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B.5.2. Corrélation entre les contraintes mécaniques résiduelles et les propriétés électriques des câbles à isolation PR

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B.5.2. Correlation between residual mechanical stresses and properties of XLPE insulated cables

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Résumé

Les contraintes mécaniques résiduelles dans l'isolation des câbles PRC pourraient, selon certaines études, favoriser les phénomènes conduisant à un vieillissement accéléré du câble. Mais est-on en mesure de quantifier précisément leur intensité? Quel traitement thermique pourrait-on mettre en oeuvre pour les réduire, voire les faire disparaître? Saurait-on corréler leur diminution avec l'amélioration d'une propriété liée au comportement du matériau lors du vieillissement?
Cette étude se focalise sur la fiabilité de l'analyse thermo-mécanique (TMA) pour mesurer ces contraintes, et l'utilise pour quantifier le bénéfice d'un traitement thermique du câble. On montrera qu'un recuit des câbles postérieur à leur fabrication peut notablement réduire l'intensité des contraintes dans l'isolation, mais que seule la distribution des charges d'espace traduit les résultats obtenus par TMA.

Abstract

According to some studies, residual mechanical stresses in XLPE insulated cables could promote the phenomema leading to an accelerated ageing of the cable.
However, are we able to precisely quantify their intensity? What thermal treatment should we apply to reduce them, or even remove them completely? Would we be able to correlate their decrease with the improvement of any property linked to the material behaviour during the ageing?
This study is focused on the reliability of the thermo-mechanical analysis (TMA) to measure these stresses, and use it to quantify the advantages of a thermal treatment of the cable. We will show that a post manufacturing annealling of the cable can significantly reduce the stress level in the insulation, but that only the space charge distribution was found to correlate the TMA results.

Introduction

If the intrinsic dielectric strength of a well-prepared polyethylene sample can easily exceed 500kV/mm, it is usual to reach a level of about 140 kV/mm on cable, after the extrusion of the same polymer and all the steps imposed to the cable by the processing/manufacturing process .
Some studies have listed all the potential stresses which could affect the polymer ageing, and therefore the properties of the insulation after some years [1]. Amongst the different factors which could influence the performances of an XLPE insulated cable, the effects of the mechanical stresses have been studied and their impact on the short term AC breakdown strength, on the initiation and growth of electrical trees has been discussed [2,3,4,5].
The physical reality hidden behind the parameter which will be measured is not so easy to define, and we will stick to the following definition: 'A residual mechanical stress is a stress that is the sum of all the stresses which have been imposed to the material during the various processing steps, which lead to a forced compression, stretching or twisting of the polymer chains'.
The aim of this study is to initiate a reflexion on a reliable quantification of the residual mechanical stresses (or frozen strain), and on the effects of the treatments which could be applied to the cables in order to release some,a lot of or all of them.
The dilatometry method used to measure the level of residual stresses has been described more than ten years ago [6], and is currently used by many people in this field [7,8]. However, this paper brings some precisions on its limits and on its reproducibility. It also deals with the influence of the sample size and of the thermal treatment which could be applied to release the stresses. The aim of this study is to develop a correlation between the mechanical stresses and a physical data easily acessible. In parallel to the TMA analysis, mechanical and electrical measurements have also been carried out.

Experimental

The system used to perform the tests is a thermomechanical analysis (TMA) device from Perkin-Elmer (Series 07), and the probe in contact with the sample has a surface of 10 mm^2.
The starting temperature is 25°C, and then raising at a rate of 5.0°C/min.
The samples are 3 mm cubes cut in the cable insulation, according to the 3-D reference axis system described in [6], i.e. with the radial axis 'z', the longitudinal axis 'y' and the tangential axis 'x'. It is worth noting that all the samples are cut just before being tested as the relaxation phenemenon also occurs at room temperature, and that they have been taken at 90 degrees from the flow junction. All the samples have been collected in a 66 kV cable (400 mm^2 Cu conductor and 17 mm insulation), except for the determination of the reference curve and for the assessement of the test method reproducibility where samples from 20 kV cables (50 mm^2 Al conductor and 5 mm insulation) have been used.
A load of 10 mN is applied on top of the sample to ensure a good contact as the two opposite faces of the cube are never exactly parallel.
When the insulation is thick, TMA measurements are always performed close to the internal semiconductor, and close to the external semiconductor, which gives a good picture of the stresses distribution mainly induced by the cable cooling.
All the ageing tests are performed in ventilated ovens (Heraeus T6060). The cables removed after treatment are left at room temperature to cool down (slow cooling).
The space charges have been measured by the thermal wave technique. The cable samples have been polarized with the anode at the core, under 50 kV at 50°C for 20 hours.
The AC breakdown test has been carried out on ribbons cut out of the cable. Their thickness is around 0.14 mm. The electrodes have a 20 mm diameter and a 2 mm radius at the edge. The voltage increase is 2 kV/mm. The silicone oil has a viscosity of 50 centiStokes.
The dissipation factor has been measured on a Tettex bridge at room temperature and at 50 Hz under a field of 1 kV/mm.