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Review

Investigation of pollution flashover on high voltage insulators using artificial neural network

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ABSTRACT

High voltage insulators form an essential part of the 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. 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. Artificial neural networks (ANN) have been used by various researches for modeling and predictions in the field of energy engineering systems. In this study, model of V_C = f (H,D,L,σ,n,d) based on ANN which compute flashover voltage of the insulators were performed. This model consider height (H), diameter (D), total leakage length (L), surface conductivity (σ) and number of shed (d) of an insulator and number of chain (n) on the insulator.

1. Introduction

Outdoor insulators are being subjected to various operating conditions and environments. The surface of the insulators is covered by airborne pollutants due to natural or industrial or even mixed pollution. 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 (Gorur & Olsen, 2006). As the surface becomes moist because of rain, fog or dew, the pollution layer becomes conductive because of the presence of ionic solids. The leakage current flows through the conducting surface film, generating heat which tends to increase the film temperature most rapidly at those points where the current density is greatest, i.e. at narrow sections of the insulator, such as the area around the pin. Eventually, the temperature in these areas approaches boiling point, and rapid evaporation of the moisture occurs producing dry areas. The development of the dry areas is independent of the insulator type, something that has also been verified experimentally, since the insulator's body diameter differs very little from one type to another (Gonos, Topalis, & Stathopulos, 2002).

Pollution flashover, observed on insulators used in high voltage transmission, is one of the most important problems for power transmission. Pollution flashover is a very complex problem due to several reasons such as modeling difficulties of the insulator complex shape, different pollution density at different regions, non-homogenous pollution distribution on the surface of insulator and unknown effect of humidity on the pollution (Dhahbi-Megriche & Beroual, 2000). The performance of insulators under polluted environment is one of the guiding factors in the insulation coordination of high voltage transmission lines. On the other hand, the flashover of polluted insulators can cause transmission line outage of long duration and over a large area. Flashover of polluted insulators is still a serious threat to the safe operation of a power transmission system. It is generally considered that pollution flashover is becoming ever more important in the design of high voltage transmission lines (Suflis, Gonos, Topalis, & Stathopulos, 2003).

Research on insulator pollution is directed primarily to understanding the physics of the growth of discharge and to develop a mathematical model, which can predict accurately the critical flashover voltage and critical current. A common feature of all the mathematical models proposed by researchers (Alston & Zoledziowski, 1963; Boeme & Obenhaus, 1966; Rizk, 1981; Wilkins, 1969) is a representation of a propagating arc consisting of a partial arc in series with the resistance of the unbridged section of the polluted layer. Alston and Zoledziowski and Wilkins proposed mathematical models for the prediction of critical flashover voltage taking into consideration the effects of different physical parameters.

The flashover of polluted insulators was the motivation for the installation of a test station in order to perform laboratory tests on

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artificially polluted insulators. Although the mentioned tests are indispensable for the study of the insulator behaviour under pollution, they are of long duration. The cost of the equipment that 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 (Dhahbi-Megriche & Beroual, 2000).

2. Modelling the pollution flashover

Flashover modelling has been a topic of interest for many researchers (Alston & Zoledziowski, 1963; Boeme & Obenhaus, 1966; Rizk, 1981; Wilkins, 1969). A major problem in all those investigations is the definition (Chaurasia, 1999; Ghosh & Chatterjee, 1995) of the value of the arc constants that affect the flashover process. Unfortunately the values of the constants determined from several investigations diverge substantially. This investigation targets the precise calculation of the arc value parameters, using relevant experimental results and close simulation of the insulator's behaviour under polluted conditions using a suitable mathematical model (Suflis et al., 2003).

The flashover process over polluted insulators is described by well-known analytical equations, published by various scientists, mainly Boeme and Obenhaus and Alston and Zoledziowski. These procedures have been used for the formulation of a mathematical model that permits determination of the parameters of the flashover under pollution of the insulators. The most known model for the explanation and evaluation of the flashover process (Alston & Zoledziowski, 1963; Wilkins, 1969) of a polluted insulator consists of a partial arc spanning over a dry zone and the resistance of the pollution layer in series. Therefore, the voltage across the insulator will be

$$U = xAI^{-n} + (L - x)R_pI \tag{1}$$

where xAI^{-n} is the stress in the arc and $(L - x)R_pI$ is the stress in the pollution layer. x is the length of the arc, L is the leakage path of the insulator, R_p is the resistance per unit length of the pollution layer, I is the leakage current and A and n are the arc constants. Their values $A = 124.8$, $n = 0.409$ have been determined using a complex optimization method (Suflis et al., 2003) based on genetic algorithms. It has been found experimentally that the value of the flashover voltage of a polluted insulator is not constant even under identical conditions. This is mainly due to random arc phenomena on the polluted surface. Such phenomena are the arc bridging between sheds or ribs, the arc drifting away from the surface of an insulator as well as the number of consecutive arcs before flashover. These random arcs will certainly affect the flashover.

The measurement of the resistance R_p of the wet zone is quite complicated. Therefore it may be substituted by the conductivity σ_P of the pollution layer

$$\sigma_P = \frac{1}{R_p}F \tag{2}$$

F is the form factor of the insulator that is given as follows:

$$F = \int_0^L \frac{l}{\pi D(l)}dl \tag{3}$$

where $D(l)$ is the diameter of the insulator that varies across the leakage path.

The critical condition for propagation of the discharge along the surface of the insulator to cause flashover is (Alston & Zoledziowski, 1963)

$$\frac{dl}{dx} > 0 \tag{4}$$

The voltage under this critical condition yields

$$U_c = x_cAI_c^{-n} + (L - x_c)KR_pI_c \tag{5}$$

Here the coefficient K was added to validate (1) at the critical instant of the flashover. Wilkins introduced this coefficient in order to modify the resistance R_p of the pollution layer considering the current concentration at the arc foot point. A simplified formula for the calculation of K for cap-and-pin insulators is (Dhahbi-Megriche & Beroual, 2000)

$$K = 1 + \frac{L}{2\pi F(L - x_C)} \ln\left(\frac{L}{2\pi F\sqrt{\frac{(\pi D_r\sigma_P A)^{\frac{1}{n+1}}}{1.45\pi}}}\right) \tag{6}$$

At the critical condition the length of the arc takes the value (Suflis et al., 2003)

$$x_c = \frac{1}{n+1}L \tag{7}$$

Further analysis (Topalis, Gonos, & Stathopulos, 2001) of the system equations at the moment of flashover yields for the critical current

$$I_c = (\pi D_r\sigma_P A)^{\frac{1}{n+1}} \tag{8}$$

and for the critical voltage

$$U_C = \frac{A}{n+1}(L + \pi D_r FKn)(\pi D_r\sigma_P A)^{\frac{-n}{n+1}} \tag{9}$$

where D_r is the diameter of the insulator.

3. Artificial neural network

An artificial neural network (ANN) as a computing system is made up of a number of simple, and highly interconnected processing elements, which processes information by its dynamic state response to external inputs. In recent times the study of the ANN models is gaining rapid and increasing importance because of their potential to offer solutions to some of the problems which have hitherto been intractable by standard serial computers in the areas of computer science and artificial intelligence (Lee & Cha, 1992).

ANN algorithm has been tried successfully on a very wide range of applications (Bressloff & Weir, 1991) including machine vision (Fukishama, 1988), speech processing (Kohonen, 1988) and radar analysis (Farhai & Bai, 1989). In electrical power systems, ANN have been used for accurate load forecasting (Hsu & Yang, 1991), alarm processing (Chan, 1989), etc. In high voltage systems, application of ANN has been reported for pattern recognition of partial discharges (Suzuki & Endoh, 1992). Another major branch of ANN application lies in function estimation. In function estimation, ANN is useful because it acts as a model of a real-world system or function. The model then stands for the system it represents, typically to predict or to control it. The useful properties of ANN, like, adaptable and non-linearity are well suited to many function estimation tasks in the real-world (Ahmad, Ghosh, Ahmed, & Aljunid, 2004; Ghosh, Chakravorti, & Chatterjee, 1995).

Processing elements in an ANN are also known as neurons. These neurons are interconnected by means of information channels called interconnections. Each neuron can have multiple inputs, while there can be only one output. Inputs to a neuron could be from external stimuli or could be from output of the other neurons. Copies of the single output that comes from a neuron could be input to many other neurons in the network. It is also possible that one of the copies of the neuron's output could be input to itself as a feedback. There is a strength connection, synapses, or weight associated with each connection. When the weighted sum of the inputs to the neuron exceeds a certain threshold, the neuron is fired