A new model for charges transport and build-up in extruded insulation (XLPE) for HVDC cables

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ABSTRACT

This paper presents a bipolar charge transport model based on new assumptions of energy levels distribution of traps and allowing to predict the XLPE electrical behaviour under DC stress. The model assumes that shallow traps are distributed over a single energy level and can participate in transport with a hopping mobility, whereas an exponential distribution is used to model the repartition of deep traps. Trapping, detrapping and recombination of charges are taken into account. Results show that the model (simulated under COMSOL Multiphysics®) reproduces the main characteristics of space charge density obtained by PEA measurement on degassed XLPE plates samples.

KEYWORDS

Charge transport modelling, Cross-linked polyethylene (XLPE), Insulating polymers, Dielectric characterizations, Space charges, Traps distribution.

INTRODUCTION

The challenge in strengthening grid interconnections between countries and in the development of renewable energies from solar or wind sources is to transmit energy over long distances, as production areas are generally far from consumption areas. To rise to this challenge, more and more power transmission systems are based on HVDC technology, and cross-linked polyethylene (XLPE) is now the most used insulation in HVDC cables, because of its suitable electrical and thermomechanical properties for service conditions, in particular its improved thermal and mechanical resistance due to the bridges (formed during the cross-linked process) between the molecular chains of LDPE. One of the issues using a synthetic insulation under DC stress is the generation and accumulation of charges inside the insulation, which can locally increase the electric field, leading to material degradation and possible dielectric breakdown, i.e. to the failure of the transmission link. Modelling charge generation and transport phenomena is a complementary way to experimental measurements to improve the understanding of charge accumulation mechanisms and associated consequences in XLPE. In this perspective, several charge transport models have been proposed in the literature over the last decades to describe and predict the electrical behaviour of polymeric insulators (LDPE, XLPE, etc.) [1-5]. In this paper, we present a new charge transport model allowing to follow the spatio-temporal charge evolution, the local electric field distribution and the current density evolution in a degassed XLPE under thermoelectric stress. Such degassed material allows to let ionic charges aside in a first attempt. The developed model is an improvement of a BCT (bipolar charge transport) model already published in the literature [1, 2]. The main difficulty with charge transport models is to describe as correctly as possible the trap distribution within the band gap, as this is what rules charge transport and accumulation in solid organic insulators. On the other hand, the trap description should be relatively simple, otherwise the resolution becomes too long due to model timesteps, or parameters identification is not tractable as processes are too interrelated. The original approach of our work is the type of energy levels distribution that is proposed and used to model the traps distribution in the material: for each type of electronic charges (electrons and holes), we assume a discrete level for shallow traps, mostly linked to physical defects, and an exponential distribution for deep traps due to chemical defects. Such description has been already proposed in the literature [4], although the present model accounts differently for most of the physical processes included in the model, and described in a further paragraph. The model accounts for the main physical processes for electronic charges such as charge injection and extraction at the electrodes, transport (drift and diffusion), trapping, detrapping and recombination of charges in a degassed XLPE. The fluid model is solved using a finite element method, and has been developed for planar (plates) geometry. To validate the model, experimental measurements of space charges and current are performed on degassed XLPE plane parallel samples and the obtained results are compared with those of the model.

EXPERIMENTAL APPROACH

A peroxide cross-linked polyethylene (XLPE) has been chosen as *model material*. Plaques of cross-linkable LDPE, i.e. containing peroxide, are first obtained using a hydraulic press. Semicon electrodes (SC) based on carbon black-doped polyethylene are added on each side of the XLPE, and the sandwich SC/XLPE/SC is crosslinked by compression molding at 190°C for 10 minutes. Adding SC electrodes allow being closer to the real configuration of an insulated XLPE cable system, and also allow having a good electrical and acoustic match during space charge measurements. The thickness of the sandwich is about 500 µm, with SC electrodes of 12 mm wide and 150 µm thick, and XLPE insulation of 70 mm wide and about 200 µm thick. After sample preparation and before experimental measurements, the samples are degassed for 3 days at 70°C to remove the XLPE cross-linking by-products, as their presence in the material and their contribution to space charge are not taken into account in the present research. Experimental space charge measurements using the Pulsed Electro-Acoustic (PEA) method and current measurements were performed on these degassed XLPE samples. The applied electric field protocol is given in Fig. 1, and consists, for a given temperature, in applying an