Influence of Voltage Type and Polarity on Electric field distribution along a Polymeric Insulator under Contaminated Conditions

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Abstract: Electric field distribution along an insulator surface is of prime importance for the long term performance of insulators. In this paper electric field and potential distribution along a standard 33 kV polymeric insulator were investigated under different pollution conditions. Effect of voltage type and polarity on the electric field and potential distribution under contaminated conditions were discussed. Pollution was modelled as a 2-mm conductive water layer and the conductivity of layer was set to 500 uS/m. Numerical simulations were carried out in Comsol Multiphysics to study the effect of AC, DC+ and DC- applied voltage on the electric field and potential distribution. The results of this study will help scientists and engineers in the selection of insulators for AC and DC applications under contaminated conditions.

Keywords: Electric filed, AC, DC+, DC-, Pollution

1. Introduction

During the last few decades, polymeric insulators are extensively used in power transmission and distribution industry. It offers the advantage of light weight, easy handling and hydrophobic characteristics [1]. Outdoor insulators are exposed to pollution and other environmental factors influencing their performance. Cost of outdoor insulators is only a few percent of the whole transmission infrastructure, but the reliability of transmission system is highly dependent on the performance of outdoor insulators [2]. Under contaminated conditions, outdoor insulators are most vulnerable to external flashover. Flashover phenomena of outdoor insulators are influenced by many factors including, humidity, ambient temperature, and air pollution [3]. It has been investigated previously that air pollution in combination with moist conditions is responsible for flashover of outdoor insulators [4]. Although polymeric insulators are used in AC applications for a long time, there is very little service experience in DC applications.

With the development of offshore renewable energy generation high voltage DC technology has become the focus of research for scientist and engineers. The non-uniform electric field under DC applied voltage due to charge accumulation on the insulator surface leads to insulator failure and subsequent power outage [5]. Electric field distribution along a uniformly polluted silicone rubber insulator under AC applied voltage has been investigated in [6, 7]. Effect of pollution severity and dry band location on electric field distribution has been discussed in [8]. Effect of voltage polarity on the electric field and potential distribution along an FRP hot stick has been studied in [9]. It was shown in [9] that the magnitude of electric field is not influenced by the voltage polarity but the arc propagation along the FRP hot stick may change due to the change in polarity. These results show that numerical computation of electric field distribution along an insulator could be used to determine the corona and dry band arcing inception conditions and arc propagation. The investigations carried out for AC voltage may not be applied to DC application due to the charge accumulation on the insulator surface in the case of DC voltage. Moreover the DC electric field is dependent on the electrical conductivity of material unlike the electrical permittivity in the case of AC electric field [10]. Due to the temperature dependence of electrical conductivity, DC electric field also changes with temperature [11]. Effect of material conductivity and temperature on DC electric field is not considered in this paper and simulations are carried out to investigate AC and DC electric field under similar contaminated conditions.

This paper addresses the effect of voltage type and polarity on the electric field and potential distribution along a standard polymeric insulator. A standard 33 kV polymeric insulator was used for simulations, and electric field distribution at AC, DC+ and DC- were calculated. The polymeric insulator consists of a metal end fitting, Fiber Reinforced Plastic (FRP) as a load bearing structure, and silicone rubber is used for weather sheds. The insulator used for simulation is shown in Fig. 1. Pollution is modelled as a 2-mm conductive water layer on the surface of insulator. Conductivity of the pollution layer is set to 500 uS/cm. Simulation parameters and insulator dimensions are given in Table 1.

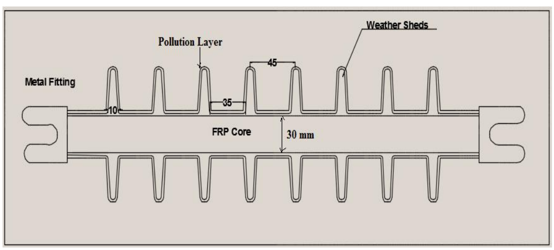


Figure 1. A Standard 33 kV polymer insulator

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
Conductivity of Pollution layer	500 uS/cm
Conductivity of SIR	1e-12 S/m
Conductivity of FRP	0.004 S/m

2. Use of COMSOL Multiphysics

Finite element numerical model was used in Comsol Multiphysics to calculate electric field and potential distribution along a standard 33 kV polymeric insulator. The electrostatic formulation was used for simulations. Mathematical equation governing the electric field and potential distribution are as follows.

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

$$\nabla E = \frac{\rho}{\varepsilon} \tag{2}$$

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

$$\varepsilon\nabla(\nabla E) = 0 \tag{4}$$

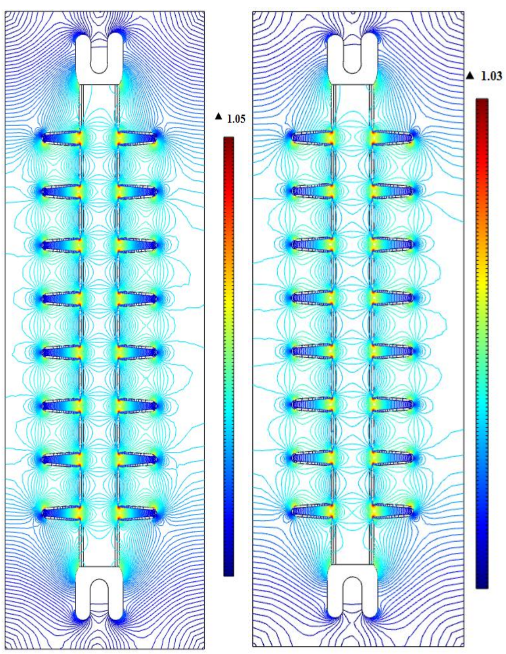
$$J = \sigma E \tag{5}$$

Where ρ is the resistivity, ε is the dielectric constant, J is the current density and σ is the conductivity of pollution layer. The cade model in Fig.1 was imported into Comsol Multiphysics to carry out simulations for AC, DC+ and DC- simulations. To improve the simulation accuracy extra fine meshing were used and the entire insulator geometry including the air boundary was divided into equal elements.

3. Results and Discussions

Electric field stress along the surface of outdoor insulators influences their long term performance. Electric field distribution along an insulator could be used as a diagnostic tool to investigate the possible damage and service life of an insulator. Various parameters like insulator geometry, material, air humidity and ambient temperature, pollution contamination, voltage type and polarity affect the electric field distribution along outdoor insulators. In this paper three important parameters are considered for investigation: pollution contamination, voltage type, and voltage polarity.

Electric field distribution along a standard 33 kV polymeric insulator under DC+ and DC- voltages are shown in Fig. 2 a and b. The electric field norm in both DC+ and DC- are almost the same and there is very little effect of voltage polarity on electric field distribution. At a pollution layer conductivity of 500 uS/cm, the maximum electric field intensity was calculated to be 1.05 and 1.03 kV/cm for DC+ and DC- respectively. Figure 3 shows the electric field distribution for AC applied voltage. The highest electric field in the case of AC applied voltage was calculated to be 0.72 kV/cm, much lower than the DC electric field stress. Figure 4 shows a comparison of DC and AC electric field. It is evident from Fig. 4 that electric field norm in the case of DC+ and DC- is quite similar but different than the AC. The higher electric field in the case of DC applied voltage is due to the static charge accumulation on the insulator surface and the dependence of material conductivity on surface temperature. Figure 5 shows the voltage distribution along the insulator for DC+ and AC voltages. The DC voltage distribution is more uniform as compared to AC due to the changing polarity in each cycle in the case of AC.



(a) (b)

Figure 2. Electric field distribution along a polluted polymeric insulator (a) DC+ (b) DC-

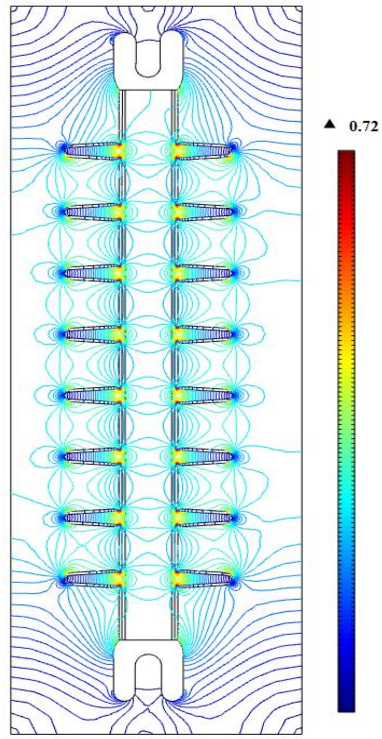


Figure 3. Electric field distribution along a polluted polymeric insulator under AC voltage

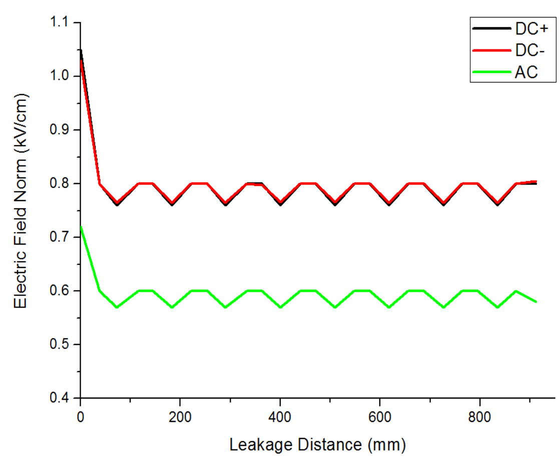


Figure 4. Electric field distribution along a polluted polymeric insulator under AC, DC+ and DC- voltage

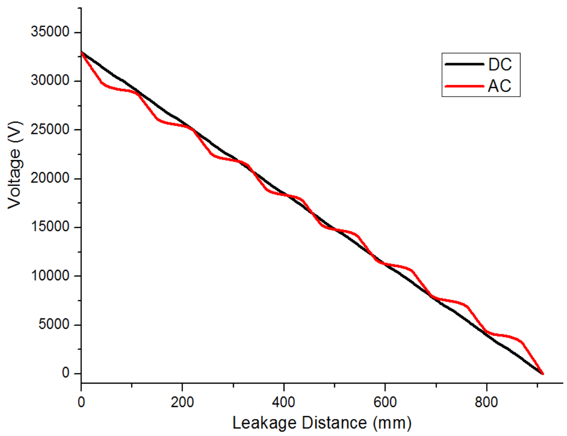


Figure 5. Potential distribution along a polluted polymeric insulator under AC, DC voltage

4. Conclusions

Effect of voltage type and polarity on electric field and potential distribution were studied in this paper. It was observed that voltage polarity has very little effect on electric field distribution but voltage type effect electric field and potential distribution. It was also found that electric field is higher in the case of DC applied voltage as compared to AC under similar service conditions. The results of this work will augment our knowledge regarding electric field and potential distribution along polymeric insulators for AC and DC applications.

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