3D modeling of Electrical Field and Electrical Potential in different contamination condition in Polymeric Insulator

A. Majzoobi*, I. A. Joneidi, S. Mohajer, H.Mohseni, A. A. Shayegani
High Voltage Lab, School of Electrical & Computer Eng., University of Tehran, Iran
*Email: <A.Majzoobi@ece.ut.ac.ir>

Abstract: Economic factor is one of the determining factors in component selection and because of economical benefits of polymeric insulators and their cost reduction, the promising future is anticipated for polymeric insulators. One of advantages of polymeric insulators is their hydrophobicity which makes insulator able to perform better in the wet and contaminated environments. In this paper distribution of electrical field and Electrical potential along energized polymeric insulators in the contaminated environment has been studied. Then the effect of water on electrical field and electrical potential has been analyzed. This simulation has been done with Finite Element Method (FEM) which is one of the numerical analysis methods that can be used for calculation of electrical field and potential of different objects. For this simulation and analysis three dimensional; 3D modeling has been chosen because of its more accuracy in comparison to two dimensional (2D) modeling.

1 INTRODUCTION

The advantages of polymeric insulators over the ceramic (porcelain and glass) ones, led to widespread usage of this kind of insulators in the electrical industry nowadays. One of the most important advantages of polymeric insulators is their lower weight in comparison to ceramic equivalents. This feature can decrease transportation and installation cost of them and also it can decrease cost of transmission line towers subsequently.

Economic factor is one of the determining factors in component selection and because of economical benefits of polymeric insulators and their cost reduction; the promising future is anticipated for polymeric insulators.

Another advantage of polymeric insulators is their hydrophobicity which can make insulator to perform better in the wet and contaminated environments[1].

According to widely and increasing usage of polymeric insulators, it's necessary to have a good understanding of their performance in different condition and environments. Especially, because it has been proved that polymeric materials performance is strongly under influence of their working environment. Pollution can accumulate on the insulator; it may distort the electric field distribution. The high electric field around water droplets on a polluted wet insulator can produce random surface partial arcs. These arcs consume the thin polymer layer around the droplet, destroying hydrophobicity. As hydrophobicity is lost, the droplets join together to form filaments that increase field intensity and surface arcing. Eventually, wetted regions form a conducting path between the electrodes. Consequently, partial arcs grow which eventually may lead to flashover[2].

Analysis of Electrical field and potential of polymeric insulators in the different contaminated environments is a good way for understanding of aging and flashover process in insulators. Also it can help manufacturers to have a better design and power utilities for better decisions about polymeric insulators usage.

In this paper distribution of electrical field and Electrical potential along energized polymeric insulators in the contaminated environment has been studied. Then the effect of water on electrical field and electrical potential has been analyzed. This simulation has been done with Finite Element Method (FEM) which is one of the numerical analysis methods that can be used for calculation of electrical field and potential of different objects. For this simulation and analysis three dimensional (3D) modeling has been chosen because of its more accuracy in comparison to two dimensional (2D) modeling.

2 SOLUTION EQUATIONS

2.1 Electric field and potential distributions calculation[3]

One simple way for electric field calculation is to calculate electric potential distribution. Then, electric field distribution is directly obtained by minus gradient of electric potential distribution. In electrostatic field problem, electric field distribution can be written as follows:

$$E = -\nabla V \qquad (1)$$

From Maxwell's equation

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

where ρ is resistivity Ω/m,

ε is material dielectric constant ($\varepsilon = \varepsilon_0 \varepsilon_r$)

ε_0 is free space dielectric constant (8.854×10^{-12} F/m)

ε_r is relative dielectric constant of dielectric Material.

Placing equation (1) into equation (2) Poisson's equation isobtained.

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

Without space charge $\rho = 0$, Poisson's equation becomes Laplace's equation.

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

2.2 FEM analysis of the electric field distribution

The finite element method is one of numerical analysis methods based on the variation approach and has been widely used in electric and magnetic field analyses since the late 1970s. Supposing that the domain under consideration does not contain any space and surface charges, two-dimensional functional *F*(*u*) in the Cartesian system of coordinates can be formed as follows:

$$F(u) = \frac{1}{2}\int_D \left[\varepsilon_x \left(\frac{du}{dx}\right)^2 + \varepsilon_y \left(\frac{du}{dy}\right)^2\right] dxdy \qquad (5)$$

where ε_x and ε_y are x- and y-components of dielectric constant in the Cartesian system of coordinates and u is the electric potential. In case of isotropic permittivity distribution ($\varepsilon = \varepsilon_x = \varepsilon_y$), equation (5) can be reformed as

$$F(u) = \frac{1}{2}\int_D \varepsilon\left[\left(\frac{du}{dx}\right)^2 + \left(\frac{du}{dy}\right)^2\right] dxdy \qquad (6)$$

If the effect of dielectric loss on the electric field distribution is considered, the complex functional $F(u)$ should be taken into account as

$$F^*(u) = \frac{1}{2}\int_D \omega\varepsilon_0(\varepsilon - j\varepsilon.\tan\delta)\left[\left(\frac{du^*}{dx}\right)^2 + \left(\frac{du^*}{dy}\right)^2\right] dxdy \quad (7)$$

where ω is angular frequency,

ε_0 is the permittivity of free space (8.85 $\times10^{-12}$ F/m), $\tan\delta$ is tangent of the dielectric loss angle, and u^* is the complex potential.

Inside each sub-domain D_e, a linear variation of the electric potential is assumed as described in (8)

$u_e(x, y) = \alpha_{e1} + \alpha_{e2}.x + \alpha_{e3}\, y$;(e = 1,2,3,..n_e) (8)

where $u_e(x, y)$ is the electric potential of any arbitrary point inside each sub-domain D_e, α_{e1}, α_{e2} and α_{e3} represent the computational coefficients for a triangle element *e*, n_e is the total number of triangle elements.

The calculation of the electric potential at every knot in the total network composed of many triangle elements was carried out by minimizing the functional *F(u)*, that is,

$$\frac{\partial F(u_i)}{\partial u_i} = 0 \;; i = 1,2,\dots np \qquad (9)$$

Where *np* stands for the total number of knots in the network.

Then a compact matrix expression

$$[S_{ji}]\{u_i\} = \{T_j\} \;; i,j = 1,2,\dots np \qquad (10)$$

Where $[S_{ji}]$ is the matrix of coefficients, $\{u_i\}$ is the vector of unknown potentials at the knots and $\{T_j\}$ is the vector of free terms. After (10) is successfully formed, the unknown potentials can be accordingly solved.

3 SIMULATION AND RESULTS

For analysis of changes in Electrical field and Electrical potential along insulator in clean condition and with presence of water drops, Comsol Multiphysics software has been used. 3D model of insulator with presence of water drops on its surface has been designed in Solidworks environment (figure 1); then, this model has been imported in Comsol.

Comsol uses FEM method for calculation of Electrical field and the boundary and subdomain settings of model are listed in table 1.

Table 1 : boundary and subdomain parameters

Parameter	σ (S/m)	ε_r
surroundings	0	1
Sheds	0	4
Metal end fittings	3.7×10^7	1
Core	0	7
Water drops	2	80

Insulator under study is 20kV insulator; therefore, maximum phase to ground voltage of 16.3 kV has been applied to insulator.

As shown in figure 2, around insulator has been surrounded by a sphere to limit calculations within that spherical area.

For FEM analysis, at the beginning of simulation, the model must be meshed (figure 3) and for accuracy improvement, the software has this ability to makes the meshes extra fine. As shown in figure 4, around water drops, the meshes are narrower than other parts.

Electrical field of insulator at presence of water drops can be seen in figures 5 and 6 and as shown In these figures, water drops make the electrical field of insulator distorted. 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 7 shows electrical field of insulator and as it can be seen, water drops have significant effect on it, although, these water drops have negligible effect on distribution of electric potential of insulator as shown in figure 8.

Figure 9 and 10 show the curve of electrical field and potential distribution along the line that have been crossed on the surface of insulator shed through water drops and as it can be seen, electric potential within water drops are zero, but outside of these water drops, electric potential is unchanged. Change pattern of electric field along water drop surface can be seen in figure 9.

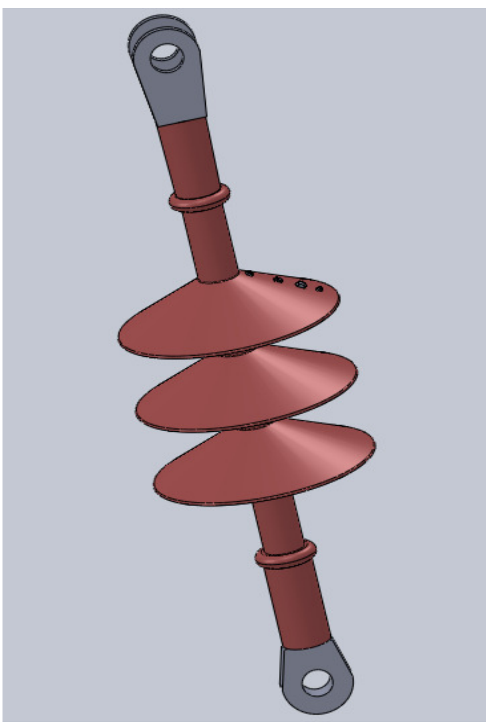

Figure 1 : insulator designed in Solidworks

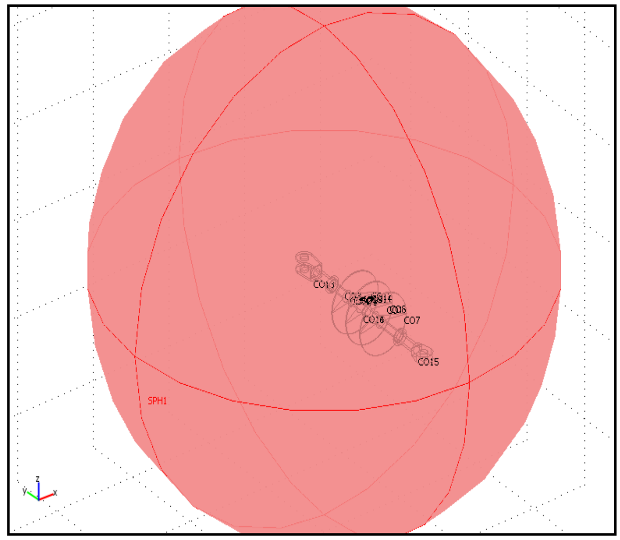

Figure 2 : the surrounding sphere

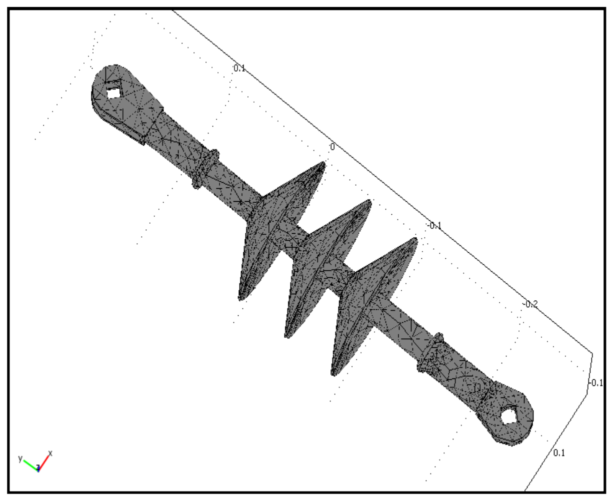

Figure 3 : meshing of insulator

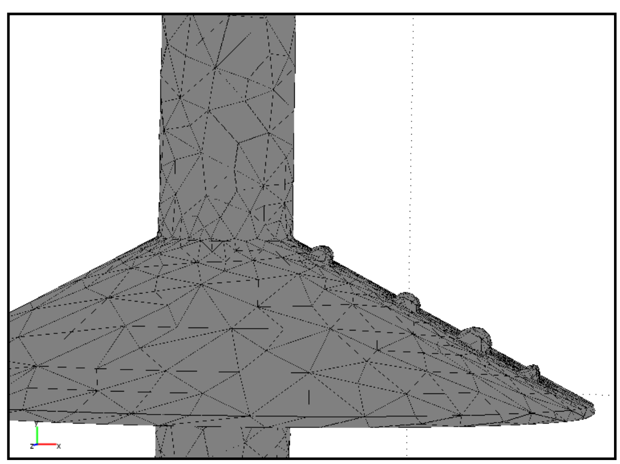

Figure 4 : finer mesh near water drops

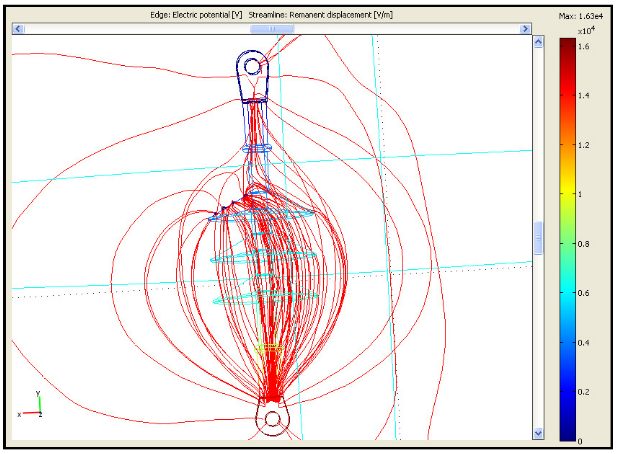

Figure 5 : Insulator electric field distribution

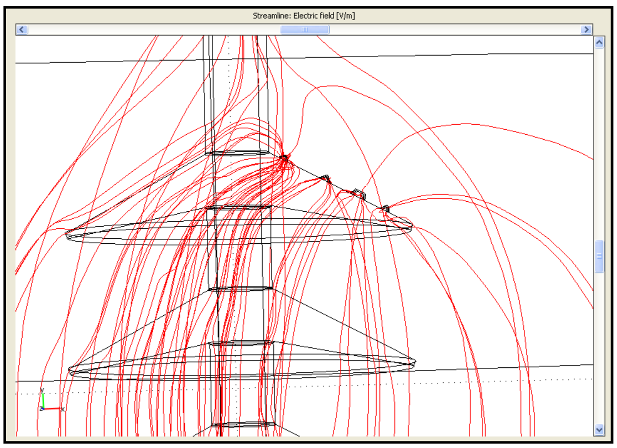

Figure 6 : Insulator electric field distribution(different view)

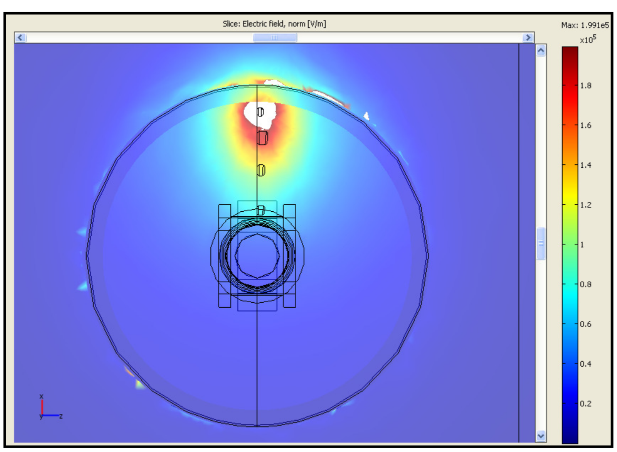

Figure 7 : Electric field changes near water drops

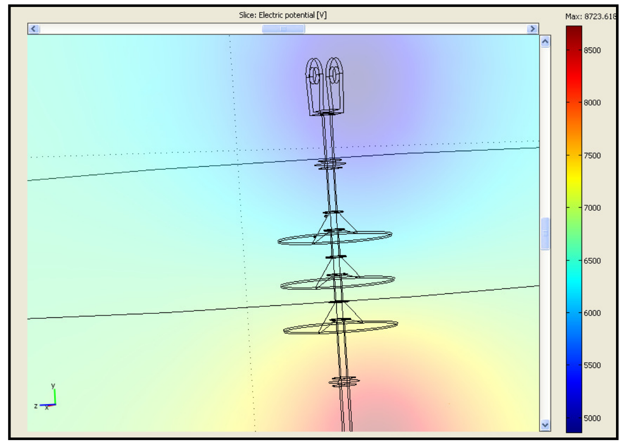

Figure 8 : Electric potential distribution

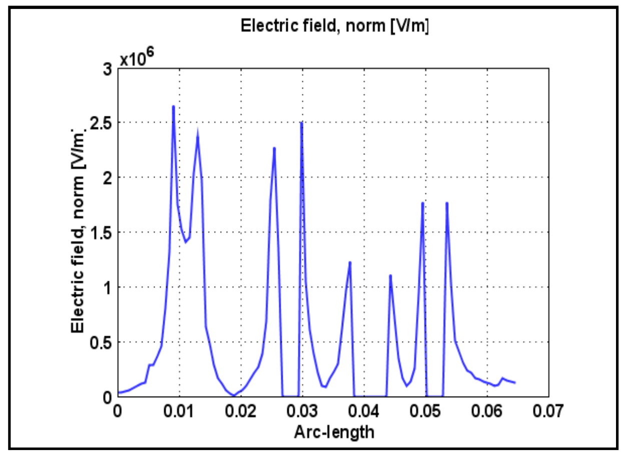

Figure 9 : Electric field distribution along insulator shed

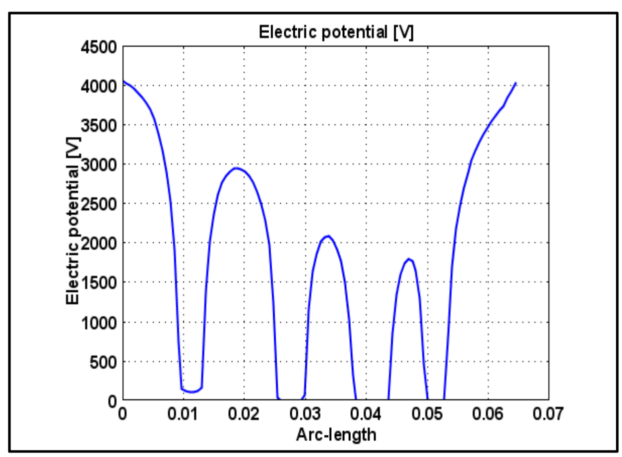

Figure 10 : Electric potential distribution along insulator shed

5 CONCLUSION

In this paper, electric field and potential distribution on polymeric insulator under wet condition have been investigated by using FEM method in Comsol software.

As shown in results, wet condition has negligible effect on potential distribution along surface of insulator, although it has significant effect on electric field distribution along insulator surface.

7 REFERENCES

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