Non-Contact Surface Metrology of Degraded Conductor Screens in XLPE Cables

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ABSTRACT

Stress-induced electrochemical degradation (SIED) structures are likely initiated at the surface of the conductor screen of insulated XLPE cables with stranded aluminum conductors due to water ingress and corrosion. In time such structures initiate severe vented water treeing which significantly reduce the lifetime to the cable.

The main purpose of this paper is to show that SIED structures are porous structures which swell and become visible after wetting in hot water, by using non-contact surface metrology characterization.

It is found that after wetting SIED structures were imaged as elevations of water saturated porous structures. The swelling was less than 10 µm and could be permanent dependent on ageing conditions.

KEYWORDS

SIED, ESC, XLPE, aluminium conductor, corrosion

INTRODUCTION

All known polymeric insulation materials are susceptible to water tree degradation when exposed to a combination of the factors electrical field, humid conditions and ions [1]. Bow-tie trees inside the insulation are initiated at contaminations in the material and will usually stop growing after some time and therefore play a minor roll. Vented water trees start from protrusions or contaminations on the semi-conductor layer and may grow across the entire insulation layer radially and cause breakdown of the insulation system. But with better manufacturing techniques and cleaner materials the occurrences of water trees has reduced significantly [2]. In polymer insulated power cables with aluminum conductor liquid water may cause corrosion of the Al strands. Corrosion zones have been found to act as initiation points for micro-cracks in the conductor screen [3] caused by environmental stress cracking (ESC). Porous structures extending into the conductor screen may form and finally bridge the screen radially, called Stress Induced Electrochemical Degradation (SIED) [2]. Ions [2], contaminants and corrosion products [4] may be transported from the conductor along the SIED structures and contribute to initiation of vented water trees at the conductor screen surface.

It has been found that formation of SIED structures is dependent on the presence of liquid water which causes corrosion [5], but is independent of both mechanical stress (tension or compression), applied voltage and load current [4]. Most polymer insulated cables today have an axial water tight design which prevents liquid water from entering the area between the conductor strands. This area is usually filled with swelling powder or strand sealing materials, which also prevents longitudinal water transport. For example the German test standard for MV cables [6] does not assume such a water tight design. Liquid water may enter between the strands after a service failure or due to condensation of water in cables with wet design.

The purpose of the present work is to characterize the surface of SIED structures after wetting in hot water during subsequent drying in ambient conditions. 3D images and microscopy pictures of the same surface locations are used to show that the structures become visible after wetting due to swelling and in some cases collapse afterwards during drying, dependent on ageing conditions of the sample.

EXPERIMENTAL PROCEDURE

Samples from two different 12 kV cables with cross-linked polyethylene (XLPE) insulation were included, both with a stranded aluminum conductor. The samples and applied characterization techniques are summarized in Table 1. Sample No. 1 had been in service for more than 20 years and has an insulation thickness of 3.67 mm. It was equipped with a strippable insulation screen, which was carefully removed to reveal any vented water trees. From Sample No. 1 a section with visible water tree growth was chosen for further analysis. Sample No. 2 was aged in the laboratory by filling the conductor with artificial sea water [7] and keeping the sample in water at 40°C for 1 month.

Table 1: Sample description and characterization techniques

Variable	Sample	
No.	1	2
Ageing	Field	Laboratory
Applied voltage	6 kV	0
Applied water	Water ingress between the conductor strands during service	Artificial sea water filled between the conductor strands and left in water for 1 month at 40 °C
Characterization techniques		
Wetting of samples	Distilled water	Tap water
Non-Contact Surface Metrology (3D imaging)	X	X
Optical microscope	X	X
Scanning Electron Microscope		X