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# Investigation on Pollution Factors on Electric Field and Potential Distribution of Polymeric Insulator

**S. Z. Moussavi[1], B. Sheikhdoragh[*1], A. A. Shayegani-Akmal[2]**

[1-] Faculty of Electrical & Computer Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran
[2-] School of Electrical and Computer Engineering, University of Tehran, Tehran, Iran

## ABSTRACT

Different factors affecting the electric field distribution are analyzed through finite element method simulations. Among them, the presence of water droplets on the insulator surface has been studied. This paper describes numerical analysis calculation of electric fields and its potential distribution in the surrounding of water droplets on an insulator surface which is used for the suspension of high voltage overhead power transmission lines. The objective of this work is to comparison the effect of contamination on potential and electric field distributions along the insulator surface. Finite element method (FEM) is adopted for this work. Also, a conductive layer on the insulator surface has been used in order to simulate the environmental pollution. The computation results show that the electric field close to the water droplets tends to be higher as number of water droplets increases.

**KEYWORDS:** Electric field, Finite element method, water droplets.

## I. INTRODUCTION

Electrical insulation materials play a vital role in engineering of many types of electrical apparatus, including generators, cables, transformers and transmission lines. Electrical insulation failure is a major causes of outages most types of electrical power apparatus. A great deal of research is intended to extend the service life and eliminate the premature failure of electrical by upgrading the electrical insulation systems being used, or by controlling the electric field stress [1].

Polymer insulators, which have been used increasingly for outdoor applications, give better characteristics over porcelain and glass types. But, aging performance of polymer material is not as good as ceramic insulator. It was proved that the performance of polymer material was degraded under certain environments. The general aging factors are polluted environments, wet condition, ultra violet, acid rain and surface discharge. The surface discharge plays an important role among these factors. There is a close relation between surface corona and degradation on polymer insulator [2].

Polymeric outdoor insulators are constantly exposed to various environmental contaminants ranging from natural, agricultural to industrial emissions during their period of service. Insulators near coastal regions for example encounter sea salt particles whereas those in the city or close to industrial area are exposed to ash, dust, and chemical emissions. These airborne particles accumulate on the insulator surface, forming a contaminant layer which becomes conductive when exposed to humid atmosphere such as fog and drizzle [3].

Many experimental and theoretical studies have been carried out to investigate the performance of polymeric outdoor insulators, with a large number focusing on the computation of electric field around the insulators. The field distribution over the insulator surface provides a better understanding of pollution problems which includes premature degradation and polymeric ageing process. Moreover, prediction of dry band formation can be made more accurately. The measurement of the electric field

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***Corresponding Author:** B. sheikhdoragh, Faculty of Electrical & Computer Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran.

distribution in practice is rather difficult. The electrostatic probe [4] can be used but is occasionally subjected to errors, although this could be improved by using a more advanced and complex field detection system [5]. As an alternative, researchers have employed numerical techniques to obtain the electric field around the insulator. This could be achieved using well-known computation methods such as Finite Element Method (FEM) [6, 7].

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 [8]. 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 [9].

Charge Simulation Method (CSM) [10] and Boundary Element Method (BEM) [11]. Moreover, rapid growth in computer technology has facilitated development of advanced numerical packages that are able to deal with most complex modeling without compromising the processing time and accuracy of the results. The objective of this paper is to study the electric field and potential enhancement effects by water droplets on the surface of polymer insulator, and to calculate the electric field and potential distribution along a polymer insulator under different conditions of water droplet.

## II. METHOD OF ANALYSIS

E-field calculations were performed with the Finite Element Modelling (FEM) tool Comsol Multiphysics ver. 3.5a [12]. Electric fields were calculated using 3-D models. The electric field strength is generally higher at the high voltage side of the insulator, than at the grounded side.

### *II.1. Electric field and potential distributions*

Simply way for electric field distribution calculation is calculate electric potential distribution. Then, electric field distribution is calculated by minus gradient of electric potential distribution. Due to electrostatic field distribution, electric field distribution can be written as follows [13]:

$$E = -\nabla V \qquad \frac{V}{m} \qquad (1)$$

From Maxwell's equation:

$$\nabla . E = \frac{\rho}{\varepsilon} \qquad (2)$$

Where ρ is Volume Charge Density in C/m$^3$, $\varepsilon_0$ is air dielectric constant which equal 8.85×10$^{-12}$ F/m and $\varepsilon_r$ is relative dielectric constant of dielectric material, then Place equation (1) in equation (2) obtained Poisson's equation.

$$\nabla . \varepsilon \nabla V = -\rho \qquad (3)$$

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

$$\nabla . \varepsilon \nabla V = 0 \qquad (4)$$

### *II.2. FEM analysis of the electric field*

A simulation model used to display the interested region of high electric field by using FEM simulation techniques. Figure 3 shows the flow chart algorithms which describe the technique of the simulation program till the potential and electric field calculations have been achieved and also the determination of maximum field direction which takes in consideration the erosion advance.

Supposing that the domain under consideration does not contain any space and surface charges, two-dimensional functional F(V) in the Cartesian system of coordinates can be formed as follows [13]:

$$F(V)=\frac{1}{2}\int_{s}\left[\varepsilon_{x}\left(\frac{dV}{dx}\right)^{2}+\varepsilon_{y}\left(\frac{dV}{dy}\right)^{2}\right].d_{x}d_{y} \qquad (5)$$

where: $\varepsilon_x$ and $\varepsilon_y$ are x and y components of dielectric constant in the Cartesian system of coordinates.

In case of isotropic permittivity distribution ($\varepsilon_x = \varepsilon_y = \varepsilon$) equation (6) can be reformed as:

$$F(V)=\frac{1}{2}\int_{s}\varepsilon\left[\left(\frac{dV}{dx}\right)^{2}+\left(\frac{dV}{dy}\right)^{2}\right].d_{x}d_{y} \qquad (6)$$

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 F (v), that is:

$$\frac{\partial F_{vi}}{\partial V_{i}}=\frac{\varepsilon_{0}\varepsilon_{r}}{2}\int_{i}\frac{\partial}{\partial V_{i}}\left(\frac{\partial^{2}V}{\partial r^{2}}+\frac{1}{r}\frac{\partial V}{\partial r}+\frac{\partial^{2}V}{\partial z^{2}}\right)drdz \qquad (7)$$

### *II.3. Characteristic of composite insulator for FEM analysis*

The polymeric insulator is composed of three main components; core, insulation housing and terminals. The polymeric housing, used as weather sheds and insulation material is made of a synthetic composite compound, Silicone Rubber (SiR), having a relative permittivity $\varepsilon_r$ = 4.5. The creepage distance along the polymeric surface is approximately 330mm. A fiber reinforced plastic (FRP) rod with a relative permittivity $\varepsilon_r$ = 6 is used as a core to provide essential mechanical support for overhead conductors on transmission towers. Surrounding of the insulator is air having relative dielectric constant 1, AC $(20\times\sqrt{2})/\sqrt{3}$ =16.3 kV is energized on the lower electrode while the upper electrode connected with ground. The high voltage (HV) and ground terminals are made of aluminum crimped to the FRP rod at a separation distance. For FEM analysis, at the beginning of simulation, the model must be meshed (figure 1) and for accuracy improvement, the software has this ability to makes the meshes extra fine. Electrical potential and field distribution of insulator without presence of water drops and pollution can be seen in figures 2-5. The Electric field magnitudes are larger close to the energized and grounded ends of insulator. Typically the energized end is subjected to the highest field magnitudes.

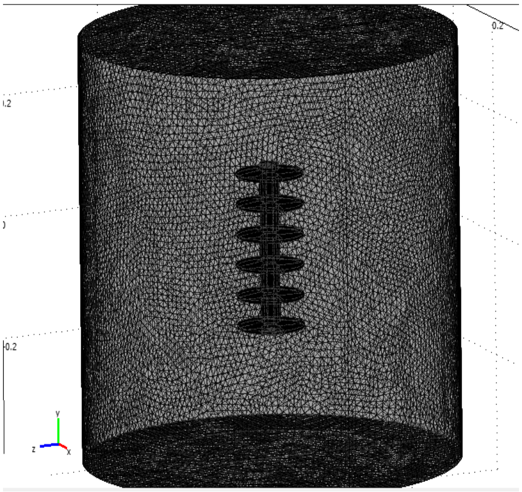

Figure 1: meshing of insulator

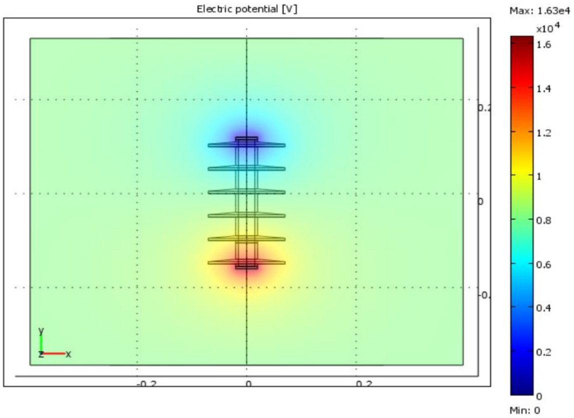

Figure 2: Electric potential distribution

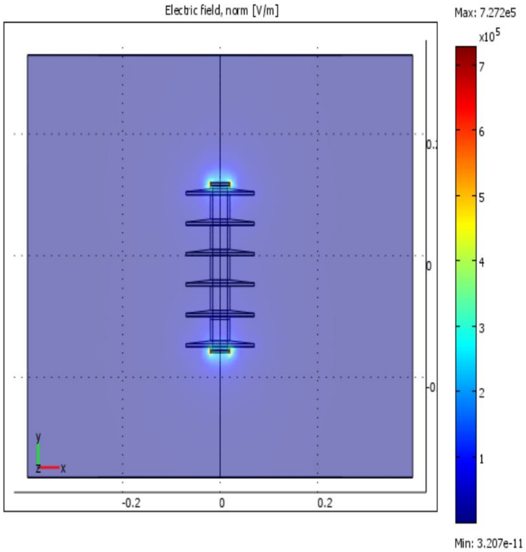

Figure 3: Electric field distribution

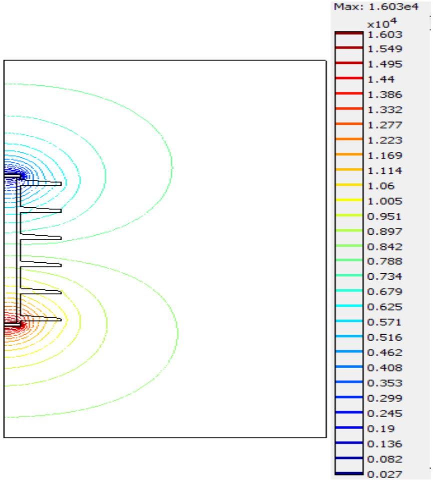

Figure 4: electric potential lines

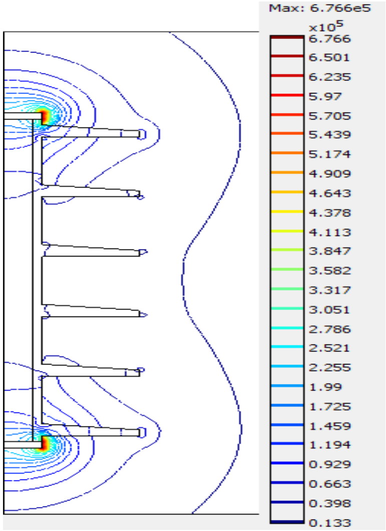

Figure 5: electric field lines

## III. Effect of Water Droplets on ELECTRIC DISTRIBUTION

There are three main regions of interest when considering the E-field distribution of composite insulators [14].

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

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. 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.

### *III.1. 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 2 mm. The placements of droplets on sheet of insulator are shown in Figure 7.

From Figure (8-10) 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.

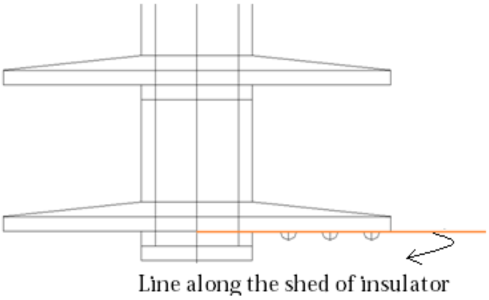

Figure 6: The placement of droplets on sheet of insulator

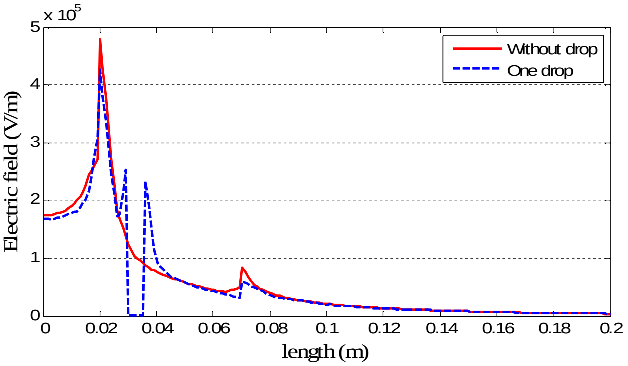

Figure 7: Compare of Electrical field distribution along the shed with one drop and without drop along line

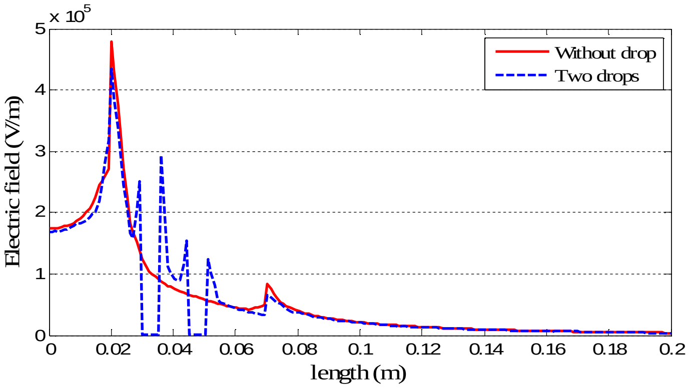

Figure 8: Compare of Electrical field distribution along the shed with two drops and without drop along

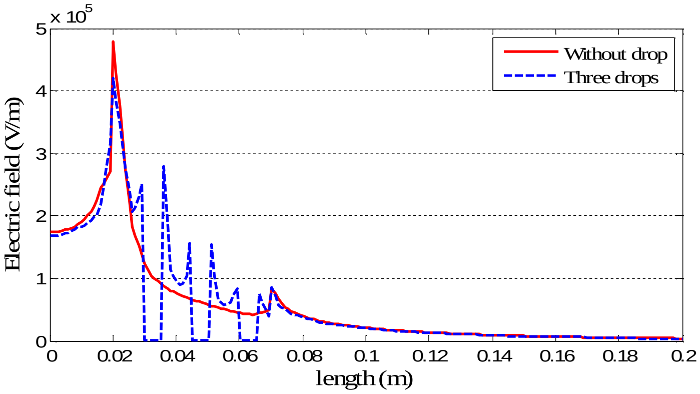

Figure 9: Compare of Electrical field distribution along the shed with three drop and without drop along

The results of figure (7-9) 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.

### *III.2. Water Droplets on the sheath*

The placements of droplets on sheath of insulator are shown in Figure 10.

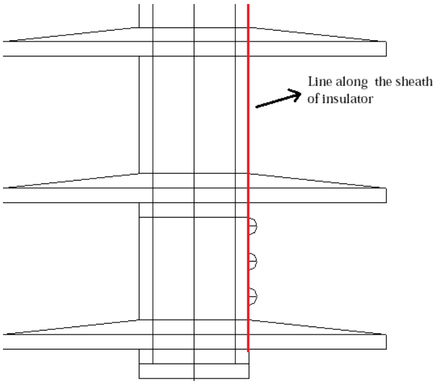

Figure 10: The placement of droplets on sheath of insulator

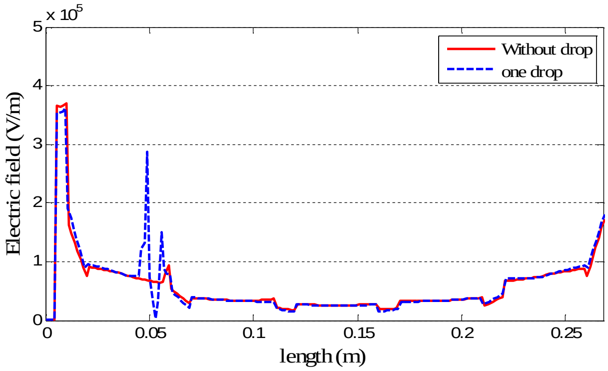

Figure 11: Compare of Electrical field distribution along the sheath with one drop and without drop along line

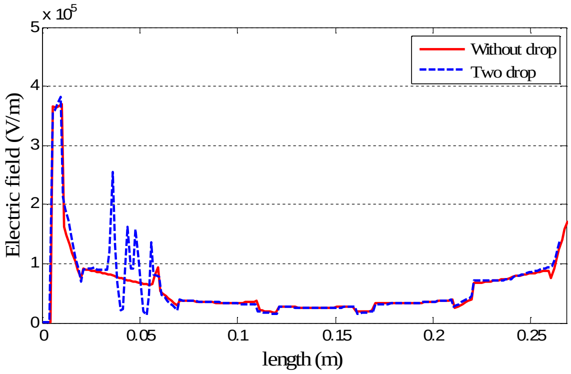

Figure12: Compare of Electrical field distribution along the sheath with two drops and without drop along line

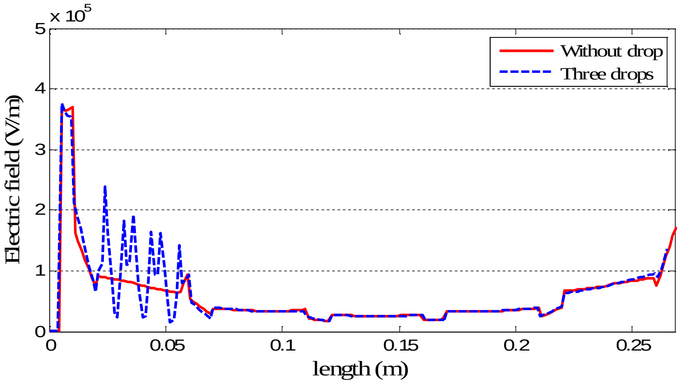

Figure13: Compare of Electrical field distribution along the sheath with three drops and without drop along

As the results of figure (11-13) 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. Influence of the pollution layer

The calculation of the electric field distribution is of great importance, when it refers to polluted insulators, because flashover accidents, which may cause breakdown of the transmission network, occur more frequently in polluted insulators. After long time exposure in the air, high voltage insulators - especially in industrial and coastal regions - are often covered with a conductive pollutant layer such as salt or dust deposition. Under high humidity conditions, the electrolytes of the contamination layer are dissolved and the surface conductivity rises. The flow of the surface leakage current leads to the formation of dry bands in the regions with higher current density and lower wetting level. As a result the voltage is redistributed and due to the higher electrical stress of the dry regions, partial arcs evolve, which may eventually cause the full insulator flashover depending on the wet layer resistance [15-17].

The environmental pollution is simulated by adding a thin pollutant layer on the surface of the insulator model. In practice, the distribution and amount of contaminants deposited on the insulator surface is non-uniform and largely depends on the nature of the environment. To reduce modeling complexity, the pollution layer is assumed to be uniform over the insulator surface. In wet atmosphere, the pollution layer becomes conductive, hence, allowing flow of leakage current along the creepage path from the HV terminal to the ground terminal.

The simulation of the polluted model is carried out with the steady state ac solver which takes into account more accurately the presence of the high surface conductivity. The voltage distributions across the top and end fitting for the non-polluted insulator model and the polluted insulator model with 3 drop and layer of contamination with conductivity $\sigma=10^{-3}$S/m are shown in Figures 14 and 15 respectively. It is obvious that the layer of polluted insulator is more highly stressed. The voltage distribution of the non-polluted insulator is capacitive, which means that it is mainly defined by the own capacitance of the insulator as well as by its stray capacitances. After adding the pollution layer the insulator surface becomes more conductive and the voltage distribution turns into resistive-capacitive. As the pollution conductivity raises the voltage distribution gradually approaches the linear resistive distribution.

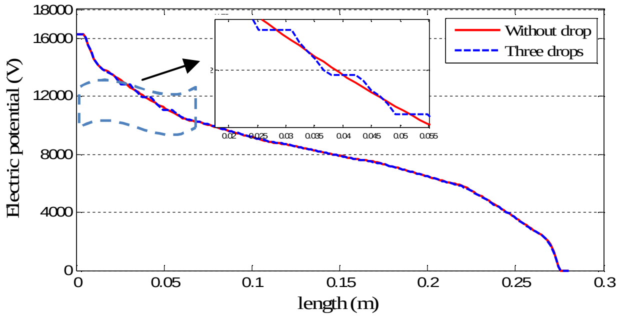

Figure 14: Compare of electrical potential distribution along the top and end fitting with three drops and without drop

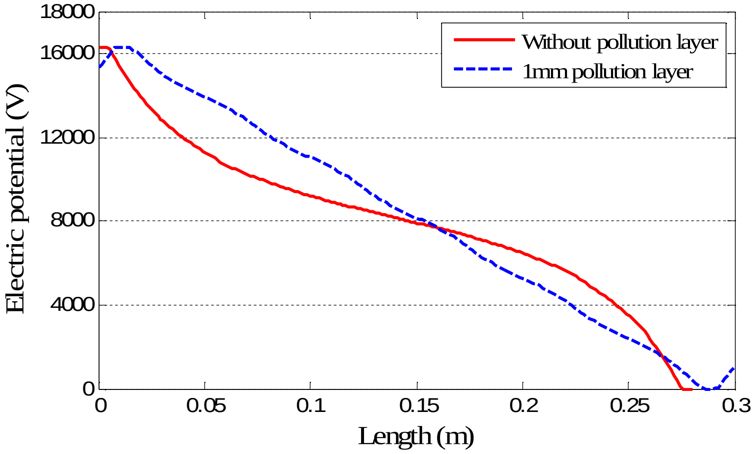

Figure15: Compare of Electrical potential distribution along the top and end fitting with pollution layer and without drop

## V. Conclusion

This paper presents the simulation results of electric field and potential distributions along surface of silicon rubber polymer insulators of 20 kV under clean and various contamination conditions. The two conditions were investigated by using FEM. Finally, a conductive layer on the insulator surface has been used in order to simulate the environmental pollution. The main observations are the increased voltage and field values and the transition to a resistive potential distribution when the values of the pollution conductivity are high. In both cases of pollution conductivity, the values of the electric field strength exceed those of the non polluted insulator. A further conclusion is that a deposition of a pollutant with higher conductivity creates higher field values and may thus cause easier flashover.

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