Modelling of electrical history effect on polymer conductivity

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ABSTRACT

A disruptive model has been developed with the purpose of simulating space charge effect in electrical conductivity of insulation. In this model, explicit calculation method based on Markov chains is used to simulate the evolution of polymer electrical properties. This stochastic model has the main advantage of being based on local interaction calculation instead of global criteria and allows very fast calculation. Furthermore, crystallinity effect on charge transport being considered, electrical properties of different polymers can be addressed. With a given set of input parameters, the developed model can accurately reproduce current density variation and space charge profile of polymer at several electric fields. It can intrinsically simulate the experimental space charge effect on current density and the presence of electric field threshold.

KEYWORDS

HVDC, insulation, modelling, space charge, electrical conductivity, semi-crystalline polymer

INTRODUCTION

The insulation system of extruded High Voltage Direct Current (HVDC) Power Cables, composed of insulation layer between two semiconductive layers, reveals physical and chemical heterogeneities at several scales. Insulation generally consists of crosslinked ethylene homopolymer, the standard being low density crosslinked polyethylene (XLPE). As a semi-crystalline polymer, XLPE presents a heterogeneous morphological structure. Moreover, its formulation with other polymers, fillers or adjuvants and its chemical crosslinking, achieved in catenary vulcanization lines, also induces chemical heterogeneities [1]. This heterogeneous microstructure, which is evolving over time, strongly impacts the electrical properties of insulation system and its durability. Some models were developed to consider these heterogeneities in the simulation of insulation electrical properties [2]. However, these models are generally based on global criteria and struggle to manage the microstructure evolution of the material without having a too high calculation time. In this context, this work aims at developing a model that simulates microstructure evolution of insulating polymer submitted to high electric field and temperature impacting its related electrical properties. The microstructure evolution is described by local evolution laws with an iterative algorithm based on Markov chains [3]. These local laws are based on experimental correlation between polymer heterogeneities and electrical properties.

ELECTRICAL PROPERTIES SIMULATION

The model is developed under MatLab software. A two-dimensional (2D) matrix is used to decompose the polymeric material in mesoscopic states. In 2D, the *x*-direction is relative to the sample thickness where voltage is applied, and the *y*-direction is relative to the direction orthogonal to the applied macroscopic electric field. 2D is preferred over 1D to avoid control of the electrical behaviour by the weakest element of the system. On the other hand, a 3D model would increase simulation time without giving more accurate simulated results. In this decomposition, 100 elements of 10 µm are present in the *x*-direction and 20 elements of 10 µm in the *y*-direction. The spatial resolution of 10 µm has been chosen relative to the maximum of spherulite size diameter found in polymer [4]. All the equations developed in this model are written for a depth in the z-direction of 1 m. The core of this model is based on solid state physics applied to insulation. To each state of this matrix are affected local electrical and thermal properties *i.e* the local electric field, the amount of electric charges, the permittivity and the temperature. To each state is also ascribed heterogeneities related to semi-crystalline structure in shown in Figure 1

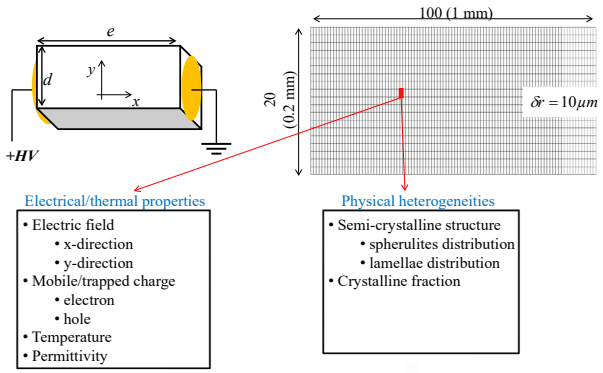

Fig. 1: Description of the matrix related to the material modelling.

Semi-crystalline structure

To model the heterogeneous spherulitic semi-crystalline structure of polymers, results from X-ray and Differential Scanning Calorimetry (DSC) measurements on polymer are used. The distribution of spherulite radius is mostly dependent on cooling rate, cooling temperature and presence of defects and can be measured with X-ray analysis. The proportion of spherulites radius follows a Gaussian law given by [4]:

$$\frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{1}{2}\left(\frac{r-r_{mean}}{\sigma}\right)^2\right) \quad [1]$$

with r_{mean} [m] mean radius and σ [m] radius standard deviation that are obtained after fitting of the X-ray data. In the model, spherulites are considered as regular polygons containing 3 to 6 faces with a circumradius R equal to the spherulite radius. This description is based on observations of polyethylene (PE) films reported in the literature [4]. The list of radius R is randomly selected from the Gaussian distribution and a list of random numbers between 3 and 6 is also drawn to define the geometry of the polygons that symbolize spherulites. Each generated spherulite is