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# Understanding inception and propagation of electrical tree discharge characteristics in XLPE nano-composites

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*Failure of underground cables due to electrical treeing phenomena in the polymeric insulating material is a major threat for the safe and reliable operation of power system network. Hence many research works are being carried out in the development of high performance insulating materials for underground cables. Nano-composites are emerging as a new class of insulating materials for demanding application in all electrical equipment used in the electric power network. Both electrical and thermal properties are improved with the addition of nano fillers in the polymeric materials. In this work, the electrical tree inception and propagation were studied in the cable insulation material at different nano filler concentrations. SiO2 nano-filler was used in the XLPE base material. Nano-fillers were added at different concentrations such as 1% and 3% by weight in the base material. Laboratory experiments were conducted as per IEC procedures at AC voltage magnitudes of 12 kV. Influence of filler concentration on the inception and propagation of electrical treeing were studied. Analysis of time to failure of XLPE materials at different nano-filler concentrations were carried out.*

***Keywords:*** *XLPE, electrical treeing,tree length ,breakdown time, nano filler.*

## 1.0 INTRODUCTION

Failure of underground cables due to electrical treeing phenomena in the polymeric insulating material is a major threat for the safe and reliable operation of power system network [1-4]. Hence many research works are being carried out in the development of high performance insulating materials for underground cables. Nano-composites are emerging as a new class of insulating materials for demanding application in all electrical equipment used in the electric power network. Both electrical and thermal properties are improved with the addition of nano fillers in the polymeric materials [5-6]. Electrical treeing causes early failure of electrical insulation structures under normal operating conditions. A tree-like tree structure or a bush type tree structure can form from the defect site and an increase in the applied voltage magnitude shows reduction in characteristic life of the insulation material. The development of high voltage XLPE cable requires fundamental understanding towards electrical treeing phenomenon of the insulation [7-11]. Electrical tree possibly starts from a weak point where the electric stress is concentrated, or as an extension of water trees. The incorporation of nanoparticles into thermosetting resins is seen to impart desirable dielectric properties when compared with conventional (micron-sized particulates) composites. Although the improvements are accompanied by the mitigation of internal charge in the materials, the nature of the interfacial region is shown to be pivotal in determining the dielectric behavior. Considering this, in this work, electrical tree inception and propagation time of XLPE material at different nano filler concentration is studied.

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## 2.0 MATERIAL AND SAMPLE PREPARATION

A silanegrafted cross link able polyethy lene compound was used in the present study as a base material. It is ensured that the base material has no filler of any type which may influence the experimental results. Silicone dioxide ($SiO_2$) of size <80 nm, purity >99% supplied by Hefei Jiankun Chemical Industry was used for making nano size filled XLPE specimens. The samples were prepared at 1% and 3% filler concentrations by weight of the nano size fillers.

The base XLPE, catalyst and fillers were weighed accurately and mixed thoroughly by using brabender mixer. After mixing the mixer was poured into plastic extruder machine at 200°C heated by a hydraulic press. The finished product has all the properties associated with cross linked polyethylene. All samples were made using appropriate moulds. Samples were prepared from each composition for testing.The transparency of the specimen is required to a certain degree in order to view the tree structure formed during the testing. The schematic diagram of the specimen with the needle inserted has been shown Figure 1.

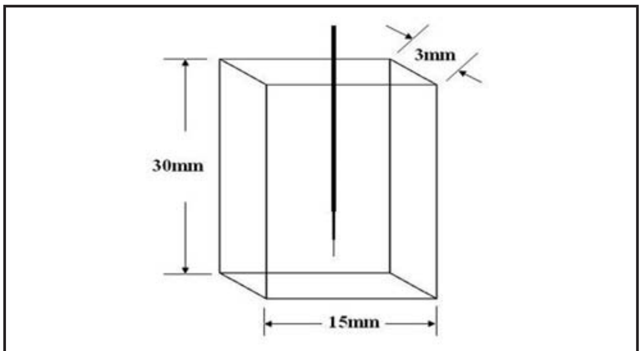


FIG. 1. SCHEMATIC DIAGRAM OF THE XLPE SPECIMEN

## 3.0 EXPERIMENTAL SET UP

Figure 2 shows the schematic diagram of the experimental setup and the electrode configuration used in the study. Needle-plane electrode was used for the examination of the electrical tree growth. Each sample had a dimension of 30mm x 15mm x 3mm and the distance between the needle tip and ground electrode was 3mm ±0.1mm. Steel needle electrode with tip radius < 10µm was used in this study. Experiments were conducted as per IEC procedures at 12 kV AC voltage magnitudes.

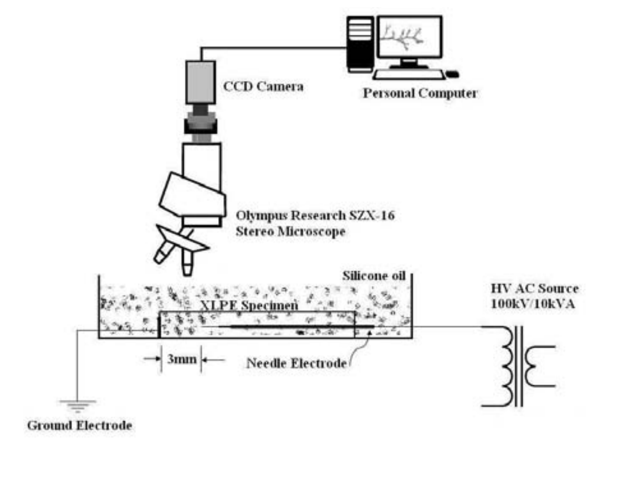


FIG. 2. SCHEMATIC DIAGRAM OF ELECTRIC TREEING EXPERIMENTAL SETUP

A 100 kV, 10 kVA, 50 Hz high voltage transformer is used for the experiments. A needle electrode inserted in the specimen produces high electric field at the tip of the electrode. The experiment is conducted at the room temperature. Due to the very high electric field, tree developed in the specimen. The sample is viewed under digital microscope, Olympus SZX-16 Research Stereomicroscope equipped with CCD Camera. The microscope is interfaced with a personal computer. This helps to record the treeing images in the computer. The magnification and pixel level of the capturing device is adjusted to get the best view of the tree. The dimension and structure of the tree is noted and observed. Likewise, a number of samples were taken and treeing images were recorded.

## 4.0 RESULTS AND DISCUSSION

### 4.1 Scanning Electron Microscope (SEM) Analysis

To examine the physical properties of the nano$SiO_2$ filled XLPE specimens, a detailed SEM investigation are made on the nano filled XLPE. Figure 3(a) and Figure 3(b) shows the filler dispersion of 1 % and 3 % of the nano filled XLPE specimens. It is observed that there is a significant difference in the dispersion of the nano particles. It is noted down that the particles are isolated and scattered uniformly over the area of specimen with less number of particles in 1% $SiO_2$ filled XLPE specimen whereas the particles are scattered over the entire area of the specimen with large number of particles in 3% $SiO_2$ filled XLPE specimen.

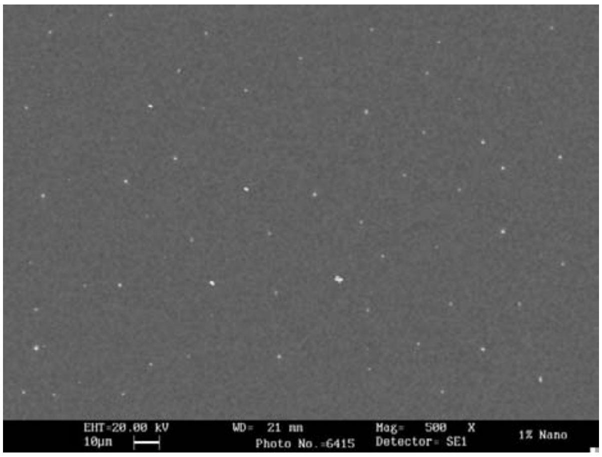


FIG. 3(A) SEM IMAGES OF 1% SIO2 FILLED XLPE

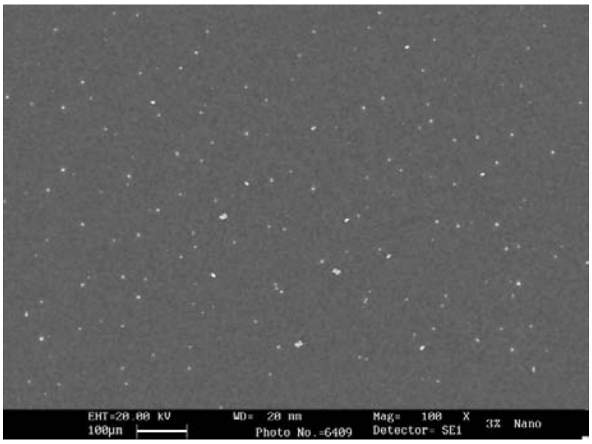


FIG. 3(B) SEM IMAGES OF 3% SIO2 FILLED XLPE

## 4.2 Tensile Strength Test

Tensile test were conducted to measure the tensile strength of the developed material. Automatic speed adjustment KMI tensile testing machine was used in this study.

Figure 4 shows the variations in tensile strength of the nano composite XLPE material. It is noticed that the tensile strength of virgin material is less compared with other nano filled material. This clearly shows that when the filler concentration is increased the tensile strength of the material has been increased.

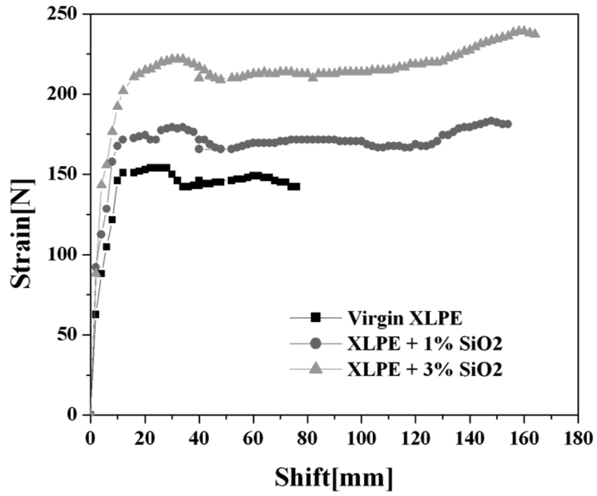


FIG. 4. TENSILE STRENGTH OF XLPE MATERIAL

## 4.3 Evaluation of Breakdown Time of XLPE Nanocomposites

In order to understand the breakdown strength of the nano composite XLPE material the electrical treeing analysis was carried out. The electrical treeing inception and breakdown time were noted likewise. The propagation of tree growth was recorded for further analysis.

It is observed from Table 1 that by addition of silica nano particle in the base material the breakdown time of the material has been increased tremendously 31.25% and 50% of improvement has been identified by adding 1% and 3% of nano silica fillers respectively.

**TABLE 1**
**BREAKDOWN TIME OF XLPE NANO COMPOSITES**

| S.No | Material | Breakdown Time (hr) | Improvement |
|---|---|---|---|
| 1 | Virgin XLPE | 16 | - |
| 2 | XLPE+ 1% Si | 21 | 31.25% |
| 3 | XLPE+ 3% Si | 24 | 50.00% |

Figure 5 shows the photographs of the tree propagation taken through the CCD camera attached with the Olympus microscope. Figure 5(iii) and (iv) shows the breakdown of XLPE nanocomposite with 1%wt and 3%wt concentration respectively.

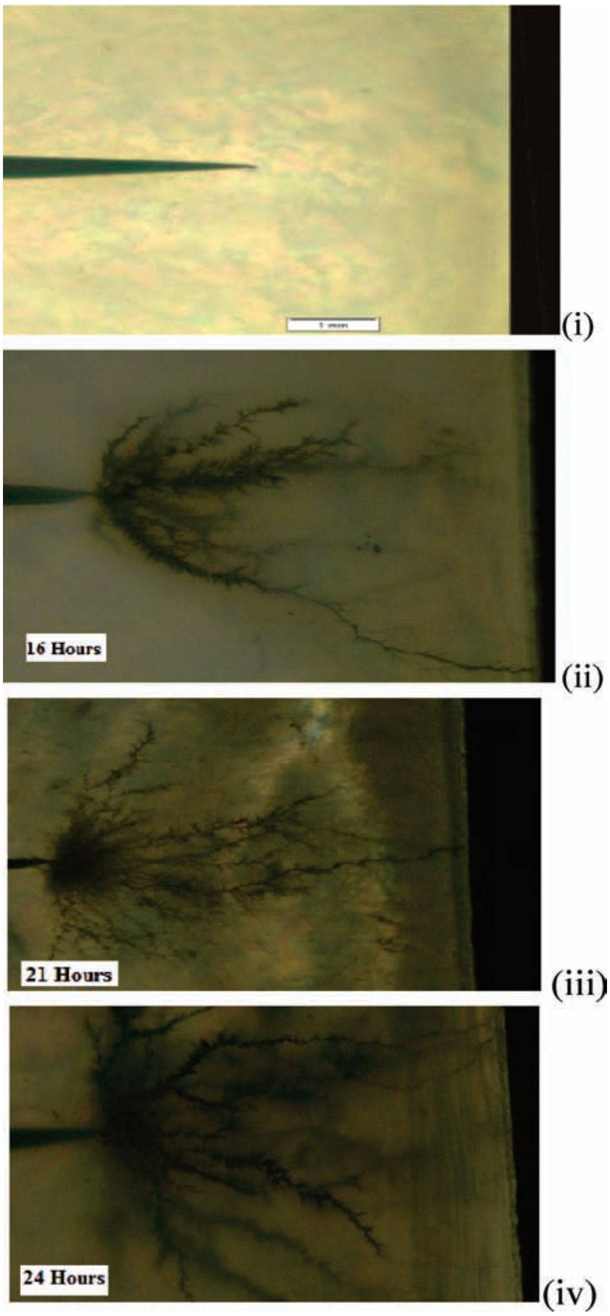


FIG . 5. PHOTOGRAPHS OF TREEING PROPAGATION IN XLPE NANOCOMPOSITES ( I) INITIAL STAGE (II) AFTER 15 HOURS (III) BREAKDOWN OF XLPE + 1% S (IV) BREAKDOWN OF XLPE + 3% S

The Electric treeing inception and Breakdown time of the Nano 1% and 3% $SiO_2$filled samples has been improved mainly due to the excellent contribution by the Si fillers.

### 4.4 Evaluation of Tree Length of XLPE Nanocomposites

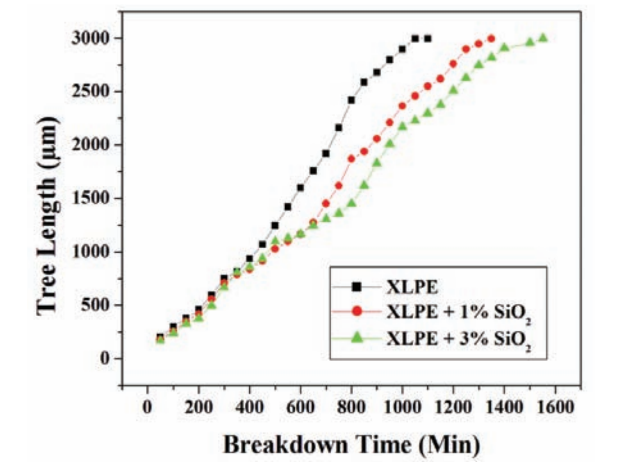


FIG. 6. TREE LENGTH OF XLPE NANO COMPOSITE MATERIAL

Figure 6 shows the tree length of XLPE nanocomposite with respect to time. It clearly shows that tree length of 1% and 3% wtnano composite is less when compared with virgin material with respect to time period.

## 5.0 CONCLUSION

Experimental results on electrical treeing characteristics of virgin XLPE material and XLPE filled with nano size $SiO_2$ fillers at different concentration levels have been presented in this paper. The propagation speed of the treeing has been relatively reduced for nano filled material. In general, nano filled material has good breakdown strength by increasing filler concentration levels. Variations in the tree length with respect to time period at different filler concentration have been analyzed clearly.

## ACKNOWLEDGEMENT

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