# Detection of Partial Discharges and its Effect on Solid Insulation used in High Voltage Cable

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***Abstract*— Most of the high voltage (HV) power equipment is made up with solid insulation like paper insulation, glass insulation, epoxy insulation etc. The oldest kind of insulating material among all insulation, the paper insulation is used in cable and nowadays the Cross linked Polyethylene (XLPE) is commonly used for cable insulation. The presence of impurities in the insulation system is one of the root causes of insulation failure as they are form a weak zone inside the healthy insulation system. Therefore, early identification of degradation process like formation of electrical tree structures inside such solid electrical insulation due to high voltage tress during its operating life is utmost requirement to prevent the electrical power equipment from a sudden and complete insulation failure. To study the growth mechanism of electrical tree structure inside the insulation with different applied high voltage a commonly used insulating material like XLPE insulation in HV power cable are consider for this present work. This work also describes the ageing process by conducting the partial discharge (PD) test on the same insulating materials. Finally, the effect of PD on insulation i.e., formation of electrical tree structure on solid insulation was observed by using Scanning Electron Microscope (SEM) and analyzed.**

***Keywords—Partial Dscharge; XLPE Cable; High Voltage; Condition Monitoring***

## I. Introduction

In the most recent years high voltage power equipment are extensively used for transmission and distribution of electrical power. Installation of underground cable system brought a revolution in power system framework by maintaining a stable and uninterrupted power supply. But the breakdown of insulator is the prime cause of power failure. Nowadays the cross linked polyethylene (XLPE) is popularly used for high voltage power cable insulation. The presence of thermoplastic and thermosetting compound and combined chain of polyethylene increased the thermal stability at relatively high temperature. Paper based insulation is the oldest insulation type which is still in application for high voltage cables. From the oldest oil paper insulation to the newest XLPE cable insulation, development of electrical tree due to partial discharge activity is the destructive hotspot for solid insulation degradation[1-4]. Partial discharge (PD) activity occur inside solid insulation due to the presence of solid, liquid or gaseous contaminants present inside it. No matter with how much care the insulation is manufactured but some impurities will always remain inside it during the curing process. Therefore, PD activity can be reduced by using insulation of high quality but it can’t be avoided totally [5]. In solid polymeric cable insulations growth of electrical tree takes place in a stepwise manner under the high voltage tress. The degree of branching is very less at the initial stage but more number of parallel branches develops before the tree reaches the ground electrode [6-7]. The geometrical shape of electrical trees dependents upon the electric field strength, insulating material and it develops in a three dimensional field [8-9]. The different methods of analysis are proposed to study the damage on insulation papers under high voltage and to observe the behaviour of leakage current due to partial discharge [10-11].

In this work, to investigate the electrical tree growth mechanism inside the XLPE insulation used in HV power cable with different applied high voltage stress are studied. This work also describes the ageing process by conducting the partial discharge test on the same insulating materials. Finally, the effect of PD on insulation i.e., formation of electrical tree structure on solid insulation was observed by using Scanning Electron Microscope (SEM) and analyzed here.

## II. Sample Preparation for Partial Discharge Test

### *A. Commertial 33 kV XLPE Cable*

Polyethylene (PE) is a thermoplastic semi-crystalline polymer widely used in the cable industry. It is produced by polymerization of ethylene ($C_2H_4$), and cross linking of ethylene gives rise to Cross linked polyethylene (XLPE). Since the end of the 1960s XLPE insulated power cables are in use. The XLPE insulated power cables are now installed in new connections and simultaneously old underground cables are replaced with the same which is shown in Fig.1. Cross linking renders PE infusible and suitable for service temperature up to 125°C. Its resistance to cold flow and abrasion are superior to conventional PE, while its dielectric properties are comparable. On the other hand the advantage of cross linking is that it makes possible higher filler loading without significant loss of physical properties. This is why XLPE cable has almost completely outclass compound filled cables in the medium voltage range. However the main difficulties of PE and XLPE insulations are their sensitive to partial discharge and the associated question of life time. It is well known that, no insulating material cannot be made 100% pure because there are always presences of unavoidable impurities in the insulating materials. Very small diameter (i.e., 1-30 µm) of cavities are impossible to eliminate from the pure insulating materials as the pure insulating materials used for cable manufacturing unit is in the same range of impurity particle. The cavities of 1-30 µm are unavoidable during manufacturing and are potential source of commonly observed partial discharge activity.

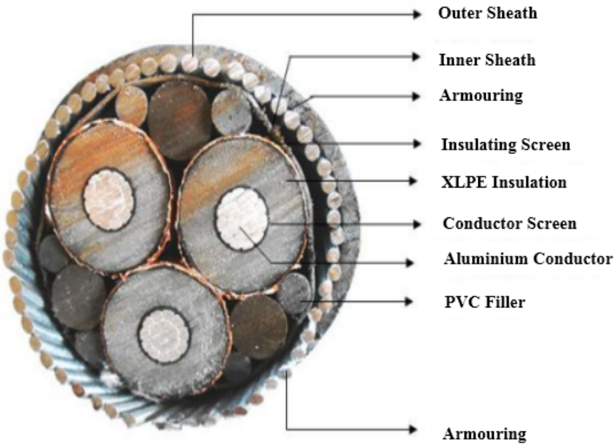

Fig. 1. Cross sectional view of three core 33kV XLPE cable

### *B. Procedure of XLPE sample preparation*

All the test specimens were taken from a commercial 33 kV XLPE distribution power cable having conductors of 12 mm diameter and XLPE insulation of 6 mm thick shown in Fig. 1. In the first step a single conductor with its XLPE insulation was taken out from the cable shown in Fig. 2 (a). There after a small piece of conductor with XLPE insulation was cut and the semiconducting material was removed from the extreme outer periphery of the conductor shown in Fig. 2 (b) and Fig. 2 (c) respectively. Then XLPE insulation was cut into many pieces of 3 mm thickness and centre conductor were taken out from the piece which shown in Fig. 2 (d). The inner semiconducting layer was also removed by the help of drilling machine, after which a hollow disc of XLPE was obtained. A stainless steel needle of tip radius 4 µm was used as high voltage electrode. The needle electrode was cleaned with absolute ethanol and dried at 60° C. The XLPE cable insulation was soften at 250° C temperature in a heating chamber. There after the cleaned needle was then inserted gently into the softened XLPE sample and keeping a needle – rod space of 2.5 mm. Figure 3 shows the needle electrode has inserted in XLPE sample specimen. With the help of above process total five samples were prepared at different needle-rod gap distance. The needle was with very sharp tip radius and almost closed to the ground electrode, hence the electric field increased near the needle tip. The local breakdown (i.e., partial discharge) phenomena were occurred at the needle tip. Therefore, the detection of partial discharge activity inside the XLPE insulation was the prime task and detail experimental arrangement of partial discharge and it analysis was carried out in the section IV and V respectively.

## III. Partial Discharge Detection and Formation of Electrical Tree in XLPE Cable

Partial discharge is the most important phenomena and responsible for insulation degradation process which actually leads to breakdown in the power system network. In medium voltage underground cables, pre- breakdown gas filled channels may incept from defective region even at a normal operating voltage. A current pulse having rise and fall time around less than 1ns is injected inside the insulation due to the effect of partial discharge. This partial discharge signals can be identified using a coupling capacitor. It is found that presence of impurities like small conducting particle or voids are one of the potential source partial discharges and formation of electrical trees.

Fig. 2. Different stages of sample preparation from a 33 kV XLPE cable, (A) Specimens taken from 33kV XLPE distribution power cable, (B) Cross-sectional view of XLPE with conductor (C) power cable after removing the external semiconductor (D) Cross-sectional view of XLPE without conductor

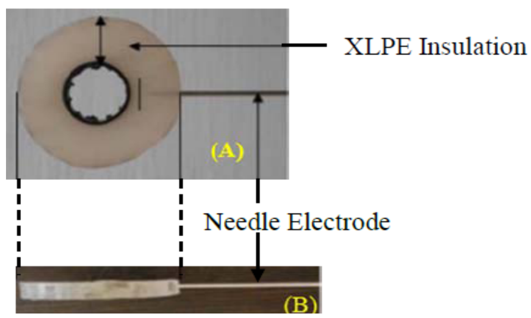

Fig. 3. Needle electrode is inserted in the XLPE cable insulation

The partial discharge phenomena results the electrical tree caused by presence of impurities inside the XLPE cable insulation under the normal operating life. The electrical tree formation is depends on the impurities presents in the insulation system, morphological structure of insulation and the applied high voltages tress. The inception, propagation and the breakdown are the major three phases of electrical tree formation processes. Considering the geometrical shape electrical trees are mainly divided in to three types i.e. branch type tree, bush type tree and mixture of two.

## IV. Experinemtal Setup

In this work, partial discharges were generated in a test cell (300mm × 200mm × 200mm) associated with needle-XLPE insulation-rod arrangement and filled with filtered new transformer oil. The test cell was made of transparent glass. The high voltage terminal was attached with needle electrode and rod electrode was linked with ground. The experiment was conducted in HV laboratory with doubled shielded room with a background noise 1.5 pC. The experimental setup, XLPE insulation and schematic diagram for generation of PDs is shown in Figure 4 (a), (b) and (c) respectively. The needle tip radius was of 2-3 µm and the 500 mm rod of 30 mm diameter was used as ground electrode. The length of the stainless steel needle electrode used for this experiment was 40 mm.

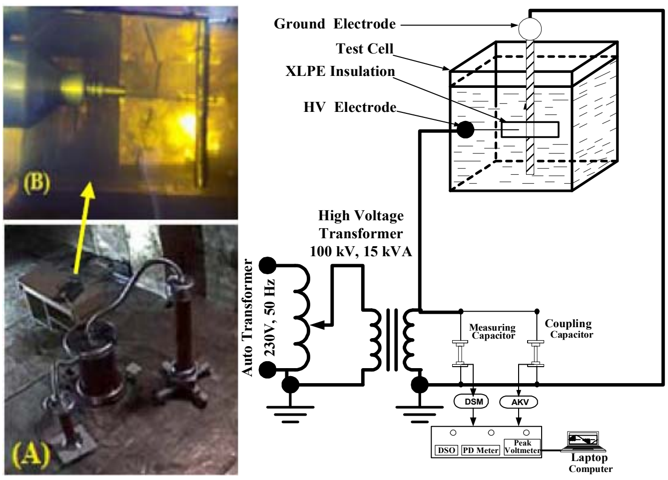


Fig. 4. Experimental setup for condition monitoring of XLPE sample (A) Photograph of HV transformer, divider and test cell (B) Needle–rod arrangement emerged inside transformer oil (C) Schematic diagram of experimental setup.

The XLPE insulation gaps between the electrodes were varied 2mm to 5mm. A computer control high voltage source of 20 kVA, 230V/100kV, 50 Hz was used to generate the partial discharges inside the XLPE insulation. To measure the applied voltage and the magnitude of the PD measuring capacitor (voltage divider), coupling capacitor and a PD meter was used respectively. A digital storage oscilloscope DSO 2022C, having 200 MHz bandwidth and a sampling rate of 2 Giga samples/sec is used for data storage and further analysis. Finally, the degradation process of the XLPE insulation due to PD activity was analyzed by using Scanning Electron Microscope (SEM) Model: JEOL JSM-6480LV. It has resolution of 3 nm and 4 nm at high and low vacuum mode respectively with an accelerating voltage of 30kV. The image magnification varies in the range of 5x to 50,000x. The vacuum pressure in the specimen chamber varies 1-270 Pa. The proposed offline method for identification of insulation damage due to partial discharges is costly as the SEM itself is costly equipment. However, to verify the morphological structure of XLPE insulator after the PD activity inside the high voltage power cables such type facility is very much essential.

## V. Results and Discussions

As per the standard IEC 60270 [12] partial discharge test was conducted and voltage was increased from 0 to 15 kV, in 1 kV steps. The PDs inception voltage of 3.3 kV was observed. The partial discharge was detected with help of conventional electrical method. Figure 5 shows the partial discharge signal recorded during the applied voltage of 10 kV between the electrodes. As the PDs were random in nature the frequency of the discharge signal were lies in the range of 40 kHz to 500 kHz shown in Fig. 6 (a).

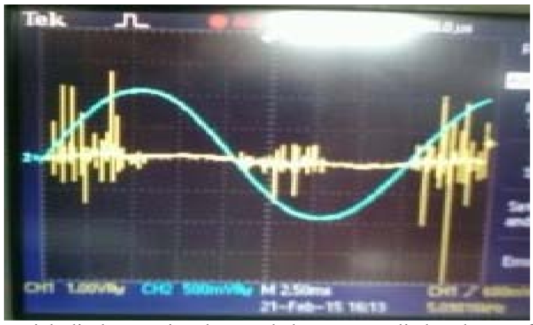


Fig. 5 Partial discharge signal recorded at an applied voltage of 10 kV between the electrodes.

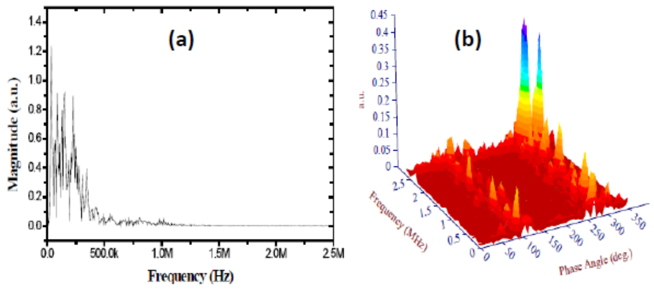


Fig. 6. Phase resolved partial discharge analysis

To investigate PD characteristic of the measured signal PRPD [13-16] known as phase resolved partial discharge analysis was plotted and shown in Fig. 6 (b). The breakdown voltage of the XLPE insulation at different gap spacing was found different shown in Fig. 7.

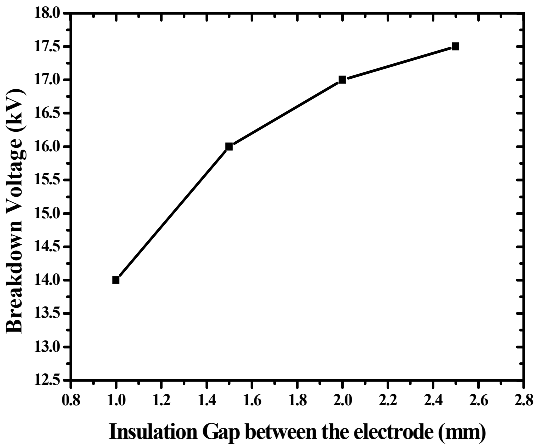


Fig. 7 Breakdown voltage varies with the insulation gap between the electrodes

The XLPE insulation samples were tested with diverse applied voltage. The applied voltage magnitude and the time taken for complete breakdown of each samples were noted. The XLPE samples were then collected and send to investigate the presence of electrical tree structure inside the XLPE insulation using Scanning Electron Microscope (SEM) image. In different sample the electrical tree was formed in different geometrical structure under the electrical stress.

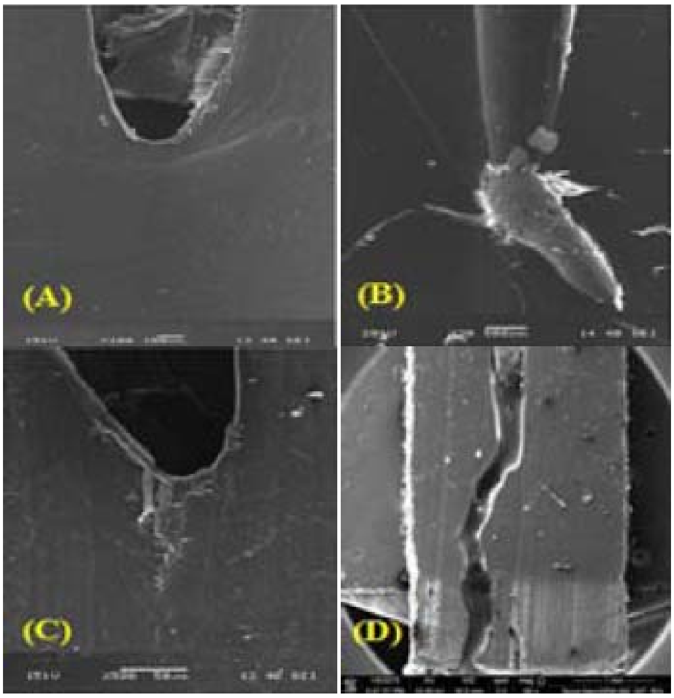


Fig.8. Different stages of electrical tree formation (A) SEM photograph of XLPE before the test (B) Inception of electrical tree under high voltage tress (C) Electrical tree propagation inside XLPE cable insulation (D) Formation of breakdown channel between the needle-rod electrodes in XLPE sample

The formations of electrical trees under high voltage stress at different stages are shown in Fig. 8. Figure 8 (a) shows sample without any voltage stress and Fig. 8 (b) shows the inception of the electrical tree and length of tree branch measured about 776 µm. Figure 8 (c) shows the propagation of electrical tree towards the ground electrode and the lengths of the electrical tree were increased. Finally, the breakdown channel was formed under the application of high voltage stress of 17 kV between the electrodes gap of 2.5 mm. The time taken for breakdown was found at 10 kV applied voltage indifferent insulation gap has depicted in table1.

**Table 1** Variation of breakdown time with different insulation gap at 10 kV applied voltage

| SL No. | Insulation Gap (mm) | Applied Voltage (kV) | Breakdown Time (min) |
|---|---|---|---|
| 1 | 2.0 | 10 | 15.00 |
| 2 | 2.5 | 10 | 18.00 |
| 3 | 3.0 | 10 | 22.33 |
| 4 | 4.0 | 10 | 26.50 |
| 5 | 4.5 | 10 | 30.00 |

## VI. CONCLUSSIONS

Early detection of partial discharge in XLPE cable insulation using conventional electrical method was carried out in high voltage laboratory. In this work, the formation of electrical tree (inception of tree and growth of tree) considered as one of the degradation phenomena inside the XLPE insulation due to partial discharges under the different high voltage tress was studied experimentally. The SEM image of XLPE cable insulation clearly showed the initiation of insulation degradation process and formation of electrical trees as well as formation of breakdown channel under the electrical stress.

In future, further many other type of solid insulation like paper insulation, epoxy insulation etc. are considered for investigates formation of electrical tree and morphological structure inside the insulating material under high voltage tress.

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