Long term performance of XLPE insulation materials for HVDC cables

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ABSTRACT

Going towards higher DC voltages and transmission capacity implies stringent demands on the insulation material system used in the extruded cables, including the long term performance. The purpose of this work is to study the long term mechanical properties as well as the effect of thermo-oxidative ageing of cable insulation with a HVDC focus using both plaques and cable samples.

KEYWORDS

XLPE, HVDC, Cable system, Ageing, Mechanical performance

INTRODUCTION

During the last decade, the use of extruded HVDC cables has increased along with the voltage and transmission capacity, driven by both the integration of renewable resources as well as increased need for interconnectors between countries and regions. Due to this demand, research and development activities on cross-linked polyethylene (XLPE) for HVDC applications have been intense and fast. To meet the future needs, a novel non-filled XLPE material has recently been introduced. Extruded HVDC cables using this material as insulation have been qualified for service voltage level of 525 kV, according to the Cigre recommendation TB 496 [1]. The electrical and short term non-electrical properties of this novel material are described by Englund et al. [2].

The high demanding HVDC application also requires good control and understanding of the long term performance of HVDC materials. This paper describes the long term performance which can be affected by the electrical, thermal, mechanical and/or environmental stresses during cable manufacturing and operation. Primarily, the long term mechanical properties of the novel material will be investigated and compared to the industry standard HVDC insulation material. The standard HVDC XLPE insulation material is seen to have very good mechanical properties at ambient as well as at elevated temperatures. As a consequence the extruded cable maintains its shape and integrity even at overload temperature, so-called memory effect. It has been demonstrated previously that also the novel XLPE insulation material displays a similar memory effect [3]. In this paper the long term mechanical performance will be assessed by discussing the creep behaviour and stress crack resistance.

Another important long term property is the thermo-oxidative characteristic. Thermo-oxidative ageing will occur during the entire life time of the insulation material and might already start during the cable manufacture. During this process, oxygen might only be present in low concentration, but it will be enough to react with the polymer and initiate a degradation process unless the material composition is sufficiently protected by an adequate stabilisation package. The involved degradation mechanisms are for example oxidation and hydrolysis reactions as well as chemical processes such as chain scission or cross-linking reactions between chains. The various mechanisms of degradation are well described and reported in the literature [4], [5]. The thermo-oxidative ageing might continue during cable installation and use. Accelerated ageing tests are essential and commonly used but surprisingly the influence of testing conditions, especially sample specimens, has been rather neglected. This parameter together with the influence of molecular changes on mechanical and electrical properties will be discussed in this paper.

MATERIALS AND METHODS

Materials

The materials investigated in this paper are two non-filled XLPE materials having high physical and chemical cleanliness levels and produced in commercial scale. Material A is the unfilled industry standard material with conventional cross-linking degree and the novel Material B is a non-filled XLPE building on the same technology platform and track record as Material A. Furthermore Material B has a substantially lower peroxide content [3]. Both materials have an $MFR_{2.16}$ of 2 g/10 min measured at 190°C and a density of 922 kg/m^3. The semi-conductive material used in the cable system is a commercially available cross-linkable XLPE for HVDC applications.

Mechanical properties

Pennsylvania Edge-Notch Tensile test

The Pennsylvania Edge-Notch Tensile test (PENT test), described in ASTM F1473, was originally designed to measure the resistance to slow crack growth (SCG) in materials used for pipes conveying gas or water under pressure. Later on, this test had been used in US for cable jacketing materials. In the PENT test, a notched rectangular specimen is subjected to tensile creep. The primary purpose of the notch is to introduce a triaxial stress state at the notch tip to ensure a brittle SCG fracture mode. The load is chosen such that the stress at the notch tip is well below the yield stress of the material. The outcome of this test is the time to complete brittle mode failure. In the present study, the PENT test was used to measure the resistance to SCG as function of cross-linking level.

- Dimensions of test specimen: 60 mm×25 mm×10 mm
- Principal notch: 3.5 mm deep
- Side notches: 0.7 mm deep
- Test temperature: 70°C
- Test stress (calculated on the un-notched cross-