Relationship between breakdown strengths and trapping parameters of a serviced XLPE cable

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ABSTRACT

In this paper, a new charge trapping/detrapping model has been developed and further applied to obtain trapping parameters of an 11-year serviced cable. Different regions of the insulation have been investigated by using the films microtomed from the cable. DC breakdown strengths in different regions have also been measured. The results suggest a close relationship exists between the trap density in the material and electrical breakdown strength. The increase in trap density results in a lower DC breakdown strength.

KEYWORDS

Space charge, trapping parameters, XLPE, cable, breakdown strength, ageing.

INTRODUCTION

The storage of space charges in the insulation system can be ascribed to the result that they can reside within the wide bandgap of insulators without jumping to conduction (valence) band directly. And these localized states, or namely traps, with density N, offer charge carriers at an intermediate energy level, i.e. trap depth E_t. Meanwhile, the ability of these traps to capture charge carriers relates to the trapping cross section area S. Assuming that traps are Coulombic-attractive type and one trap site could only accommodate one charge carrier, thus the cross-section area could be calculated as $S = \pi r^2$, where r is the distance between the capturing site and its trapped charge. To summarize, trap density N, trap depth E_t, and trapping cross-sectional area S are generally called trapping parameters, which depict the attributes of traps.
In recent years, many approaches have been developed on determination or estimation of these trapping parameters for various insulation materials, especially polyethylene [1-5]. Chen proposed a trapping-detrapping model based on two energy levels [1]. And thereafter in [2,3], by employing the charge detrapping part in the model established by Chen, trapping parameters of low density polyethylene(LDPE) and also gamma-irradiated LDPE were estimated. It has been revealed that physical and chemical modifications brought by irradiation process can be reflected on the changes in trapping parameters. In the case of epoxy resin, Dissado et al proposed a model considering charge detrapping process within three steps [4]. Furthermore, with such model, trapping parameters of different-time aged cross-linked polyethylene (XLPE) cable peelings [5] were evaluated. Similarly, the changes in trapping parameters between XLPE peelings in different conditions were reported. The basic idea of these two approaches to estimate trapping parameters have something in common: (i) Both numerical models are applied to condition of charge relaxation after the removal of the external voltage; (ii) The trapping parameters were obtained by fitted curve of specific model parameters with experimental data from only the depolarization tests, i.e. data from polarization tests were not exploited; (iii) Observed charge decay after the removal of the applied voltage was thought to be caused by detrapping process, or in other words, any charges escaped from the trap sites were presumed to flow away instantly; (iv) Both studies tried to separate traps with a range of energy levels into two equivalent levels [1] or ranges [4]. And it is noteworthy in the work based on Chen's model [1-3], the two types of trap with different energy levels, i.e. shallow and deep traps, have been reported relating with physical and chemical defects in polymeric materials respectively.
In the present paper, a new approach has been proposed, which not only inherits many merits of the previous two model works but also improves from many aspects, to estimate the trapping parameters of insulation materials. In terms of inheritance, trapping parameters are also determined by optimum curve fitting results with experimental data and meanwhile charge decay data are still meaningful information to the data fitting process. Except for that, following the previous works, the present model also classifies the all the traps into shallow and deep traps. More importantly, comparing to previous works, the improved model in the present paper has two distinctive features: (i) In addition to use charge relaxation dynamics after the removal of the applied voltage, the preceding space charge accumulation characteristics during voltage-on stage have been included within the simulation works; (ii) Observed space charges in the bulk are considered to be consisted of trapped charges and mobile charges, which refer to those charges transporting between traps. Based on the improved model, in the present work, trapping parameters of 11-year serviced cable peelings have been estimated. The comparison of obtained parameters from different layers, together with DC breakdown strength, has been used to examine the applicability of trapping parameters as ageing marker.

BRIEF SUMMARY OF THE MODEL

In our improved model, the observed charges are no longer treated as trapped charges only but include a non-negligible amount of mobile charges as well. Typically, space charge profile with homocharge injection could be divided as positive and negative charge region with thicknesses respectively equalling to $\boldsymbol{d_h}$ and $\boldsymbol{d_e}$, as shown in Fig. 1. Therefore, the mean number density of net charges in either region can be calculated as:

$$n_{h,e} = \frac{Q_{h,e}}{d_{h,e}A} \tag{1}$$

where $Q_{h,e}$ is the total charge amount in either charge region and A is the electrode area. The density of net charge $n_{h,e}$ in either region equals to the sum of trapped charge and mobile charge density, i.e.:

$$n_{h,e} = n_{t_{h,e}} + n_{m_{h,e}} \tag{2}$$