Disruptive modelling of HVDC insulation system electrical properties from ab-initio material analysis

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ABSTRACT

A disruptive model has been developed with the purpose of simulating the electrical properties of insulation by considering both influencing physical and chemical heterogeneities and highlighting the impact of micro-structure modification over time on these electrical properties. To do so, a new model approach is used based on Markov model and local evolution. This stochastic model has the main advantage of being based on local interaction calculation instead of global criteria. Its main strengths are the simulation of DC electrical behaviour of polymers only from physical and chemical material analysis and simulation of system evolution with a faster solving time.

KEYWORDS

HVDC, insulation, modelling, microstructure evolution, physical and chemical heterogeneities, electrical properties

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.

PRINCIPLE OF THE MODEL

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 is 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 physical and chemical heterogeneities related to the studied polymer as shown in Figure 1. These heterogeneities are presented in the next parts.
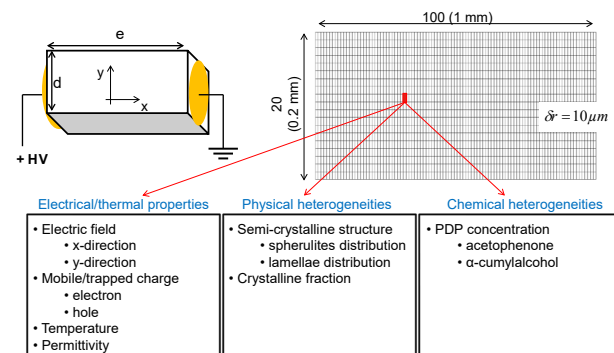

Fig. 1: Description of the matrix related to the material modelling.

To simulate space charge evolution, a 2D bipolar charge transport is considered comprising for both electrons and holes, injection, transport, trapping and extraction. In each state of the matrix, describing the material, is assigned a density of mobile and trapped electrons and holes. A temporal discretization is used with an adaptive step time δt to make evolve this system. Between t and $t + \delta t$, each element of the system will be modified according to local laws. These local evolution laws are based on the principle of Markov chains [3]. It means that the law related to each element of the system is only dependent on the properties of the element and on the properties of the neighbouring elements at the instant t. Furthermore, these laws follow a random evolution process which coincides with the random aspect of polymer microstructure evolution. First laws are defined to calculate the amount of injected, transported, trapped and detrapped charges in each element of the matrix at each step time δt. It has been considered that the electrical behaviour of polymer cannot be described with the presence of valence and conduction bands in an energy diagram, as there is no order in the amorphous