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Electric Field along Surface of Silicone Rubber Insulator under Various Contamination Conditions Using FEM

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Abstract— Power line insulators are used to support the high voltage current carrying conductors. Silicone rubber provides an alternative to porcelain and glass regarding to high voltage (HV) insulators and it has been widely used by power utilities since 1980's owing to their superior contaminant performances. The main objective of this paper is to carry out simulation on the electric field distribution of energized silicon rubber insulator using MATLAB. Failure of outdoor high voltage (HV) insulator often involves the solid air interface insulation. As result, knowledge of the field distribution around high voltage (HV) insulators is very important to determine the electric field stress occurring on the insulator surface, particularly on the air side of the interface. Thus, we analyze the electric field distribution of energized silicone rubber high voltage (HV) insulator and the effect of water droplets on the insulator surface is also included. The electric field distribution computation is accomplished using FEM. The finding from this shows that existence of water drops would create field enhancement at the interface of the water droplet, air and insulating material. If the thickness of the dust increases, the highest stress point will deviate and move outward from the interface point of the water droplet, air and insulating material.

Index Terms— Cement dust, Electric field distribution, Electric potential, Finite element method, Plywood dust, Silicone rubber insulator, Simulation, Water droplet.

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1 INTRODUCTION

There are several methods for solving partial differential equation such as Laplaces 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). In contrast to other methods, the Finite Element Method (FEM) takes into accounts for the nonhomogeneity of the solution region. Also, the systematic generality of the methods makes it a versatile tool for a wide range of problems.

Numerical techniques have long been recognized as practical and accurate methods of field computation to aid in electrical design. Precursors to the Finite Element Method (FEM) are Finite Differences and Integral Equation techniques. Although all these methods have been used and continue to be used either directly or in combination with others for design, Finite Element Method (FEM) has emerged as appropriate techniques for low frequency applications.

2 SIMULATION METHOD

The Finite Element Method (FEM) is a numerical analysis technique used by engineers, scientists, and mathematicians to obtain solutions to the differential equations that describe, or approximately describe a wide variety of physical and nonphysical problems. Physical problems range in diversity from solid, fluid and soil mechanics, to electromagnetism or dynamics.

The underlying premise of the 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 other words, using the Finite Element Method (FEM), the solution domain is discretized into smaller regions called elements, and the solution is determined in terms of discrete values of some primary field variables φ (e.g. displacements in x, y & z directions) at the nodes. The number of unknown primary field variables at a node is the degree of freedom at that node. For example, the discretized domain comprised of triangular shaped elements is shown below in Fig. 1. In this example each node has one degree of freedom.

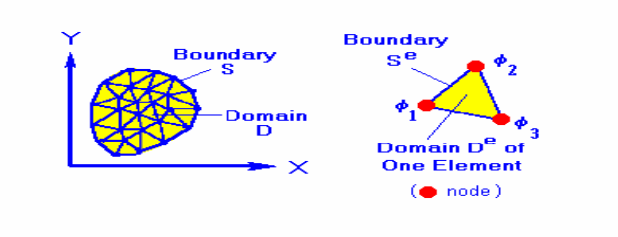


Fig. 1. Typical finite element subdivisions of an irregular domain and typical triangular element.

The governing differential equation is now applied to the domain of a single element (above right). At the element level, the solution to the governing equation is replaced by a continuous function approximating the distribution of φ over the element domain, expressed in terms of the unknown nodal values Φ1, Φ2 and Φ3 of the solution Φ. A system of equations in terms of Φ1, Φ2 and Φ3 can then be formulated for the element.

Once the element equations have been determined, the elements are assembled to form the entire domain D. The solution Φ(x, y) to the problem becomes a piecewise approximation, expressed in terms of the nodal values of Φ. A system of linear algebraic equations results from the assembly procedure.

For practical engineering problems, it is not uncommon for the size of the system of equations to be in the thousands, making a digital computer a necessary tool for finding the solution. Furthermore, for most practical problems, it is impossible to find an explicit expression for the unknown, in terms of known functions, which exactly satisfies the governing equations and the boundary conditions. The purpose of the Finite Element Method (FEM) is to find an explicit expression for the unknown, in terms of known functions, which approximately satisfies the governing equations and the boundary conditions. However, the approximate solution may satisfy some of the boundary conditions exactly.

Each region is referred to as an element and the process of subdividing a domain into a finite number of elements is referred to as discretization. Elements are connected at specific points, called nodes, and the assembly process requires that the solution be continuous along common boundaries of adjacent elements.

2.1 Steps Included in Finite Element Method (FEM)

Theoretically, a Finite Element Method (FEM) analysis is composed by four different consequent steps. Those steps are as listed below:

- Discretizing the solution region into finite number of subregion or element.
- Deriving governing equation for a typical element.
- Assembling of all elements in the solution region.
- Solving the system of equations obtained.

In practical terms the Finite Element Method (FEM) analysis procedure consists of three steps. All of these steps basically, include four steps mentioned previously. These steps are:
a) Pre-processing. b) Solution. c) Post-processing.

a) Pre-processing: Defining the Finite Element Model

Pre-processing, or model generation, is the most user-intensive part of the analysis. Perhaps up to 90% of the analyst's time is taken up creating the finite element mesh. In pre-processing, the analyst defines the geometry and material properties of the structure and the type of element 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.

In most modern finite element programs, mesh generation is a two-stage process. The first stage is to create a solid model of the structural geometry in terms of geometrical entities such as points, lines, areas and volumes. Once the geometry is defined, the solid model is automatically discretized into a suitable finite element mesh using a variety of meshing tools. Usually, the mesh is created to give smaller elements in areas of stress concentration to enhance the accuracy of the solution.

Almost all finite element modeling is now done interactively. The analyst either types in commands from a keyboard or selects commands from a menu system using a mouse. The program executes these commands and stores the generated data in a file or database. Graphical representations of points, lines, nodes, elements, etc can then be viewed to ensure the model definition is correct.

b) Solution: Solving for Displacement, Stress, Strain, etc.

In most of the types of analysis performed the solution procedure is linear and straightforward. However, in non-linear problems or problems in which the boundary conditions vary with time (transient analysis) the user must define the loading history and define control parameters for the solution.

c) Post-processing: Reviewing Results in Text and Graphical Form

The results of the analysis are reviewed in the post-processing stage. Finite element programs generate huge amounts of data and it is convenient to use computer graphics to represent the results in graphical form, for example, pictures of the deformed shape of a structure or contour plots of temperature variation in a thermal analysis.

2.2 Types of Elements

A wide variety of elements types in one, two, and three dimensions are well established and documented. It is up to the analyst to determine not only which types of elements are appropriate for the problem at hand, but also the density required to sufficiently approximating the solution. Engineering judgment is essential. In general, it is a geometrical shape (usually in solid color in modern programs) bounded by dots (nodes) connected by lines. Some solid and shell elements are illustrated in Fig. 2 below.

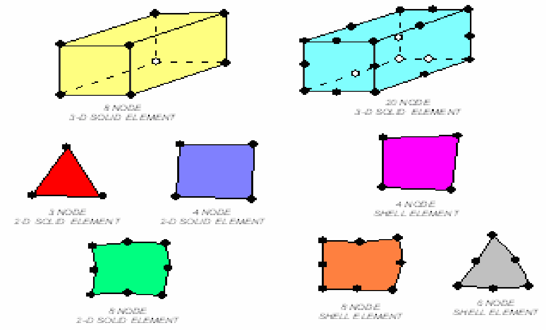


Fig. 2. A variety of solid and shell finite elements.

3 SILICONE RUBBER INSULATOR

Silicon rubber composite insulators, which are now extensively accepted, did not come out until 1970s, and Germany is the first country developing and using this kind of insulator. Compared to conventional porcelain and glass insulators, composite insulators such as silicon rubber insulator offer more advantages in its application.

Compared with conventional porcelain and glass insulators, composites insulators have the following advantages:

- Light weight.
- High mechanical strength.
- Good electrical performance.
- Excellent Hydrophobicity.
- Small volume.
- Excellent contamination flashover resistant.
- Simple producing art.
- Convenient maintenance.

Hence it is very advantageous to go for Silicon Rubber Insulator. So to analyze the characteristics, Silicon Rubber Insulator is modelled and simulated with different effects.

To visualize the effect of a water droplet along silicon rubber insulator surface, a set up as shown in Fig. 3 is used to simulate the electric field and voltage distribution. It consists of a flat silicon rubber sample of 100mm length and 10mm thickness where it is being connected to electrodes at it ends and surrounded by air. The live electrode is supplied by 100V while the water droplet on test is located at the middle of the silicon rubber sample and it is hemispherical in shape with 5mm radius. Also, the contact angle of the incident water droplet is set to be 90^o. The permittivity of water droplet, silicon and air is given by 81, 4.3 and 1 respectively.

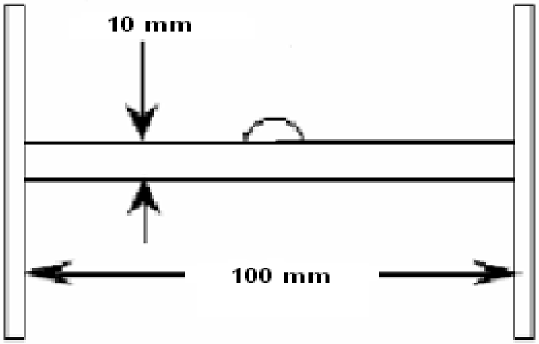


Fig. 3. Set up for analyzing effect of a water droplet on silicon rubber surface.

After analyzing the effect of thickness of different dust material like cement dust, plywood dust, etc. on the insulator surface, it is found that the highest field stress point will move outward. The two types of dusts used to analyze the movement of highest field stress point are cement dust and plywood dust.

4 SIMULATION RESULTS

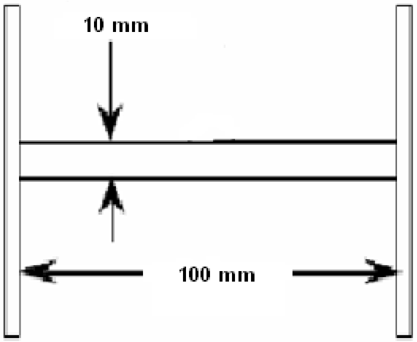
In this study, clean and contaminated conditions were simulated using FEM in MATLAB. The Two Dimension of SiR Insulator under clean and contaminated conditions for FEM Analysis are shown in Fig. 4 and Fig. 5. The results of FEM discretization were shown in Fig. 6 and Fig. 7 respectively. As illustrated in Fig. 8 and 9, water droplets have significant effect on potential and electric field distributions.

In case of cement dust, increase in the dust thickness has no effect on potential distribution along insulator and dust surfaces, as illustrated in Fig. 10. No significant difference in potential distribution can be seen. In contrast, in case of electric field as in Fig. 11, highest field stress point along insulator surface moves outward from interface point of the water droplet, air and SiR material as dust thickness increases along SiR surface.

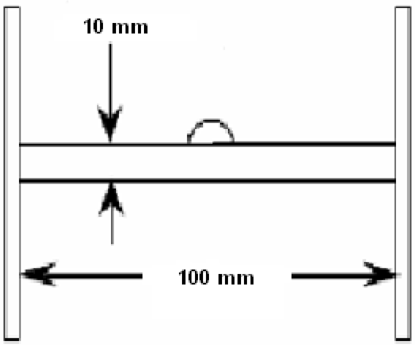
In case of plywood dust contaminated condition, increase in dust thickness has no effect on potential distribution along insulator and dust surfaces, as illustrated in Fig. 10. No significant difference in potential distribution can be seen. In contrast, in case of electric field as in Fig. 11, highest field stress point along insulator surface moves outward from interface point of the water droplet, air and silicon rubber material as dust thickness increases along SiR surface.

Fig. 8 and Fig. 9 display the voltage and field profile respectively, surface of silicon rubber without water droplet and surface that comprises one water droplet. Voltage profile of silicon rubber surface without water droplet exhibit a linear relationship while for surface with water droplet, the voltage maintain its magnitude within 49V to 50V along the surface that is directly touched with the water droplets. It is observed that the maximum field stress that occurs along insulator surface is 2 V/mm.

Comparison of results illustrated in Fig. 16, 17, 18 & Fig. 19 shows that the highest field stress point moves outward as the dust thickness increases along insulator surface. However increase in thickness of dust along insulator surface has no effect on electric potential distribution as shown in Fig. 12, 13, 14 & Fig. 15.

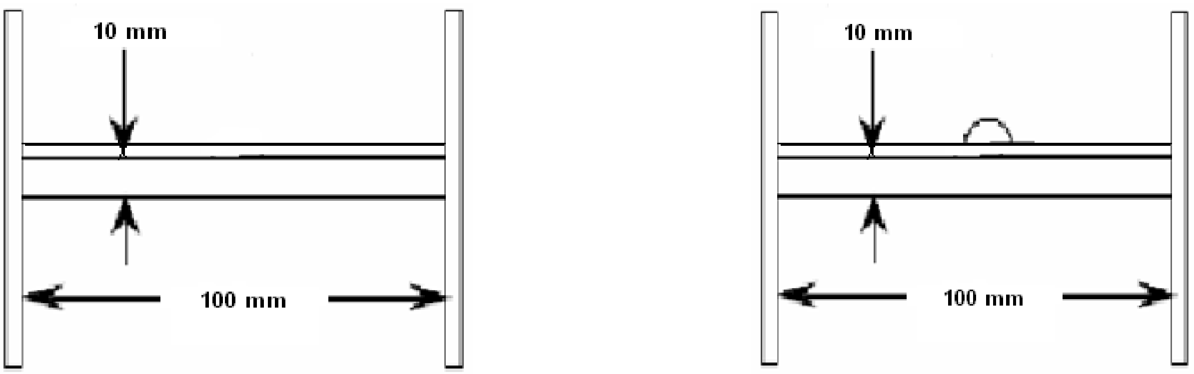


a) Without Dust and Water drop



b) Without Dust but with Water drop

Fig. 4. Two Dimension of SiR Insulator under clean condition for FEM Analysis.

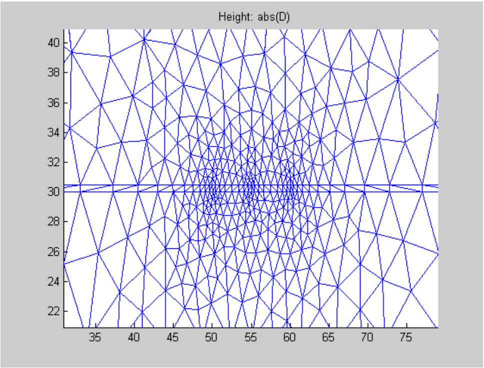


c) With dust but without Water drop

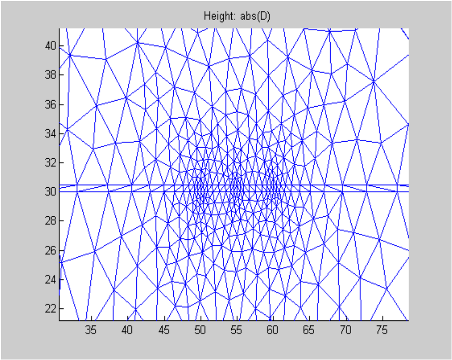
d) With Dust and Water drop

Fig. 5. Two Dimension of SiR Insulator under contamination on surface for FEM Analysis.

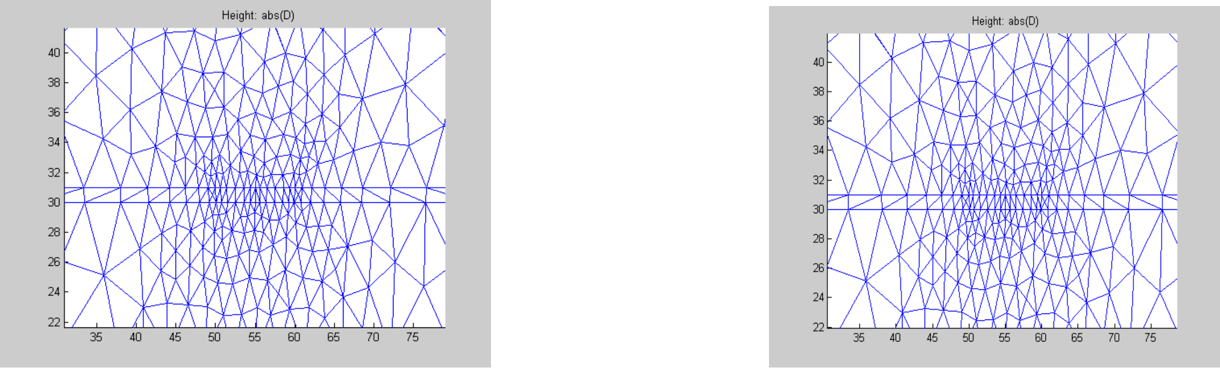
Fig. 6. Finite Element Discretization Results for clean condition.



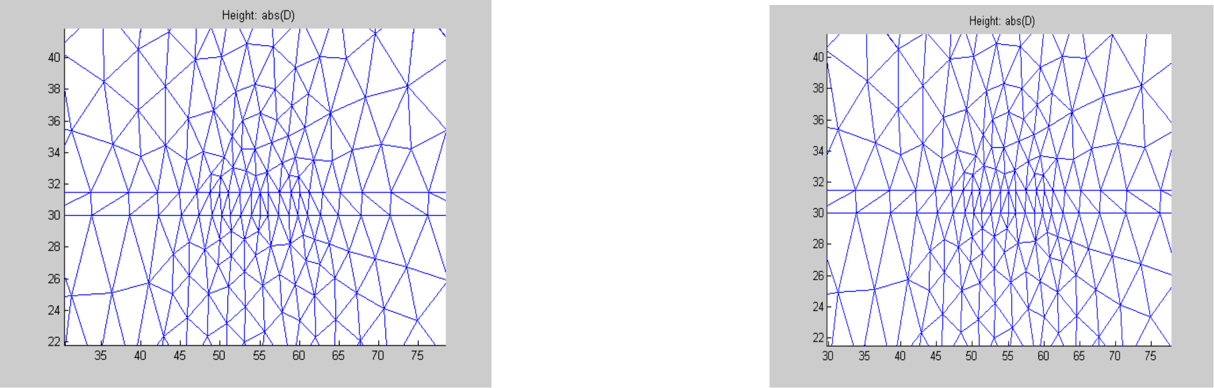
a) with 0.5 mm cement dust



a) with 0.5 mm plywood dust



b) with 1 mm cement dust b) with 1 mm plywood dust



c) with 1.5 mm cement dust c) with 1.5 mm plywood dust

Fig. 7. Finite Element Discretization Results for contamination condition.

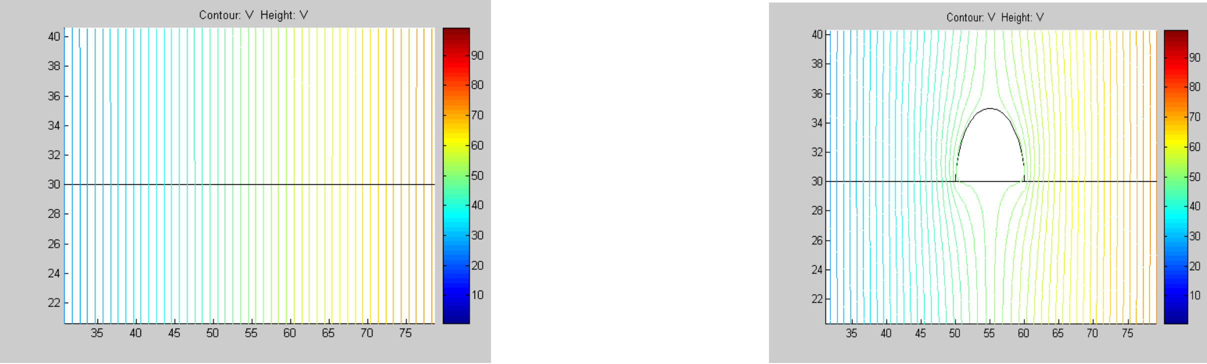


Fig. 8. Potential Distribution under clean condition.

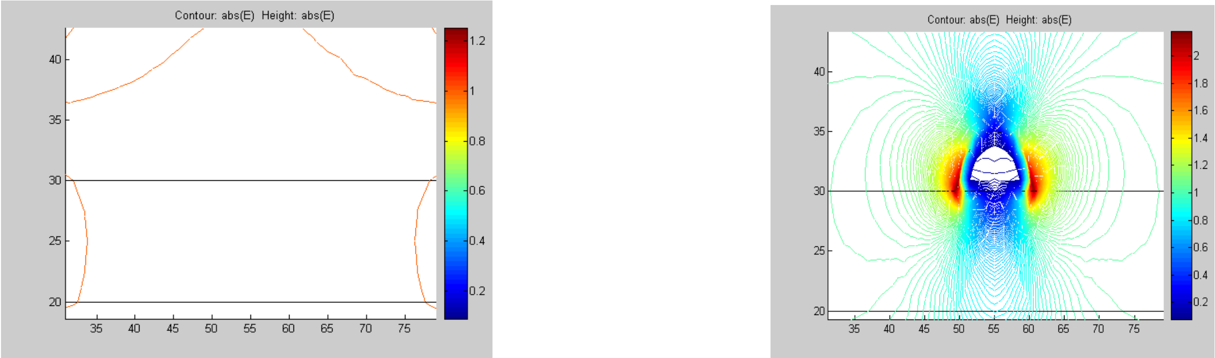
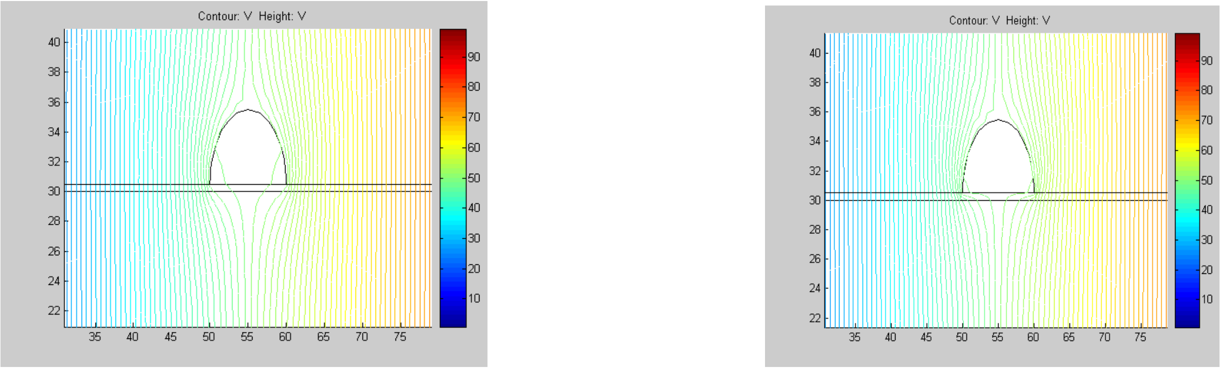
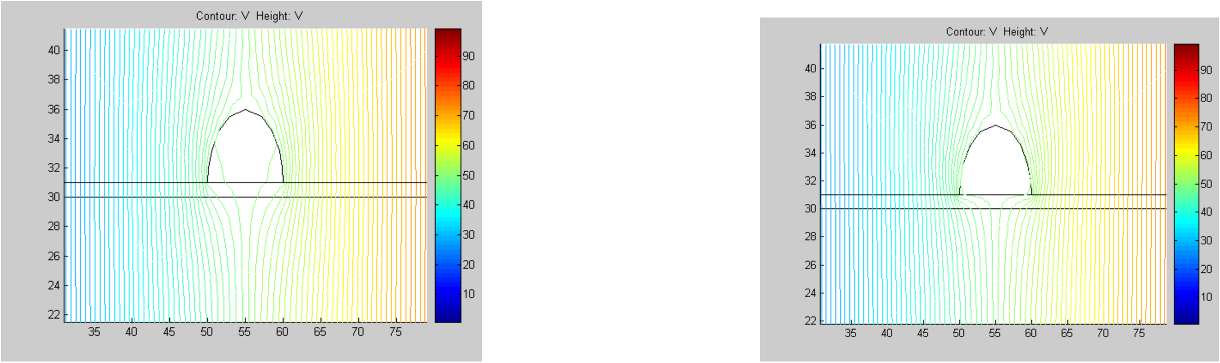


Fig. 9. Electric Field Distribution under clean condition.



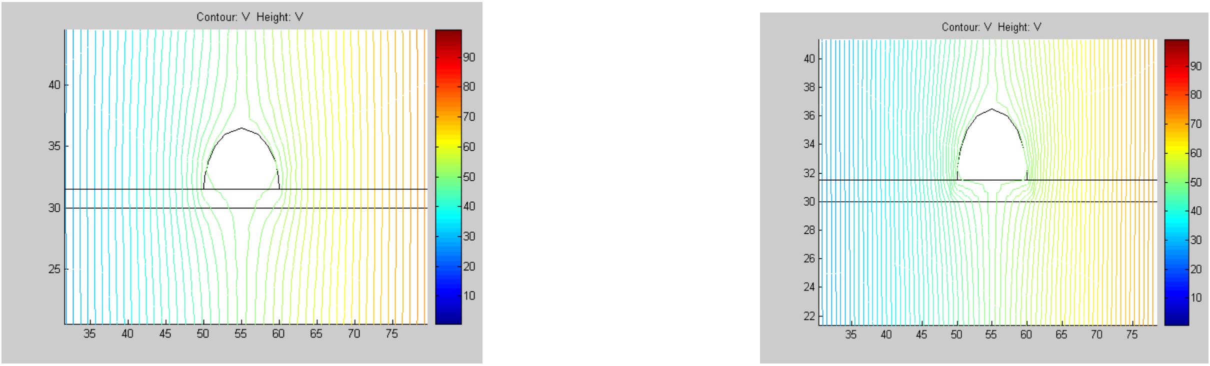
a) with 0.5 mm cement dust

a) with 0.5 mm plywood dust



b) with 1 mm cement dust

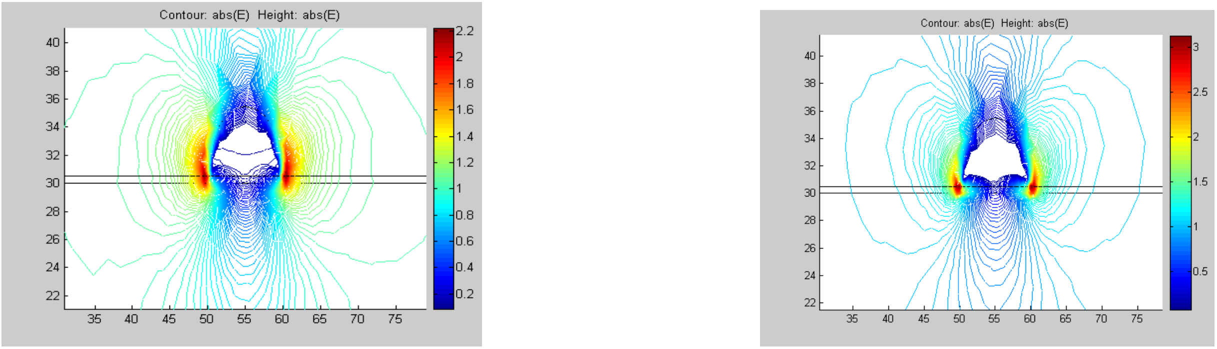
b) with 1 mm plywood dust



c) with 1.5 mm cement dust

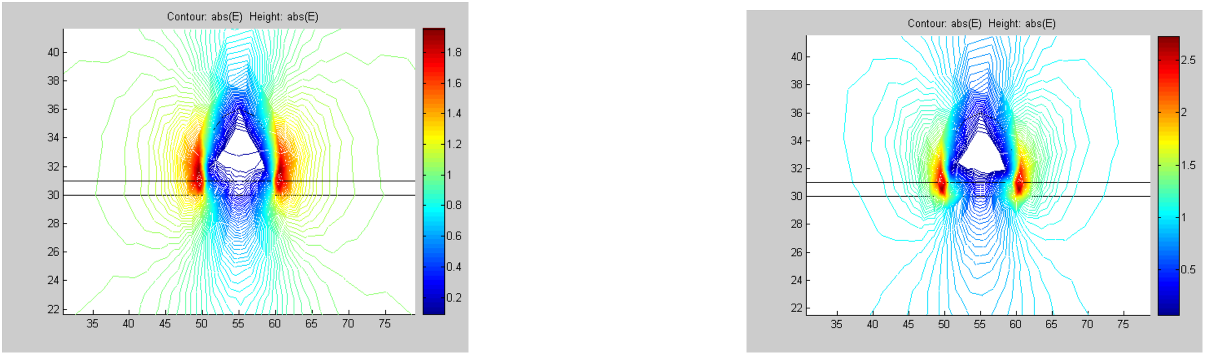
c) with 1.5 mm plywood dust

Fig. 10. Potential Distribution under contaminated condition.



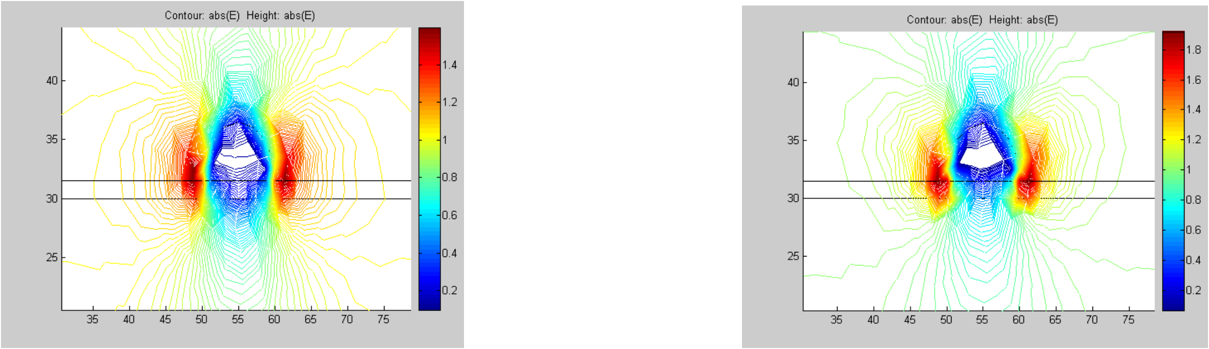
a) with 0.5 mm cement dust

a) with 0.5 mm plywood dust



b) with 1 mm cement dust

b) with 1 mm plywood dust



c) with 1.5 mm cement dust

c) with 1.5 mm plywood dust

Fig. 11. Electric Field Distribution under contaminated condition.

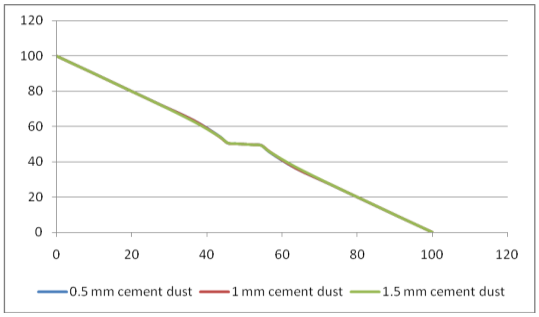


Fig. 12. Electric Potential comparision along cement dust surface.

Fig. 13. Electric Potential comparision along plywood dust surface.

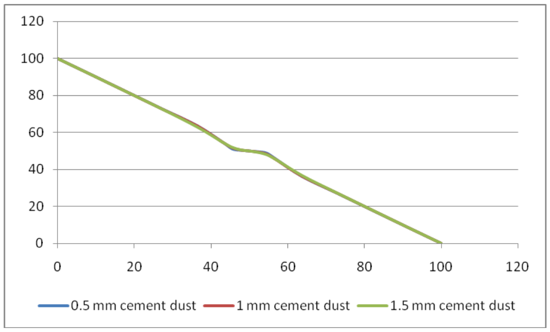


Fig. 14. Electric Potential comparision along SiR surface with cement dust.

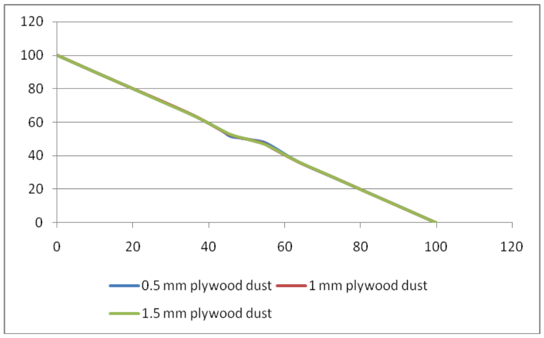


Fig. 15. Electric Potential comparision along SiR surface with plywood dust.

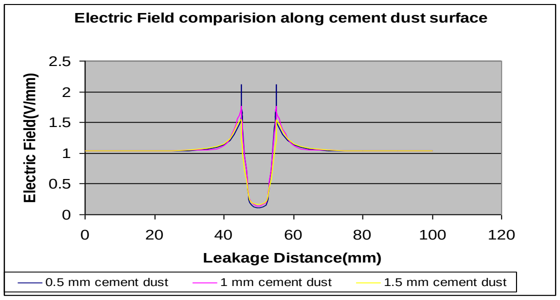


Fig. 16. E values along cement dust surface.

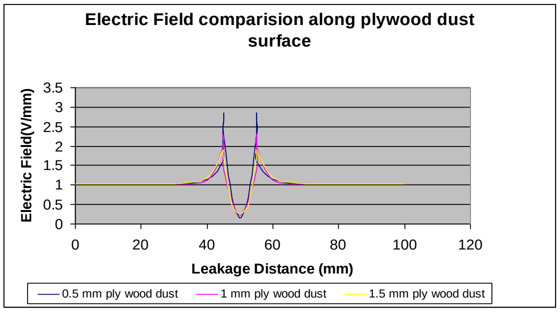


Fig. 17. E values along plywood dust surface.

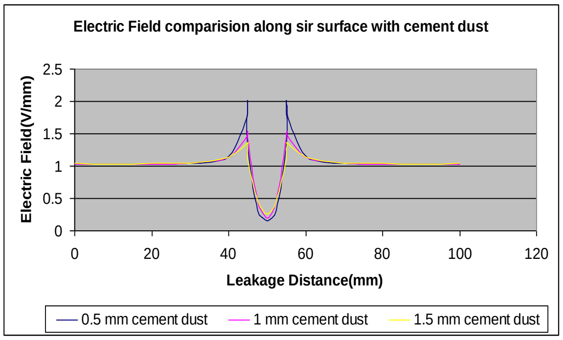


Fig. 18. E values along SIR surface with cement dust.

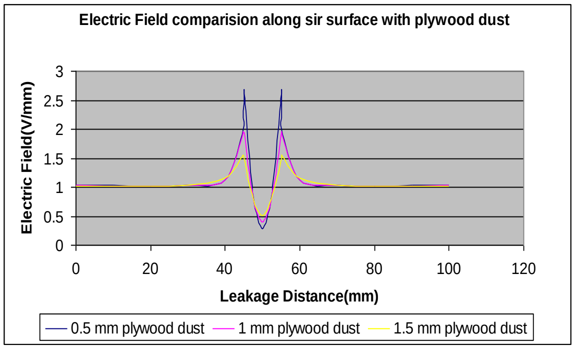


Fig. 19. E values along SIR surface with plywood dust.

5 CONCLUSION

In this paper, electric potential and field distributions on silicone rubber insulator surface with different thicknesses of dusts were investigated by FEM. As per the results, thickness of contaminants has no effect on potential distribution along insulator surface. However, for electric field distribution as the thickness of dust increases, the highest field stress point moves outward along insulator surface from interface point of the water droplet, air and silicon rubber material. The simulation results confirmed good electrical performance of silicone rubber insulator.

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