A Low-Cost Spiral Shed Silicone Rubber Insulator and Its Processing Technique

Ganesh C Basak, Ishant Jain*, Bhanwar Lal, Raghav Upasani & Samsul Ekram
*Corresponding Author

Abstract—Electrical insulators are critical components in the Transmission and Distribution (T&D) sector. Traditionally porcelain and toughened glass were the preferred materials for fabrication of insulators housings. Recently, polymeric materials, such as Silicone, Ethylene propylene, and Ethylene propylene diene monomer have emerged as alternates to the century-old inorganic insulators. Particularly, the remarkable properties of Silicone; lightweight, high water repellency, easy handling, maintenance-free, high strength to weight ratio, good mechanical strength and environmental stability led to its widespread application for insulators in western countries and it's also replacing the conventional ceramic and glass insulators in power transmission all over the world. However, the cost barrier is hindering its adaptability in India at similar levels. The major component contributing to the pricing of the insulator is processing costs. The widely used method for the manufacturing of polymer insulators is by a compression molding technique. The compression molding involves the injection of Silicone into the shaped cavities of a mold followed by the curing of the polymer. The mold incurs high capital expenditure, limiting the manufacturers to produce just a few selective sizes and ratings. The polymeric insulator is expensive as compared to ceramic insulators. This price difference can be minimized by either reducing the processing cost of the insulators or by reducing the cost of the material used or by applying both. In this research work, a lower-cost processing method of spiral extrusion has been developed. When it comes to the material, an alternate to Silicone is not feasible at present since the introduction of new material will take ages to be accepted in the market. Therefore, we can only explore the blends of Silicone. Silicone is very difficult to blend with other rubbers or thermoplastics or TPEs. The inherent batch processing of components in compression molding limits productivity, adding to the cost of the insulators. An alternate method that is continuous and involving no mold could make polymeric insulators cost-effective for is being developed in this study.

Index Terms— Insulator, Transmission and Distribution sector, Processing, Compression Molding, Spiral Extrusion, Hydrophobic, Silicone Rubber

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1 INTRODUCTION

AN insulator is mostly a substance that offers high resistance to the flow of electric current. This is generally made up of tough and high dielectric strength materials. Its' play a significant role in the transmission and distribution lines. Electrical insulators are mainly used to hold conductors in their respective position and concurrently isolated them from one another and from surrounding assemblies. It creates a barrier between energized parts of an electric circuit and restricts the flow of current to wires or other conducting paths as desired.

A good insulator should have possessed the following characteristics such as;

1. High Mechanical Strength
2. High Electrical Resistance
3. High Relative permittivity
4. Non-porous and free from impurities
5. High ratio of puncture strength to flashover voltage

Insulator generally works both in the operating voltage as well as abnormal voltages which is occasionally come across in the power system. It also supports the conductors too. The performances of an insulator usually depend upon various interconnected features, such as the quality of raw materials, design, manufacturing technique, and quality control.

Silicone rubber insulators offer superior electrical performance over their porcelain and glass counterparts for outdoor service [1,2]. They are easy to install and offer superior long-term insulating properties in high-voltage power transmission lines. The silicone insulators primarily retain hydrophobicity and control leakage currents during service in harsh environments [3]. Silicone rubber exhibits the capacity to recover its hydrophobicity even after being stressed and contaminated. This ability assumes greater importance in the climatic conditions of Saudi Arabia, which is characterized by high temperature- humidity regimes.

The aim of this study was to prepare silicone rubber insulator at low cost. Literature survey and patent both reveal that few companies like MacLean [4, 5], ABB [6], Lapp [7], TE [8], and Hydro Quebec [9] have developed continuous processing methods for manufacturing of polymeric insulators. The patent US7128860 from Lapp, explores the use of a two-stage process to obtain spiral-shape insulators. On the contrary, the patent from ABB, US6702975, claims a direct extrusion of Spiral insulator on insulating structures. Sediver [10], US 5973272, proposes a modified process for spiral-shaped sheds, wherein a T-shaped profile is extruded and wrapped around a composite core followed by consolidation of the material. Moreover, form IP landscaping, a total of 84 patents were analyzed and it has been observed that out of 84 patents, 9 patents are relevant to process

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- *Author name is currently pursuing masters degree program in electric power engineering in University, Country, PH-01123456789. E-mail: author_name@mail.com*
- *Co-Author name is currently pursuing masters degree program in electric power engineering in University, Country, PH-01123456789. E-mail: author_name@mail.com*
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and manufacturing and 4 patents are appropriate to the extrusion process.

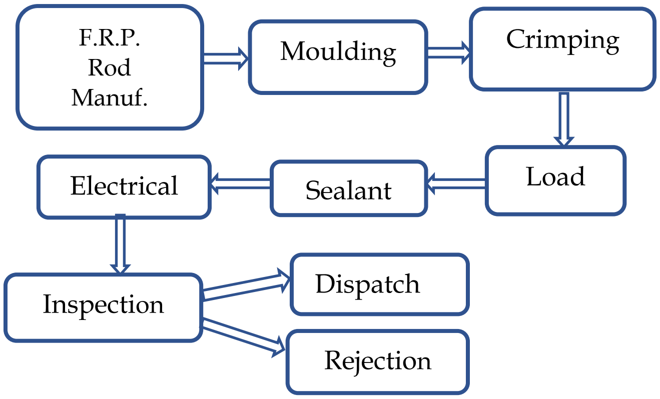

Fig. 1. A flow diagram highlighting the preparation stages of the polymer

2 EXPERIMENTAL SET-UP

2.1 Material, Mixing & Moulding

All the materials used for this research work were commercially available and were used as received without any further treatment or modification. POWERSIL® 310 is a single component peroxide curing compound that cures to an electrically-insulating, highly erosion-resistant silicone elastomer. Several formulations containing silicone rubber were prepared and presented in Table 4.1. The mixing was carried out in a Haake internal mixer for 10 min at a rotor speed of 100 rpm. The individual elastomers and the blends were compounded with DCP on a two-roll mill at room temperature. Vulcanization was performed with a hydraulically operated press at 170°C and 15 bars for 10 min.

TABLE 1
IDENTIFICATION OF MATERIAL USED

Material	Grade	Manufacturer
Silicon rubber, poly (dimethysiloxane)	Powersil 310 E	Wacker-Chemie, Germany
Di cumyl peroxide	98 % active	Hercules Inc. USA

FRP rods of diameter 20.5 mm with E-glass fibre was procured from M/S Agni Fibre Boards Pvt. Ltd., Vadodara, India. Worked with M/S Wacker Metroarc Chemical Pvt. Ltd., Kolkata, India to tailor HTV high dielectric Silicone rubber - Mooney viscosity, modified as per flow requirements to suitable for extrusion process and received the materials for trials.

2.2 Equipment Used for Processing

Silicone rubber extruder crosshead of diameter 55 mm with an automatic temperature control system for better process control has been developed with the help of a vendor, M/S Megha Engineering Works, Mumbai, India. A customized cross-header for forming the shed and sheath of the insulator has also been fabricated from the same manufacturer. A two-roll mixing mill specifically modified for silicone rubber has been procured from M/S Santosh Rubber Machinery Pvt. Ltd., Mumbai, India. A microprocessor-based control system to draw and rotate the FRP rod, to tailor the shed profile to result in a Spiral was designed by Raychem Innovation Centre and developed with the help of a vendor, M/S Harshil Enterprise, Ahmedabad, India.

2.3 Equipment Used for Characterization

Equipment used for Mechanical characterization, Dielectric and Contact angle measurements have been utilized, given in Fig 1.

Extrusion is a continuous process in which silicone rubber is squeezed through a die and then vulcanized as shown in Fig 2. The die provides the shape of an extrudate. The essential pressure is formed via a conveying screw, in which the material is homogenized, compressed, and completed. Extrusion is mainly used for the following products: 1. Tubing, 2. Profiles, 3. Cables, 4. Flat tape and 5. Round cord.

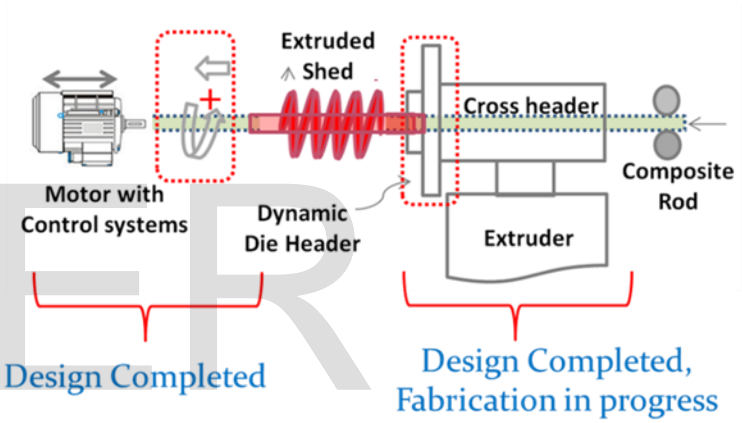

Fig. 2. Schematic of the Extrusion process

2.4 Cross-Header & Profile Managing System

The extrusion die regulates the profile of the cured rubber. Any specific measures for silicone rubber are not required for Die design purposes. In the extrusion process, die swell can be compensated and cured products manufactured with diameters smaller than the die orifice.

2.5 Equipment Used for Processing

Spiral shaped insulators sheds are like a screw and the sheds round their core is like the screw-thread. The spiral sheds generally enhance water flow on the insulator. It has been observed that the voltage distribution on the insulators with standard sheds is more non-uniform due to the great difference between shed and core diameters whereas this problem can be taken care of by using spiral shed insulators which are given in Fig 3. Additionally, it has also been observed that the flashover voltage of insulators with spiral-shaped sheds is typically lower than the flashover voltage of insulators with standard sheds.

One disadvantage associated with a spiral-shaped insulator is the single discharges at the upper flange. The design of spiral sheds, matching with the conventional discrete shed 11 Kv insulator, according to the IEC/TS 60815-3 standard has been completed and is given underneath in Fig 3.

The design of experiments (DOEs) for the spiral extrusion process for 11 kV insulators has been carried out. The process parameters, pulling speed, rotating rpm for shaping the spiral shed of the insulators and temperature, screw speed, and silicone rheology characteristics for the feed have been evaluated. In Fig. 3, ten number of spiral shed samples have been fabricated which can be used for further characterization. Fig. 3 implies that steps for metal and end fittings to the insulators are also being carried out.

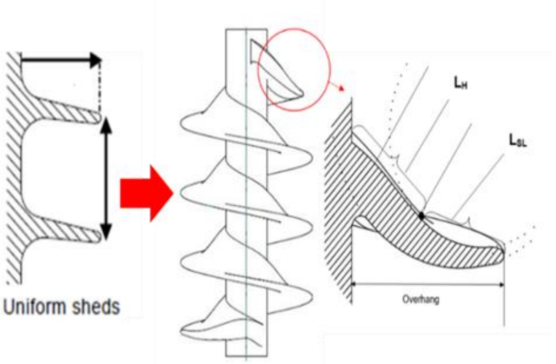

Fig. 3. Design of Spiral Sheds [as per IEC/TS 69815-3 Standards]

The following activities were carried out while preparing a design for spiral sheds insulator;

1. Optimized process parameters for spiral shed extrusion.
2. Extruded 11 Kv spiral shed insulators and finalized metal end fittings method.
3. Characterization has been done for measurement of electrical, mechanical, and hydrophobicity properties of 11 kV spiral shed insulators.
4. Design of spiral sheds, matching with the conventional discrete shed 66 kV insulator (Fig. 4).
5. Successful trials completed for 66kV hollow-core insulators - wrapping of sheds over the hollow-core Insulator
6. Extruded 66 kV spiral shed insulators and finalized metal end fittings method (Fig. 5)
7. Modification of silicone rubber with nano-fillers for further improvement is in progress.

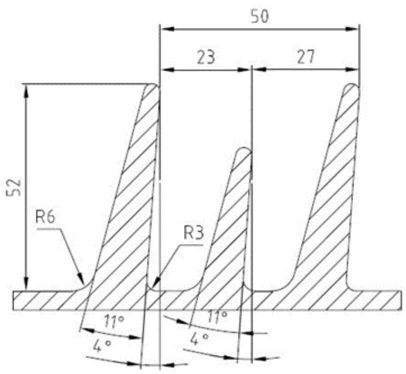

Fig. 4. Design of Spiral Sheds as per IEC/TS 60815-3 Standards

It was found from various research which has been carried out in different countries that the pollution behavior of spiral insulator is usually inferior to that of standard sheds insulator. It is also observed that the profiles of many spiral insulators help the formation of a dry band on their top. Therefore, it was kept in mind while preparing the spiral shed insulator that the profile of spiral shed insulator should be carried out in such a fashion which ultimately inhibits the flow of electrolyte down along the spiral.

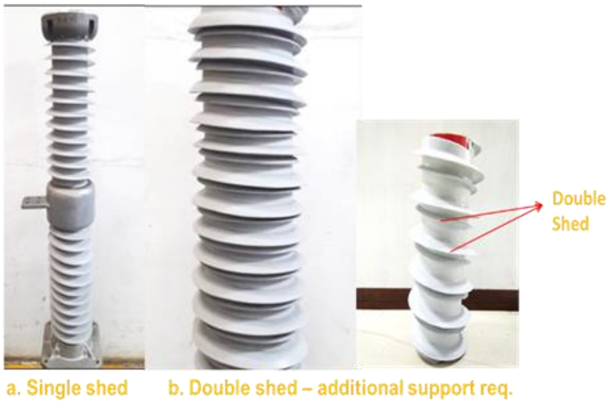

Fig. 4. Extruded 66 kV Spiral Shed Insulator

Powersil 314 is a peroxide cure system that is generally crosslinked under elevated temperature to an elastomer of high hardness. Additionally, it will provide good electrical properties especially suitable for outdoor use in the Transmission and Distribution applications. This silicone rubber has several other advantages like high tracking and arcing resistance, hydrophobic characteristics, and good dielectric properties. Silicone rubber samples were compounded as per standard formulation given in Table 1.

3 FEA ANALYSIS USING COMSOL MULTIPHYSICS

3.1 Mechanical Load Time Test

Boundary Condition: The insulator is subjected to a tensile load, applied between the couplings. The tensile load is increased rapidly but smoothly from zero to approximately 75 % of the SML, and then gradually increased to the specified mechanical load (SML) in a time between 30 sec. to 90 sec as per IEC 61109 shown in Fig 6.

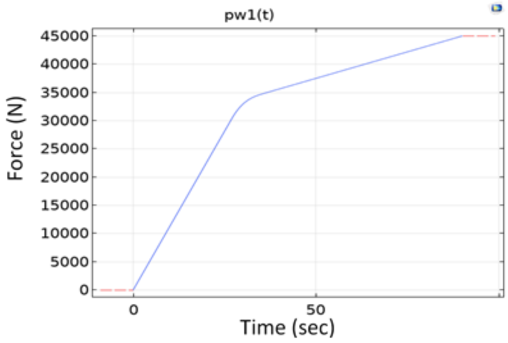

Fig. 6. Load-Time Curve for tensile test

One end of the insulator is fixed, and the tensile load is applied at the other end of the insulator as shown in Fig 7.as per specification given in the standard. With the proper boundary condition, insulator assembly was simulated with proper mesh refinement and FEA results were obtained using COMSOL Multiphysics shown in Fig. 8, Fig. 9, Fig. 10 and Fig. 11.

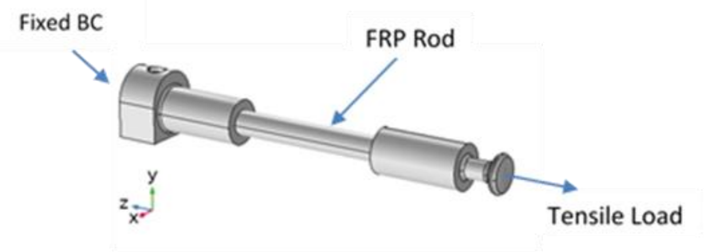

Fig. 7. Geometry with BC's – Tensile Load

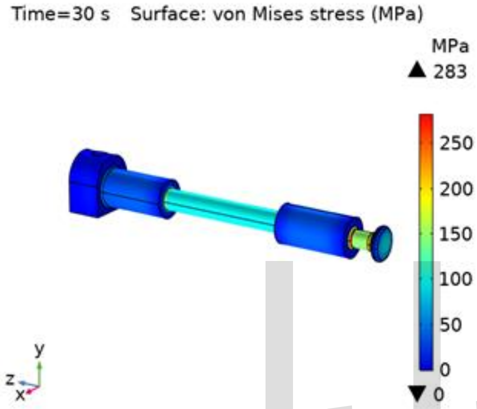

Fig. 8. Von Mises stress at 30 secs

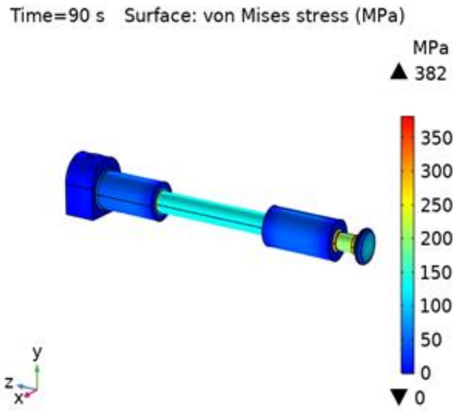

Fig. 9. Von Mises stress at 90 secs

For the given time of 90 sec, maximum stress generating in the 11-kV insulator assembly is 382 MPa which is lesser than the tensile yield strength of the galvanized steel having a value in between 520 – 610 MPa. Also, the stresses value near the interface of the FRP rod and end fitting are in the range of 230-250 MPa and are also within the tensile strength of FRP having 760 MPa.

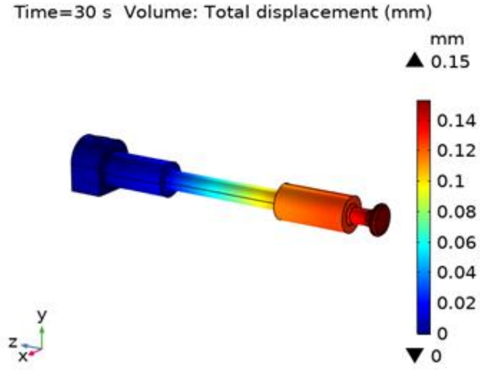

Fig. 10. Total Displacement at 30 secs

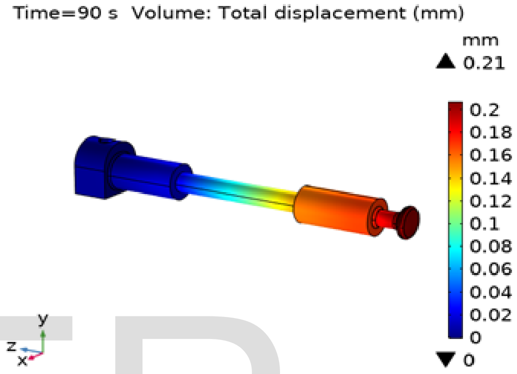

Fig. 11. Total Displacement at 90 secs

As per FEA analysis, the assembly passed the design test as stress-induced are well within yield stress. It can be concluded that there will not be any fracture of metal as well as pull-out of the core from the end fitting.

3.2 Bending Load Test

Boundary Condition: The insulator is subjected to a tensile load, applied between the couplings. The tensile load is increased rapidly but smoothly from zero to approximately 75 % of the SML, and then gradually increased to the specified mechanical load (SML) in a time between 30 sec. to 90 sec as per IEC 61109 shown in Fig. 12.

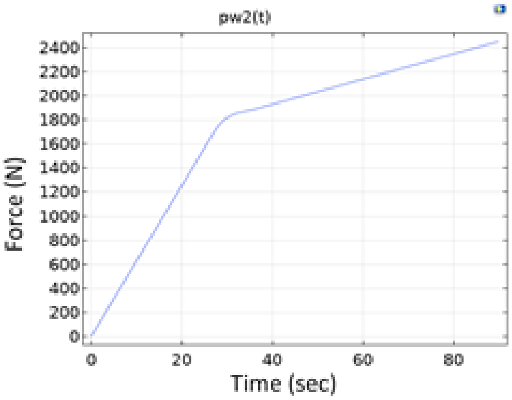

Fig. 12. Bending Load-Time Graph

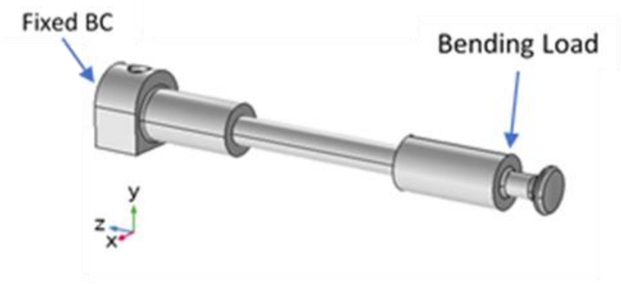

Fig. 13. Geometry with BC's – Bending Load

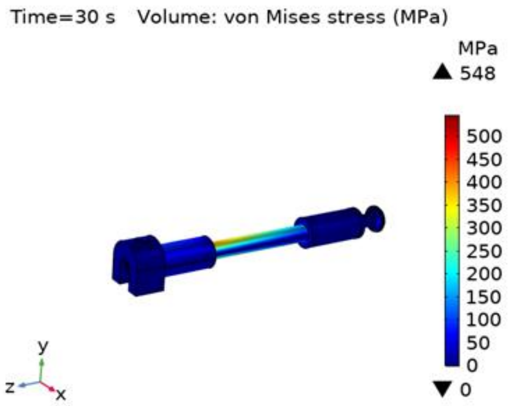

Fig. 14. Von Mises stress at 30 secs

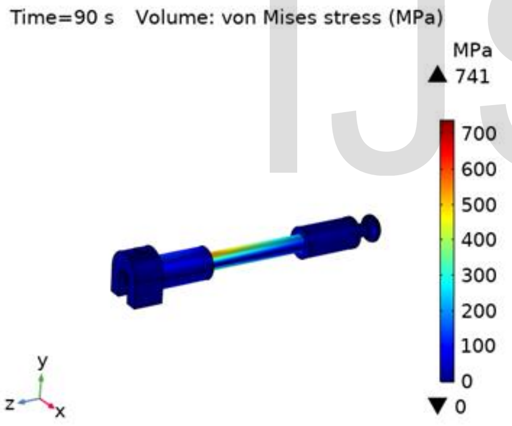

Fig. 15. Von Mises stress at 90 secs

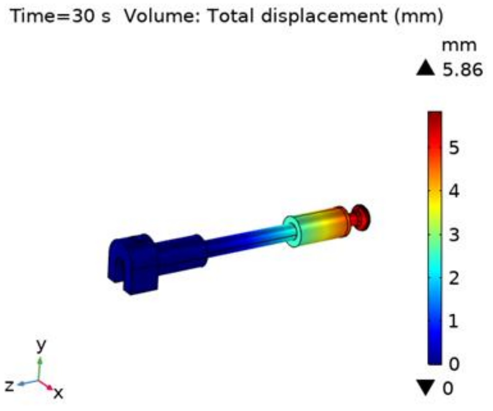

Fig. 16. Total Displacement at 30 secs

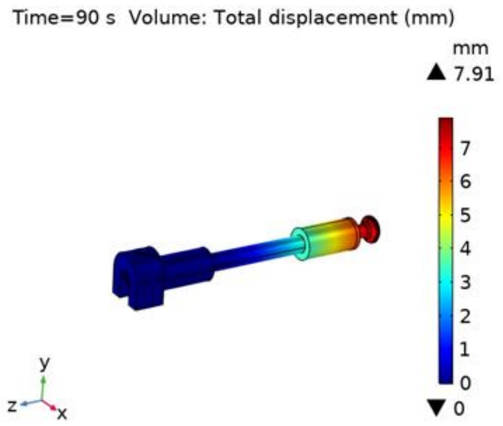

Fig. 17. Total Displacement at 90 secs

Maximum Von Mises stress of 741 MPa is induced at FRP rod due to the bending load of 2.5 KN, as shown in Fig. 15, but the flexural strength of the sample FRP rod is 900 MPa. Hence the insulator assembly is safe and will not fail under the application of bending load. The conclusion of the same is presented in Table 2.

TABLE 2
OBSERVATIONS OBTAINED FROM DIFFERENT TEST OF INSULATOR ASSEMBLY

Test	Max stress (MPa)	Permissible stress (Mpa)	Remark
Mechanical Load-Time Test	382	520-610	Safe
Bending Load test	741	900	Safe

The mechanical load time test and bending load test were performed experimentally on the sample at Central Power Research Institution (CPRI), Bangalore. There was no relative movement of the end fitting of the insulator and even core sustained given tensile load during the mechanical load time test. Similarly, no abnormality and deformation were observed during the bending load. Hence, the simulations were validated experimentally at CPRI.

In our study, we have tried to develop a silicone rubber insulator which should possess all the characteristics required for our low-cost insulator like it should be a continuous and quick process, easily adaptable for different sizes and reduce human efforts as well as a good quality product at low cost. Additionally, we have not done any characterization as silicone grade, which was used for this study, was collected from Wacker Chemie AG. Therefore, we have studied some of its electrical and mechanical properties despite its characterization part.

4 CONCLUSIONS

Polymer insulators have shown an outstanding level to withstand in a polluted environment and proved to be better than the conventional porcelain insulators. In this report, a new processing technique for silicone rubber products has been suggested and studied for its pollution performance. The use of silicon rubber insulators in the electric power sub-stations, distribution and transmission lines are beneficial because of its many advantages such as contamination performance, easy handling, lightweight, reduced construction costs, low maintenance, vandalism resistance, and compact design.

In cases where the initial purchase price is the intervening consideration, ceramic and glass insulators may still be the obvious choice. Even though composite insulators can be produced at very low costs, glass and porcelain still tend to be inexpensive. However, the end-user should also consider the costs involved in the long run. The silicone rubber doesn't require any extra cost as like porcelain and glass insulators which are broken down (~ 7 to 10%) during transport, storage, and installation.

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