Evaluation of Dielectric and Electrical Properties of 6-AYKCY 3x240 PVC Insulated Cables during the Thermal Ageing by Means of Unconventional and Conventional Diagnostic Methods

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Abstract — **The aim of the experiment was to observe changes in individual measured dielectric or electrical parameters by using different measurement methods and their subsequent comparison. This paper will discuss in detail the evaluation of individual measurements and comparison of measurement methods implemented in the framework of the experiment and the appropriateness of their use for these types of measurements. In our experiment cable samples, type 6-AYKCY 3x240, with PVC insulation were used.**

Keywords — Cable, insulation, VLF methods, dissipation factor.

I. Introduction

Cables are exposed to several internal as well as external factors. Internal factors are the power parameters, applied voltage, current and frequency. External factors are related to factors such as temperature, humidity, water presence, chemicals or radiation, as well as vibrations etc. In relation to the factor type that influences material, evoked aging could be distributed evenly throughout the volume of the insulation, such as the exposure to increased temperature; or changes are not evenly distributed in volume but in direction to volume weaknesses. The example is influence of ultraviolet radiation on the insulation. In our experiment, we focused on the analysis of changes of the parameters of 6kV cable type 6 – AYKCY – 3x240 mm2 exposed to a long-term influence of high temperatures, thermal aging. Subsequently, the electrical insulation parameters of the samples analyzed by the method of VLF high voltage method and Modulab MTS systems from Solatron Analytical Ltd. measurements were carried out in the frequency range from 0.01 Hz to 1 MHz.

II. Thermal Aging

The thermal aging represents complex of physical-chemical processes on the surface and throughout the volume of the exposed insulation. Finally, these processes lead to irreversible changes in the insulation and insulator properties. Thermal aging generally contains two main branches: the progress of chemical and physical changes as a result of chemical degradation reactions, polymerization, depolymerization, diffusion and thermo-mechanical effects caused by forces due to thermal expansion and contraction [1, 2].

Cable insulation degradation due to temperature is well described by the Arrhenius equation. This equation is based on the description of a chemical reaction speed in dependence on temperature. Basically, if the failure control mechanism, respectively degradation process, depends strongly on temperature, then this dependency can be expressed precisely by Arrheinus equation for the degradation reaction speed r_A

$$r_A = A\exp(-\frac{E}{kT}) \tag{1}$$

where T is the absolute temperature in K, and k is the Boltzmann constant. The exponential formula expresses the increase in the number of molecules with energy E (in practice – activation energy), sufficient for the reaction with increasing temperature. Basically determines the steepness of the degradation processes speed on the value of $1/T$. Equation agrees very good with experiment for insulation systems if maintained condition $\Delta E >> kT$. Where Arrhenius equation can be then rewritten in the formula:

$$L = B\exp(-\frac{E}{kT}) \tag{2}$$

where L in this case is the lifetime. Then, substituting the appropriate lifetime values (assuming the functional dependency) for two temperatures the activation energy of the reaction can be determined. Afterwards, it is possible with this value to perform in the relevant temperature range lifetime calculations. For the electrical insulation materials are the values of the activation energy in the range of eV units.

For most materials and the equipments it is valid that the temperature increase by approximately 10 K decreases the lifetime of the system by half. Although this argument does not apply to all materials and material systems, it can be indicative use. For most thermoplastic materials we achieve good conformity [3–6].

III. VLF METHOD

The principle of the low frequency dielectric spectroscopy method is based on the measurement of dielectric parameters in a wide frequency range. Its usage is in measuring currents of low and medium voltage cables samples at the voltage with the applied frequency of 0.1 mHz to 10 kHz. The measurements in a wide frequency range can be used to estimate the degradation of insulation PILC or PE cables. Taking the example of PE cable, then during the test the PE cable system is connected to a low-frequency high voltage test generator with a frequency band of 1 mHz to 1 kHz. During the test at the given frequency and voltage the system measures values of loss and capacitive currents. If there is a synchronic increase in the loss and capacitive currents, the loss factor is not significantly changed since it is the ratio of these currents. The advantage of this test is to separate recording of the value of the loss and capacitive currents as a function of voltage and frequency and from their changes to determine insulation condition.

A. VLF-34E 34 kV VLF Tester

In our experiment, we used the professional industrial measuring device, to achieve the test results that can be obtained by means of conventional testing equipment, with a source of VLF test voltage VLF-34E 34 kV VLF tester and the measuring probe TD-34E VLF-TD CABLE DIAGNOSTIC TESTING.

The VLF-34E is a VLF AC hi-pot source that uses a solid state design with microprocessor controls. It meets the requirements of applicable world standards regarding cable testing up to 25kV class maintenance testing. It is light, compact, rugged, and very portable. Its sine wave output is suitable for using optional external PD and TD detection equipments. Using a TD and PD options, the VLF-34E is all that is needed for nearly all cable testing up to 25kV class. [7, 8]

Fig. 1. VLF-34E 34 kV VLF tester with measuring probe TD-34E VLF-TD CABLE DIAGNOSTIC TESTING [3–4].

B. The ModuLab MTS System

ModuLab® MTS Materials Test System is a highly versatile test system for measuring characteristics of materials. A number of modules are combined into a single chassis, avoiding the need for stacking and wiring separate units. The modules are arranged in groups, known as instrument groups, each with a materials core module to enable DC measurements to be taken. Other modules in the group may provide AC functionality and analyses, or the measurement at high voltages, measurement of high impedances, or use for high power applications. Each instrument group in a chassis may perform a separate experiment, so there can be multiple experiments running simultaneously.

Using this device is useful for low voltage time domain and impedance tests on a wide range of materials.
For time domain analysis (open circuit, DC, I-V, or pulse) many of the voltage waveform for experiments can be used.

For impedance, capacitance (C-V), permittivity or electrical modulus analysis voltage controlled impedance tests can be used.

In our case we used the Modulab MTS system to get results and data from a wide, especially very low frequency measurement on the cable samples in delivered state and after 13 years of performance in the temperature range from RT to 100 °C, to get complex and precise information about dielectric spectra and comparison of these results with data from conventional measurement techniques.

IV. MEASUREMENT RESULTS

For measurements three types of 6 kV three-core power cable samples of lengths between 2.93 m – 3.33 m with a sector, stranded aluminium core 3x240mm2, PVC insulation were used. The inside sheath is made of PVC and copper shield is a wire with tape counterhelix. The samples were produced in 1997 and located in real operation. The samples were labelled as followed:

sample 1 – length 3,33 m, 13 years of service,

sample 3 – length 2,93 m, 13 years of service,

sample 7 – length 3,05 m, reference sample.

The samples (marked as 1/3, 3/3 and 7/3) were subjected to thermal aging in a thermostat with air circulation at 100°C. The aging took place in cycles, wherein each diagnostic cycle the diagnostic measurements were performed. Before the aging initial measurements were made. Frequency dependence measurements of the dissipation factor at room temperature at voltage 1 kV in the frequency range 0.01 – 0.1 Hz were carried out on the cable samples – the cable 1, wire 3: 1 + 2 + 0 (1/3), the cable 3, wire 3: 1 + 2 + 0 (3/3) and the cable 7, wire 3: 1 + 2 + 0 (7/3) – which serves as a reference sample. Results are shown in Fig. 2. Measurements were performed by use of the professional industrial measuring device VLF-34E.

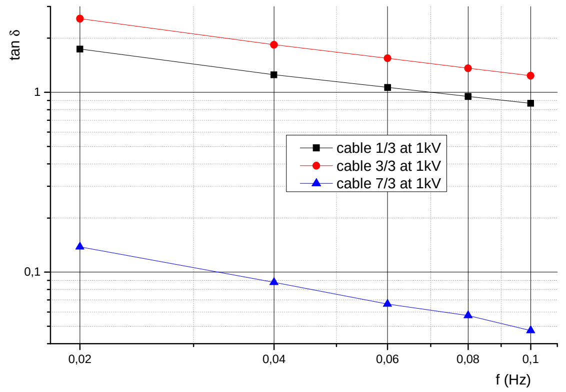

Fig. 2. Frequency dependence of the dissipation factor of the cable samples 1, 3, and 7 measured at 1 kV in the frequency range 0.01–0.1 Hz at room temperature.

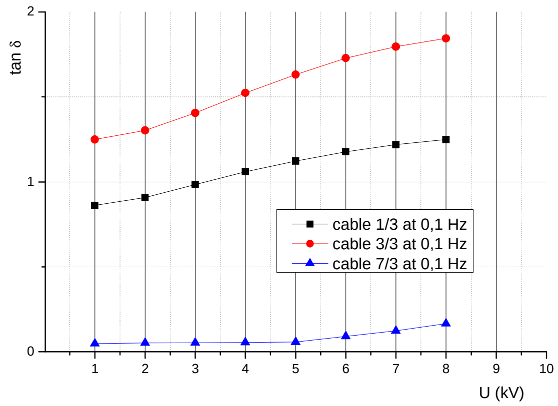

Fig. 3. Voltage dependence of the dissipation factor of the cable samples 1, 3, and 7 measured at the frequency 0.1 Hz in the voltage range 1–8 kV at room temperature.

Furthermore the voltage dependence of dissipation factor measurements at room temperature in the voltage range 1–8 kV were performed at measurement voltage frequency 0.1 Hz (Fig. 3). Results of initial measurements showed increased values of the dissipation factor for samples after 13 years of service in the whole voltage and low frequencies range.

In addition, we compared the dissipation factor values changes during the ageing. Figures 4 and 5 show the change in values of the dissipation factor versus time at frequencies of 0.1–0.02 Hz for the samples 1/3 and 3/3.

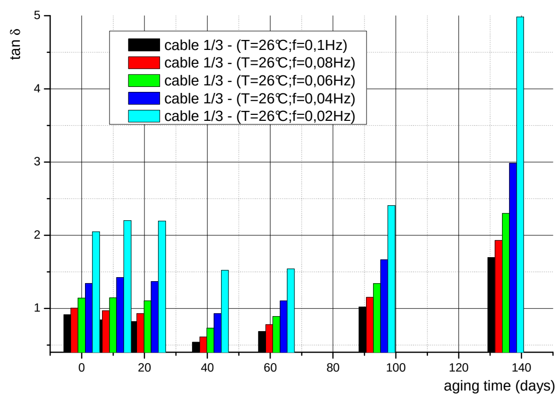

Fig. 4. Time evolution of the dissipation factor of the cable 1/3 samples during the aging measured at 1 kV in the frequency range 0.02–0.1 Hz and ambient temperature 26 °C.

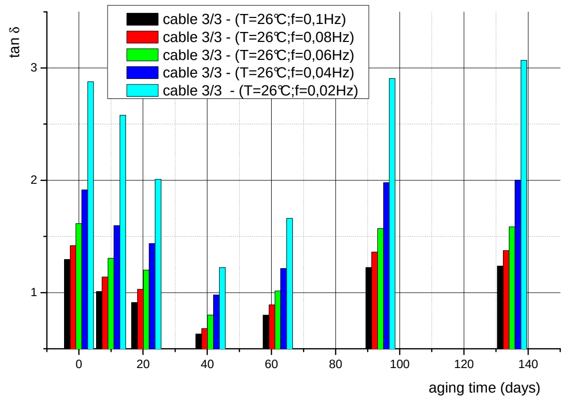

Fig. 5. Time evolution of the dissipation factor of the cable 3/3 samples during the aging measured at 1 kV in the frequency range 0.02–0.1 Hz and ambient temperature 26 °C.

Changes in the frequency dependence of the dissipation factor values were measured with the unconventional measurement system Modulab MTS in the frequency range from 0.01 Hz to 1 MHz with measurement voltage 6 V. The aim of the measurements was to analyse changes in the dissipation factor values during the thermal ageing in a wide frequency range and in the temperature range up to 100 °C.

Figures 6 and 7 show the dissipation factor frequency dependence for the samples 1/3 and 3/3 in the temperature range from 20 °C to 100 °C, after 13 years of service and subjected to thermal aging for 160 days.

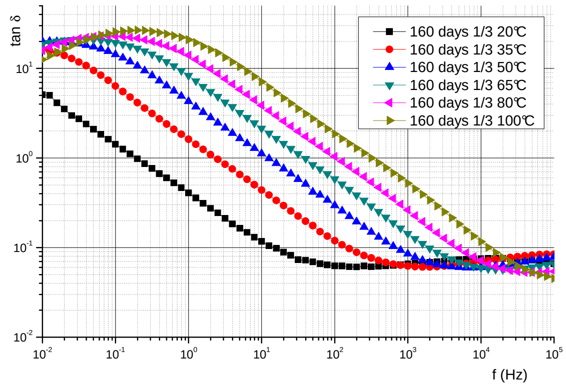

Fig. 6. Frequency dependence of the dissipation factor of the cable 1/3 samples measured at 6 V in the frequency range 0.01 Hz – 1 MHz and in temperature range 20 °C – 100 °C.

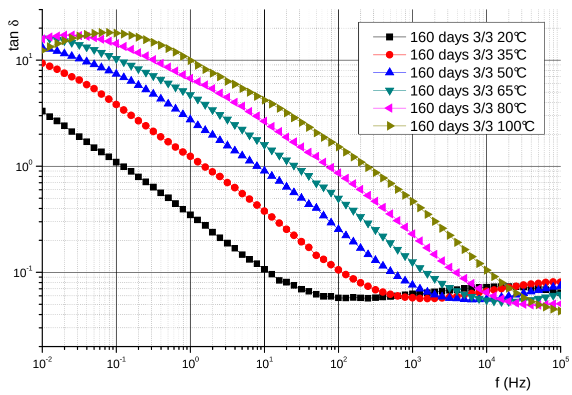

Fig. 7. Frequency dependence of the dissipation factor of the cable 3/3 samples measured at 6 V in the frequency range 0.01 Hz – 1 MHz and in temperature range 20 °C – 100 °C.

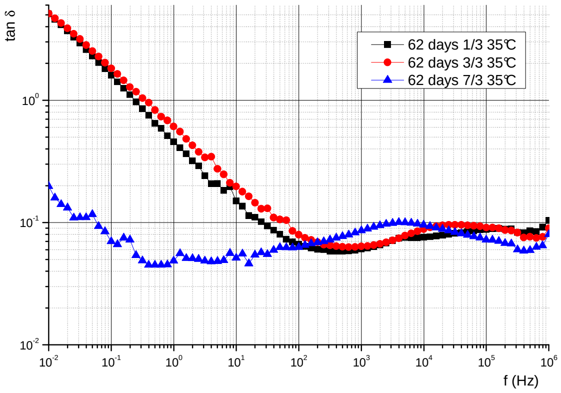

Fig. 8. Comparison of dissipation factor frequency dependence behaviour for the new (7/7) cable sample and cable samples after 13 years of service (1/3, 3/3) and 62 days of thermal ageing, measured at 35 °C.

From the frequency dependence behaviour of dissipation factor values on Figs. 6 and 7 the shift of the polarization maxima to higher frequencies with increasing temperature can be observed. This phenomenon is conditioned by the physical nature of the polarization process with increasing temperature where with increasing temperature the duration of the relaxation times are narrowing (shortening).

Figure 8 shows frequency dependence of the dissipation factor of the samples 1/3 and 3/3 after 13 years of service and reference sample 7/3, all samples after 62 days of thermal ageing. Dependences were measured at temperature 35 °C. From the dependence it can be stated, that at lower ambient measurement temperatures cables after 13 years of service can be identified by means of measurements in a low frequency range.

These measurements show that this unconventional method of the dissipation factor values measuring in a wide frequency range, especially in very low frequency range, is suitable to identify the samples with deteriorated properties by service condition, or laboratory thermal treatment. But it is necessary in addition to this method to comprehensively assess the state of the cable system insulation by the conventional methods.

V. Conlusion

In the presented experimental results very low frequency measurements performed with the professional HV VLF dissipation factor analyzer are compared with wide range frequency laboratory measurements of the dissipation factor on the samples PVC based insulated cables after 13 years of service and reference sample during the thermal aging cycles. Based on the comparison of the measurement results for all samples it can be stated that both measurement approaches show that the reference sample has a much lower value of the dissipation factor compared with samples 1/3 and 3/3 after 13 years of service measured at room temperature in a very low frequency range. It means that the samples have significantly poorer dielectric and electrical properties. In terms of the suitability of the chosen method it can be stated the method is able to determine the changes of the dielectric parameters of the cable samples and is suitable for measurement and comparison of changes in the dissipation factor due to degradation processes induced by thermal aging even by measurements at room temperature.

On the other hand, results of the temperature dependence measurement of the dissipation factor in a wide frequency range during thermal degradation give more complex information about electrical and dielectric properties even for higher operating temperatures and their influence on the overall cable performance.

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