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Measurement of Dielectric Parameters of XLPE Cables

Abstract. The present study shows changes of dielectric parameters depended on degradation of high voltage insulation material. The article deals with the measurement of dielectric parameters of XLPE cables in the initial stage of ageing and cables after services degradation. The measurement was carried out using isothermal relaxation current analysis (IRC analysis) and measurign capacity in 50 Hz frequecy. IRC analysis used direct voltage step with 100 V magnitude and capacity and dissipation factor measurements applied voltage from 500V to 2 000V.

Keywords: XLPE cable, IRC analysis, capacity, ageing of XLPE, dissipation factor.

Introduction

In the present is dominated increased demand for electricity and therefore are required greater security and reliability for high-voltage electrical equipment. These requirements relate mainly to the insulation system, which is an important and sensitive part of any electrical equipment. Damage of insulation can lead to equipment failure and other disorders.

Cross-linked polyethylene (XLPE) is widely used as electrical insulation material for high-voltage distribution cables. This material provides excellent physical, chemical and electrical properties. The cables may be exposed to high currents and voltages and they are critical parts of the transmission infrastructure. Therefore, is expected their high resistance against possible failures [1].

The cables are permanently exposed to thermal aging during operation. It may cause change in dielectric parameters of cables and also irreversible damage of cable insulation. The primary initiators for the degradation of cable insulation are high currents, voltage, mechanical, chemical and thermal stress and pollution of environment. Interaction various factors together may significantly speed up the degradation processes. Process of aging of insulation is the most acting on the parameters and quality of insulation. There are several methods for detection of insulating state of XLPE insulation.

This paper presents results of the analysis of XLPE insulated power cables at an initial stage of ageing and cables of operationally unknown technical condition.

Analysis methods

IRC analysis is one of the DC non-destructive methods which offer possibility to investigate the degradation processes in the material. The state of insulation can be determined by measuring the relaxation currents in the time domain.

Real dielectrics contain electric charges bound by electrostatic forces and there are also free charge carriers, which create undesirable conductivity. Dielectric polarization is a phenomenon that occurs under the effect of electric field and causes the movement of free charge carriers [2], [3].

After connecting voltage to dielectric material current starts flow through dielectric. In case of ideal dielectric the current has not real component. In practice is real component of current caused by processes of polarization and conductivity. These processes are dependent on kind of dielectric in which they are occurs.

Slow polarization processes are measured by charging and discharging currents.

Polarizing current $i_{pol}(t)$ can be expressed as:

$$(1) \qquad i_{pol}(t) = C_0 U_C \left[\frac{\sigma_0}{\varepsilon_0} + f(t) \right]$$

As a result of a DC voltage U_C, polarizing current is composed of two parts. The first part is related to conductivity of the investigated object and the second part is related to activation of different polarization processes inside the investigated material [4], [2].

If the DC voltage UC is removed at the time T_C and the material is grounded, depolarization current $i_{depol}(t)$ starts to flow through the material.

$$(2) \qquad i_{depol}(t) = -C_0 U_C \left[f(t) - f(t + T_C) \right]$$

where:
f(t) - monotonically decreasing function [4]

The total polarizing current flowing through the dielectric can be following assumption of existence the independent Debye's polarization processes and Maxwell-Wagner equivalent model, expressed as the sum of currents with exponentially decreasing amplitude with definite-time component, which represents the individual of the polarization occurring in the material by the equation:

$$(3) \qquad i(t) = \frac{U}{R_0} + \sum_{i=1}^{n} I_{mi} \exp\left(\frac{-t}{\tau_i} \right)$$

where:
U – applied DC voltage
R_0 – DC insulation resistance after an infinitely long time
I_{mi} – amplitude of i-th component of Debye's elementary current
τ_i – relaxation time constant of the i-th component [2]

The parameters I_{mi}, τ_i are correlated with the material properties [5].

Performing the IRC-Analysis every relaxation current component can be associated with a time function [6].

Number of members of expansion n is dependent on the structure and homogeneity of the dielectric and the time at which the polarizing action are measured [2].

During ageing, it is observed increase of slower polarization process at using IRC analysis. The ageing leads to the amplified formation of the current amplitudes in a time period greater than 100 seconds [2].

The time characteristic of the isothermal relaxation current varies significantly with the residual strength of polymeric composite specimens [6].

The dissipation factor and capacity measurement are classical methods for the actual condition evaluation of insulating systems. It gives important parameters for the aging condition evaluation of an insulation system. For a comparison, the measurement must be done at the same conditions than in the past [2], [7].

The classical circuit for the evaluation of capacity and dissipation factor is a "C / tan δ" Schering Bridge. It is characterized by the fact that the object reality is stressed closed to high voltage, which can be measured [7].

The value of the dielectric loss factor is related to dielectric loss and its value can be regarded as a measure of the quality of the insulation system. Dissipation factor is strongly dependent on temperature [2], [7].

Capacity and dissipation factor measurements are diagnostic methods wide used for quality changes monitoring of insulation material in electric power equipments. The measurement of dielectric dissipation factor tan δ at power frequencies (50 Hz or 60 Hz) is a usual test, applied to insulation. The measured value of tan δ depends also on geometrical composition of insulation. Therefore, just insulation systems with similar composition can be compared [7].

Degradation and ageing of XLPE

Polyethylene in its cross-linked forms is the insulation material of a XLPE and it is a single homogeneous dielectric.

Stability of microstructure and composition of the insulating material is changing due to degradation processes. These changes result to changing behaviour of insulation material from view of polarization processes. Based on this fact, is possible to characterize degree of degradation and ageing.

Ageing in a polymer changes the electrical, physical, mechanical and morphological properties of the insulation [14]. All these properties are influencing the dielectric parameters and characteristics of insulation [8].

Ageing of XLPE cables is related to the temperature of the insulation. The normal maximum operating temperature of XLPE cables is 90℃. Increasing the operating temperature of the cables will reduce the service life. Small increase in temperature has a significant impact on the ageing of the XLPE. The cable will be subject to stress cracking and electrical failure at positions of mechanical stress. Tests have shown that XLPE cables can operate at a temperature of 105℃ for a limited time without significantly reducing the service life of cables [9].

At temperatures in excess of 105℃ deformation of XLPE readily occurs, particularly at positions where the insulation is under mechanical stress. The maximum overload temperature of XLPE is limited to 105℃ [2], [9].

When the cables are ageing in hydrothermal condition for a period of time, the mechanical and electrical properties of the XLPE insulation may degrade, which may lead to an apparent deterioration in dielectric performances such as electric conductivity, permittivity and dielectric loss. The physical form and chemical structure of XLPE cables will be altered. During thermal ageing, several structural changes occur such as variation in crystalline, chain scission and variation in heat of fusion and in melting point [10].

Quantitative assessment of aging or damage of the XLPE insulations can be separated assessment of the relaxation mechanisms.

Experimental measurements

Diagnostic measurement was performed by the IRC analysis for six samples of HV XLPE cables. The three samples of cables have been operationally unaged and undamaged and the other three have been cables of operationally unknown technical condition. As the metering instrument was used programmable electrometer Keithley 617. Circuit configuration for measurement is shown in Figure 1, where C_X is measured sample of cable.

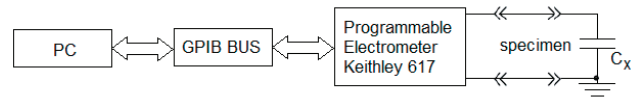Acquired data was processed by Agilent HP VEE software and Matlab.

Fig. 1 Schematic diagram of measuring circuit

All of cables have been a power cables with an aluminium core and XLPE insulation. Samples of cables were approximately 1 m long and protective cable jacket and semiconducting layer have been removed (8 cm at both ends) and shielding taken out. Time of measurement was 1000 s. During this time, it is can measure by IRC analysis only 7 types of polarization.

Sample of cable was connected to test voltage (100 V) by Keithley 617 electrometer and the sample was subjected to affect of this electrical field for 1000 seconds. By means of software were obtained the currents I_{mi} and the times τ_i .

Dielectric parameters dissipation factor and capacitance was measured by precision dissipation factor and capacitance Shering's bridge. The capacity and loss factor were measured at voltages from 500 V to 2 kV in increments of 500 V.

Aim measuring has been comparison and evaluation of measured dielectric parameters and dependence of charging current of six samples of cable. The cables at an initial stage of ageing are marked as a group of samples A and the cables of operationally unknown technical condition are marked as a group of samples B.

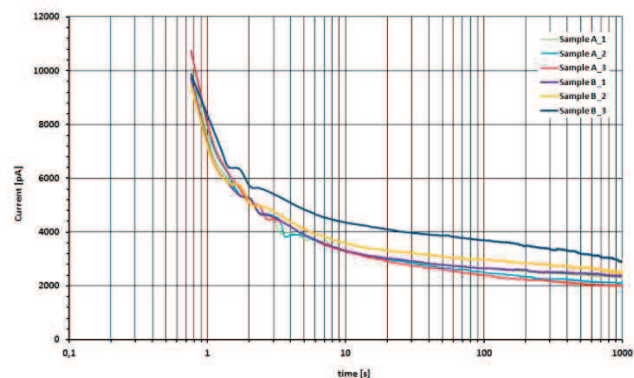The measured time dependences of charging currents of cable samples is shown in Figure 2.

Fig. 2 I-t characteristics of cable samples

Table 1. The comparison of time constant for 5 polarization

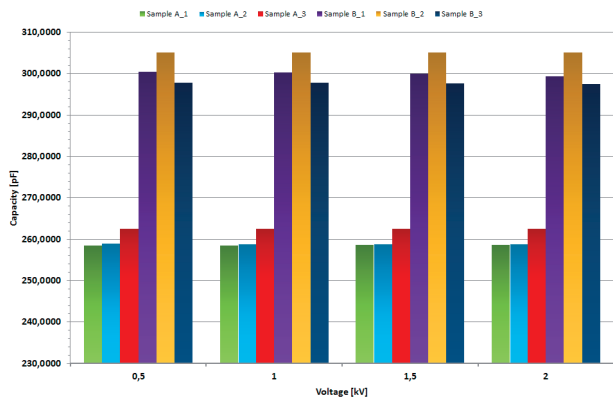| τ	Sample of cable					
	A_1	A_2	A_3	B_1	B_2	B_3
τ_{51}	0,24	0,28	0,36	0,24	0,22	0,41
τ_{52}	1,37	1,84	3,6	2,94	2,7	3,12
τ_{53}	8,73	13,81	36,53	28,76	16,74	12,35
τ_{54}	108,87	123,03	327,76	148,39	104,68	112,41
τ_{55}	**12023,4**	**13384,96**	**922843,76**	**13125,2**	**6817,98**	**5005,25**

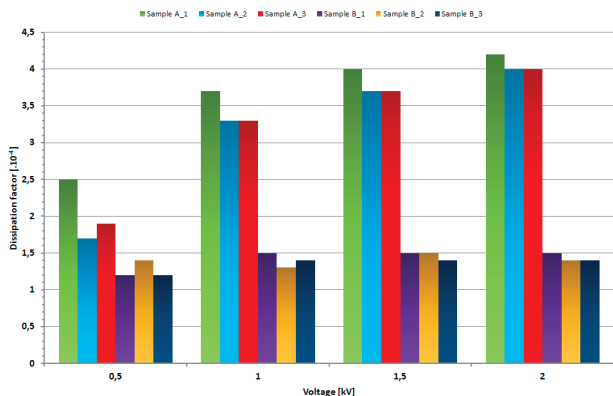Fig. 3 Comparison of capacitance for six cable samples

Fig. 4 Comparison of dissipation factor for six cable samples

The constants of elementary currents and relaxation times for seven polarization processes were calculated from measured dependence of charging currents.

For further interpretation was excluded the development of these amplitude of current and relaxation time, which included values less than or equal to 0 and negative values, because it is not possible that currents were negative values. For this reason, the values τ_i and I_{mi} for n=5 polarization processes were used in analysis.

The comparison of time constant for 5 polarization processes is shown in Table 1. The Figure 3 and Figure 4 show the comparison of capacitance and dissipation factor for six cable samples, respectively.

From presented by comparisons (Figure 3 and Figure 4) is seen a small dispersion of capacity and dissipation factor in each group of samples. Between groups of samples it can be seen significant difference in values of capacity and dissipation factor. From comparison of time constant can be seen difference of τ_{55} between samples. Based on this fact it can be concluded a different degradation and ageing status of each samples.

Conclusion

Aim of this paper was to measurement of dielectric parameters of six samples of XLPE cable. The part of samples was in the initial stages of aging, operationally non-degraded. The other part of samples was cables of operationally unknown technical condition. It is known that ageing changes the properties of insulation.

It was found a difference of dielectric parameters from the evaluation of the measured values. The small dispersion of the values of capacity in individual group of samples was probably caused by unequal specimen sizes. Dispersion of values of dissipation factor was caused by the dispersion values of capacity.

Comparison of time constants τ_{55} shows the difference in values for individual samples. We thus conclude that the samples are different degraded and aged. It is also possible to assume a slightly different samples layout, resulting in changes in the polarization processes occurring in these samples. The measured I-t characteristics not show large local abnormality. It is possible thus to assume that the trend rate of polarization processes occurring in insulation of samples is the same. By measurement of I-t characteristics it was found higher values of current for sample B_3 compared to other samples.

In conclusion, the observed dispersion of dielectric parameters in individual group of samples was not significant and can't exclude the surrounding of a disturbance during the measurement, which could affect the measured results. Measured samples are suitable for next investigation.

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