Electron Avalanches Near a Charged Insulator

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Abstract

Electron avalanches near a charged solid insulator have been simulated using four different electric field profiles: Linear, exponential, rectangular and triangular. Photoemission from the solid dielectric has been incorporated in the growth of an avalanche. Results indicate the sensitivity of electron avalanche growth to the electric field profile and to a large extent to the photoemissive contribution from the insulator.

1: Introduction

In order to understand the mechanisms associated with surface flashover in a compressed gas insulated system, it is essential to investigate the role of a solid dielectric surface in such a system. The formulation of the growth of electrons near a solid dielectric interface is complicated due to the propagation of electrons in the non-uniform field. It can be assumed that the electron growth takes place primarily in the gas and nearby solid surface contributes to the ongoing avalanche in the form of (i) non-uniform electric field due to charging of an insulator and (ii) photoemission. The detailed procedure for such a simulation was discussed in our previous papers [1,2].

Prediction of exact electric field profile near a solid dielectric is difficult due to the presence of surface charges. There is a considerable variation in the nature and magnitude of a surface charge [3,4]. This variation is usually attributed to the surface condition, defects, type of dielectric, etc. Therefore, there will be a considerable variation in the nature of electric field profiles near a solid dielectric. In the present paper, four different profiles of electric field near a solid dielectric have been assumed and the electron avalanches simulated in nitrogen gas at 0.1 MPa. Photoemission from the solid dielectric surface has also been taken into account in the form of a photoemission coefficient ($\gamma_s$). Localized triangular and exponential profiles are assumed for the photoemissive contribution.

2: Electric field profiles

2.1: A linear profile

As indicated in Figure 1, a field enhancement near cathode and a corresponding field reduction near anode have been assumed. The variation of electric field in the enhancement and reduction regions is assumed to be linear. A positive surface charge on a dielectric could give rise to such a variation of the electric field. In the linear profile $f_a = 0.125$ and $f_c = 1.0$.

2.2: An exponential profile

This is similar to linear profile except the fact that actual variation of the field enhancement ($f_c$) and field reduction ($f_a$) factors is described by the following equations.

$$f_c = -\frac{1}{a_1} \cdot \ln(x + 0.9)$$

$$f_a = -\frac{1}{a_2} \cdot \ln(1.2 - x)$$

where $a_1 = 0.1035$ and $a_2 = 9.5623$. 


In order to compare different profiles, it is essential to keep the areas formed by enhancement and reduction profile triangles to be constant. With each area $= 0.05$ and $x_e = 0.1$ and $x_m = 0.2$, the values of $f_e$ and $f_b$ were found out (Fig. 2). ($x_e$ represents the extent of enhancement and $x_m$ represents the start of reduction.)

2.3: A rectangular profile

An enhancement near both triple junctions and a corresponding reduction in the central part of the gap gives rise to a rectangular shaped electric field profile (Fig. 3). Once again, enhancement and reduction factors were evaluated by assuming the total area on enhancement side (both rectangles) to be same as the area on the reduction side, each area being $= 0.05$.

2.4: A triangular profile

Field enhancement was assumed near both triple junctions and a corresponding reduction at the central part of the insulator (Fig. 4). The variation of field enhancement and reduction factors was assumed to be linear and is described by the following equations.

$$f_1 = 1 + f_e \cdot (x_e - x)/x_e$$  
$$f_2 = 1 - f_b \cdot (x - x_e)/(x_b - x_e)$$  
$$f_3 = 1 - f_b \cdot (x_a - x)/(x_a - x_b)$$  
$$f_4 = 1 + (f_a \cdot x)/(1 - x_a) - (x_a/(1 - x_a))$$
3: Photoemission profiles

Figure 5 illustrates two photoemission profiles. In the triangular profile, only 10% of the length of the insulator was photoemissive at any time. In the exponentially decreasing profile, the entire length of the insulator was photoemissive. Since $x$ is a variable, it should be noted that these are spatially moving profiles.

![Photoemission Profiles](image)

Fig. 5: Photoemission Profiles, (a) Triangular and (b) Exponential.

4: Results and discussions

Growth of electrons with primary ($\alpha$) and secondary ($\gamma$) ionization processes was simulated by following the procedure described in the previous papers [1,2]. Electron avalanches near a solid insulator having linear electric field profile along with two different photoemission profiles are illustrated in Figure 6. Similarly, results of electron avalanche simulation with exponential, rectangular and triangular electric field profiles are illustrated in Figures 7, 8 and 9, respectively. All simulations were performed with a 1 cm long insulator, an external voltage of 30 kV and at 0.1 MPa of nitrogen gas.

Comparison of Figures 6(a), 7(a), 8(a) and 9(a) indicates that with an applied voltage of 30 kV and the secondary ionization coefficient for solid insulator ($\gamma_s$) to be seven times that of the nitrogen gas, all avalanches die down. Sharp spikes superimposed on avalanches with rectangular and triangular electric field profiles can be easily observed. These spikes are due to abrupt changes in the electric field profiles and appear somewhat like corona pulses.

![Figure 6(a)](image)

Fig. 6(a): Electron Avalanche with a Linear Electric Field and Triangular Photoemission Profile.

![Figure 6(b)](image)

Fig. 6(b): Electron Avalanche with a Linear Electric Field and Exponential Photoemission Profile.
Fig. 7(a): Electron Avalanche with an Exponential Electric Field and Triangular Photoemission Profile.

Fig. 8(a): Electron Avalanche with a Rectangular Electric Field and Triangular Photoemission Profile.

Fig. 7(b): Electron Avalanche with an Exponential Electric Field and Exponential Photoemission Profile.

Fig. 8(b): Electron Avalanche with a Rectangular Electric Field and Exponential Photoemission Profile.
Comparison of Figures 6(b), 7(b), 8(b) and 9(b) indicates that with an external voltage of 30 kV and the secondary ionization coefficient for solid insulator ($\gamma_s$) to be only 30% of that in nitrogen gas, all avalanches do not die down. Although $\gamma_s = 0.3\gamma$, it should be noted that the entire length of the insulator was considered photoemissive. A significant deviation in the avalanche in Fig. 8(b) seems to lead towards breakdown. Once again, abrupt changes in electric field profile result in coronalike pulses.

5: Conclusions

Simulated electron avalanches near a charged and photoemissive solid insulator in nitrogen gas indicate extreme sensitivity to the electric field profile and to the photoemission profile. Rectangular and triangular electric field profiles result into high frequency oscillations which appear somewhat like corona discharges. Precise measurements of optical radiation along the length of the solid insulator are needed for gaining knowledge of the photoemission profile: either a localized triangular or an exponential all along the length of the insulator.

6: References


