Effect of Pollution Layer Conductivity and Thickness on Electric Field Distribution along a Polymeric Insulator

Arshad*[1], A. Nekahi[1], S.G. McMeekin[1], M. Farzaneh[2]

[1] School of Engineering and Built Environment, Glasgow Caledonian University

[2]Canada Research Chair on Atmospheric Icing Engineering of Power Networks (INGIVRE) www.cigele.ca Université du Québec à Chicoutimi, QC, Canada

[*] 70 Cowcaddens Road Glasgow, G4 0BA, United Kingdom, arshad@gcu.ac.uk

Abstract: Electric field distributions along a polymeric insulator under wet and contaminated conditions were studied in this paper. To study the effect of pollution layer conductivity and thickness on the electric field distribution along a standard polymeric insulator, simulations were carried out with commercial simulation package Comsol Multiphysics. Pollution layer was modelled as a conductive water layer and conductivity was varied from 10^{-6} to 10^{-3} S/m. Similarly, thickness of pollution layer was varied from 0.5 to 2 mm in steps of 0.5. It was observed during simulations that electric field intensity increases with increase in pollution layer conductivity and thickness. The result of this study will further our knowledge regarding the performance of polymeric insulators under various polluted environments.

Keywords: electric field, pollution, polymeric insulators.

1. Introduction

High voltage insulators are used extensively in power transmission and distribution industry and are exposed to various types of contaminations. Theses contaminants can range from sea salt to cement dust and various type of fertilizers used for agricultural purpose [1]. Deposition of pollution constituents on the insulator surface may not influence its dielectric characteristics during dry conditions but during rain, mist or cold fog, the insulator surface becomes wet and forms a conductive layer. Leakage current is driven along the wet insulator surface by the electric field. The flow of leakage current along the insulator surface leads to surface heating, dry band formation, partial arcs and under certain conditions leads to flashover [2].

Electric field stress at any point along an insulator is very important for the long term performance and need to be analyzed. Electric field distribution around polymeric insulators has been investigated in literature [3-5]. Most of the previous studies were based on the effect of water droplets on the electric field distribution and does not consider uniform pollution layer [6, 7]. Due to the high electric field stress at the junction of water droplet, insulator surface and air, water droplets elongates in the direction of electric field. Elongation of water droplets leads to the formation of a uniform layer along the insulator surface which facilitates the flow of leakage current [8]. Effect of uniform pollution layer on the electric field and potential distribution was studied in [5]. Pollution was modelled as a uniform water layer of 2 mm thickness and conductivity of pollution layer was varied to simulate light, medium, heavy and very heavy polluted environments. Effect of dry band width and location on electric field distribution was studied in [9] and concluded that electric field intensity increases with increase in dry band width and highest electric field stress exist at the junction point.

In this paper, electric field distribution along a standard 33-kV polymeric insulator was studied under polluted environments. Conductivity and thickness of the pollution layer was varied to investigate their effect on the electric field distribution. In this study a regular shed polymeric insulator was used as shown in Fig.1.

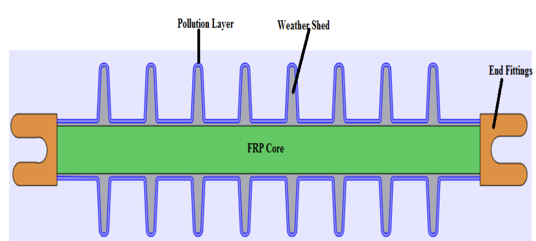


Figure 1. Regular shed polymeric insulator

The polymeric insulator in Fig.1 consists of a Fiber Reinforced Plastic (FRP) core, silicone rubber as weather sheds material and metal end fittings [9]. All the dimensions of the insulator and simulation parameters are given in Table 1.

Table 1: Insulator and simulation parameters

No. of Sheds	8
Leakage Distance	900 mm
Shed Diameter	105 mm
Sheath Diameter	30 mm
Service Voltage	33 kV
SIR Relative permittivity	4.3
FRP Relative permittivity	7.2
Relative permittivity of water	81

2. Use of COMSOL Multiphysics

Electric field distribution along a standard 33 kV polymeric insulator was calculated with Comsol Multiphysics. Electric currents formulation was used to study the effect of pollution conductivity on the electric field distribution. Thickness of pollution layer was changes from 0.5 to 2 mm in steps of 0.5 mm with different combination of layer conductivity to investigate effect of pollution layer thickness on electric field and potential distribution. The equation governing the electric field computation in Comsol is given below [10].

$$\nabla.J = Q_j \tag{1}$$

$$J = (\sigma + j\omega\varepsilon_0\varepsilon_r + J_e) \tag{2}$$

$$\nabla E = \frac{\rho}{\varepsilon} \tag{3}$$

$$-\nabla(\nabla E) = \frac{\rho}{\varepsilon} \tag{4}$$

$$\varepsilon\nabla(\nabla E) = 0 \tag{5}$$

$$J = \sigma E \tag{6}$$

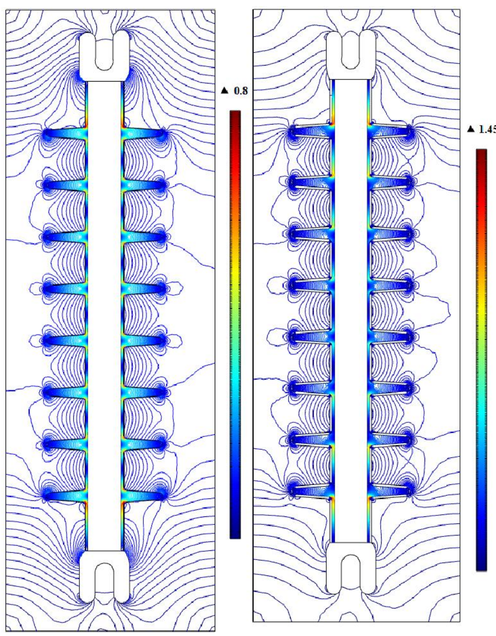
Where ρ is the resistivity, ε is the dielectric constant, J is the current density and σ is the conductivity of pollution layer

3. Results and Discussion

Electric field stress at any point along the insulator surface is considered to be responsible for corona and dry band arcing under certain conditions [11]. Non-uniform electric field distribution along the insulator surface can affects their flashover characteristics and can damage the insulator in long term due to corona discharges. It has been investigated in literature that corona and dry band arcing are closely related with the ageing, erosion and degradation of insulator surface [12]. Electric field distribution along a standard 33 kV polymeric insulator was investigated under contamination conditions to evaluate the effect of pollution on electric field stress along the insulator surface and the possibility of corona and dry band arcing initiation. It was observed during simulations that pollution layer thickness, and conductivity changes the electric field distributions along the insulator surface. This trend was more evident in the case of change in thickness as compared to conductivity. As the pollution layer thickness was changed from 0.5 to 2 mm, the electric field increase from 0.8 to 1.45 kV/cm as shown in Figs. 2 and 3. Conductivity of the pollution layer was kept constant at 500 uS/cm for the first case. Although conductivity of the pollution layer is same, but increase in layer thickness leads to increase in current density and subsequently electric field.

Effect of pollution severity on electric field distribution was studied in [5], and it was shown that electric field intensity increases with increase in pollution severity. Similarly it was shown in [7] that the threshold limit for electric field to initiate a discharge along the insulator surface is 0.45 kV/mm. In this section simulation were carried out at four different conductivities of pollution layer and results are shown in Figs.4 and 5. It can be seen from Fig.4 that as the pollution conductivity increases, electric field intensity increases. Highest electric field stress was calculated for layer conductivity of 10^{-3} S/m.

Pollution layer thickness was kept constant at 1 mm. Based on the simulation results, it was observed that electric field is dependent on pollution layer conductivity as well as thickness. It was also observed that increase in electric field intensity is more pronounced with increasing layer thickness as compared to conductivity.



(a) (b)

Figure 2. Electric field distribution along a polymeric insulator with pollution layer thickness (a) 0.5 mm (b) 2.0 mm

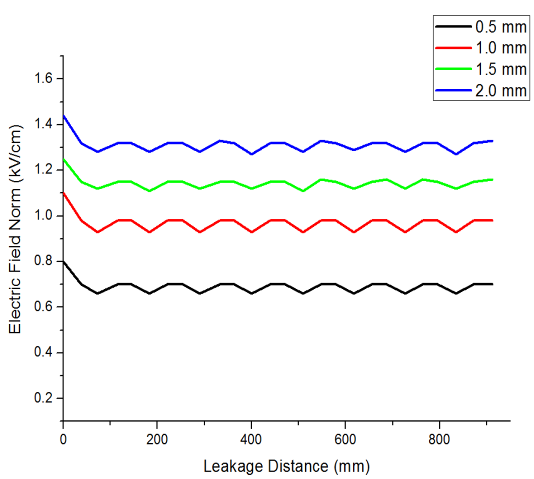
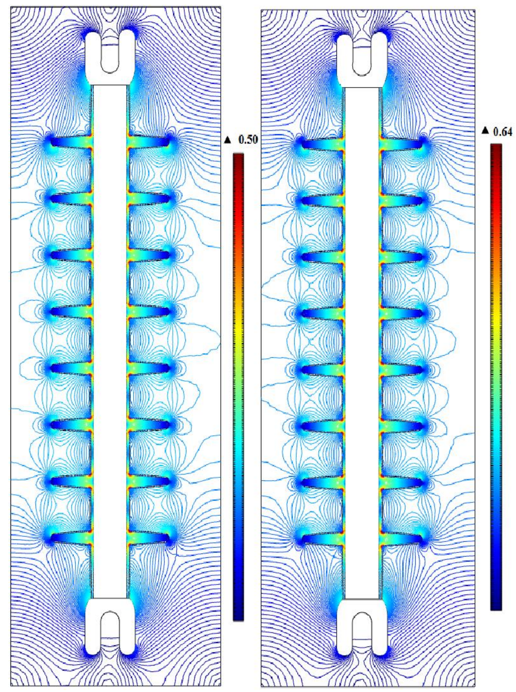


Figure 3. Electric field distribution along a polymeric insulator with different pollution layer thickness



(a) (b)

Figure 4. Electric field distribution along a unifromly polluted polymeric insulator with layer conductivities (a) 10^{-6} S/m (b) 10^{-3} S/m

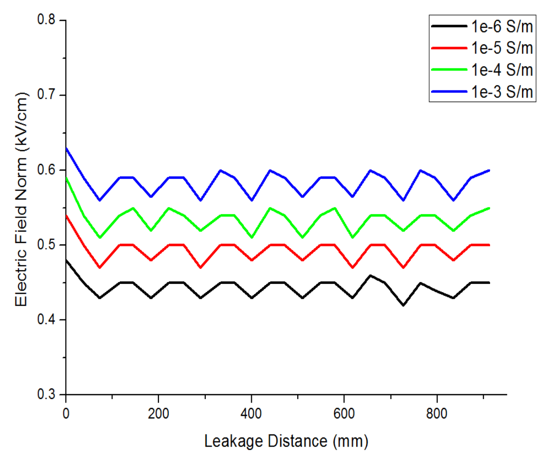


Figure 5. Electric field distribution along a unifromly polluted polymeric insulator with different layer conductivities

4. Conclusions

Simulations were carried out with Comsol Multiphysics to study the effect of pollution layer thickness and conductivity on the electric field distribution along a standard 33 kV polymeric insulator. Based on the simulation results it was concluded that electric field is greatly influenced by pollution layer conductivity and thickness. As the pollution layer conductivity and thickness increases, electric field intensity increases. The highest electric field was observed to be 1.45 kV/cm in the case of a 2-mm thick pollution layer. The results of this study could be used for the design and selection of polymeric insulators for polluted conditions.

5. References

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