Stress prediction of high voltage XLPE cable insulation system with regard to water tree ageing

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ABSTRACT

The stress state of extruded crossed-linked polyethylene power cables is numerically investigated by means of finite element analysis. Previous studies have indicated that the stress state in the insulation can affect water tree growth based on the mechanical damage theory. Hence it is of interest to understand the residual stresses in the insulation resulting from extrusion and how these are affected by subsequent external loads such as tension and bending. The combined stress state is calculated to be compared to an experimental study of water tree ageing.

The numerical study shows that the residual stresses after extrusion are tensile in axial and tangential direction, while the radial stress component reaches 2 MPa of contact pressure towards the conductor.

KEYWORDS

Cross-linked polyethylene; residual stresses; water tree ageing

INTRODUCTION

Extruded crossed-linked polyethylene (XLPE) is used as insulation for high voltage cables laid in wet environments, without a metallic water barrier, up to a voltage level of 72 kV. Early deployments of this wet design cable had a high failure rate due to water ingress and the formation of tree-like water structures, resulting in insulation breakdown.

Water trees can be classified into two fundamental types based on their origin and shape: vented water trees, which originate from either the conductor or the insulation screen and grow radially; and bow-tie trees, which are randomly distributed in the insulation. Fig. 1 shows a schematic representation of the two types of water trees.

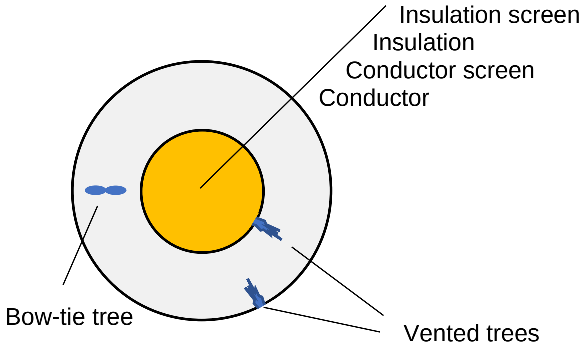

Fig. 1: Schematic illustration of bow-tie and vented water trees.

The two predominant water tree initiation theories are the mechanical damage theory and the stress induced electrochemical degradation theory (SIED). The mechanical damage theory refers to the formation of micro cracks and voids, in which condensation of water is lowering the insulation capacity. The SIED theory proposes that water between aluminum conductor strands creates porous channels in the semiconductive layer due to the formation of a galvanic cell; where the conductor is an anode, the semiconductive layer is a cathode and water is an electrolyte. Moreover, the ionic products from the corrosion site enhance this process [1].

This paper is related to the mechanical damage theory, and in particular the combined effect of residual stresses in the insulation system and externally applied load. Residual stresses are formed during the extrusion process of the polymer and are of considerable magnitude, while the applied stresses refer to external loads such as bending variations experienced by a dynamic cable. The combined stress state is of importance as the damage theory implies that compressive strains will prevent the formation of micro cracks, while tensile strains will promote the formation.

The geometry and loading used in this numerical study are chosen to enable comparison to an experimental study conducted by Ilstad et. al. [2], who have made considerable contribution to the field of water tree ageing the by means of experimental studies of combined electrical and mechanical loading.

METHODOLOGY

The residual stresses, and the sensitivity thereof, is numerically calculated by the general-purpose finite element solver Abaqus using a custom material model for the XLPE. The additional loading is then applied as tension or bending.

The stress state is numerically identified for tension and bending. In order to enable direct comparison, also the experimental setup used by Ildstad et. al. [2] has been studied.

Comparison to experimental study

Ilstad et. al. conducted experiments on a medium voltage cable by subjecting it to static and dynamic loading in terms of tension and bending with simultaneous 50 Hz voltages. The basic mechanical principles of the tests are illustrated in Fig. 2.

Tensile strains arise from both bending and tension. A uniform axial strain is achieved from the tensile test, while linearly varying axial strain between the tension and compression side is the result of bending. Loading was applied so that a maximum of 1% strain was achieved. The tensile test was conducted at 20°C, while bending at 40°C. Please note that the conductor was removed in the tensile test.