Evaluation & comparison of non-uniformity of EF and Heat generated in Straight and Alternate shed insulators

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***Abstract* — Transmission line insulators are used to support the High Voltage (HV) current carrying conductors. Silicone Rubber (SiR) is an alternative material to that of porcelain and glass regarding to HV insulators and it has been used by power companies since 1980's owing to their superior performances. Outdoor insulator failure involves the solid air interface insulation. So, the knowledge of the Electric Field (EF) distribution is very important to determine the EF stress occurring on the surface of the insulator. The degree of uniformity (η) is a measure of field uniformity and it enables one to make a comparison of the uniformity of fields formed between two electrodes. The heat generated in surface of insulator plays a major role in the formation of dry bands over the surface of insulator and therefore will lead to partial arcing and surface degradation of the polymeric insulator. When the arcing continues and elongates, it will result in flashover. In this paper the degree of uniformity & heat generated in the surface of insulator are calculated and simulation is carried out on EF distribution of SiR insulator using finite element method (FEM). The effect of various contaminations on the surface of insulator is also included in simulation. The finding from this shows that under polluted conditions the non-uniformity is higher when compared with clean and dry conditions. This confirms that the EF distribution of polymeric insulator is highly non-linear at wet and polluted conditions. Also, degree of non-uniformity and heat generated in case of straight shed insulator are higher compared to alternate shed insulator. Therefore under polluted conditions alternate shed insulators are to be used compared to that of straight shed insulators.**

I. INTRODUCTION

Power line insulators are used to support current carrying conductors at towers or poles. SiR is an alternative material to that of ceramic insulators regarding to HV insulators and it has been used by power companies since 1980's owing to their superior performances. SiR insulator failure involves the solid air interface insulation. The knowledge of the EF distribution is very important to determine the EF stress occurring on the insulator surface. There are several methods for solving partial differential equations to determine EF.

The methods used for solving partial differential equations are Finite Difference Method, Finite Element Method, Boundary Element Method and Charge Simulation Method. In contrast to other methods, the Finite Element Method (FEM) takes into account 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.

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.

II. METHOD USED FOR SIMULATION

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 non-physical 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.

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.

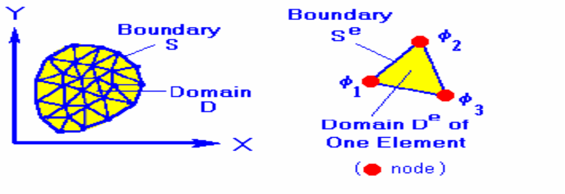


Fig. 1 Typical discretized domain and typical triangular element.

A. *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 nodes connected by lines. Some solid and shell elements are illustrated in Fig. 2 below.

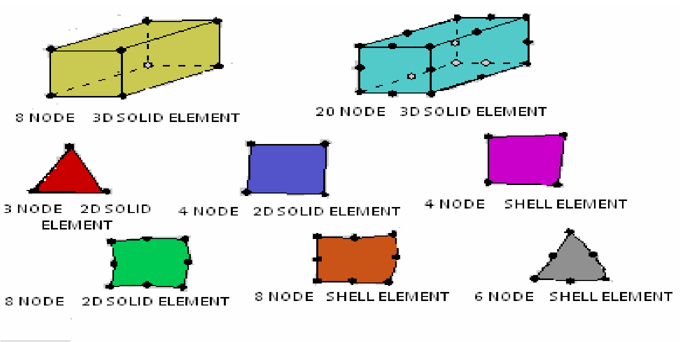


Fig. 2 A variety of finite elements

III. 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. They are 1) Light weight 2) High mechanical strength 3) Good electrical performance 4) Excellent Hydrophobicity 5) Small volume & 6) Excellent contamination flashover resistant.

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.

Structure of SiR Insulator is shown in Fig. 3. The basic design of a SiR insulator is as follows; fiber reinforced plastic (FRP) core, attached with two metal fittings, is used as the load bearing structure. The presence of dirt and moisture in combination with electrical stress results in the occurrence of local discharges causing the material deterioration such as tracking and erosion. In order to protect the FRP core from various environmental stresses, such as ultraviolet, acid, ozone etc., and to provide a leakage distance within a limited insulator length under contaminated and wet conditions, weather sheds are installed outside the FRP core. Silicone rubber is mainly used for polymer insulators or composite insulators as housing material.

To visualize the effect of various contaminations along silicon rubber insulator surface cement dust, plywood dust, etc. are placed along insulator surface. A fiber reinforced plastic (FRP) core attached with two metal fittings, is used as the load bearing structure. Weather sheds made of HTV silicone rubber having relative dielectric constant of 4.3 are installed outside the FRP core. Surrounding of the insulator is air having relative dielectric constant 1.0. A 15 kV voltage source directly applies to the one electrode while the other electrode connected to ground.

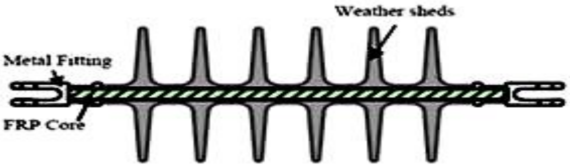


Fig. 3 Structure of SiR Insulator

IV. SIMULATION RESULTS

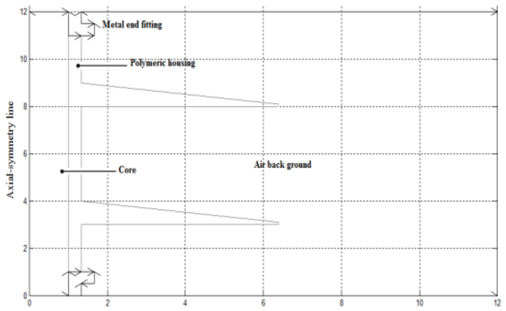
The computer simulation based on the finite element method is used to compute electric field distributions along the creepage path of weather sheds housing. The insulator model is developed and simulated under various contaminated conditions with simplifying assumptions of a uniform pollution layer. It should be emphasised that, under normal conditions, polymeric insulators would rarely be subjected to a uniform wetted surface situation, due to their excellent hydrophobic surface properties when new or undegraded. Nevertheless, the simulation results help to identify the high field region that is vulnerable to dry band formations on the insulators.

The insulators that were considered in this investigation are shown in Fig. 4 (a) & (b).

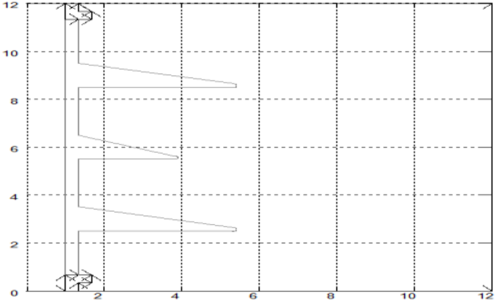
(a) Straight shed (b) Alternate shed

Fig. 4 polymeric insulators under consideration

The models of the polymeric insulators were created using partial differential equation tool available in the MATLAB. Since the insulator structure is cylindrical in shape, the modelling can be simplified into a two-dimensional (2D) problem instead of a full three-dimensional (3D) model. This simplification can save considerable memory and processing time without affecting the accuracy of the simulation results.



(a) Straight shed insulator



(b) Alternate shed insulator

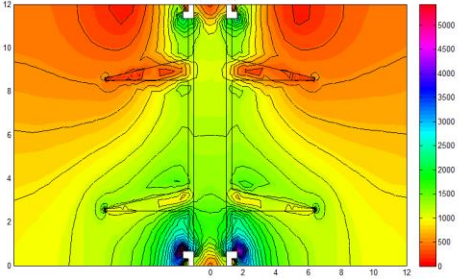
Fig. 5 2D axis-symmetric insulator models

In this paper, insulators made with silicone rubber polymeric materials were considered for simulation. Geometrical parameters of the straight and alternate shed type polymeric insulators used in the simulation study are shown in Table 1. The partial differential equation tool available in MATLAB based on FEM is employed for the modeling insulators. Fig. 5 shows the FEM model of polymeric insulators used in the study. This paper investigates the electric field distribution of the11kV straight and alternate shed type polymeric insulators under different surface conditions such as i) Dry & clean condition ii) Insulators with water drops on their surfaces iii) Insulators with cement dust on their surface iv) Insulators with ply wood dust on their surface v) Insulators with cement dust and water drops on their surface vi) Insulators with ply wood dust and water drops on their surface.

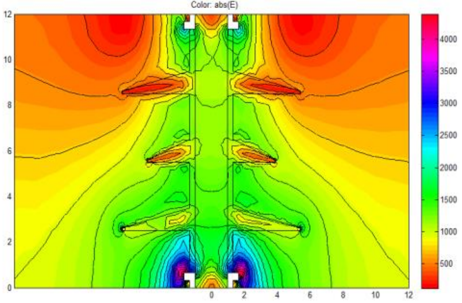
Table 1 Geometrical Parameters of Polymeric Insulators

Type of insulator	**Straight shed**	**Alternate shed**
Total length	106.8mm	116.8mm
Disc diameter	128mm	78 mm & 108.4 mm
No.of Discs	2	3
Creepage distances	290mm	320mm

Fig. 6 shows the electric field distributions of straight shed & alternate shed silicone rubber insulators under clean surface condition.



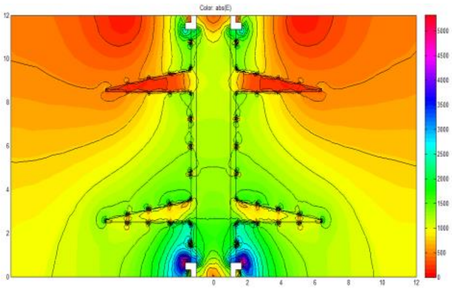
(a) Straight shed insulator



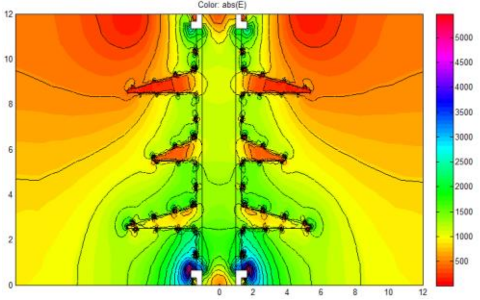
(b) Alternate shed insulator

Fig. 6 Simulation results of Straight & Alternate shed Silicone Rubber Insulators under Clean Surface Condition

In straight & alternate shed SiR insulators, situation of contamination is simulated by placing various contaminations on their surfaces. Fig. 7 shows the electric field (EF) distributions of silicone rubber insulators under various contaminated surface conditions. It is observed that the electric field distribution of the polluted insulators are significantly distorted over the insulator surface from line end to ground end due to the presence of the pollution layer. In addition, the maximum electric field stress is noticed near high voltage end, when compared with other portions of insulator.

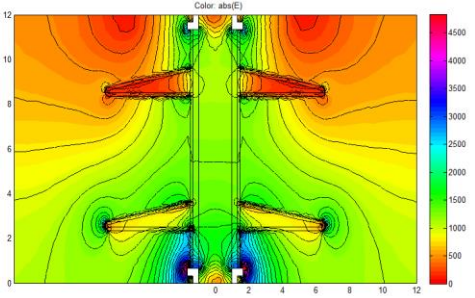


(a) Straight shed insulator

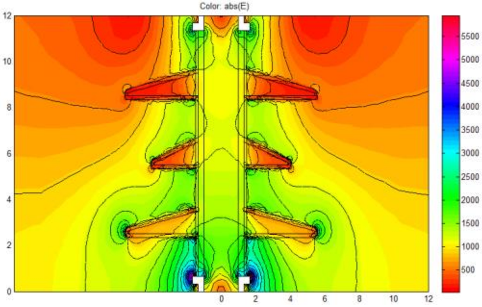


(b) Alternate shed insulator

i) EF distribution with water drops.

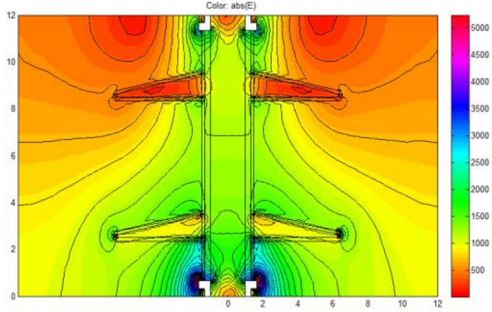


(a) Straight shed insulator

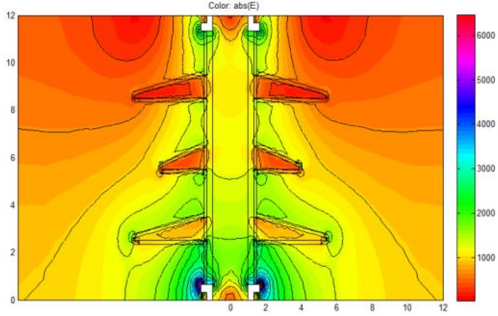


(b) Alternate shed insulator

ii) EF distribution with cement dust.

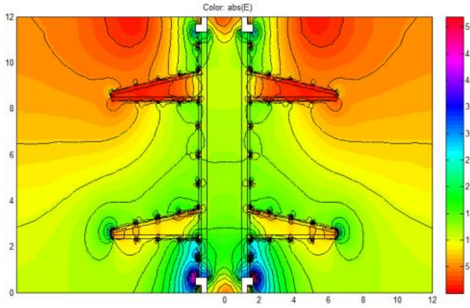


(a) Straight shed insulator

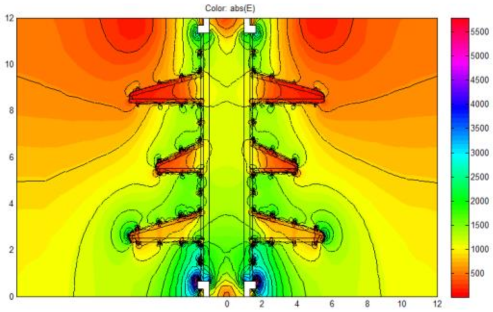


(b) Alternate shed insulator

iii) EF distribution with plywood dust

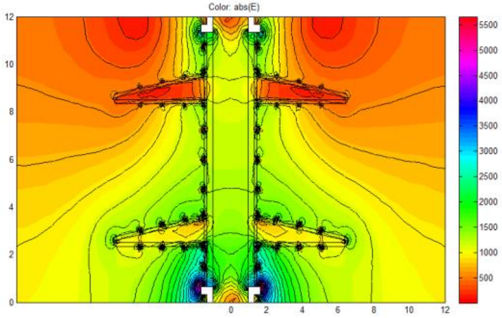


(a) Straight shed insulator

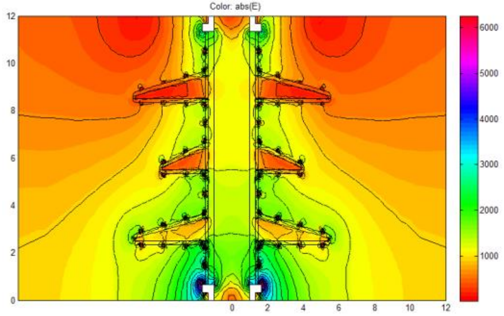


(b) Alternate shed insulator

iv) EF distribution with cement dust and water drops



(a) Straight shed insulator



(b) Alternate shed insulator

v) EF distribution with plywood dust and water drops

Fig. 7 Simulation results of Straight & Alternate shed Silicone Rubber Insulators under Polluted Conditions

Table 2 shows maximum electric fields occurring on straight and alternate shed insulators under various polluted conditions. Under clean condition maximum electric field occurring on straight shed insulator is 10% higher than alternate shed insulator. With cement dust on surface of insulators maximum electric field occurring on straight shed insulator is 11% higher than alternate shed insulator. With water drops on surfaces maximum electric field occurring on straight shed insulator is 13.8% higher than alternate shed insulator. Under cement dust and water drops condition maximum electric field occurring on straight shed insulator is 15.6% higher than alternate shed insulator. With plywood dust on surface of insulators maximum electric field occurring on straight shed insulator is 17.75% higher than alternate shed insulator. Under plywood dust and water drops condition maximum electric field occurring on straight shed insulator is 23.37% higher than alternate shed insulator.

Table 2 The Maximum E-fields (MEFS) on insulator surface under different conditions

Insulator under various Conditions	**Maximum E-Field (kV/cm)**	
	on Straight shed insulator	**on Alternate shed insulator**
Dry and clean condition	3.486	3.182
Insulator with cement dust on its surface	3.757	3.383
Insulator with water drops on its surface	4.095	3.598
Insulator with cement dust and water drops on its surface	4.632	4.007
Insulator with plywood dust on its surface	5.016	4.26
Insulator with plywood dust and water drops on its surface	5.521	4.475

V. EVALUATION OF THE DEGREE OF NON-UNIFORMITY

The degree of uniformity (η) is a measure of uniformity of a field and it is defined as,

$$\eta = \frac{V}{d * E_{\max}}$$

Where E_{max}= Maximum electric field strength and V= Applied voltage

Thus η , dimensionless quantity enables one to make a comparison of the uniformity of fields formed between two electrodes. The degree of non-uniformity (1-η)of the electric field is evaluated at different surface conditions of polymeric insulators and it is reported in Table 3. It is observed that under polluted conditions the non-uniformity is high when compared with clean and dry conditions. This confirms that the electric field in polymeric insulator is highly non-linear at wet and polluted conditions. Also degree of non-uniformity is higher in straight shed insulator compared to alternate shed insulator.

Table 3 The Degree of Non-Uniformity

Insulator under various Conditions	**The Degree of Non-Uniformity of EF on**	
	Straight shed insulator	**Alternate shed insulator**
Dry and clean condition	0.71	0.7
Insulator with cement dust on its surface	0.73	0.72
Insulator with water drops on its surface	0.75	0.73
Insulator with cement dust and water drops on its surface	0.78	0.76
Insulator with plywood dust on its surface	0.8	0.77
Insulator with plywood dust and water drops on its surface	0.82	0.79

VI. EVALUATION OF THE HEAT GENERATED IN THE SURFACE OF INSULATOR

Under clean and dry surface conditions the possibility for surface heat generation is very less. Whereas, under various polluted conditions considerable amount of heat generation observed on the insulator surface. This heat generated plays a major role in the formation of dry bands over the insulator surface and therefore will lead to partial arcing and surface degradation of the polymeric insulator. When the arcing continues and elongates, it will result in flashover.

Therefore it becomes necessary to understand the amount of heat generated in polymeric insulators in order to improve its thermal resistance during manufacturing process. The heat generated by the A.C is given by,

$$W_{ac} = \frac{E^2 f \varepsilon_r \tan\delta}{1.8 * 10^{12}}$$

Where E = E_{max} and f = 50 Hz. Using the above formula, the heat generated in the surface of the insulator was evaluated and presented in Table 4. It is observed that more heat is generated on the surface of straight shaed insulator compared to alternate shed insulator. Therefore the possibility of surface degradation of straight shed insulator is more when compared with alternate shed insulator.

Table 4 Heat generated in polymeric insulator

Insulator under various Conditions	**Heat Generated W_{ac} (mW/cm^3)**	
	in Straight shed insulator	**in Alternate shed insulator**
Dry and clean condition	0.00822	0.0056
Insulator with cement dust on its surface	0.00892	0.0062
Insulator with water drops on its surface	0.00978	0.0070
Insulator with cement dust and water drops on its surface	0.0109	0.0079
Insulator with plywood dust on its surface	0.0126	0.0093
Insulator with plywood dust and water drops on its surface	0.0138	0.0103

VII. CONCLUSION

The degree of non-uniformity around insulator surface and heat generated in insulators has been analyzed in this paper. This analysis showed that the presence of pollution layer on the surface of polymeric insulator significantly altered the electric field distribution along the length of the insulator. Under uniformly polluted conditions without any dry band formation, higher electric field stress is observed near high voltage end also at the small radius of curvature of the weather sheds. The heat generated on the insulator surface is evaluated and it indicates that the possibility of surface degradation of the polymeric material nearer to high voltage end is high when compared with other sections of the insulator. It is observed that under polluted conditions the non-uniformity is high when compared with clean and dry conditions. This confirms that the electric field in polymeric insulator is highly non-linear at wet and polluted conditions. Also non-uniformity is more in straight shed insulator compared to alternate shed insulator. Therefore under polluted conditions alternate shed insulators are to be used compared to straight shed insulators.

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