Simulation and Experimental Analysis of Straight and Alternate shed insulators

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***Abstract* — Electrical insulators are used to provide support to the electrical conductors at towers or poles and also to separate them electrically. SiR (Silicone Rubber) is an alternative material to that of ceramic materials such as porcelain & glass and it has been used by many companies owing to their superior performance. The knowledge of the EF (Electric Field) around high voltage insulators is important to determine the EF stress occurring on the insulator surface. The degree of uniformity (η) is used to compare the uniformity of field formed between electrodes. The electric field stresses on insulator plays an important role in the formation of dry bands and which will lead to partial arcing and degradation of the polymeric insulator surface. When the arcing continues and elongates along insulator, it will result in flashover. In this paper the degree of uniformity of field is calculated and simulation is carried out on EF around SiR insulator using MATLAB. As a complement to the simulation work, experimental work is also carried out on practical insulator to visually examine the electrical stress occuring on the surface of polymeric surface.The effect of various contaminants on insulator surfaces are included in simulation and experimental works. The finding from this shows that under polluted conditions the uniformity is lower when compared with clean condition. This confirms that the EF distribution of SiR insulator is non-linear under contamination conditions. Also, degree of uniformity in case of straight shed insulator is lower compared to alternate shed insulator. Therefore under polluted conditions alternate shed insulators are to be used compared to straight shed insulators.**

I. Introduction

SiR insulators are used to support line conductors at towers/poles and also to separate them from each other. SiR is an alternative material to that of ceramic insulators and it has been used by many companies since 1980's owing to their superior performances. Failure of SiR insulator involves the interface of solid and air insulation. The EF around insulator is very important to determine the EF stress occurring on the insulator surface.

The various methods used for solving PDE's (partial differential equations) are differential equation methods(Finite Difference Method & Finite Element Methods) and integral equation methods (Boundary Element Method & Charge Simulation Methods). Out of all methods available, the FEM (Finite Element Method) 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 methods have been recognized as accurate methods of electric field computation. Precursors to the FEM are Finite Difference and Integral Equation methods. Although all these methods have been used and continue to be used either directly or in combination with others for design, FEM has emerged as appropriate techniques for many applications.

II. Technique Used for Simulation

The FEM is a numerical technique used by mathematicians, engineers & scientists to obtain solutions to the differential equations that approximately describe a 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 technique states that any irregular or regular domain can be divided into a number of regions of smaller size in which the partial differential equations are solved. By assembling and solving the set of equations of all sub domains, the behavior over the entire domain can be obtained.

The discretized region comprised of triangular elements is shown in Fig. 1. In this example each node has one degree of freedom as shown.

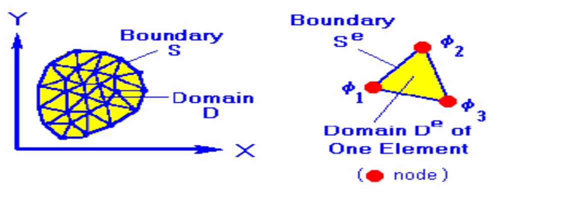


Fig. 1 Typical discretized domain and triangular element.

A. *Elements used for discretization*

A number types of elements used in one dimension (D), 2D & 3D are well established and documented. It is up to the analyst to determine which element is suitable for the problem under consideration and also the density of elements required in approximating the solution. In general, it is a geometrical shape (usually in solid color in modern programs) bounded by a number of nodes interconnected by lines. Some of them are shown in Fig. 2.

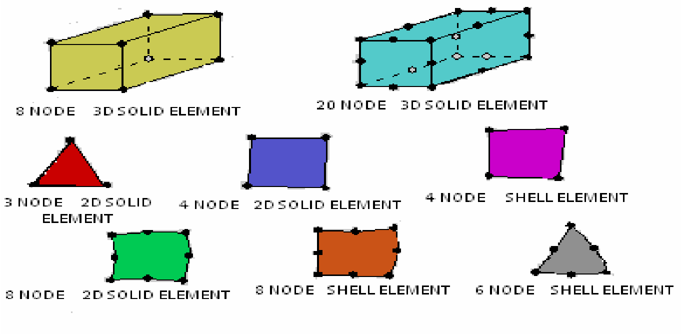


Fig. 2 Finite elements used

III. Composite Insulator

Silicon rubber insulators did not come out until 1970's and the first country developing and using SiR insulators is Germany. Compared to conventional insulators, composite insulators such as SiR insulators offer many advantages in their applications. They are 1) Light weight 2) high strength to weight ratio 3) Excellent tracking resistance avoids erosion 4) Excellent hydro phobicity 5) Easy handling & 6) Excellent contamination flashover resistant.

So it is very advantageous to use SiR Insulator. In order to analyze the characteristics, SiR insulator is modelled and simulated under different conditions.

Structure of SiR insulator is shown in Fig. 3. The SiR insulator consists of fiber reinforced plastic core and two metal end fittings. The presence of dust and moisture in combination with electrical stress results in the occurrence of electrical discharges causing deterioration of material such as tracking and erosion. In order to protect the fiber reinforced plastic core from various stresses, such as ultraviolet, acid, ozone etc., and to provide a leakage distance within a limited length of insulator under various conditions, weather sheds are installed outside the FRP core. SiR is mainly used for composite insulators as housing material.

To visualize the effect of various contaminations on silicon rubber insulator surface various dusts are placed along its 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 over 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 is at ground potential.

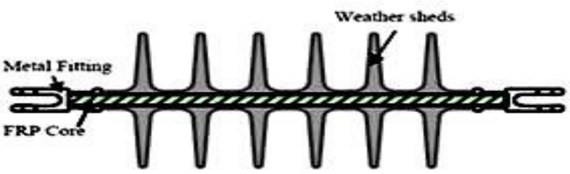
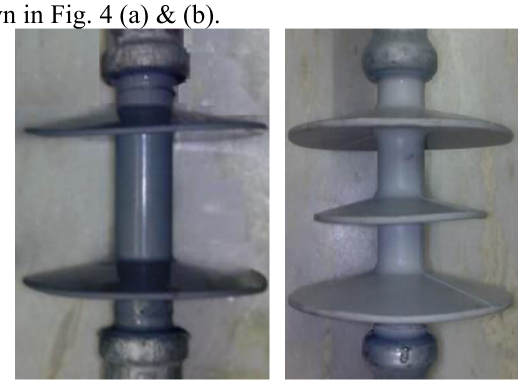


Fig. 3 SiR Insulator

IV. Simulation Results

The simulation based on the FEM is used to compute electric field along the creepage path of SiR insulators. The insulator structure is developed and simulated under various polluted conditions with assumption of a uniform pollution layer. 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.

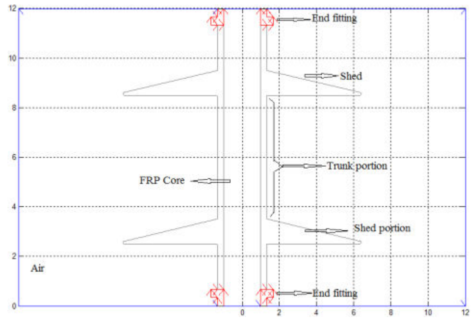
The insulators that were considered in this investigation are shown in Fig. 4 (a) & (b).



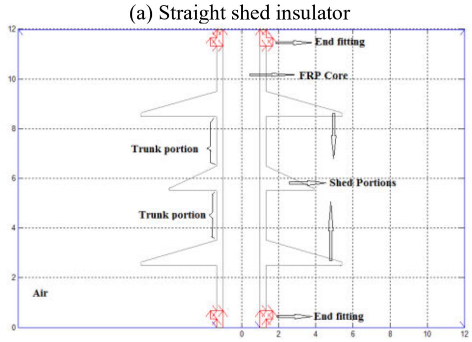
(a) Straight shed (b) Alternate shed

Fig. 4 polymeric insulators

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



(a) Straight shed insulator



(b) Alternate shed insulator

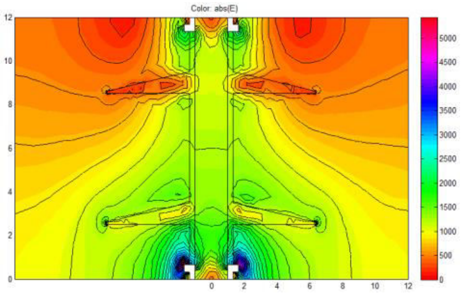
Fig. 5 2D insulator models

In this paper, insulators made with SiR composite materials were considered for simulation. Geometrical parameters of the straight shed and alternate shed polymeric insulators used in the simulation study are shown in Table 1. The PDE tool available in MATLAB based on FEM is employed for the modeling insulators. Fig. 5 shows the 2D FEM models of composite insulators used in the study. This paper investigates the electric field distribution of the11kV straight and alternate shed type composite insulators under different surface conditions such as i) 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.

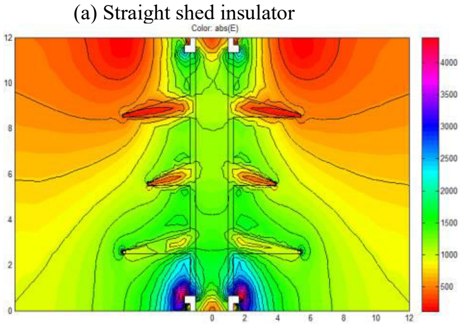
Table 1 Geometrical Parameters of Polymeric Insulators

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.



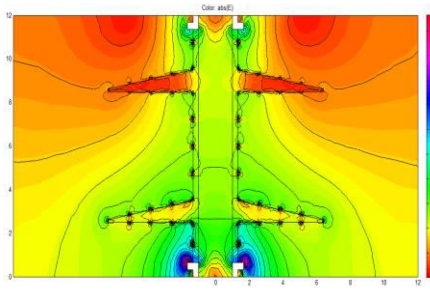
(a) Straight shed insulator



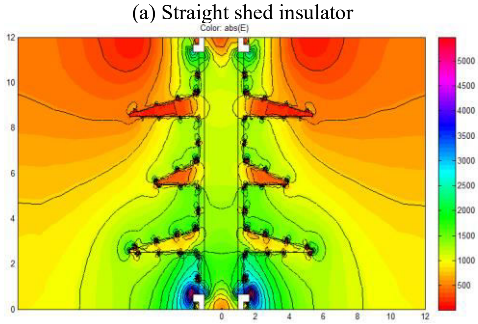
(b) Alternate shed insulator

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.

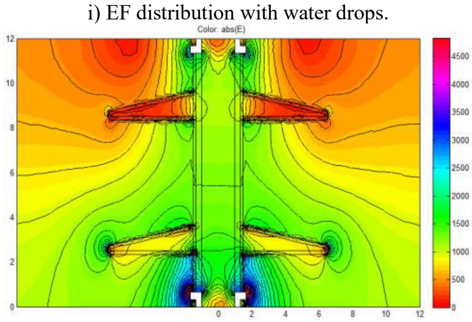


(a) Straight shed insulator

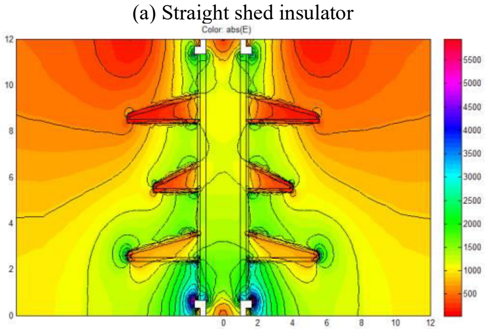


(b) Alternate shed insulator

i) EF distribution with water drops.

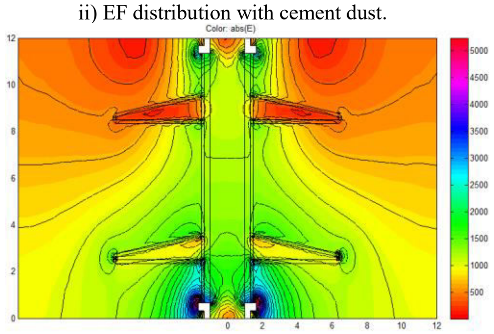


(a) Straight shed insulator

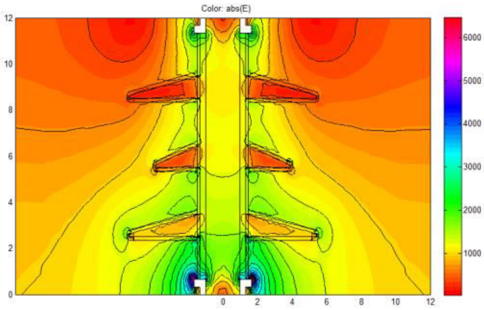


(b) Alternate shed insulator

ii) EF distribution with cement dust.

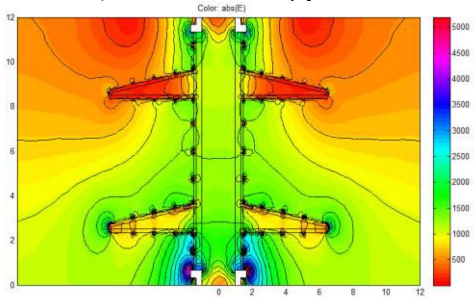


(a) Straight shed insulator

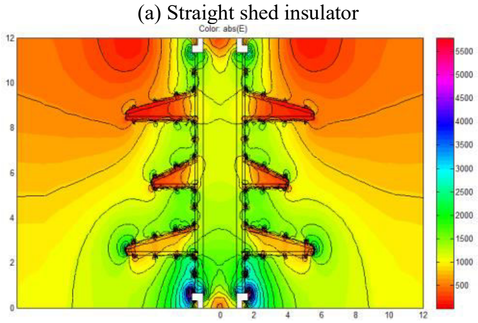


(b) Alternate shed insulator

iii) EF distribution with plywood dust

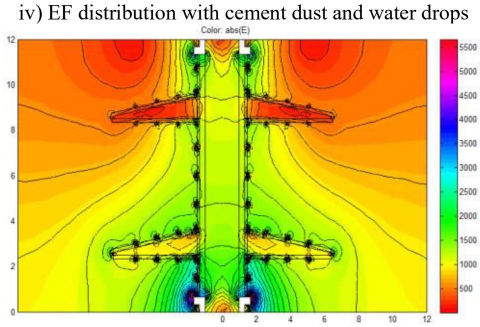


(a) Straight shed insulator

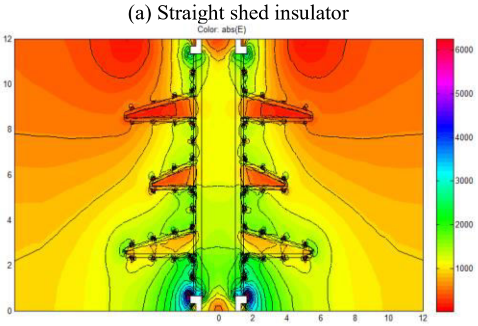


(b) Alternate shed insulator

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 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

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.

V. Evaluation of the Degree of 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 uniformity (η) of the electric field is evaluated at different contamination conditions of composite insulators and it is reported in Table 3. It is observed that under contamination conditions the uniformity is low when compared with clean conditions. This confirms that the electric field in composite insulator is non-linear under various polluted conditions. Also degree of uniformity is lower in straight shed insulator compared to alternate shed insulator.

Table 3 The Degree of Uniformity

Insulator under various Conditions	The Degree of Uniformity of EF on	
	Straight shed insulator	Alternate shed insulator
Dry and clean condition	0.29	0.3
Insulator with cement dust on its surface	0.27	0.28
Insulator with water drops on its surface	0.25	0.27
Insulator with cement dust and water drops on its surface	0.22	0.24
Insulator with plywood dust on its surface	0.20	0.23
Insulator with plywood dust and water drops on its surface	0.18	0.21

VI. Experimental Results and Its Correlation with Simulation Results

The flashover voltage measurement is done on 11 kV alternate shed and straight shed insulators under clean and various contamination conditions. The contamination conditions considered are (1) Clean condition, (2) Cement dust condition, (3) Plywood dust condition, (4) Cement dust and water drops condition, (5) Water drops condition & (6) Plywood dust and water drops condition. The contamination conditions considered are similar to that exists on overhead line insulators in industrial areas.

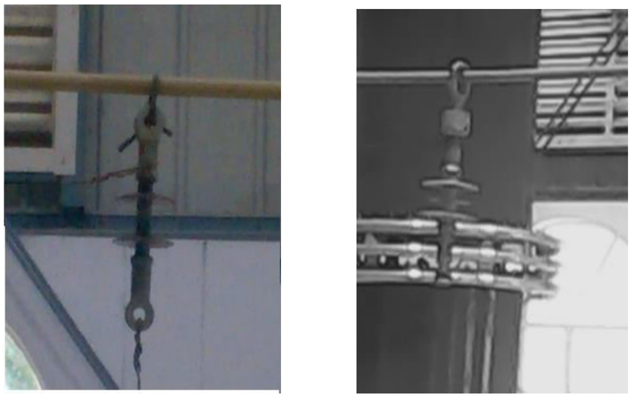
After washing the insulator samples with water, kept dry for 24 hours, they are placed in the experimental setup with a ground clearance of approximately two meter. One end of the insulator was connected to high voltage side and the other end to ground.

The straight shed and alternate shed insulators under clean condition in test are shown in Figure 8. They are energized to measure the flashover voltages under clean and contaminated conditions. The occurrence of flashovers of straight and alternate shed insulators is shown in Figure 9.

The straight shed and alternate shed insulators are tested under various conditions and flashover voltages are noted down. A comparison is made between the flashover voltages of the two types of insulator samples under different contamination conditions. The plot drawn between flashover voltages and various dust conditions is shown in Figure 10 for corresponding values given in Table 4.

Table 4 Flashover voltages under various contamination conditions

S. No.	Insulator under various Conditions	FOV of Alternate shed insulator	FOV of Straight shed insulator
1	Clean	85 KV	76 KV
2	Cement dust	83 KV	74 KV
3	Water drops	71 KV	61 KV
4	Cement dust & Water drops	62 KV	53 KV
5	Plywood dust	58 KV	49 KV
6	Plywood dust &Water drops	54 KV	42 KV



(a) Straight shed (b) Alternate shed

Fig. 8 Arrangement of insulators

Fig. 9 Flashover of (a) straight shed Insulator (b) alternate shed insulator

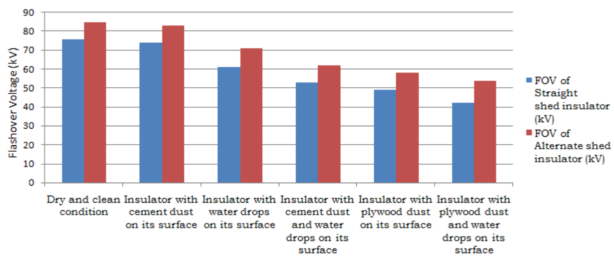


Fig. 10 Comparison of flashover voltages of insulators under clean and various contaminated conditions

From above graph the flashover voltages of alternate shed insulators are higher than that of straight shed insulators under different polluted conditions. Also flash over voltage is lower for polluted insulator compared to unpolluted insulator.

The insulation material should have a breakdown strength that is high enough than the electric stress exerted by the voltage between the two electrodes. The mean electric field between the electrodes can be calculated using equation (1).

$$E_{mean} = V/d \quad \text{------------ (1)}$$

Where E_{mean} is the average electric field in V/c.m., V is the voltage between the electrodes and d is the distance in c.m. between the electrodes.

A non-dimensional value can be defined from the mean electric field and the maximum electric field, as given in equation (2). As the mean electric field is given by dividing the line voltage by the distance

$$\eta = E_{mean}/\ E_{max} = V\ /\ dE_{max} \quad \text{----------- (2)}$$

If flashover of the insulator is due to E_{max}, insulator flashover voltage is given by

$$V = \eta d E_{max} \quad \text{----------- (3)}$$

From above equation (3), it can be said that the flashover vo ltage depends on uniformity of electric field.

From simulation results in Table 3 it is observed that the degree of uniformity (η) in straight & alternate shed insulators is decreasing for various contaminations. According to equation (3) as degree of uniformity is decreasing flashover voltage will decrease for both insulators. Experimental results in Figure 10 also show decrease in flashover voltages under various polluted conditions. This indicates correlation between simulation and experimental work.

Therefore in polluted environments alternate shed insulators are to be used compared to straight shed insulators because de gree of uniformity & flashover voltages are higher in alternate shed insulator compared to straight shed insulator. From the r esults obtained we can predict the schedule maintenance or re placement of the insulators under different contamination con ditions.

VII. CONCLUSION

The electric field along insulators, degree of uniformity of electric field and flashover voltages has been analyzed in this paper. This analysis showed that the presence of pollution layer on the surface of composite insulator significantly altered the electric field distribution along the length of the insulator. Under polluted conditions without any dry band formation, higher electric field stress is observed near high voltage end. It is observed that under polluted conditions the uniformity is low 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 uniformity is more in alternate shed insulator compared to straight shed insulator.

From simulation results in Table 3 it is observed that the degree of uniformity (η) in straight & alternate shed insulators is decreasing for various contamination conditions. According to equation (3) as degree of uniformity is decreasing flashover voltage will decrease for both insulators. Experimental results in Figure 10 also show decrease in flashover voltages under various polluted conditions. This indicates correlation between simulation and experimental results. Therefore under polluted environments alternate shed insulators are to be used compared to straight shed insulators.

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