standby system with three possible states of units, that is, good, partially failed and failed state by introducing the concept of human repair. Chung (1987, 1989) extended the idea to a repairable system subjected to failure due to common cause failure and critical human error. Such systems are very common in our day to day life.

Kaushik and Singh (1994) performed the reliability analysis of the naphtha fuel oil and water system under priority repair used in thermal power plant. Sridharan and Mohanavadivu (1996) discussed the reliability and availability analysis for two identical unit parallel systems with common cause failure and human errors.

The priority in repair is given to the components which work at 100% capacity rather than standby component which work at 30% capacity. Kuo-Hsiung et al. (2006) discussed the four different systems with warm standby components and standby switching failures based on their reliability and availability. k-out-of-n structure is also a very popular type of redundancy and is applied in industrial and military systems. Reliability and availability of such systems have been analyzed by various researchers including Chiang and Niu (1981),

Chaung (1990), Shao and Lamberson (1991), Li and Chen (2004). Pham (2010) evaluated the modeling of a shared load k-out of-n: g system. The analysis of consecutive k-out of -n: f systems with single repair facility were discussed by Kumar and Gopalan (1997). Vanderperre (2004) discussed the reliability analysis of a renewable multiple cold standby system. The effect of switch failure on 2-redudant system was discussed by Singh (1980).

Cost is the most important factor to increase the availability of the process industries. Prabhuswami (1997) studied the reliability based optimization of manufacturing systems. Gupta et al. (1993) discussed with profit analysis of a two unit priority standby system subject to degradation and random shocks. Subramanian and Anantharaman (1994) carried out reliability analysis of a complex standby redundant system, and estimated the comprehensive cost function. Profit analysis of two unit cold standby system was discussed by Siwach et al. (2001). Zhao (1994) discussed the availability for repairable components and series systems. The dependability modeling using petri net based model was discussed by Malhotra and Trivedi (1995).

Vanderperre (2000) calculated the long run availability of a two unit standby system subjected to a priority rule. Chander and Bansal (2005) discussed the profit analysis of single unit reliability models at different failure modes. Wang and Chiu (2007) calculated the cost benefit of the availability of a warm standby unit with imperfect coverage. The cost analysis of two dissimilar units was discussed by Mokadies and Matta(2010). Maintainability and availability are two main aspects, which are closely related to reliability. In a reliable system, breakdowns are less frequent and hence availability is high (i.e. system functions well and is available for use). Maintenance analysis helps in determining how often the system and its components should be maintained for reliable performance. Over the last two decades, many methods/techniques have been developed / presented in number of research papers to determine the optimal maintenance schedule.

Barlow and Hunter (1960) studied the preventive maintenance models with minimum repairs. Gaver (1963) suggested a method to estimate maintenance performance. Fukuta and Kodama (1974) discussed the mission reliability for a redundant repairable system with two dissimilar units. Nakagawa (1977) developed a model for imperfect preventive maintenance in which the effective age of the system is reduced by ‟ ‟ the time units at each preventive maintenance. In (1980) he also developed optimum preventive maintenance policy for repairable system. Gandhi and Wani (1999) evaluated maintainability index of mechanical systems using digraph and matrix method. An algorithm for preventive maintenance policy was developed by Lie and Chaun (1986). Ntuen (1991) proposed a generalized models for determining minimum cost preventive maintenance.

Jayabalan and Chaudhary (1992) presented a model for cost optimization of maintenance scheduling for a system with assured reliability. The reliability optimization of complex systems through-SOMGA was studied by Kusumdeep and Dipti (2009). A multi objective optimization of imperfective preventive maintenance policy with hidden failure rates was calculated by Wang and Pham (2011). Dekker (1995) has given an overview on the role of operation research model for taking maintenance decision. Schabe (1995) presented a method for obtaining optimum replacement time of a complex system.

Dijkuizen and Heijden (1995) proposed a series of mathematical models and optimization techniques, to obtain the optimal preventive maintenance. Vaurio et al. (1999) discussed the availability and cost functions for periodically inspected preventively maintained units. Ma et al. (2001) calculated the optimization of a preventive maintenance scheduling for semiconductor manufacturing systems. Chan and Asgarpoor (2001) discussed the preventive maintenance with markov process. Grall et al. (2002) presented a preventive maintenance structure for a gradually deteriorating single-unit system. Ramakrishna and Bawa (2005) have discussed optimization of machine design criteria for higher reliability and maintainability in food processing industry.

The earlier researchers in the field of reliability analyzed the systems using Laplace Transform and matrix method. Most of these workers discussed the systems exhibiting markovian properties. A methodology for failure analysis in process plant was developed by Priel (1974). Singh (1977) discussed the preemptive repeat priority repairs and failure of non failed component during system failure of complex system. Kumar et al. (1991) discussed the behavior analysis of paper production system with different repair policies.

Cox (1955) analyzed the non markovian system using supplementary variables. The system having non markovian property can be converted to a system having markovian nature, by introducing some new variables called supplementary variables. Weiss (1962) introduced semi markov process to solve maintainability problem. Singh and Dayal (1989) used supplementary variable technique for problem formulation.

3. Reliability Concept and Analysis

Reliability concepts and analytical techniques are the foundation of this thesis. Many books dealing with general and specific issues of reliability are available, see e.g., Barlow and Proschan (1981), Hoyland and Rausand (1994), Elsayed (1996), and Blischke and Murthy (2000). Some basic and important reliability measures are introduced in this chapter. Since computing system reliability is related to general system reliability, the focus will be on tools and techniques for system reliability modeling and analysis. Since Markov models will be extensively used in this book, this chapter also introduces the fundamentals of Markov modeling. Moreover, Nonhomogeneous Poisson Process (NHPP) is widely used in reliability analysis, especially for repairable systems. Its general theory is also introduced for the reference.

Reliability Measures

Reliability is the analysis of failures, their causes and consequences. It is the most important characteristic of product quality as things have to be working satisfactorily before considering other quality attributes. Usually, specific performance measures can be embedded into reliability analysis by the fact that if the performance is below a certain level, a failure can be said to have occurred.

Definition of reliability

The commonly used definition of reliability is the following.

Definition: Reliability is the probability that the system will perform its intended function under specified working condition for a specified period of time.
Mathematically, the reliability function R(t) is the probability that a system will be successfully operating without failure in the interval from time 0 to time t,

$$R(t) = P(T > t)\ ,\ t \geq 0$$

where T is a random variable representing the failure time or time-to-failure. The failure probability, or unreliability, is then

$$F(t) = 1 - R(t) = P(T \leq t)$$

which is known as the distribution function of T.

If the time-to-failure random variable T has a density function f (t) , then

$$R(t) = \int_0^\infty f(x)dx$$

The density function can be mathematically described as

$$\lim_{t\to 0} P(t < T \leq t + \Delta t)$$

This can be interpreted as the probability that the failure time T will occur between time t and the next interval of operation, t + Δt. The three functions, R(t), F(t) and f(t) are closely related to one another. If any of them is known, all the others can be determined.

4. Reliability Analysis of the Conveyer System of a Thermal Power Plant

Belt conveyor is most suitable system to handle coal in the power stations. Belt driven conveyor consists of a belt moving over two pulleys. The belt used in power plants is made of canvas.
The wagons fuel of coal, are stationed on the wagon tipplers lines and the wagons are unloaded into underground hoppers with the help of wagon tipplers. From the underground hoppers the coal is transferred to either of the two conveyors provided by means of vibrating feeders. Gates of adequate size are provided to feed the coal to any of the two conveyers (A, B). From the conveyor (A) coal is sent to crusher house through a longer conveyor (B). Conveyors (A) and (B) have the same carrying capacity but the conveyor (B) is a longer unit so its failure rate is higher than that of conveyor (A).

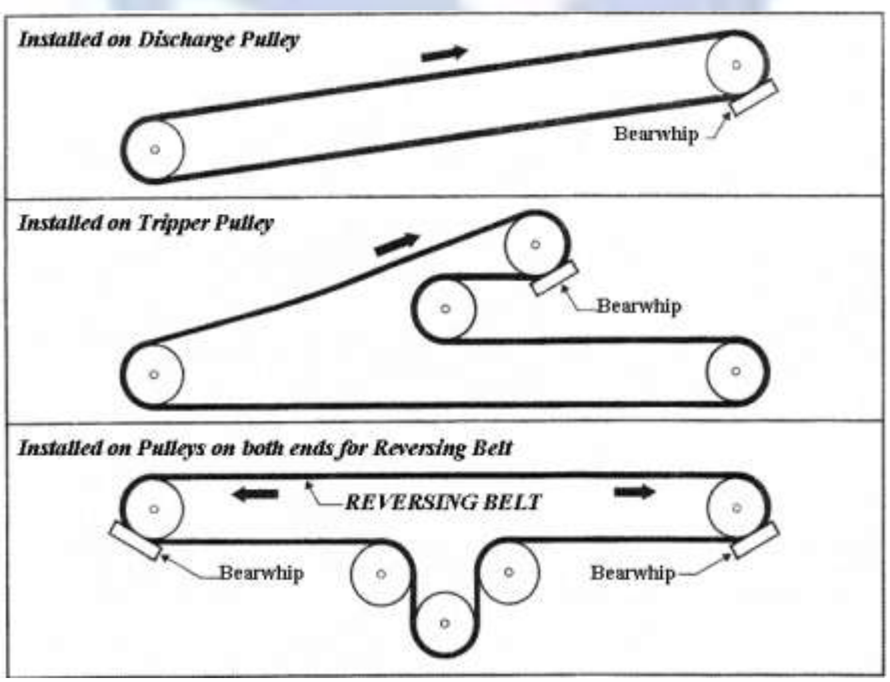

Fig. 1: Installation of pulleydrive

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DESCRIPTION OF THE SYSTEM

The system consists of two sub-system (A) and (B) in series and a standby system having 50% capacity (working capacity) and same configuration. The stand- by system is used is anyone subsystem (conveyor) fails due to any reason.

(i) The conveyor (A) has only one unit, failure of which forces to work with the stand-by sub-system (conveyor). Complete failure of the system occurs only when the stand-by sub-system (conveyor) fails.
(ii) The conveyor (B) also has only one unit, failure of which forces to work with the standby conveyor. Complete failure of the system occurs only when the stand-by conveyor fails.

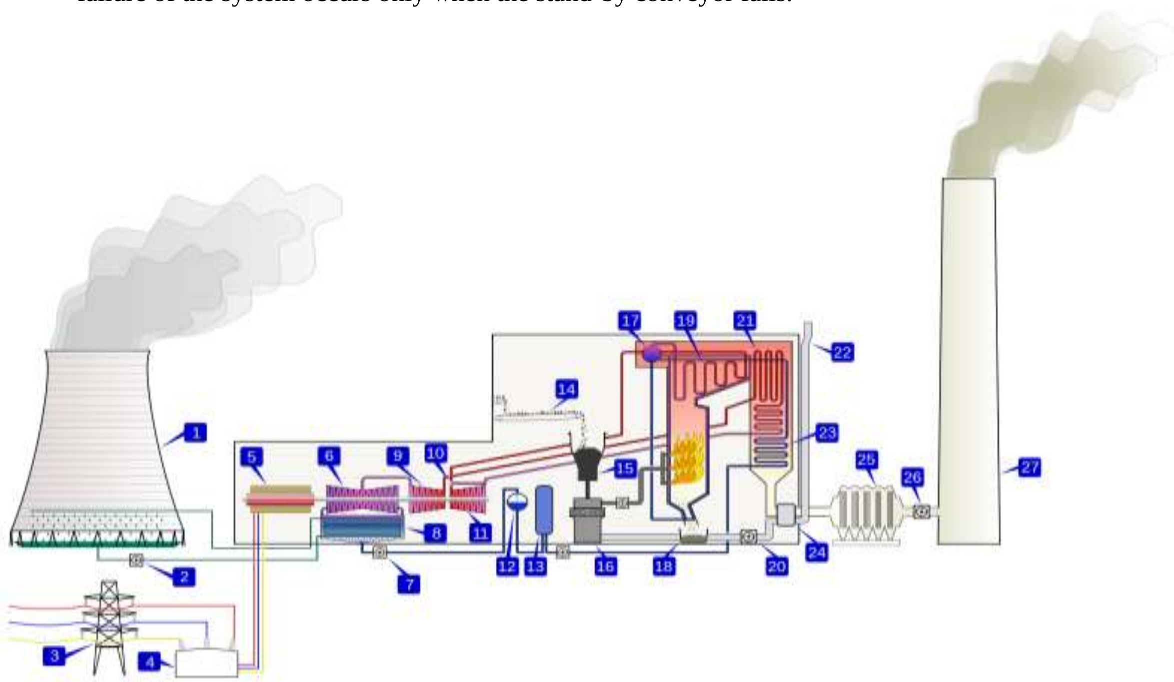

Fig. 2: Typical diagram of a coal-fired thermal power station

1. Cooling tower	10. Steam Control valve	19. Superheater
2. Cooling water pump	11. High pressure steam turbine	20. Forced draught fan
3. transmission line	12. Deaerator	21. Reheater
4. Step-up transformer	13. Feedwater heater	22. Combustion air intake
5. Electrical generator	14. Coal conveyor	23. Economiser
6. Low pressure steam turbine	15. Coal hopper	24. Air preheater
7. Condensate pump	16. Coal pulverizer	25. Precipitator
8. Surface condenser	17. Boiler steam drum	26. Induced draught fan
9. Intermediate pressure steam turbine	18. Bottom ash hopper	27. Flue gas stack

ASSUMPTIONS

(i) Failure and repair rates are constant.
(ii) Failure and repair rates are statistically independent.
(iii) A repaired product is as good as new.
(iv) There is no simultaneous failure in sub-system.

(v) The priority of repair of conveyor (B) over conveyor (A).
(vi) Repair facility is always available.
(vii) Service includes repair and /or replacement of the component in concerned unit.

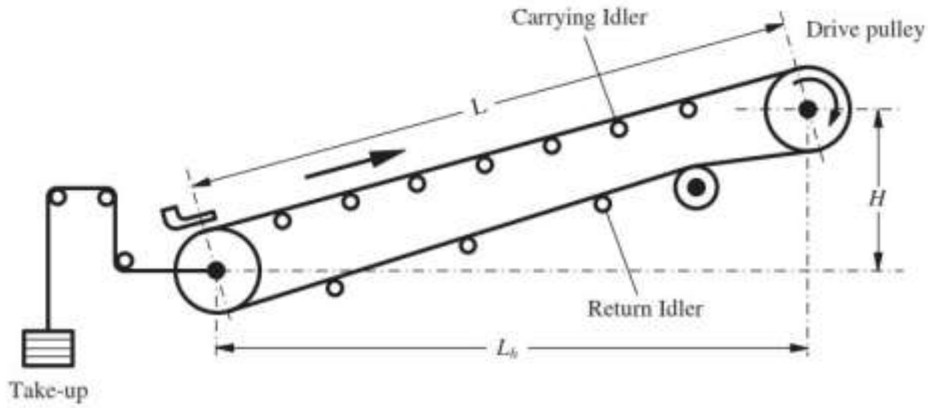

Fig. 3: Typical profile of belt conveyer

NOTATIONS

A, B indicates that the units are in good state, and is working in full capacity
Ā, B indicates that original unit of sub-system is in failed state.
a , b indicates that the system is in failed state due to failure in the subsystem.
$P^{AB}(t)$ probability that at time t all units are good and the system is working in full Capacity where A, B are replaced by Ā,B, a ,b for the failure of respective unit.
f_A constant failure rate of sub-system (A)
f_b constant failure rate of sub-system (B)
r_A constant repair rate of sub-system (A)
r_B constant repair rate of sub-system (B)
S Laplace transform parameter

The state transition diagram using the above notations and assumptions is shown in figures.

Conclusion

In the present problem, the author has reviewed reliability modeling and analysis of mechanical system of a thermal power plant. Besides discussing the limitations and scope of the techniques developed in the earlier sections for calculating the time dependent and steady state availability has also been discussed in this concluding section. The author critically review the analytical methods developed in this work for analyzing the effects of repair and failure rates on availability and the limitations and scope of the methods used are also discussed in this paper.

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