Impact of mechanical stress on electrical properties of XLPE for DC applications

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ABSTRACT

In this study, the impact of mechanical stress on high field DC conductivity, dielectric constant, and dissipation factor of crosslinked polyethene (XLPE) used in HVDC cables are investigated.

The results indicate that that there is no observable impact in the high-field apparent conductivity of the XLPE samples exposed to mechanical preconditioning. Furthermore, based on the dielectric spectroscopy measurements, the changes in the dielectric constant and dissipation factor are insignificant, with regard to the very large strains applied to the XLPE samples.

KEYWORDS

HVDC; conductivity; mechanical stress.

INTRODUCTION

Globally, there is an increasing focus on lowering the consumption of fossil fuels in energy sector. Climate concerns and global energy security have enhanced the focus on transition toward green sources for electricity generation. DC cables have been a major enabler in this transition. In the recent years, the interest in HV and EHV DC crosslinked polyethene (XLPE) as the cable insulation material has increased, and there is large demand for XLPE DC cables in the future energy transmission market.

Power cables are exposed to mechanical stress during, manufacturing, handling, testing, installation, and operation. Hence it is important to understand how mechanical stress affect the cable performance. As such, international test standards and recommendations [1] [2], require the cable system to be mechanically preconditioned before the cable system undergoes electrical testing.

The impact of mechanical stress on polymeric material under AC conditions has been well studied in the literature in last decades. To mention a few, the investigation done in [3] showed that the mechanical strain could ease the initiation of water trees under AC voltage. In [4], the influence of mechanical stress on electrical treeing resistance of LDPE and XLPE was investigated. It was concluded that the samples with the highest values of residual stresses showed the shortest inception times and the longest trees under AC voltage.

Regarding the DC performance aspects, on the other hand, the available literature is not as abundant as AC aspects. In [5] the impact of mechanical deformation on space charge accumulation in undeformed and deformed XLPE samples peeled from a 66 kV AC cable was investigated. While both samples showed heterocharge accumulation, extra heterocharge was observed in the deformed sample. This was attributed to by-products trapped within the molecular chains.

Reference [6] a medium-voltage XLPE cable was mechanically stress and DC leakage current was measured. The results indicated there was no clear impact from static mechanical stress on the conductivity of the material which were subjected to tension and compression. In [7] the effect of mechanical stress on the insulation properties of high-density polyethylene material was studied. The DC conductivity of the samples stressed by 30 % elongation decreased by 7 % compared to the samples which were not mechanically stressed.

Although there have been studies on the impact of mechanical stress on dielectric and electrical properties of different insulation, there is still a need to further understand how the electrical properties of XLPE material intended for DC applications are affected by mechanical preconditioning. DC conductivity of insulation is a key parameter which dictates the electric field distribution in the insulation [8] [9]. Permittivity and dielectric loss of insulation also affect the AC and impulse performance of the insulation. Hence, this paper focuses on characterization of tensile tested DC XLPE samples with respect to high-field DC conductivity, dielectric constant, and dissipation factor.

EXPERIMENTAL PROCEDURE

In the following section the XLPE sample preparation, mechanical preconditioning and testing are elaborated.

Sample preparation

Cross-linked polyethylene (XLPE) insulation samples were prepared by press moulding pellets within protective aluminium films of 50 µm thickness. Dicumyl peroxide is the crosslinking agent used that is well dispersed in the pellets. The press moulding program includes melting pellets at 120 °C for 4 minutes at 36 bars and crosslinking polyethylene and forming plaque samples at 180 °C for 12 minutes at 250 bars. It is then followed by cooling to room temperature. Prepared XLPE samples have a square shape with a side of 270 mm and thickness of 1.0 mm. After press moulding, protective aluminium films were removed and XLPE samples were heat treated in an oven at 70 °C for 24 h to degas the cross-linking by-products. The degassed XLPE samples were then wrapped in aluminium foil and stored in a freezer before the start of tensile test and electrical measurements.

Mechanical preconditioning

Cables can experience several forms of mechanical stresses. In this paper tensile stress was applied on XLPE samples, in order to mechanically precondition them before performing electrical tests. This was done by a tensile testing machine, for which a special holder was manufactured, as shown in Fig. 1.