Effect of Contaminant Flow-rate and Applied Voltage on the Current Density and Electric Field of Polymer Tracking Test

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• Abstract

Electrical failure due to surface discharge on the insulation material will cause material degradation and eventually leads to system failure. The flow of leakage current (LC) on the insulator surface under wet contamination was used as the technique for determining the material degradation level. According to IEC 60587 standard, the LC exceeding 60 mA for more than two seconds is considered as failure. The analysis of electric field and current density distributions on the linear low-density polyethylene (LLDPE) and natural rubber blend material using finite element method (FEM) analysis was conducted. The physical parameters used in FEM simulation were applied voltage and contaminant flow rate which is in term of contaminant conductivity. Tracking test condition of IEC 60587 standard was applied as the reference work in simulation using FEM software of QuickField. The results show that the electric field and current density were critical in higher applied voltage and contaminant flow rate. The highest average and maximum current density and electric field reported in both applied voltage of 6 kV and flow rate of 0.90 mlmin^{-1}.

Keywords. Finite Element Software; Electric field; Current density; Surface discharges; Polymeric insulator; IEC 60587.

1 Introduction

Surface discharge is a phenomenon of failure on insulating surface due to intensive leakage current (LC) flow by heating the insulating surface which eventually causes a tiny arc under contaminated conditions. The arcing will burn the polymer based material causing carbon track which can bridge the conductor and hence leading to electrical failure. Online monitoring LC are widely used by many researchers to investigate the tracking and erosion resistance of the materials [1, 2]. The result shows that LC is proportional to the degree of material degradation [3]. The simulation of electrical stresses due to water droplet and void was studied by the researchers [4-6]. It was found that the electric field, admittance, and dielectric loss increase in defective void insulator. When applied voltage is increased, the electric field intensity and current density loss increase [4]. Tracking is more severe in defective samples in which the presence of surface contamination increases the distortion of electric field around the defect [6]. Electric field was enhanced at the contact edges between electrodes and polymer surface and at the triple point of polymer, water, and air when water droplet was placed at the center of the gap [5]. In this work, the distribution of electric field and current density on the insulator surface were conducted using Finite Element Software under wet condition. The analysis was performed using linear low-density polyethylene (LLDPE) and natural rubber blend material. The simulation of finite element analysis (FEA) complies with the test set-up configuration of IEC 60587 standard tracking and erosion test. The controlled parameters used in the simulation were applied voltage, electric conductivity and permittivities of insulating sample and contaminant solution.

2 Methods

2.1 FEM Simulations

The electric field and current density distribution on the insulating model were solved using FEA software of QuickField. The test configuration methods used for evaluating resistance to tracking and erosion particularly IEC 60587 standard was used as simulation reference model. Figure 1 presents the simulation drawing of two-dimensional (2D) model plane parallel. According to inclined plane tracking method of IEC 60587 standard, a rectangular sample with a size of 50 mm x 120 mm and thickness of 6 mm was used [7].

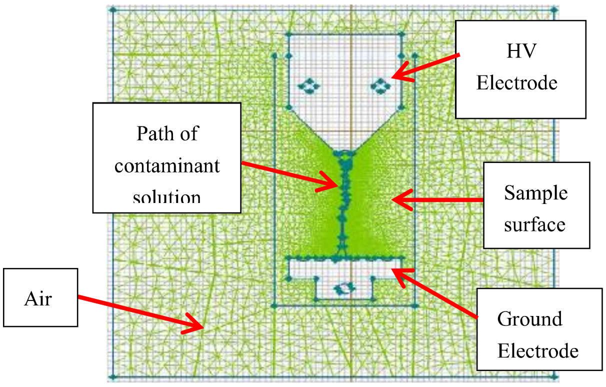

Figure 1: Simulation model of test specimen with the electrodes

The high voltage (HV) was connected to upper electrode and grounded at bottom electrode. The path of contaminant solution was drawn according to the actual pattern captured from the experiment. Materials properties of electric conductivity and relative permittivity of the sample, contaminant solution and air were required for simulation purpose. The relative permittivity and conductivity of the air is 1 and 2 x 10^{-4} Sm^{-1} [8], respectively. The relative permittivity of contaminant solution is 81 [9]. The formulated thermoplastic elastomer material composed of Linear Low-Density Polyethylene with Natural Rubber (LLDPE/NR) with 80:20 ratios was chosen. Table 1 shows the material properties for insulator sample. The conductivity and capacitance were measured using polarization and depolarization current (PDC) measurement and inductance, capacitance, resistance (LCR) meter between upper and bottom electrode, respectively.

2 **Table 1.** Material properties

3

Capacitance (pF)	Relative Permittivity	Conductivity(S/m)
91.9	31.13	3.137 x 10^{-08}

In this paper, parameters used to study the electric field and current density distributions were contaminant flow rate and applied voltage. To indicate the change in contaminant flow rate in the simulation works, conductivity of contaminant solution was used. According to the IEC 60587 standard, the volume of contaminated solution was different for each contaminant flow rate. Therefore, the conductivity of contaminant solution was altered based on equation (1) and (2) respectively. Table 2 shows the electric conductivity of contaminant solution.

$$\sigma = \frac{1}{\rho} \qquad (1)$$

$$R = \frac{\rho\, l}{A} \qquad (2)$$

where R ,ρ, l and A are the resistance , resistivity, length of contaminant solution and area of contaminant solution respectively.

4 **Table 2.**Electric conductivity of contaminant solution.

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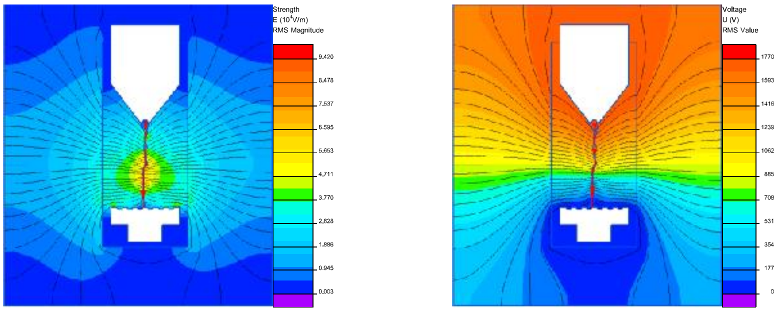
Contaminant flow rate (ml/min)	0.15	0.30	0.60	0.90
Volume of contaminant (cm^3)	0.15	0.30	0.60	0.90
Area of contaminant (cm^2)	0.70	0.77	1.18	1.24
Resistance (kΩ)	65.83	32.92	16.46	10.97
Resistivity (Ω.m)	92.16	50.7	38.85	27.2
Conductivity (S/m)	0.011	0.020	0.026	0.037

3 Results and Discussion

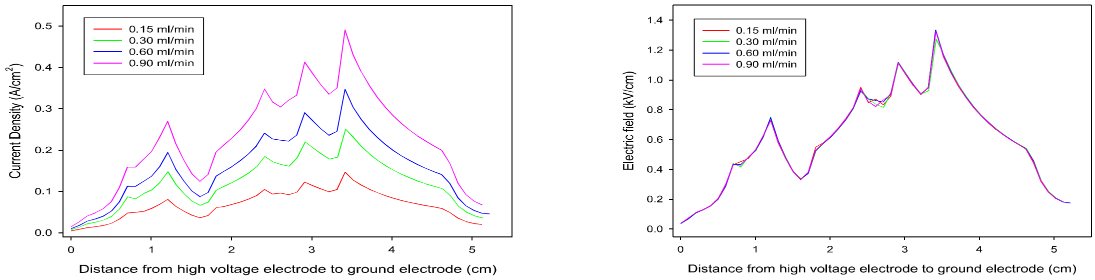
In FEM analysis, AC conduction analysis was selected to solve the electric field and current density distribution on the insulator surface caused by alternating currents and voltages in imperfect dielectric media. Figure 2 shows the electric field and voltage distribution on the insulator surface.



(a) (b)

Figure 2. (a) Electric field distribution, (b) Voltage distribution

6 The applied voltage was set to be constant with different contaminant flow rate. The contaminant flow rate was varied to 0.15 mlmin^{-1}, 0.30 mlmin^{-1}, 0.60 mlmin^{-1}, and 0.90 mlmin^{-1}. It is worth to mention that the conductivity of the contaminant solution was varied with fixed applied voltage. Figure 3 represents the graph of current density and electric field distribution from HV electrode to a ground electrode with a constant voltage of 4.5 kV. The current density distribution was increased with the increase of contaminant water conductivity. As the contaminant layer become thick, the resistance on the surface reduces and hence more LC density at that particular location. However, the electric field distribution shows no changes as the applied voltage were constant.



(a) Current density (b) Electric field

Figure 3. Current Density and electric field for constant voltage of 4.5 kV

The same method was then repeated, but the contaminant flow rate was fixed while the applied voltage was varied to 2.5 kV, 3.5 kV, 4.5 kV and 6.0 kV. Figure 4 shows the graph of current density and electric field for constant flow rate of 0.90 mlmin^{-1} that equivalent to 0.037 Sm^{-1} for electric conductivity. Result in Figure 4 shows that the increase in applied voltage raises the current density and electric field distribution on the insulator surface. Table 3 reported the maximum current density and electric field value for constant contaminant flow rate of 0.90 mlmin^{-1} and it was concluded that increase of applied voltage will increase in both current density and electric field. The high electric field strength shows the increase in current density at certain location and hence the electric discharge activity will exist on the insulator surface. The high LC flow will cause uniform heating which may lead to dry band arcing and eventually damages the insulator surface. When heated, it causes evaporation in contaminant film. This film breaks up into small portions and each of them tends to interrupt a segment of LC causing a small partial discharge (PD). PD can occur along the surface of insulator, if the surface tangential of electric field is high enough to cause a breakdown along the insulator surface.

7 **Table 3.**Current Density and Electric Field for different level of applied voltage in constant contaminant flow rate.

Applied voltage (kV)	2.5	3.5	4.5	6.0
Maximum Current Density (A/cm ^{2})	0.08	0.21	0.35	0.63
Maximum Electric Field (kV/cm)	0.70	1.06	1.33	1.70

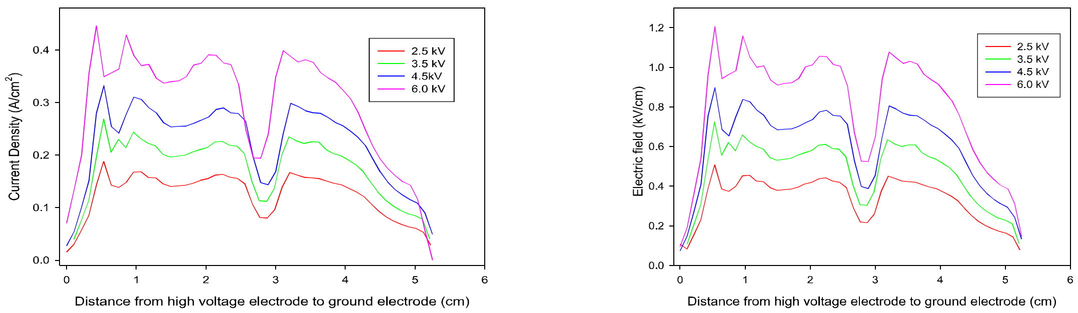


Figure 4. Current Density and electric field for constant contaminant flow rate of 0.90 ml/min.

4 Conclusion

In investigating the electric field and current density distributions on the insulator surface, the geometry plane parallel was established using Finite Element Analysis. The inclined plane tracking test (IEC 60587) was used as reference in the simulation. The simulation analysis shows that the increase in contaminant flow rate and applied voltage will contribute to the increase in current density and electric field distribution.

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