Dielectric spectroscopy response and Mechanical properties of XLPE mini-cable aged under thermal stresses

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ABSTRACT

This paper focuses on the potential impact of thermal stresses on both mechanical and dielectrical properties of XLPE material, a major constituent of electrical cables. Fully formulated XLPE pellets, representative of typical formulations used on today's cable market, have been purchased and processed for characterization.

XLPE plate samples were tested for mechanical properties in tensile mode. The very good insulating properties could be tracked with dielectric spectroscopy on long mini-cables designed much like realistic cables.

The series of results have further been understood and related to the XLPE structure using complementary characterizations: infrared spectroscopy and differential scanning calorimetry.

KEYWORDS

XLPE cable; thermal ageing; tensile tests; dielectric

INTRODUCTION

In most countries today, the increasing energy demand further increases the load on the already overstressed and sometimes unstable electricity network. This, combined with the intrinsically complicated nature of the electric grid causes serious network bottlenecks. These trends will continue, and their impacts on usability may be aggravated by the spread of electric vehicles, batteries and other electric and electronic applications. In the current energy transition situation, a deeper understanding of the equipment ageing mechanisms might improve operator knowledge about the conditions of the distribution system, and help initiate more efficient and reliable maintenance operations. The ageing of each constituting material could certainly be studied separately, but particular attention should be paid on the insulation system, mainly responsible of electrical breakdowns in electrical cables.

The focus of present study is to determine the effect of various thermal constraints on the functional behavior of polymer-insulated cables, which insulating layer mainly consists in cross-linked polyethylene XLPE in case of medium voltage cables. As the maximum operating temperature expected from these systems is about 70 to 90°C, samples of plates and mini-cables (made using a representative XLPE formulation) have been studied during ageing in air at different temperatures going from 70 to 110°C. A careful sampling combined with complementary characterization methods – like tensile tests, Fourier transform infrared spectroscopy, differential scanning calorimetry and frequency domain spectroscopy – allowed us to understand the chemical, mechanical and dielectric behavior of XLPE materials under the effect of the temperature stress.

MATERIALS AND METHODS

A. Samples preparation

Three types of samples (noted P1, P2 and E) have been used:

- P1 and P2 are plate samples of respectively cross-linked polyethylene (XLPE) fully formulated with a typical composition used for electrical cables production, and the corresponding low density polyethylene (PE) without any additive.
- E is an electrical mini-cable using the same XLPE insulating material than P1. This mini-cable has been manufactured by a cable supplier. It possesses four layers of different thicknesses: a 0.69 mm central conductor made of copper, a 1.5 mm XLPE insulation layer sandwiched between two semi-conductors of 0.7 mm each.

Plate samples were made using a press and a 2 mm spacer according to the following procedures. For P1 samples: Melting of formulated PE pellets at 120°C for 60 seconds – Heating ramp from 120 to 180°C at 18°C/min at a pressure of 20 bars – Crosslinking reaction at 180°C for 480 seconds at 200 bars – Cooling from 180°C to 35°C at 15°C/min at 200 bars. For P2 samples: Melting of raw PE pellets at 120°C for 60 seconds at 20 bars – Increase of pressure to 200 bars for 2 min – Cooling from 120°C to 35 °C for 400 seconds at 200 bars.

Differential scanning calorimeter analyzes were performed on P1 and P2 plate samples. Crystallinity and melting temperature of the pure PE plates are respectively 40% and 111°C. These two parameters are lower concerning XLPE plates (respectively 35% and 107°C). This is a consequence of the crosslinking reaction of polyethylene using dicumyl peroxide [1]. This crosslinking process involve structural changes of polyethylene. Thus, the carbonyl index is often slightly higher and acetophenone and cumylic alcohol appears. These impurities can be detected and analyzed using infrared spectroscopy [2]. Before thermal ageing process, the XLPE plates were degassed at 80°C under vacuum for 48 hours to remove these volatile molecules.

B. Ageing conditions

Plates and cables were thermally aged at different temperatures between 70 and 110°C, using universal air-ventilated MEMMERT lab ovens. Samples were hanged in order to avoid contacts with metallic warmer zones.