Remnant Static Mechanical Stresses and Water Tree Ageing of XLPE Power Cables

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ABSTRACT

The main purpose of the work presented in this paper was to experimentally examine possible enhancement of water treeing caused by remnant mechanical stresses, frozen-in during the manufacturing process of extruded XLPE power cables.

The experiments were performed using 3m long samples of 12 kV XLPE cable cores, exposed to water and different static tensions during ageing at an effective 50 Hz AC voltage of 14 kV (E_{max} = 5.2 kV/mm). Reference cable samples as well as mechanically stressed cable samples were examined at 20, 40 and 60 °C. At each temperature the following 3 types of samples were examined: i) Reference cable sample, with conductor, ii) non-strained cable sample, without conductor, iii) mechanically 2 % strained cable sample, without conductor. After removal of the cable conductor at 20 °C the insulation was found to longitudinally shrink by a about 0,8%.

The degree of water tree degradation was characterized using optical microscopy investigation of 0.5 mm thick methylene blue stained slices.

The resulting density of bow-tie trees were found to slightly increase when applying mechanical tension. Highest numbers of water trees were found in the reference and the mechanically stressed cable samples. The results support previous findings and are in good agreement with the mechanical damage theory of water treeing.

KEYWORDS

XLPE cable, mechanical tension, water treeing

INTRODUCTION

At the highest system voltages premature failure of XLPE insulated cables is rarely caused by water tree degradation. The main reason for this is the common application of outer metallic sheaths, preventing ingress and absorption of water. In addition new more water tree retardant insulations systems, including purer insulation and semiconducting materials are in wider use [1]. Nevertheless, in some cases it is considered economically favorable to use cables without metallic sheath barriers, for example at distribution voltages, below approximately 36 kV, and at special short term off-shore and marine applications. For example cables intended for free floating grid connections for offshore oil-and gas installations and wind-farm towers.

Previous investigations have shown that initiation and growth of water trees in XLPE cable insulation will be enhanced by either static or dynamic mechanical tension and retarded by compressive stresses [2]. This is particularly so if the strain of the insulation exceeds the yield point of about 2 %.

The main purpose of the work presented here has been to experimentally study to what extent water tree degradation of XLPE cable insulation will be affected by remnant mechanical stresses, frozen-in during the manufacturing process of extruded medium voltage XLPE power cables.

THEORETICAL CONSIDERATIONS

i) The mechanical damage theory

Water tree structures are known to consist of a large number of small voids, which are filled with water when the insulation is kept saturated. In general the electric field inside or in close proximity to the tree structure, depend on its shape, the local dielectric constant and the conductivity of the tree structure.

Experience shows that initiation and growth of water trees is facilitated only when AC voltage is applied and the relative humidity of the insulation exceeds a limit causing localized formation of liquid water.

According to the mechanical damage theory water treeing is caused by local mechanical overstressing and craze formation, due to a combined effect of water condensation and external mechanical and electrical stress.

From fracture behaviour of polymers it is known that Crazes initiate cracks at stresses well below what is needed to cause bulk shear yield. These localized regions of plastically deformed low density polymer, consists of voids and polymer fibrils [3], facilitating condensation of water. Measures known to reduce such stress cracking are: introduction of compressive stresses, increasing the molecular weight, annealing and addition of copolymers.

Generally, at the tip of such water filled channels the electric field applied may provide sufficient mechanical stress to create new crazed regions. – It has been shown that at the tip of energized water filled voids Maxwell forces may generate tensile stress with magnitudes larger than 10 MPa at relatively low voltage stresses.

Such 100 Hz mechanical stresses likely result in new low density crazing zones, into which water condensation is eased, subsequently establishing a situation for further growth of vented and bowtie water.

It is therefore likely that the effect of applying mechanical tension to cable insulation is to ease micro voids and subsequently water tree formation, while compressive