A STUDY ON THE INVESTIGATION OF SURFACE TRACKING IN POLYESTER INSULATORS

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ABSTRACT

Electrical aging of insulators is associated with a wide variety of phenomena such as breakdown, discharges, treeing, electron interactions with charges, phonons, matters, etc. Several test methods have been developed to examine the performance of polymeric materials, however usually they exhibit too many random factors associated with them, which reduce their reliability. Surface tracking is one of the severe degradation mechanisms observed on polymeric insulators.

In this study, by using the ASTM D 2303 Inclined Plane Tracking Test method the effects of longitudinal compressive and tensile stress, ultraviolet (UV) radiadion and wind pressure from different positions with respect to the surface of the sample under test have been investigated in detail. The structure and topography of surface tracking patterns generated on the surface of polyester resin have been examinated using fractal dimension model.

INTRODUCTION

Since the introduction of electricity in 19[th] century, there has been a growing demand for electrical energy. Higher voltages led the researchers to develop new types of insulators. Many natural insulators, which were widely used at the beginning of this century have been replaced by ceramic or porcelain materials [1]. Many of these suffer from low impact strength, brittleness, inflexibility, cracking during the manufacturing process, etc. New polymeric materials are advantages in such cases [2-14]. Polyester resin mixed with other materials is becoming to be used throughout the electrical industry. However as with other polymeric insulating materials under abnormal long term stress conditions it suffers from several breakdown mechanisms such as treeing, surface tracking or erosion. Electrical aging of insulators is associated with a wide variety of phenomena such as breakdown, discharges, treeing, electron interactions with charges, phonons, matters, etc. Several test methods have been developed to examine the performance of polymeric materials, however usually they exhibit too many random factors associated with them, which reduce their reliability.

Surface tracking is one of the severe degradation mechanisms observed on polymeric insulators. There are too many factors associated with the degradation process, hence it is not easy to make an estimation about the useful service life of an insulator. However it is possible to reduce the variability observed in the tracking initiation times and tracking patterns by testing the samples in laboratory under predefined conditions (4kV applied voltage and 36ml/h flow rate of liquid).

In this study, by using the ASTM D 2303 Inclined Plane Tracking Test method the effects of longitudinal compressive and tensile stress, ultraviolet (UV) radiadion and wind pressure from different positions with respect to the surface of the sample under test have been investigated in detail [15-18]. The structure and topography of surface tracking patterns generated on the surface of polyester resin have been examinated using fractal dimension model.

Three alternative mathematical algorithms have been used to establish the fractal dimensions of the tracking patterns as a function of the above three parameters.

EXPERIMENTAL

All samples have been prepared by using polyester resin without any accelarator. The test samples with the dimensions of 100mm*55mm*9mm were mounted at 45° to the horizontal of the test set-up [19]. All experiments were performed at 4kV applied voltage and 0.36ml/h contaminant flow rate. Furthermore, all of the experiments have been performed by using Inclined Plane Tracking Test, which is quite useful in representing the "wet tracking" phenemone. ASTM D 2303 suggests that for 4kV a flow rate of 36 ml/h provides the optimum results, which means short tracking initiation and track growth times and also rapid crossover from the high voltage electrode to the earth electrode. This rapid process might lead to an unbranched tracking pattern with minor damage to the surface. All specimens were tested in a closed cabinet with an open roof and minimum air circulation. For each set at least 5 samples were used. ASTM D 2303 recommends to continue the test until the tracking pattern reaches 25 mm from the earth electrode, however to enable a complete structural pattern analysis, the experiment was not stopped until the gap between the earth and HV electrode has been crossed completely. After each experiment, specimens exhibit a carbonised, highly damaged, black tracking patterns and due to the burning, discoloured surface sections. Initially each specimen after the test was rinsed completely with distilled water. After complete drying, the discoloured sections (mostly ligth black in pure polyester resin) are cleaned smoothly with emery paper and sharp knife. Finally the tracking pattern image of the samples were transferred to the PC by using a digital camera. The patterns were obtained by image processing.

MATHEMATICAL ANALYSIS

Fractals can be described as geometric shapes that repeat their structure on ever finer scales [19-25]. Theoretically fractal object are infinitesinally sub-divisible in this way; each sub-set; however small, containing no less detail than the complete set, basically fractal dimension measures result and discussions. Several methods for estimating the fractal dimension of complex surfaces have been proposed. This work was performed by using capacity, corelation and information dimension methods.

CAPACITY DIMENSION

Capacity dimension is used to calculate the fractal dimension of complicated shapes [22-23]. The basic idea of the capacity dimension is to cover the trajectory with equal square boxes till not any part of the pattern remains uncovered. All the boxes containing a part of the pattern are caunted. Capacity dimension(D_{cap}) was calculated using the following equation,

$$D_{cap} = \lim_{\varepsilon \to 0} \frac{\ln N(\varepsilon)}{\ln\left(\frac{1}{\varepsilon}\right)} \qquad (1)$$

where '$N(\varepsilon)$' is the number of boxes, ' ε ' is the side length of the box.

CORELATION DIMENSION

Corelation dimension method provides fast and easy solution to determine the value of the fractal dimension. It can be denoted as,

$$D_G = \lim_{\varepsilon \to 0} \frac{\ln \sum_{i=1}^{N(\varepsilon)} P_i^2}{\ln(\varepsilon)} \qquad (2)$$

$$P_i = \lim_{N \to \infty} \frac{n_i}{N} \qquad (3)$$

where n_i = number of points Iying in the i'th volume element, N = total number of points in the trajectory.

It differs from capacity dimension in the matter that corelation dimension is a probabilistic type of dimension where it calculated the relative frequency of visitation of a typical trajectory.

INFORMATION DIMENSION

Information dimension mainly based on calculating the probability of finding a point in a certain cell. It is quite similar to the correlation dimension. It can be shown as,

$$D_i = \lim_{\varepsilon \to 0} \frac{\ln \sum_{i=1}^{N(\varepsilon)} P_i \ln P_i}{\ln(\varepsilon)} \qquad (4)$$

$$P_i = \frac{n_i}{N} \qquad (5)$$

where n_i = the number of point in the cell, N = the number of total points belonging to the image, $N(\varepsilon)$ = minimum number of boxes size ε to cover the image.

RESULTS AND DISCUSSION

In previously works, the structure and topography of surface of polyester resin using the international standart procedure(ASTM D 2303 inclined- plane Tracking test) have been studied and three factors effecting the lifetime of a polyester insulator have been investigated. [26], and than tracking patterns of this samples have been analysed by using Cellular Neutral Networks [27].

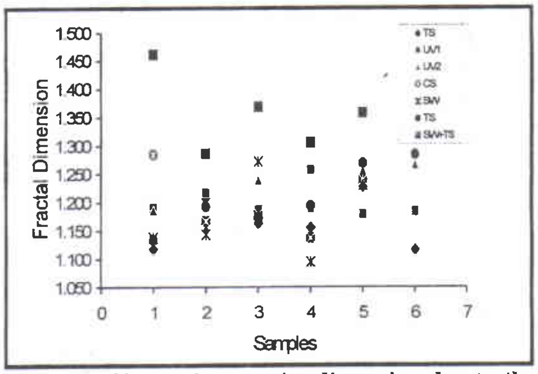

Figure 1. Change in capacity dimension due to the environmental conditions, RT: Room temperature, UV: ultraviolet radiation (1 Front side, 2 right side), CS: Compressive stress, SW: straight air circulation, TS: tensile stress, SW+TS: straight air circulation and tensile stress

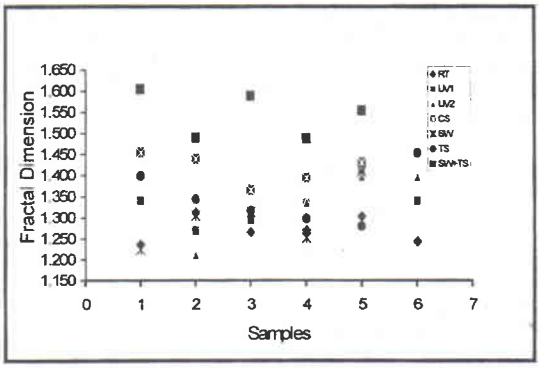

Figure 2. Variation of correlation dimension with the environmental conditions

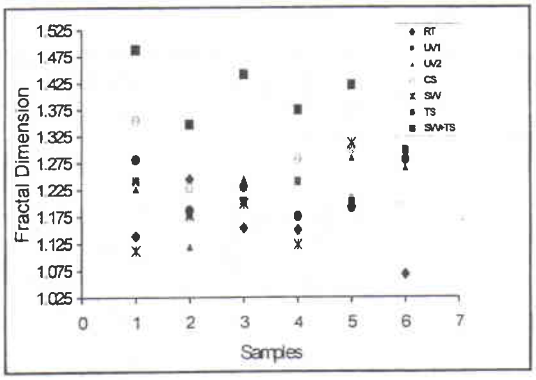

Figure 3. Change in information dimension due to the environmental conditions

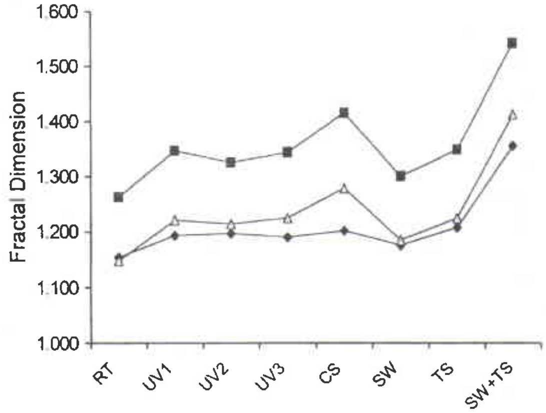

Figure 4. Variation of fractal dimension with environmental conditions: ♦ Capacity □ Corelation Δ Information

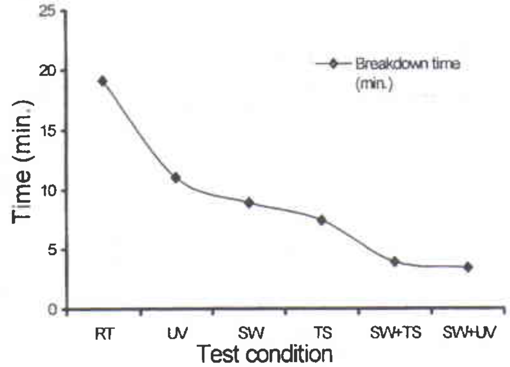

Figure 5. Change in breakdown times due to the environmental conditions RT: room temperature, UV: ultra viole radiation, SW: straight air circulation, TS: tensile stress, SW+TS : straight air circulation and tensile stress, SW+UV: straight air circulation and ultraviolet

In this study three alternative mathematical algorithms have been used to establish the fractal dimensions of the tracking patterns as a function of UV, Mechanical and wind effect. Those three algorithms mentioned above are static methods, which analyse the structure of surface tracking patterns. For each condition three different fractal dimensions have been calculated.
The dependence of capacity , information, correlation dimensions for various enviromental factors such as ultraviolet adiation, compressive stress, tensile stress , wind effect and tensile stress + wind effect has been shown in Figures 1, 2and 3 , respectively.

As it is shown in those Figures, fractal dimension values of polyester insulator were shown that the highst values were observed in straight air circulation + tensile stress case while the lowest ones were from ideal case. Recently, dependence of breakdown times of polyester insulator on applied voltage have been reported in the literature[28].

Numeric values of capacity, information and correlation dimensions were 1.15-1.36, 1.14-1.42 and 1.26-1.54, respectively. The results illustrated in Figures 1, 2,and 3 shows parallelity to the results obtained from Cellular Neural Networks Methode [27]. Experimental observations of surface tracing in polyester insulators shows that the correlation dimension are closer to the estimated dimension.
Change in fractal dimensions due to the enviromental conditions is shown in Figure 4. Breakdown times of polyester insulator for all conditions is given in Figure 5 [26]. Investigation of Figure 4 and 5 shows that fractal dimensions are in good agreement with the experimental results.

CONCLUSION

Fractal dimension methode is intented to analyse the structure of surface tracking patterns in polyester outdoor insulator. In this study three alternative mathematical algorithms have been used to establish the fractal dimensions of the tracking patterns as a function of environmental conditions. Results show that maximum distortion has been observed at straight air circulation and tensile stress. This results is found to be good agreement with experimental tracking initiation time.

This work was suppoted by the Research Fund of the University of Istanbul. Project number 1333/280799.

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