EQUIPMENT FOR FAST WATER TREES RESISTANCE MEASUREMENT OF POWER CABLE INSULATIONS

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ABSTRACT

In this paper novel equipment for fast water trees resistance measurement using high frequency test (3 – 5 kHz) is presented. This is composed of a power source with variable voltage and frequency, a sample holder, a system for separating and protecting the samples from breakdowns and a data acquisition system connected to a host computer. The software installed on the host computer allows the adjustment of all the test parameters (applied voltage, frequency, reading speed, current etc.), as well as advanced online and after test data processing. Using high frequency electric fields of 4 kV/mm and 3 – 5 kHz, 200 – 300 μm long water trees could develop in 3-4 days.

KEYWORDS

Water treeing, accelerated ageing, computerized set-up, cable insulations, water treeing resistance measurements.

INTRODUCTION

Under the influence of the electric field and in the presence of water, in polymeric insulations water trees develop [1-2].

Water trees are water filled micro - cavities linked by very thin channels (of microns order). They appear in regions with high electric fields, like the interface insulation/conductor (vented trees) or in the vicinity of cavities and impurities (bow tie trees) and start to develop from the areas where the electric field is more intense towards the areas where the electrical field is less intense [3 - 4].

The growth of water trees causes an increase of the electric conductivity, permittivity and dielectric losses in insulations, a local intensification in the electric field, a decrease in the partial discharges inception voltage, a decrease of the dielectric strength and of the breakdown voltage, respectively a premature breakdown of the insulations [4-8]. For this reason it is necessary to determine the resistance to water treeing of polymers and cables insulation.

To investigate the water treeing phenomenon, the reproducibility under controlled conditions is required. As the experiments under normal operating parameters (rated voltage, 50 Hz) implies a long time period, accelerated ageing tests are necessary. For these last tests strong and/or high frequency electrical fields are necessary.

Many researchers report laboratory tests concerning accelerated water trees development in samples subjected to electric fields of high frequencies [9 - 13]. Setups used in these tests implied high voltage and frequency power supplies [8 - 9] or various generators followed by power amplifiers and step-up transformers for the task [10-11]. As tests are performed simultaneously on several insulation samples, a permanent control of samples condition is required. Also is advisable to shut off test for samples having reached a current above a certain admissible upper bound due to initial manufacturing faults in insulation, large tree formation development or breakdown occurrence.

In this paper a completely automated test equipment for fast water trees development (AEWTD) is presented.

EQUIPMENT

The test system used for water tree development in polymeric insulations is presented in the block scheme from Figure 1. The measurement chain starts with a direct digital synthesizer generator (DDS) providing sin-wave signals with frequency in the range of 10 Hz to 20 kHz, 0.01 Hz resolution.

The output voltage level of the generator is controlled by a digital potentiometer, which, among the PID loop of the system, provides a 0.1 V voltage resolution on the insulation probes.

The power amplifier, following the generator, performs a voltage and power gain of the signal providing the necessary energy to the step-up voltage transformer.

Current and voltage in amplifier output are measured with appropriate sensors of the data acquisition system. The current is monitored and actions are taken to limit the power on amplifier output for protection reasons.

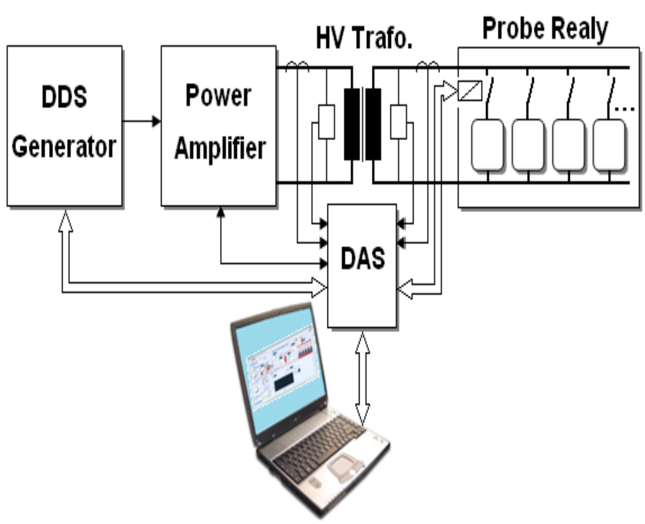

Fig. 1: Block scheme of the ageing test system

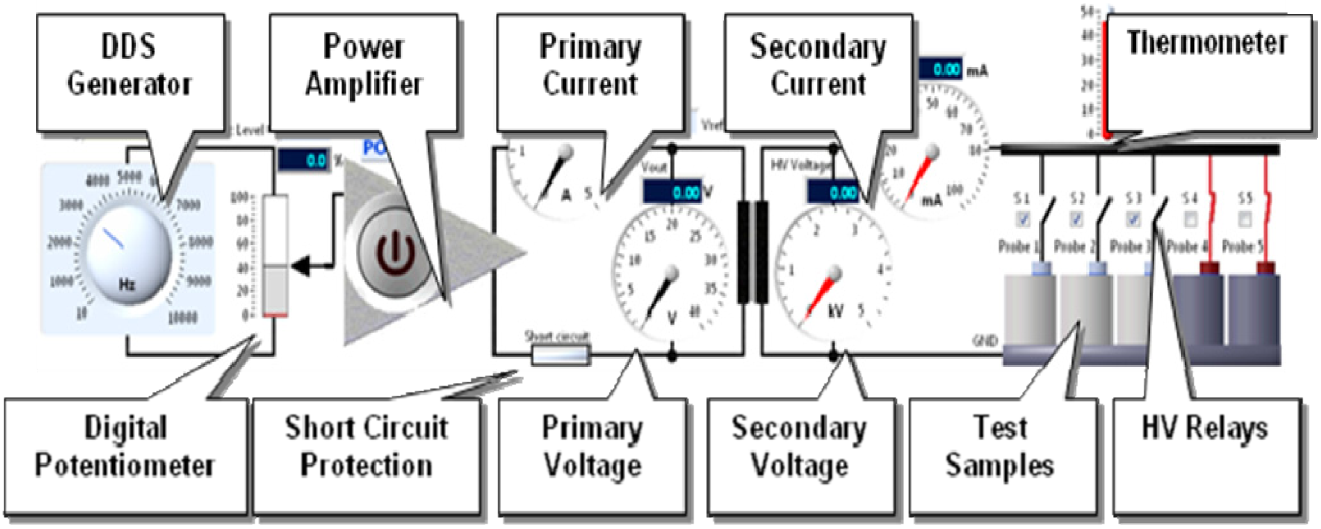

Fig. 2: Functional blocks in the main window related with system hardware

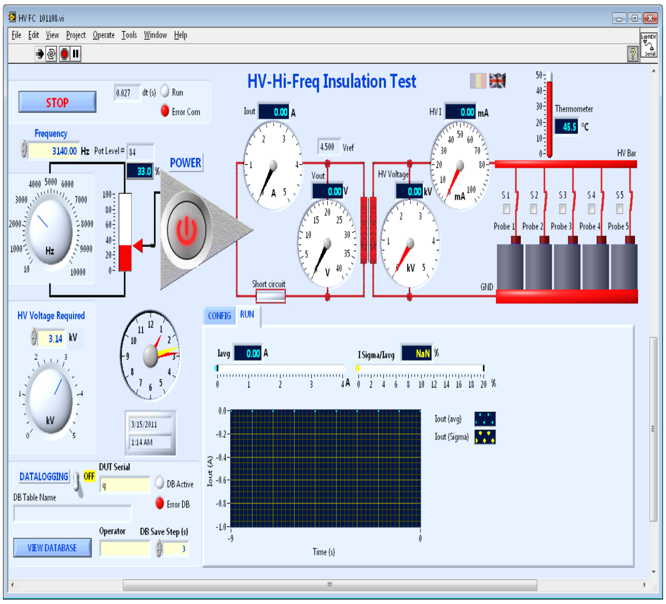

Fig. 3: Front panel window of the Lab VIEW program

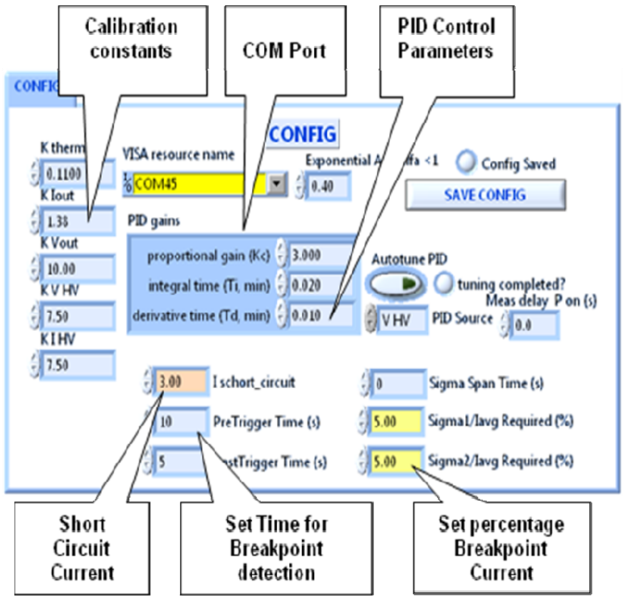

Fig. 4: Configuration and calibration window

The secondary of the step-up transformer supplies the test probes through a set of high voltage relays (which connect or disconnect individual samples in the test). The whole system is controlled by a data acquisition system linked to the host computer.

A LabView developed program is resident on the host computer providing system control and monitoring. The main front panel window of the system is illustrated in Figure 2.

The detailed functionality of system blocks is explained in Figure 3 and the system configuration and calibration window are presented in Figure 4.

All information about test settlement, commands and data acquired in the process may be saved in real time in the systems database. For higher processing flexibility, data may be transfer from this database to Excel for further manipulation and processing.

Basic metrological performances of the system are:

- DDS generator frequency resolution: 0.01 Hz;
- DDS generator control range: 10 Hz - 10 kHz;
- Control range for test voltage: 0 - 5 kV;
- Test voltage step resolution 20 V;
- Temperature measurement range : 0 - 50 ºC;
- Temperature resolution: 0.1 ºC;
- RMS current measurement accuracy : ±(0.5% of reading +3 digits);
- RMS voltage measurement accuracy : ±(0.2% of reading +3 digits);

EXPERIMENTS

The system presented was used for accelerated development of water trees in the XLPE insulation of a 110 kV cable. For this purpose samples were extracted using the microtomy method. Samples have a circular crown shape with an outer diameter D_e and an inner diameter D_i and the thickness g = 0.5 mm. On one face of the sample superficial defects were made by using abrasive paper.

Insulation samples were glued on two insulating cylinders forming a cell where a NaCl test solution was introduced (with a concentration of 0.1 mole/l). This cell, illustrated in Figure 5, represents the ageing test probe. Groups of five test cells are fixed inside a sample holder and subjected to accelerated electrical ageing.

After ageing, samples are introduced in a rhodamine solution and finally sliced for microscope visualization and water trees dimensions and density measurement [14]. For a defined ageing time, densities, lengths, diameters, transversal areas and total volumes of at least 10 water trees were measured and their average values were calculated.

In Figure 6 the time evolution of water trees development for U = 2 kV and f_a = 5 kHz is presented. For longer ageing times an increased number and dimensions of water trees can be seen.

Variations with the ageing time τ of the area, volume, growth rate and water trees density are presented in Figures 7-9. An increase of all quantities with the ageing time τ, due to the water penetration under the electric field action can be seen. Also, the increase of the ageing frequency leads to the increase of the density and water trees growth rate.

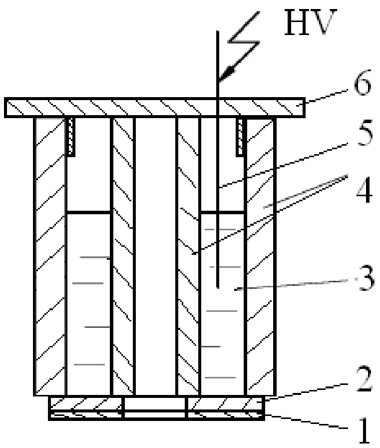

Fig. 5: Water tree development cell: - Semiconducting layer, 2- Sample, 3 - NaCl solution, 4 - Polyethylene tubes, 5 - Platinum electrode, 6 - Cap

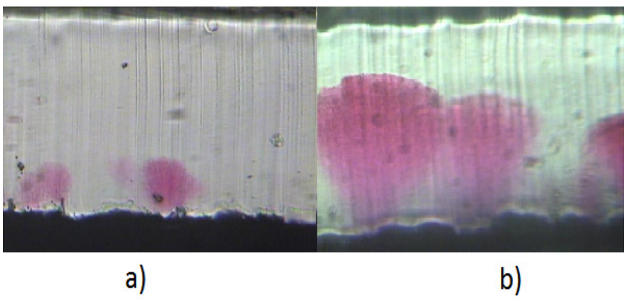

Fig. 6: Water trees in accelerated electrically aged XLPE samples for τ = 48 (a) and 96h (b) (U = 2 kV, f_a = 5 kHz)

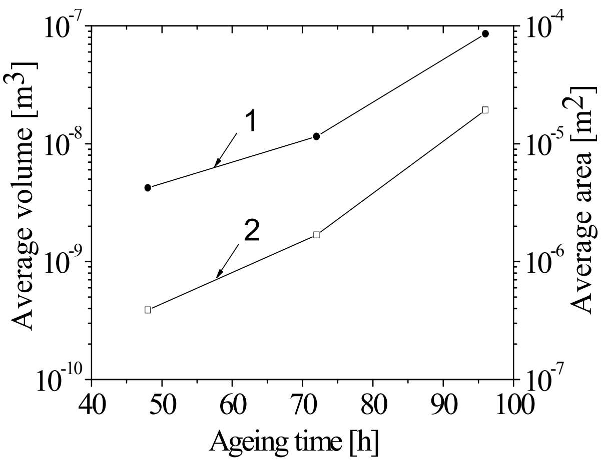

Fig. 7: Water trees average area (1) and average volume (2) versus ageing time for f_a = 5 kHz (U = 2 kV)

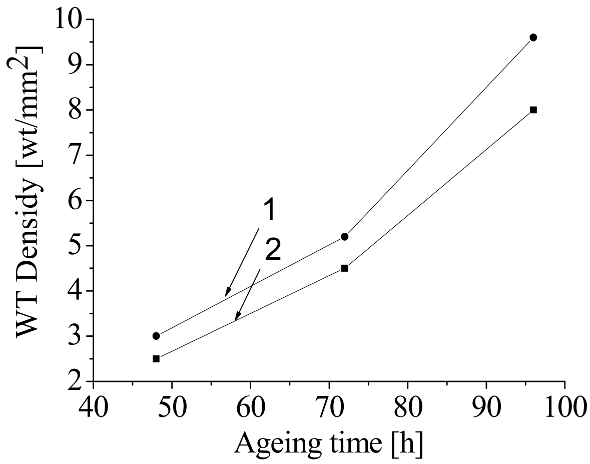

Fig. 8: Water trees average density versus ageing time for f_a = 3 kHz (1) and f_a = 5 kHz (2) (U = 2 kV)

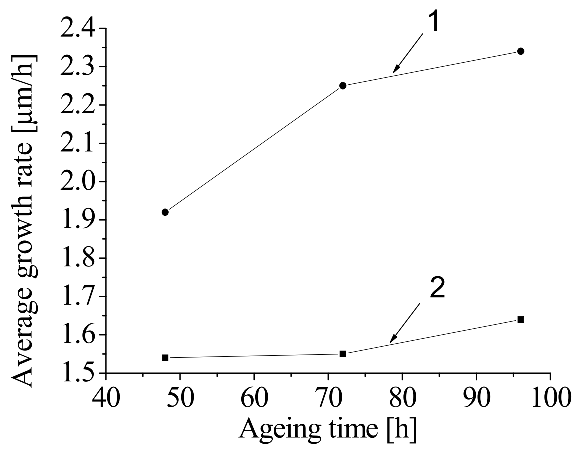

Fig. 9: Water trees average growth rate versus ageing time for f_a = 3 kHz (1) and f_a = 5 kHz (2) (U = 2 kV)

CONCLUSIONS

The computerized insulation test system, presented in this paper, performs an accelerated ageing test using a combined high frequency and high voltage test. Additionally, this system allows a permanent control of sample conditions during the tests, as well as the possibility to disconnect each sample if the individual sample current increased over a preset value.

Increasing test frequency from 3 to 5 kHz, facilitated by the new setup, produces a significant development in size, density and volume for water trees dimensions, allowing better accuracy in evaluation of equivalent ageing of the power cables insulations.

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GLOSSARY

XLPE: Cross-linked polyethylene
AEWD: Accelerated ageing water trees development test
DDS: Direct digital synthesizer
PID: Proportional, integral, derivate