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Optimization of cable terminations equipped with non-linear stress control tubes

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Abstract
A significant electrical field grading in HV cable terminations can be achieved by using stress control tubes (SCTs), obtained by adding a controlled amount of conducting fillers, as carbon black or silicon carbide, to polymeric insulating matrices. Nevertheless, no data can be found in the literature concerning the influence played by the SCT length, thickness and position around the cable termination on the grading performances of these accessories. The purpose of this paper is to investigate on such interesting aspects by evaluating the electric field distributions inside cable terminations characterized by different arrangements of the SCT.
The numerical evaluations of the electric field are carried out by adopting a model based on the electroquasi-static approximation of Maxwell equations.

Résumé
Une réduction significative du champ électrique dans les terminaisons de câble HT peut se réaliser par des tubes répartiteurs de champ (SCTs), obtenus en ajoutant une quantité contrôlée d'additif conducteur, par exemple du noir de carbone ou du carbure de silicium, à une matrice polymérique. Néanmoins aucune donnée ne peut être trouvée dans la littérature en ce qui concerne l'influence jouée par la longueur et l'épaisseur du SCT et par sa position autour de la terminaison du câble sur les performances de ces accessoires. Le but ce cet article est d'étudier de tels aspects intéressants en évaluant les distributions de champ électrique à l'intérieur des câbles caractérisée par différents agencements des SCT. Les évaluations numériques du champ électrique sont effectuées en adoptant un modèle basé sur l'approximation électroquasistatique des équations de Maxwell.

Introduction

A significant stress control, i.e. a more uniform field distribution, in cable terminations has been achieved by adopting *stress control tubes* (SCT) which provide the desired field reduction at the screen truncation [1]. Such performances are achieved due to the high values ($\varepsilon_r > 20$) of the permittivity and a non linear behaviour of the electrical properties (conductivity and permittivity) vs the electric field.
Two kinds of technologies are adopted nowadays: the more traditional "heat shrinking technology" making use of carbon black loaded polyolefins [1], and the more recent "cold shrink technology" employing either low-cost EPDM (ethylene propylene-diene monomer), or more expensive, high performance silicone rubber [2].
In both cases equivalent non-linear conductivity and permittivity appear, which are worth considering for an accurate evaluation of the field distribution inside the component which, in turn, represents a crucial aspect in the design of reliable cable accessories.
The numerical evaluation of the electric field distribution along the SCT material has been generally carried out by adopting the well known transmission line model [3-8], in which the stress relief material is modeled by means of longitudinal non-linear RC cells and the main insulation is described by transversal capacitances. However, such model is not able to provide the field map in the whole termination. In fact, it cannot appropriately take into account the influence of different cable end arrangements on the field distribution, the presence of objects surrounding the termination (live or grounded bars, additional screens, wires or conductors,...) and the effect of the deposits due to environmental pollution on the exposed surfaces which determine different boundary conditions. Moreover, in many cases, it is unreasonable to neglect the displacement current field taking place in the air around the termination.
In [9] the limits of validity of the transmission line model are clarified and the approximations involved with the circuital approach are discussed; moreover, a new model of the cable termination, based on the electroquasistatic (EQS) formulation of the Maxwell equations and on the thin layer approximation of the SCT is presented. In this model the Laplace equation in the nonconducting regions and the 1-dimensional approximation of the non-linear diffusion equation are solved separately, in space, by using the finite difference and the Galerkin method respectively; the Galerkin equations are integrated in time through the backward Euler method.