FEM Based Electric Potential Distribution Analysis of Porcelain Insulator using MATLAB PDE tool

B Mallikarjuna, K N Ravi, V Muralidhara, N Vasudev

Abstract*: *In high voltage transmission porcelain materials are important one. To mount the transmission line on a transmission tower we need an insulation material. Many literatures deal about the silicon and rubber-based insulators. In this paper the porcelain is modelled as FEM model using the PDE tool and electric potential distribution is analyzed. the PDE tool come in handy to draw the shape of the insulator. In this paper the straight shed and alternate shed insulators are analyzed with the MATLAB PDE tool and results are analyzed. then using some random water droplets in the insulator, the impact is observed.

Keywords: Porcelain Insulator, Partial Differential Equation, Finite Element Method, Potential Distribution Analysis

I. INTRODUCTION

To operate the power system in a protected environment then the power system is operated in reliable way. To ensure that power system protection is one of the important methods [1,3]. The power system usually has the generators, transmission and distribution. While transmitting the high voltage has to be transmitted. While transmitting high voltages the towers need a proper insulator. Usually the towers are used here with ceramic insulators. But as the power transmission is done on outdoors the contamination is more. The major problem is pollution on insulators [2, 5]. The dry insulators have no problem in performance. But if the insulators are contaminated while it is placed near the road ways then there will be dust and water droplets. If so then the current leakage may happen due to the water droplets [4]. This leakage current may create flashover due to arcing [7]. This makes the interruption of transmitting the power. Determining the electric field around the insulator with water droplets are important [6]. This analysis may show whether the insulators are in safe region even with random water droplets. Many literatures are used to understand the concept which are listed in [8-26]. In this paper the porcelain insulator is added with water drop. Then it is discussed with straight shed and alternate shed insulators. The electric field and potential field is analyzed with Partial Differential Equation (PDE) tool in MATLAB.

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II. STATEMENT OF THE PDE PROBLEM

The power system requires a detailed simulation study before it is implemented. There are many simulation studies available to design the power system parameters like electrical quantities such as Voltage rating, current rating, power rating of the devices. And also studying the impact of fault like security studies. But any of these described studies not including the physical parameters and environmental parameters. So, there is a problem in power system reliability when the transmission system insulators are placed in the out space. It has many impacts like due to rain, dust and temperature effects. To analyse these effects, we go for Partial Differential Equation modelling of the devices which can analyse the electromagnetic effects with temperature change. By calculating the potential distribution, the electric field can be calculated. The field can be obtained by minus gradient of electric potential distribution.

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

Using maxwell's equation

$$\nabla E = \nabla(-\nabla) = \frac{\rho}{\epsilon} \quad (2)$$

$where,\quad \rho - resistivity\ \Omega/\mathrm{m}$

$\epsilon - dielectric\ constant\ of\ the\ material\ (\epsilon = \epsilon_0\epsilon_r)$

$\epsilon_0 - dielecrtic\ space\ constant\ \left(8.854 \times 10^{-12}\frac{F}{m}\right)$

$\epsilon_r - relative\ dielectric\ material\ constant$

Substituting equation (1) in (2) Poisson's equation is obtained as

$$\epsilon.\nabla(\nabla V) = -\rho \quad (3)$$

Substitute $\rho = 0$ the equation (3) shows

$$\epsilon.\nabla(\nabla V) = 0 \quad (4)$$

Cartesian system coordinates can be shown as equation $F(u)$

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

$where, \epsilon_x and\ \epsilon_y\ are\ x\ and\ y\ components\ of\ the\ dielectric\ constant. u\ is\ the\ electric\ potential.$

In the condition of isometric permittivity distribution by substituting $\epsilon = \epsilon_x = \epsilon_y$,

Equation (5) can be reformed as

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

$$F^*(u) = \frac{1}{2}\int_D \omega\epsilon_0(\epsilon - j\epsilon.tg\delta)\left[\left(\frac{du^*}{dx}\right)^2 + \left(\frac{du^*}{dy}\right)^2\right]dx\ dy \quad (7)$$

$\omega - angular\ frequency,$

$\epsilon_0 - perrmitivity\ of\ free\ space$

$tg\ \delta - tangent\ of\ dielectric\ loss\ angle$

$u^* - complex\ potential$

A linear variation of electric potential is assumed as shows below,

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

$u_e(x,y) - electric\ potential\ of\ arbitraty\ point$

$D_e, \alpha_{e1}, \alpha_{e2}, \alpha_{e3}\ are\ the\ computational\ coefficient$

by minimizing hte follwong eauartion the the electric potential is calculated,

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

Here np is total number of knots in the network.

III. RESULTS AND DISCUSSIONS

The simulation is carried out for the two straight shed porcelain insulators. And with alternate shed insulator. The dimensions are taken from the standard insulator size. Here to draw the porcelain insulator in 2D, PDE tool in MATLAB is used. The polygon tool in the PDE is helpful to draw the entire shape of the insulator. Then the draw mode is switched to boundary mode. Here the values of boundary are set using Dirichlet boundary equation. Then drawing formula is set in the PDE tool to get the exact shape. When double clicking on the boundary the values of the boundaries can be changed. The simulation is carried out for triangularization and electric potential distribution contour graph. This analysis is done for,

straight shed without water drops
straight shed with water droplets
alternate shed without water drops
alternate shed with water drops

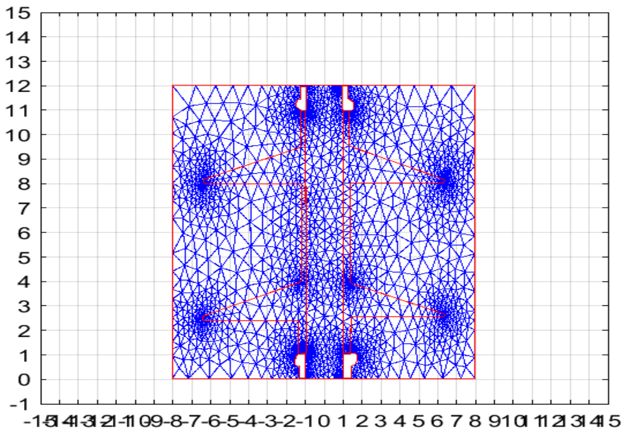

Figure 1 triangularization of straight shed insulator without water droplet

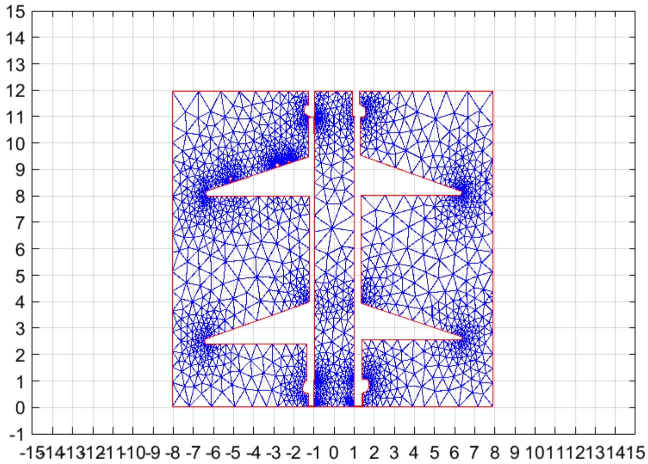

Figure 2 triangularization of straight shed insulator with water drops on left side of sheds

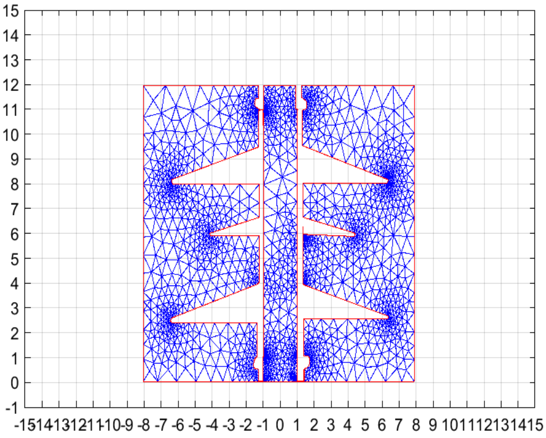

Figure 3 triangularization of alternate shed insulator without waterdrops

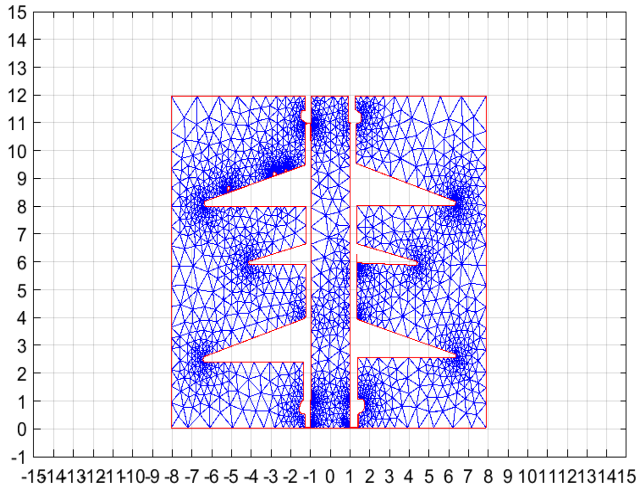

Figure 4 triangularization of water drops on the left side of first shed in alternate shed

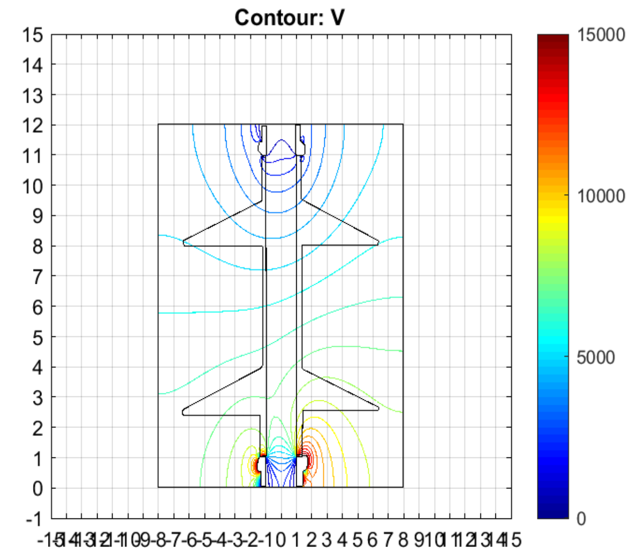

Figure 5 potential distribution of straight shed insulator without water drops

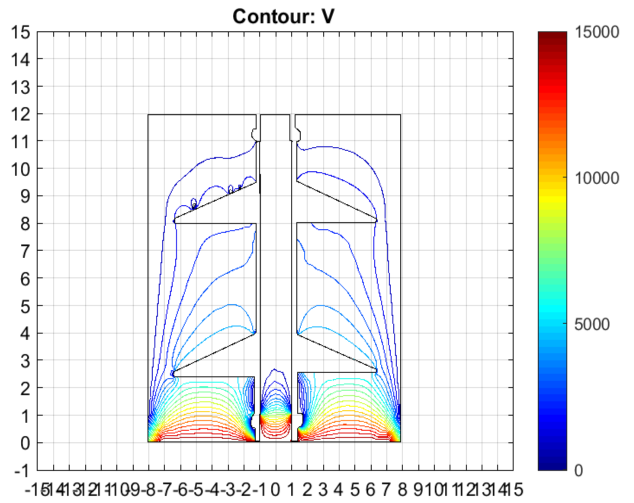

Figure 6 potential distribution of straight shed insulator with water drops

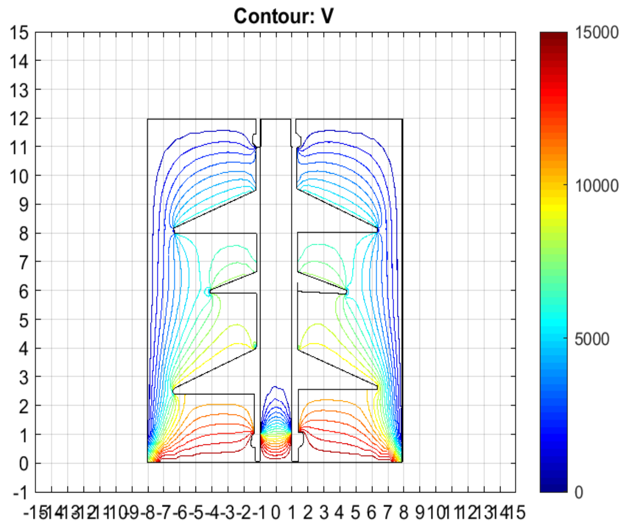

Figure 7 Potential distribution of alternate shed insulator without water droplets

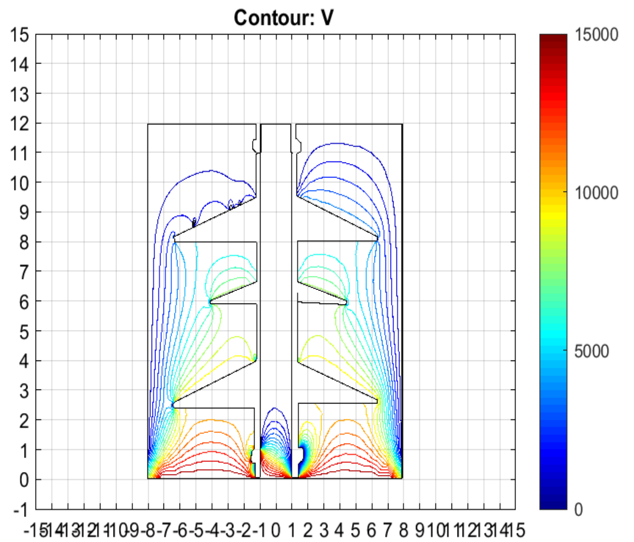

Figure 8 potential distribution of alternate shed insulator with water drops.

The Figure 9 shows the triangularization of straight shed insulator without water droplet. It shows that the edges of the insulators are dense in triangles. Then the Figure 10 shows the triangularization of straight shed insulator with water drops on left side of sheds. It shows that the triangularization is affected due to the random water drops. Then the Figure 11 shows the triangularization of alternate shed insulator without waterdrops. Here also the edges of the insulators are dense in triangles. Then the Figure 12 shows the triangularization of water drops on the left side of first shed in alternate shed. Here also the triangularization is getting affected by water drops. The Figure 13 shows the potential distribution of straight shed insulator without water drops. The potential distribution shows the high potential in red. Medium voltage in yellow then low voltage in blue. Near to the insulator lower end it is red and it has more potential effect. Moving toward the peak of the insulator it is becoming as blue. Then the Figure 14 shows the potential distribution of straight shed insulator with water drops. It can be shown that the water drops affect the potential distribution. The Figure 15 shows the Potential distribution of alternate shed insulator without water droplets. Then the Figure 16 shows the potential distribution of alternate shed insulator with water drops. In alternate shed also the potential gets affected by not severe like in the straight shed.

IV. CONCLUSION

For the testing the laboratory conditions water drops are added in the simulation with an ideal model. For the wet and dry conditions, the insulator surface is considered as tangential. The denser colored area is identified as the polluted region of the insulator. From the graphs the property of the insulator can be identified before the practical implementation .

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