

Evaluation of Various Maintenance Strategies for Reliability Assessment of Thermal Power Plants

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Abstract

In recent years, the world has had a phenomenal economic growth due to the acquisition of innovative technologies and globalization. In the meantime, electrical power plants are regarded as a fundamental element in industrial and production, and any deficiency in supplying may lead to significant financial detriment. Regard to the deep dependency of modern lifestyle to electricity, providing a high-quality and reliable electricity for consumers has taken on paramount importance. The reliability of a power plant depends on the configuration of elements and the reliability of each utility. The reliability, continuous service, flexibility in operation, simplicity, maintenance, development availability, meeting required standards etc. constitute the decisive factors for selection of a utility. Hence, each component of a power system must maintain the adequate level of reliability. In general, the maintenance approaches are classified into two parts: 1) The maintenance which must be carried out within determined and specified time intervals; 2) The maintenance which must be performed when required or in emergencies. To evaluate the maintenance and its effect on reliability, two types of deterministic and probabilistic approaches are presented. In this paper, a comprehensive description of both models is issued, and a detailed comparison is drawn. The results obviously show that the probabilistic models have considerable priority to deterministic models regard to their abilities for maximization of reliability or minimization of costs.

Keywords: Maintenance strategy; Reliability; Probabilistic mathematical method; Deterministic mathematical method; Effectiveness of maintenance program

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1. Introduction

Nowadays, the passive maintenance model or failure maintenance (also known as run to fail maintenance) is the most common model of maintenance of industrial equipment. In another word, the equipment doesn't have usually a predefined preventive maintenance program, and assessment does not perform to evaluate their condition. Whenever a failure in equipment occurs, the replacement or repair measure will be performed. From public opinion point of view, the maintenance is a measure which must be performed when a failure or breakdown occurs or equipment is damaged. However, this kind of mindset has resulted in huge detriments. In the industries, the maintenance program does not perform based on mathematical and scientific concepts, but they perform regard to experimental concepts between fix periods. Nevertheless, the accurate required time between maintenance or health check-up can be estimated based on probabilistic models and mathematical data and equations. It is obvious that the total detriments of the failures are terrifically high because of inflicted damages and lack of operation and supplying energy, time dissipation, and increased maintenance costs. Maintaining a maintenance program increases the continuity and decreases the unpredicted outages [1-4].

The main factor in keeping a system in the normal state is to establish a comprehensive maintenance program, to extend the lifelong of the system. By implementation of such program, many problems are discovered in initial steps and an appropriate measure must be performed for prevention of deterioration and heavier damages. In the last 10 years, many thermal power plants substituted classical experimental maintenance programs, which are conducted in constant periods, with novel programs based on analysis and required preferences or based on persistent monitoring of condition. Such maintenance, which is known as preventive

maintenance, is constituted of some reliability-centered maintenance (RCM). RCM is a maintenance strategy which is implemented for optimizing the maintenance program of a facility. In another word, RCM is a process to guarantee that a component continues to perform what their users need in their present operating context. In an RCM approach, various maintenance policies can be compared, and the most economic one can be adopted. RCM programs are implemented as an effective administrative tool in some thermal power plants. Since such approaches require a large amount of data, which takes a lot of time to be provided, some mathematical models are proposed to ease the maintenance program. In the following parts, a concise overview of diverse maintenance programs is presented and their features are discussed. In the following, the RCM programming is described and investigated, and two deterministic and probabilistic models for effectiveness assessment of proposed RCM program in thermal power plants is presented [5-6].

2. Various Maintenance Strategies of Thermal Power Plants

The prime goal of most preventive maintenance programs is to preserve the utilities against failures and alleviate the effects of failures on components. Some different types of maintenance approach such as run to fail maintenance (RTF), time-based maintenance (TBM), condition-based maintenance (CBM) and reliability-centered maintenance (RCM) are discussed below. However, the RCM approach regard to containing a combination of features of preventive, predictive and corrective maintenance are more desired. Hence, this type of maintenance will be discussed thoroughly. The most maintenance strategies adoption for RCM method is based on the operating point of the system or component and the managing mindset about costs versus maintenance advantages [7].

2.1. Run to Fail Maintenance

In such an approach, measure will not be performed until the occurrence of an event. The eroding equipment would be repaired or replaced when the equipment is unavailable due to erosion or breakdown. Hence, the RTF can be only useful for non-critical components [8].

2.2. The Assessment and Repair if Required

This approach is a developed model of RTF. The repairmen perform the maintenance in an irregular form or in more or less regular periods. In such a method, the initial failures are fixed before converting to a catastrophic problem, particularly whenever the repair is inevitable regard to devastating failure implications [9].

2.3. Time-based Maintenance

This kind of maintenance is known usually as preventive maintenance (PM). In such program, the repair or replacement measure must be performed at specific times based on hourly operation rate (lifetime) or based on the number of operations (quantitative). The appropriate model of repair usually is recommended by the manufacturer or industrial standards. The TBM approach is suitable for components, which have a critical role in a system and the security plays an inevitable role in them. In TBM model, the overhaul must be performed at a definite time regardless to prioritizing the maintenance based on the security or other maintenance indices and regardless of asset evaluation and benefit maximization [10].

2.4. Condition-based Maintenance

The CBM approach, which is known as predictive maintenance, is a developed model of TBM, in which non-destructive testing techniques is used to evaluate the condition of utilities. In this approach, the maintenance performs based on the historical data of last operations and last repair data. When this approach combines with PM method, the maintenance will be highly effective and efficient. The reason is that the priority of maintenance schedule performs based on the aging process, resources, and personal experiences [11].

2.5. Reliability-centered Maintenance

This strategy is so that the condition of utilities, the state of being a critical component in the system, the failure history, and the lifetime expenses are included in providing a logical

maintenance method. RCM takes advantages of the power of preventive and predictive and corrective maintenance in order to maximize the reliability and accessibility of components. This is a progressive process which evolves and augments steadily. Hence, a maintenance measure is not repetitive and must be assessed separately. The RCM process mitigates the inherent uncertainty corresponded with the reliability of components by using risk assessment method and evaluation of period of a system's condition. By use of appropriate metering and measurement devices, the proper condition of the component, failure borders, transitions, and restrictions can be achieved. Thus, regard to this information, the executive maintenance groups determine the amount of risk of permanent operation of the component and the risk of postponement of repairing. The maintenance-related researchers have proposed a simplified RCM which provide a good perception about benefits of the program when the electrical or mechanical structures of components have a catastrophic risk. The simplified RCM has targeted the critical components rather than all components. This approach is generally based on condition monitoring and eliminates the low-repair-demanding components. This approach requires a good understanding of monitoring methodologies, root cause failure analysis techniques (RCFA) and failure modes and effects (FMEA) analysis [12].

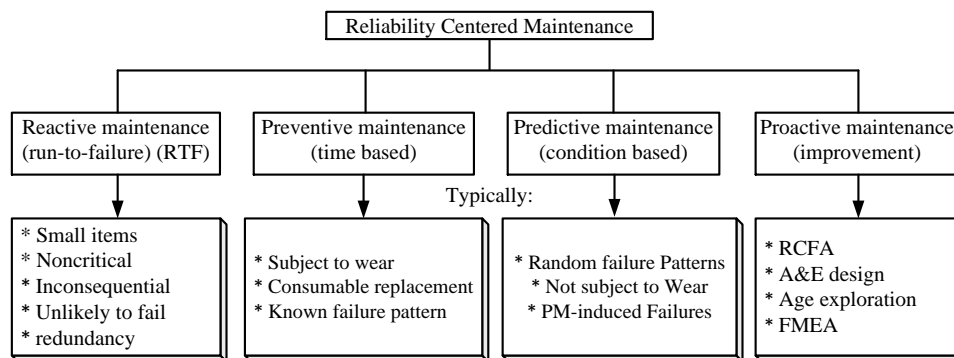


Figure 1. The prevalent applications of RCM strategies

The elaborate RCM programs, in its common concept, consists of all details of failure modes and analysis, the probability of failures, the frequency of failures and the model of historical and present data gathering for a specific component which in overall requires a fair knowledge and domination over the details of the component or system. Due to being time-consuming and costly, the most suitable applications of RCM are exclusively related to the systems, in which the failure sequences contain a massive risk for security, environment or economic condition [13].

3. The Maintenance Programming Methods

3.1. A Probabilistic Model for Including Reliability in the Maintenance Program

The mathematical models can be of deterministic or probabilistic models. Both models can be applicable for maintenance studies. Various applications of these models are mentioned in (7). However, if there is uncertainty in values and data, the probabilistic models can be more useful. In the following parts, a probabilistic model is described to assess the relationship between reliability and maintenance. The failures are composed of two types, which may be occurred accidental or be caused by the aging process. A maintenance process is depicted in Figure 2.

As it can be seen, the aging process continues until reaching to a breakdown. This number of steps can vary from a utility to another. To obtain these steps, periodic inspections are required. If these steps cannot be obtainable, the mean time between steps cannot be calculated. Thereby, the selection of steps must be performed based on the data and personal experiences. The illustrated processes in Figure 2 are depicted based on the mathematical probabilistic models. If the transition between states is performed with

a constant rate, such a model is known as Markov model. When the failure rate is supposed to be constant, the probability of occurrence of it in all next steps will be the same. The goal of the maintenance program is to enhance the lifetime of utilities. A process of maintenance on a utility is demonstrated in Figure 3, where in the case of b, after each aging step, a maintenance process is performed on the equipment. In the case of accidental failures, the assumption of constant failure rate leads the outcomes to not be improved due to maintenance program. It is because the occurrence of a failure during next steps is inevitable with and without maintenance on system or equipment [14].

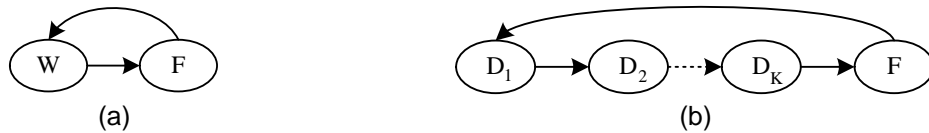


Figure 2. (a) State diagram of accidental failures and (b) the failures due to the aging

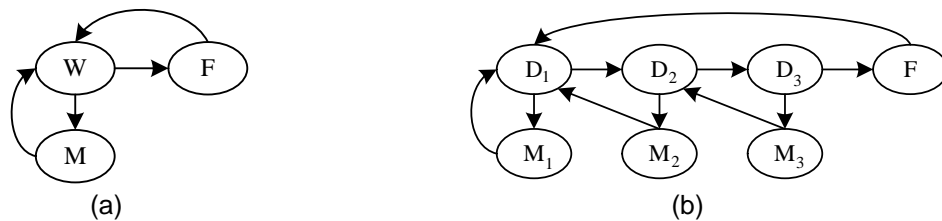


Figure 3. (a) State diagram including maintenance for accidental failures (b) and the failures due to the aging

This fact contradicts with the statement of "if ain't broke don't fix" that means if the equipment is not broken yet, it is not needed to perform any preventive maintenance and is inconsistent with the aging process. It should be noticed that aging processes are a subcategory of failure models, where the failure rate increases as the time elapse. If the failure is accidental, the failure rate is constant and the maintenance will not perform.

3.2. The Deterministic Model and Comparison with Probabilistic Model

The probabilistic model has been introduced and described regard to Figure 3. Another model for the maintenance programming are deterministic approaches. The example of deterministic model is depicted in Figure 4, where it can be seen that the component must be replaced after a 10-year period. If the repair measure be performed for the component at each 3-year period, it can extend its lifetime for one more year at each period. As it can be noticed from figure (4-a), the repairing and breakdown of component is correlated to each other by a mathematical equation. According to this trend of maintenance the lifetime of the component is extended up to 14 years [15].

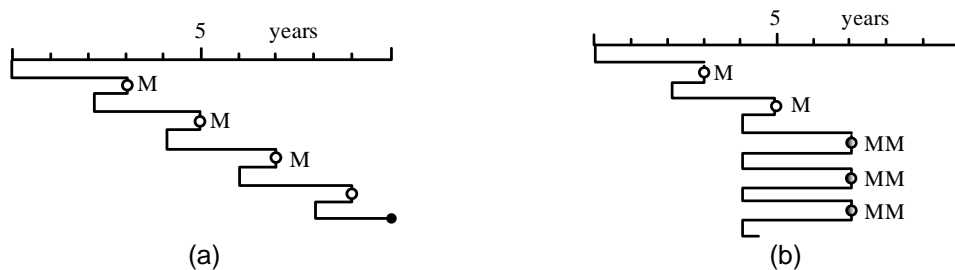


Figure 4. (a) 3-year maintenance (b) 3-year maintenance until 6th year and then implementation of overhaul

When the improvement of the lifetime due to maintenance program is less than repairing time (mean time to repair), particularly when it approaches the end of the lifetime of the component, the component must be so repaired that the improvement be equal or more than aging time. As it is shown in Figure (4-b), before 6th year, minor maintenance is implemented which has little improvement. Then, after each 3-year period, a major maintenance must be implemented which extend the lifetime of the components to infinity. The deterministic approach expresses that the effectiveness of minor maintenance is lower than aging process effects and the improvement is not sufficient to prevent the breakdown of the component. Similar to figure; (a) if the variables simulated as probabilistic models, the failure will occur eventually sooner or later; which is compatible with reality. In all. It can be said that deterministic models can be led to false maintenance programming whereas probabilistic models have more acceptable solutions, even though they have more sophisticated structures.

3.3. Probabilistic Asset Management Program (AMP)

The main concept of AMP is to investigate the aging process with separate steps by employing probabilistic models. In most applications, three level of maintenance can be adequate. At the initial step of D_1 a minor repair should be performed. At the second segment (D_2) the overhaul must be carried out. Finally, at the last segment (D_3) the component is in the aging mode and must be replaced after breakdown. The end of this process is fail step, when the component needs an enormous amount of maintenance or complete replacement. These facts can be observed in upper part of Figure (5). It is supposed that the component returns to initial condition and intact after occurrence of failure and repairing. It should be noted that this assumption can be neglected. In this imaginary model, the regular inspections are done, which is denoted by I . The results of inspections can be included in making decision for minor or major maintenance or overhaul or continuing operation without doing any repair. This part of process can be seen in lower part of Figure (5). The next decision making, must be done when minor maintenance must be performed that occasionally may be led to immediate overhaul or postponement of overhaul. The consequence of all maintenance measures arises a stepwise improvement in aging process [16-19].

Although it is not impossible for components to be deteriorated after any maintenance or no improvement be yielded, but it has very low probability. In addition, the probability of occurrence of such breakdowns after minor or major maintenance is not the same. For instance, the occurrence of D_1 , D_2 , and D_3 have the probabilities of 0.1, 0.6 and 0.3 after implementation of minor maintenance of M_2 whereas it has the probabilities of 0.01, 0.09 and 0.9 after performing MM_2 respectively. It should be noted that the diagram of the Figure (5) only exhibits a basic model. If it is required, the user can easily modify the three level of maintenance or restore the state of component to any point of D_1 , D_2 and D_3 . The probabilities selection should be selected by the user and can be estimated based on the historical data of component. Figure (5) can be presented based on the Markov chain process and be solved by various approaches. The solution of this model contains probability of all possible states and sequence and mean time of each state [20].

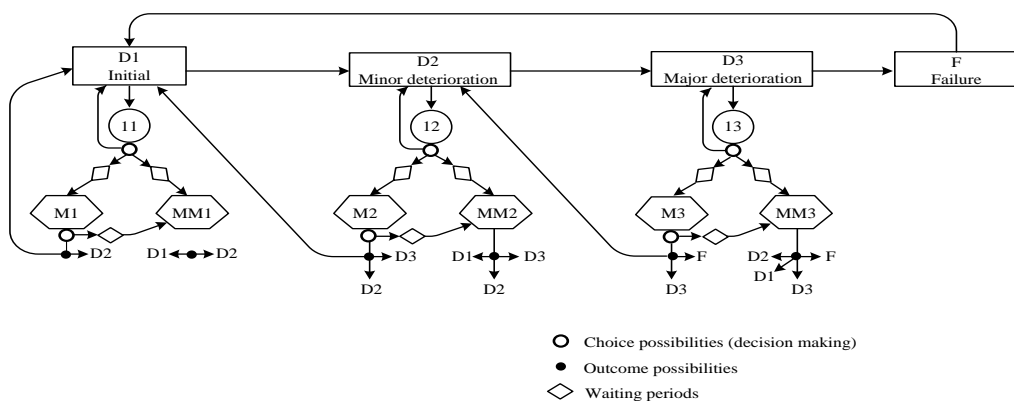


Figure 5. The proposed diagram of AMP model

4. Results and Analysis (Case Study: Montazeri Thermal Power Plant)

In below, an example of circuit breakers is proposed which belongs to Shahid Mohammad Montazeri thermal power plant, located in Iran, Isfahan. This survey is according to analysis of some circuit breakers and their historical data of last operations and maintenances. Regard to the real model, the transition rate and the mean time between failures' values are illustrated in Figure (6). As it is evident if no inspection and maintenance have not been performed, the dedicated time in the beginning of the period is 3 years, and in the case of minor and major maintenance are 3 and 5 years respectively. In the case of without maintenance and inspection, the mean time between installation and replacement or breakdown is 9.5-2+3.5+3 years. The Figure (7) depicts possible probabilities in various decision makings of points and represents the probability of any failure related to any maintenance measure. These values are estimated by the user through historical data of component and related experiences. According to Figure (6), the decision making about implementation of major maintenance is different in point 2 versus 3. The waiting time for maintenance in aging level 3 supposed to be 1 period (day) while it is about 90 periods (days) in aging levels of 1 or 2.

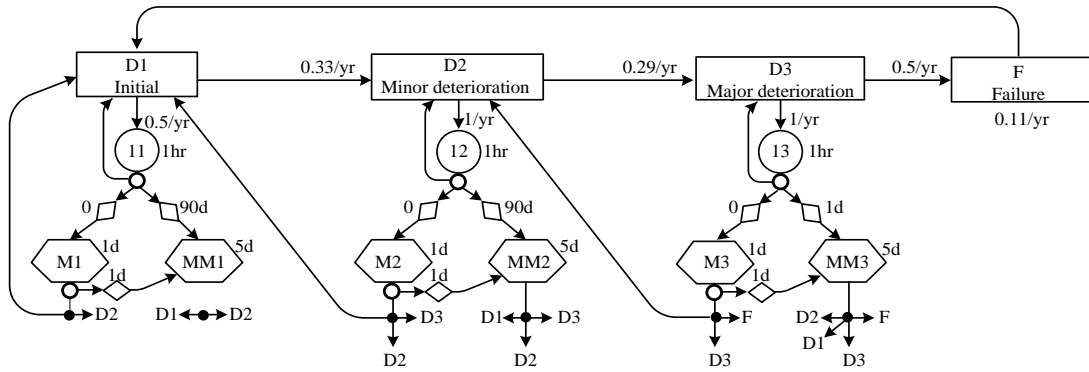


Figure 6. The failure rate and mean time to repair for practical example

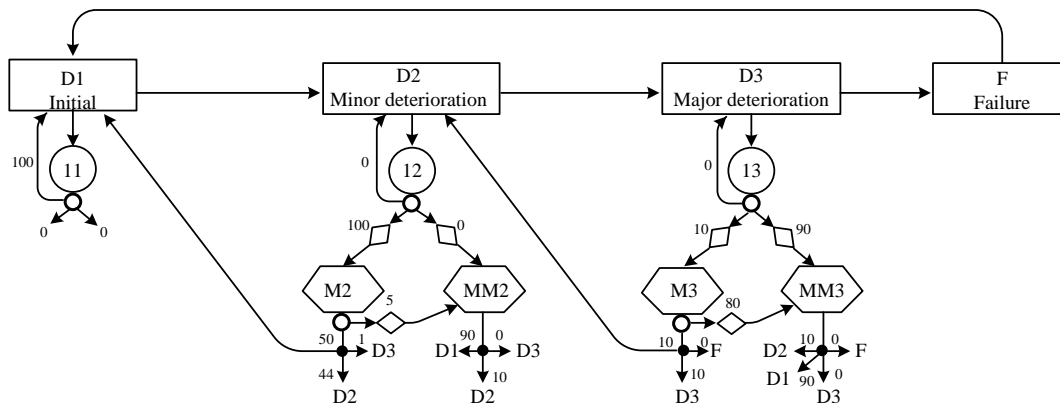


Figure 7. Different probabilities and selections and the failure rate of practical example

In order to perform an economic evaluation, when various strategies are compared and optimized solutions are determined, the costs of any measure must be specified. In our example, the following data are supposed. The average cost of each inspection is \$250, the cost of minor maintenance is about \$1300 and the cost of major maintenance is \$15100 and the average cost of maintenance after fail state is \$150000. When the procedure of maintenance

shown in Figure (5) is implemented and the schedule is represented, the mean time to failure can be calculated. The overall annual cost of this schedule is \$5700 with inclusion of maintenance and \$1800 without the inclusion of maintenance. Hence, the advantages of preventive maintenance can be obviously comprehensible.

5. Conclusion

By consideration of proposed models for both deterministic and probabilistic approaches, it has proved that probabilistic methods have more superiority over deterministic methods. Although probabilistic methods have more complexity, but the outcomes are more logical and more similar to practical experiences. The probabilistic approaches, by taking advantages of Markov chain models, can easily evaluate the maintenance trend and aging process. By this method, the effect of maintenance on the reliability of system or component can be evaluated and the aging process indices and mean time to failure value can be calculated. Many of maintenance approaches, RCM included, can affect on reliability indices and facilitate the decision making for managers and planners regard to restrictions in resources and operational constraints.

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