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Reliability and Cost Model of P.M. in A Component of an Electrical Distribution System Considering Ageing Mechanism

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ABSTRACT

Application of Reliability Centered Maintenance (RCM) in a system results in a decrease in component failure rates and as such improvement in the system reliability. One of the major subjects of the RCM is focused on the Online and Offline Preventive Maintenance (OPM and FPM which together will be denoted by OFPM) of the components which repairing the component needs or doesn't need to stop the mission carrying out by it. The RCM is classified as a preventive maintenance policy and has significant contribution in practical applications. However, little research has been devoted to modeling the online and offline Preventive Maintenance. This research assumes that the component failure rate will be improved if the OFPM is performed for a long period of time as a part of an RCM program. Application of an OFPM program could cause the component set at least to "as bad as old state but cannot reach the "as good as new" state. The emphasis of this research is to model the OFPM for critical components or any equipment with critical failure in a system. The proposed model is based on the concept of PM and improvement factor of reliability in a system with critical components which their failure could cause a failure in the system (first-order cut- sets).

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1. INTRODUCTION

It has been shown that preventive maintenance will definitely enhance the working condition or reduce the failure of a system (or a component) [1], [2].

Based on the working condition of a component being restored after performing maintenance activities, the maintenance can be Classified into three categories: Perfect maintenance, Minimal maintenance, and Imperfect maintenance [3].

Perfect maintenance means all actions performed to restore the component working condition to as good as new. Minimal maintenance means the actions performed to restore the component to the Condition right before the actions, which is often called as bad as old state. Imperfect maintenance restores the component working condition to somewhere between as good as new and as bad as Old. Perfect maintenance may be reasonable for systems with only one component and the minimal maintenance seems rational for failure behavior of systems when only one or few components is replaced by a new one. Thus, perfect maintenance and minimal maintenance are often found very limited uses in practical applications. Normally, the failure rate under imperfect maintenance is somewhere between as good as new and as bad as old. On the other hand, maintenance can also be classified into corrective maintenance and preventive maintenance according to the status of a component before maintenance is performed [2].

Corrective maintenance (CM) is any maintenance when a component is failed and preventive maintenance (PM) is the maintenance actions when a component is operating or can continue its mission. The outage and aging problems of a component can be reduced through preventive maintenance [4].

Practitioners introduce the Reliability Centered Maintenance (RCM) to improve Component outages effect and component availability. The major effort of the OPM program focuses on the preventive maintenance (PM). An important PM activity of the OPM program is the Online and offline Preventive Maintenance (OFPM). These maintenance activities are intended to prolong the useful life of a component. It should be noted that the reliability could be improved through the OFPM activities for equipment of which system failure is critical.

In this paper, the effect on system reliability and the cost issue are studied when applying the OFPM activity. The concept of preventive maintenance has been discussed by many researchers [1, 2, 4, 5, 6, 7]. They proposed that the effective age of a system is reduced by a certain units of time after each imperfect maintenance [8, 9, 10].

Canfield [1] has presented the effect of imperfect PM on hazard function of which the hazard rate at age is restored to the hazard rate at a younger age, while the hazard level remains unchanged. The concept of improvement factor is proposed by Malik [9] and Lie and Chun [7], which is similar to the idea presented by Nakagawa [12], that is, the post-maintenance age of a system is reduced from t to $\frac{t}{\beta}$ and the pre-maintenance reliability of the system $r(t)$ has become $r(\frac{t}{\beta})$ A similar concept has been presented in [5, 15, 16], in which it is assumed that maintenance will restore the system to a better condition (but not to the as-good-as new state). The degree of improvement of a system's reliability is a random variable which depends on the component's age.

The method stated in the above studies has been discussed by Pham and Wang [12] and is designated as "the improvement factor method". The research areas of the imperfect preventive maintenance have been focused on the issues of optimal PM or replacement policies, including scheduling models and algorithms by minimizing the average cost-rate (cost/time) of a system [1-7, 10, 13, 15, 16].

The degree of maintenance can be measured by either the frequency of PM or the average time interval between PM interventions [1-2, 4, 5, 7-16]. In this research, each component in a distribution system is treated as a system with many components. It is also difficult to measure the degree of maintenance for the OFPM in a short period of time. Thus, this paper uses the total cumulative time done by the OFPM activity for a component at age t as a measure for the degree of maintenance.

The reliability is compared for the component that is with and without implementing the OFPM. Since the OFPM normally does not include parts replacement, it is assumed that the shape of the failure distribution is not changed but the effective age of a component is reduced by units of time if OFPM is performed.

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The reliability is compared for the component that is with and without implementing the OFPM. Since the OFPM normally does not include parts replacement, it is assumed that the shape of the failure distribution is not changed but the effective age of a component is reduced by units of time if OFPM is performed.

2. ASSUMPTIONS AND CONSIDERATIONS

The characteristics associated with the OFPM are short maintenance intervals, short maintenance time in online PM and little improvement of the reliability. As a result, it is necessary to define the assumptions based on the above characteristics to develop a model. The assumptions to the model are:

1. In practice, the OFPM is executed in short intervals and the frequency may be fixed, for instance, once a week or two times a week. Since it is known that the reliability of the system will be slightly improved due to executing the OFPM for a component, this research will focus on the total cumulative time spent in the OFPM activity for a long period of time.

2. Since the OFPM is performed by the in-line operators, the maintenance cost of the OFPM is considerably lower than that of any other kinds of maintenance.

3. The increase of the total cumulative time spent in the offline preventive maintenance activity will reduce the available time in production and so increase the production loss cost. But production loss cost in online preventive maintenance is close to zero.

4. Since the OFPM involves only minor maintenance without any replacement or repair activity, it is assumed that they only postpone the failure occurrence but keeping the shape of component's failure distribution.

5. Suppose that the degree of improvement for the component's reliability is m. Then, m is a function of both the total cumulative time (t_p) spent in the OFPM and the age of the component (t'), i.e., m (t_p, t'). For practical applications, the m (t_p, t') function can be obtained from the historical data of a component.

3. MATHEMATICAL MODELING

According to Assumptions 4, the failure probability density function (pdf) of a component with and without implementing the OFPM are shown in Figure 1, where $f_1(t)$ and $f_0(t)$ are respectively the failure pdf of a component with and without implementing the OFPM. It can be seen from Figure 1 that the failure density of a component with the OFPM at age t' is the same as the failure density of the component without executing the OFPM at age t".

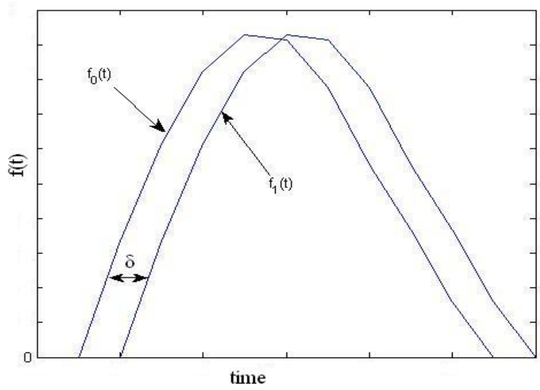

Figure 1. Pdf of a component with and without OFPM Application

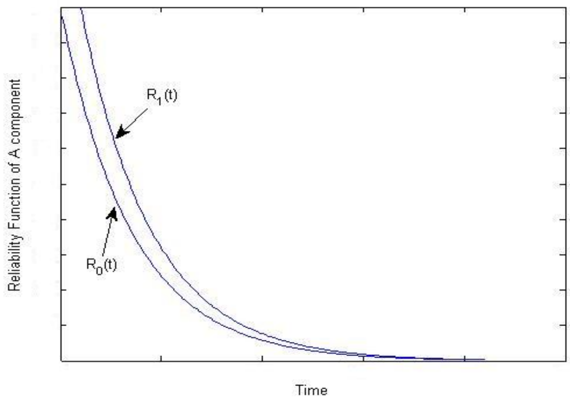

Figure 2. Reliability function of a component with and without OFPM Application

This means that the component with the OFPM plan is t'-t" (say δ) units of time younger than the component without it. Thus, δ can be treated as the improvement of aging. In other words, the OFPM activity delays the failure occurrence by δ units of time. It can be proved that the mean of $f_1(t)$, say m_1, is also greater than the mean of $f_1(t)$, m_1 by δ units of time.

Assume that $\Delta R(\delta)$ is the difference of the reliability at t' between $f_1(t)$ and $f_0(t)$. Let $R_0(t^{'})$ be the reliability of the component without executing the OFPM and $R_1(t^{'})$ be the reliability of the component with the OFPM activity as shown in Figure 2. Assume that the total cumulative time of component spent in the OFPM activity at age t' is t_p. Then, based on the concept of the Improvement Factor method, the degree of improvement for the component's reliability at age t' is $D(t_p)$, where:

$$D(t_p) = \Delta R(\delta) = R_1(t^{'}) - R_0(t^{'}) \quad (1)$$

From Figure 2, $R_0(t^{'})$ and $R_1(t^{'})$ are the integrated area of $f_0(t^{'})$ and $f_1(t^{'})$ after t', respectively. Where;

$R_0(t^{'}) = 1 - f_0(t^{'})$ And

$R_0(t^{'}) = 1 - f_0(t^{'})$

Since the total cumulative time, t_p, of a component spent in performing the OFPM activity will not directly equal to the improvement of aging from the OFPM, the relation between t_p and δ need to be obtained. In real world, $D(t_p)$ is unknown and is difficult to be measured. However, $f_0(t^{'})$ can be obtained from the equipment vendors and $f_1(t^{'})$ can be analyzed from the maintenance history data of the component.

Thus, the value of δ for the component at age t' can be calculated and the value of $D(t_p)$ can then be obtained. Based on Figure 1, it can be found that when t' increases, the degree of improvement of component's reliability will become slow down due to the value of δ being fixed. Thus, in addition to t_p, the component age, and t', is another factor to affect the degree of improvement of component's reliability. Therefore, $D(t_p)$ can be modified to be $D(t_p,t^{'})$. Similarly, $\Delta R(\delta)$ becomes $\Delta R(\delta,t^{'})$ and $D(t_p,t^{'})$ will be $\Delta R(\delta,t^{'})$, that is, Equation (1) can be modified as:

$$D(t_p,t^{'}) = \Delta R(\delta,t^{'}) \qquad (2)$$

4. CASE STUDY

For an example we can consider the distribution system shown in figure 4 which is a part of an urban electric power distribution system in Sweden the total system consist of:

Medium voltage underground cables and overhead lines (11 and 20 kV): 515, 5 km totally.
Power transformers from substations having 20/0,4 kV and 11/0,4 kV voltage: 637 totally.
Medium voltage breakers (11 kV and 20 kV) are 538 in number
Medium voltage switches (11 kV and 20 kV) are 1350 in number.

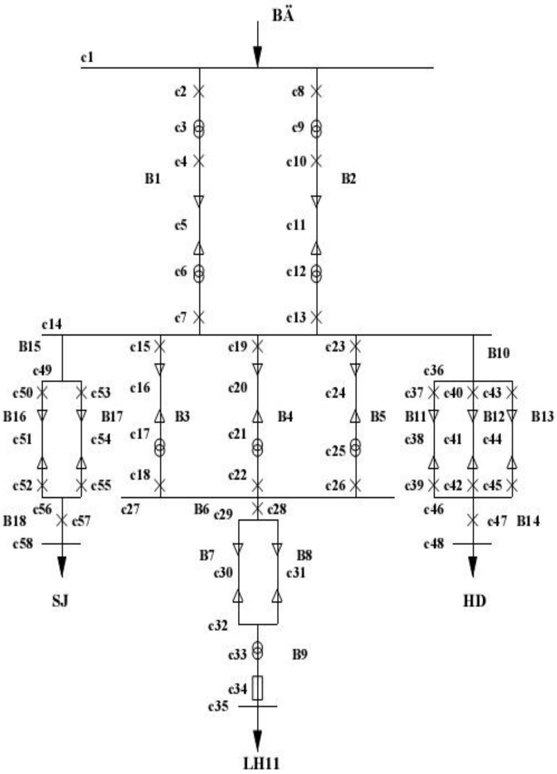

Figure 3. A part of test distribution system

For the C33 transformer which is a first order cut-set; we can generate a cumulative weibull distribution function as shown in figure 4 using statistical data for the component.

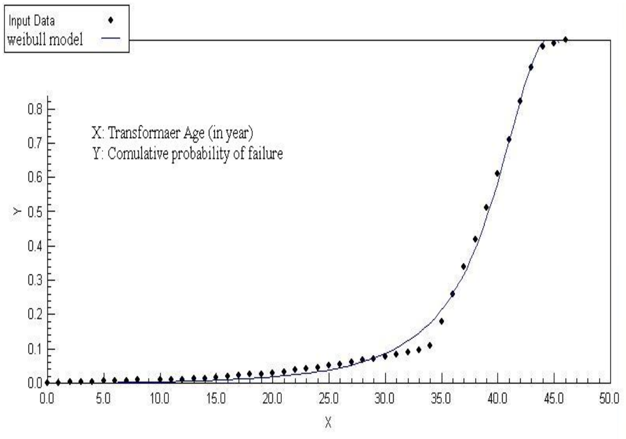

Figure 4. Cumulative probability of failure weibull Distribution function

Using weibull cumulative probability of failure Model constants presented in figure 4 $C(t_p, t^{'})$ Function is illustrated by applying $C_d = 0.45$, $C_r = 180$, $\gamma = 0.0000073$, $\beta = 1.725$, $\alpha = 0.0005$, $\varepsilon = 1.05$, and $\eta = 0.0005$ when t' = 2100 units of time and is shown in Figure 5. By applying t' = 2100, it can be found that the optimal total cumulative time of the OFPM (t_p^{*}) is 97.32 units of time; the degree of improvement in reliability $D(t_p, t^{'})$ is 0.1208; the difference of failure rate Δh is 0.000267; the difference of expected number of failure $(\Delta\Lambda)$ is 0.341; and the saved cost P is 10.342. From the above example,

It can be noted that the improvement in reliability and reduction in cost are significant when the OFPM is applied. It is also shown that the effect of the OFPM strongly depends on the component's failure distribution.

Figure 5 shows an example of C (t_p, t') function at $C_d = 0.45$, $C_r = 180$, $\gamma = 0.0000073$, $\beta = 1.725$, $\alpha = 0.0005$, $\varepsilon = 1.05$, and $\eta = 0.0005$

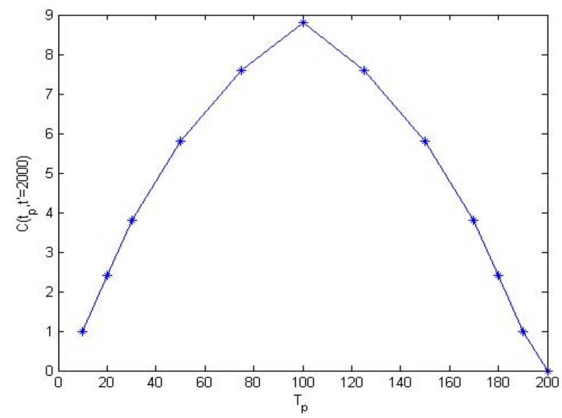

Figure 5. Cost function at t'=2100 units of time for offline PM when γ =0.0000073 and $\beta = 1.725$

We can also found that the optimal total cumulative time of the OFPM (t_p*) is 97.32 units of time, the degree of improvement in reliability is calculated as D (t_p, t') = 0.1208, the difference of failure rate (Δh) is 0.000267, the difference f expected number of failure $(\Delta\Lambda)$ is 0.341, and the cost saved is as P = 10.342. It can be seen from this example that the degree of improvement in reliability is more significant than the reduction in cost when the OFPM is applied. It can also be shown that the effect of the OFPM strongly depends on the component's failure distribution.

5. CONCLUSION AND SUMMARY

Based on the concepts of the Preventive Maintenance and the Improvement Factor Method, the OFPM model is conducted with several assumptions being made. Both the total cumulative time t_p and the age of the component (t') are incorporated in the proposed model.

An optimum total cumulative time (t_p) can be obtained by the numerical analysis method with the consideration of the effects of the cost and component reliability. An example has been given and shown that the proposed OFPM model might be an approach of choosing maintenance policy for critical components in a system.

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