Electrical Power and Energy Systems 68 (2015) 304–312

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

A model for optimizing maintenance policy for power equipment

César L. Melchor-Hernández *, F. Rivas-Dávalos, S. Maximov, V.H. Coria, J.L. Guardado

Instituto Tecnológico de Morelia, PGIIE, Av. Tecnológico No. 1500, Lomas de Santiaguito, C.P. 58120 Morelia, Mich., Mexico

ARTICLE INFO

Article history:
Received 2 December 2013
Received in revised form 19 December 2014
Accepted 24 December 2014
Available online 13 January 2015

Keywords:
Power equipment
Analytic method
Power law process
Maintenance optimization

ABSTRACT

Electrical utilities have the problem of applying complex mathematical models for maintenance optimization of power equipment. This is because the models presented in the literature lack the simplicity desired to carry out evaluations, and some others require a great number of input data, which may not be easily available. In order to overcome these difficulties, a new analytical optimization method for preventive maintenance (PM) policy with minimal repair at failure, periodic overhaul, and replacement is proposed for power equipment with historical failure time data influenced by a current PM policy. The method includes a new imperfect PM model based on Weibull distribution and incorporates the current overhaul interval T_0 and the optimal overhaul interval T to be found. The Weibull parameters are estimated using a new analytical method. Based on this model, the optimal number of overhauls and the optimal overhaul interval for minimizing the expected total maintenance cost are also analytically determined. Several study cases were designed in order to test the proposed model, demonstrating its applicability and simplicity to determine an optimal maintenance policy.

© 2014 Elsevier Ltd. All rights reserved.

Introduction

Power equipment is subject to continuous wear and deterioration along its service life. Sooner or later this leads to failures, which will interrupt the normal energy supply process. The lack of proper preventive maintenance (PM) policy inevitably results in higher costs and unnecessary downtime, and although increased maintenance can effectively reduce the downtime, the associated costs will reduce utility profits. Hence, an optimal PM policy is necessary in order to ensure safety and reliability of equipment, to decrease the frequency and severity of failures, to reduce high maintenance and breakdown costs, and to improve equipment availability.

Power equipment that deteriorates with age receives along its service life preventive maintenance actions, which involves minimal repairs, periodic overhauls, and replacement actions. A minimal repair is generally carried out in order to remove a failure with minimal effort (e.g. repairing just the failed components). Since power equipment consists of many components, it is commonly assumed that minimal repairs do not change the Rate of Occurrence of Failures (ROCOF) of the equipment. Extensive research assuming minimal repairs has been conducted in [1–3]. On the other hand, an overhaul usually involves a set of preventive maintenance actions such as oil changing, cleaning, greasing, and replacing some worn components in a piece of equipment. In practice, power equipment is subject to routine or periodic overhauls, which improve its condition, but they do not return it to the state "as good as new". This is the reason why overhauls can be considered as imperfect maintenances, with the ROCOF being slightly modified by maintenance actions.

In 1995, the IEEE subcommittee on Application of Probability Methods established a task force to investigate the present status of maintenance strategies in the power industry. The results of this investigation were reported in [4]. The main conclusion of this investigation was that maintenance at fixed intervals is the most frequently used approach, and strategies based on reliability-centered maintenance (RCM) are increasingly considered for application. This can be observed recently in some applications of RCM in transmission systems [5], distribution systems [6], and wind turbines [7], just to mention a few examples. Also, other studies have proposed probabilistic maintenance models based on state diagrams. State diagrams can be directly converted into mathematical models called Markov models which can be easily solved using standard methods and analytical equations [8–11]. Other approaches have been proposed in the reliability engineering literature to model the impact of imperfect PM on the hazard rate of repairable systems (in this literature, the ROCOF is called hazard rate). These imperfect PM models can be classified into three groups [12]: age reduction models, hazard rate models, and hybrids of both. Age reduction models assume that there is an effective age reduction right after a PM action, and that the hazard

* Corresponding author. Fax: +52 (443)3171870.
E-mail address: cemehe@gmail.com (C.L. Melchor-Hernández).

http://dx.doi.org/10.1016/j.ijepes.2014.12.066
0142-0615/© 2014 Elsevier Ltd. All rights reserved.

rate continues to be a function of the effective age [13–15]. The hazard rate models assume that right after a PM action, the hazard rate reduces to zero, and then increases faster than it did in the previous PM interval [14–17]. In the hybrid models, the hazard rate becomes a combination of both age reduction models and hazard rate models [18,19].

The imperfect PM models have made important contributions to this research field, however, in practice the main problem is how to take decisions or make inferences about the unknown factors involved in these models. Numerous approaches have been proposed based on guessing the values of these factors by subjective means, which is fine, as long as there is enough expert knowledge to perform this task properly. Other approaches are based on estimating these factors from observed data. These statistical inference techniques are very good if there are sufficient data to estimate the factors accurately. However, in practice, few data are available in many areas of maintenance and replacement [20]. In the power industry, the study reported in [4] concluded that mathematical models, deterministic or probabilistic, are as of yet rarely used because they lack the simplicity required for evaluations which are often carried out in the field; besides, they require a multitude of input information which may not be readily available. To some extent, these statements and observations are still valid nowadays.

In addition to the aforementioned issues, generally a PM model requires to estimate the parameters of the lifetime distribution used to determine the hazard rate function on which the model is based. The two-parameter Weibull distribution is one of the most popular distributions for modeling stochastic deterioration of power systems because it is very flexible, and can model many types of failure rate behaviors through an appropriate choice of parameters. The estimation of these parameters has been addressed in the literature by various techniques, such as probability plotting, moment estimation, modified moment estimation and maximum likelihood estimation (MLE). In the case of MLEs, the corresponding likelihood equations need to be solved numerically and related software programs need to be applied [21]. Moreover, since the solution is numerical, issues of existence and uniqueness of the estimates have to be addressed, which gets quite involved in the case of scarce data [22].

In this paper, the authors consider the following maintenance optimization scheme for repairable power equipment. A piece of power equipment is subject to three kinds of maintenance actions: minimal repair, overhaul, and replacement, with different costs. The piece of equipment receives a minimal repair whenever a repairable failure occurs, and overhauls are made periodically at equal time intervals of length T. In addition, the piece of the equipment is replaced by a new one at the Nth overhaul. In this sense, the time-based maintenance (TBM) strategy has been selected as the basis for this research. In TBM, maintenance decisions (e.g., preventive overhaul times/intervals) are determined based on failure time analysis. TBM assumes that the failure behavior (characteristic) of a piece of equipment is predictable. This assumption is based on hazards or ROCOF trends, known as bathtub curves [23]. Also, to analyze the failure pattern, the non-homogeneous Poisson process is considered in this research [24].

In order to solve the optimization problem, it is proposed a new ROCOF function based on the two-parameter Weibull distribution in order to assess the impact of imperfect PM actions on the reliability of repairable power equipment. The proposed ROCOF function does not require adjustment factors as the ones presented in the literature since it is formulated as a function both, the current overhaul interval T_0 and the optimal overhaul interval T to be estimated. The overhaul interval T_0 refers to the PM policy that is currently influencing the failure times behavior of a piece of equipment. Also, this paper proposes an analytical method to estimate the Weibull shape β and scale α parameters that define the ROCOF function. By using the MLE method, a closed-form expression is obtained for the β parameter. The closed-form expression for the α parameter is a function of the β parameter, and it is obtained directly from the partial derivative of the log-likelihood function. Finally, a cost function with the proposed ROCOF function is applied to estimate the optimal N and T so that the expected total maintenance cost can be minimized. The model performance is analyzed by using several numerical examples.

The model

A piece of power equipment can be considered as a repairable device. This is because after failing to perform at least one of its main functions, the device can be repaired to perform again all its original functions. Since the exact occurrence of any failure in a power device is uncertain, its time to failure from the time at which the device is put into operation is represented mathematically by a random variable. The device is back into operation through corrective maintenance (repair) and continues functioning properly until its next failure. Thus, the failure process of a repairable power device consists of a series of failures. A collection or sequence of random variables forms a random (uncertain) or stochastic process [25].

Fig. 1 shows a portion of a sample pattern of a stochastic point process representing the successive failures of a single device (such as a transformer, circuit breaker, reactor, etc.), where $S_i, i = 1, 2, 3, \ldots, n$, measures the total time from 0 to the ith failure and is called the arrival time to the ith failure (S_i is a random variable); $X_i, i = 1, 2, 3, \ldots, n$, is the inter-arrival time between the $(i-1)$th and the ith failures, where $X_0 = 0$ (X_i is also a random variable); and it is clear that $S_i = X_1 + X_2 + \cdots + X_i$. $M(t)$ can be defined as the number of failures which occur during $[0, t)$. The expected value of $M(t)$ is $V(t) = E[M(t)]$. It will be assumed here that $V(t)$ is absolutely continuous and its derivative, $\rho(t) = V'(t)$, is known as the Rate of Occurrence of Failures or ROCOF. Also, $\rho(t)dt$ is the probability that a failure, not necessarily the first, occurs in the interval $(t, t + dt)$. Most of the repairable power equipment shows a trend towards long term reliability degradation with repeated overhauls and replacement. This has the effect that successive times between failures are dependent as well as coming from different distributions (not identically distributed). There are presently two main directions of development in the analysis of non-homogeneous data [24]: models based on the Non-Homogeneous Poisson Process (NHPP) [26–28] and models based on Proportional Hazards [29]. Both trends have its own characteristics and play an important role in the development of failure analysis techniques for repairable equipment. In this paper it is

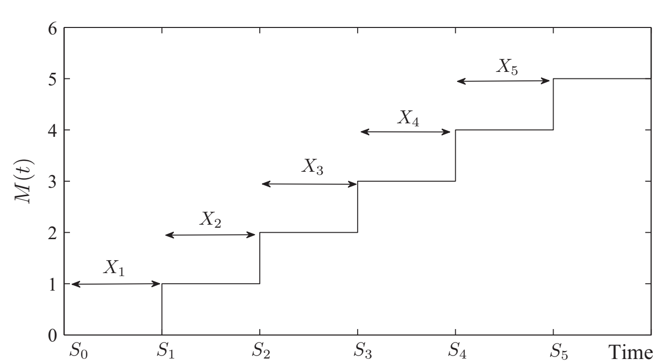

Fig. 1. Successive failures of one repairable device. $M(t)$: number of failures, X_i: inter-arrival times between failures, and S_i: time of failure.

Download English Version:

https://daneshyari.com/en/article/398580

Download Persian Version:

https://daneshyari.com/article/398580

Daneshyari.com