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Determination of preventive maintenance periodicities of standby devices

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Abstract

This article presents a statistical approach of analysis and decision that uses reliability techniques to define the best periodicity for preventive maintenance of power system protective relays. Relays are standby devices and may stay in the hidden failure state when they are not working. This state of failure generates difficulties in the determination of preventive maintenance periodicities. A case study presented in this work deals specifically with the reliability of the transmission and distribution system protective relays of CEMIG (the state owned Electrical Power Company of Minas Gerais, Brazil). Preventive maintenance data of protective relays obtained during a 4-year period were used in the proposed method. The choice of the periodicities, distinguished by groups of similar relay and voltage operation levels of the protected systems, is made according to the failure risk level that the company is willing to take. The main result obtained by using this method is a substantial reduction of 62% in the amount of preventive maintenance work load for the relays of the distribution system.

Keywords: Exponential models; Inspection interval; Protective relays; Reliability model

1. Introduction

It is important to reduce failure occurrence of a system during operation when such an event is dangerous and costly. The purpose of this study is to find a way to better determine when system replacement becomes necessary. Age replacement practice is a known maintenance policy for dealing with these kinds of situations [2,3]. Other maintenance policies such as age replacement with minimum repair, block replacements are also considered in the literature [1]. However, there are some equipment types with special features that make the implementation of these policies difficult or even impossible.

This article deals with two main issues related to the preventive maintenance: (1) which is the best preventive maintenance periodicity of power system protective relays and (2) what is the link between the preventive maintenance periodicity and the failure patterns of the several operating equipment types. Relays are standby devices and usually stay in the hidden failure state when they are not working. This state of failure generates difficulties in the determination of preventive maintenance periodicity. In general, there is a great deal of subjectivity in the usual way the frequency of preventive maintenance of these devices is defined since it is usually based on the experience and judgment of technicians and maintenance engineers. This problem is directly related to the inability of the several methodological strategies to objectively answer a question that is crucial to the effectiveness of maintenance: when should the preventive tasks be done? It can be assumed that the approach developed for relays may serve as a basis for the development of similar models for other types of equipment.

A protection system can be defined as a set composed of components endowed with electrical characteristics that are specific and compatible to each other, intended to automatically determine the operative condition limits of power systems or parts of those systems. Usually, a protection system is made up of four subsystems: measurement transformers, protection relays, circuit breakers and communication channels. The main parts are the relays—the intelligence units, and the circuit breakers—the opening units. Fig. 1 presents a typical general scheme of a protection system.

Relays are standby devices, that is, they should only be active in the presence of an operational demand. Basically, these devices have two failure modes:

(a) failure to operate, in the presence of an operational demand, also known as operational failure;
(b) unnecessary operation, in the absence of operational demand, also known as safety failure.

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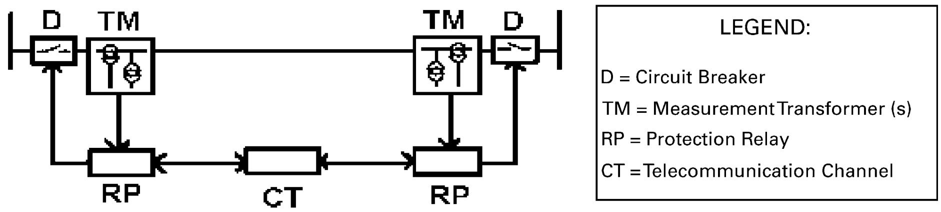

Fig. 1. General scheme of a protection system [8].

A relay usually stays in the hidden failure state either until being discovered through a preventive inspection or through the occurrence of an operational failure. The latter case is also called a multiple failure, that is, a failure of the protected function with the protection device in a hidden failure state. Usually the reliability studies of protection systems only compute the operational failures, thus over-estimating the reliability of these systems. The hidden failures must be included in reliability studies because the majority of failures that occur in protective devices tend to stay in a hidden condition for a long period, if these devices are not periodically inspected. In general, the anomalies found through these periodic inspections are fixed and the device once again becomes, in reliability terms, 'as good as new'. This assumption can be supported by the fact that the periodical relay inspections are complete. It means that all operational features are verified and adjusted if necessary.

In this study, the operational failures of the relays were identified as well as their hidden failures, so that the inspection interval could be properly determined. Safety failures (improper operation) were not included, because they are usually caused by external random factors and they are not registered by the computerized maintenance management systems.

It is clear that an incorrect determination of inspection intervals may restrict the protection availability and thus, put the electric system at risk of operational failure. The reliability of the protection systems plays a crucial role in the reliability of power systems, especially nowadays when the transmission lines are more and more overloaded and working almost at their capacity limit. Several blackouts that have occurred in the linked electrical system of the Southern, Southeastern and Centralwestern areas of Brazil, in the past 15 years, may confirm that this system is currently overloaded.

This paper proposes a statistical approach to analysis and decision that uses reliability techniques to define the best periodicity for preventive maintenance of power system protective relays. The choice of the periodicities, distinguished by group of similar relays and voltage operation levels of the protected systems, is made according to the failure risk level that the organization is willing to accept. An outline of this paper is as follows. Section 2 presents the probability expression of a multiple failure. A brief description of the case study is presented in Section 3 following which is a reliability analysis in Section 4. The model is applied in Section 5 and the results obtained are presented in Section 6.

2. Preventive maintenance approach for relays

The model is based on the multiple failure probability, that is, the probability that the protected equipment will fail between the relay hidden failure and the next relay inspection. In order to do this, it is necessary to define the following events:

A_1: relay is in hidden failure;
A_2: protected equipment fails in the period that the relay is in hidden failure.

These two events are independent, and therefore:

$$P_{\mathrm{MF}}(A_1 \cap A_2) = P(A_1)P(A_2). \tag{1}$$

That is, protected equipment is damaged only if a relay is in hidden failure and there is an operational request.

Assuming an exponential distribution for times to failure of relays (T_{R}) and protected equipment (T_{PE}), it is possible to derive the multiple failure probability at time T_{I}. That is

$T_{\mathrm{R}} \sim \exp(\lambda_{\mathrm{R}})$, which means:
$P(A_1) = P[T_{\mathrm{R}} < T_{\mathrm{I}}] = 1 - \mathrm{e}^{-\lambda_{\mathrm{R}} T_{\mathrm{I}}}$ and
$T_{\mathrm{PE}} \sim \exp(\lambda_{\mathrm{PE}})$, which means:
$P(A_2) = P(T_{\mathrm{I}} > T_{\mathrm{PE}} > T_{\mathrm{R}})$.

The latter probability is given by:

$$P(T_{\mathrm{PE}} > T_{\mathrm{R}}) = \int_0^{T_{\mathrm{I}}} \int_{t_{\mathrm{R}}}^{T_{\mathrm{I}}} \lambda_{\mathrm{R}} \lambda_{\mathrm{PE}}\, \mathrm{e}^{-\lambda_{\mathrm{R}} t_{\mathrm{R}}}\, \mathrm{e}^{-\lambda_{\mathrm{PE}} t_{\mathrm{PE}}}\, \mathrm{d}t_{\mathrm{PE}}\, \mathrm{d}t_{\mathrm{R}}$$

$$= \frac{1}{\lambda_{\mathrm{R}} + \lambda_{\mathrm{PE}}} \left[\lambda_{\mathrm{R}} + \lambda_{\mathrm{PE}}\, \mathrm{e}^{-T_{\mathrm{I}}(\lambda_{\mathrm{R}} + \lambda_{\mathrm{PE}})} - (\lambda_{\mathrm{R}} + \lambda_{\mathrm{PE}}) \mathrm{e}^{-\lambda_{\mathrm{PE}} T_{\mathrm{I}}} \right].$$

By plugging in these two probabilities in Eq. (1), multiple failure probability is obtained at time T_{I}. Estimates of λ_{PE} were obtained from historical information available in the company.

The exponential distribution assumption can be justified in theoretical terms by a renewal process [6]. This type of process takes place when a number of individual processes combine to form an overall process, which is called a superimposed process. The overall process tends to be a