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Risk-based decision making method for maintenance policy selection of thermal power plant equipment

F.G. Carazas, G.F.M. Souza*

Polytechnic School, University of São Paulo, São Paulo, Brazil

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ABSTRACT

This study presents a decision-making method for maintenance policy selection of power plants equipment. The method is based on risk analysis concepts. The method first step consists in identifying critical equipment both for power plant operational performance and availability based on risk concepts. The second step involves the proposal of a potential maintenance policy that could be applied to critical equipment in order to increase its availability. The costs associated with each potential maintenance policy must be estimated, including the maintenance costs and the cost of failure that measures the critical equipment failure consequences for the power plant operation. Once the failure probabilities and the costs of failures are estimated, a decision-making procedure is applied to select the best maintenance policy. The decision criterion is to minimize the equipment cost of failure, considering the costs and likelihood of occurrence of failure scenarios. The method is applied to the analysis of a lubrication oil system used in gas turbines journal bearings. The turbine has more than 150 MW nominal output, installed in an open cycle thermoelectric power plant. A design modification with the installation of a redundant oil pump is proposed for lubricating oil system availability improvement.

1. Introduction

The main objective of any electric power generation system based on hydroelectric or thermoelectric power plants is to supply the amount of energy demanded by the market and to comply with the regulatory requirements defined by government laws.

To attain the objective, one of the most important requirements for any power generation system is to guarantee its technical availability.

The availability of a complex system such as a thermal power plant is strongly associated with the parts reliability and maintenance policy. That policy not only has influence on the parts repair time but also on the parts reliability affecting the system degradation and availability [3,7,8].

Availability is a measure of the percentage of time in which a plant is capable of producing its end product at some specified acceptable level. In a simple way, availability is controlled by two parameters:

- Mean time to failure (MTTF) which is a measure of how long, on average, the plant will perform as specified before an unplanned failure occurs, being associated with equipment reliability;
- Mean time to repair (MTTR) which is a measure of how long, on average, it will take to bring the equipment back to normal serviceability when it does fail.

Although reliability can be at least estimated during the plant design stages, its availability is strongly influenced by the uncertainties in the repair time. Those uncertainties are influenced by many factors such as the ability to diagnose the cause of failure or the availability of equipment and skilled personnel to carry out the repair procedures.

The maintenance policy of some power plant equipment, such as gas and steam turbines, must follow very stringent recommendations defined by the manufacturer. Most of the maintenance procedure tasks, involving periodical inspection and replacement of parts, are related to parts subjected to very high temperatures. The periodical inspection schedule is based on the number of equipment start-ups and operational hours.

For auxiliary system, such as the lubricating oil system, heat recovery steam generators feed water pumping systems, and other auxiliary systems, the manufacturer recommends periodical inspections but does not clearly define what kind of maintenance policies could be applied to the components of those systems.

In order to guarantee the plant operational performance, the Reliability Centered Maintenance (RCM) philosophy can be applied to define maintenance policy, [4] and [7], mainly for equipment that are not submitted to stringent maintenance tasks. The main

* Corresponding author. Tel.: +55 11 3091 9656; fax: +55 11 3091 5461.
E-mail address: gfmsouza@usp.br (G.F.M. Souza).

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Nomenclature

A	uniform payment in the equal-payment-series capital recovery
C_f	fixed cost of failure (cost of spare parts)
C_v	the variable cost per hour of down time, including labor rate and crew size
Consequences_i	consequences associated with the sequence represented by the ith cause-consequence diagram branch
DT	power plant down time [in fraction of h]
EMV	expected monetary value
$F(t)$	failure probability at time t
j	interest rate
MTTF	mean time to failure
MTTR	mean time to repair
p	probability that the maintenance action is carried out unsatisfactorily
$p(\text{branch}_{i/\text{initial event}})$	probability of occurrence of the sequence represented by the ith cause-consequence diagram branch, given the occurrence of the initial event.
$p_{\text{initial event}}$	probability of occurrence of the initiating event
P	present value in the equal-payment-series capital recovery
PL	energy production loss [MWh]
$R(t)$	reliability at time t
Risk_i	risk associated with the sequence represented by the ith cause-consequence diagram branch
SP	selling price of generated electricity [$/(MWh)]
t	time period [h]
T	time interval between two consecutive preventive maintenance actions
T_i	time interval between two consecutive predictive maintenance actions
ΔT_i	time to failure of the ith equipment failure
β	Weibull distribution shape parameter
η	Weibull distribution characteristic life [h]
λ	Exponential distribution shape parameter [failures/h]

goal of that philosophy is "to determine what must be done to ensure that any physical asset continues to do whatever its users want it to do in its present operating context". The main difficulty for that application is the decision-making process regarding the cost-effectiveness of a given maintenance policy selected for the power plant equipment.

1.1. Objective

The aim here is to present a risk-based maintenance policy selection methodology for power plants equipment.

The proposed method is based on risk analysis and decision-making concepts. The risk analysis concepts are used to structure the process of equipment failure consequences assessment considering the power plant operational profile. The decision-making concepts are used to balance the costs associated with a given equipment maintenance policy and its failure probability aiming at the minimization of the mean power plant operational costs in a given operational profile.

The methodology can be considered complementary to the Reliability Centered Maintenance (RCM) philosophy. According to the decision-making diagrams proposed by the RCM philosophy, the maintenance cost-effectiveness must be considered as a decision variable for maintenance policy selection. The risk-based method presented in the paper can be used for cost-effectiveness analysis supporting the maintenance managers to select the most useful maintenance policy among a set of technically feasible maintenance alternatives, [4,5].

The method integrates financial and technical aspects associated with all applicable maintenance policies for an equipment, including the evaluation of the equipment reliability when assisted by a given maintenance policy and the costs associated with the equipment failure, named cost of failure consequences. That cost is estimated based on the equipment failure effects over the power plant operation, including environmental, safety and operational aspects, mainly the reduction of power plant output that causes production loss.

2. Method development

Based on RCM concepts, a primary maintenance practice selection procedure for equipment can be developed. That procedure, presented in Table 1, is based on the presence of symptoms that indicate whether a given failure mode is being developed and on the pattern of failure occurrence frequency that can be random or repetitive.

According to RCM concepts, equipment failed states are known as functional failures, because they occur when the equipment is unable to fulfill a function to a standard of performance which is acceptable by the user. In addition to the total inability to function, this definition encompasses partial failures, where the equipment still functions but at an unacceptable level of performance.

In Fig. 1 a graphic indicates, in a generic way, the functional behavior of equipment, the performance of which presents degradation during operational time. If the time to failure (ΔT_i) recorded in the maintenance database is quite similar (repetitive failure pattern), the equipment presents a frequency of failure that is almost constant during the operational period. If the failure root-cause analysis indicates that most of the failures are caused by the same age-related degradation mechanism, the equipment failure mode presents a repetitive pattern. The aging failure is a gradual failure, meaning that the performance of the equipment is gradually drifting out of the specified range. According to Table 1, preventive maintenance tasks may be used to lower that frequency of failure. Those tasks, based on the scheduled replacement or restoration of components the failure of which causes the operational performance degradation of the equipment, aims at restoring the initial performance of equipment at a specified operational time limit, regardless of its apparent condition at the time. The frequency of scheduled maintenance tasks is governed by the operational age at which the equipment shows a rapid decrease in performance. If the equipment presents performance degradation (named as failure symptoms), as shown in Fig. 1, due to some component loss of performance associated with a failure mode development, a monitoring system may be used to detect failure mode development aiming at the use of predictive

Table 1
Simple decision-making procedure for maintenance selection.

		Failure frequency of occurrence	
		Random	Repetitive pattern
Equipment failure	With symptom	Predictive	Preventive or predictive
	Without symptoms	Corrective	Preventive