DESIGN OF POLYMER COMPOSITE BASED ELECTRICAL INSULATOR FOR INDUSTRIAL APPLICATIONS USING COMSOL MULTIPHYSICS

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Abstract: *The use of polymer composite insulators has grown in the recent past power generation, transmission and distribution. There are many materials which are being used in polymer composite insulator and several testing is needed. But, it is time consuming to test the material and requires lots of equipment. Even each and every insulator design has to undergo a series of test before using it in transmission and distribution lines. In order to reduce the cycle time of design work and the cost of prototype testing, technical software packages are used. Once the design was done, it can be tested under various parameters in the package itself and no direct inspection or testing is needed. Here, COMSOL-Multiphysics - technical package is used to model the insulators under several applied voltages and relative electrical stress. The package is used to analyze different shed placements for various profiles based on creepage distance. The insulators are designed according to the standard specifications which are simulated in AC/DC module workspace in the Multiphysics simulation software. The model is simulated to verify the electrical stress and electric field distribution (across sheds). From the results it is highly evident that the design enhances the electrical behavior and long term performance of the composite insulator. Thus, it reduces the cost of production and installation which are highly beneficial to the industries.*

Key words*: Silicone Rubber (SR), Fiber Reinforced plastics (FRP), COMSOL-Multiphysics, Ethylene Propylene Diene Monomer (EPDM), Ethylene Propylene Silicon (EPS), Electric field distribution*

1.0 Introduction

Polymeric insulators are also known as non-ceramic insulators or composite insulator. Two main materials have been used extensively as polymeric insulators are silicon rubber and Ethylene Propylene Diene Monomer (EPDM) [1]. Their Ethylene Propylene Silicon (EPS) combination is used to improve surface properties and material strength. A polymeric insulator is lighter weight since the insulator is made from fiber rod as the core and polymeric materials as the outer sheath [2]. The most important property is their hydrophobic surface which prevents the formation of continuous wet paths along its surface [3-6]. With this advantage, they can perform better in polluted condition. The insulating property of polymeric insulator can be improved by adding nano-fillers in its composition [7-10]. Depending upon the filler and the matrix material the relative permittivity, thermal conductivity, treeing, tracking, erosion, and breakdown voltages varies [11- 14].

Recent research on the polymeric insulator failure shows insulator aging and degrading are caused by high electric field on the high voltage terminals [15]. The electric fields around the polymeric insulator especially near the high voltage terminals plays a major role in the performance of insulator under various environmental conditions [16-21]. It can be optimized using various optimizing techniques [22-23]. The model with the standard specifications of high voltage polymer insulators can be simulate in a technical package COMSOL-Multiphysics [24]. The performance of insulators can be analysed in all type of environment [25-26].

The insulators selection for different voltage rating is depend on the minimum specific creepage distance and IEC 60815 standard requirements. The detailed structure of polymer insulator is shown in Figure.1

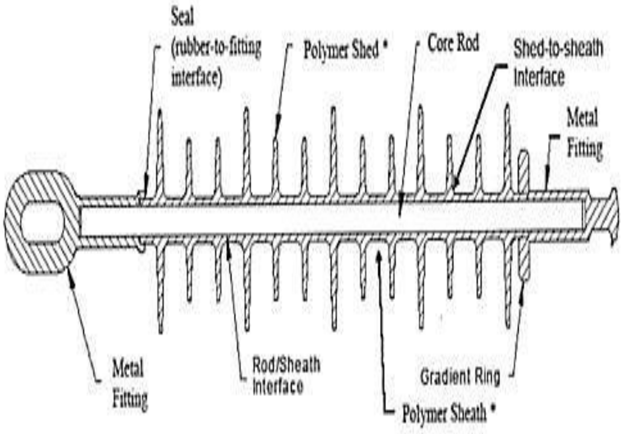

Figure 1: Polymeric insulator structure.

2.0 Problem Statement

Although polymeric insulators perform well in polluted conditions, it will degrade because of it chemical changes on its surface. Continuous contamination due to environment and chemical exposure will cause the contaminants to accumulate on the insulator surface. Although it hydrophobicity ability will cleans it surface during rain and wind flow, the formation of contaminants on the surface may become conductive when expose to moisture due to fog and dew. This will leads to conductive film formation on its surface. The conductive film and resulting leakage current will cause dry band arcing.

Dry bands arcing occur when the leakage current flowing on the insulator surface produces heat which causes the moisture conductive film to evaporate. Combination of potential gradients and high electric field will trigger electrical discharges on the surface. One of the causes of electric discharge on the insulator surface is due to the electric field distribution on the insulator surface which controls the current density. During wet condition, electric field around the insulator will be high due to discharge cause by high permittivity of the water contact with silicone. High electric field near the high voltage terminals will cause corona activity during dry condition.

3.0 Degradation of Polymeric Insulators Surfaces

Polymeric insulators can degrade faster compared to other insulators due to it compound chemical bond is subjected to chemical reaction. Beside insulator material and design, other factors that contribute to it degradation and ageing is electrical, mechanical and environmental stress.

3.1 Electrical Stress

The Electric Field Distribution is not uniform along high voltage insulator where the highest field regions are at the high voltage end terminals and core areas. Electric discharges in the form of corona, dry band arcing and flashover will occur due non-uniform and high fields on the insulator.

3.2 Wetting Discharge

The presence of water droplets during rain, fog and dew condition increases the electric field around the insulator. If the magnitude of the surface electric field strength exceeds a threshold value of 0.5-0.7 kVrms/mm, water droplet corona discharges may occur. These discharges usually occur between water droplets and degrade the polymer hydrophobicity material surface. The high temperature of this discharge also thermally degrades the insulator surface. As such, the surface corona discharges due to water droplets will accelerate the aging of the polymer material. This will cause the surface damage due to tracking and erosion and increase the possibility of flashover of the polymeric insulator.

3.3 Insulator Flashover:

Continuous corona, wetting and dry band discharge leads to thermal heating and cause further drying on the insulator surface. Under favorable condition, flashover may occur when the electrical discharge elongated over many dry bands on insulator.

4.0 Field Optimization Techniques

Electric field distributions in polymeric insulators are usually highest at high voltage terminal ends. Continuous corona and surface discharge process on the insulator contribute to premature degradation. As such, various techniques can be used to minimize the degradation factor

4.1 Weather Shed Insulation Profile

The electric field on polymeric insulator depends on the insulator geometry which results in different capacitance for different shape. The electric field at the region near energize end is the highest, it is important to control the electric field at this region. Polymeric housing with large arc radius can reduce the electric field by redistribute equipotential lines over a wider surface area. If the radius is sufficiently large, the arcs between two sheds will merge to form a rounded surface on the shank regions. The stress is reduces when increasing the insulator axial length, shed and arc radius. However, the increase core radius causes slight improvement on the insulator surface.

5.0 Designing Process

The method to investigate electric field along the creepage path along the polymeric is shown. The purpose is to locate the highest field region and from the result, electric field optimization techniques are applied to minimize the electric field, and hence, improve the polymeric insulator reliability. There are two methods can be used to determine the electric field distribution,

- Experimental measurements
- Numerical computations

For this paper, numerical computation using Finite Elements Method is used to investigate the electric field distribution. Advance in computing technology has enabled various numerical computational simulations to solve various engineering problems. For any problem investigation, it is important to identify the process that involved in obtaining desired result. Figure 2 shows simulation process during the electric field study.

6.0 Finite Element Method

Finite element method (FEM) is a numerical method to solve various partial differential equations (PDE) that represents a physical system. It discretizes the entire domain problem to a number of smaller non-overlapping subdivisions called domain. FEM is suitable for small domain problems with limited and closed boundary conditions and less effective for solving large problem with open boundary condition. In this paper, COMSOL Multiphysics is used to simulate the finite elements for the insulator.

7.0 Insulator Model

In this paper, a standard 11 kV polymeric outdoor insulator as shown in Figure 3 is used as model for electric field investigation [25]. The insulator is simulate under dry-clean and uniform wet conditions for electric field investigation.

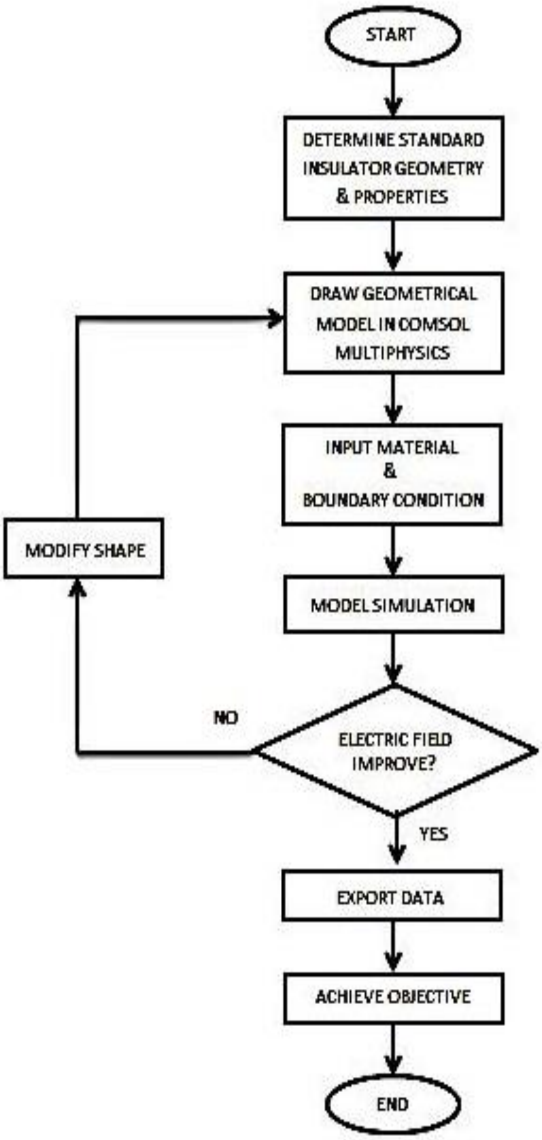

Figure 2: Process flow for electric field optimization

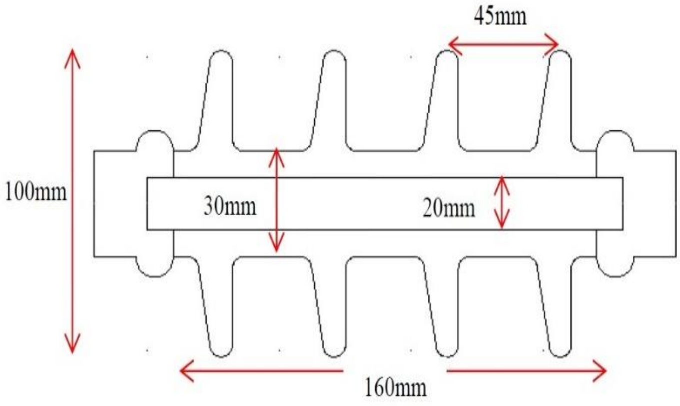

Figure 3: Line Diagram

7.1 Modeling Simulation

The polymeric insulator model as shown in Figure 3 was created by using CAD drawing tools available in the COMSOL Multiphysics. Since the insulator geometry is cylindrical shape, the modeling is simplified into a two-dimensional (2D) problem. The simplification made the simulation faster without affecting the simulation result accuracy. Figure 4 and Figure 5 shows the model of two different designs of sheds using 2D asymmetric geometry.

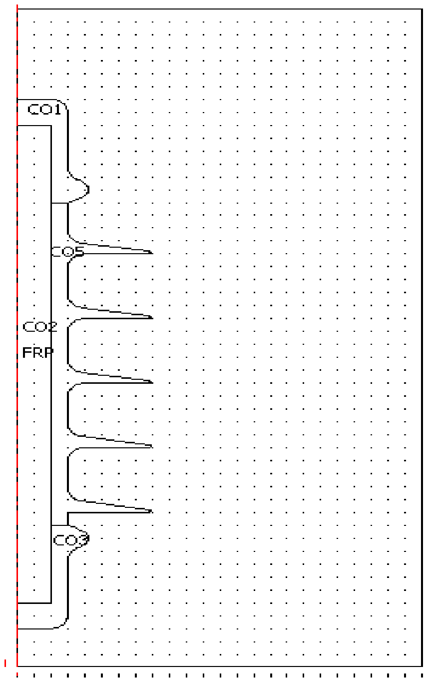

Figure 4: Design-1

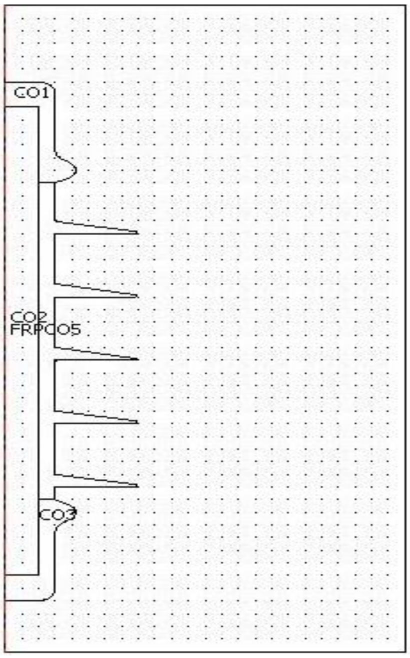

Figure 5: Design-2

7.2 Material Properties

In finite elements methods, each component material properties and boundary need to be assigned for mathematical calculation. The components materials are available in standard material library where each material property can be changed according to required specification.

Table 1: Material properties in this simulation

Materials	Relative Permittivity, ε_r	Conductivity, σ (S/m)
Forged steel	1.0	5.9×10^{-7}
FRP core	7.1	1.0×10^{-13}
Silicone Rubber	4.3	1.0×10^{-13}
Air Background	1.0	1.0×10^{-14}

The HV and ground terminal are from forged steel with conductivity, σ = 5.99x107 S/m. The FRP core and silicon rubber housing has low conductivity, σ = 1.0x10-13 S/m. The air surrounding insulator was specified with a very low conductivity, σ = 1.0x10-14 S/m.

7.3 Boundary Conditions

In this paper simulation, the HV terminal is set at 11 kV, while the ground terminal is 0 V. The air is made large enough to minimize it effect on electric field distribution along the insulator and both terminals. The insulating part is termed as continuity.

7.4 Meshing

After completing all the material properties and boundary conditions, the entire domain problem was discretized into non-overlapping triangle elements during meshing process. The mesh of the design-1 is shown in Figure 6. The mesh of the design-2 is shown in Figure 7. For better accuracy on the interest region, the meshing refinement can be done by selecting proper meshing size. The smaller the meshing size, higher will be the accuracy.

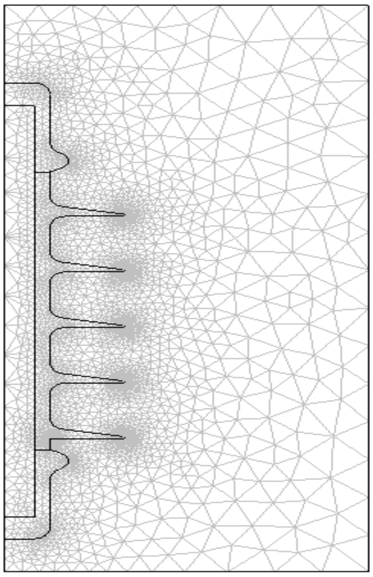

Figure 6: Free triangle mesh of design-1.

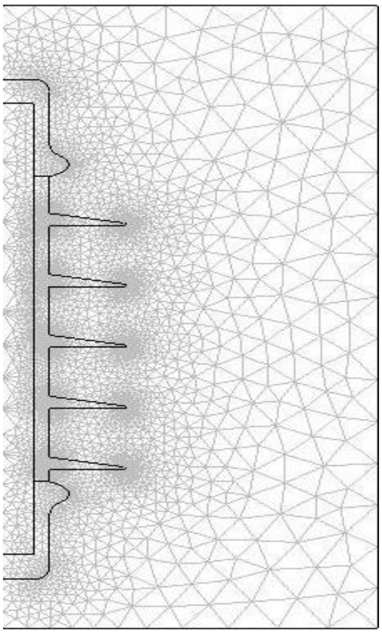

Figure 7: Free triangle mesh of design-2.

8.0 3D- Model of Insulators

A 2-D model designed using COMSOL can be easily converted into a 3-D model. The 3-D model of the design-1 is shown in the figure 8. The 3-D model of the design-2 is shown in the figure 9.

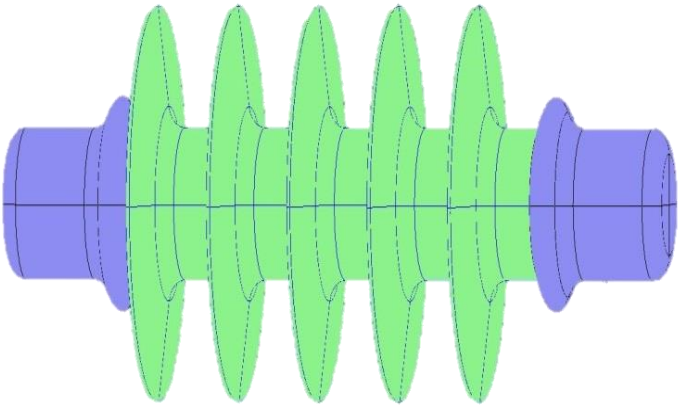

Figure 8: 3-D of design-1.

Tangential Electric Field (v/m) $*10^5$	Design-1	Design-2
High voltage End	0.43	1.3
Low voltage End	0.32	1.15

Table 2: Comparison of tangential electric field

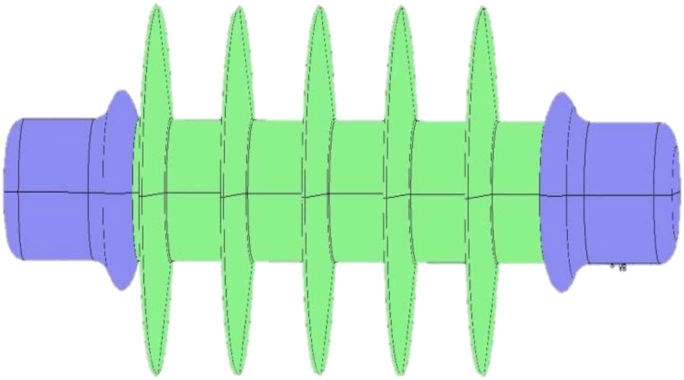

Figure 9:3-D of design-2.

9.0 Equipotential distribution

Equipotential lines are a quantitative way of viewing electric field potential in two dimensions. The contour distance between the equipotential lines represent the electric potential distribution.

The two insulator models were simulated by using AC/DC quasi-static electric current solver. Figure 10 shows the equipotential lines around the design-1. Figure 11 shows the equipotential lines around the design-2.

To analyze the voltage potentials along the leakage path, the leakage distances are measured along the polymeric insulator, starting from the ground terminal and moving up to the high voltage terminal. The voltage increase along the leakage path as the leakage path near the energize ends. The tangential electric field distribution of the two different designs of insulator shows that the insulator with design 2 reduces the electric stress and shows better performance.

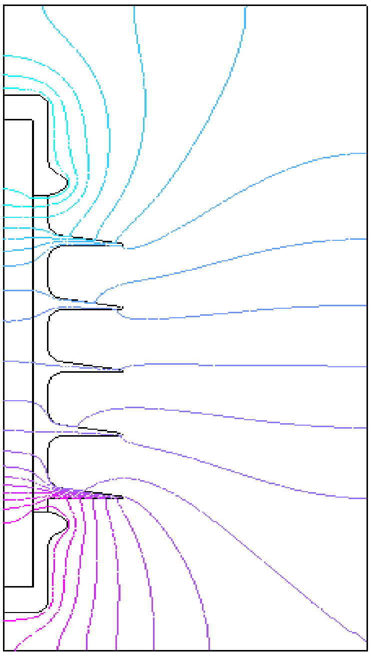

Figure 10: Equipotential lines around polymeric insulator design-1.

The graphical representations of the equipotential line for the two different designs are taken. Figure 12 and 13 shows the equipotential distribution of insulator design 1 and 2.

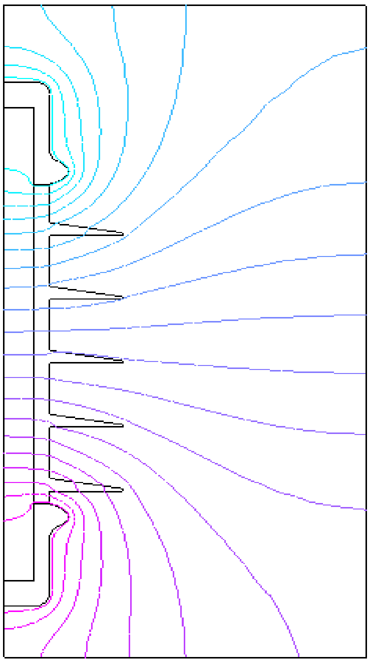

Figure 11: Equipotential lines around polymeric insulator design-2.

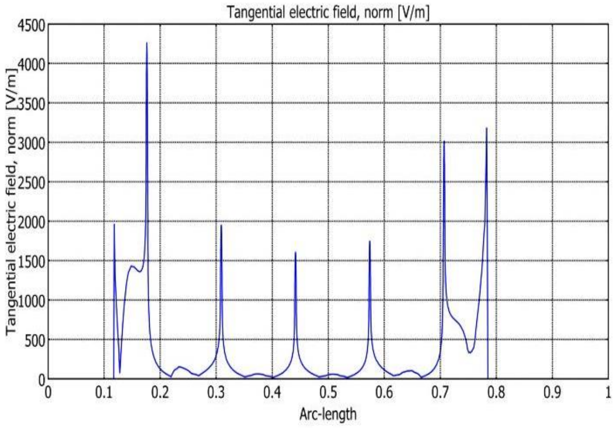

Figure 12: Equipotential distribution of insulator design-1

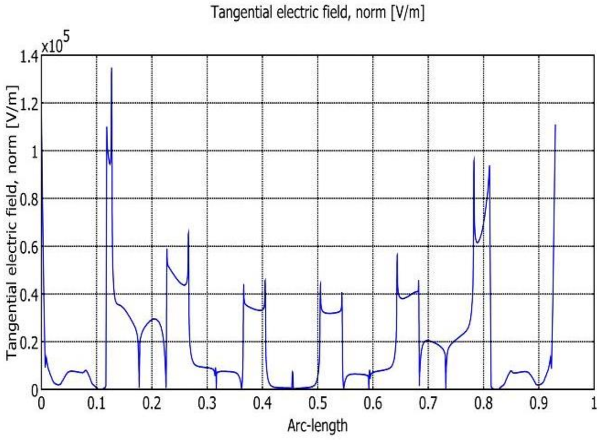

Figure 13: Equipotential distribution of insulator design-2

The electric field difference between the high voltage end and the low voltage end must be minimum or zero for a high efficient insulator model. From table 2 the electric field difference between the two end is minimum for design 2 than design 1.

10.0 Conclusion

From the electric field computations in the polymer insulators, it is to be found that the electrical stress is high near the energized end due to the higher magnitudes. In this paper the electric field influences discharge activity near the end fittings. While comparing the performance of two different designs (design-1, design-2) shows better result and the electric field magnitudes near the end fittings is reduced. Thus from the content in the table 2 it clearly that, the design-2 has less electrical stress when compared to design-1. Thus the design-2 shows better results. Furthermore, to enhance the electrical behaviour and long term performance of the polymer composite insulator we can use Nano-fillers to reduce the electrical stress near the end fittings.

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