Identification number: DOI : 10.1109/CEIDP.2010.5724017
Official URL: http://dx.doi.org/10.1109/CEIDP.2010.5724017

Influence of Moisture on the Electrical Properties of XLPE Insulation

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Abstract— **During their operating service, insulated power cables can be exposed to wet environment. The presence of moisture in cables surroundings may affect the properties of the used insulation material for instance, XLPE widely employed in MV and HV power cables insulation and therefore the reliability of the insulated cables. In order to examine the influence of wet aging conditions on the performances of XLPE insulated cables, samples (plates moulded from granules HFDE 4201-EC) of the same insulation material were exposed during 5600 hours to wet environment inside a cell simulating moisture. The XLPE material used in the present investigation is employed as insulation for medium voltage (MV) cables (18 / 30 kV). This work presents the results of the effect of aging under wet conditions on the electrical properties of XLPE. The goal of this paper was to investigate the eventual degradation of XLPE insulation under humidity effect by characterization techniques. For this purpose, measurements of dielectric losses factor, relative permittivity, volume resistivity and dielectric strength were performed.**

Index Terms— **XLPE, cables, aging, Moisture, Characterization techniques, Electrical properties.**

I. INTRODUCTION

Cross-Linked Polyethylene (XLPE) is widely used as power cable insulation because of its excellent performances [1,2]. However, it is now well known that regardless of its good properties, XLPE can degrade when exposed to stress conditions. During their operating service, XLPE insulated power cables are expected to work under wet environments. In fact, Submarine insulated cables are immersed in water and underground ones are located in humid places [3,4]. Although their high safety designs, a physical damage caused by mishandling of the cables can allow water penetration into the insulation and may lead to water treeing [5,6]. Numerous studies have reported the possible mechanisms of moisture permeation and water absorption of insulating materials from the environment [3,7]. From many hypotheses, the water condenses at defects such as contamination, voids or interfacial cavities by the effect of electrical stress [8,9]. The absorption of water within a solid dielectric (XLPE) depends on the body structure and on the distribution of electrical charges within the body-water or water vapour absorbed in the insulation of solid [7]. The water can be put in cable conductors during cable manufacture, transportation, stocking, laying, service, etc. [10]. The existence of moisture in cables surroundings may affect the basic characteristics of the insulating material and therefore the reliability of XLPE insulated cables. Several experimental and theorical studies [11] have been performed to understand and to describe the phenomena in a cable context. In order to investigate the influence of wet aging conditions on the performances of XLPE insulated cables, press moulded XLPE samples of plates were exposed to wet environment inside a cell simulating moisture. The samples were exposed to moisture during 5600 hours. Periodically, about two plates were removed from the aging cell and cut into samples having a circular shape to subject destructives and non destructives tests accordingly to IEC 540 publication [12]. The aim of this paper was to characterize the degradation of XLPE insulation subjected to wet aging conditions. Evolution of dielectric losses factor (tan δ), permittivity (ε_r), volume resistivity (ρ) and dielectric strength (E_b) versus aging time were investigated. Temperature dependence of tan δ and ε_r before and after aging were also studied.

II. EXPERIMENTAL PROCEDURE

A. Samples and wet aging conditions

Square plates of 300 mm x 300 mm with 2 mm thickness of XLPE were aged under wet environment inside a cell simulating moisture. The plates of XLPE were moulded and cross-linked at 180°C under a pressure of 300 bars from granules of Union Carbide Low Density Polyethylene Compound HFDE 4201-EC using pressurized heat press. The cross- linkable material contains 2% dicumyl peroxide (DCP) to generate cross-links and 0.2 wt. % of a hindered phenol (HP) as antioxidant. The studied material is used as insulation for medium voltage cables (18 / 30 kV). The samples were vertically suspended and exposed to 100% RH-relative humidity during 5600 hours inside an oven generating moisture using water heated by electrical resistance. After each 240 hours, about two plates were removed from the oven and cut into samples having a circular shape of 7.5 cm diameter to subject electrical tests. The destructives and non destructives tests investigated in the current work were performed accordingly to IEC 540 publication [13].

B. Electrical properties measurements

The electrical properties tests were performed on five circular shaped samples. The dielectric losses factor and the relative permittivity were measured under the tolerated service temperature (90°C) of XLPE at the same time using TETEX AG Schering bridge with an applied voltage of 2 kV, 50 Hz. The measurements of the volume resistivity were carried out by a megohmmeter with a DC voltage of 500 V during 10 minutes application. Test temperatures were varied by means of a regulator. The Alternating Current (AC) Breakdown Voltage (BDV) tests were carried out with a BAUR OLPRUFGERAT PGO 90 A, Automatic apparatus using a microprobe cell immersed in insulating oil of BORAK 22 to avoid flashover. Uniform AC voltage at 50 Hz was increased linearly at 2 kV / s until breakdown. The dielectric strength (breakdown field) is evaluated from the breakdown voltage and the thickness of the sample.

III. RESULTS AND DISSCUSSION

In this section, we present results showing the evolution of the electrical properties of XLPE as a function of aging time under wet conditions. Some dielectric properties (tan δ, ε_r) with respect to test temperature are also investigated.

A. Dielectric losses factor

The measurement of dielectric losses factor (tan δ) is an important non-destructive method for testing HV insulated systems. It can serve as a representative indicator of other insulating material properties relevant to the aging phenomena. Figure 1 displays the XLPE dielectric losses factor variations with respect to aging time. The measurements were made at the temperature of 90°C with an applied voltage of 2 kV, 50Hz.

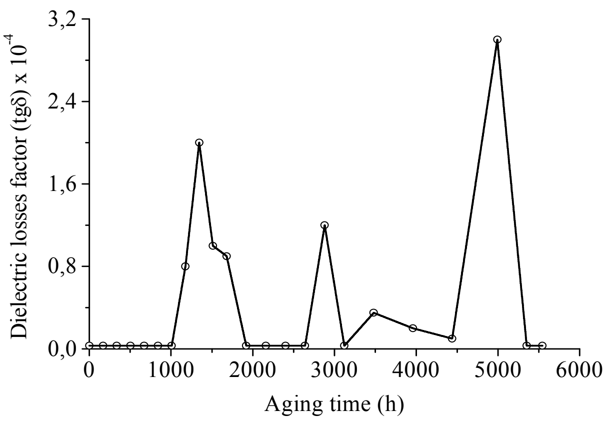

Fig. 1. Dielectric losses factor variations with respect to aging time.

The curve of tan δ presents variations characterized by the presence of some peaks having the following values: 1.7×10^{-4}, 1.2×10^{-4}, 0.4×10^{-4} and 3×10^{-4} obtained after 1350 h, 2800 h, 3500 h and 5000 h, respectively. Theses peaks could be explained by movements of XLPE macromolecular chains segments [13]. The dissipation factor (loss angle tangent) was also performed on the temperature range of 30°C to 140°C using a Schering bridge coupled with a temperature regulator. The measurements were carried out before and after aging under wet conditions (Fig.2).

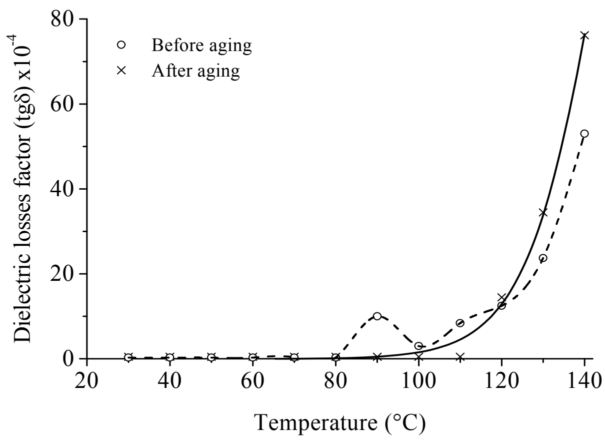

Fig. 2. Temperature dependence of dielectric losses factor before and after wet aging.

The curves for tan δ are seen to increase rapidly with increasing temperature particularly over 100°C which is slightly superior than the acceptable operating temperature (90°C) of XLPE insulated cable. We mention that the values of tan δ after humidity exposure are higher than those obtained in virgin samples.

B. Dielectric constant

Measured simultaneously at the same conditions as the dissipation factor, the dielectric constant varies around the value of 2.0 with the time of moisture exposure (Fig. 3).

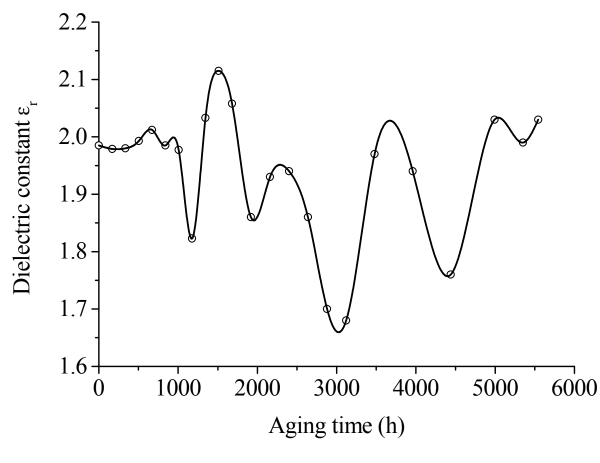

Fig. 3. Changes in the dielectric constant as a function of aging time.

As can be seen in the figure 3, the peaks appeared practically at the same aging time observed on tan δ curve. The temperature dependence of the relative dielectric constant was investigated too. The obtained results indicate that the relative permittivity curves present the same variation law (slight temperature dependence) before and after wet aging conditions (Fig. 4). The relative permittivity ε_r decreases slightly as the test temperature progresses and its values after aging are relatively superior to those obtained prior to aging. In fact, at the XLPE maximum operating temperature ε_r increases from 1.91 to 2.0 representing a rise of 6.8 %.

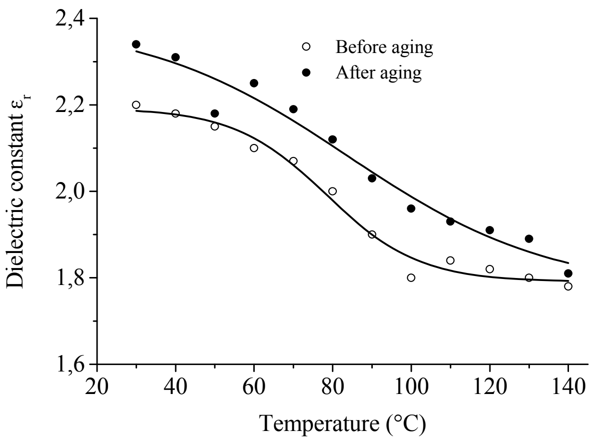

Fig. 4. Temperature dependence of dielectric constant before and after moisture exposure.

In unaged samples, the dielectric constant versus test temperature drops from the value of 2.35 to 1.83 corresponding to a reduction of 22.12%. After moisture exposure, ε_r diminishes from 2.0 to 1.8 representing a decline of 10 % of the property measured. The reduction in the dielectric constant values as a function of the temperature is believed to be caused by the diminution of the material density [14].

C. Volume resistivity

Volume resistivity is one property representing average deterioration of dielectric material. It constitutes a diagnostic tool for aging characterization. Performed under DC voltage of 500 V and at 90°C, the changes in the XLPE volume resistivity versus duration of moisture exposure are depicted in figure 5.

Qualitatively, we remark that the volume resistivity of the studied material shows variations with respect to the time of humidity exposure. Theses variations are categorized by the existence of some peaks. Indeed at the beginning, the property increases from about 10^{13} Ω·cm to 10^{14} Ω·cm value, then slopes down but not monotonously to reach a value of 10^{12} Ω·cm after 5600 hours of aging under moisture.

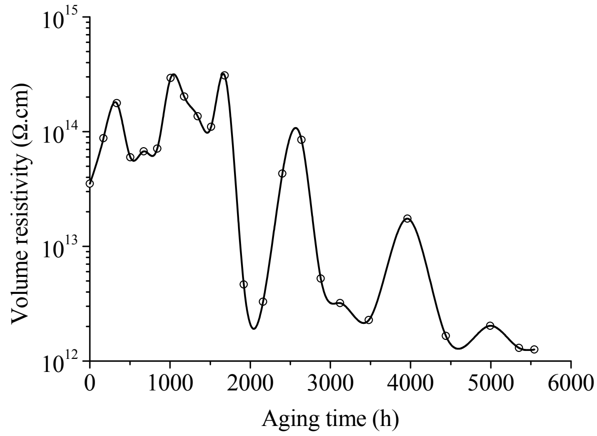

Fig .5. Volume resistivity evolution versus aging time.

D. Dielectric strength

The dielectric strength measurement is a destructive test used to diagnosis insulating materials dielectric state. The experiments were conducted by BDV equipment using a microprobe cell arrangement. The changes of dielectric strength as a function of aging time is presented in figure 6.

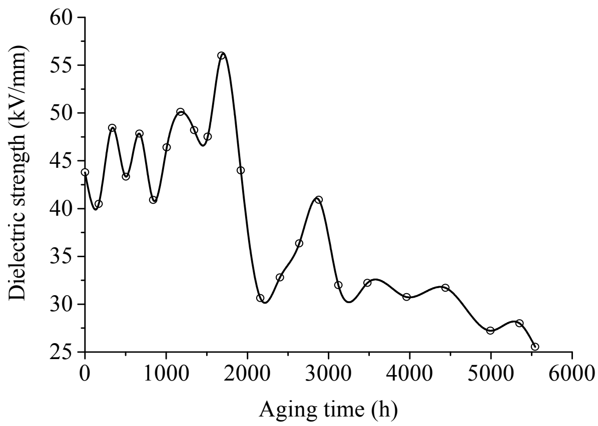

Fig. 6. Dielectric strength changes versus aging time.

It is seen in the curve that the breakdown field (E_b) exhibits variations versus moisture exposure time. In unaged XLPE samples, the dielectric strength value was 42.5 kV/mm. After a long aging time (5600 hours), a decline in the breakdown field is clearly apparent. In fact, E_b has decreased to a value of 24 kV/mm corresponding to a change of 43.3% of the dielectric property measured on virgin samples. It can be noticed that a long exposure under moisture seems to have significant effect on the dielectric strength of the XLPE.

IV. CONCLUSION

In this work, we investigated the effects of wet aging conditions on the electrical properties of XLPE, insulating material of MV cables (18/30 kV). For this purpose, square plates of the same material were aged under moisture environment inside a cell simulating moisture. Based on the obtained results, the moisture influences slightly the dielectric constant. However, we observed a significant degradation of the used material (XLPE) under the aging conditions above-mentioned. This degradation is characterized by the dissipation factor increase and the decrease of volume resistivity and dielectric strength. For a better knowledge of the XLPE degradation under wet conditions, DMA, FTIR, TGA-DTA and DSC analysis would be performed.

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