WATER TREES IN MEDIUM VOLTAGE XLPE CABLES: VERY SHORT TIME ACCELERATED AGEING TESTS

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ABSTRACT

This paper describes a pragmatic method to assess the resistance of polymeric insulation cables to watertreeing. Water trees are produced in 12 days in the polyethylene insulation of a real cable by use of a high frequency, high voltage power supply. The first objective was to provide a source of information for asset management (remaining lifetime estimation of installed cables) but it is also applicable for the assessment of new products and allows a rapid comparison between different materials.

INTRODUCTION

The estimation of water trees resistance and lifetime of cable insulations represents all over the world an important issue for cable owners. The reproduction of water trees in a laboratory in a reasonable duration is highly helpful not only to provide advices for specificators and purchasers but also to plan the maintenance programs. A lot of accelerated tests has already been developed on flat polyethylene samples with defects created by abrasive paper or on a bulk sample using needles. In order to take into account the global morphology (polyethylene chemical composition, material structure) of a cable used in the network, we decided to perform water trees growth on sections of real cable.

CONTEXT

Extruded insulations such as cross-linked polyethylene (XLPE) were first used as insulation of medium voltage distribution cables in the 1960's instead of paper insulation. The watertreeing phenomenon was discovered in the US in the late sixties. It reduces drastically the estimated lifetime of the polyethylene cables by the initiation of an electrical tree (figure1) or by a thermal runaway. New standards were issued to guaranty the resistance of cable to water treeing. Besides a better design of the water barriers, an improved cable manufacturing, better extrusion processes and compound quality as well as laying practices, two basically different solutions were brought to improve the main insulation. Presently the main part of Europe uses a copolymer whilst American cable insulation is made of homopolymer with water tree retardant additives. What we call copolymer is in fact a mechanical blend of Low Density PolyEthylene and ethylene acrylate copolymer. The water trees retardant additive are high molecular weight polymer added in small quantity (<1%). Watertreeing is a complex phenomenon. A lot of parameters as voltage stress, frequency, availability of water, presence of contaminants, polymer structure and temperature influence the growth of water trees and unfortunately neither theoretical nor practical models integrating all the influencing parameters are accessible.

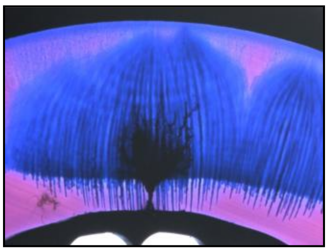

Fig. 1: electrical tree

DESCRIPTION OF THE SET-UP

In order to perform an accelerated test we apply high frequency and high voltage to the insulation placed in a salted water solution (figure 2). It has been demonstrated [5] that up to at least 30kHz the water trees growth is proportional to the applied frequency therefore we decided to perform the accelerated test at maximum 5kHz in order to obtain a reliable translation to network frequency (50 Hz). The applied voltage is about 1,5 times the nominal voltage in order to observe phenomenon's as close as possible of the one responsible for degradation in the field.

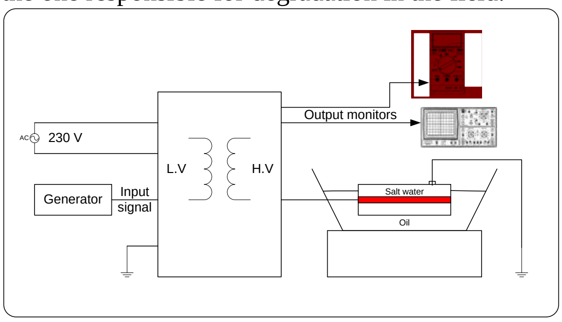

Fig. 2: test set-up

During observation of highly degraded cable the presence of Cl^- ions was measured therefore we perform the test with NaCl in a water solution .

Power Amplifier

The insulation of cables is submitted to high voltage and high frequency in our accelerated ageing installation. The experimental set-up (figure 3) includes a 30 kV, 5 kHz, 40mA power amplifier and a cell containing a water solution with 0.1 mol/l NaCl.

Fig. 3: power amplifier

Preparation of the samples

Samples of 10cm were studied. The tests were carried out with and without external semiconductive layer and with and without superficial calibrated defects.

Fig. 4: creation of calibrated defects

Duration and test conditions

After some repeatability tests and first results the duration of twelve days was decided (even in new cables significant water trees were measured). The average applied electric field is about 3,8 kV/mm and the frequency is put at 3kHz.

Visualization of the water trees in the insulation

After growing of the water trees, thin slices of 600 µm of the insulation are taken using a microtome and dyed with methylene blue. It reacts with water present in the water trees and allows the visualization by a microscope (figure 5) and the analyse of the length and shapes of the water trees.

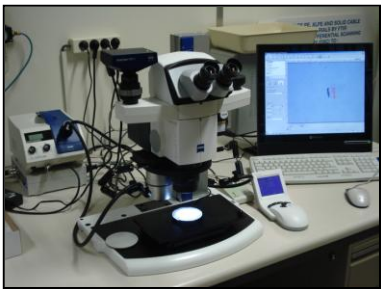

Fig. 5: microscope

TESTED SAMPLES

Feasibility tests were performed at the university of Bucharest where water trees were measured in a cable with an insulation made of homopolymer without any additive. Up to now five samples were tested in Belgium. Currently, the equipment is in continuous use and more results will be soon available. The 3 first tests were performed on samples typically used, presently or in the past, in the Belgian network.

Samples 0

Insulation type: Homopolymer without tree retardant additive
Nominal Voltage: 15kV
Conductor cross-section: 150 mm²
Insulation thickness: 4,5 mm
Manufacturing year: 2004
Test voltage: 17,4 kV
Test duration: 7 jours
Semi-conducting layer: removed

Sample 1

Type: EAXeCWB
Insulation type: Copolymer
Nominal Voltage: 8,7/15kV
Conductor cross-section: 150 mm²
Insulation thickness: 3,6 mm
Manufacturing year: 2007
Test voltage: 13,8 kV
Test duration: 11,5 days
Semi-conducting layer: removed

Sample 2

Same cable as sample 1. The semi-conducting layer is present and some calibrated defects are done.
Test voltage: 13,8 kV
Test duration: 7 days

Sample 3

Same characteristics as sample 1 and 2. The semi-conducting layer is removed. One side of the sample is polished up with very thin abrasive paper.
Test voltage: 13,8 kV
Test duration: 12 days

Sample 4

Insulation type: Homopolymer with tree retardant additives
Nominal Voltage: 11,6/20kV
Conductor cross-section: 150 mm²
Insulation thickness: 4,5 mm
Manufacturing year: 2008
Semi-conducting layer: removed
Test voltage: 17,3 kV
Test duration: 12 days

Sample 5

Insulation type: Homopolymer with tree retardant additives
Nominal Voltage: 11,6/20kV
Conductor cross-section: 95 mm²
Insulation thickness: 3,6 mm
Manufacturing year: 2008
Semi-conducting layer: removed
Test voltage: 13 kV
Test duration: 12 days

RESULTS

Samples 0: Homopolymer without tree retardant additive

The repeatability test was performed on three samples of the same cable. The results are similar. Each sample shows vented trees (figure 6) longer than 800 µm and some darker point are visible inside the insulation. Some other tests aborted with homopolymer present the same phenomenon.

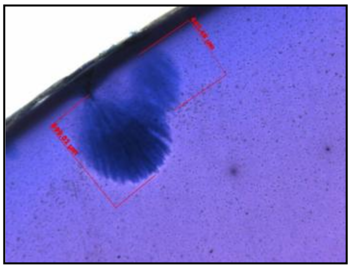

Fig. 6: water trees in sample 0

Sample 1: Copolymer

The longest measured water tree is about 300 µm (figure 7) measured after the test. The shape of the trees are basically the same as those obtained in the homopolymer (samples 0).

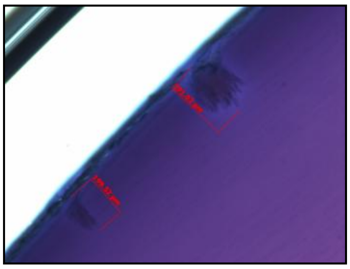

Fig. 7: water trees in sample 1

Sample 2: Copolymer

The defects created on the semi-conducting layer did not perforate the layer. No water trees were measured. The diffusion of the ions through the semi-conducting layer is probably to slow and is in any case not accelerated by the applied field (equipotential). Further tests will be performed with the semi-conducting layer with a preconditioning (3 weeks at 55°C) following the HD620 (Cenelec) instructions.

Sample 3: Homopolymer with tree retardant additives

The longest water tree in the polished side is 512 µm and 240 µm in the other side (comparable with sample 1)

Sample 4 and sample 5: Homopolymer with water tree retardant additive

Small water trees with a different shapes (figure 8) are observed.

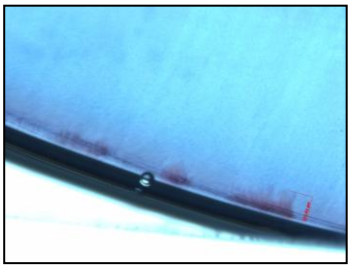

Fig. 8: water trees in sample 4

FUTURE INVESTIGATIONS

Preconditioning

Preconditioning on cable with their semi-conductive layer will be performed in order to be as close as possible of the real situation and study the influence of the semi-conductive material on the water tree growth.

Influence of the parameters

The different parameters (solution, frequency, voltage, duration…) will be changed in order to evaluate their influence on the growth rate.

Investigation on aged cables

Cables removed from the field will also be placed in the equipment in order to see their resistance to water treeing and advise distribution companies about the estimated lifetime of their cables. The same guidance service can also be provided to all DNO's or industry partners worried about their cables lifetime.

CONCLUSION

The first tests realized with the method described in this paper demonstrate its ability to create significant and repeatable water trees in real cable samples in only twelve days. The comparison between water trees found in cables removed from the field and water trees measured in cables coming from the accelerated tests should provide useful information for the translation of the results to intrinsic life time determination. The investigation on aged cables will give an indication of the expected future degradation and therefore on the asset management (planned replacement or further use). Different types of XLPE (homopolymer, copolymer, homopolymer with water tree retardant) have been tested so far and the results are promising regarding the assessment of insulation materials for medium voltage cables.

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