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A.9.2. Arborescence électrique dans le polyéthylène sous contrainte mécanique

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A.9.2. Electrical treeing in mechanically stressed polyethylene

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Résumé

Les isolants au polyéthylène basse densité et polyéthylène réticulé ne sont pas seulement soumis à des contraintes électriques et thermiques, mais aussi à des contraintes mécaniques provenant soit de contraintes résiduelles créées lors de la fabrication, soit de forces extérieures lors de la flexion d'un câble ou des contraintes thermomécaniques dues à la différence des coefficients d'expansion thermiques entre le conducteur et le matériau isolant. De plus, les contraintes mécaniques résiduelles ne sont généralement pas uniformément distribuées dans le volume de l'isolation et présentent des points de concentration. Dans le but d'étudier l'influence possible de ces contraintes mécaniques, des mesures ont été effectuées sur des échantillons pointe-plan de PEBD et de PRC contenant des contraintes mécaniques de différentes intensités autour de l'électrode incluse. Le temps d'initiation, le taux de croissance et la forme des arbres électriques croissant à différents niveaux de tension sont rapportés dans cet article. Les temps d'initiation les plus courts et les arbres les plus longs après une heure de vieillissement ont été observés pour les échantillons contenant les contraintes mécaniques les plus élevées. Lorsqu'il fut permis à ces contraintes de relaxer, la résistance à l'arborescence s'améliora de façon significative.

Abstract

XLPE and LDPE insulations used in high-voltage cables are not only subjected to electrical and thermal stresses, but are also exposed to mechanical stresses, whether residual internal stresses created during the cooling process of the fabrication, external forces when cables are bent or thermomechanical stresses caused by differential thermal expansion between the conductor and the insulating material. Furthermore, the internal mechanical stresses usually have a non uniform distribution in the insulation volume, presenting a number of points of stress concentration. In order to investigate the possible influence of these mechanical stresses, measurements were conducted on pin-plane XLPE and LDPE samples with various magnitudes of mechanical stresses around the embedded electrode. The time-to-inception, the growing rates and the shape of the electrical trees under different voltages are reported in this paper. Specimens with the highest values of residual stresses were found to have the shortest inception times and the longest trees after one hour of aging under different voltages. When the mechanical stress was allowed to relax, the treeing resistance was measured to be significantly improved.

Introduction

Extruded crosslinked polyethylene (XLPE) and low density polyethylene (LDPE) insulations are widely used in high voltage cables, presenting attractive features such as excellent dielectric properties and good thermomechanical behavior. However, under dry conditions, failure could occur after a certain aging time by a mechanism called electrical treeing growing from protrusions or sharp defects. How other stresses, mechanical, thermal and environmental affect this phenomenon still remains to be fully clarified.

The insulation of full-sized cables is always exposed to a more or less high level of internal mechanical stresses created during the cooling process of the fabrication [1] or occurring in-service from thermomechanical effects. The latter subject has received a considerable attention over the past years [2, 3]. External forces occurring when the cables are bent during installation superimpose on the internal mechanical stresses.

The aim of this paper is to investigate the influence of mechanical stresses at the tip of plane-needle specimens on the electrical treeing behavior in LDPE and XLPE. Internal stresses due to the differential thermal expansion between the conductor and the polymeric material were created by various cooling processes. They were initially quantified using a three-dimension stress distribution model, similarly to [4]. The time-dependency of the treeing resistance from the fabrication date is also examined to take into account the stress decay due to stress relaxation. The influence of external forces when the specimens were subjected to a step of compressive strain is also investigated.

Experimental

Specimens preparation and characterization

2-mm thick XLPE and LDPE parallelepipeds with 5 or 10 µm tip radius steel needle electrodes were prepared by compression molding between highly polished copper plates in a Carver press equipped with heating platens. The insulating material used was cable grade pellets with an antioxidant (Irganox 1035) and with or without dicumyl peroxide (DCP) for the XLPE and LDPE specimens respectively. For the XLPE specimens, the pellets containing DCP were molded and cross-linked according to the curing profile illustrated at Fig. 1b. Sol fractions of 17.3 ± 0.6% were measured on 12 different specimens using the ASTM D-2765-90 method (method A with xylene). LDPE specimens were molded at 130°C during 90 min. using pellets without DCP. All the specimens (XLPE and LDPE) were cooled at room temperature by circulating water into the platens of the press, which yields an average cooling rate of about 15°C/min. These samples will be referred in the following text as the water-cooled samples (WC). No cavity was detected at the electrode-polymer interface when the electrode tip was inspected under an optical microscope at a magnification of 200. The dimensions of the specimens are illustrated in Fig. 1a. XLPE specimens were degassed in a rough vacuum for about 100 h in order to reduce the concentration of cross-linking by-products, such as acetophenone and cumyl alcohol. Since the presence of oxygen in the free volume of the polymer strongly affects the degradation rate of the polymeric material and therefore the electrical tree inception time [5, 6], the degassed specimens were left 100 h in air, so that all specimens will be considered uniformly air-impregnated.