Effect of static mechanical strain on the DC conductivity of extruded cross-linked polyethylene cable insulation

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ABSTRACT

DC current measurements were performed on a medium voltage XLPE cable at voltages from 8.5 to 65 kV (average field from 2.5 to 19 kV/mm). To assess the effect of mechanical strain on the conductivity of the insulation, the cable was wrapped around a tube with an outer diameter of 110 mm (max strain of 15.4%). Measurements of the currents through the compressed and tensioned sections were facilitated by using longitudinal guards in the insulation screen. No significant effect of the applied mechanical strain on the conductivity was found.

KEYWORDS

Electrical conductivity, medium voltage cable, mechanical strain, DC.

INTRODUCTION

Developing safe, efficient and economical ways of transporting power from environmentally friendly renewable energy sources, such as offshore wind power, is essential in order to achieve a sustainable power production.

Connection of offshore floating windmills to the grid requires high voltage cables capable of withstanding tough environmental and mechanical conditions during service. Such cables will be subjected to both dynamic and static mechanical strain. In particular the mechanical strain subjected to the cables might accelerate the degradation of the cable insulation for AC cables through water treeing if the cable is subjected to humidity [1]. For DC cables an important unknown is the long and short-term effect of mechanical strain on the space charge accumulation and DC conductivity of the insulation. While most cables subjected to dynamic and static mechanical strain today are AC cables, a series of new designs for transformer less wind farms has been proposed where rectifiers are placed right at the generator and the wind mills are either connected in series or parallel [2]. For such systems reliable dynamic DC cables will be required. In addition to offshore windmills, dynamic power cables also comprise power supply for direct electrical heating (DEH), floating oil and gas platforms, and subsea equipment.

The motivation for performing the work presented in this paper is to study the effect of static mechanical strain on the electrical conductivity of the cable insulation (XLPE). This is an important parameter when assessing the long-term electrical performance of the cable insulation, especially for HVDC systems, as it governs the electrical field distribution in the cable insulation.

BACKGROUND

Electrical conductivity

Applying a step voltage across a dielectric gives rise to a current density expressed by:

$$\boldsymbol{J}(t) = \sigma(E,T)\boldsymbol{E}(t) + \frac{d\boldsymbol{D}(t)}{dt} \tag{1}$$

where σ is the conductivity, $\boldsymbol{E}$ is the electric field, $\boldsymbol{D}$ is the electric displacement field, T is the temperature, and t is the time from the voltage is applied [3]. The first term is due to the conductivity of the material, while the second term is due to the polarization of the material. After some time the contribution from the dielectric displacement/polarization vanishes. Consequently, at this point, only a steady state conductive current flows through the insulation. If the sample is short circuited the molecules in the dielectric will relax to their original random orientation and the resulting current is termed the depolarization current. For a dielectric with no space charge accumulation in the bulk, see Fig. 1, an approximation of the conductivity can be found based on the difference between the polarization and depolarization currents [3]:

$$\sigma \approx \frac{\epsilon_0}{C_0 U}\left(I_p(t) - I_d(t)\right) \tag{2}$$

where ϵ_0 is the vacuum permittivity, C_0 is the geometric capacitance of the insulation, and U is the applied voltage during the polarization current measurement. For high field measurements the injected space charge can generally not be neglected, and the polarization/ depolarization currents may be quite different. In such cases it may be more appropriate to estimate the conductivity based on the steady state current. The estimated conductivity will then include the effect of space charge in the system, as the space charge will distort the field distribution.

The electric conductivity is given by

$$\sigma(E,T) = \sum \mu_i(E,T) q_i n_i(E,T) \tag{3}$$

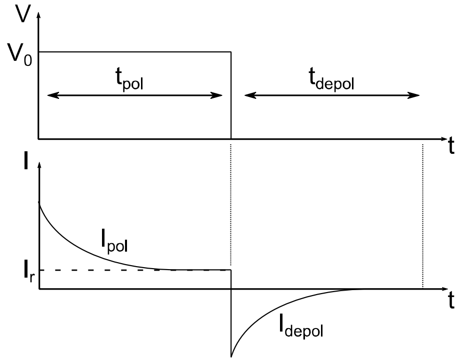

Fig. 1. Illustration of polarization (I_{pol}) and depolarization currents (I_{depol}) as a function of time.