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Numerical Simulation of the Electric Field and Potential Distribution Analysis in a 20 kV Polymeric Insulator Under the Influence of Mechanical Defects and Various Non-Uniform Pollution Patterns

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Abstract

The electrical performance of polymeric insulators is affected by surface pollution and mechanical defects. This study investigates the effects of uniform and non-uniform pollution, including ring-shaped (RNU) and ring-longitudinal (RLNU) patterns, as well as shed damage and core defects, on the electric field and potential distributions of a 20-kV polymeric insulator using COMSOL Multiphysics. For the RLNU pattern, heavy pollution was assumed near the electrodes and light pollution in the middle region. For the RNU pattern, equal inner and outer areas were considered, with pollution applied to the inner region. The results show that uniform pollution produces a higher maximum electric field than the investigated non-uniform patterns. Furthermore, shed damage and core defects significantly affect the potential distribution and increase the maximum electric field in the high-voltage, middle, and low-voltage regions compared with a healthy insulator.

Keywords: Polymeric insulator; Electric potential distribution; Electric field Distribution; Mechanical defects; Non uniform pollution; FEM analysis.

1. Introduction

Polymeric insulators are widely used in electrical transmission and distribution networks due to their favorable insulating properties and hydrophobic characteristics [1]. However, surface pollution and environmental conditions, particularly humidity and fog, can alter the electric field and potential distributions, increasing the likelihood of surface discharges and electrical flashover [2-3]. Furthermore, different pollution patterns, including uniform, non-uniform ring-shaped, and ring-longitudinal patterns, can affect the electric field intensity and insulation performance due to variations in pollution distribution [4-5].

In addition to surface pollution, mechanical defects in the sheds and core of polymeric insulators can affect the electric field distribution by altering the geometry of the insulating structure. Despite previous studies on the effects of pollution and structural defects, investigating their combined influence on the electrical behavior of polymeric insulators remains important [6-7].

Accordingly, this study investigates the electric field and potential distributions in a 20-kV polymeric insulator under different surface conditions, including clean, uniformly polluted, non-uniform ring-shaped polluted, and ring-longitudinal polluted conditions, using the finite element method implemented in COMSOL Multiphysics. The effects of mechanical defects in the sheds, with defect levels of 6.5%, 12.5%, and 25%, as well as core defects, are also evaluated by considering the pollution layer thickness and defect location. The main objective is to identify regions susceptible to electric field concentration and investigate the effects of surface pollution and mechanical defects on the electric field and potential distributions of the insulator.

2. Simulation Considering Pollution and Mechanical Defects

The investigated insulator is a 20-kV polymeric suspension insulator consisting of a fiberglass core, a silicone rubber housing, and galvanized steel end fittings. The numerical analysis was performed using the electrostatics module of COMSOL Multiphysics based on the finite element method. An AC voltage of 16.3 kV was applied to represent the maximum phase voltage. The pollution layer was modeled with an electrical conductivity of (10^{-6}) S/m, while its thickness was varied to investigate the effect of pollution severity. A hybrid mesh was employed to discretize the computational domain. The electric field and potential distributions were evaluated along the creepage and arcing distances under clean, uniformly polluted, RNU, and RLNU conditions. Furthermore, shed defects with damage levels of 6.5%, 12.5%, and 25%, as well as a defective core near the high-voltage electrode, were considered to assess the influence of mechanical damage.

3. Results and Discussion

The results demonstrate that pollution distribution significantly influences the electric field intensity and potential distribution. Under clean conditions, the maximum electric field along the arcing distance was 0.204, 0.068, and 0.219 kV/mm in the high-voltage, middle, and low-voltage regions, respectively. Under uniform pollution, these values increased to 0.245, 0.103, and 0.253 kV/mm. In comparison, the corresponding values for RNU were 0.229, 0.084, and 0.237 kV/mm, while those for RLNU were 0.204, 0.072, and 0.232 kV/mm. These results indicate that uniform pollution produces the highest maximum electric field among the investigated pollution patterns.

The effect of pollution layer thickness was also investigated for values of 0.4, 0.8, 1.6, and 2 mm. The results show that increasing the pollution layer thickness from 0.4 to 2 mm increases the maximum electric field by 6.3%, 3.49%, and 4.5% under uniform, RNU, and RLNU pollution conditions, respectively. This finding confirms the significant influence of pollution severity on the electric field distribution.

The investigation of mechanical defects revealed that shed damage and core defects increase the maximum electric field compared with the healthy insulator. Under RNU pollution, the maximum electric field in the high-voltage region increased from 0.317 kV/mm for the healthy insulator to 0.367 kV/mm for a 25% shed defect. In the middle region, the corresponding value increased from 0.088 to 0.166 kV/mm. For the defective core, the maximum electric field in the middle region reached 0.191 kV/mm. These results indicate that the middle region is particularly sensitive to mechanical defects. Furthermore, the location of the defect significantly influences the electric field distribution, with defects in the middle region producing higher field concentrations than those near the electrodes.

4. Conclusion

The numerical results demonstrate that both pollution distribution and mechanical defects significantly affect the electric field and potential distributions of a 20-kV polymeric insulator. Uniform pollution produces a higher maximum electric field than the investigated non-uniform pollution patterns, while increasing pollution layer thickness intensifies the electric field. Mechanical defects, particularly those located in the middle region, lead to additional field concentration and increase the maximum electric field compared with the healthy condition. These findings highlight the importance of considering pollution patterns, pollution layer thickness, defect severity, and defect location in the electrical assessment of polymeric insulators. The proposed numerical analysis provides useful insight into the identification of critical regions and the evaluation of insulator performance under polluted and mechanically damaged conditions.

References

- [1] Li, W., and Y. Zhang. "Comparison of dielectric properties of polymeric materials in high-voltage applications." *Journal of Electrical Engineering* 76, no. 3 (2024): 211–220.
- [2] Tanaka, T., and G. C. Montanari. "Polymer nanocomposites as dielectrics and electrical insulation." *IEEE Transactions on Dielectrics and Electrical Insulation* 18, no. 5 (2020): 1482–1517.
- [3] George, G., and M. J. Thomas. "Studies on tracking resistance of polymeric outdoor insulators." *IEEE Transactions on Dielectrics and Electrical Insulation* 17, no. 3 (2020): 899–906.
- [4] Hackam, R. "Outdoor HV composite polymeric insulators." *IEEE Transactions on Dielectrics and Electrical Insulation* 6, no. 5 (2020): 557–585.
- [5] Ghiasi, Z., et al. "FEM analysis of electric field distribution for polymeric insulator under different configuration of non-uniform pollution." *Electrical Engineering* (2021): 1–10.
- [6] Kone, G., C. Volat, and H. Ezzaidi. "Numerical investigation of electric field distortion induced by internal defects in composite insulators." *High Voltage* 2, no. 4 (2017): 253–260.

[7] Fasani, D., R. Tallarida, C. Medrano, and M. Rossi. "Diagnostics of internal defects in composite overhead insulators using an optic E-field sensor." *Sensors* 24, no. 5 (2024): 1359.