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Original Article

Performance Assessment of High Temperature Vulcanized Silicone Rubber Insulators Using Ansys 3D Analysis

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***Abstract** - Pollution flashovers have a significant impact on power transmission and distribution line safety. When rainwater or condensation mixes with the dirt, grime, and salt that make up the pollution layer on insulators, a conductive path is created-a flashover, or sudden electrical discharge, results from this, equipment damage, power outages, and gearbox line failure can all result from this discharge. Anti-pollution flashover coating is widely acknowledged as one of the best methods for preventing and mitigating pollution flashover events. High Temperature Vulcanized (HTV) silicone rubber is now the anti-pollution flashover coating for power transmission and distribution line insulators that are used the most. Even though HTV insulating materials are hydrophobic, they can still be eroded and tracked when exposed to environmental stressors, including dampness and pollution. Therefore, it is critical to investigate polymer insulating materials' tracking and erosion. An approved Test method (Inclined Plane Testing) for evaluating resistance to tracking and erosion of polymeric insulating materials is provided by Indian Standard IS 9947: 2011. This research uses a comprehensive 3D analysis approach to investigate the effects of voltage distribution and electric field intensity on HTV silicone material under various contamination situations using the Finite Element Method software (Ansys). The work also presents a comparative study utilizing Ansys 3D simulation between an HTV insulating material and a traditional ceramic insulating material so as to save money and time on testing and prototyping-based approaches.*

***Keywords** - Ansys 3D simulation, Composite insulators, High temperature vulcanization, Silicon rubber, Tracking and Erosion.*

1. Introduction

The ability of insulators to tolerate and reduce pollution has a major impact on the credibility of the power system. Many failures of insulators have been reported in outdoor settings where temperature, humidity, and pollution have negatively impacted insulator performance [1-3]. Due to the notable rise in pollution levels noted in some areas of our country, it is now imperative to reduce the amount of transmission and distribution line interruptions brought on by pollution [4].

Glass and porcelain insulators have been used in transmission and distribution lines for a long time [5, 6]. Numerous methods, including hot-line cleaning and greasing, can be used to lessen the problem of pollution-related outages [7]. While hot-line washing is thought to be an expensive procedure, the greasing technique is quite dirty [5, 7, 8]. The ability of solid electrical insulating materials to withstand electrical stress and contamination is assessed using the inclined plane tracking erosion test [9-11].

The resistance of insulating materials to moisture, pollution, and voltage is accurately evaluated by the inclined plane tracking test, which improves composite material tracking and deterioration. For surface tracking studies, it is not easy to incorporate realistic field simulation into the Inclined Plane Tracking Test (IPT) [10].

Up until recently, field simulations in inclined plane tracking testing, particularly surface tracking research received little attention. Few researchers have worked on a 2D model of the insulator using FEMM 4.2 and FEM software of Quickfield [12-14].

In tests of inclined plane tracking, there has been a dearth of simulation, particularly surface tracking. Therefore, experiment results may be predicted by field simulation in IPT testing. Field simulation during IPT testing can be utilized to evaluate the surface tracking resistance of HTV insulating material if the simulation method can anticipate experimental IPT results.

A number of significant pieces of academic research emphasize the necessity of using Electromagnetic (EM) field computation to study the effects of electric field and voltage distribution on high-temperature silicone rubber that has been vulcanized under various contamination scenarios [5, 6, 7, 15].

Ansys 3D modeling and thorough 3D analysis make this feasible. Electrical insulation frequently uses high-temperature vulcanized silicone rubber compositions because of their resistance to a broad range of voltages and electric fields. The material's dielectric properties and breakdown strength are impacted by contamination conditions such as dust, pollution, and moisture [1]. Advanced understanding of the electric field and voltage distribution and safety of electrical systems.

Overstressed materials can result in equipment and crew injuries due to electrical faults and failures. Breakdown-prone locations can be found by modeling these occurrences and utilizing EM field calculations [14]. With this proactive strategy, the electrical system is safer.

Moreover, EM field computation enhances the design of insulating materials. Conventional approaches may be costly, time-consuming, and frustrating when testing in various contamination conditions. Virtual simulations enable quicker and less expensive scenario evaluation thanks to Ansys 3D modeling.

Real prototypes are not as necessary with this strategy since they enable quick design revisions and iterations in a virtual environment. The voltage distribution and electric field of the material are fully studied using Ansys 3D modeling. For better representation of real-world settings, a near-realistic surface tracking model has been incorporated into the IPT test simulations.

This work attempts to assess the performance of HTV SiR and porcelain with the wide scenarios of contamination using various indicative performance parameters employing Ansys 3D simulations. Primarily, by performing simulation studies, researchers and manufacturers can have the foresight and may save money and time on testing and prototyping through traditional testing approaches.

2. Simulation Study and Assessment Approach

2.1. FEM Analysis and Assessment Approach

This work presents a thorough explanation of the methodological strategy used to assess, using the ANSYS finite element programme, the performance of high-temperature vulcanized silicone rubber insulators.

This work aims to elucidate the intricate interactions between voltage and electric field distribution that occur on the surface of insulating materials. According to the internationally recognized reference IEC 60587, [9] which governs the evaluation of electrical properties in insulating materials under electrical stress, the simulation meets all of the requirements. Evaluations of erosion resistance and electrical tracking are included in this. A well-known finite element analysis application called ANSYS makes it easier to simulate and understand complex engineering problems. This work uses ANSYS to do finite element modeling, a numerical technique for estimating the behavior of complicated systems like silicone rubber insulators.

The vulcanization of silicone rubber insulators at High Temperatures Vulcanized (HTV) is the main topic of this work [7]. The primary objective of the simulation is to examine the distribution of voltage and electric field across the surface of the insulating samples. Understanding the electrical properties of insulators and their dependability in practical applications requires an understanding of this crucial information.

A preset test configuration is used to execute the simulation in accordance with the guidelines given in the IEC 60587 standard [9]. This international standard provides a comprehensive framework for examining the electrical properties of insulating materials under electrical stress, including standards for evaluating electrical tracking and erosion resistance.

The electrodes and the insulating sample are the only parts that are included in the simulation; all other accessories and parts are not. This type of reduction is widely employed in finite element simulations to decrease computational complexity and concentrate on the key variables. The insulating sample is sandwiched between two electrodes, one of which is connected to a High Voltage (HV) source and the other to the ground. Examining the distribution of the electric field across the insulating sample when the voltage is applied is made simpler by this arrangement.

To determine how pollutants affect the insulating sample, actual Insulation Performance Testing (IPT) experiments are used to choose the contamination pattern [16]. The electrical behavior of the insulator is greatly influenced by surface pollutants, which can lead to issues with erosion and electrical tracking [17, 18].

Within the predefined parameters of the test design, electrode layout, and pollutant pattern, the 3D simulation is run using ANSYS. The programme takes into account the boundary conditions, material properties, and geometry of the insulator when solving the governing equations for the distribution of the electric field using the finite element approach.

Following the simulation's completion, the collected data are carefully scrutinized. Data analysis and visualizations can be used to get a knowledge of the distribution of voltage and electric field on the insulator surface, as well as its susceptibility to electrical erosion and tracking in the presence of impurities.

In conclusion, this comprehensive explanation makes clear the subtleties of the performance assessment of the HTV silicone rubber insulators using ANSYS 3D analysis. The work provides valuable insights into the electrical behavior of insulators under different contamination cases by employing a targeted simulation setup and following Indian and international standards. This can help improve insulator design and dependability.

2.2. 3D Simulation Modeling and Samples Properties

Finite element analysis of the electric field distribution over contaminated insulator surfaces aims to identify the regions with high electric field intensity. The FEM Ansys Electromagnetic Compatibility (EMC) software is utilized for examining the current density, voltage, and distribution of electric field across the surface of insulating samples.

The simulation was conducted following the guidelines outlined in the Indian Standard IS 9947 : 2011 (Equivalent to IEC 60587 : 2007), which specifies an approved test method (Inclined Plane Testing) for evaluating resistance to tracking and erosion of polymeric insulating materials [9, 10].

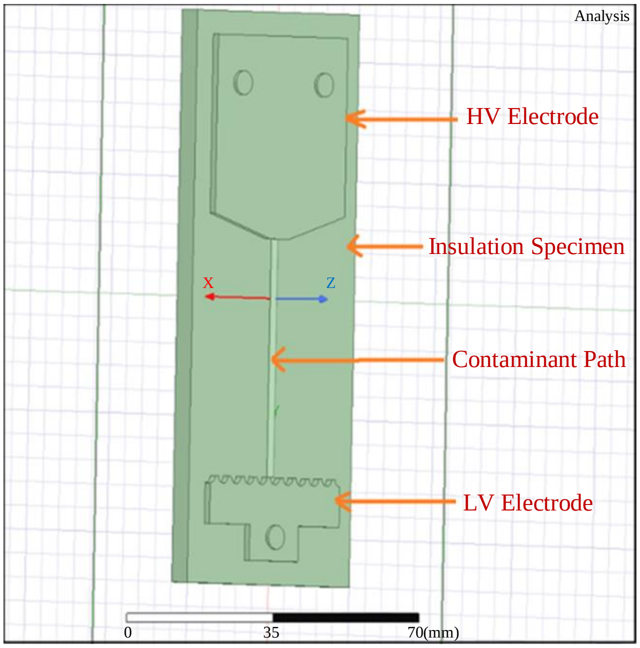

Fig. 1 3D insulating material sample for simulation

The sample prepared for simulation is a 3D rectangular specimen measuring 50 mm x 120 mm with a thickness of 6 mm, as shown in Figure 1. To assess the impact of contaminants on both types of insulating materials - Porcelain and HTV Silicone rubber, different patterns of contaminant solutions were employed, as specified in Table 2.

In this simulation, the air's relative permittivity was set at 1, while its conductivity was set at $2\times10{-}4\,\mathrm{S\,m}^{-1,}$ and the relative permittivity of the contaminant solution was 81 [13]. Table 1 indicates material properties used for simulation purposes [12, 19].

Table 1. Material properties

Properties / Material	Porcelain	Si Rubber
Relative Permittivity	6.48	2.67
Relative Permeability	1	1
Bulk Conductivity	1.00143×10^{-9} siemens/m	8.16905×10^{-13} siemens/m
Thermal Conductivity	1.88944 W/m-C	0.244949 W/m-C
Mass Density	2338.63 kg/m^3	1115.53 kg/m^3
Specific Heat	364.863 J/(kg °C)	1074.71 J/(kg °C)
Young's Modulus	69952500000 N/m^2	15811400 N/m^2
Poisson's Ratio	0.174929	0.474896

2.3. Theoretical Analysis of Finite Element Method (FEM)

The relationship between the electrical potential distribution (V) and the electric field distribution (E) is given by the gradient of the potential. The mentioned equation can be used in calculating the distribution of the electric field [20].

$$E = -\nabla V \tag{1}$$

Here, E represents the electrical field strength, and V represents the Voltage. Considering Maxwell's equation, which describes the behavior of electric and magnetic fields.

$$\nabla \cdot E = {}^{\rho}/_{\varepsilon} \tag{2}$$

Here, ρ represents the volumetric density of the charge, and Ɛ represents the permittivity of the dielectric material.

The equation for the complex vector of active current density (J) can be expanded as follows:

$$J = \sigma E \tag{3}$$

Here, J is the current density, σ represents the conductivity, and E represents the electrical field strength [20].

2.4. Used Cases

Table 2. Contaminant configurations

Case	Contaminant Configuration Details
A	Contaminants - Bubble in a Straight Line
B	Contaminants flow in Narrow Straight Pipe
C	Contaminants flow in Wider Straight Pipe
D	Contaminants flow as Tracking Trees
E	Contaminants - Bubbles Random Configuration

Table 2 gives details of various cases taken for simulations by considering variations in contaminants and their paths. For each case, simulation results are compared for HTV SiR and porcelain as insulating materials.

3. Results and Analysis

3.1. Case - A: Contaminants - Bubble in a Straight Line

3.1.1. Porcelain Insulator

Porcelain insulators have a smooth surface and low hydrophobicity, which makes them prone to water droplets forming on them and bubble trails developing along them. This is significant because pollutants arranged in a straight line have the ability to create an uninterrupted electrical route.

This kind of arrangement can lead to surface charge accumulation and concentrated electric field intensities, which increases the insulator's vulnerability to electrical tracking and degradation. These phenomena' consequences highlight silicone rubber insulators' surface characteristics, as demonstrated by the analytical capabilities of Ansys 3D simulations. In order to improve silicone rubber insulators' performance and resilience against electrical tracking and erosion concerns, a greater understanding of these issues is essential.

Figures 2 and 3 indicate how contaminants alter the electric field within the porcelain and HTV Silicon Rubber material. Regions of high electric field intensity indicate locations where the material is more prone to breakdown or flashover, particularly when the electric field exceeds the material's breakdown strength.

It can further be observed from these plots that Silicon Rubber is relatively less stressed along the contamination trajectory and a bit more stressed near the electrodes in comparison to porcelain. Further, porcelain has a less uniform electric field intensity and surface charge dispersion than porcelain. This can make porcelain more susceptible to breakdown and flashover under certain situations, particularly in locations with high electric field intensity or charge density.

3.1.2. HTV Silicone Rubber Insulator

It is essential to emphasize the unique properties of silicone rubber insulators when examining using Ansys 3D analysis. These insulators, which are highly regarded for their superior hydrophobicity and water-repellent qualities, are essential in reducing the risk of bubble formation along their surfaces.

Silicone rubber's hydrophobic properties are crucial in inhibiting the formation of continuous bubble trails, acting as a safeguard against adverse outcomes like increased electric field intensities and surface charge accumulation. The hydrophobic surface characteristic of silicone rubber insulators not only enhances their overall durability but also functions as a strong barrier, reducing the potential hazards linked to elevated electric field concentrations and the consequent accumulation of surface charges.

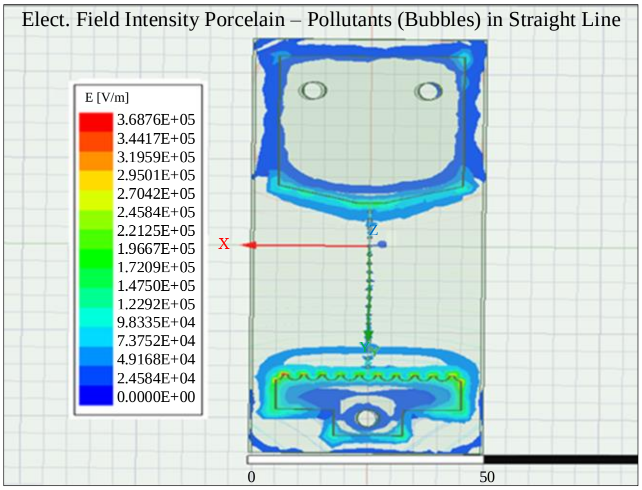

Fig. 2 Electric field intensity distribution - porcelain

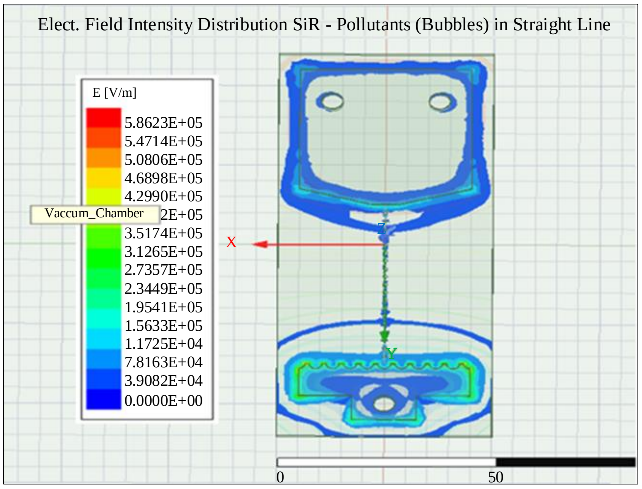

Fig. 3 Electric field intensity distribution – Si rubber

3.2. Case - B: Contaminant Flow in Narrow Straight Pipe

3.2.1. Porcelain Insulator

The purpose of this scenario is to study the surface circumstances where a linear arrangement of impurities causes a conductive channel to form along the insulator's surface. In localised places, this specific design raises the likelihood of a continuous conductive channel, a phenomenon that could result in concentrated areas of high electric field intensity.

It is extremely dangerous for such a continuous conductive channel to form because it can cause concentrated areas of intense electric fields. Thus, there is a considerable risk associated with this increased intensity, which could result in unfavorable consequences, including erosion and electrical tracking. Investigating these interdependent dynamics is essential to gaining a thorough grasp of the consequences related to the linear contamination arrangement on insulator surfaces.

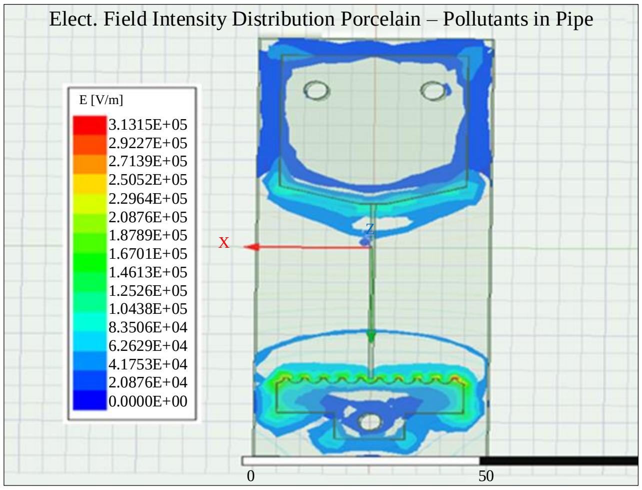

Fig. 4 Electric field intensity distribution – porcelain

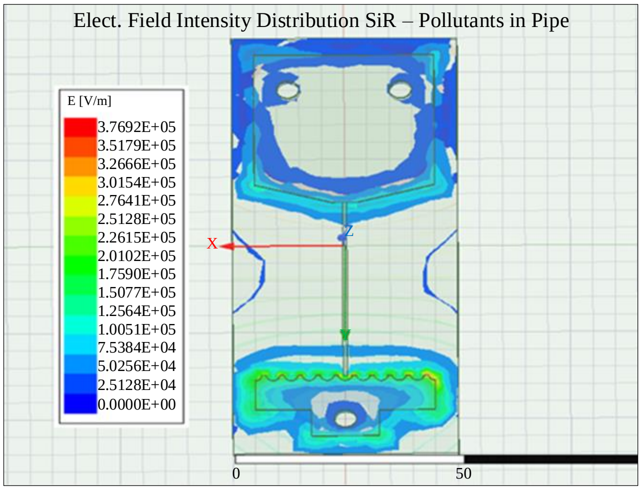

Fig. 5 Electric field intensity distribution – Si rubber

3.2.2. HTV Silicone Rubber Insulator

Research on silicone rubber insulators identifies a notable property inherent in their hydrophobic surface. This characteristic works to prevent the accumulation of impurities grouped linearly, which reduces the likelihood of a continuous conductive channel forming along the surface of the insulator. As a result, the distribution of the electric field intensity becomes more uniform, offering a noteworthy defense against the possible risks of electrical tracking and erosion. One of the main factors influencing these results is the hydrophobic silicone rubber insulator surface, which functions as a strong barrier to prevent straight-line impurities from moving forward.

The significance of comprehending the nuances of material properties in relation to electrical insulation is highlighted by this subtle interplay. These discoveries not only add to the body of basic information in the scholarly discourse but also have applications in the design and improvement of silicone rubber insulators, which may advance electrical engineering.

From Figures 4 and 5, it can be observed that both materials exhibit a higher electric field intensity in the area of the pollutants due to their varying permittivity. The characteristic of HTV is lower permittivity in comparison to porcelain, meaning that the total electric field is usually weaker.

On the other hand, local field concentrations near contaminants are highly significant. Porcelain has a stronger electric field due to its higher permittivity. This leads to the nearby isolated field that contains much higher concentrations of contaminants.

Furthermore, HTV shows less surface charge buildup due to its likely hydrophobicity. On the other hand, contaminant flow interferes with this process and causes localized charges to build up. On the counterpart, the porcelain frequently exhibits a larger surface charge accumulation due to its hydrophilicity. Flowing contaminants leads to aggravate the accumulation of contaminants even more, especially at corners and edges.

3.3. Comparison of Electrical Field Distribution between Porcelain and HTV SiR

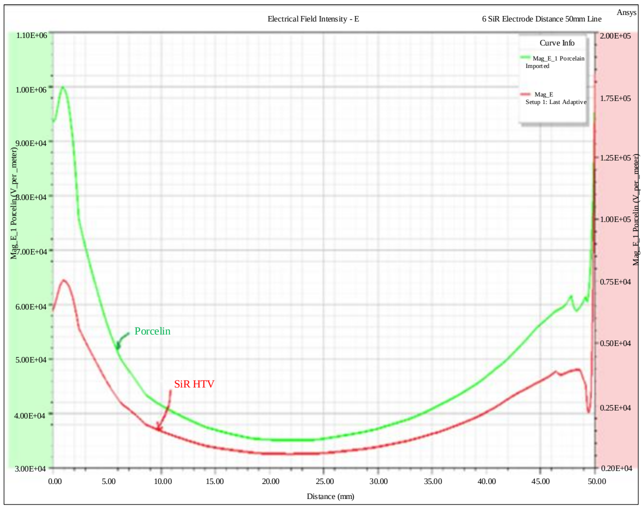

Fig. 6 Comparative plot of electric field intensity distribution - porcelain & HTV SiR

Table 3. Magnitude of electric field intensity in kV/m

	Electrical field Intensity in kV/m	
Distance	**Porcelain**	**HTV SiR**
0 mm	94.09	87.98
2.5 mm	35.39	31.04
5.0 mm	100.68	183.35

Figure 6 displays a comparative plot of electric field intensity for both materials. Table 3 gives the magnitude of electric field intensity in kV/m for both materials. From Figures 6 and 7 it is evident that HTV generates weaker electric fields than porcelain as a result of its lower permittivity. Moreover, porcelain exhibits significant electrostatic fields as a result of its elevated permittivity, which, if not effectively managed, may cause extensive tracking and erosion.

3.4. Comparison of Electric Flux Density Distribution between Porcelain and HTV SiR

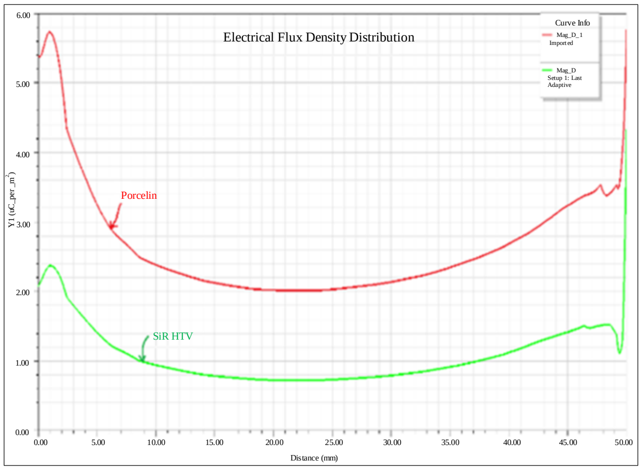

Fig. 7 Comparative plot of electric flux density distribution - porcelain & HTV SiR

Figure 7 displays a comparative plot of electric flux density distribution for both materials.

Table 4. Magnitude of electric flux density in $\mu C/m^2$

	Electric Flux Density in $\mu C/m^2$	
Distance	Porcelain	HTV SiR
0 mm	5.39	2.08
2.5 mm	2.03	0.73
5.0 mm	5.77	4.33

Further, in comparison to porcelain, HTV shows a lower flux density due to its lower permittivity, and a greater permittivity in porcelain corresponds to a greater flux density, which elevates the material's overall tension and may result in extensive erosion.

While strong electric fields induce widespread tracking in porcelain, which is subsequently followed by attrition propelled by the material's high flux density. Thus, lower field and flux density values for HTV indicate the possibility of improved erosion resistance and tracking, and flux density signifies an increased vulnerability of porcelain to tracking and erosion, particularly when subjected to severe conditions.

3.5. Case - C: Comparison of Plot of Electric Field Intensity Distribution along the Surface of SiR with Contaminants in Narrow Pipe and Contaminants in Broad (Wider) Pipe

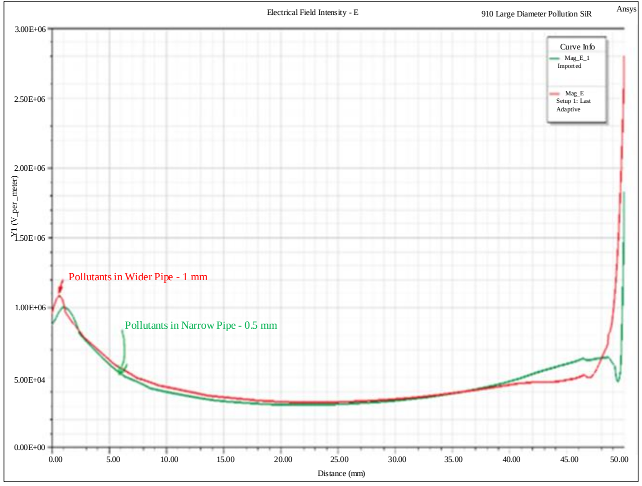

Fig. 8 comparative plot of electric field intensity distribution – contaminants in a narrow and broad path

Figure 8 shows a comparative plot of electric field intensity distribution along the surface of SiR with pollutants in a narrow pipe and pollutants in a broad (wider) pipe. From Figures 6 to 8, it can be observed that pollutants, particularly conductive ones, cause permittivity changes inside the HTV, which may result in localized zones with high electric field intensity. These places will be more prone to collapse, which might result in tracking or erosion.

In the case of a narrow pipe, the electric field and contaminants are limited, potentially increasing their impact on field dispersion when compared to larger geometries. In the case of a border pipe, the spatial distribution of contaminants within the border pipe has a considerable influence on field dispersal. Densely packed pollutants are causing widespread field distortions.

Further, the contaminants at pipe edges also cause considerable field distortions due to the rapid permittivity change. These edge regions are especially prone to breakdown, which can result in flashovers or surface discharges, which are relatively higher in the case of broader pipes has been considered.

Table 5. Magnitude of electric field intensity in kV/m

	Electrical Field Intensity in kV/m	
Distance	**Narrow Pollutant Pipe**	**Wider Pollutant Pipe**
0 mm	87.98	96.08
2.5 mm	31.04	32.65
5.0 mm	183.35	280.70

Moreover, the electric field intensity grows equally throughout the HTV sample as the applied voltage increases. At higher voltages, localized field concentrations become more noticeable due to permittivity fluctuations, surface imperfections, and potential space charge effects.

Also, as the voltage rises higher, the localized high-field zones may exceed the material's breakdown strength, resulting in localized breakdown, tracking, or flashover. Table 5 gives the magnitude of electric field intensity values in kV/m for comparison cases of pollutants in narrow pipes and pollutants in broad (wider) pipes.

3.6. Comparative Plot of Electric Field Intensity Distribution along the Surface of SiR with an Increase in Applied Voltage

The samples were simulated at different voltage levels: 2.5 kV, 3.5 kV, 4.5 kV, and 6.0 kV. Simulation results in Figures 9 and 10 indicate that the average value of Electric field Intensity increases with the increased magnitude of applied voltage.

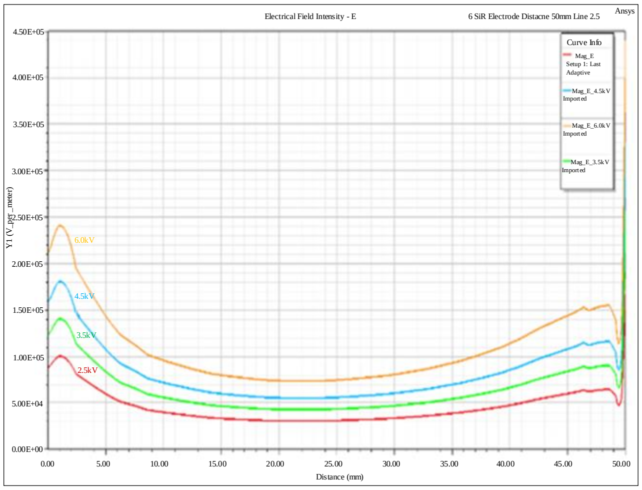

Fig. 9 Contaminants as a narrow path at different voltages

It has been observed from Figures 9 and 10 that the higher magnitude of the applied voltage gives higher energy to electrons to get deposited on the insulator surface. The presence of this higher charge increases the surface conductivity and it leads to the increase of discharge magnitude.

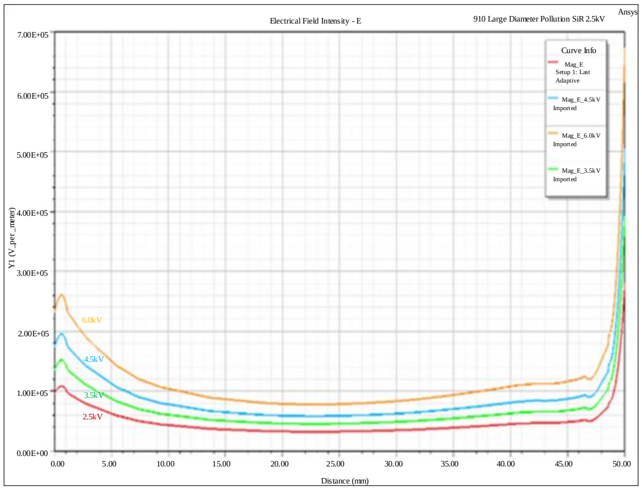

Fig. 10 Contaminants as a wider path at different voltages

3.7. Case - D: Contaminants Flow as Tracking Trees

3.7.1. Plot of Electric Field Intensity Distribution – Tracking Trees for SiR

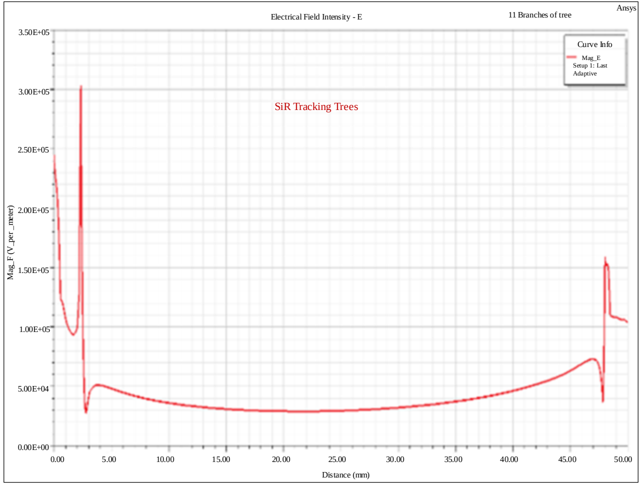

Fig. 11 Plot of electric field intensity distribution – tracking trees

3.7.2. Electric Field Intensity Distribution with Contaminants Flow as Tracking Trees

Figures 12 and 13 display the distribution of electric field intensity with contaminants flow as tracking trees in SiR and Porcelain, respectively. In the presence of tracking trees (contaminants), both materials suffer greater electric field intensity in specific places around the contaminants, particularly at sites of contact or concentration. Also, the electric flux density is proportional to the electric field intensity and permittivity of the material and hence, higher electric field intensities produce higher electric flux densities. Therefore, in the case of porcelain, which exhibits higher electric flux densities, particularly in locations with higher electric field intensities due to tracking trees whereas, HTV silicon rubber is expected to have lower electric flux densities than silicon rubber under similar conditions.

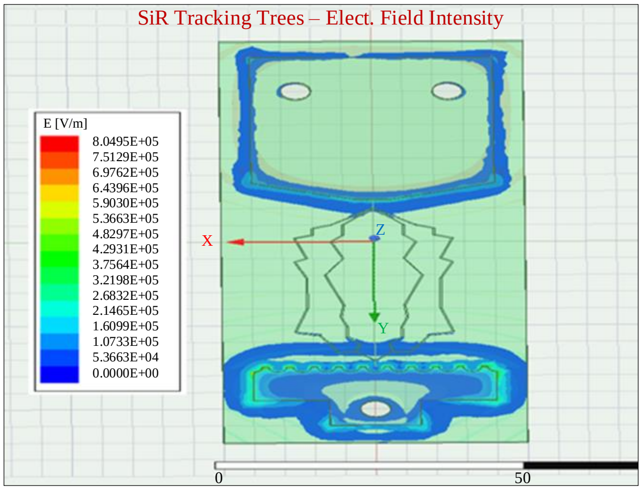

Fig. 12 Electric field intensity distribution - tracking trees – SiR

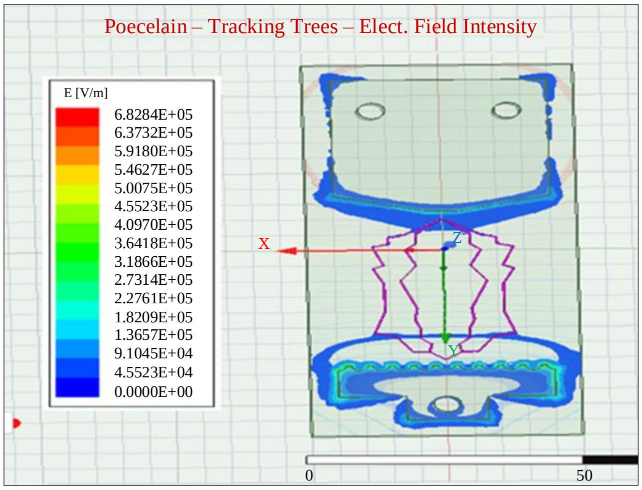

Fig. 13 Electric field intensity distribution - tracking trees - porcelain

Further, tracking is the process of forming conductive channels on the surface of an insulating material as a result of localized breakdown and erosion happens as these routes wear down the material over time. So, higher electric field intensities and electric flux densities, as seen in porcelain, may result in faster tracking and degradation compared to silicon rubber.

While silicon rubber has a more uniform electric field distribution and lower electric flux densities, making it more resistant to tracking and erosion. In a nutshell for the considered case, porcelain is anticipated to have higher electric field intensities and electric flux densities than HTV silicon rubber in the presence of tracking trees, potentially leading to faster tracking and erosion.

3.8. Case - E: Contaminants (Bubbles) in Random Configuration

Due to their hydrophilic and low impurity shedding, porcelain insulators present unique electrical insulation issues. Hydrophilic porcelain insulators are more susceptible to inadvertent impurity formation, often in the form of bubbles. Porcelain insulators are less effective than hydrophobic ones at preventing pollution exposure and shedding.

Based on Figure 14, one can observe that the hydrophilic tendency causes random impurities to develop, disrupting the electric field on the insulator surface. Disorganized pollutant organization leads to restricted areas with high surface charge density and electric field intensity and, hence, may promote localized breakdown events like surface erosion and electrical tracking.

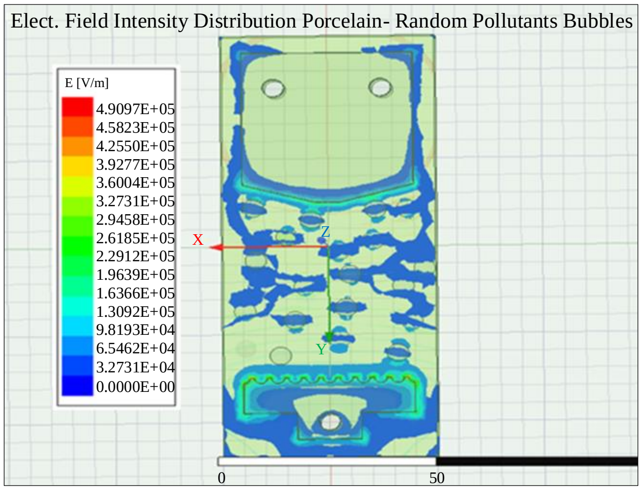

Fig. 14 Electric field intensity distribution –contaminants bubbles random – porcelain

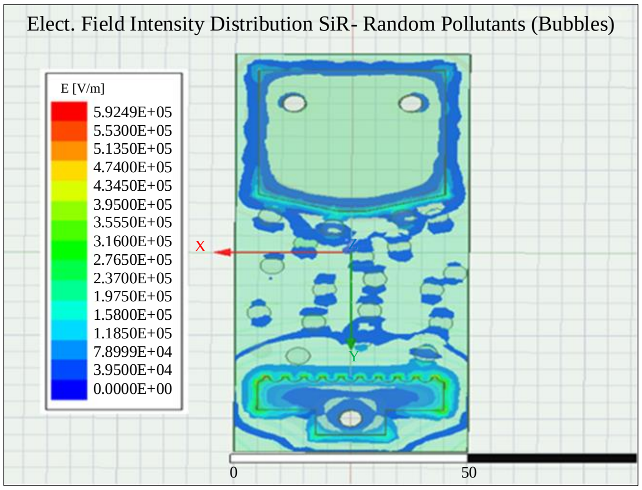

Fig. 15 Electric field intensity distribution –contaminants bubbles random – Si rubber

Figures 15 displays the distribution of electric field intensity with contaminants in random bubble patterns in Porcelain and HTV SiR, respectively. From this plot, it is evident that insulators made of hydrophobic silicone rubber are less prone to absorbing the rare impurities that can cause bubbles to develop. The hydrophobic nature of the silicone rubber repels water and other impurities. Thus, water and pollutants are swiftly repelled, reducing the likelihood that they will adhere. This disperses the electric field more evenly and prevents an accumulation of charges on the surface of the insulator.

3.9. Comparison of Voltage Distribution in HTV SiR (Different Cases)

As depicted in Figures 16 to 20, the voltage Distribution changes in Contaminated High-Temperature Vulcanized Silicone Rubber. HTV contaminants impair power distribution, which affects its efficiency and breakage. When Pollutant bubbles move straight due to mismatched permittivity levels, every bubble creates a large voltage concentration surrounding it.

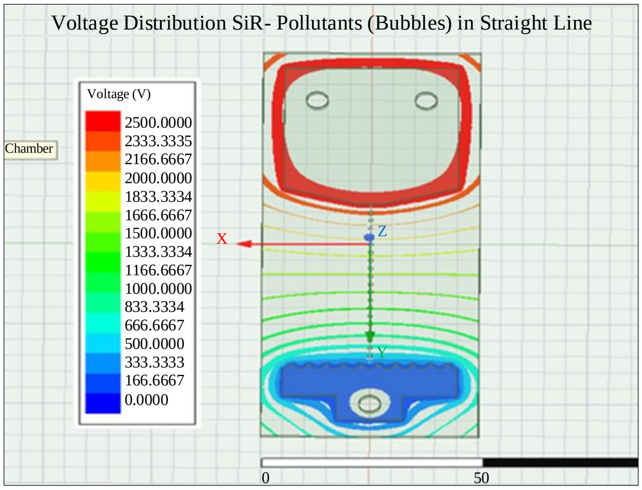

Fig. 16 Voltage distribution – contaminants as bubbles in a straight line

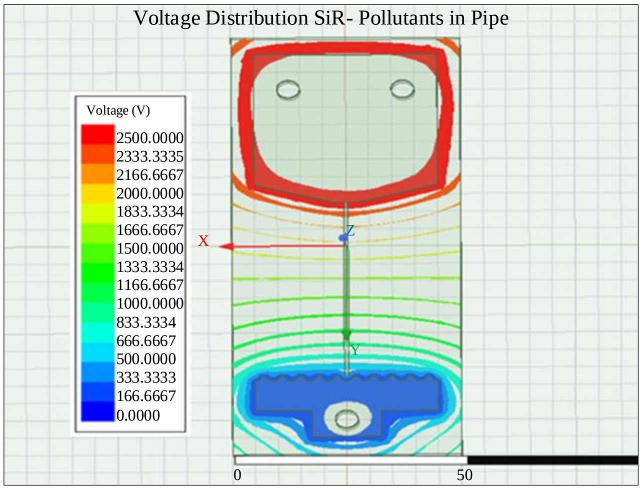

Fig. 17 Voltage distribution – contaminants flow in a narrow path

Variations in voltage are visible along the bubbles. Also, when pollutants travel narrowly, these moving pollutants modify permittivity like bubbles. Therefore, the path has a relatively higher voltage than the material around it, causing a distorted voltage distribution. This voltage distortion depends on flow rate and impurities. Narrow channels or gaps in insulators increase failure risk. Further, when the path is considered wider the higher voltages are getting distributed a little better in comparison to the narrower path.

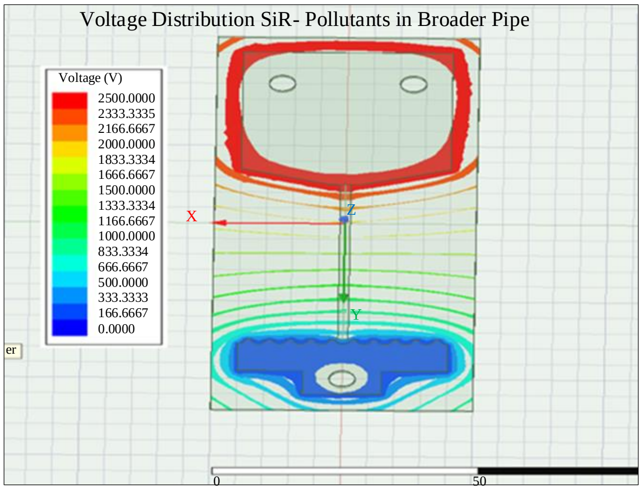

Fig. 18 Voltage distribution – contaminants flow in the broad path

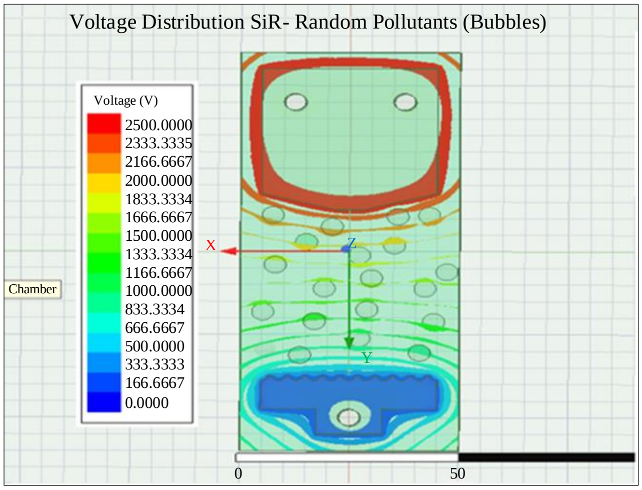

Fig. 19 Voltage distribution – contaminants as random bubbles

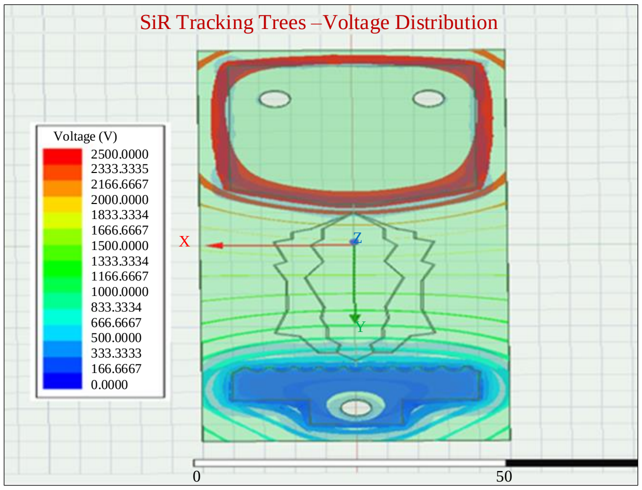

Fig. 20 Voltage distribution – contaminants as tracking trees

The random distribution complicates and makes the voltage pattern harder to anticipate. Due to bubble size and position, there may be multiple high-voltage areas. Thus, high-voltage zones along tree branches can be stronger than the material's breaking point and result in more failure risk compared to straight and/or random bubble distribution paths considered here above.

3.10. Comparison of Electric Field Intensity for - Different Polymeric Materials with Different Filler Loadings

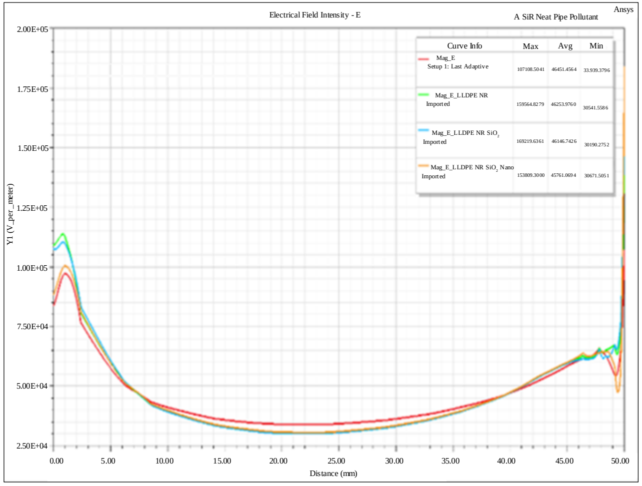

Fig. 21 Plot of electric field intensity - different polymeric material with different filler loadings

Fillers can dramatically affect HTV's electric field intensity and electrical properties. An investigation of the impact under uniform test conditions for the indicated polymeric materials to evaluate electric field intensity has been performed.

As depicted in Figure 21, in the case of the HTV with Micro Alumina Trihydrate (ATH), the field distribution is equal and local field concentrations are lower than any other combinations shown in Table 6 amongst different polymeric materials.

Table 6. Different polymeric samples

Type	Polymeric Material	Filler Details
A	HTV SiR	Micro ATH
B	Neat LLDPE + NR	No Filler
C	LLDPE + NR	Micro SiO_2
D	LLDPE + NR	Nano SiO_2

Table 6 shows the compound and designation of the polymeric samples used for simulation [15]. Nano silica (SiO_2) has a higher surface area than micro SiO_2 and can increase permittivity. Further, nano SiO_2's huge permittivity increase and LLDPE + NR's lowered permittivity, hence resulting in the maximum electric field intensity.

4. Performance Criteria and Observations

The performance parameters of silicone rubber and porcelain insulators were summarized after rigorous comparison. Silicone rubber insulators reduce contaminants like bubbles in random and straight patterns better.

This research suggests that silicone rubber insulators will have a more equal electric field intensity distribution than porcelain ones. This expected consequence significantly reduces electric field intensity in selected places, improving electrical performance.

Silicone rubber is hydrophobic; therefore, voltage distribution along the insulator surface should be more uniform. This material-specific property prevents electrical tracking, making the insulator more reliable and useful in various electrical applications.

Silicone rubber insulators have a reduced surface charge density, according to this study. Silicone rubber's self-cleaning properties prevent contaminants from accumulating. Thus, reduced surface charge density reduces erosion and electrical tracking.

A higher surface charge density and lower electric field intensity near the electrodes promote porcelain tracking and degradation earlier. This may increase leakage current. It also shows how water droplets on the insulator's surface alter surface charges and electric field strength but not voltage distribution.

The findings from our HTV silicon rubber insulator investigation support the premise that silicone rubber is better than porcelain. HTV silicone rubber's hydrophobicity and self-cleaning properties improve voltage distribution, surface charge density, and electric field uniformity. HTV silicone rubber is more durable against electrical tracking and degradation, making it a good material for insulator technology.

5. Conclusion and Remarks

This study analyses the important relationship between composite insulator discharge activity and electric field distribution. Exceeding critical electric field magnitudes can cause excessive discharge activity, which can damage the insulator over time. The amplitude and direction of the local electric field determine discharge location, magnitude, and occurrence.

Rain or fog intensifies the electric field on a polymer insulator. Water droplet surface corona discharges accelerate material ageing. The work highlights the importance of understanding polymer insulator voltage distributions and electric fields in wet situations to understand ageing and pollution flashovers.

This study examines how water droplets boost polymer insulators' electric fields. The electric field distribution across a polymer insulator under varied water droplet conditions is calculated using a 3D ANSYS FEM simulation. This study examines how pollution layer conductivity and thickness affect insulator performance.

ANSYS is used for 3-dimensional computing to assess contaminants on the polymer insulator. Results include voltage measurements, electric field distribution, and maximal electric field evaluations. The results show that the electric field is larger towards the energized end than the grounded end.

This shows how pollution layer conductivity and thickness affect the electric field at the insulator's head and end. As applied potential increases, the electric field should grow. Electron energy increases with applied voltage, making them more attracted to the insulator. The investigation found that the electric field at 6 kV is much stronger than 2.5 kV, indicating a higher voltage.

The study found that insulator surface conductivity affects current density and field intensity. The investigation indicated that through simulation results, manufacturers can foresight experimental IPT results and can save money and time on testing and prototyping-based approaches.

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