Measurement of Current due to Space Charge Present in PVC Sheaths after Aging under AC Sinusoidal High Voltage by the Thermal Wave Method

Youcef ZEBBOUDJ, Abdelkrim LAIFAOUI, Hakim AIT SAID and Jean Michel REBOUL

Abstract- Several techniques exist to characterize the presence of remanent polarization and / or space charge in an insulating material. Among them which may be mentioned thermal methods such as the Thermal Wave Method (TWM). Among the most widely used polymers in electrical insulation, we find the polychloride vinyl (PVC). In this work, we describe the characterization of PVC sheaths to improving the reliability of power transmission cables. We set the objective to adapt the TWM for space charges measures in this material and under this cylindrical form. The study concerns a few samples of PVC sheaths, part of which has undergone aging until 4250h under alternating voltage of 20 kV sinusoidal AC voltage in the electrical engineering laboratory of Bejaia (LGEB). Also we have another lot of samples in new condition for comparison. The space charge measurements were made at LUSAC in Cherbourg. After presenting the specific banc measurement of MOT for this type of samples, we present the first current measurements on samples aged under tension between 500 and 4250 hours. The first analyzes show that the current of MOT increase gradually but irregularly depending on the aging time.

Keywords: Thermal Wave Method; Space charge, current of MOT, PVC sheaths, Electrical aging, Heat front, Thermal gradient.

I.   Introduction

In the solid insulators subjected to high electrical constraints, a number of poorly known mechanisms often lead to the establishment of a space charge distribution [1] that breaks the electrical neutrality of certain regions of the insulator. This situation persists or progresses slowly, even after switching off the external electrical constraint which gave it birth. Space charge accumulated in these areas has the effect of introducing a non-uniform distribution of the electric field enhances the degradation and aging of the material and reduces the lifetime of devices working under high voltage such as cables and capacitors [2].

The space charges are electric charges not cleared and / or gradients of dipoles oriented in a preferential direction, which are divided in the volume of an insulator. Their appearance intervenes as soon the elaboration of the material and inevitably continues during use under the effect of applied constraints (electric field, electrical and / or thermal aging, exposure to ionizing radiation ...). The accumulation of these charges in certain zones of the insulator distorts the external electric field applied when the material is under voltage and has for effect, a risk to prime the electrical breakdown. Several techniques exist to characterize the presence of these charges in the volume of the insulator [3]. Among these methods, we are interested especially in that whose principle uses a variation of temperature and can be described by "thermal methods". If the temperature variation is important during measuring and if it changes the electrical state of the sample by removing all or part of the charges stored, the method is said "destructive". In contrast, when the temperature variations are weak or do not leave the domain of electrical stability of the sample, the method is said "non-destructive" [4-6]. This latter case is interesting because it allows the repetition and verification of the reproducibility of measurements. It is also suitable for follow-up studies of the evolution of a sample over time.

II. Thermal Wave Method

The so-called "thermal wave" method (MOT in french) has been developed in Montpellier since twenty years ago. This method is a reference method for measuring space charge especially in cables [6-12]. It is based on the diffusion of a heat front applied to one side of the insulator and on the non-uniform dilatation that results. This generates a current due to the local movement of space charges in the material during dilatation (or contraction). This method has proven extremely efficient for samples of planar geometry [13] or cylindrical [14] and for a wide range of thicknesses ranging from hundreds of microns to a few centimeters. A numerical method of deconvolution that includes the experimental currents and the temperature distribution in the sample during the measurement permits to estimate the charge density [15].

III.   Samples

The study was conducted on 15 samples of soft PVC sheaths (length of 80 cm, internal diameter of 4 mm and thickness of 1.5 mm). The samples were cut from a roll of duct of 100 m

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provided by the Electro-Industrial company (ENEL Azazga, Algeria). Some of these samples have undergone aging electrical at laboratory temperature for a period ranging from 500 to 4000 hours under AC voltage of 20 kV 50Hz. Another part of these samples is stored in new condition for comparison. To avoid breakdowns of air by circumvention, only a length of 10 cm, corresponding to the middle of the sheath has been polarized.
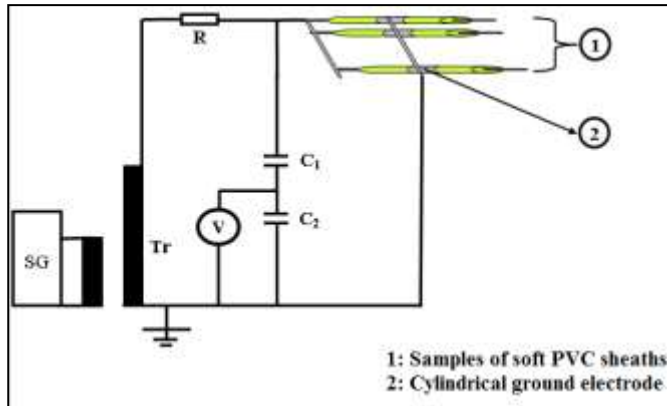

Figure 1. Device aging test

The aging device comprising the following elements described in Figure 1:

- SG : A voltage source with several speeds of rise of the ramp.

- Tr : HT 100 kV transformer can output a voltage from 0 to 100 kV for tests under AC voltage.

- A capacitive voltage divider ($C_0 = 0,1\ \mu F$ and $C_u = 41,4\ \mu F$).

- A peak voltmeter (U_{cr}) AC / DC type MU11, digital display for measuring, according to the electrical circuit, high AC voltages, or continuous.

- A protective resistor R = 106 kΩ limiting current.

- A built used for the whole test tube and electrodes.

- A stainless steel electrode inserted within the sheath serving as a high voltage electrode.

- The cylindrical ground electrode of stainless Aluminum wound on the outer part of the sheath.

- A protective cage.

The tests consist in polarizing under alternating voltage of 20 kV AC AC 50Hz, samples of sheaths for an increasingly long period. Aging takes place in the open air and the ambient temperature of the laboratory.

IV. Experimental Implementation

For flat samples, the thermal front, echelon shaped, is conventionally obtained by supplying hot or cold liquid in hydraulic radiator which also serves as an electrode. The sample is initially at ambient temperature in contact with this one and is subjected to a thermal shock on one of its faces. The measurement takes place during the change in temperature of the sample which also corresponds to the progression of a temperature front through its thickness. The French name of the method originates from this phenomenon. The theory shows that the distribution of space charge in the sample causes an experimental current that depends on speed progression of the thermal front passing through the sample. Experimentally we seek to maximize this parameter to obtain even more detectable because measuring signals can be very weak. n practice the values attained locally are of the order of ±10°C/s. In case of thermal shock causing heating of the sample, the harmful temperature can be reached rapidly, we prefer therefore a thermal shock producing cooling.
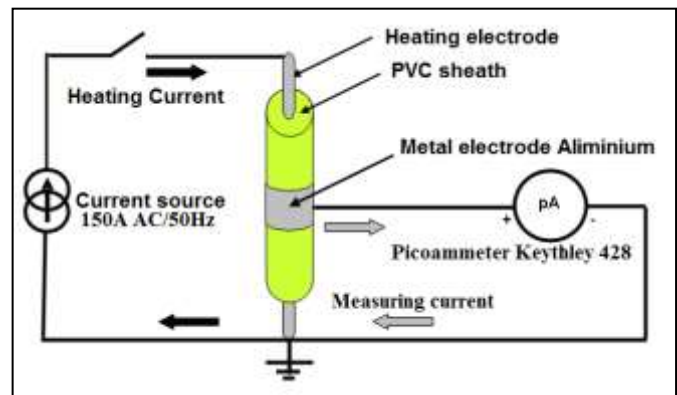

Figure 2. Measuring device MOT

However, for our samples of cylindrical shape, we have developed and perfected a radiator that heats up the sample a few degrees above ambient temperature. A rapid heating is obtained by the Joule effect using a radiator inserted inside of the sheath (Figure 2). The heating time is short and limited to maximum 3 s so that the maximum temperature attained in the heart of the sheath does not degrade the dielectric state of the sample (35°C). This allows repeated measurements after returning to ambient temperature by natural cooling of the sample. The measurement electrodes are formed on the one hand, by the aluminum adhesive tape bonded to the outside of the sheaths over a length of 10 cm, and by metallic radiator on the other. The assembly forms a cylindrical capacitor whose dielectric is constituted by the sheath to be tested. The current is measured using a picoammeter Keythley 428, and temperature by two fast thermocouples type K , one on the edge of the sheath and the other inside in contact with the heating electrode.

A brief heating current of 150 A - 50Hz AC is applied to the axial electrode to cause a thermal shock inside the sheath.

One can measure the abrupt rise in temperature inside the sheath caused by the Joule effect of heating electrode (about 15°C in 3 seconds at an average speed of rise of 5°C/s) then

slow natural cooling. The temperature measured on the outside of the sheath increases more slowly and attains its maximum 20 seconds after the start of heating. This gives an idea of time of crossing the heat front through the sheath. The sample is then returned to the ambient temperature in order to start a new measurement to confirm the previous results. Given that the sample has not undergone of harmful overheating the measurements are non-destructive and reproducible under these conditions (Figs. 5a and 5b). During the heating phase, the picoammeter saturates due to electromagnetic radiation of heater current and switches to mode"security".
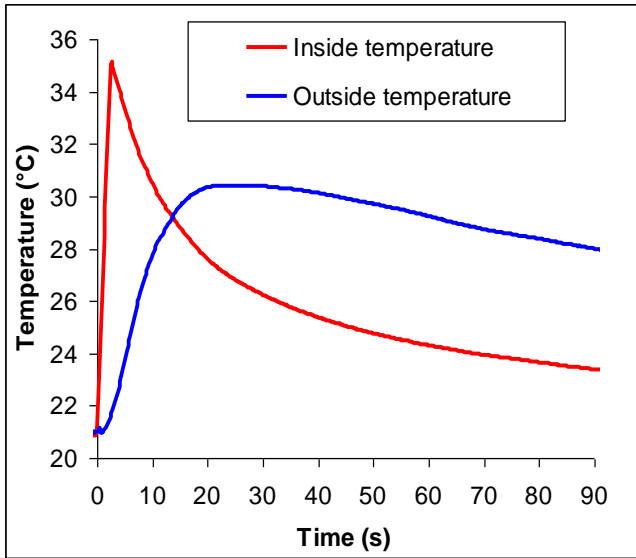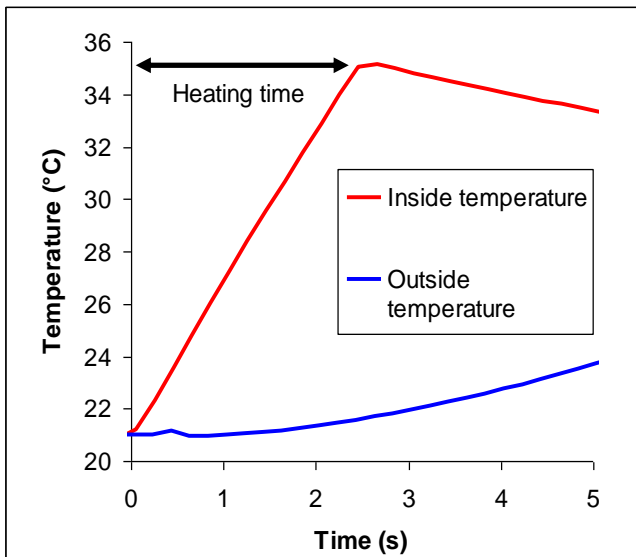

Figure 3a. Temperature graph

Figure 3b. Focus on the first moments for temperature measurements (b)

Although the MOT current theoretically begins from the first moment of heating of the sheath, it did not prove possible to measure it with our means to date. The first three seconds of recording our current MOT corresponding to the generation of

heating are not significant. Measuring the experimental current during these moments constitute a margin of undeniable progress.
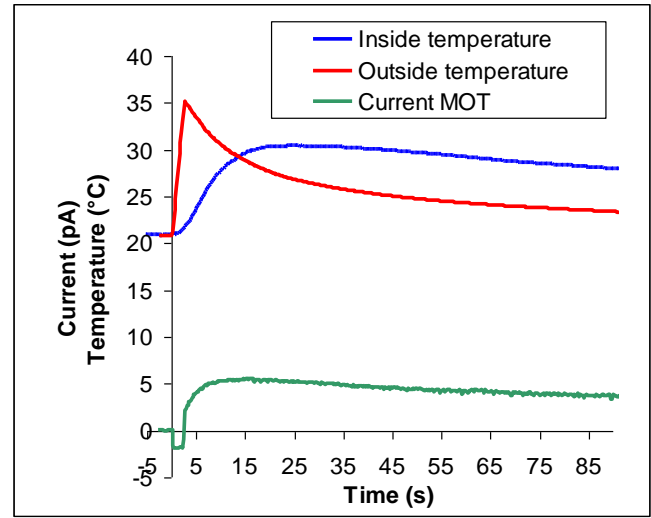

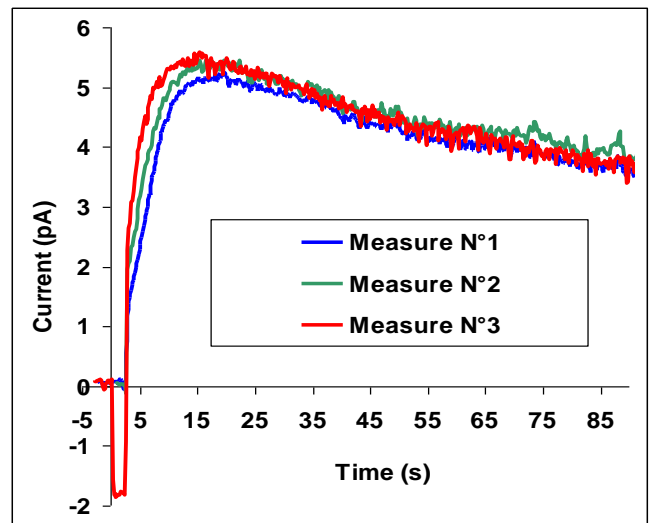Figure 4. Recording current MOT and temperature of the sheath

Figure 5a. Repeatability test

Analysis of the curves of the currents, will therefore focus on the second part of measurement corresponding to the phase in which the heating is cut off.

V. Results And Discussions

Figures 6a and 6b show the currents measured on the sheaths for different duration of aging. All currents present maxima occurring before that the heat front has completely crossed the sheath, just before the first 20 seconds of recording, then amortized more slowly. The analysis of maxima values gives a quantitative idea on space charge density stored in the sheath.

We observe an increase of current amplitudes with the aging duration. However, we can suspect that the phenomenon of

charges installation has several phases. Indeed the increase of current amplitudes is not linear with the aging duration. The current is extremely small on the reference sample but increases abruptly and regularly for ageing from 1500 to 2500h. From 3000h, the increase is more straightforward.
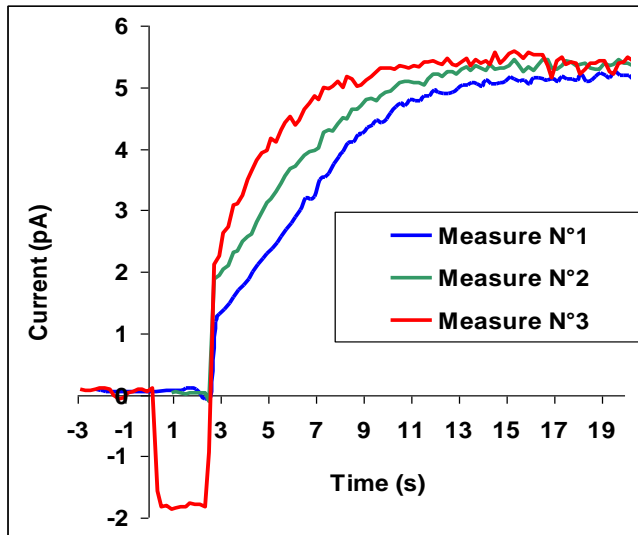

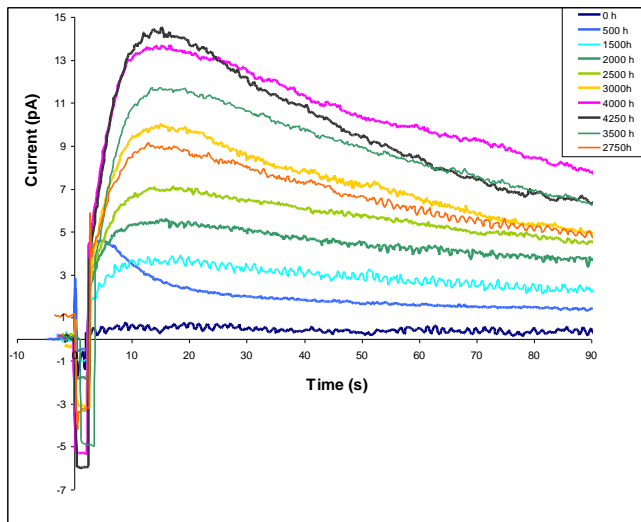Figure 5b. Focus on the first moments for current measurements.

Figure 6a. MOT Currents for different aging times

Finally, the ageing of 4000 and 4250h give currents of the same amplitude and the strongest of the serie. This irregular increase reveals an installation of space charge according to a complex phenomenon.

VI.   Conclusion

We have developed a measurement bench of space charges with thermal wave of sheaths of inside diameter of 4 mm and a thickness of 1.5 mm. A short warm-up is obtained by Joule

effect inside the sheath and permits to measure currents associated to space charges in a reproducible manner.
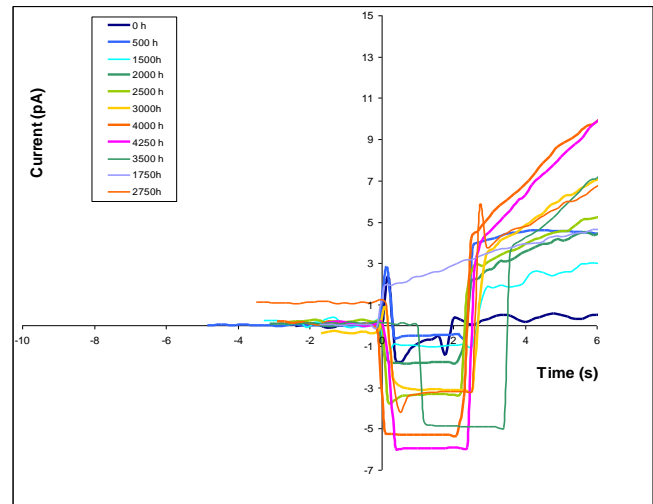

Figure 6b. Zoom on the first moments for measuring currents of MOT

The study focused on a group of 15 aged PVC sheaths under AC voltage of 20 kV AC 50Hz for a period ranging from 500 to 4000 hours. The first results show a progressive increase but irregular of currents associated to space charges with the ageing duration.

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