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Influence of Design Parameters on Surface Leakage Current of Silicone Rubber Insulator

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***Abstract*: In Overhead Transmission line, outdoor insulators play an important role. They give support to the transmission line and also provide insulation between the overhead conductor and supporting structure. Nowadays silicone rubber insulators are widely used due to their better performance. However, as the silicone rubber is an organic material, its property will be deteriorated due to surface contamination and leakage current will start to flow on surface. Due to this surface leakage current, flashover may occur which is known as the contamination flashover. The objective of this paper is to propose modified design of Silicone rubber insulator which provides less leakage current thus the performance of insulator and its life can be improved. Finite element method software ANSYS MAXWELL has been used to calculate surface leakage current. Result shows that proposed modified alternate shed design gives less surface leakage current compared to the previous regular shed design.**

***Keywords*: contamination; finite element method; leakage current; outdoor insulator**

1. Introduction

In power system, function of outdoor insulator is to support the transmission line conductor and to insulate that conductor from the tower that is at ground potential. Different type of insulators has been used by the utility like porcelain, glass and polymer. Now a day's silicone rubber insulators are widely used due to their hydrophobic nature, easy handling, light weight, high mechanical strength and so on [1], [2]. Construction wise polymer or composite insulator is quite different from the conventional porcelain and glass insulators. Structure of the polymer insulator is shown in figure 1. The basic design of the polymer insulator has a fiber reinforced plastic (FRP) core, two metal fittings and Weather sheds. FRP core is used as a load bearing structure. To protect the FRP core against various environmental stress and provide a leakage distance, weather sheds are formed outside the FRP core [3]. Actual Silicone rubber insulator is shown in figure 2. One end fitting supports live conductor and another end fitting is connected with the tower. However, since the polymer insulators are made of organic materials deterioration through ageing is unavoidable [4]. The insulators used in overhead transmission line are subjected to various environmental conditions and these conditions are varying from a region to another. Depends upon the location of the insulator, there are various type of pollution like cement, plywood dust, silica, sulphur, etc. [5]. One of the serious problems with the HV/EHV transmission line is the contamination of this atmospheric pollution over the surface of the insulator. Due to this contamination, an ideal path is created in on the surface of the insulator through which the leakage current can be flow. This surface leakage current deteriorates the electric characteristics of the insulator which leads to the flashover of the insulator. This type of flashover is known as a contamination flashover. The effect of design parameters like shed diameter, rod diameter and shed angle on surface resistance and hence on current density were calculated for non-ceramic profile based on circuit theory by Young et al. [6], [7]. It was concluding that the shed angle had only a small effect in reducing the surface resistance while the shed diameter had greater effect on surface resistance. By using larger shed the surface resistance was dropped considerably which may allow surface leakage. However, in their computation, the effect of creepage distance was not shown and also there is not any leakage current magnitude found out.

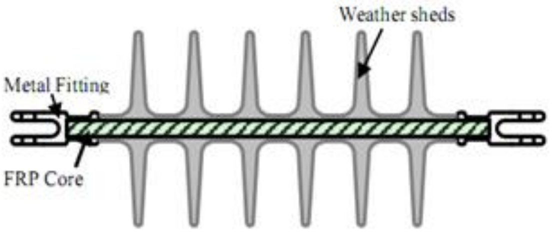


Fig. 1. A Clean Model of Silicone rubber insulator

Fig. 2. Actual Silicone rubber insulator

The paper presents the finite element method approach to find the leakage current on the surface of the insulator while the conductive pollution layer has been created on the surface. In practice the conductivity of surface layer find out from the Equivalent Salt Deposit Density (ESDD)[8].The actual design parameters of the regular shed insulator has been taken from the one company, Hi-tech Trans power Pvt. Ltd. The modified design with change in shed diameter and creepage distance has been proposed which provides less leakage current compared to the previous regular shed insulator.

2. Proposed solution technique

For the analysis like potential and electric field distribution, Laplace and Poisson equation has been used. There are several methods for solving partial differential equation such as Laplace and Poisson equation. The most widely used methods are Finite Difference Method (FDM), Finite Element Method (FEM), Boundary Element Method (BEM) and Charge Simulation Method (CSM) [9]. In this paper Finite Element method is used as a numerical technique with the aid of ANSYS MAXWELL software. In contrast to other methods, the Finite Element Method (FEM) takes into accounts for the non-homogeneity of the solution region. Also, the systematic generality of the methods makes it a versatile tool for a wide range of problems. This method states that a complicated domain can be sub-divided into series of smaller regions in which the differential equations are approximately solved. By assembling the set of equations for each region, the behavior over the entire problem domain determined. In MAXWELL, three different types of electric solvers are available: electrostatic, DC conduction and AC conduction. As the finding for this paper is leakage current under AC stress, AC conduction solver has been used. The AC conduction field simulator computes steady state 2D electric field in conductor due to applied potential. The AC conduction solver allows you to analyze conduction current due to time varying electric field in conductors and lossy dielectrics. It can be used to analyze current distribution, electric field distribution and potential distribution. Using ANSYS MAXWELL software, the Finite Element Method (FEM) analysis procedure consists of three steps [10].

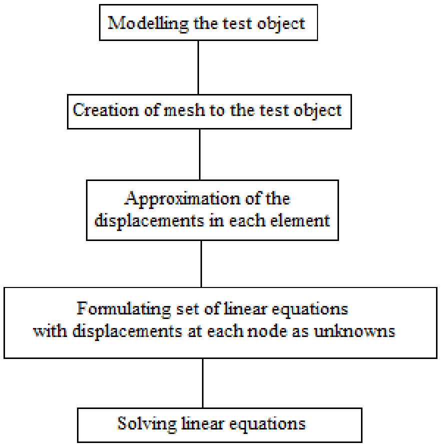


Fig. 3. Flow chart for the solution process for Insulator

These steps are Pre-processing, Solution and Post-processing. In preprocessing, one should define the geometry and material properties of the structure and the type of solver to use. The finite element model, or mesh, is created by defining the shapes of element, the sizes of element and any variation of these throughout the model. Once the geometry is defined, the solid model is discretized into a suitable finite element mesh using a variety of meshing tools. The great care has to take while doing the meshing. Here triangular element has been selected for meshing. Usually, the mesh is created to give smaller elements in areas of stress concentration to enhance the accuracy of the solution. The boundary condition and loads are applied in this stage. Derichlet boundary condition has been used between dielectric-conductor surfaces while Neumann has been used for the dielectric-dielectric boundary. Boundary condition defines the behavior of the Electric field lines when it enters from one medium to another medium. The FEM provide solution of domain based closed boundary problem while outdoor Insulator is an open boundary problem as it has to work in open environment. To make the insulator closed, a fictitious boundary is created surrounding insulator. Fig. 3 shows the general Flow chart for the solution process in Ansys Maxwell.

3. Problem solution equation

A. *Electric field and potential distribution calculations*

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 [11].

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

From Maxwell's equation

$$\nabla E = \nabla\left(-\nabla V\right) = \frac{\rho}{\varepsilon} \tag{2}$$

Where, ρ is surface charge density, C/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 (1) into (2), Poisson's equation is obtained.

$$\varepsilon \cdot \nabla\left(\nabla V\right) = -\rho \tag{3}$$

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

$$\varepsilon \cdot \nabla\left(\nabla V\right) = 0 \tag{4}$$

B. *FEM analysis of electric field*

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 ($\varepsilon = \varepsilon_x = \varepsilon_y$), (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

$$F(u^*)=\frac{1}{2}\int_D\omega\varepsilon_0(\varepsilon-j\varepsilon\cdot tg\delta)\left[\begin{matrix}\left(\frac{du^*}{dx}\right)^2+\\ \left(\frac{du^*}{dy}\right)^2\end{matrix}\right]dxdy \qquad (7)$$

where ω is angular frequency, ε_0 is the permittivity of free space (8.85×10^{-12} F/m), tgδ 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)

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

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,

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

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

Then a compact matrix expression

$$\lfloor S_{ij}\rfloor\{u_i\}=\{T_j\} \quad ;i,j=1,2,\ldots,np \qquad (10)$$

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.

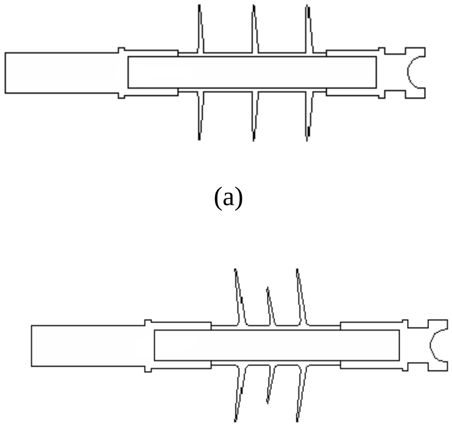
C. Current density and leakage current calculation

Once the current density is find out, by taking surface integration of pollution layer, surface Leakage current can be find out with the help of following equation (11) where J is the current density and S is the surface area.

$$I=\int_s J.ds \qquad (11)$$

4. Fem model

The simulation model that being applied within the software, ANSYS MAXWELL by using finite element method, can be categorized into two design: Regular shed and Proposed modified alternate shed design. The model with the dimension mentioned in Table I, has been shown in fig. 4. Contamination layer of 2 mm thickness has been created on the surface of both the design of insulator. Permittivity and conductivity has been assigned according to the material type. Technical Specification has been shown in table 1 for both the mentioned design. Fig.5 shows the input output flow of simulation activity.



(a)

(b)

Fig. 4. Simulation Model (a) Regular Shed Design (b) Proposed Alternate shed Design

5. Results and discussion

Fig. 6 (a) and (b) shows meshing of regular and alternate shed respectively. Fine triangular meshing has been done at the edges of the insulator. Fig. 7 shows comparison of potential distribution between Regular shed design and proposed Alternate shed design. From the Fig. 6 it is clear that the potential distribution is more linear in alternate shed design compared to the regular shed design. Electric field distribution

Table 1
Technical Specification of Regular Shed Insulator

Structure Parameters	**Regular shed**	**Modified Alternate shed**
Rated Voltage	11 kV	11 kV
No. of shed	3	3
Dry arcing Distance	155 mm	155 mm
Min. Creepage distance	340 mm	320 mm
FRP rod diameter	24 mm	24 mm
Shed Spacing	44 mm	25 mm
Shed diameter	105 mm	126 mm
Shed diameter(small)	-	93 mm

is shown in Fig. 8. For regular shed design the maximum electric field stress is 6.96 × 10^5 V/mm while for the alternate shed it is 3.34 × 10^5 V/mm., which indicate that the maximum electric field stress magnitude is minimum for the Alternate shed design.

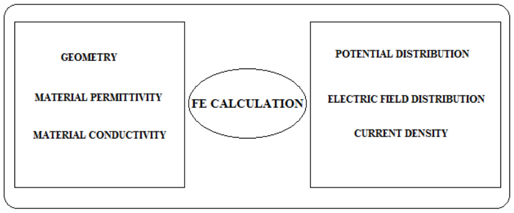


Fig. 5. Input output flow of simulation activity

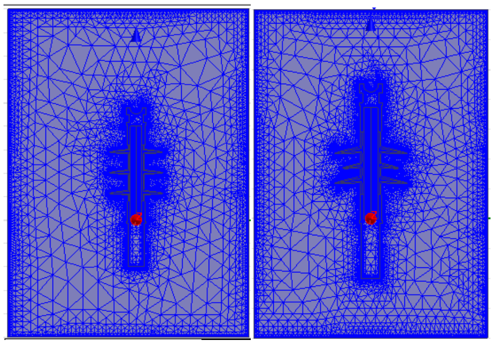


Fig. 6. Meshing of (a) Regular shed design (b) Alternate shed design

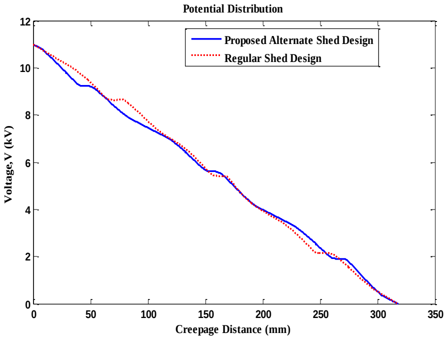


Fig. 7. Comparison of potential distribution between regular shed design and proposed alternate shed

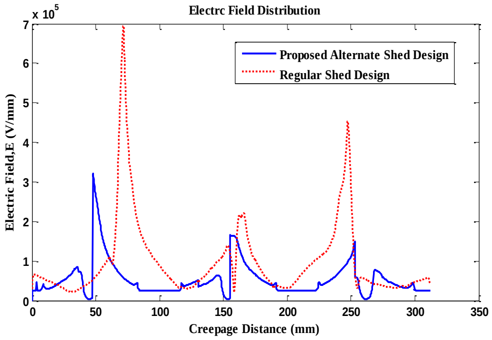


Fig. 8. Comparison of electrical field distribution between regular shed design and proposed alternate shed

Highest electric field stress was observed at the shed tip and minimum at the trunk region. We can also observe that due to the contamination the electric field becomes non-uniform especially at the trunk portion of the insulator. Fig. 9 represents current density distribution along the surface of the insulator. In alternate shed design the middle shed has less area and due to that it will offer high resistance to the leakage current path

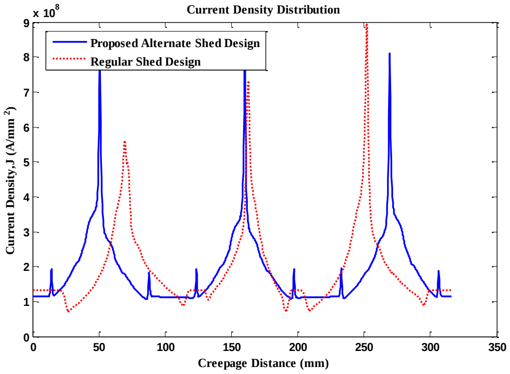


Fig. 9. Comparison of current density distribution between regular shed design and proposed alternate shed

By taking the surface integration of the current density for mentioned both the design, leakage current has been found. It is observed that the proposed alternate shed design provides 40% reduction in the magnitude of leakage current. The value of the leakage current are 1.7 mA and 1.3 mA for the regular shed design and proposed alternate shed design respectively.

6. Conclusion

The design parameters of insulator are one of the major influence factors for the Electric field stress and leakage current. The maximum electric field is less in alternate shed design which is proposed here. It is also found that the magnitude of leakage current is less in case of alternate shed design so chances of flashover are reduce in case of proposed design. It is also observed that the voltage distribution is somewhat linear in case of proposed design compared to the regular shed design. With the help of Finite element method, the design of the composite insulator has been optimized.

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