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Prediction of flashover voltage of insulators using least squares support vector machines

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ABSTRACT

The importance of the research on insulator pollution has been increased considerably with the rise of the voltage of transmission lines. In order to determine the flashover behavior of polluted high voltage insulators and to identify to physical mechanisms that govern this phenomenon, the researchers have been brought to establish a modeling. In this paper, a dynamic model of AC flashover voltages of the polluted insulators is constructed using the least square support vector machine (LS-SVM) regression method. For this purpose, a training set is generated by using a numerical method based on Finite Element Method (FEM) for several of common insulators with different geometries. To improve the resulting model's generalization ability, an efficient optimization algorithm known as the grid search are adopted to tune parameters in LS-SVM design.

In addition, two different testing set, which are not introduced to the LS-SVM during the training procedures, is used to evaluate the effectiveness and feasibility of the proposed method. Then, optimum LS-SVM model is firstly obtained and the performance of the proposed system with other intelligence method based on ANN is compared. It can be concluded that the performance of LS-SVM model outperforms those of ANN, for the data set available, which indicates that the LS-SVM model has better generalization ability.

1. Introduction

High voltage insulators form an essential part of high voltage electric power transmission systems. Any failure in the satisfactory performance of high voltage insulators will result in considerable loss of capital, as there are numerous industries that depend upon the availability of an uninterrupted power supply. Outdoor insulators are being subjected to various operating conditions and environments. Contamination on the surface of the insulators enhances the chances of flashover. Under dry conditions the contaminated surfaces do not conduct, and thus contamination is of little importance in dry periods. In cases when there is light rain, fog or dew, the contamination on the surface dissolves. This promotes a conducting layer on the surface of the insulator and the line voltage initiates the leakage current. High current density near the electrodes results in the heating and drying of the pollution layer. An arc is initiated if the voltage stress across the dry band exceeds the withstand capability. The extension of the arc across the insulator ultimately results in flashover.

The flashover of polluted insulators can cause transmission line outage of long duration and over large areas. This problem was the motivation for the installation of a test station in order to perform laboratory tests on artificially polluted insulators. Although the mentioned tests are indispensable for the study of the insulator behavior under pollution, they are of long duration. The cost of the equipment which is necessary for these experiments is very high. For the above reasons, it seems to be very useful to predict the performance of insulators under pollution conditions using analytical expressions and computer models (Gonos, Topalis, & Stathopulos, 1999).

In the last two decades, a variety of prediction models have been proposed in the literature that include time-series models, regression models, artificial neural network (ANN) models, adaptive neuro-fuzzy inference system (ANFIS) and support vector machine (SVM) models. The use of ANN in engineering has increase gradually. This is mainly because the effectiveness of ANN modeling systems has improved a great deal in the engineering area. ANN offers satisfactory accuracy in most cases but tends to overfit the training data. Recently, SVM has been used as a popular algorithm developed from the machine learning community (Vapnik, 1998). Due to its advantages and remarkable generalization performance (i.e. error rates on test sets) over other methods, SVM has attracted

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attention and gained extensive applications. As a simplification of traditional of SVM, Suykens and Vandewalle have proposed the use of the least squares support vector machines (LS-SVM) (Suykens & Vandewalle, 1999). LS-SVM has been used for classification in various areas of pattern recognition (Hanbay, 2009; Polat, Kara, Latifoglu, & Gunes, 2007), lately has been handled regression problems successfully (Vonga, Wong, & Li, 2006; Kang et al., 2008). LS-SVM encompasses similar advantages as SVM, but its additional advantage is that it requires solving a set of only linear equations (linear programming), which is much easier and computationally more simple. Thus, LS-SVMs are very attractive for the modeling FOV on insulators.

In this paper, a dynamic model of AC flashover voltages of the polluted insulators is constructed using the LS-SVM regression method. For this purpose, the training data is generated by using a numerical method based on FEM for the several of common insulators with different geometries. To improve the resulting model's generalization ability, an efficient optimization algorithm known as the grid search are adopted to tune parameters in LS-SVM design (usually referred to as hyperparameters). In addition, two different testing set, which was not introduced to the LS-SVM during the training procedures, is prepared to evaluate the effectiveness and feasibility of the proposed method. Then, optimum LS-SVM model is firstly obtained and the performance of the proposed system with other intelligence method based on ANN is compared. It can be concluded that the performance of LS-SVM model outperforms those of ANN, for the data set available, which indicates that the LS-SVM model has better generalization ability.

2. Pollution flashover of insulators

In this section, a brief definition and a literature review of modeling of the polluted high voltage insulators is presented.

Failures of high voltage insulators on transmission lines can lead to transmission line outages, thereby reducing system reliability. One form of insulator failure is flashover, the unintended disruptive electric discharge over or around the insulator. Contamination on the surface of the insulators such as from salts for de-icing streets and sidewalks enhances the chances of flashover. Contamination on outdoor insulators enhances the chances of flashover. Under dry conditions, contaminated surfaces do not conduct so contamination is of little concern. Under environmental conditions of light rain, fog or dew, surface contamination dissolves. This promotes a conducting layer on an insulator's surface which facilitates a leakage current. High current density near the electrodes results in the heating and drying of the pollution layer. An arc is initiated if the voltage stress across the insulator's dry band exceeds it's withstand capability. Extension of the arc across the insulator ultimately results in flashover. The contamination severity determines the frequency and intensity of arcing and, thus, the probability of flashover (Anon., 2006).

In order to determine FOVs of insulators, a number of studies on model-based techniques were reported in the literature.

Among these, a model was firstly proposed for contamination flashover by Obenaus. Obenaus outlined the computational steps that were required to calculate the flashover voltage (Obenaus, 1958). The actual computation was completed by Neumarker who derived an expression that relates flashover voltage and surface conductivity (Neumarker, 1959). In this theory, flashover process is modeled as a discharge in series with a resistance as shown in Fig. 1. Here the discharge represents the arc bridging the dry band and the resistance represents the un-bridged portion of the insulator. The voltage drop across the resistance is taken as a linear function of current. The equations derived for critical voltage gradient (Ec) and critical current (Ic) are (Rizk, 1971; Rizk, 1981),

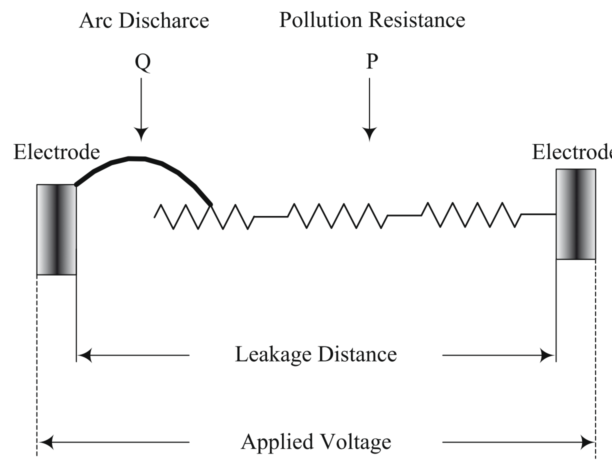

Fig. 1. Obenaus model of polluted insulator (Obenaus, 1958).

$$E_C = N^{(1/(a+1))} \cdot R_p^{(a/(a+1))} \tag{1}$$

$$I_C = \left(\frac{N}{R_p}\right)^{(1/(a+1))} \tag{2}$$

$$R_p = \frac{R_{poln}}{L_d - L_{arc}} \tag{3}$$

where R_p denotes the uniform surface resistance per unit length of the pollution layer, N is the reigniting constant, a is the arc equation exponent, R_{poln} is the series resistance of the pollution layer and L_d, L_{arc} is the leakage distance and arc length, respectively.

Various other researchers proposed alternative models to that of Obenaus. Hampton proposed a theory on the basis of an experiment in which he used a water jet to simulate a contaminated long rod insulator (Hampton, 1964). According to Hampton's theory, flashover voltage was treated primarily as a stability problem. Hampton stated that an unstable situation occurs if there is a current increase when the discharge root is displaced in the direction of flashover. Subsequently it was mathematically proven by Hesketh that Hampton's two criteria of voltage gradient and current increase were identical only in the case of a long rod insulator (Hesketh, 1967). Alston and Zoledziowski later on proposed an algebraic derivation for the critical conditions of flashover (Alston & Zoledziowsky, 1963). They incorporated the discharge length in the condition of flashover. According to their theory the voltage required to maintain local discharges on polluted insulators may increase with an increase in discharge length.

Most of the models studied so far are static in nature in the sense there is no arc propagation criterion accounted for in these models. The static models assume that once the arc is initiated it propagates unextinguished. Thinking in terms of reality, arc propagation is a rapid time varying phenomena, an arc will propagate only when conditions are conducive. Static models do not consider variations in arc and pollution resistance and arc current with time. These limitations in static models led to the development of dynamic models. The dynamic model was initially proposed by Jolly, Cheng, and Otten (1974). In this model the arc propagation criterion used was the variation in arc electrode gap. With this model it was possible to predict the time to flashover for electrolyte strips. Even though a good correlation was observed on one dimension, it was defective for 2D and 3D. Subsequently, various authors proposed dynamic models (Rizk, 1981). However, significant improvement in the development of a dynamic model was undertaken by Sundararajan (1993). In her work the various factors like arc propagation criteria, change in arc parameters with time, effect of various contaminants on flashover and the role of geometry, were all considered.