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Prediction of Polymeric Insulator Leakage Current under Water Droplets Using Neural Network

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Abstract

In this paper, the parameters of electric field and leakage current (LC) amplitude in polymeric insulator are calculated using finite element method (FEM) and predicted in the neural network. The variable angle and electrical conductivity of water droplets are changed. Increased electric field due to the presence of water droplets on the insulator surface causes the insulator breakdown probability. In this paper, for predicting the on the polymeric insulator leakage currents a neural network model was proposed, which could arrange for references to prevent contamination flashover. Through the study of a LC data obtained via the FEM simulation, the characteristics of the LC combined with BP neural network. Simulation results illustrate that enhancement in leakage current and electric field values are created when the values of the electrical conductivity and drop contact angle is increased.

Keywords: neural network, polymeric insulator, water droplet, leakage current, finite element method
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1. Introduction

One of the essential components of the electric power transmission network is high voltage lines, including insulators. The importance of insulator is due to their reliability in energy transferring [1]. The adverse environmental and weather conditions much affect the electrical efficiency of the insulators [2].

Electrical stresses such as corona, dry-band arcing, and erosion of surface can damage the polymeric materials while the environmental factors such as moisture, ultraviolet, light, heat are exacerbated [3-4]. As the stated environmental conditions lead to an intensification of the electric field, the partial discharge begins [5]. With continuous conductor channels, water droplets are formed on the surface of polymeric insulators [6].

When the energized insulator surface is coated with a conductive contamination layer, the surface leakage current will result in dry bands formation in areas with high current density and low humidity [7]. The progress of leakage current and flashover are inhibited by these conditions [8].

Insulator surface leakage current (LC) is the most important parameter that informs the behavior of dielectric materials [9-11]. When a high amount of leakage current is established between the high voltage side and the ground side of an insulator, flashover follows resulting in a power outage from the system [12]. If the level of LC can be predicted, it can be prevented for accelerated aging tests and insulator failure due to aging [13].

In [14], the influence of contaminated water droplets in arid areas on composite insulators is studied. Under DC voltage, the effect of electrical conductivity with different droplets and the number of water droplets on the corona inception voltage has been studied. The results indicate that high electrical conductivity reduces the inception voltage, and the number of droplets strongly affects the inception voltage.

In [15] the experimental study to calculate leakage current in different conditions such as clean, polluted insulator, and wet conditions carried out. In [16], characteristics of electric field and dynamic distribution of water droplets on a polymeric insulator in the coastal power grid have been investigated using COMSOL Multiphysics software. There is a direct relationship between water droplet diameter, electrical conductivity, and maximum surface field.

Many applications, such as pattern recognition, prediction, and control, use artificial neural networks (ANNs). Numerous studies have been performed using ANN on external insulators, such as leakage current classification according to waveforms and harmonics. [17].

This study is focused on a 2D model of water droplets for 20kV polymeric insulator with varying the contact angle of drops and, the number of drops on the surface for calculating the E-field distribution and leakage current under an applied ac voltage in wet condition using finite element software and neural network. Through the study of a LC data obtained via the FEM simulation, the characteristics of the LC combined with BP neural network.

2. FEM Modeling

Modeling of insulator and water droplets is performed based on the finite element method (FEM). The relative permittivity (ε_r) for polymeric material was set to 4, while its conductivity is 10^{-12}(S/m). For the mechanical strength, a fiber-reinforced plastic (FRP) rod with a relative permittivity ε_r = 6.5 is used as the core. The air insulation is assumed around the insulator, and its relative permittivity is 1. $(20\times\sqrt{2})/\sqrt{3}\times\sin(100\pi\cdot t) = 16.3\sin(100\pi\cdot t)$ kV is energized on the lower electrode while the upper electrode connected to ground. Due to the cylindrical property of the polymeric insulator, half of its geometry is required for modeling and simulation. The symmetrical two-dimensional (2D) structure of the insulator is shown in Figure 1.

Water droplets are modeled in different modes with a relative permittivity and electric conductivity of 81 and $180\times10^{-6}\mathrm{S/m}$, respectively [1]. At first, two drops (one drop on the shed and one drop below the shed) are placed. Then, for each shed, a large number of drops are considered (Figure 2).

Two contact angles are modeled according to Figure 3. The diameter of water droplets is set on 4.6 mm throughout the study.

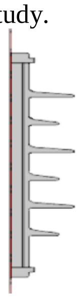

Fig. 1. Symmetrical 2D configuration for polymeric insulator modeling

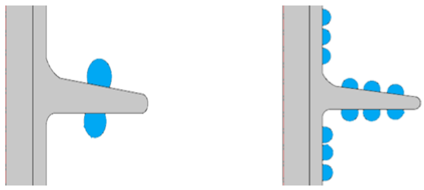

Fig. 2. Placement of droplets on the shed of the insulator (a) Two-droplets (b) Many droplets

Fig. 3. The contact angle of the water droplet (a) $0° < \theta < 90°$ (b) $90° < \theta < 150°$

3. Electric Field and LC in FEM Simulation

The finite element software is used to solve field equations through numerical technique. It calculates the electric field and leakage current in the investigated problem. In the FEM, instead of solving the equation continuously in the designated area, the equations are solved in a finite number of points. For this purpose, FEM uses meshing.

The calculations of the electric field and leakage current are performed using the following equations [18- 19]. In general, the equations of current stability are solved. The sum of the currents entered to a node must be zero. These equations are expressed by ohm's law as follows:

$$J = \left(\sigma + \varepsilon_0\varepsilon_r\frac{\partial}{\partial t}\right)E + J_e \quad (1)$$

where σ is electrical conductivity, ε_0 is the air relative permittivity which equals 8.85×10^{-12}F/m, ε_r is the material relative permittivity, and J_e is the current density that is injected externally. Also, J is the density of the current.

During water droplets are being deposited on the insulator surface, their intensity can change the field distribution in comparison with dry conditions. The primary purpose of this simulation is to determining water droplet effectiveness on electric field distribution along with leakage distance of polymeric insulator. In particular, the leakage current values are compared and evaluated for the various conditions where the water droplets are placed on the insulator surface.

In this study, to achieve more contribution of the effects of water droplet characteristics on electric field distribution and leakage current values, three scenarios, including without water droplet, two drops per shed, and many drops per shed are defined and implemented. The placements of droplets on the shed of the

The electric field amplitudes have the highest values near the energized and grounded electrodes of the insulator. The environmental condition is simulated by adding water droplets on the surface of the insulator model. The insulator model is firstly simulated under dry-clean conditions without considering the water droplets.

The electric field distribution and leakage current for the different conditions such as clean, two-droplet, and many-droplet on the surface of insulator sheds are compared to each other in Figures 4 and 5. The electric field distribution on the polymeric insulator is particularly nonlinear near the active electrode and usually has the highest value.

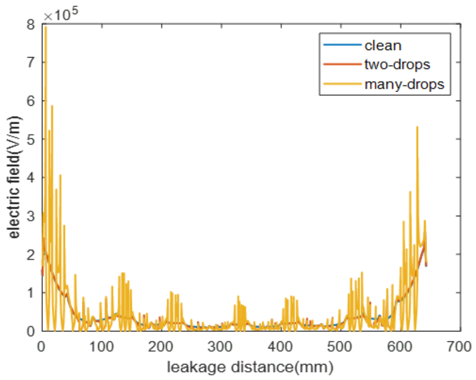

Fig. 4. Comparing electric field distribution with the water droplet for various states.

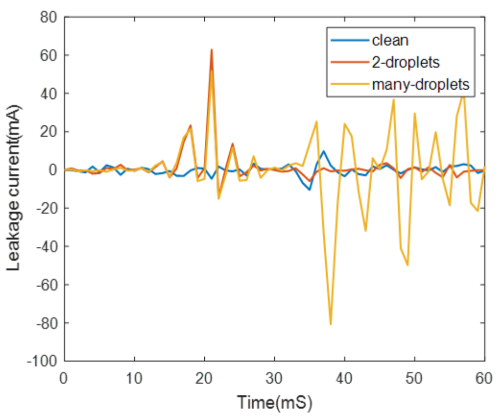

Fig. 5. Comparing leakage current with the water droplet for various states.

Increasing the number of water droplets on the insulator surface affects the non-uniformity of, especially in the place of droplets, the intensity of the electric field is noticeability increased. As shown in Figure 4, adding water droplets leads to several peak value, besides, non-uniform electric field distribution. Increasing electric field values and non-uniform distribution of the electric field for the long term have detrimental effects on polymeric insulators.

It is observed that when the contact angle (θ) of the drop with the surface increases, the field intensity will be increased. A comparison of the electric field distribution along the arc length (near the HV electrode) is shown in Figures 6, through different contact angles.

At the different contact angles, the number of droplets due to surface adhesion is higher for smaller angles and lower for larger angles. However, in this study, due to the same number of droplets, the electric field increases for larger angles.

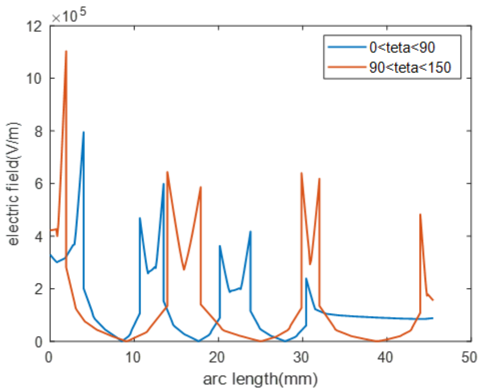

Fig. 6. Comparing electric field along arc length for three water droplets with different θ.

The leakage current is commonly used to evaluate the degree of contamination severity in the insulator model. In the wet atmosphere, the layer on the insulator surface becomes conductive, because of allowing the flow of leakage current along the leakage distance from the HV terminal to the ground terminal.

Three various electrical conductivity of water droplets are considered to obtain the insulator surface Leakage current in the simulations. The results indicate that the leakage current of the insulator surface is directly related to the electric conductivity of the water droplets on the surface. The increase in electrical conductivity leads to the increase in the leakage current.

Figures 4-7 shows the simulation result of water droplet behavior on electric field distribution; in this regard, the variation of water droplet distribution, variation of drop number with the same amount of water, and different electrical conductivity are modeled. It can be realized that increasing drop numbers or large values for drop electrical conductivity leads to increasing value and intensity of the electric field.

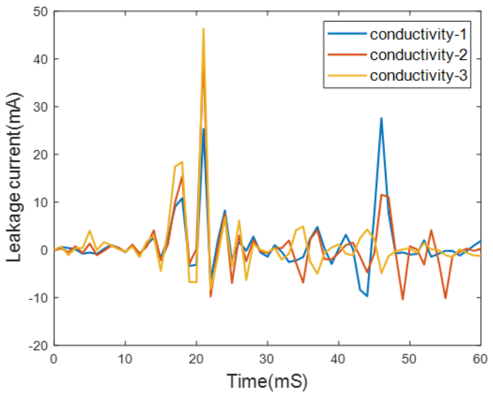

Fig. 7. Comparing leakage current in different electrical conductivity of water droplets. (conductivity1=180×10^{-6}(S/m), conductivity2=1×10^{-6}(S/m), conductivity3=1×10^{-4}(S/m))

Table.1.
Comparing leakage current in different electrical conductivity for two contact angles of water droplets

	σ_1=180 × 10^{-6}(S/m)	σ_2=1 × 10^{-6}(S/m)	σ_3=1 × 10^{-4}(S/m)
	LC, mA	LC, mA	LC, mA
3-drops ($0 < \theta < 90$)	7	7.2	8.7
3drops ($90 < \theta < 150$)	24.7	40.1	46.2

The leakage current is obtained for both different states and various electrical conductivity of drops. By comparing the results in Table 1, it is realized that by increasing electrical conductivity of the water droplet, the leakage current increases and these increment at the $90 < \theta < 150$ angle has the more significant impact so that the leakage current can be high and may lead to electrical discharge.

Comparing the results of Figure 7 express that with a 100% increase in electrical conductivity, the leakage current increases by about 42%. The effect of electrical conductivity variation on the leakage current is greater than the number of droplets.

As a result, by increasing moisture on the surface of the insulator, the leakage current reaches close to 58mA, and electrical discharge can be probable.

4. Simulation of Neural Network

In this section for predicting the LC (I_f) knowing the initial amount of LC (I_s) and the initial slope (S) is considered. A suitable NN has been used to predict the LC in early period of the insulators aging. The two data (I_s,s) are the network inputs and I_f is the network output.

Using NN toolbox of MATLAB package the network was simulated. For the training and verifying the technique 47 cases were used. Feedforward back propagation and cascade-forward back propagation of network are considered. The network weights and biases in the direction in which the performance function updates by the simplest application of back propagation learning process the gradient negative, declines most rapidly.

One of the very complex nonlinear system is neural network, which can be used for processing of fuzzy information with several factors and imprecise conditions. The most commonly used neural network is the BP model of neural network, which can found any nonlinear mapping connection between input and output. In this section, the prediction of leakage current with BP neural network is carried out. The prediction model structure is shown in Figure 8. Four layers in the structure is considered; input layer, two hidden layers and output layer. Time, pollution of surface and humidity are influencing factors of insulator surface leakage current.

In the input layer, the water droplets, relative humidity and temperature difference are used as the inputs for estimating. According to the input variables number, 3 layers is the neurons number in the input layer.In this paper, the prediction of leakage current is purpose so, only the leakage current amount is assumed as the output and there is only one neuron in the output layer. The output layer transfer function is selected as the purelin function, that is, the linear transfer function. The hidden layer setting is essential for BP neural network. There is no standard technique to define the neurons number in the hidden layer.

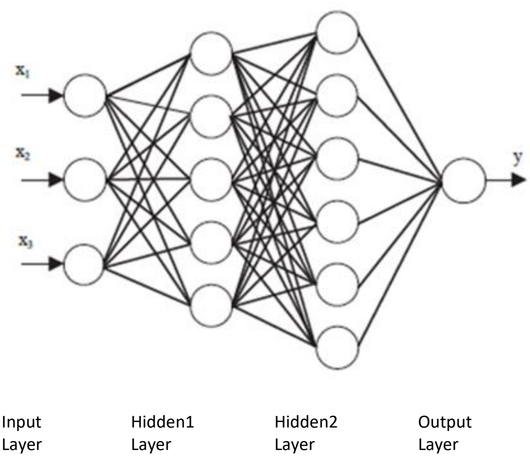

Fig. 8. BP neural network prediction model

In this paper, the hidden layer number is 2, the neurons number in the first hidden layer is 5, and the neurons number in the second hidden layer is 6. Tan-sigmoid function uses as the transfer function between hidden layers.

The maximum number of training is 2000, the learning rate is 0.05, the target precision is 0.00001, and the maximum number of failures is 5. In the progression of Forecast, the model of neural network is trained according to the corresponding data and the leakage current is predicted by this model, which can eliminate the influence of pollution variations in different regions and times.

Two parts is considered for divided data: training data and simulation data. Train the recognized BP neural network model is in the training data part, and for calculating the prediction results of the recognized BP neural network model, the simulation data are used. The process is shown in Figure 9. The simulation leakage current values are compared with the predicted results in Table 2.

Table.2.
Comparing leakage current of simulation with predicted results

Leakage current(mA)	*prediction of the leakage current (mA)*	*Relative error*
7	4.1	70%
8.7	6.4	36%
24.7	22.2	11%
40.1	39.8	0.7%
6.6	3	120%

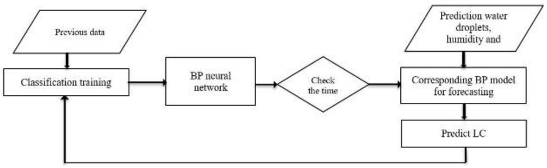

Fig. 9. Flow chart of prediction

As is shown in Table 2, the error between the forecast leakage current and the simulation value is small, when the leakage current is large. On the other hand, when the leakage current is small, there is a large error between the predicted value and the simulation value. However, these errors will not have a considerable influence on the flashover voltage, which means that the error will not affect the estimate of the degree of insulator pollution. So, it can be considered for the leakage current prediction, the neural network model is operative.

5. Conclusion

This paper presented the simulation results to obtain the electric field distributions and leakage current along with leakage distance and desired arc length near the HV electrode of polymeric insulator. The two conditions, including clean and dry, and the presence of water droplets is investigated using FEM. The water droplet characteristics on the insulator surface, such as droplet contact angle, droplet number, and electrical conductivity of the droplet and its effect on the electric field distribution and leakage current, are studied.

This paper proposed a neural network model to predict the polymeric insulator leakage current, which could be suitable references for forecasting contamination flashover. The results of the suggested method provide an operative approach to predict possibility of insulation breakdown event for different areas with existence of water droplets after rainy weather.

A further result is that the accumulation of water droplets with higher electrical conductivity produces a larger electric field and leakage current values, and it may lead to easier flashover. This investigation can be developed as a future work by studying polluted polymeric insulator with water droplets, especially in the case of asymmetrical contamination.

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