

## CRITICAL REVIEW OF THREE CAPACITOR MODEL FOR PD ESTIMATION IN MICRO-VOIDS OF POLYMER INSULATED CABLES

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### ABSTRACT

*Dealing with optimization of production process of high voltage and extra high voltage power cables and accessories, it may be necessary to link the size of a defect (cavity, delamination, interface, etc.) to the amplitude of the partial discharges generated by the defect itself. Literature offers various models for PD amplitude. This paper provides a brief review of existing PD models, highlighting their limits and introducing a novel method for advanced modelling of electronic avalanche, which allows the discharge to be simulated, accounting for the main physical phenomena controlling its development, through an iterative procedure.*

### KEYWORDS

Partial discharge amplitude, Three capacitor model, ABC circuit, PD simulation.

### INTRODUCTION

PD occurring in gas-filled cavities of power cable systems are electronic avalanches generated by ionization of gas molecules under the effect of the electric field. The energy of the electron avalanche is released to the cavity walls, causing a localized degradation of the insulation properties. The severity of the defect is thus related to the PD charge and, therefore, this quantity is widely used as an acceptance criterion for cable testing.

The first attempt to link quantitatively the cavity size with the PD amplitude was the so-called three capacitor model, based on the change of the capacitance of the system during the discharge process. This approach has shown significant physical inconsistencies: absence of any change in capacitance during the discharge and the absence of an equipotential surface at the wall of the void [1 - 2].

A better approximation is provided by the induced charge model, which offers a simple way for the calculation of PD amplitude, provided that the potential collapse across the cavity due to the PD is known [1-6]. In that case [7, 8]:

$$q = \pm \epsilon_0 \pi l g \Delta U_{PD} \quad [1]$$

where  $\epsilon_0$  is void permittivity,  $l$  is the cavity length along the electric field  $E_0$ ,  $\Delta U_{PD}$  is the potential collapse across the cavity due to PD,  $g$  is a dimensionless factor.

Although formula (1) is valid for both streamer and Townsend discharges, it can be used in practice only for streamers, in which the PD residual field can be assumed constant. For the Townsend PD the amplitude must be calculated according to an exponential law, depending on Townsend's coefficients, and based on different parameters from those of eq. (1).

The induced charge model is thus appropriate for

estimating PD charge only in the specific case of streamer discharges and lacks, therefore, generality. Furthermore, since the damage of cavity walls is related to electron energy (being some electrons not energetic enough to cause damage), besides the number of electrons per PD, the electron energy distribution would be required to assess correctly degradation rates.

In order to obtain the number and energy distribution of the electrons impinging at the cavity walls, the PD avalanche should be analyzed resorting electron and ion transport equation. This approach [9-11], brought a deep understanding of the discharge process and a clarification of the terminology used for the various kinds of observable discharges [12]. Following this, the first attempt to quantify the damage and consequently the ageing generated by a partial discharge has been performed for HVDC applications [13-15].

With the aim of developing ageing model for insulating materials subjected to PD under HVAC, the present paper introduces a simplified yet complete discharge model [16]. The approach presented in this paper provides a single model to account for the transition between Townsend and streamer discharges, resorting only to physical parameters.

### SIMULATION METHOD

An electronic transport phenomenon can be described through the Boltzmann equation, expressed in terms of electron distribution function  $n_e(x, p, t, F)$ , where  $x$  is spatial position,  $p = m_e \cdot v$  is electron momentum ( $m_e$  and  $v$  are the electron mass and the electron velocity),  $t$  is time and  $F = q_e \cdot E$  force ( $E$  the electric field). The Boltzmann transport equation has the following form:

$$\frac{\partial n_e(x, p, t, F)}{\partial t} + \frac{\partial n_e(x, p, t, F)}{\partial x} \cdot \frac{p}{m_e} + \frac{\partial n_e(x, p, t, F)}{\partial p} \cdot F = \left. \frac{\partial n_e(x, p, t, F)}{\partial t} \right|_{coll.} \quad [2]$$

in which the member of the second term takes into account the variations of the electron distribution function due to the scattering events associated with the electron collisions with the gas molecules.

The simulation approach presented in this paper applies to the cases of low energy and low density plasma, like the partial discharges processes which is the object of the present paper. In order to study the cases, in which the electric field in the air gap cannot be considered uniform, the problem is approached resorting to a spatial meshing of small intervals,  $dx$ , in which the electric field can be considered constant and uniform. Then eq. (2) can be solved in each spatial mesh point with interval  $dx$ , neglecting the dependence on the spatial coordinate (i.e.