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MORPHOLOGICAL STUDIES OF ELECTRICAL TREE DUE TO HIGH ALTERNATING ELECTRIC FIELDS IN EPOXY SOLID DIELECTRICS

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ABSTRACT

In polymeric insulation system electrical treeing phenomenon is the significant cause for the failure of the insulating material. The treeing phenomenon in insulators is strongly related to the type of insulator and the nature of flaw in the insulator during the manufacturing process. In this research Epoxy resin samples are prepared to carryout electrical treeing studies under High alternating electric fields of power frequency (50Hz). Needle plane electrode configuration is used to investigate the electrical tree growth characteristics. Partial discharge (PD) patterns during the initiation and propagation are obtained from PD measurement system. The correlation between the electrical tree propagation and the Partial discharge phenomenon is discussed. The morphological patterns during the tree growth are studied and the physical aspects of degradation during tree growth are analyzed in correlation with the partial discharge patterns obtained during the treeing process.

Keywords: polymeric insulation, partial discharge, morphological patterns.

INTRODUCTION

The wide usage of Epoxy resins in many insulation devices has increased due to its great adhesion property to different materials, excellent strength, toughness and resilience. They provide high resistant to chemical attack and to moisture. The wide usage of Epoxy based insulation systems are increasing day by day because of its excellent properties. Usually the insulation system of power apparatus degrades when exposed to thermal, mechanical, electrical and environmental stresses during its operating conditions. Mainly the initiation of the degradation due to electrical stress happens at stress concentrated regions such as voids and contaminants within the insulating material.

Many research works reports that electrical treeing is a major cause for polymeric insulation failure and it is of major concern for power utilities since the treeing degradation related breakdown lead to poor reliability of power components. In insulating polymeric materials the electrical treeing process is a long term degradation mechanism under high electric stress and it resembles the form of a tree. Hence it becomes imperative that degradation of dielectric material initiated by treeing is detected and diagnosed to ensure better reliability of the insulation system [1] - [4].

Partial discharge (PD) is an electrical breakdown that occurs in a restricted and localized region of dielectric system of power apparatus. Usually electrical tree emanates from the sharp points in an extremely non uniform electric field point due to internal partial discharge in the insulation system. Hence it is important to detect the inception and propagation of electrical tree to prevent the insulation failure of any power apparatus. PD characteristics during the treeing process can be studied using PD measurement systems. By analyzing the PD data the remaining life of the insulating material can be analyzed [5] - [8].

This work investigates the effect of power frequency high alternating fields on the electrical tree growth morphology and the breakdown characteristics of Araldite CY 230- 1 epoxy resin system. This epoxy resin is one of the important hard cast-types of resins used in the high voltage insulation system [9]. The systematic study of electrical tree growth in a controlled laboratory environment is carried out and the morphological behavior during the degradation process has been studied. This study also investigates the relationship between partial discharge characteristics and the growth patterns of electrical tree.

Experimental procedure

A. Preparation of the test specimen

The epoxy resin used in this experimental study is the Araldite epoxy system consisting of epoxy resin Araldite CY 230-1and a hardener Aradur HY 951. A proper mixture ratio of (CY 230-1) 100:10 (HY 951) parts by weight is used for the preparation of the test specimen. The resin and the hardener were mixed at a uniform rate and the mixture filtered in order to remove fine impurities. Care must be taken so that the mould is free of any void or contaminations. Pin-plane Aluminium electrode geometry is selected for the preparation of the test specimens. Plane aluminium electrodes of diameter 60mm and a thickness of 5mm were adopted. A steel needle electrode of tip radius of about 10μm is utilized in order to provide a high divergent electric field. The separation between the High voltage (HV) pin- and Ground plane electrode is maintained about 4mm during the molding process. The curing of the specimen was carried out at room temperature for 24 hours and the final specimen was taken from the mould and cleaned properly before carrying out the electrical treeing experimental study. Figure-1 and Figure-2 show the sample configuration and the prepared Epoxy Araldite dielectric specimen respectively.

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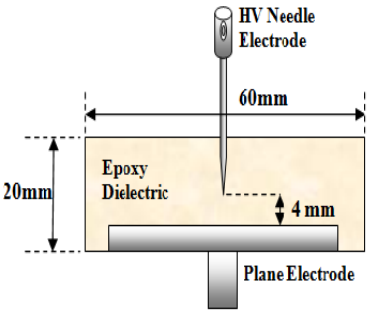

Figure-1. Sample configuration.

Figure-2. Epoxy dielectric specimen.

B. Experimental test setup

The detailed experimentation and analysis has been performed utilizing a 10kVA, 100kV, 50Hz test transformer with a Digital PD Measurement and Acquisition System (Model No.: DTM-D ®) comprising a digital storage oscilloscope (TDS 2002B ®) and a tunable narrow-band filter (Model: DFT-1®) at a variable center frequency of range 600 kHz-2400 kHz at 9 kHz bandwidth. The direct (straight) PD detection and measurement setup as recommended in IEC 60270 is utilized in this study since the tests have been carried out in a controlled laboratory environment.

However, to ensure appropriateness in real-time studies, noise mitigation techniques are employed wherein the PD system comprises window gating facility to mask redundant background noise during measurement. A coupling capacitor (1nF) was also added to the test setup to augment the transfer characteristics and to provide an appropriate wave shape of output response. Appropriate calibration is carried out using an electronic reference calibrator (Model: PDG ®). PD Gold® package is interfaced with the PD measurement system for recoding and acquiring the PD signatures [10].

The pulses are displayed either in sinusoidal or elliptical forms selectable in auto or manual mode. The manual mode provides an option for recording and acquiring for a considerable period and hence most suited for treeing studies. Figure-3 shows the generic experimental test setup utilized for PD initiated electrical treeing studies.

The electrodes and the samples were immersed in the mineral oil to avoid potential flashovers. It also avoids the influence of any leakage current over the surface the specimen.

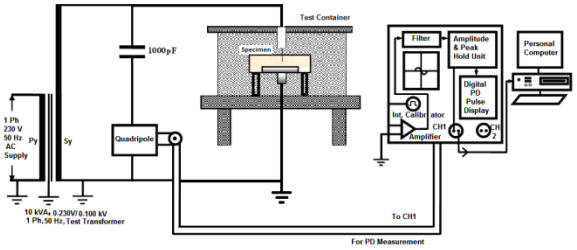

Figure-3. Experimental test setup for PD initiated electrical treeing studies.

RESULTS AND DISCUSSIONS

Tree morphology and PD patterns

During to the application of high alternating field at the pin electrode the initiation of first tree branch was observed by slowly increasing the applied voltage and inspecting the specimen. For easy detection of electrical tree a transparent test container along with transparent mineral insulating oil was chosen. The tree shapes was acquired by a high resolution digital camera at different tree growth time and at the same time partial discharge measurements were acquired by means of PD measurement system. Typical branch type tree patterns obtained during the experiment are shown in Figures 4, 5, 6 and 7.

Since PD activity is generally an indicator for degradation phenomenon of the insulation system. The pattern and the characteristics of PD pattern relate the defects in the insulation system. PD measurements are carried out to investigate the treeing degradation studies during the experiment. During PD measurements the Discharge Inception Voltage was obtained at 2kV (DIV). In order to accelerate the aging studies the voltage was increased to a higher level to investigate the tree initiation and growth process. By observing the change in PD magnitude the growth characteristics of electrical tree can be studied.

The applied voltage was increased to 5kV and kept for a period of 20 minutes initially to observe the tree initiation process. After that the voltage stress was removed and the specimen was inspected for tree initiation. It was observed that there was tree branch in the specimen and consequently no change in PD signature and hence the voltage was increased to higher level to observe the tree initiation process. Tree inception has been observed at a voltage of 16.5 kV after 85 minutes of the application of the high voltage. Once the first branch had been created the tree grew in small branches up to the plane ground electrode. The accelerated treeing process has been carried out for about 2 hours and the complete dendrite morphology which is of branch type tree pattern has been recorded. Table-1 shows the applied voltage during the study and visual observations made with regard to tree patterns.

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Table-1. Visual observations during treeing studies.

Applied voltage (kV)	Duration	Visual observations
2.0 (After DIV)	20 Minutes	No treeing
5	20 Minutes	No treeing
10	20 Minutes	No treeing
16.5	25 Minutes	Initiation of small tree branch
20	25 Minutes	Formation of Branch type tree
28 (Accelerated Aging Test)	70 Minutes	Growth of Branch type tree
28	20 Minutes	Tree branches approaches the plane electrode
28	30 Minutes	Formation of thick pipe-shaped conducting channel leads to the breakdown of the Sample.

Figure-4 shows the tree morphology during the initiation period. The voltage stress was removed and the image of the tree was photographed. Then the voltage was raised again to a higher voltage level, then it was removed after some time interval and again the image of the tree with more branches has been recorded. The experiments were carried out with a higher voltage of 28kV in order to obtain the complete images of branch type tree.

Figure-5 shows the widened tree channels during the tree growth process. It was observed that during the growth a small branch reached the plane electrode and the breakdown of the sample did not occurred. It was assumed that the small branch with very low conductivity may have lower value of conduction current flow which is insufficient to cause the breakdown. Figure-6 shows the tree with more number of branches and hence more tree branch volume between needle tip and the plane. The small branches were widened and thick branches were created before the breakdown.

The thickness of the widened branches was increasing and finally breakdown occurs and the widened branch structure changed to hollow pipe shaped channel. Figure-7 shows the thick hollow pipe shaped conducting channel formed after the breakdown of the test sample. The morphological studies carried out clearly shows the formation of the tree branches during the application of alternating fields. The tree patterns obtained was used to study the growth behavior as a function of test voltage.

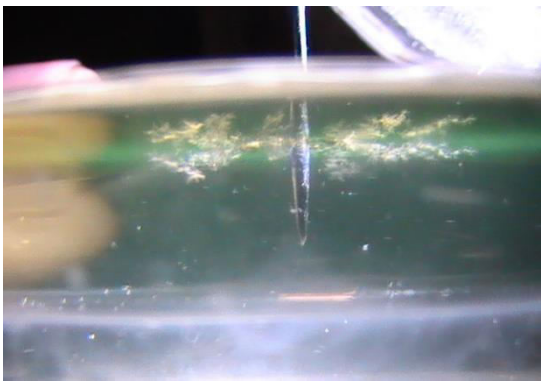

Figure-4. Initiation of few tree branches.

Figure-5. Widened tree channels.

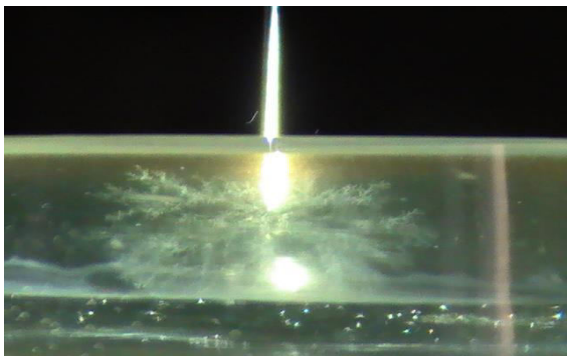

Figure-6. Tree pattern just before breakdown.

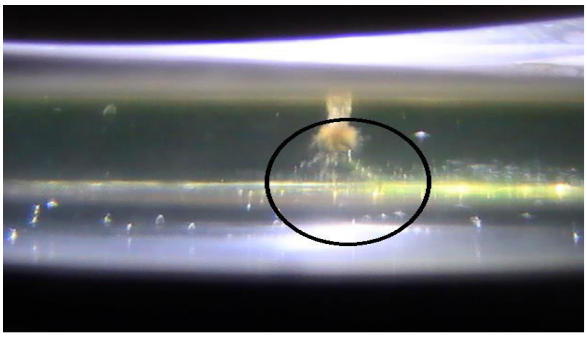

Figure-7. Widened pipe shaped tr hgee channel.

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The PD signature obtained during the experimentation is shown is Figure-8, Figure-14. The test voltage was increased in steps of 0.5kV per minute. The discharge inception voltage was observed at 2.0kV and the corresponding PD signature was recorded and it is shown in Figure-8. The test voltage was kept at 2.0kV for 20 minutes duration. The test voltage was then increased and kept at 5kV for 20 minutes. During the application of the voltage PD signature was continuously recorded. No tree pattern was observed until 16.5kV test voltage for a cumulative duration of 60 minutes as shown in Table-1. A small tree branch initiation was observed at 85th minute and the corresponding PD signature was recorded. Figure 9 Shows the PD signature recorded at 16.5kV.

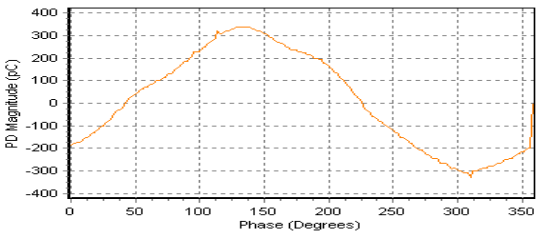

Figure-8. PD signature pattern at DIV of 2kV.

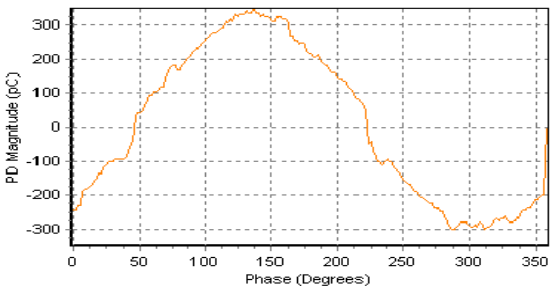

Figure-9. PD signature pattern during tree initiation at 16.5 kV- after 85 minutes.

To accelerate the treeing degradation mechanism the voltage was increased to a higher level and kept at 28kV. The tree growth was observed and the corresponding rise in PD magnitude was observed. The PD signature during the growth of the tree was recorded. The change in PD pattern during tree process clearly shows the relationship between PD magnitude and the tree morphology.

The PD magnitude was increased from 350pC to 600 pC during the widening of tree branches. Figure-10 and Figure-11 clearly shows the increase in PD magnitude which was recorded at 120th and 160th minute during the treeing process. From the morphological pattern it was observed that widening of tree few tree channels were dominating during this time period.

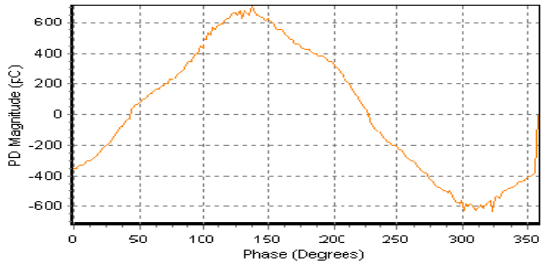

Figure-10. PD signature pattern during tree growth at 28kV - after 120 minutes.

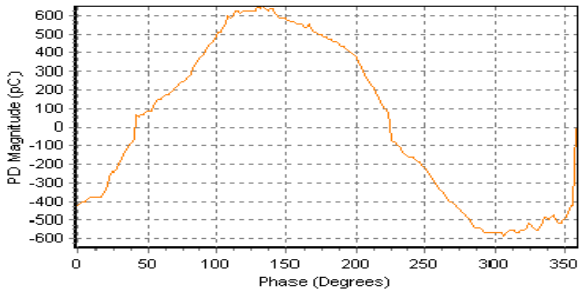

Figure-11. PD signature pattern during tree growth at 28 kV - after 160 minutes.

It was observed that during the time interval 160-180 minutes there was a sudden decrease in the PD magnitude from 600 pC to 400pC. The morphological study during this time period shows that the widening of tree branches ceases in this period and only the formation of small branches had been observed and the branch volumetric space between needle and the plane was increasing. It was assumed that the growth of only small branches with low conduction current might have resulted in the reduction of PD magnitude. This reduction in PD is shown in Figure-12. After 180 minutes the PD magnitude was increased to much higher value of around 1000pC and finally breakdown of the test specimen recorded at 230th minute. The PD signature obtained before breakdown at 220th minute is shown in Figure-13.

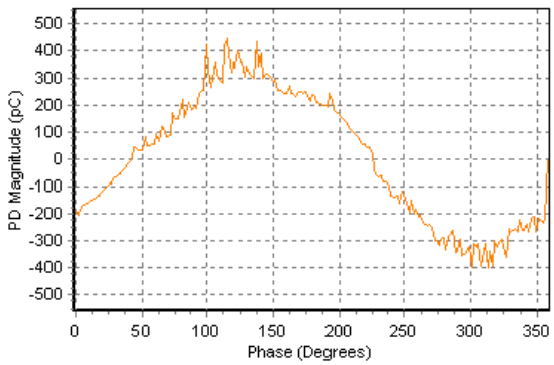

Figure-12. PD signature pattern during tree growth at 28 kV - after 180 minutes.

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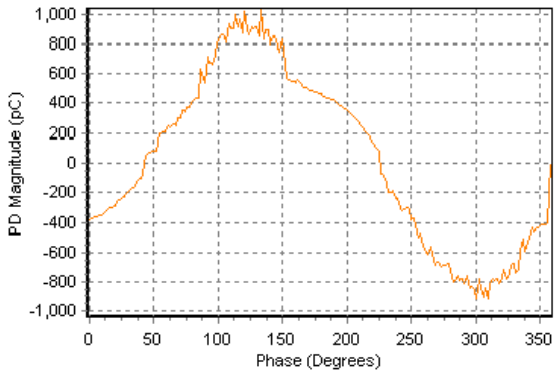

Figure-13. PD signature before the formation of hollow pipe shaped conducting channel - at 220 minutes.

Electrical treeing experimental studies carried out in the Epoxy resin samples can be classified in terms of three major stages with regard to its morphological patterns and the corresponding PD magnitude measurements. During tree inception stage very few thin conducting branches were observed and the corresponding partial discharge magnitude was significantly low. During the tree growth stage branch type tree patterns were observed. Even though few thin tree branches approaching the plane electrode did not cause complete breakdown of the test sample. It was assumed that the small branch with very low conductivity may have lower value of conduction current flow which is insufficient to cause the breakdown. During the tree growth stage the PD magnitude was significantly increased which can be correlated to the branch type morphological pattern obtained. In the next stage widening of the tree branches were observed and in few tree branches widening ceases after sometime and only small branch structure growth was observed. During this period a reduction in the PD magnitude was observed. Before breakdown of the test sample the channel diameter was increased and finally a hollow pipe shaped channel is formed which leads to the breakdown of the sample and step-like rise in PD magnitude was observed just before breakdown of the test specimen. Although the PD measurement of Epoxy test samples shows a correlation between the PD magnitude and physical degradation of the sample under test, a systematic residual life criterion must be further developed by considering various mechanisms which leads to PD initiated treeing in the epoxy resin insulation system.

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