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Finite Elementary Modelling for Suspension Glass Type Insulator Under the Contamination Effects

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ABSTRACT

This paper presents the modeling of glass insulators, specifically focusing on the effects of contamination with and without Room Temperature Vulcanizing (RTV) coating. The study selected 132 kV cap and pin glass suspension insulators because of their popularity in transmission systems. The glass insulator has strong dielectric strength to ensure the reliability in transmission system. Despite their advantages, glass insulators can suffer significant performance degradation when exposed to contaminants, leading to increased maintenance and instability in transmission systems. To address these challenges, this research employs Finite Element Modeling (FEM) using Ansys Maxwell in a 3D simulation environment. The study examines the electrical performance of clean uncoated insulator, polluted uncoated, and RTV-coated insulators to evaluate the effectiveness of RTV coatings in mitigating contamination effects. Results demonstrate that polluted insulators experience increased in electric field and current density distributions, which can compromise performance and increase the possibility of flashover and arcing. In contrast, RTV-coated insulators exhibit enhanced performance under polluted conditions, showing significant reductions in both electric field and current density distributions. These findings underscore the importance of RTV coatings in improving the reliability of glass insulators in contaminated environments, thereby reducing maintenance and enhancing the overall performance of transmission lines.

Keywords: Finite Elementary Modelling (FEM); Suspension glass insulator; Contamination effects; Electric field; Current density;

1. INTRODUCTION

In transmission systems, glass insulators serve a dual function by providing mechanical support for cables and reducing the risk of flashover currents and electrical breakdowns in both transmission and distribution systems [1]. As global electricity demand continues to rise, ensuring the stability and reliability of power transmission becomes increasingly important [2]. Glass suspension insulators are typically composed of a series of cap and pin glass discs [3]. These insulators remain popular in transmission lines due to their good dielectric strength and corrosion resistance, which help minimize the likelihood of flashover currents and voltage breakdowns [4]. Any failure of insulators can cause the short circuits and damage to high-voltage equipment [3]. Among the various services, contamination is one of the key factors that affecting the electrical performance of outdoor insulators in high-voltage transmission system [5], [6]. Glass insulators, especially those located near coastal regions, are susceptible to contamination from marine environments. Salty, charged atmospheric particles such as salt and ionic particles can deposit on the surface of glass discs, initiating contamination [7].

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When exposed to wet or humid environment, these deposits may absorb the moisture and develop a conductive pathway on the insulator's surface. Under adverse conditions, partial discharges may extend over the conductive path of the glass disc surface, potentially leading to insulator flashover [8].

While glass insulators are designed with sufficient creepage length to prevent flashover, the presence of conductive particles can reduce the effective creepage distance. To address this issue, Room Temperature Vulcanizing (RTV) coatings have been introduced to glass insulator for the electrical performance enhancement in polluted environments [9], [10]. Figure 1 illustrates an uncoated glass insulator and a red RTV-coated glass insulator.

(a) Without RTV coating (b) With RTV coating

Figure 1. Figure of glass insulator (a) Without RTV coating (b) With RTV coating

The main advantage of RTV coatings is their hydrophobic performance, which improves insulator performance in contamination situations [11], [12]. While previous research has extensively examined the effects of contamination or pollution on insulators, studies on the performance of RTV-coated for 132 kV glass insulators remain limited. This paper aims to evaluate the electric field distribution and current density profile of the glass insulators, both with and without RTV coatings, under contamination effects using Finite Element Modeling (FEM).

2. Glass insulator

2.1 Insulator specifications

In this simulation study, the standard model glass insulator was selected. A glass disc insulator is composed of three parts: a metal cap, a glass disc, and a metal pin. These glass discs are connected in series to form a glass suspension insulator. The dimensions of the glass disc are detailed in Figure 2 and Table 1 [13]. Table 2 presents the materials and electrical parameters of the glass insulator used in the simulation.

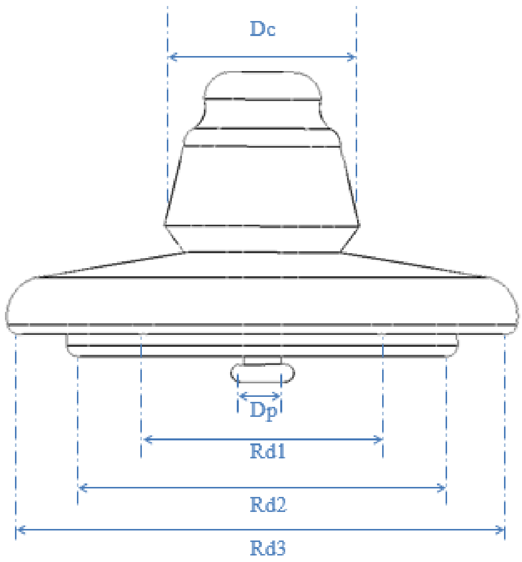


Figure 2. Glass disc insulator profile and its dimension

Table 1 Technical specification of the glass discs [14]

Parameter	Value
Creepage length, Cd	320 mm
Disc diameter,D	255 mm
No of ribs	4
Rib Distance 1,Rd1	50 mm
Rib Distance 2,Rd2	120 mm
Rib Distance 3,Rd3	190 mm
Rib Distance 4,Rd4	255 mm
Pin Distance, Dp	30 mm
Cap Diameter, Dc	80 mm
Weight of glass disc	4 kg

Table 2 Materials and electrical parameters of the glass insulator [15]

Type of Materials	Relative Permittivity (εr)	Bulk conductivity (σ) S/m
Glass	4.2	0
Cement	15	1×10^{-4}
Insulator cap	1000	5.9×10^{-7}

Insulator pin	1000	5.9×10^{-7}
RTV silicon rubber	2.9	1×10^{-13}

2.2 Types of contamination of the insulator

Unlike indoor insulators, outdoor insulators are exposed to atmospheric conditions, making them susceptible to pollution from dust and charged particles in the environment. Table 3 categorizes the types of air contamination affecting insulators.

Table 3 Type of insulator and its effect to insulator [16], [17]

Type of air contamination	Effect on insulator
Industrial pollution	Factories in industrial areas release tiny particles such as conductive and non-conductive particles into the surrounding area. These particles can be carried into transmission grid zones by the wind, eventually forming a pollution layer on the surface of glass insulators over time, depending on various environmental factors. Because industrial pollution on insulators is unpredictable, controlling leakage current from the insulator surface is essential.
Marine pollution	Insulators nearby to coastal areas can develop a conductive layer on their surfaces. Although this salt layer is not hazardous under dry conditions, it becomes dangerous in humid or foggy conditions. Over time, this layer can become thick enough to create a conductive path. The level sodium chloride salinity contamination can be measured and calculated in Equivalent Salt Deposit Density (ESDD), with the units of mg/cm^2. Once the ESDD reaches a critical value, maintenance of the glass insulator becomes necessary.
Desert pollution	In desert zones, transmission systems are exposed to dusty areas. The presence of sand and dust will reduce the electrical performance of insulators and can lead to flashover or arcing. This usually happens under the wind action, the high-speed sand particles can strike the insulator surface, causing material erosion. This condition worsens when sand is accompanied by rain, as the sand deposits accumulate on the insulator surface with high adhesive force.
Biological pollution	Contaminants from living organisms, such as feces from birds and algae, could potentially degrade the surface of insulators to create uneven surfaces and grooves for the pollutant. For instance, oxalic acid released by algae can corrode the insulator surface. The presence and impact of these contaminants are highly dependent on temperature and humidity.

In coastal areas, natural sea salt, primarily composed of sodium chloride (NaCl), is the main contaminant affecting glass insulators. According to IEC 60507, there are four levels of NaCl salinity i.e. 10, 20, 30 and 40 g/L that indicate critical levels of contamination for glass insulators. The relative permittivity of NaCl solution εr = 81 remains constant across all salinity levels [18]. Table 4 presents the electrical parameters associated with each salinity level, representing different contamination levels of electrical insulators which salinity of 40g/L was selected in this study.

Table 4 Level of senility the glass insulator[18]

Salinity Sa (g/L)	Volume Conductivity (σ) S/m
10	1.60
20	3.00
30	4.20
40*	5.60

(Note:* selected pollution level in the simulation work)

In transmission systems, contamination is measured based on salt deposit density. An increase in salt density leads to higher conductivity of the substances, as salt consists of electrostatic charge particles. The presence of these charged particles on the insulator's surface can reduce its efficiency in insulating the flow of electricity [19].

3. Methodology

In this study, Ansys Maxwell 3D was selected to chosen to conduct Finite Element Analysis (FEA) on glass disc insulator. The model of insulator was developed in accordance with standard technical specifications. Figure 3 provides an overview of the insulator model without the RTV coating, while Figure 4 illustrates the RTV-coated glass insulator.

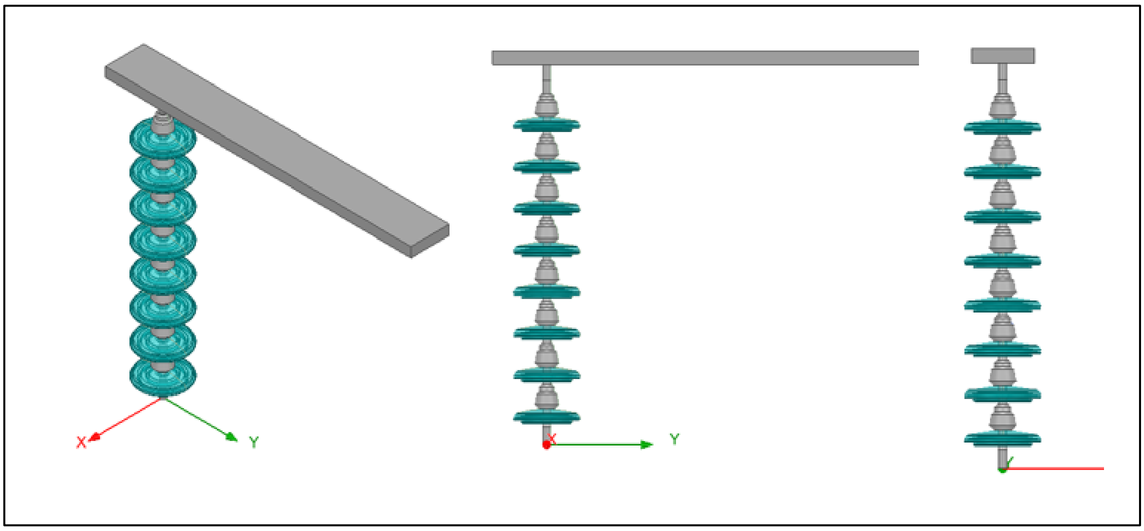


Figure 3. Overview of the 3-Dimensions glass insulator model without RTV coating

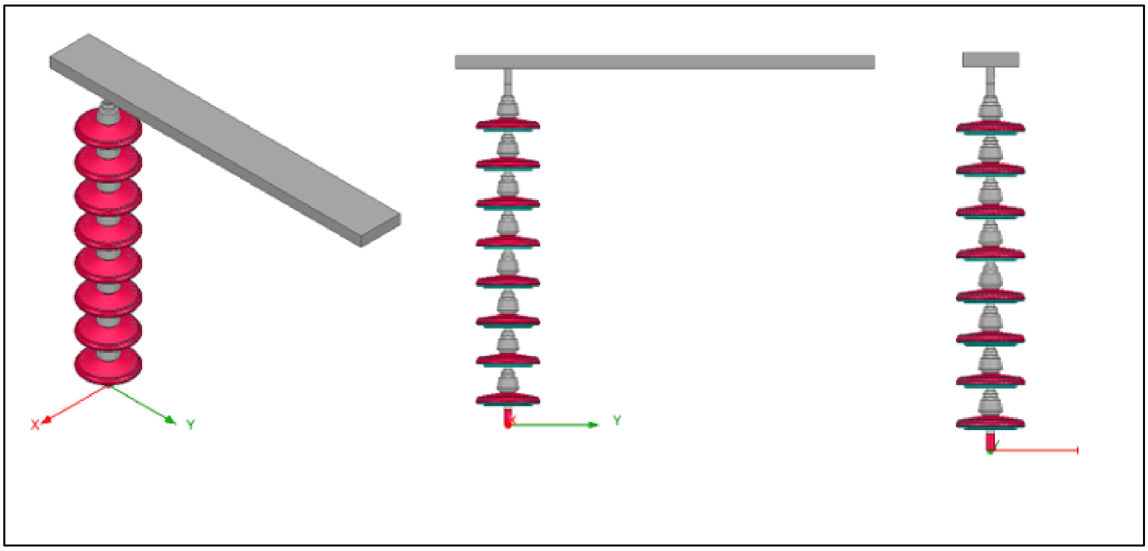


Figure 4. Overview of the 3-Dimensions glass insulator model with RTV coating

Next, the electrical parameters of the 132 kV glass insulator were assigned based on the material properties of each component. Electrical parameters which the relative permittivity and the conductivity were determined using the manufacturer's datasheet and material specifications. The modeling process involved five key components: the metal cap, steel pin, glass discs, steel fittings, and cross arm. Incorporating air into the model as the surrounding environment was essential for accurately simulating real-world conditions. Additionally, a vacuum region was added to define the boundaries of the simulation and serve as a secondary boundary condition. This restricted area, depicted in red in Figure 5, ensures precise modelling by delineating the limits of the simulation space for the insulator.

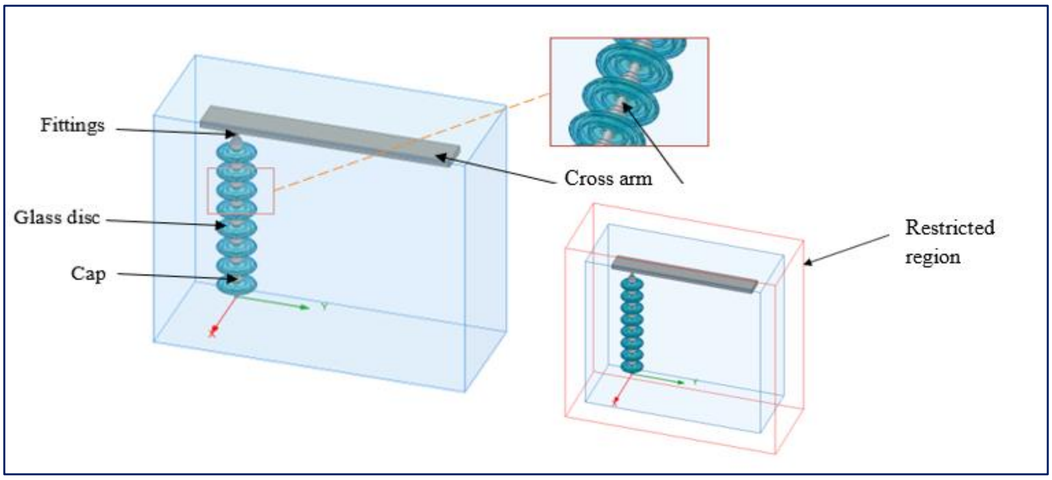


Figure 5. Glass insulator model with service condition air modelling boundry

The insulators were modeled under polluted conditions with a salinity level of 40 g/L, representing a severely polluted environment. Electrical performance was then evaluated under humid conditions, both with and without RTV coating, to allow for comparative analysis. The modeling of 132 kV glass insulators required nodal analysis, necessitating meshing as a precursor to performing Finite Element Modeling (FEM).In this study, a higher mesh gradient was applied to the cross arm, fittings, metal cap, glass disc, and pin, with a resolution of up to 15 mm, to achieve optimal mesh density for accurate results. In contrast, a coarser mesh size of 400 mm was used for air regions. Re-meshing was conducted iteratively until no significant changes in the results were observed, ensuring consistency and accuracy. Figure 6 illustrates the mesh plot of the FEM model.

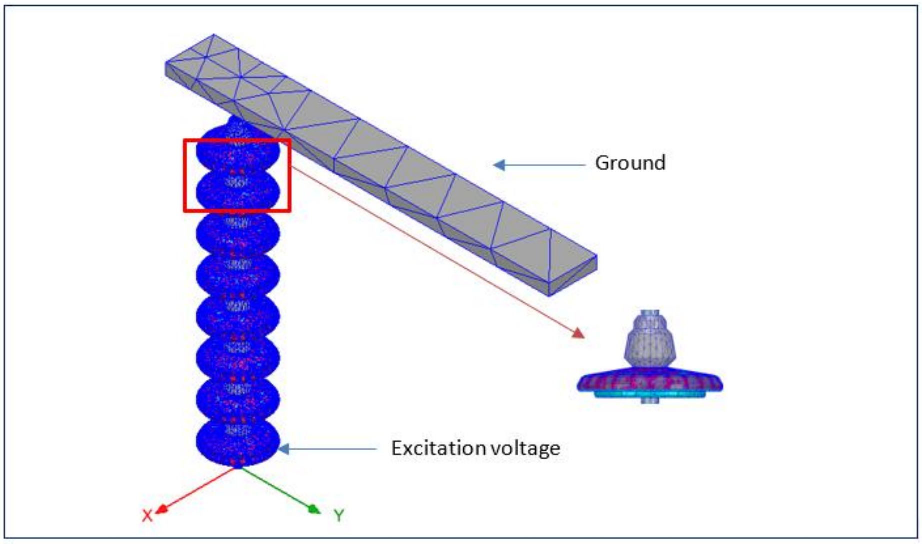


Figure 6. Mesh plot of the glass insulator

4. Results

This study evaluated the electrical performance of glass insulators under the effects of sodium chloride (NaCl) contamination. Simulations were conducted for both clean and contaminated insulators. The contour plots of the insulator illustrate that increased electric fields surrounding the insulator increase the risk of discharge and flashover. Figure 7 presents the contour plot diagram of the electric field distribution along the insulator string.

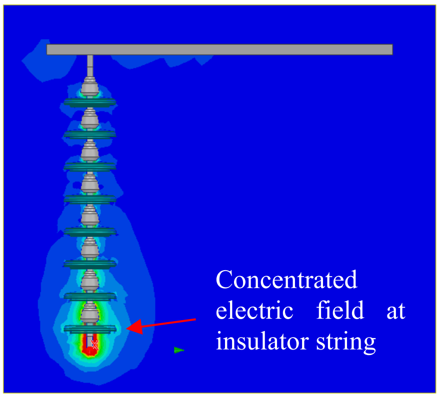
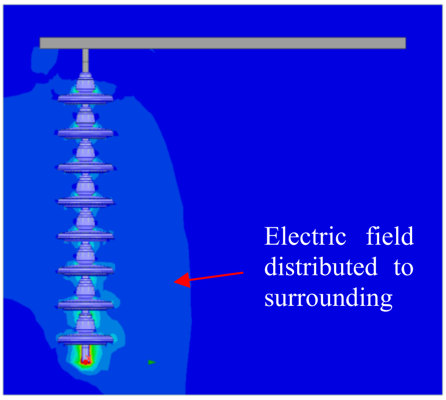
<table>
<tr><th>Clean insulator</th><th>Polluted insulator</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>The electric field was concentrated along the insulator string rather than in the surrounding air, indicating that the glass disc effectively provided electrical insulation to prevent shorting from phase to ground.</td><td>Under the effects of pollution, the electric field was distributed to the surrounding area of the insulator. In other words, the insulation capability of the insulator was reduced due to the conductive surface of pollution layer.</td></tr>
</table>

Figure 7. Counter plot of electric field distribution

By comparing the current density distribution along the insulator, the results show an increase in current density under polluted conditions. This indicates unstable performance, which demonstrated by the rise in leakage current along the insulator, as shown in Figure 8.

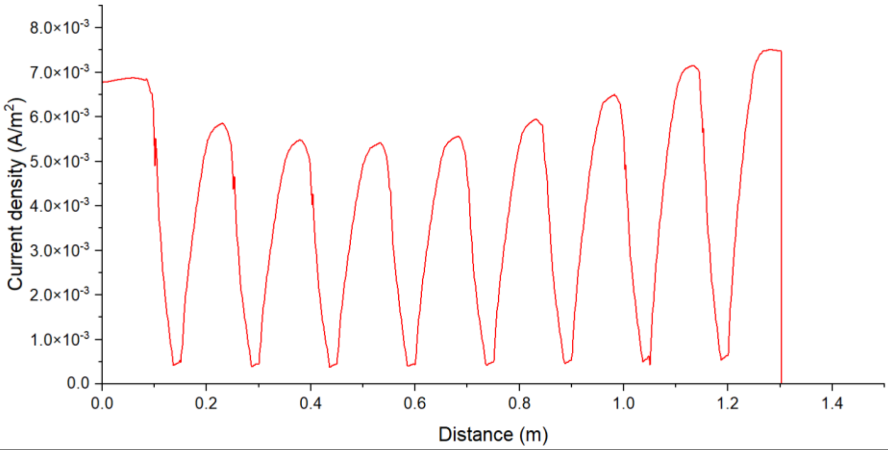
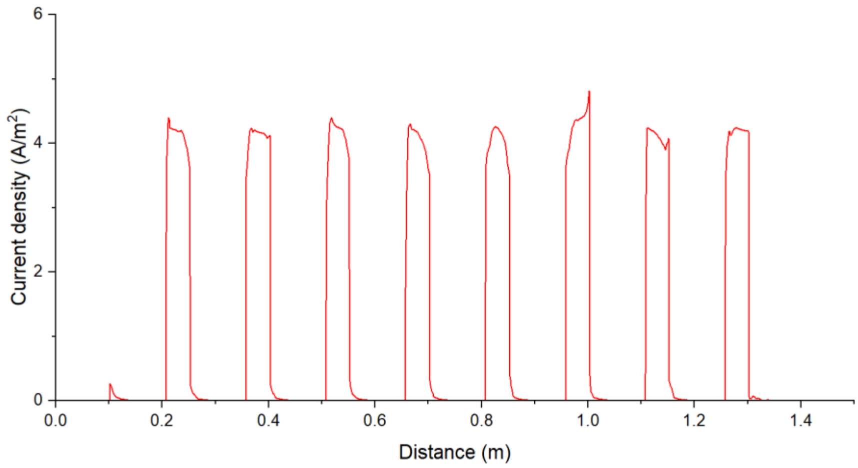
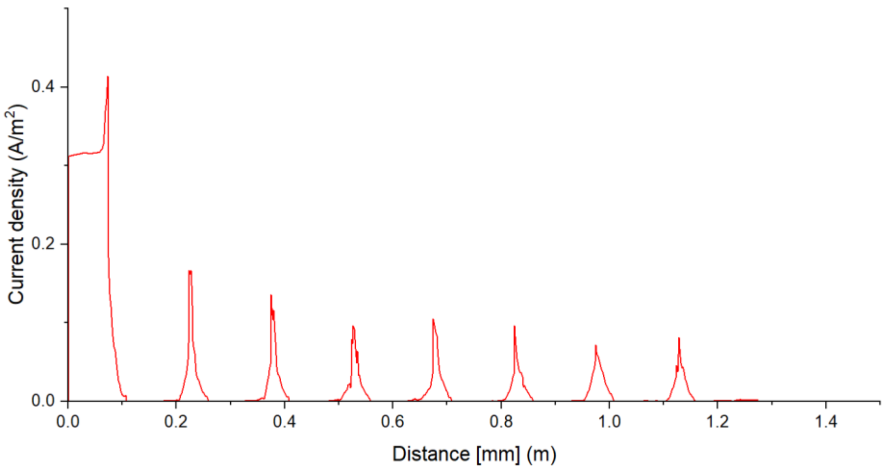
Insulator Type	Current density distribution of glass insulator
Clean insulator	
Polluted insulator	
Polluted insulator with RTV coating	

Figure 8. Current density distribution of the insulator

The results indicate that the clean insulator exhibited a current density of 0.007 A/m^2 under normal operating conditions. However, a sudden spike in current density to a maximum of 4.812 A/m^2 reflects the insulator's unstable performance under polluted conditions. This is possible due to the high conductivity of the contamination level under the effect of electric field distribution [20]. In contrast, the RTV-coated insulator, when exposed to the same pollution level, showed a significant reduction in current density to 0.414 A/m^2. The current density distribution suggests that the RTV-coated insulator maintains stable performance in a polluted environment. Table 5 presents the electric field distributed across the glass insulators, and Figure 9 illustrates the current density distribution along the polluted and RTV-coated glass insulators.

Table 5 Maximum electric field on the glass insulator

No. of the Glass discs	1st	2nd	3rd	4th	5th	6th	7th	8th
Polluted insulator without RTV (1×10^5 V/m)	8.85	4.63	4.77	6.05	6.29	7.49	7.68	5.97
Polluted insulator with RTV (1×10^5 V/m)	6.87	2.95	2.51	1.81	1.98	1.83	1.37	1.57
Reduction	22%	36%	47%	70%	69%	76%	82%	74%

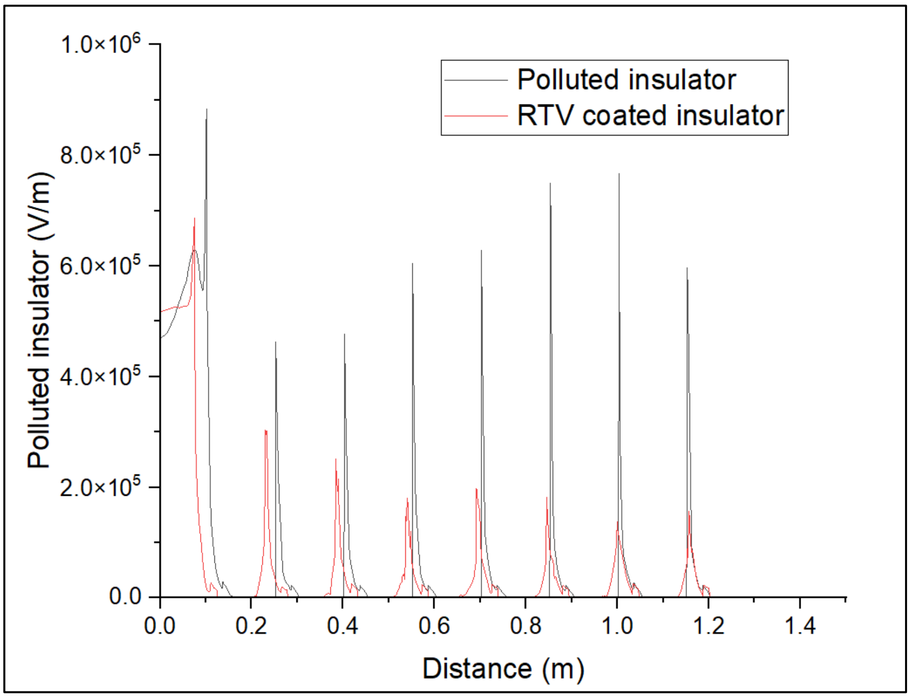


Figure 9. Current density distribution along the polluted glass insulator

The electric field distribution of the glass disc showed a significant reduction with the use of RTV coating. Notably, a substantial decrease in the electric field was observed near the high-voltage end of the insulator, with reductions of up to 82%. The 3D contour plot for the glass disc insulator in Figure 10 illustrates the electric field distribution, particularly focusing on glass disc No. 8.

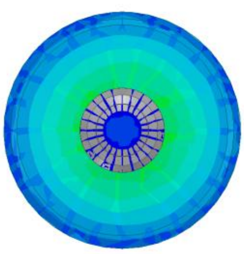
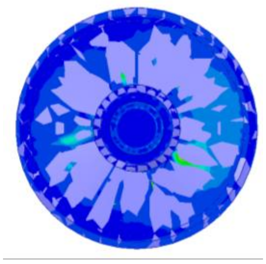
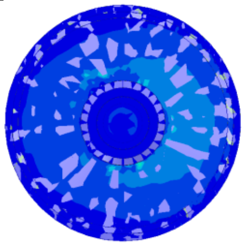
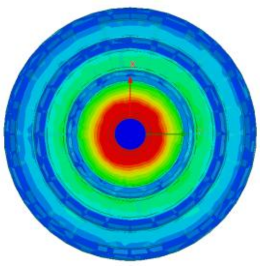
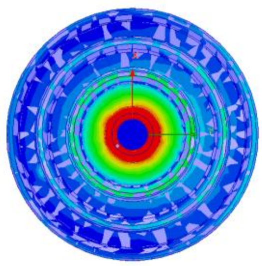
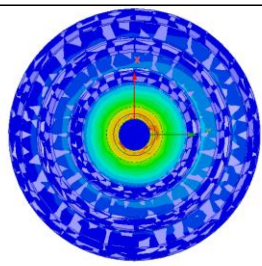
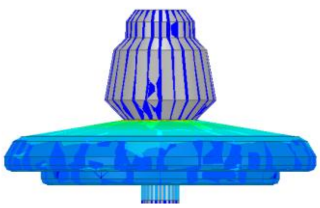
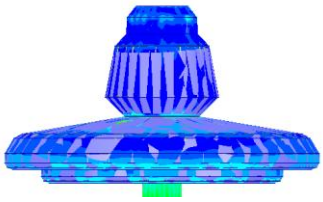
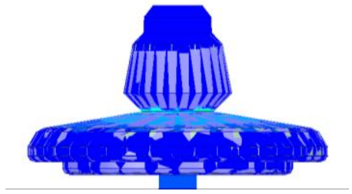
Clean	Polluted	RTV
		
Top surface	Top surface	Top surface
		
Bottom Surface	Bottom Surface	Bottom Surface
		
Side View	Side View	Side View
Reference plot indicator Max: 5.0 x 10^5 V/m Min: 0	Reference plot indicator Max: 5.0 x 10^5 V/m Min: 0	Reference plot indicator Max: 5.0 x 10^5 V/m Min: 0

Fig. 10. Comparison of the electric field distribution across the glass disc

In clean insulators, the electric field is uniformly distributed across the glass discs, indicating optimal electrical performance without intense electric field concentration in any specific area. This uniformity is desirable as it reduces the risk of electrical failure. However, when the glass discs become polluted, the electric field distribution becomes uneven, especially on the top surface of the insulator. Intense electric fields can form conductive pathways due to pollution, increasing the likelihood of dry band formation, which can trigger arcing and flashover if the electric field exceeds the breakdown threshold [21], [22]. This non-uniform distribution is also seen on the side and bottom surfaces, but the top surface experiences the highest electric field concentration. After applying RTV coating to the polluted insulator, the electric field distribution improved significantly. The top and bottom layers exhibited a more uniform distribution, and the electric field spread over a larger area compared to the uncoated polluted insulator. This improvement helps reduce the risk of flashover or electrical breakdown.

5. Conclusion

This paper presented an analysis of the electrical performance of glass insulators under polluted conditions. The electric field and current density were evaluated using 3D Finite Element

Modeling. Results indicated that the unstable distribution of current density along the insulator reached a maximum value of 4.812 A/m² in polluted conditions. However, with the application of RTV coating, the current density was significantly reduced to 0.414 A/m², reflecting a much more stable performance. Furthermore, the RTV coating reduced the electric field distribution across the glass discs by up to 82% due to its excellent hydrophobic properties, which resist contaminants. The presence of RTV coating effectively minimized the risk of flashover, arcing, and leakage current by reducing localized electric field concentrations and current density at critical points. In summary, RTV coating significantly enhances the reliability and stability of glass insulators in polluted environments, making it a valuable solution for improving the electrical performance of transmission systems.

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References

[1] N. A. Othman, M. A. M. Piah, Z. Adzis, and N. A. M. Jamail, "Effects of broken glass insulator on charge distribution along insulator strings," IET Conference Publications (2016) vol. 2016, no. CP688

[2] T. Ahmad and D. Zhang, "A critical review of comparative global historical energy consumption and future demand" Energy Reports, vol. 6, (2020) pp. 1973–1991

[3] M. Othman, S. H. K. Hamadi, and M. Isa, "Simulation Analysis for 33 kV Porcelain Insulator String Based on Room Temperature Vulcanize Coating," 2023 IEEE 3rd International Conference in Power Engineering Applications, ICPEA 2023 (2023) pp. 94–98

[4] N. A. Othman, "Characterization of charge distribution on the high voltage glass insulator string," J Electrostatic, (2014) vol. 72, no. 4, pp. 315–321

[5] A. A. Salem, R. A. Rahman, and S. Al-Ameri, "Pollution Flashover Characteristics of High-Voltage Outdoor Insulators: Analytical Study," Arab J Sci Eng, (2022) vol. 47, no. 3, pp. 2711–2729

[6] L. Maraaba, K. Al-Soufi, T. Ssennoga, A. M. Memon, M. Y. Worku, and L. M. Alhems, "Contamination Level Monitoring Techniques for High-Voltage Insulators: A Review," Energies 2022, (2022) Vol. 15, vol. 15, no. 20, pp. 7576

[7] C. Sun, "Study of pollution accumulation and insulation performance of roof insulators for trains in the coastal environment," AIP Adv, (2023) vol. 13, no. 11

[8] A. A. Salem, "Effect of Pollution Distribution Scenarios on Flashover Characteristics on Outdoor Insulators," 2020 IEEE Student Conference on Research and Development, SCOReD 2020, (2020) pp. 319–324

[9] A. A. Salem , "Pollution flashover characteristics of coated insulators under different profiles of coating damage," (2021) vol. 11, no. 10

[10] S. Huzaimah Kamal Hamadi, M. Isa, S. Nizam M.A. Hashim, and M. Othman, "Review on RTV Silicone Rubber Coatings Insulator for Transmission Lines," IOP Conf Ser Mater Sci Eng, (2020) vol. 864, no. 1

[11] E. A. Cherney, "RTV silicone rubber pre-coated ceramic insulators for transmission lines," IEEE Transaction, (2013) vol. 20, no. 1, pp. 237–244

[12] M. Taghvaei, M. Sedighizadeh, N. NayebPashaee, and A. S. Fini, "Reliability assessment of RTV and nano-RTV-coated insulators concerning contamination severity," Electric Power Systems Research, (2021) vol. 191, p. 106892,

[13] A. A. Salem, "Pollution Flashover Under Different Contamination Profiles on High Voltage Insulator: Numerical and Experiment Investigation," IEEE Access(2021) Vol. 9, pp. 37800–37812

[14] A. A. Salem, "Risk assessment of polluted glass insulator using leakage current index under different operating conditions," IEEE Access, (2020) vol. 8, pp. 175827–175839

[15] M. Othman, M. Isa, Z. C. M. Kasa, M. N. Mazlee, and M. A. M. Piah, "Effect of RTV coating on the electrical performance of porcelain insulator string under dry condition," (2020) in IOP Conference Series

[16] J. A. Ramos Hernanz, J. J. Campayo Martín, J. Motrico Gogeascoechea, and I. Zamora Belver, "Insulator pollution in transmission lines," Renewable Energy and Power Quality Journal, (2006) vol. 1, no. 4, pp. 124–130

[17] G. N. D. S. Surya M, K. P. Rani, and K. V. S. R. Murthy, "Effect of Pollution on Insulators in High Voltage Transmission Line," Advances in Transdisciplinary Engineering, (2022) vol. 27, pp. 400–405

[18] M. Izadi, M. Z. A. A. Kadir, C. Gomes, M. Syahmi, and M. Hajikhani, "Effects of air humidity on the performance of a polymer insulator under lightning induced voltage conditions," 2016 33rd ICLP 2016 (2016)

[19] M. M. Hussain, S. Farokhi, S. G. McMeekin, and M. Farzaneh, "The effects of salt contamination deposition on HV insulators under environmental stresses," Proceedings of the IEEE International Conference, vol. (2015), pp. 616–619

[20] N. Sunthrasakaran, N. A. M. Jamail, M. H. A. S. Kandar, and N. A. Muhamad, "Electric field and current density characteristic of contaminated solid insulator," International Journal of Integrated Engineering, (2018) vol. 10, no. 8, pp. 120–126

[21] A. A. Salem and R. Abd-Rahman, "A Review of the Dynamic Modelling of Pollution Flashover on High Voltage Outdoor Insulators," in Journal of Physics: Conference Series, Institute of Physics Publishing (2018)

[22] Arshad, A. Nekahi, S. G. McMeekin, and M. Farzaneh, "Effect of pollution severity and dry band location on the flashover characteristics of silicone rubber surfaces," Electrical Engineering, (2017) vol. 99, no. 3, pp. 1053–1063