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Degradation of the PE insulation due to electrical treeing

Streszczenie. (Degradacja izolacji PE powodowana drzewieniem elektrycznym). *Drzewienie elektryczne jest jedną z przyczyn długoczasowej degradacji materiałów polimerowych używanych do zastosowań wysokonapięciowych. Artykuł przedstawia wyniki badań charakterystyk wzrostu drzewek elektrycznych w próbkach PE oraz opisuje charakterystykę defektów występujących w kablach.*

***Abstract**. Electrical treeing is one of the reasons for long term degradation of polymeric materials used in high voltage AC applications. In this paper we report an investigation of electrical tree growth characteristics in PE samples. This paper describes characterization of cable defects.*

Słowa kluczowe: drzewka elektryczne, izolacja PE, wyładowania niezupełne
Keywords: electrical trees, PE insulation, partial discharges

Introduction

Cable insulation and accessories may be defected or deteriorated in installation and in use. After-laying tests with diagnostic measurements should detect faults and defects caused by transport and installation. Successful measurements give fingerprint for further diagnostics during the service of the cable system. Partial discharges (PD) are one of the major reasons for degradation of cable system insulations in service. Thus, PD measurement is an important diagnostic tool. After installation or long time using, the insulation of cable or accessories may include small voids and cavities, conductive or insulating contaminants, or conductive protrusions in different interfaces. The installation may also cause other defects like mechanical cuts. During the service the temperature variation and other environmental stresses as well as electric field and heating due to load current may enlarge these defects, and partial discharges may be incepted. These effects may also introduce cavities in originally sound cable insulation or enlarge original micro voids. Erosion by ion bombardment and chemical effects gradually change small defects to electrical trees with consequent final breakdown. In addition, water trees may appear depending on the outer sheath of the cable, and finally these also cause breakdown. Different insulating materials (extruded, paper-oil, others) have different PD levels, PD behaviour and dielectric strength.

The electrical PD measurement methods are most important and preferred and they have received much attention in recent years. Apparent charge, PD inception voltage as well as number and distribution of PD-pulses are the most important quantities. Identification with certain PD-patterns and localization of PD are most important aspects and tasks. Different ways to suppress external noise is applied to detect signals with high sensitivity also in difficult on-site conditions.

Interaction between partial discharge and insulation

The PD induced degradation of the dielectric is roughly due to two processes: chemical degradation and physical attack by bombardment of particles (nitrogen ions) [1]. The interaction between PD in a cavity and the surrounding dielectric is complex and many effects have been identified and studied.

Part of the complexity stems from the fact that the dielectric is changed (aged) due to the PD activity but at the same time the PD mechanism is affected by the aging dielectric [1].

The scenario depicted here considers the situation of a flat cavity or a gap between electrodes covered by a dielectric in which hydrogen, carbon and oxygen are present, either in the gas or in the dielectric [1]. The aging process is now more or less generally accepted to proceed along the following lines (Fig. 1).

1. The conductivity of the surface of the cavity increases due to the reaction processes of humidity and the dissociation products of air as caused by the PD. Indeed, many authors have detected an increase of the surface conductivity not long after the PD process was initiated [2]. When the cavity surface is observed more closely, often a liquid layer or droplets are found.
2. In the following stage the surface roughness is seen to increase due to charge carrier bombardment and deposition of PD by-products.
3. Further PD activity leads to the formation of localized solid by-products, i.e. crystals which have been positively identified as hydrated oxalic acid [3].
4. The field enhancement at crystal tips leads to a further intensification and localization of the PD process and often pit formation is now observed. As a consequence tree growth is initiated [1].
5. Eventually, the tree growth may lead to breakdown. When fillers are present in the dielectric, the insulation between filler particles usually is most severely degraded [1].

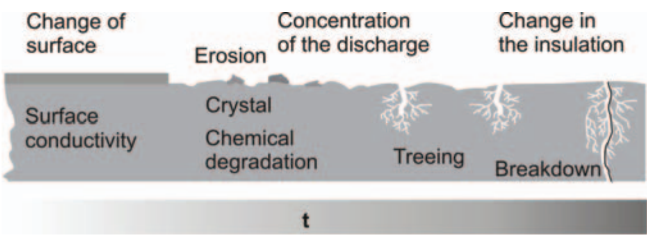

Fig. 1. Stages of PD-induced damage at the insulator surface [1]

PE Insulation

Low-density polyethylene (LDPE) was often applied as an insulating material for extruded cables. Nowadays, most polyethylene extruded cables have XLPE insulating materials. Other types of PE are medium-density polyethylene (MDPE) and high-density polyethylene (HDPE) used for sheath production in modern cable technology.

Polyethylene's, $(CH_2\text{-}CH_2)_n$, are very long macromolecules. The CH_2 groups are strongly joined by bonds of the shared electron valence type. The ends of the different chains contain methyl ($-CH_3$) or vinyl ($-CH=CH_2$) groups [4]. The mechanical properties of the different polyethylenes are mainly determined by the density of these materials. The density in turn is strongly related to the molecular length and the number and length of side chains per macro molecule [4]. This is illustrated in Table 1.

Table 1: Relation between density and number and length of side chains for LDPE and HDPE [4]

Polyethylene	LDPE	HDPE
Density [g/cm^3]	0,91 – 0,94	0,95 – 0,965
Average molecule length	1500 - 3500	7000 - 14000
Number of side chains [/1000 chain atoms]	20 – 40 *	< 5
Length of side chains [number of atoms]	2 – 5 *	< 4

* Occasionally there is a side chain with an average molecule length

The PE is a thermoplastic: the upper operational temperature is limited to ≈ 70°C. By crosslinking of the macromolecules the operational temperature is increased to ≈ 90°C. In XLPE the macro molecules are incorporated in a network in which the effective molecular weight has become infinite [4].

The polymer, either crosslinked or not, is semi-crystalline, which means that it is partly crystalline and partly amorphous. The crystalline part shows a folded regime of macromolecules organized into platelets with dimensions strongly depending on the production process [4]. Usually the thickness is ≈ 10nm, they are generally several µm wide and long. Between the platelets are interconnecting chains and chain ends which form part of the amorphous regions [4].

Recognition of electrical trees in phase

The PD classification is based on recognition. There are two basic possibilities for recognizing discharges: phase related and time resolved recognition [5].

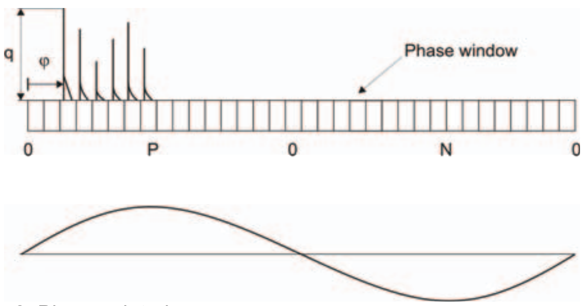

Fig. 2. Phase related

Each impulse on the display in the figure 2 is specified by its magnitude (charge) q and its phase angle φ. The resulting pattern of all impulses is characteristic for the type of discharge.

Phase related recognition

This method uses the classic discharge detector and studies the patterns which occur in the 50 or 60 Hz sine wave. These patterns are familiar to us in the shape of the widely used ellipse on a 50 or 60 Hz time base [5]. Each discharge pulse in the pattern reflects the physical process at the discharge site and a strong relationship has been found between the shape of these patterns and the type of defect causing them. Phase related recognition offers a number of advantages, especially for use at industrial components [5]. The method is independent of the electrical path between defect and detector. As long as the detection circuit reveals the phase angle and the relative height of the impulses it does not matter whether a discharge signal comes from a complicated set of PE sample or from a simple capacitor: the characteristics φ and q in the figure 2 are of interest only. Moreover, for the same reason this method is independent of the type of detector or its coupling circuit. The shape of the single pulses is not relevant, only their relative height and phase angle. The only requirement is on the detector resolution, which should be in the order of ~ 1 µs [5]. Phase related recognition makes use of classic discharge detectors which are standard equipment in a HV laboratory.

Measuring of partial discharges in the PE pattern

Discharges occurred in the PE patterns were measured using the circuit, which is shown in the figure 3. The testing object was supplied by A.C. voltage 230V. The voltage was increased through a regulating voltage and with high voltage transformer step by step from the starting creation discharge into the patterns.

The current impulse of partial discharge was processed through a coupling capacitor C_x, measuring impedance Z_m and the amplifier of partial discharges MTE -3. To the MTE-3 was connected the digital oscilloscope, which recorded the signals of partial discharges and consequently they were sent to personal computer, where they were processed by evaluated program. The oscilloscope worked like fast analog-digital converter.

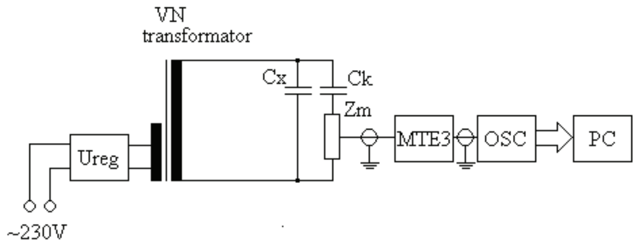

Fig. 3. Measuring circuit

Discharge due to electrical treeing in PE

Figure 4 shows phase angle φ and maximum charge q. Charges q due to in the pattern of partial discharges, which forms of electrical treeing in PE. From the figure 4 it is seen that positive and negative discharges observed in the treeing. Electrical trees are mainly of triangle shape, as we can see on the figure 4. Results presented in the figure 4 were measured at 16 kV.

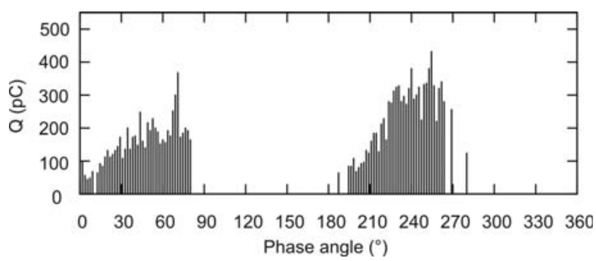

Fig. 4. Discharge by electrical treeing

The figure indicates that the magnitudes of negative discharges were slightly higher than positive discharges. The figure also indicates that the magnitude of the discharge reflects the applied voltage while the discharge took place around the zero cross of the applied voltage and distributed up to the peak which is strongly correlated with the time derivative of the applied voltage. At the figure 5 electrical tree in PE insulation is shown.

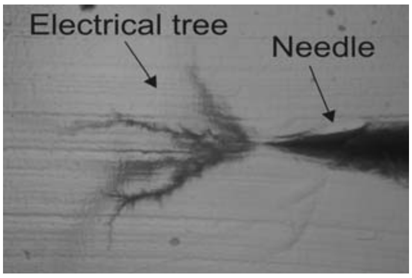

Figure 5: Electrical tree in the PE pattern

Conclusion

Insulation is an important part of a high voltage apparatus. The obtained results can help us by evaluating of unknown defects by the working conditions. It is needed to remark, that presence of partial discharges with high amplitude must not necessarily lead to breakdown of insulation and on the other side the rejection of the cable from operation could sometime cause non-significant discharges. The insulation has to be able to withstand the operational electric field in order to make the apparatus working well. Due to high voltage and several extreme conditions, the insulation discharges may take place in the insulation.

For silicone oil similar results were obtained while for electrical treeing in PE, the discharges were spread before the zero cross of the applied voltage up to the peak at both positive and negative half cycles.

For electrical treeing it was observed that the discharge occurrence was strongly affected by the time derivative of the applied voltage (d*v*/d*t*).

This work was supported by Scientific Grant Agency of the Ministry of Education of Slovak Republic and the Slovak Academy of Sciences under the projectVEGA no. 1/3142/06 and APVV-20-006005.

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