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MEASUREMENT AND MODELING OF SPACE CHARGE ACCUMULATION IN POLYMERIC HVDC CABLE SYSTEMS

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ABSTRACT

This paper describes a numerical model for the calculation of the dynamic electric field distribution in high-voltage (HV) direct current (DC) cable insulation. The model includes space charge phenomena in the insulation bulk and at dielectric interfaces, such as those encountered in cable accessories. The numerical modelling has been supported by laboratory measurements of space charge and electric field. Theoretical and experimental results pointed out that both the temperature and the temperature gradient experienced by the insulation have a significant effect on the time-dependent distribution of the electric stress in the cable system.

KEYWORDS

HVDC, DC, cable, cable system, interface, space charge, temperature gradient.

INTRODUCTION

Accumulation of space charge plays a major role in determining the electric field distribution in the insulation of polymeric HVDC cable systems. In fact, if space charge is present, the total electric field across the insulation is given by both the Laplacian and the space-charge field. If space charge accumulation is not controlled, the total electric field can be locally enhanced, affecting significantly the performance of the insulation system.

In this paper a model is presented for the calculation of space charge dynamics in cables and at dielectric interfaces, such as those encountered in joints and terminations. The model predicts space charge accumulation on the basis of macroscopic properties of the cable insulation, e.g. permittivity and conductivity. By considering those quantities as functions of temperature and electric field, the model is able to calculate the space charge accumulation for different cable loads and for different voltage conditions, including the voltage polarity reversal.
The model has been validated by means of space charge measurements performed on cable models (medium-voltage size) and on models of dielectric interfaces. To that purpose, the pulsed electro-acoustic (PEA) method [1] has been used for the measurements. Space charge profiles and the relative electric field plots have been measured for several applied fields and at several temperature conditions, including the case in which the cable insulation experiences a temperature gradient.

NUMERICAL MODEL FOR THE CALCULATION OF SPACE CHARGE AND ELECTRIC FIELD

Background

One of the intrinsic properties of DC cable insulation is the accumulation of charges. Insulating materials allow a weak electrical conduction. This weak flow of charge within the insulation may not be uniform, because of a local non-homogeneity of the material.
According to the current density continuity equation, when an inequality occurs between the flow of charges into a region and the flow of charges out of that region, charge accumulates in that region, see equation (1):

$$\nabla \cdot \vec{j} + \frac{\partial \rho}{\partial t} = 0 \qquad (1)$$

In equation (1), j is the current density, ρ is the charge per unit volume (also called space charge density or simply space charge) and t the time. According to Gauss' law, a space charge field E_ρ is associated to a charge distribution:

$$\rho = \nabla \cdot \left(\varepsilon_0 \ \varepsilon_r \ \vec{E}_\rho \right) \qquad (2)$$

where ε_0 is the vacuum permittivity and ε_r the relative permittivity of the insulation. Therefore, the electric field E within the insulation in the presence of space charge is given by the sum of two contributions: the space charge field and the external field E_0 (also called Laplacian field), which is induced by the applied voltage, see equation (3).

$$\vec{E} = \vec{E}_0 + \vec{E}_\rho \qquad (3)$$

In the AC situation, the flow of charges inverts its direction too quickly to allow a significant growth of space charge at the insulation inhomogeneities, at least for conventional insulating materials. This means that the space charge field can be neglected. On the other hand, under DC stressing condition, the flow of charge maintains the same direction. This allows a build-up of charge, which, in general, significantly affects the electric field distribution inside the insulation.

Polymeric insulation can be considered a weakly conductive continuum in which a non-homogeneity can be induced by a non-uniform applied stress. This is the case of loaded DC cables and of the majority of HVDC devices. In fact, in those components a conductivity gradient is induced by the non-uniform electric field and/or by the temperature drop across the insulation.