FRI-10.326-1-EEEA-02

TOWNSEND AVALANCHES MODEL BASED CURRENT-VOLTAGE CHARACTERIZATION OF DIELECTRIC BARRIER DİSCHARGE

Prof. Hafiz Alisoy, DcS
Department of Electronics and Communication Engineering, Namik Kemal University, Tekirdag, Turkey
Tel.: (+90)282 2502386
E-mail: halisoy@nku.edu.tr

Asst. Prof.B.BarısAlagoz, PhD
Department of Computer Engineering, Inonu University, Malatya, Turkey
Phone:
E-mail: baykant.alagoz@inonu.edu.tr

Assoc. Prof.GulizarAlisoy, PhD
Department of Mathematics, Namik Kemal University, Tekirdag, Turkey
Phone: (+90)282 2502734
E-mail: galisoy@nku.edu.tr

Abstract: *This paper presents an analytical method for Current –Voltage characterization (I-V) of partial discharges in corona electrode systems. In this method, an analytic average current model based on Townsend avalanche density of electrodes surface is derived for I-V characterization of corona electrode systems. The method is applied to current analysis of plate electrode system.*

Keywords: *Partial discharges, Townsend avalanche, Current –Voltage characterization.*

INTRODUCTION

This study considers the avalanche density of electrodes surfaces for average current estimation of corona discharges. The avalanche density of an electrode surface can be defined as average frequency of electron avalanches, which are initiated from an unit area of the avalanche generative surface of electrodes. The avalanche generative surface is an area on electrode surface that is capable of initiating Towsend avalanches as depicted in Fig 1. This area depends on geometry of electrodes and electrode potential. Because, an avalanche generative surface (S_g) appears on the sections of corona electrode (S), where the electric field intensity in the vicinity of these electrode sections exceeds corona inception field (E_c). Hence, on the boundary of an avalanche generative surface, the electric field intensity is equal to E_c .

In a statistical point of view, avalanche generative surfaces is regions covering the electrode surface where distribution of the avalanche density is greater than zero. Since the electrical field intensity distribution is not uniform on electrode surface, the distribution of avalanche density around electrode surfaces does not be uniform except an infinite parallel electrode system that can provide a uniform electrical field intensity distribution on the surface of electrode system.

Overall current leaking trough the electrode gap is assumed to be the superposition of the currents that are mostly carried by concurrent electron avalanches initiated from S_g regions. That is why, the avalanche density distribution on the S_g region of corona electrode determines magnitude of average current of electrode system.

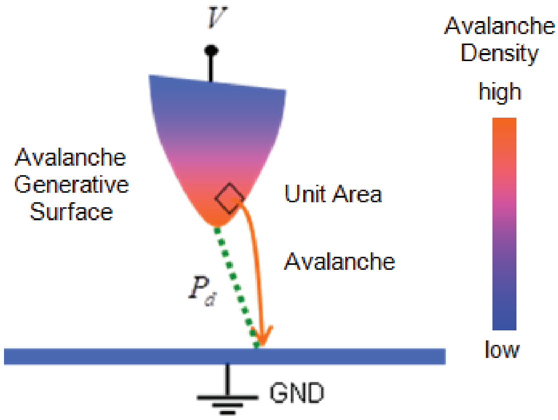

Figure 1. The electrode system in which the electron avalanche extends

METHODOLOGY

Avalanche Density Modeling for Average Current Leakage Trough an Electrode Gap

Number of electron concentration in a Townsend avalanches grows exponentially in space. This process was well defined by

$$\frac{\partial N}{\partial r} = \alpha \cdot N \,, \tag{1}$$

where N is the electron concentration in the electron avalanche and variable r represents the distance to the point where an electron avalanche begins to grow, the parameter α is Townsend ionization coefficient, that is, the number of ionization events performed by electron in a 1 cm range along electric field. It is required to know the analytical expression of the ionization α - and attachment η- coefficients, which depend on the electrical field, pressure and physicochemical properties of medium such as electron energy distribution function, mean free path, collision cross section and drift velocity of the electrons. Also, the expressions of $\frac{\alpha}{p} = f\left(\frac{E}{p}\right)$ and $\frac{\eta}{p} = f\left(\frac{E}{p}\right)$ denoting the dependence of those coefficients on E/p must be known (Raizer,1987, Niemeyer,1995&, Alisoy,2011, Alisoy,2013). The ionization coefficient for binary gas mixture is obtained as (Alisoy, 2011)

$$\left(\frac{\alpha}{p}\right) = \frac{E}{p}\sum_{j=1}^{k} A_j \exp\left(-\frac{B_j}{(E/p)}\right). \tag{2a}$$

If each $A_j exp\left(-\frac{B_j}{E/p}\right)$ term in Eq. (2a) is expanded by using Fourier series, then the ionization coefficient for binary gas mixture is expressed as

$$\left(\frac{\alpha}{p}\right) = \sum_{j=1}^{k} a_j \left(\frac{E}{p} - b_j\right)^2 , \tag{2b}$$

where, expression a_j and b_j are coefficients that are obtained from the simplification of Eq. (2a). Especially, the coefficient b_j has a physical meaning for electronegative gases. In electronegative gases, negative ions occur because of attachment phenomena due to the inelastic collision of electrons with molecules besides ionization, dissociation and excitation phenomena. Formation of negative ions decreases the ionization effects in the gas medium (Alisoy, 2011). So, in electronegative gases the effective ionization coefficient defined as $\alpha_{eff} = \alpha - \eta$, must be considered. In this case, the coefficient b_j corresponds to the intersection point of α/p and η/p curves and defined as critical value of $(E/p)_{cr}$ (see Alisoy, 2011).

After Equation (1) is solved and assuming that avalanges initiates by a single electron $N(r=0)=0$ and there exits none-avalanching electrons, number of electron in a single avalanches was obtained as,

$$N(\alpha_{eff},r)=\exp(\alpha_{eff}\cdot r)+N_o\,, \tag{3}$$

where N_o is the number of electrons, which does not result in an electron avalanches but moves in electrode gap.

Let $w(s)$ denote a avalanche density function on the S_g , the number of electron generated from a unit area of S_g in a per unit time can be written as $w(s)\cdot N(\alpha_{eff},r)\cdot ds$. In an electrode gap, many electron avalanches is supposed to be initiated from S_g region of corona electrode surfaces at the same time, the total number of electrons generated in electrode gap in a second can be written as,

$$N_T=\int_{S_g} w(s)\cdot N(\alpha_{eff},r)\; ds\,. \tag{4}$$

When equation (3) is used in equation (4), total number of avalanche electron generated in per unit time can be expressed in a general form as,

$$N_T=\int_{S_g} w(s)\cdot(\exp(\alpha_{eff}\cdot r)+N_o)\; ds\,. \tag{5}$$

Average current leaking the electrode gap will be determined by total charge arrived at the cathode in a per unit time. In a corona electrode system, these charges are carried by electrons in electron gap as to be a free electrons or electrons attached to negative ions. In this reason, the total number of electrons generated in electron gap in an unit time will determine average value of the current. So, considering equation (5), average current leaking in the electrode gap can be expressed depending on electron charge (e) as the following:

$$I=eN_T=\int_{S_g} e\cdot w(s)\cdot(\exp(\alpha_{eff}\cdot r)+N_o)\; ds \tag{6}$$

Equation (6) expresses the average current of any electrode configuration. Here, effect of the electrode configuration (e.g. shape, surface texture etc.) on the average current is conveyed by $w(s)$ avalanche density distribution over an S_g area.

The avalanche density, which is avalanche frequency initiated from a unit area of S_g , can be expressed with respect to the avalanche period $T(s)$, as $w(s)=1/T(s)$. In previous works (Florkowska1993, Florkowska2011, Illias et al.,2011), avalanche period was considered as the presence time of charge carriers in electrode gap. (This is due to the fact that a new avalanche can be initiated after completion of the previous one. The conditions should be suitable for generation of a new avalanches.) The charge presence time can find by solving the following motion equation of a charge carrier particle for a distance between corona electrode and ground plate electrode.

$$\frac{dr}{dt}=v_d=\mu\cdot E(r) \tag{7}$$

Here, v_d is drifting velocity of charge carrier particles along the drifting paths. Parameter μ is mobility of charges and $E(r)$ is average value of electrical field on the drifting path of particles. Then, for a ds element on S_g, the presence time of charge carrier particle in electrode gap can be written as,

$$T(ds) = \int_0^{P_d(ds)} \frac{1}{\mu \cdot E(r)} dr . \tag{8}$$

When the equation (8) is solved for a P_d drifting path from a ds unit area of S_g to ground plate electrode and assuming that $E_a(r)$ is average electrical field on the drifting path of particles from ds, one can write

$$T(ds) = \frac{P_d(ds)}{\mu \cdot E_a(ds)} . \tag{9}$$

By considering the equation (9), avalanche density function for a ds unit area can be simply obtained as,

$$w(ds) = \frac{1}{T(ds)} = \frac{\mu \cdot E_a(ds)}{P_d(ds)} . \tag{10}$$

In this equation, $P_d(ds)$ for each ds unit area of S_g should be determined with respect to electrode geometry and curvatures. Average electrical field $E_a(ds)$ depends on electrode geometry as well as voltage applied to corona electrode. In the further sections, average current given by equation (6) will be written for plate electrode configurations.

Average Current Leakage in Parallel Plate Electrode Systems:

In a plate electrode system (see Fig.2), distance between electrodes does not vary on the S_g surface, that is, one can assume $P_d(ds) = L$ because infinite paralell plate system forms almost an uniform electrical field intensity distribution between the electrode gaps, which was expressed as $E = V / L$. For unit area consideration, one can easly assume an uniform electrical field distribution $E_a(ds) = V / L$. In this case, avalanche density function can be simplified as the following:

$$w = \frac{\mu \cdot V}{L^2} \tag{11}$$

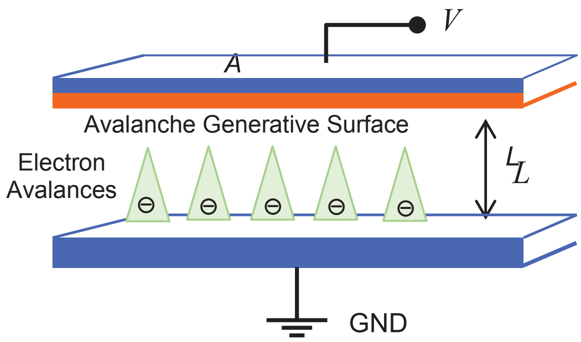

Figure 2. Schematic diagram of parallel plate electrode systems

Here, parameter V represents voltage drop between electrodes and parameter L denotes distance between paralell plate electrodes. Considering the equation (6) and $r = L$ for paralell plates, the average current leaking in the electrode gap can be obtained,

$$I = \frac{A \cdot e \cdot \mu \cdot V}{L^2} \cdot (\exp(\alpha_{eff} \cdot L) + I_o, \tag{12}$$

where $I_o = \frac{A \cdot e \cdot \mu \cdot V}{L^2} \cdot N_o$ is the leakage current of electrode system that is not subject to Townsend avalanches. The A represents area of plate electrodes which is written as $A = \int_{S_g} ds$.

One can express $\exp(\alpha_{eff} \cdot L)$ in form of $\exp((\frac{\alpha_{eff}}{p}) \cdot (pL))$ to consider effect of pressure (p), the equation (12) can be rearranged as,

$$I = \frac{A \cdot e \cdot \mu \cdot V}{L^2} \cdot \exp((\frac{\alpha_{eff}}{p}) \cdot (pL)) + I_o. \tag{13}$$

By using equation (2b) in (13), one obtains,

$$I = \frac{A \cdot e \cdot \mu \cdot V}{L^2} \cdot \exp(\sum_{j=1}^{k} a_j (\frac{E}{p} - b_j)^2 \cdot (pL)) + I_o. \tag{14}$$

CONCLUSION

An analytical model for analysis of Townsend avalanche currents is proposed for partial discharges in corona electrode systems. In this modelling, avalanche density function and avalanche generative surfaces are proposed to consider effects of electrode system geometry. Therefore, a general analytical expression based on the density of Townsend avalanches on the surface of electrodes is derived. For illustration purposes, the method was applied to a plate electrode system and the average current formula was obtained with respect to electrode system parameters such as the area of electrode system, pressure, distance between plates.

REFERENCES

Raizer Y.P. (1987). *Gas Discharge Physics*, Springer-Verlag.

Niemeyer, L. (1995). A generalized approach to partial discharge modelling. *IEEE Trans. Dielectr. Electr. Insul.*, 2, (4), 510– 528.

Florkowska, B., Włodek, R. (1993). Pulse height analysis of partial discharges in air. *IEEE Trans. Electr. Insul.*, 28, 932–940.

Alisoy H. Z., Ali Yesil, Murat Koseoglu, Ibrahim Unal. (2011). An Approach for Unipolar Corona Discharge in N2/O2 Gas Mixture by Considering TownsendConditions. *Journal Of Electrostatic,* 69, 284-290.

Illias, H., Chen, G., Lewin, P.L., (2011). Modeling of partial discharge activityin spherical cavities within a dielectric material, IEEE Electr. *Insul.Mag.*, 27, 38–45.

Florkowska, B., Florkowski, M., Roehrich, J., Zydron, P. (2011). Partial discharge mechanism in a non-uniform electric field at higher pressure, *IET Sci.Meas.Technol.*,5, (2), 59– 66.

Alisoy H. Z., Alagoz S., Alisoy G. T. and Alagoz B. B. (2013) An Investigation of Ionic Flows in a Sphere-Plate Electrode Gap. *Plasma Science and Technology*, 15(10), 1012–1019.