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Electric Field Distribution under Water Droplet and Effect of Thickness and Conductivity of Pollution Layer on Polymer Insulators Using Finite Element Method

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Abstract—**This paper presents the results of electric field and potential distributions simulation along surface of silicone rubber polymer insulators. Finite element method (FEM) is adopted for this paper. Identification of the electrical field and the potential distributions at the dielectric insulation has always been important; The water droplets increase the electric field strength at the insulator surface because of their high permittivity and conductivity, at first the results of water droplets existing on the surface of silicone rubber materials has been investigated and electric field distribution along the surface are shown. Then Different Thickness and conductivity of pollution layer on polymer insulator has been considered and electrical field distribution has been analyzed.**

Index Terms—**Electric field, silicon rubber, FEM, conductivity, pollution layer.**

I. INTRODUCTION

Highlight The pollution performance of polymer insulators is well known. The polymer insulators are more susceptible to chemical changes, because of the weak bonds of polymer materials. During the service life of an insulator the combined effects of electric and environmental stresses such as the energizing voltage, corona and arcing. The water droplets play several roles in the pollution flashover and aging of composite insulators, because of high permittivity and conductivity of water droplets, electric field intensity increase at the insulator surface. The surface corona discharges from water droplets age the weather shed material of the insulator [1], [2]. The corona discharge demolishes the hydrophobicity causing the dispersed of water and adjacent water droplets to coalesce. One of the ageing mechanisms responsible for the failure of the insulators is Discharges on the surface of polymeric insulators [3]. The discharges usually take place between water drops on the surface of insulators and create several radicals and ionized species that may chemically react with the insulator surface so, change the original properties of the insulator material. The situation is further aggravated by the high temperature of such discharges which thermally degrades the insulator surface [3]. These effects and Changes in the surface properties of material may cause flashover of the insulator. Recognize of electrical field and potential distribution at the dielectric insulation has always been important as a result of the general necessity to reduce the physical size of HV systems and to ensure a high degree of reliability in operation. Improvement of HV systems reliability demands progress in the design criteria as well as a better understanding of the insulation behavior [4]. At higher voltages field can be high enough to cause damage to the insulator sheath due to the corona discharge, hence grading devices need to be used to reduce the electric field to acceptable levels [5]. Calculation of stress levels on an insulator when subjected to a high voltage provides an important insight into the safety measures pertaining to high voltage transmission lines. If the E-field magnitude in any regions exceeds critical values, excessively large magnitudes of discharge activity can ensue, and the long or short term performance of the insulator may be affected, there is a direct relationship between the E-field distribution and the resulting discharge activity within composite insulators. The presence, location and magnitude of discharges are a function of the magnitude and direction of the local E-field [6]. Under rain and fog conditions, the presence of water droplets intensifies the electric field strength on the surface of a polymer insulator. As a result, the surface corona discharges from water droplets accelerate the aging of the shed material of a polymer insulator. The study of the electric field and voltage distributions of polymer insulators under wet conditions is important for the in-depth understanding of the aging process and the pollution flashover beginning mechanism for polymer insulators [7]. The objective of this paper is to study the electric field enhancement effects by water droplets on the surface of polymer insulator, and to calculate the electric field distribution along a polymer insulator under different conditions of water droplet, and investigate the effect of thickness and conductivity of pollution layer with 3-D simulation with FEM, because of the presence of water droplets at the surface of polymer insulator.

II. PROCEDURE OF SIMULATION

In order to analysis affects of contaminants on surface of polymer insulator, 3-D calculation method is applied. For the studies described in this paper, Comsol program has been employed. Voltage, electric field distribution and maximum electric field are examined by results of calculation.
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A. Equations for Electric Field and Potential Distributions Calculation

Simply way for electric field distribution calculation is calculate electric potential distribution. Then, electric field distribution is calculated by minus gradient of electric

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potential distribution. Due to electrostatic field distribution, electric field distribution can be written as follows [8]:

$$E = -\nabla V \tag{1}$$

From Maxwell's equation:

$$\nabla . E = \frac{\rho}{\varepsilon} \tag{2}$$

where ρ is resistivity Ω/m,

ε is dielectric constant of dielectric material

ε_0 is air dielectric constant (8.85×10^{-12} F/m)

ε_r is relative dielectric constant of dielectric material

Place equation (1) in equation (2) obtained Poisson's equation.

$$\nabla . \varepsilon \nabla V = -\rho \tag{3}$$

Without space charge ρ=0, Poisson's equation becomes Laplace's equation.

$$\nabla . \varepsilon \nabla V = 0 \tag{4}$$

B. Equation for FEM Analysis

The calculation of the electric potential at every knot in the total network composed of many triangle elements was carried out by minimizing the function W(v), that is:

$$\frac{\partial W_j}{\partial V_i} = \frac{\varepsilon_0 \varepsilon_r}{2} \int_i \frac{\partial}{\partial V_i} \left(\frac{\partial^2 V}{\partial r^2} + \frac{1}{r} \frac{\partial V}{\partial r} + \frac{\partial^2 V}{\partial z^2} \right) drdz \tag{5}$$

C. Characteristic of Composite Insulator for Fem Analysis

Composite insulators essentially consist of a fiberglass core rod covered by weather sheds of silicone rubber and equipped with metal end fittings, the basic design of a polymer insulator is as follows; a fiber reinforced plastic (FRP) core having relative dielectric constant 6, attached with two metal fittings, is used as the load bearing structure. Weather sheds made of HTV silicone rubber having relative dielectric constant 4.5 are installed outside the FRP core. Surrounding of the insulator is air having relative dielectric constant 1, AC 20 kV is energized on the lower electrode while the upper electrode connected with ground.

III. EFFECT ON WATER DROPLETS ON ELECTRIC DISTRIBUTION

There are three main regions of interest when considering the E-field distribution of composite insulators.

1) On the surface of, and in the air surrounding, the polymer weather-shed surface and surrounding the end-fitting seal [9].

2) Within the fiberglass rod and polymer rubber weather-shed material, as well as at the interfaces between these materials and the metal end fitting.

3) On the surface of, and in the air surrounding the metallic end fittings and attached corona rings [10]-[12]. If the E-field magnitude in any of these three regions exceeds critical values, excessively large magnitudes of, discharge activity can ensue, and the long or short term performance of the insulator may be affected. There is a direct relationship between the E-field distribution and the resulting discharge activity on and within composite insulators. The presence, location and magnitude of discharges are a function of the magnitude and direction of the local E-field. In this paper we investigate the effect of droplet on the insulators in two stages.

A. Water Droplets on the Shed

In order to examine electric field distribution by water droplets, 3 water droplets exposed to the shed of insulator, and electric field distribution are investigated. The distances between droplets are 1.5mm. The placements of droplets on sheet of insulator are shown in Figure 1.

From Figure (2-8) shows electric field analysis result, it can be found that the maximum of the electric field appeared at the beginning and end of polymer insulator.

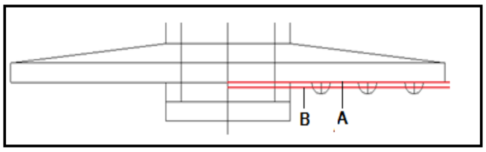

Fig. 1. The placement of droplets on sheet of insulator

The results of figure (2-7) are evident that electrical field changes along the horizontal line are due to the change in the dielectric constant of dielectric. The E-field distribution on composite insulators is nonlinear with the regions close to the energized end normally being subjected to the highest magnitudes, for most transmission line applications, the dominant direction of the E-field is along the axis of the insulator. As can be seen from figures the magnitude of the E-field close to the energized end is higher than that at the grounded end. Increasing the number of droplets on the insulator surface causes non-uniform field in insulator. Increasing of electrical field and non-uniform field in long term periods cause adverse effects on electrical insulators.

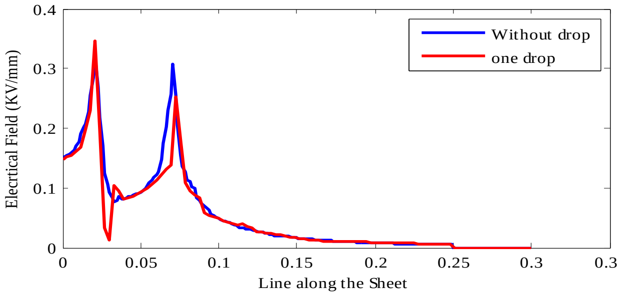

Fig. 2. Compare of electrical field distribution along the sheet with one drop and without drop

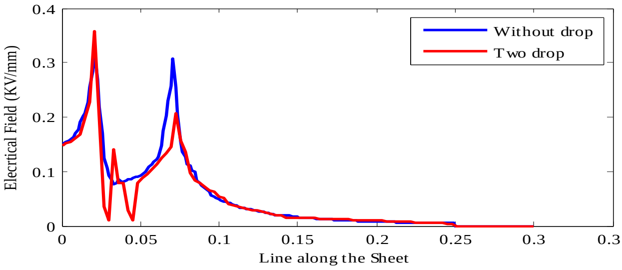

Fig. 3. Compare of electrical field distribution along the sheet with two drops and without drop

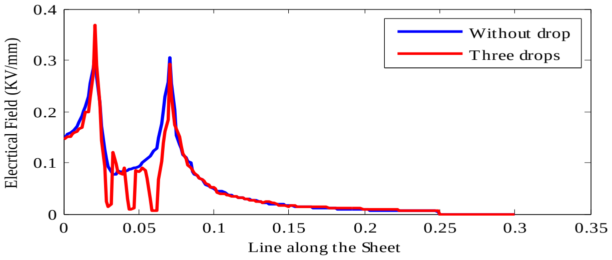

Fig. 4. Compare of electrical field distribution along the sheet with three drops and without drop

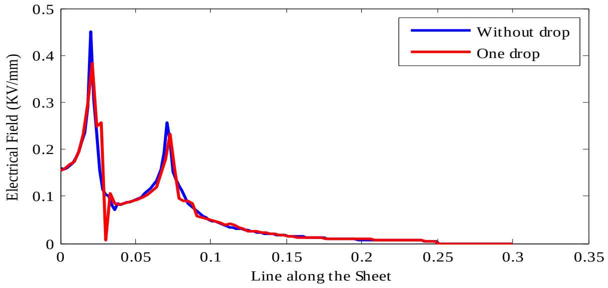

Fig. 5. Compare of electrical field distribution along the sheet with one drop and without drop (m)

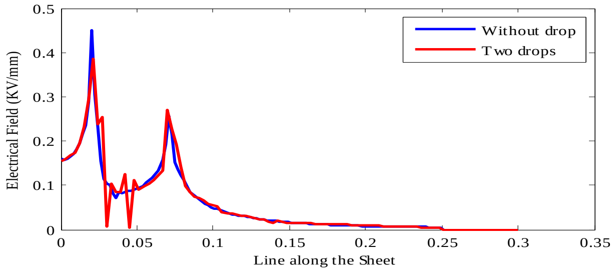

Fig. 6. Compare of electrical field distribution along the sheet with two drops and without drop (m)

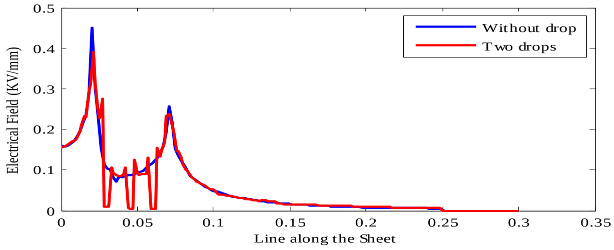

Fig. 7. Compare of electrical field distribution along the sheet with three drops and without drop (m)

B. Water Droplets on the Sheath

The placements of droplets on sheath of insulator are shown in Figure 8.

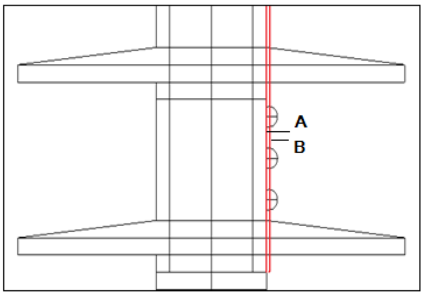

Fig. 8. The placement of droplets on sheath of insulator

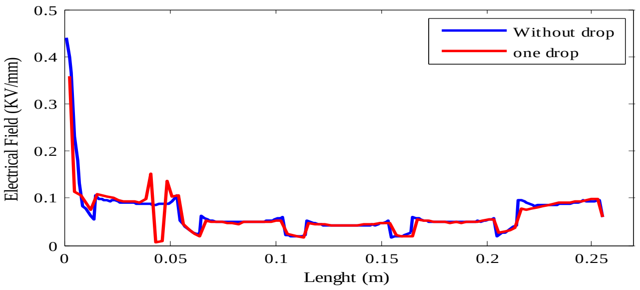

Fig. 9. Compare of electrical field distribution along the sheath with one drop and without drop along line A

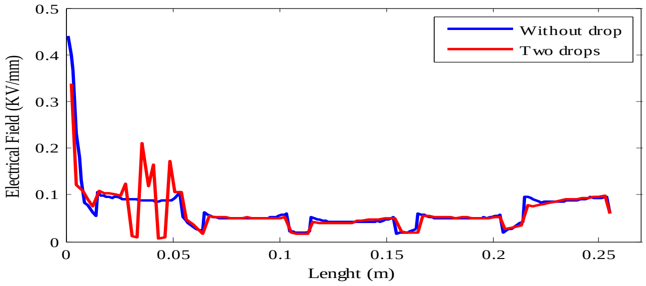

Fig. 10. Compare of electrical field distribution along the sheath with two drop and without drop along line A

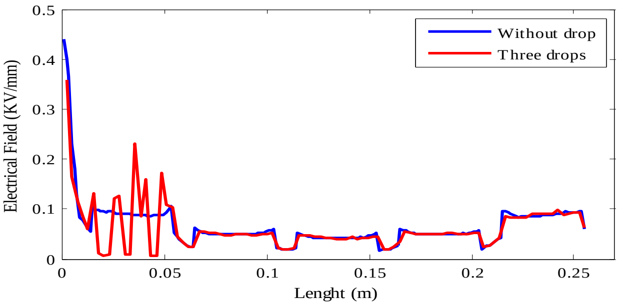

Fig. 11. Compare of electrical field distribution along the sheath with three drop and without drop along line A

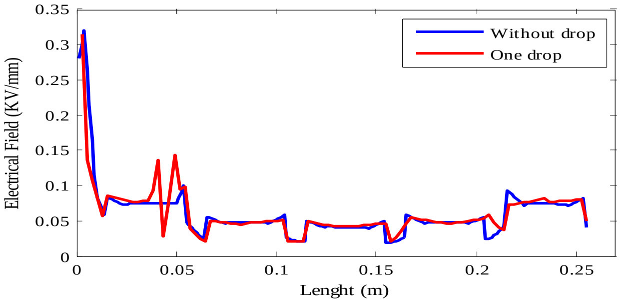

Fig. 12. Compare of electrical field distribution along the sheath with one drop and without drop along line B

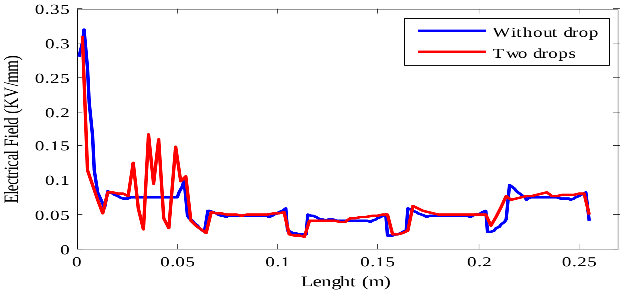

Fig. 13. Compare of electrical field distribution along the sheath with two drop and without drop along line B

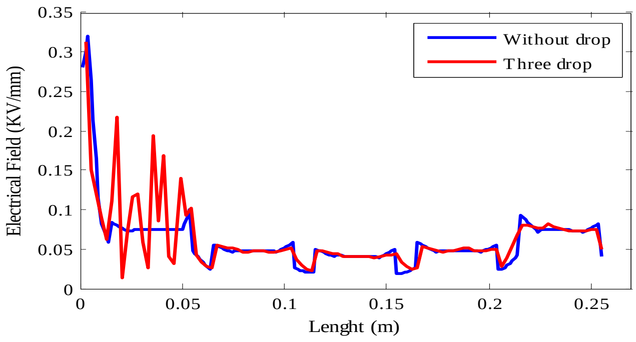

Fig. 14. Compare of electrical field distribution along the sheath with one drop and without drop along line B

As the results of Fig. 9-Fig. 14 were observed, adding water droplets can be causing the peaks and non-uniform of electrical field distribution completely. Peaks are due to the difference in the dielectric constant on core, air and shed.

IV. EFFECT OF POLLUTION LAYER ON ELECTRIC FIELD DISTRIBUTION

Due to small droplets, electrical field does not special effects on the core of insulator, so the pollution as a uniform layer on the insulators considered and changes in the electrical field has been investigated. As the insulator ages in the field, the quantity of pollution on its surface increases. Different thickness and conductivity of pollution layer on polymer insulator has been considered and changes the electrical field has been analyzed. Fig. 15-Fig. 17 are shown the result of simulation.

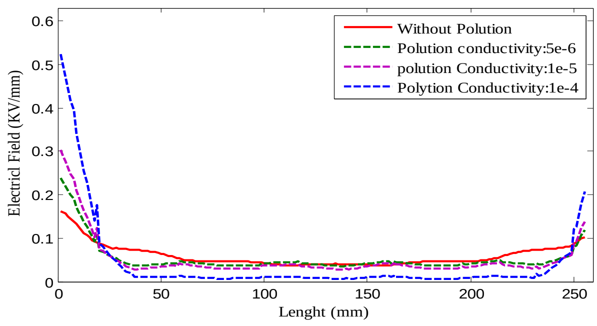

Fig. 15. Electrical field distribution of pollution layer with difference conductivity and 1mm thickness

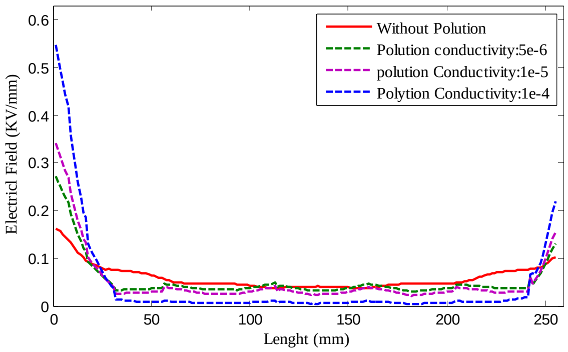

Fig. 16. Electrical field distribution of pollution layer with difference conductivity and 1.5mm thickness

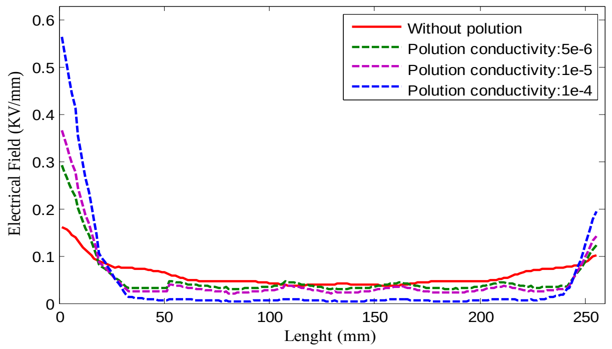

Fig. 17. Electrical field distribution of pollution layer with difference conductivity and 2mm thickness

V. CONCLUSION

In the present study simulation of electric potential and electric field for the actual composite insulators of 20kV, has been carried out using 3-D analysis in Comsol program. The result shows that increasing the number of droplets on the insulator surface causes non-uniform field in insulator. As can be seen from result, the magnitude of the E-field close to the energized end is higher than that at the grounded end. Thickness and conductivity of pollution layer on polymer insulator change magnitude of the E-field at the head and end of insulator.

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