Electrical treeing behavior in XLPE insulation due to content AL₂O₃ nanoparticles

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Abstract: XLPE is currently commonly used in high voltage underground cables. Several researchers recently chose several nanofillers to improve the electric tree's strength in the polymer matrix. Alumina AL₂O₃ nanofiller have been utilized to investigate the effects on the electrical treeing in XLPE. The percentage concentration were used as follows with different amounts "0.3wt." % and "1wt."% from weight of base material. The needle-plane electrodes were used in this investigation and gap selected between needle and plane earth is 3 mm. The growth and morphology of treeing in XLPE insulation have been observed by using charge coupled device camera CCD and microscope system. Scanning of electron in base material . microscopes SEM has been investigated the nanoparticles spread. The outcomes show the tree inception voltage TIV values 12.5, and 14.8 KV "0.3wt." % and "1wt." % respectively in XLPE composites that mean the TIV increase with increase concentration nanofiller, while the tree propagation time at 2mm length increase about 40 min and 2 hours in "0.3wt." % and "1wt." % AL₂O₃/XLPE, respectively compared with unfilled XLPE, as well as the breakdown time BDT enhancement by 4.347% and 13.043% for 0.3wt% and 1 wt% nano AL₂O₃ composites compared with unfilled XLPE insulation. And showed pictures taken with a SEM Diffusion and accumulation of nanoparticles in the XLPE material.

Keywords: underground cables, XLPE, Nanoparticles, Electrical treeing, TIV, BDT.

1. Introduction

Cross-linked Polyethylene (XLPE) is a polymer material widely used as a high-voltage cable insulator, because of its great dielectric characteristics, high flexibility and mechanical resistance, good chemical resistance, low price and easy processing [1],[2]. In spite, the employed XLPE insulation in distribution and underground cables in most cases exposed to external factors such as unforeseeable weather Contaminations not under control led to insulation breakdown.

Electrical treeing is one of the major failure mechanisms of XLPE cable insulation when the tree begins to expand through insulation and eventually leads to cable failure[3]. Different approaches have been attempted to prevent electrical tree growth such as enhancement of material processing, the addition of treeing inhibition, material modification and etc., to improve electric tree strength in high-voltage cable accessories [4].
Polymer composites containing nano fillers have attracted considerable attention with the development of the nano technology because they have the potential to improve the electrical, mechanical and thermal properties without modifying polymer compositions and processing compared with the nature polymers [3],[5].as well as Nanocomposites are known to enhance dielectric characteristics, such as increasing dielectric breakdown, eliminating partial discharge (PD) and space charge and reducing the treeing, etc[6]. Therefore, nanomaterials are a modern approach of inhibiting the electrical treeing in insulation as well as improve insulation performance, and generally thus extend the life of the equipment. Various studies have found that the treeing resistance in cross-link polyethylene is improved by using nanofiller materials [7],[8],[9]. Chen et al studied the tree initiation time of pure epoxy resins and discovered that nanoparticles could improve tree initiation time [10]. S. Chandrasekar et al was discovered that adding 3 and 5% wt silica nano particles SiO2 improves the BDT of XLPE content[8].In the present work, electrical tree attitude was described in XLPE containing AL2O3 nanoparticles The XLPE electric tree characteristics were calculated at "0.3" and "1 wt."% various AL2O3 nanofiller concentrations. Results of the investigation of TIV, tree propagation length, BDT was tested and compared with unfilled XLPE.

2. Experimental procedure

2.1 Preparation samples nanocomposites

Samples were prepared in this study by using XLPE pellets supplied by Al-rowad cables company and Alumina AL2O3 nanofiller having particle size 20nm and a high purity degree (>99.99%) provided by sky spring nanomaterials, Inc(USA) ‘figure 1’ (a) and (b) illustrates the pellets XLPE and nanoparticles have been employed in this investigation. The samples that consist of nanomaterials and polyethylene granules were mixed by a mechanical mixer and after the completion of the mixing process, the samples were poured in to the machine extruder at 200°C [8]. After extruder process the Samples are poured into a mold with a thickness of 5 mm and exposure to a pressure of 6 bar for 15 minutes by a heat press. Table 1 showed various percentages of nanoparticles as 0.3 and 1 "wt."% and the same specimen symbols used in this study.

Figure 1 (a) image of XLPE pellets (b) photograph of AL2O3 nanoparticles
Table 1. Specify the test specimens

| Base material | type of nano particles | %wt particles percentage | Specimen symbol |
|---------------|------------------------|--------------------------|-----------------|
| XLPE          | AL₂O₃                  | 0.3                      | B               |
|               |                        | 1                        | C               |

2.2 Implementation of test samples
The XLPE is rectangular in form and consists 0.3wt%, 1wt% AL₂O₃ nanoparticles. The dimensions of the rectangle specimen (20mm x 15mmx 5mm). The needle-plane electrodes were used in the experiments. Stainless steel needle with a diameter of 1 mm, a tip radius of 5 m, and a tip angle of 30° was cautiously inserted into each XLPE/ZrO2 nanocomposites. A segment of copper was used as a earth plane-electrode, and the needle-plane electrode distance is 3 mm, as shown in ‘figure 2’

![Figure 2. styling of specimens](image)

2.3 Components of the test system
The system consists of several components, as shown in the ‘figure 3’ a and b .below. The stereo microscope was installed with and linked up with a CCD camera for the purpose of capturing electrical trees, and a personal computer PC has been used to document the tree's growth images [11]. The experiments were performed in a test acrylic cell containing silicone oil to prevent flashover That happens during insulation breakdown and to control temperature, as well as adopting a high voltage source (transformer 220/15 kV) ac voltage of 50Hz and a low-voltage power supply and voltage regulator 2KVA with rated capacity 2000 VA, 50 HZ. All samples had been measured at room temperature.
3. Results and discussion

3.1 Components of the test system

The observed results, as shown in the figure below ‘figure 4’, show that TIV increases linearly as the proportion of nanoparticles Al_2O_3 nanofillers rise. TIV values of 11.2, 12.5, and 14.8 KV for XLPE Without additions, "0.3wt.%", "1wt.%", respectively, were obtained. Another word a neat XLPE is less than 0.3% to 1% wt nano Al_2O_3. The homogeneous dispersion of the filler increases TIV when the concentration of nanoparticles increases [11,12]. Possible reasons for increasing the XLPE TIV in this section was discussed. The rise in the concentrations of nanofillers will lead to higher electron empathy. The free electrons are captivated by polymers and Surround with needle ways to optimize nanocomposites' TIV morphology[14]. Increased TIV can also influence electrical field dispersed on the needle electrode through added nanofillers[15].

![Figure 3(a). Image of electrical treeing lab experimental setup](image3a.png)

![Figure 3(b). Schematic of electrical treeing experimental setup](image3b.png)

![Figure 4. Tree inception voltage behavior on various XLPE/Al_2O_3 nanocomposites](image4.png)
3.2 Treeing propagation

The tree growth morphology in the neat XLPE and XLPE nanocomposites XLPE /AL\textsubscript{2}O\textsubscript{3} have been observed by adopting microscope system when the tree has been reach 2mm of the needle tip. The ‘figure 5’ clarify the microscope photograph of electrical treeing development. Growth stages of the tree, when it reaches a length of 2 mm, were documented for each sample. The findings demonstrate that the tree growth phase has always been the same type of tree on all samples which was branch types of tree. Excluding the time of tree development there is very different from one sample to another.

The time duration necessary to achieve a length of 2 mm at different AL\textsubscript{2}O\textsubscript{3} nanofiller concentrations in the XLPE is illustrated in the ‘figure 6’. The results showed that the tree progressed on XLPE 0.3wt% and 1wt% nanoparticles lower than unfilled XLPE that is mean rise in the growth time of tree by 40 min and by two hours Comparative with unfilled XLPE. The reduction in nano compound inter-particle distances could be attributed to the improved development of electric treeing nanofillers in XLPE for "0.3 wt\% and "1 wt\% AL\textsubscript{2}O\textsubscript{3}.

![Figure 5](image1)

**Figure 5.** photos of neat XLPE and XLPE / AL\textsubscript{2}O\textsubscript{3} tree growth until length reach 2 mm.
(a) unfilled. (b) 0.3wt%. (c) 1wt%

![Figure 6](image2)

**Figure 6.** Average time diagrams taken to achieve length of 2 mm for electrical treeing.
3.3 Breakdown time

Electrical treeing studies have been carried out in order to understand the breakdown strength of the nano AL₂O₃ XLPE material which was considered the last phase of treeing as followed an insulation breakdown. The specimens were subjected to AC voltage during the experiments. For the purpose of comparing the breakdown time between the XLPE/AL₂O₃ nanoparticles and pure XLPE, a working method has been followed, by applied a voltage to the needle electrode. This leads to the formation of an electrical tree as a result of the high electrical strength arising at the tip of the needle, which grows continuously inside the insulating material heading towards the earth electrode. When it reaches to the other pole, a breakdown occurs in the insulating material.

From the observed results, it was observed that the addition AL₂O₃ particles significantly improved the breakdown time compared with unfilled XLPE. The improvement is as follows 4.347% and 13.043% for 0.3wt% and 1 wt% nano AL₂O₃ composites, respectively while C. Kalaivanan et al was obtained improvement in BDT 12.5% and 31.25% for 1% and 3% nano SiO₂ XLPE composites, respectively[11]. The results of the improvement are briefly shown in Table 2. Finally, "the improvement in the breakdown time of the insulation will reflect positively" on the life of the insulation. ‘figure 7’ Figure A shows the magnitude of the improvement percentage between the XLPE/AL₂O₃ particles and pure XLPE.

| S.P.no. | Material         | Breakdown time (h) | Enhancement in % |
|---------|------------------|--------------------|------------------|
| A       | XLPE             | 23                 | –                |
| B       | 0.3wt% AL₂O₃     | 24                 | 4.347            |
| C       | 1wt% AL₂O₃       | 26                 | 13.043           |

**Figure 7.** Breakdown time of XLPE/AL₂O₃ and unfilled XLPE
3.4 SEM analysis
To clarify the extent of the dispersion of AL$_2$O$_3$ nanoparticles in the XLPE material, scanning electron microscope SEM device was used as shown in ‘figure 8’. The physical properties of the XLPE/ AL$_2$O$_3$ particles were examined with the SEM. A sample with dimensions of 3 mm×3 mm×3 mm is cut from the XLPE nanocomposites and coated with a thin layer of gold and And dry it carefully. By applied voltage 30KV and utilize the 1002 X magnification to observed microstructure of XLPE nanocomposites. The result show the nanoparticles dispersion and agglomeration in XLPE nanocomposites.

![SEM image of AL$_2$O$_3$/XLPE sample](image)

Figure 8. SEM image of AL$_2$O$_3$/XLPE sample

4. Conclusion
The influence of AL$_2$O$_3$ nanoparticles on electrical treeing attitude in XLPE has been investigated and as follows:

1. TIV Directly proportional to the increase in the concentration ratios. The results are as follows TIV values of 11.2, 12.5, and 14.8 KV for XLPE Without additions, 0.3wt%, 1wt%, respectively.
2. The tree's progression neat XLPE was faster compared with 0.3 wt % 1 wt % AL$_2$O$_3$ nanoparticles. When adding 0.3wt% nano the growth time was increased by 40 minutes and two hours at 1wt%. In all cases it was observed the branch type of tree.
3. The use of AL$_2$O$_3$ nanoparticles increased the breakdown times dramatically compared to the unfilled XLPE. The enhancement is the following 4.347 and 13.043 percent nano-AL2O3 composites, respectively, for 0.3wt% and 1wt% nanoparticles.
4. Through observed microstructure of XLPE nanocomposites by using SEM device noticed the dispersion and agglomeration of nanoparticles in sample.
5. Reference

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