ELECTRIC FIELD SIMULATION ALONG SILICONE RUBBER INSULATORS SURFACE

M. Talaat
Electrical Power and Machines, Faculty of Engineering, Zagazig University, Egypt.
Email: <m_mtalaat@zu.edu.eg>

Abstract: This paper presents the analysis of electric field and potential distributions along surface of silicon rubber polymer insulators under clean and contamination conditions. Straight sheds insulator having leakage distance 290 mm was used in this study. 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. As results, contaminations have no effect on potential distribution along the polymer insulator surface. However, for electric field distribution they caused highly non-uniform electric field distributions. The simulation results confirmed good electrical performance under contamination conditions.

1 INTRODUCTION

Electrical insulation materials play a vital role in engineering of many types of electrical apparatus, including generators, cables, transformers and transmission lines [1- 4]. 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 [3-5], or by controlling the electric field stress [1-2, 5].

Polymer insulators, which have been used increasingly for outdoor applications, give better characteristics over porcelain and glass types. The advantages of silicon rubber polymer insulators are as follows [6]: First, silicon rubbers have low surface tension energy and thereby maintain a hydrophobic surface property, resulting in better insulation performance under contaminated and wet conditions. Second, polymer insulators have higher mechanical strength to weight ratios compared with those of porcelain or glass insulators. Third polymer insulators are less prone to serious damage from vandalism such as gunshots.

The disadvantages of polymer insulators are as follows [6]: First, polymer insulators are made of organic materials and so subjected to chemical changes on the surface. Second, polymer insulators may suffer from erosion and tracking [3], which may lead ultimately to failure of the insulators.

Structure of a polymer insulator [7], is shown in Figure 1. It constructs of fibres reinforced plastic (FRP) core, attached with two metal fittings. Due to dirt or moisture in combination with electrical stress results in the occurrence of local discharges causing tracking and erosion. In order to protect the FRP core from various environmental stresses, and to provide a leakage distance within a limited insulator length, weather sheds are installed outside the FRP core. Silicone rubber is mainly used for polymer insulators or composite insulators as housing material.

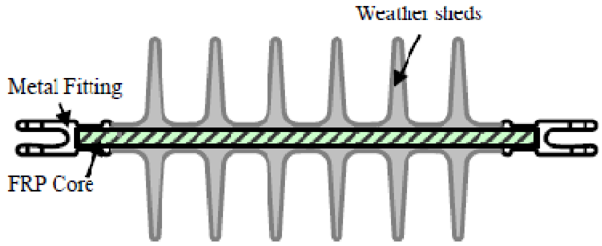

Figure 1: Structure of a polymer insulator [7].

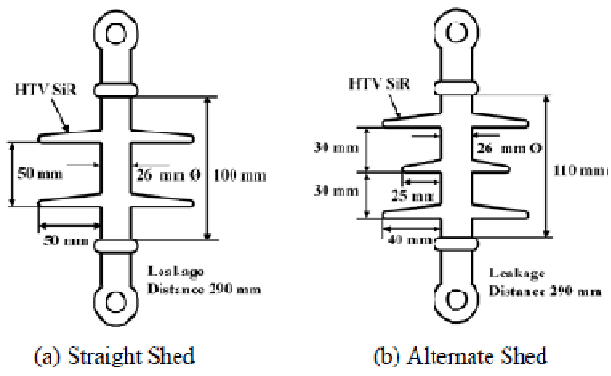

Figure 2: Dimensions of simulated specimens.

Figure 2, described the dimensions of the simulated specimens used in the simulation program with the basic structure shown in Figure 1. Finite element method (FEM) is adopted for this work as mathematical tool for simulation electric field and potential distributions. Effect of contamination condition was simulated and analyzed.

2 METHOD OF ANALYSIS

2.1 Electric field and potential distributions

The electric field intensity E , can be obtained from [8]:

$$E = -\nabla V \qquad V/m \tag{1}$$

where: $V =$ Potential Field in Volt (V)

The divergent of the electric flux density D , is given by:

$$\nabla \cdot D = \rho_v \qquad C/m^3 \tag{2}$$

where: $\rho_v =$ Volume Charge Density in (C/m^3)

From the relation between electric field intensity E and electric flux density D,

$$D = \varepsilon_o \varepsilon_r E \qquad C/m^2 \tag{3}$$

where: $\varepsilon_o =$ is the dielectric constant of air which equal $8.854 \times 10^{-12}\ F/m$, and $\varepsilon_r =$ is the relative permittivity of the dielectric medium. Then,

$$-\nabla \cdot (\varepsilon_o \varepsilon_r \nabla V) = \rho_v \qquad C/m^3 \tag{4}$$

$$\nabla^2 V = -\frac{\rho_v}{\varepsilon_o \varepsilon_r} \tag{5}$$

This is called Poisson's equations, without volume charge density $\rho_v = 0$, Poisson's equation becomes Laplace's equation.

$$\nabla^2 V = 0.0 \tag{6}$$

2.2 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 [9]:

$$F(V) = \frac{1}{2}\int_S \left[\varepsilon_x \left(\frac{dV}{dx}\right)^2 + \varepsilon_y \left(\frac{dV}{dy}\right)^2\right] \cdot dx\, dy \tag{7}$$

where: ε_x and ε_y are $x-$ and $y-$ components of dielectric constant in the Cartesian system of coordinates. In case of isotropic permittivity distribution $(\varepsilon = \varepsilon_x = \varepsilon_y)$, equation (7) can be reformed as:

$$F(V) = \frac{1}{2}\int_S \varepsilon \left[\left(\frac{dV}{dx}\right)^2 + \left(\frac{dV}{dy}\right)^2\right] \cdot dx\, dy \tag{8}$$

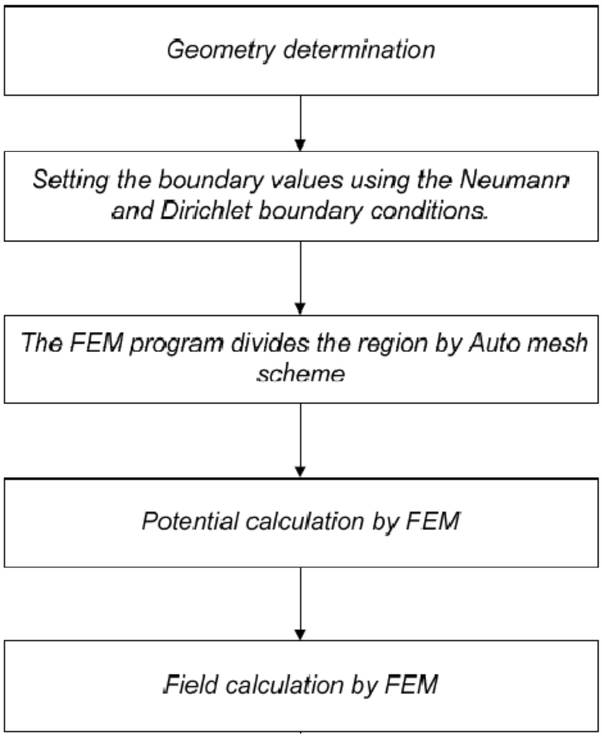

Figure 3: Flow chart of the simulation algorithms.

The calculation of 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,

$$\frac{\partial F(V_i)}{\partial V_i} = 0.0 \quad ; i = 1, 2, \ldots, n_p \tag{9}$$

Where: n_p stands for the total number of knots in the network.

2.3 Steps for simulation

The relative dielectric constant for each part of the basic design is given in Table 1.

Table 1: relative dielectric constant

Design part	ε_r	Applied voltage (kV)
FRP	7.1	15
Weather sheds	4.3	15
Water droplet	81	15
Playwood	1.5	15
Cement dust	8.0	15

The whole problem domains in Figure 4 are fictitiously divided into small triangular areas called domain. The potentials, which were unknown throughout the problem domain, were approximated in each of these elements in terms of the potential in their vertices called nodes. Details of Finite Element discretization are found in [10]. The most common form of approximation solution for the voltage within an element is a polynomial approximation. PDE Tool in MATLAB is used for finite element discretization. The results of FEM discretization for clean and contamination conditions illustrate in Figure 5.

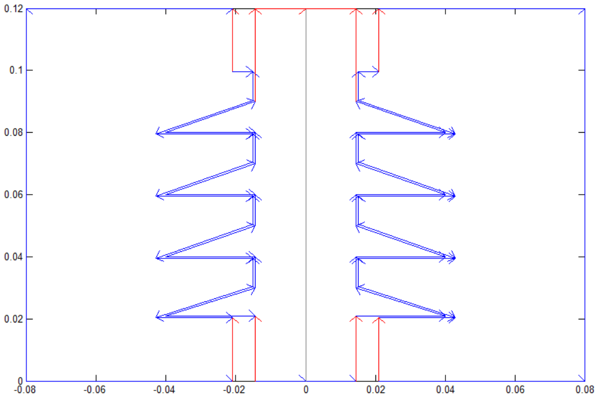

Figure 4: Two dimensions of the multiply straight sheds polymer insulators for FEM analysis.

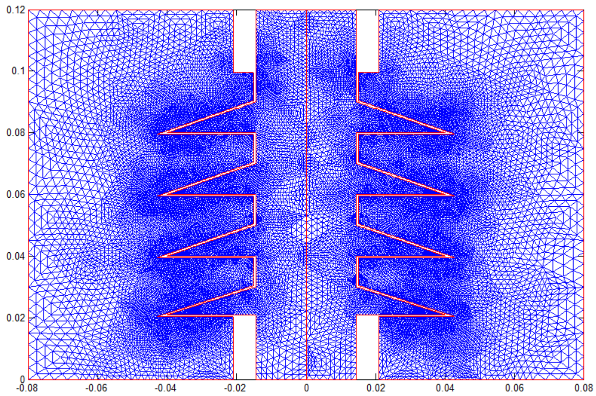

Figure 5: Finite element discretization results.

3 RESULTS AND DISSCUSSIONS

In this study, clean and contamination conditions, were simulated using FEM via PDE Tool in MATLAB. As illustrated in Figures 6 and 7, contamination conditions have no effect on potential distribution along the insulator surface. No obvious difference in potential distribution can be seen. In contrast, in case of electric field distribution, significant difference in electric field distribution can be seen even clean surface. In addition, electric field intensity on the trunk portion increased in concentration distribution but decrease in its absolute value with a number of contamination conditions, as illustrated in Figures 8 and 9.

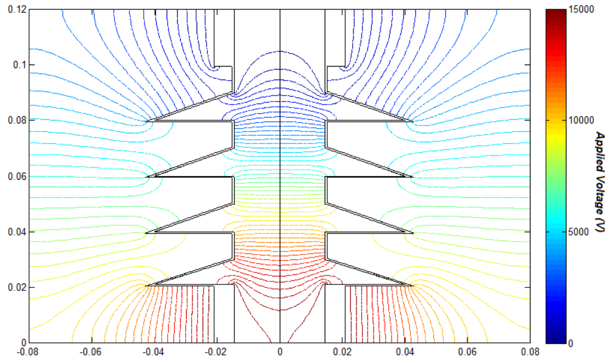

Figure 6: FEM analysis results under clean condition, (Potential distribution).

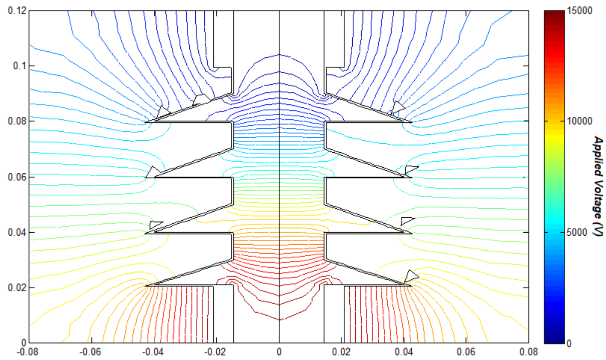

Figure 7: FEM analysis results under contamination conditions, (Potential distribution).

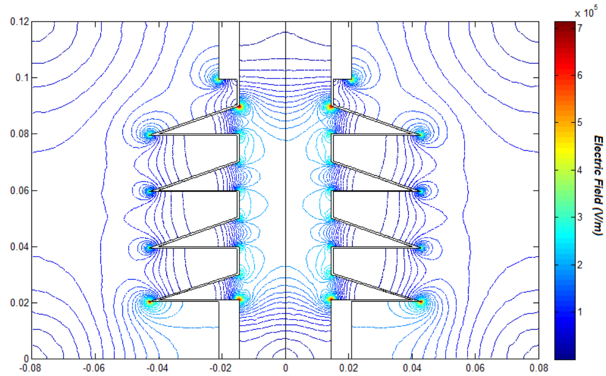

Figure 8: FEM analysis results under clean condition, (Electric field distribution).

Figures 10 and 11, shows the 3D-FEM analysis results under clean and contamination conditions to clear the differences in the electric field distribution, although the decreasing in the electric field absolute values, the non-uniformity of the field lines increases the stress especially on the trunk portion.

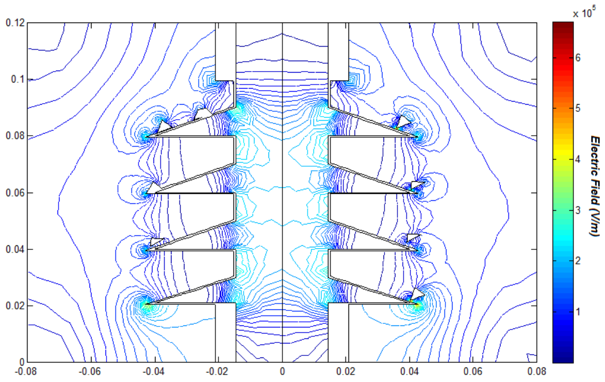

Figure 9: FEM analysis results under contamination conditions, (Electric field distribution).

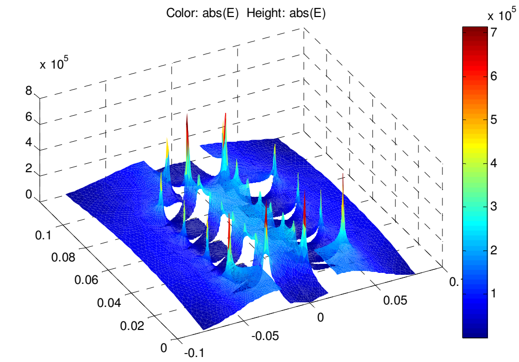

Figure 10: 3D-FEM analysis results under clean condition, (Electric field distribution).

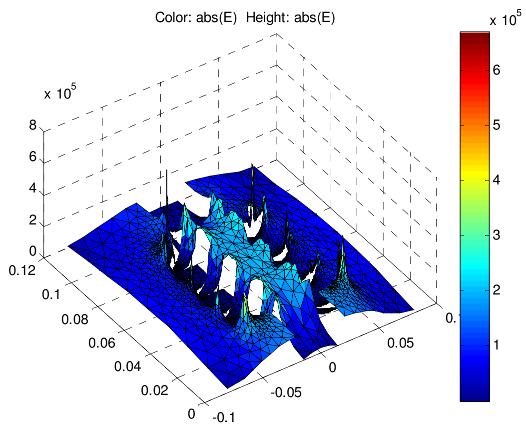

Figure 11: 3D-FEM analysis results under contamination conditions, (Electric field distribution).

4 CONCLUSION

This paper presents the simulation results of electric field and potential distributions along surface of silicon rubber polymer insulators under clean and various contamination conditions. The two conditions were investigated by using FEM. The simulation results show that contaminants have no effect on potential distribution along the polymer insulator surface. However, for electric field distribution they caused highly non–uniform electric field distributions especially on the trunk portion. The simulation results confirmed good electrical performance under contamination conditions.

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