Close and Return

ASSESSMENT OF WATER TREED CABLE INSULATION CONDITION BY MICROSCOPY AND SPACE CHARGE MEASUREMENTS

Cristina **STANCU,** INCDIE ICPE CA, 313 Splaiul Unirii (Romania), cstancu@icpe-ca.ro
Mihai G. **PLOPEANU,** Politehnica Univ. of Bucharest, 313 Splaiul Independentei (Romania), mgplopeanu@elmat.pub.ro
Petru **NOTINGHER jr,** Université Montpellier 2, Place E. Bataillon, Montpelllier (France), petru@univ-montp2.fr
Petru V. **NOTINGHER,** Politehnica University of Bucharest, 313 Splaiul Independentei (Romania), petrunot@elmat.pub.ro

ABSTRACT

In this work, the ageing condition of water treed cable insulation was assessed by optical microscopy and space charge measurements (thermal step method). Model cables were aged in the presence of water and ac electric field, during various times and at different frequencies. The dimensions and densities of grown water trees were determined in each case, and thermal step currents (images of the electric charge and polarization in the sample) were measured after a brief low dc poling of the samples. It has been found that the current amplitude increases with the growth of the water treed regions in the samples (dimensions and concentration of water trees), showing the potentiality of this quantity as a non destructive marker for the state of water-treed cables.

INTRODUCTION

Under the combined action of electric field and water the polyethylene insulations of power cables suffers degradations known as water trees [1].

Water tress represent very thin micro-channels filled with water, which develop in high electric field areas respectively in regions where defects (like impurities, micro-cavities) are presented or in the semiconductor layers vicinity [2].

Water trees contribute to the local enhancing of the electric field [3] and electric strength of insulations [4], having as consequence their premature breakdown. According to the available statistics, water trees represent more than 30 % of total causes of medium voltage cables breakdown [5].

Water trees development is influenced by a series of factors like ions inside the insulations [6]. On the other hand the charge related to the ions, leads to a local enhancement of the electric field [7], leading to the reduction of partial discharge and electric trees inception voltage. In order to estimate the space charge and electric field repartition in flat samples several methods are available [8]. In cylindrical samples (cables), the thermal step method is often used [9].

Determination of resistance to water trees is an important test for lifetime estimation of insulations. The achievement of such attempts at 50 Hz implies long periods, of months order. In order to reduce these periods, electric fields or frequencies higher than the service ones are used to accelerate water trees development [10]. In this case, it is important to know the influence of these parameters on the trees development and characteristics, respectively the space charge related to water trees [3].

This paper concerns an experimental study made on low density polyethylene-insulated model cables. The condition of the cables (aged at frequencies comprised between 50 Hz and 3 kHz) is analyzed in terms of water tree characteristics (dimensions, densities, volumes) and space charge, with the aim of evaluating the possibility of using a space-charge based methodology for assessing non-destructively the insulation state.

EXPERIMENTS

Samples

Commercially-available low density polyethylene-insulated cables have been used. The insulating thickness was 0.8 mm, and the copper conductor diameter was 1.1 mm. The experiments were performed on 50 cm-long samples cut from cable rolls.

Development of water trees

In order to develop water trees in the studied samples, the setup presented in Figure 1 was used. Groups of 2 samples were introduced in a PMMA cell filled with NaCl solution (concentration: 0.1 mol/l). A sinusoidal voltage of RMS voltage U = 5 kV has been applied to the samples. Three ageing frequencies have been used on several samples: 50 Hz (ageing time: 55 days), 2 kHz and 3 kHz (ageing time: 24 to 96 hours).

For a fast development of water trees, superficial defects have been made with abrasive paper on the outer surface of insulation, by using a special device. The water trees were visualized and their dimensions were measured after ageing by using the setup presented in [9].

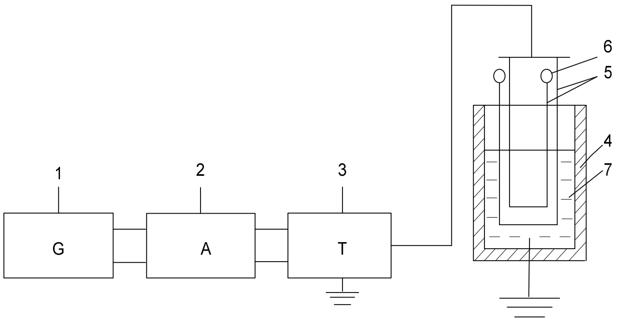


Fig. 1: Setup used for water trees development: 1- Tektronix CFG 253 voltage generator, 2- Amplifier, 3- High frequency transformer, 4- Ageing cell, 5- Samples, 6- Metal balls to avoid discharges, 7- Water/NaCl solution

Measurement of water tree characteristics

In order to determine the dimensions and the densities of water trees, the aged samples were introduced in a rhodamine solution during 72 h at a temperature T = 60°C. From each sample, 5 slices of thickness g = 0.2 mm were cut and the dimensions of water trees (Fig. 2) were measured using an optical microscope.

The average lengths (L_{wt}) and diameters (D_{wt}) of water trees were determined by using the relations:

$$L_{wt} = \frac{1}{N_{wt}} \sum_{k=1}^{N_{wt}} L_k \qquad [1]$$

$$D_{wt} = \frac{1}{N_{wt}} \sum_{k=1}^{N_{wt}} D_k \, , \qquad [2]$$

where N_{wt} represents the total number of water trees (on 5 slices), L_k is the length of tree k and D_k its diameter.

The number of water trees N_{wt1} was determined on each sample by delimiting a 1 mm^2 square. The density of water trees was then calculated with the relation:

$$c_{wt} = \frac{N_{wt1}}{A}. \qquad [3]$$

The volume occupied by water trees V_{wt} (from the total volume of the sample) was calculated with the relation:

$$V_{wt} = A_l L_{wt} c_{wt} A_{wt}, \qquad [4]$$

where $A_l = 2\pi R_e h$ is the lateral area of sample, R_e = 1.35 mm – outer radius of cable insulation, h = 30 cm – the generator length of the cylinder where the trees were developed, L_{wt} – the average length of trees, c_{wt} – trees density from 1 mm^2 and $A_{wt} = \pi D_{wt}^2/4$ – the cross area of a single water tree.

The average growth rate v_{dwt} of water trees was calculated with the relation:

$$V_{dwt} = L_{wt}/\tau, \qquad [5]$$

where τ represents the ageing time.

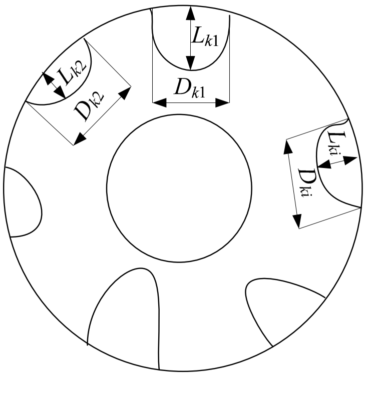


Fig. 2: Model for measuring the dimensions of water trees

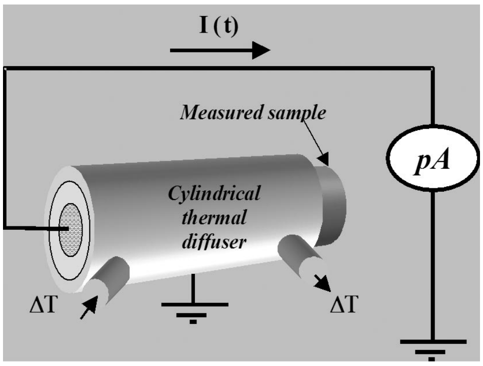


Fig. 3: Thermal step method used on a cable

Thermal step measurements

Aged cable samples were evaluated by thermal step measurements. The technique consists of applying a thermal step to a short-circuited or dc biased insulating sample and to measure a transient current, which depends on the internal electric field and space charge distribution and amplitude across the insulation. In the case of a coaxial dielectric homogeneous in the z-direction (Fig. 3), the thermal step current is given by [11]:

$$I(t) = -C \int_{r_i}^{r_e} \alpha(r) E(r) \frac{\partial T(r,t)}{\partial t} \mathrm{d}r \qquad [6]$$

where $I(t)$ represents the thermal step current, r_i represents the outer radius of the insulation, r_e is the inner radius of the insulation, $\alpha = \alpha_d - \alpha_\varepsilon$ is the difference between the thermal expansion coefficient α_d and the permittivity variation factor with temperature α_ε, C is sample capacitance, $E(r)$ is the value of the electric field at a point of radius $r \in [r_i, r_e]$, and $T(r, t)$ is the temperature at the point of coordinate r at instant t. The electric field is related to the space charge via the Poisson equation.

In the case of the present study, the samples have been submitted to a thermal step of -30 K and the thermal step currents have been recorded during 20 s. As this type of measurement requires the existence of a conducting layer on the outer region of the cable insulation, each sample has been provided with a semi conducting shrinking sleeve before the measurements.

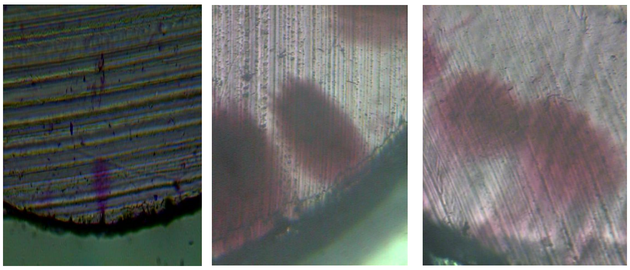
RESULTS AND DISCUSSION

Examples of water trees obtained at the three frequencies (50 Hz, 2 and 3 kHz) are presented in Figure 4. The dimensions, densities, volumes and growth rates of water trees obtained on the model cables aged are presented in Table 1. As expected, it can be seen from these data that:

a) For a given frequency, the increase of the ageing time leads to the increase of dimensions, density and volume of water trees;

b) For a given ageing time, the increase of the frequency leads to the increase of dimensions, density and volume of water trees.

Close and Return



a) b) c)

Fig. 4: Water trees obtained at 50 Hz (a), 2 kHz (b) and 3 kHz (c) (*U* = 5 kV RMS)

Table 1 Characteristics of water trees measured in the samples conditioned

τ [h]	*f* [kHz]	L_{wt} [μm]	D_{wt} [μm]	c_{wt} [mm^{-2}]	V_{wt} [mm^3]	v_{dwt} [μm/h]
48	2	187	107	1	4.27	3.9
48	3	278	184	2	37.5	5.8
96	2	218	134	3	23.4	2.3
96	3	329	259	4	176	3.5
1320	0.05	165	150	1	7.41	0.125

The growth rate is strongly influenced by the frequency of the electric field: the increase of the frequency from 50 Hz to 3 kHz leads to the increase of water trees average growth rate values by 46 times. Also, the above data show that 200 μm-long trees are obtained in 96 h at 2 kHz and in 48 h for a frequency of 3 kHz, with respect to 165 μm water trees that are obtaines after more than a thousand hours at 50 Hz.

On the other hand, a decrease of the growth rate with the ageing time can be noted. This is probably due to the fact that, for longer water trees, the electric field decreases in the front of the trees [3].

The increase of the ageing time leads not only to the increase of water trees dimensions, but also of the ion concentration inside them [12]. Thus, the survey of the evolution of the electric charge associated to water trees may be an image of the water trees growth. For this purpose, thermal step measurements have been made on the samples in order to assess a correlation with the amount of water trees.

Indeed, after been taken off from the ageing cells, samples have been preserved in tubes containing the ageing solution during one week (time needed for transport from the ageing location to the measurement one). Then, after the application of a shrinkable conducting sleeve on the outer region of the insulator, each sample has been dc poled during 2 hours with a negative 3 kV dc voltage, at 40 °C. The low poling has been made in order to facilitate charge separation and migration toward the interfaces.

Thermal step currents on the insulations with water trees developed at different frequencies are presented in Figure 5. It can be seen that the lowest thermal step current correspond to the sample that has the smallest water tree length and concentration, i.e. the one conditioned at 50 Hz. The sample conditioned at 2 kHz during 96 hours, which has a higher concentration of water trees than the one conditioned at 50 Hz, also present a higher thermal step current. The samples with the longest trees and highest tree concentrations (i.e., the ones aged at 3 kHz) also exhibit the highest thermal step currents. For these two latter, an increase of the order of 40% of the signal is observed when the ageing time is increased from 48 hours to 96 hours (Fig. 6): this has the effect of doubling the water tree concentration and increasing significantly the average water tree length (Table 1).

It must be recalled that the thermal step current amplitude depends on the electric field across the samples and on the electric charge contained in the insulation. Drawing the local distribution of the field for each measured sample is not an easy task due to the non homogeneity of treed areas in the length direction. Nonetheless, the increase of the thermal step currents with the treed areas is clearly related to an increase of the electric charge associated to water trees and to the interfaces between untreed and treed regions, which are likely to favor charge accumulation under the effect of the dc field applied after ageing.

The presented results, which show a continuous increase of the thermal step currents amplitude with the length and the concentration of water trees, strongly suggest that the state of degradation by water trees may be directly assessed by non destructive space charge measurements using the thermal step method. However, these results need to be comforted by more experimental work on model samples with various water trees length and concentrations, and eventually on real size medium voltage cables on which water trees with controlled lengths are to be developed.

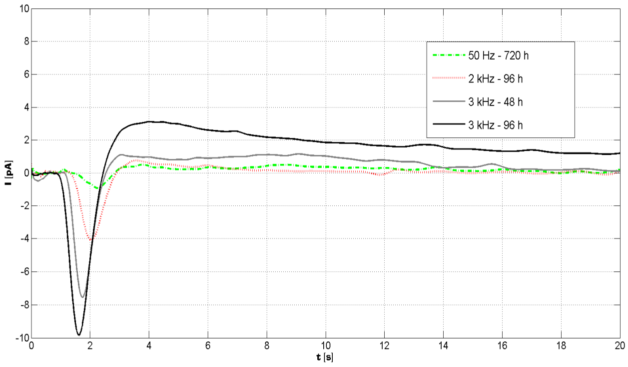


Fig. 5: Thermal step currents measured on samples aged in different conditions (*U* = 5 kV)

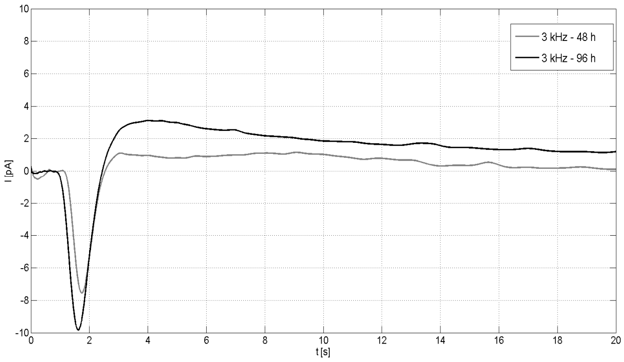


Fig. 6: Thermal step currents measured on samples aged at 3 kHz (*U* = 5 kV)

CONCLUSIONS AND PROSPECTS

In the present work, model cables were aged in the presence of water and ac electric field, during various times (24 h to 55 days) and at different frequencies (50 Hz to 3 kHz). The characteristics of the water trees grown in the aged samples were determined by optical measurements and correlated to charge-related results obtained via the thermal step method. The results have shown that the amplitudes of the thermal step currents, which are determined by the amount of electric charge present in the samples, increased all the long with the increase of the water tree length and concentration.

The confirmation of such encouraging results via additional experimental work would allow to consider the development of non-destructive methodologies based on space-charge-derived quantities for assesing the condition of water-treed cables.

Acknowledgment

The authors are grateful to the Romanian Ministry of Education, Research, Youth and Sport for the financial support under the project DEDIC 34/2010 and CABDIAG 22122/2008.

REFERENCES

[1] E. Steennis, F. Kreuger, 1990, “Water Treeing in Polyethylene Cables”, IEEE Transactions on Electrical Insulation, vol. 25, no. 5, 989 – 1028

[2] J. Chen, J. Filippini, 1993, “The morphology and behavior of the water tree”, IEEE Transaction on Electrical Insulation, vol. 25, pp. 271 – 286

[3] C. Stancu, P.V. Notingher et al., 2009, “Computation of the Electric Field in Cable Insulation in the Presence of Water Trees and Space Charge”, IEEE Transactions on Industry Applications, vol. 45, no. 1, 30 – 43

[4] L. Dissado, J. Fothergill, 1992, Electrical degradation and breakdown in polymers, Peter Peregrinus Ltd

[5] H. Faremo et al., 1997, “Service experience for XLPE cables installed in Norway – from graphite painted insulation screens to axially and radially water tight cable construction”, 14th Int. Conf. and exhibition on electricity distribution, vol. 3, 2 – 5

[6] R. Ross, 1998, “Inception and propagation mechanisms of water treeing”, IEEE Transaction on Dielectrical and Electrical Insulation, vol. 5, no. 5, 660 – 680

[7] J. Zhao et al., 2010, “Numeric description of space charge in polyethylene under ac electric fields”, Journal of Applied Physics, vol. 108, no. 12

[8] O. Gallot-Lavallée, V. Griseri, G. Teyssedre, C. Laurent, 2002, “Mesure de la charge d’espace par la méthode électro-acoustique”, 3éme congrès annuel de la Société Française d’Electrostatique

[9] C. Stancu, 2008, “Caractérisation de l’état de vieillissement des isolations polymères par la mesure des charge d’espace”, PhD Thesis, UP2-UM2

[10] Accelerated Water Treeing Test (AWTT), AEIC CS6 -79

[11] P. Notingher jr., A. Cernomorcenco, C. Stancu, P.V. Notingher, J. Castellon, S. Agnel, A. Toureille, 2010, “Determination of electric field and space charge in non homogeneous dielectric media with cylindrical geometry using the thermal step method”, Proceedings SFE 2010, pp. 91-96

[12] O.Visata, 2001, “Influence des arborescences d’eau sur les propriétés diélectriques des polymères”, PhD Thesis, Université POLITEHNICA de Bucarest - Université Joseph Fourier Grenoble