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Probabilistic method for planning of maintenance activities of substation components

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Abstract

This paper suggests a probabilistic method for the calculation of operation cost throughout a planning period and availability evaluation of substation components, in connection with planned maintenance activities. This method is conceived to provide lower operation cost, consisting of failure repair cost and maintenance cost, and higher availability of substation components. The method identifies minor and major failures. It is assumed that each component has two independent, competing failure modes: wear-out failure mode, modelled by a two-parameter Weibull distribution, and a chance failure mode, characterized by an exponential distribution. The application of the method suggested is demonstrated for a 145 kV air-blast circuit-breaker. By applying the method, influence of condition monitoring systems application on operation cost is evaluated. Also, because of comparison, expected operation cost in case of time-based maintenance performing is calculated.

Keywords: Probabilistic method; Substation components; Minor and major failures

1. Introduction

Operation cost during exploitation period of substation consists of preventive maintenance cost and major failure repair cost.

The purpose of traditional, time-based, preventive maintenance is to extend substation component lifetime, i.e. the mean time between failures. Time-based preventive maintenance is performed after T_{BM} time units of continuing operation without failure. If a failure occurs prior to T_{BM}, then repair is performed at the moment of failure. In either case, we assume the component is returned to “as good as new” condition. Practically, the expected operation cost during period of T_{BM} time units equals

$$C_{TBM}(T_{BM}) = e^{-\lambda_{MF} T_{BM}}\ C_{pm} + (1 - e^{-\lambda_{MF} T_{BM}})C_{MF}. \qquad (1)$$

Many electric power utilities have planned, up to now, preventive maintenance activities based upon their experience or manufacturers’ recommendations. Too frequent performing of maintenance demand unnecessary expenditures. On the other side, too little maintenance may have very costly consequences (high cost of failure repair and the loss of revenue).

The aim of this paper is to propose a model enabling the evaluation of frequency of preventive maintenance performing, in order either to minimise the operation cost or to maximise component availability.

Due to proper estimation whether certain plans are acceptable or not, it is worth noting two facts:) >

- It is necessary to have a precise operation data for a certain type of substation component (reliability data, cost of preventive maintenance and cost of failure repair);
- Since the substation component consists of several functional parts (HV-parts, electrical control and auxiliary circuits, operating mechanism, etc.), it is necessary to perform an analysis for each functional part and, after that, based on the results, select the most favourable schedule of maintenance activities.

In the following section, a cost model and a limiting availability model for a repairable component are formulated.

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2. Model development

2.1. State-space and probability calculation model

At any point of time, status of the repairable component can be classified as either operating or failed. In operating status, the component can be in one of the two states:) >

- state 1: component is "good as new",
- state 2: there is either minor or major deterioration of the component, but it does not affect component fundamental functions.

Failed status (state 3) is a result of major failures. The space-state diagram of repairable component is shown in Fig. 1.

The probability of state 1 equals

$$p_1(t) = \mathrm{e}^{-(t/\alpha)^{\beta}}\,\mathrm{e}^{-(x\lambda_{\mathrm{MF}}+\lambda_{\mathrm{mf}})t}, \tag{2}$$

i.e. we assume that the component has two independent failure modes: a wear-out failure mode, modelled by two-parameter Weibull distribution, and a chance failure mode, characterized by the exponential distribution.

Certain percentage of chance failures can be eliminated by maintenance. However, the most rigorous and costly maintenance program probably cannot significantly reduce these failures. Ratio x presents a relative part of total major failures which develop rapidly.

With regard to Fig. 1, we have [1]

$$p_2(t) = \int_0^t p_1(u)\lambda_{12}(u)p_2(t-u)\,\mathrm{d}u, \tag{3}$$

$$p_3(t) = 1 - p_1(t) - p_2(t). \tag{4}$$

The general form of Eq. (3) [1] is

$$p_2(t) = \int_0^t f_1(u)F_2(t-u)\,\mathrm{d}u. \tag{5}$$

Let us split integration interval (0, t) into q equal time-steps Δt yielding

$$t = q\,\Delta t. \tag{6}$$

Then, by applying the trapezoidal integration formula (1), we obtain

$$p_2(q\,\Delta t) \approx \frac{\Delta t}{2}[f_1(0)F_2(q\,\Delta t) + f_1(0)F_2(q\,\Delta t)] + \Delta t \times \sum_{j=1}^{q-1} f_1(j\,\Delta t)F_2((q-j)\Delta t). \tag{7}$$

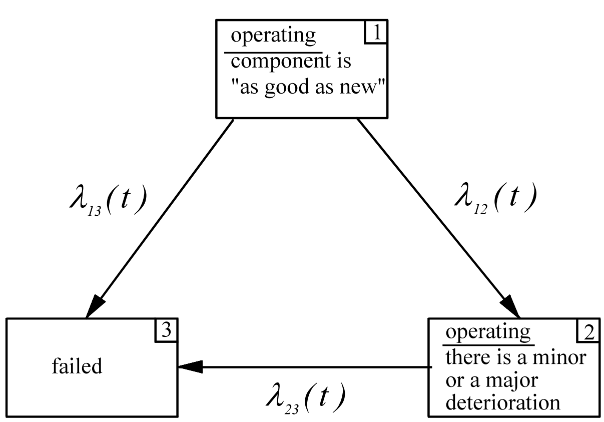

Fig. 1. Space-state diagram before first time passage [1].

2.2. Calculation of expected operation cost and component availability

As we noted in the previous section, it is assumed that after performing of failure repair or preventive maintenance, the component will be returned to "as good as new" condition (state 1). The expected operation cost during period of T_{r} time units equals

$$\begin{aligned} C_{\mathrm{u}}(T_{\mathrm{r}}) &= p_3(T_{\mathrm{r}})C_{\mathrm{MF}} + p_1(T_{\mathrm{r}})C_{\mathrm{i}} + p_2(T_{\mathrm{r}}) \\ &\quad\times [C_{\mathrm{i}} + pC_{\mathrm{MR}} + (1-p)C_{\mathrm{mr}}] \\ &= p_3(T_{\mathrm{r}})C_{\mathrm{MF}} + (1-p_3(T_{\mathrm{r}}))C_{\mathrm{i}} + p_2(T_{\mathrm{r}}) \\ &\quad\times [pC_{\mathrm{MR}} + (1-p)C_{\mathrm{mr}}]. \end{aligned} \tag{8}$$

The term inspection includes performing of diagnostic procedures with the aim to verify the integrity of the fundamental parts of the component. If there are no worn-out parts and if the values of all relevant parameters are in acceptable ranges, the component will be put in service without performing of maintenance actions. Otherwise, depending on the degree of deterioration, major or minor maintenance will be performed.

The common type of preventive maintenance policy employed for *mission systems* is age replacement [2]. This policy can be described as follows. If the system operates without failure for a period of length T_{ms}, the system is shut down and replacement is performed. Expected cost equals

$$C_{\mathrm{ms}}(T_{\mathrm{ms}}) = p_3(T_{\mathrm{ms}})C_{\mathrm{MF}} + (p_1(T_{\mathrm{ms}}) + p_2(T_{\mathrm{ms}}))C_{\mathrm{R}}. \tag{9}$$

An optimal age replacement time is one that either minimises the expected cost per unit time or maximises the availability. The expected cost per renewal cycle as a function of T_{ms} equals [2]

$$c(T_{\mathrm{ms}}) = \frac{C_{\mathrm{ms}}(T_{\mathrm{ms}})}{\int_0^{T_{\mathrm{ms}}}(p_1(t) + p_2(t))\,\mathrm{d}t}. \tag{10}$$

To find the optimal age replacement policy minimising the expected cost per unit time, it is necessary to solve the equation