Prediction of Power Cable Failure Rate Based on Failure History and Operational Conditions

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ABSTRACT

In this paper, the failure causes of cables are classified into two types, random and ageing. The piecewise power-law non-homogeneous Poisson process and stochastic electro-thermal model is proposed to predict the total annual and ageing failures, respectively, and the amalgamation of the two models is used to estimate the random failures. The proposed methodology is successfully applied to real data of vintage unjacketed XLPE cables. The result shows that these cables have average 39 years of ageing life. However, failure of these cables is dominated by random failure which cause many of these cables to fail earlier in their life.

KEYWORDS

Failure, Operational conditions, Ageing, Poisson process

INTRODUCTION

All utility companies aim to improve the reliability of cables without increasing the service cost. This can be achieved by taking right decisions regarding replacements and maintenance of cables which fails due to unpredictable random causes and ageing. The unpredictable random failure occurrences are due to poor workmanship, sudden mechanical shock and manufacturing defects which cause intrinsic weakness when these defects develop into water tree, electrical tree or partial discharge. These failures mechanisms have unpredictable nature and techniques to detect them are not easy for utility companies to apply [1]. The failures due to slow and continuous degradation or ageing by the operational stress can be predicted. They are dominated by the synergistic effect of electrical and thermal stress [2]. Such ageing failures result from the accumulation of electro-thermal stress in daily load cycles due to seasonal load demands and ambient temperatures [3]. The electrical stress is associated with the electric field due to voltage and, thermal stress from generation of heat within the cable and impedance of heat dissipation to the surroundings due to high ambient temperature. The failure rate any point of time is the combined failure rate due to unpredictable and predictable causes.

Many statistical models have been developed to predict the failure of power cables. At present the UK regulatory approach is based on Normal distribution and Monte Carlo simulation for the evaluation of forecast uncertainties [4]. Another model which classifies the failure rate based on the cable constructional features is proposed in [1]. Weibull models are commonly used to fit the cable failure data. In paper [5], Ainscough and Forrest, have used the Weibull distribution to predict the failure of medium voltage underground XLPE and Bucci *et al*. [6] have proposed a similar method to predict the failures of underground feeder cables. The models based on non-homogenous Poisson process (NHPP), are used for failure predictions.

Most methods utilize either historical failure data or condition monitoring data for failure predictions. There are a few weaknesses in these methods. Firstly, most approaches ignored the fact that the life of the cable largely depends on the operational stress encountered during service life. Therefore, the failure rate varies with the operational conditions such as load level, installation methods and location. Secondly, condition monitoring (CM) techniques are utilized to continuously monitor the condition of the cable. However, this method is not applicable to a wide population of cables due to the cost to implement the CM. Additionally, the method to analyze data collected from CM is not yet fully developed [7]. Thirdly, methods to model failure data are widely based on fitting the data to a parametric distribution, especially, in Weibull distribution which assumes that cable is non-repairable component [1] [6]. However, in reality cable sections are repairable.

When cables which are prone to high failure rates are replaced or repaired, such interventions reduce cable failures and bring a transition in the failure rate function. Therefore, failure prediction based on a single model is not appropriate for the entire timeframe due to the difference in the failure rate function before and after replacement. To overcome this shortfall the piecewise Non-Homogeneous Poisson Process (NHPP) has been developed [8][9].

In this paper, a piecewise power law NHPP model is proposed to predict and capture the trend of total annual cable failures due to both ageing and random causes. Another electro-thermal ageing model based on operating conditions of the cable is proposed to estimate the cable ageing failures. The two models are amalgamated to estimate the proportion of cable failures in a year due to ageing and random causes, such information can be utilized to take decisions regarding replacement. Finally, a case study is demonstrated on unjacketed XLPE cables.

METHODOLOGY

The proposed methodology as shown in Figure 1, allows prediction of the amount of cable failures in each year due to unpredictable random failure and ageing. The total number of failures each year (f_k) due to the combination of both failure modes is obtained from the power-law NHPP model. By utilizing operational data such as daily seasonal load, electric field, ambient and conductor temperature, the stochastic electro-thermal model is built to estimate the cable ageing failures (a_k) due to operational stress [10]. The deduction of the number of ageing failures (a_k) from the total failures each year (f_k) provides the number of random failures of each year. Therefore, the amalgamation of these two models can predict the expected number of random and ageing failures in a year.