Effect of Voltage Type and Geometric Shape on the Tracking Performance of Polymeric Materials by using Liquid Pollution

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Abstract:

This paper presents an experimental investigation of two types of polymeric materials having circular shapes with different diameters. The investigation is carried out by tracking a high voltage and earth electrodes on their surfaces using liquid pollution. The materials have been tested under DC and AC high voltages and the results show that initial tracking voltage increases linearly with increasing the disc diameter and the silicone rubber (SR) samples exhibited better characteristics compared to the Ethylene Propylene Diene Monomer rubber EPDM samples. The test is

also revealed that the pollution problem is more serious for DC insulators than for AC ones.

Introduction:

It is observed that the modern technology is becoming more complex and is increasing the demands on engineering properties of materials. Electrical insulation is no exception in this respect. In the past the function of the insulation materials was just to isolate the conducting components from each other and from the earth, but nowadays in modern insulation systems the insulation materials should provide many functions, starting with electrical insulation and ending with a high resist to a rapid temperature rise.

It is generally expected that the life of outdoor insulators is between 25 and 40 years [1], but only porcelain can be guaranteed to succeed in the majority of circumstances. On the other hand, in particular places and under certain conditions, special insulation materials are needed. However, during the last 40 years new materials called polymers were developed and were regarded as a replacement to porcelain and glass [1]. They are now being used in high voltage applications such as, polluted areas, areas with a high incidence of vandalism, etc. However, it is not just a simple problem of considering a polymer that looks like a porcelain part, because, before using such materials in the applications of outdoor insulating, more details should be considered such as chemical and molecular structures, electrical properties, mechanical properties, surface discharge resistance, surface leakage effects, effect of environment, and so on [2].

It has been shown that there are many problems involved in employing a polymeric insulator as a replacement for the glass and porcelain insulators. Careful consideration has to be made of the area where polymeric materials do not have the same properties as those of porcelain or glass. Proper control of the material formulations and processing can reduce the effect of the dissipation factor; (tan δ) [3]. Careful attention paid in the choice of the materials for the required applications enables weathering to be overcome. Formulation and electrical stress control can reduce the effects of tracking. Reinforcing materials may have to be added in order to give the required mechanical strength and mechanical creep. When this is done,

care must be paid to insuring that proper bonding is made between the polymer overcoat and the reinforcing materials.

In short, as in all technological progress, good solid effort can give some striking results, such as the advantages of polymers over porcelain and glass may be made advantage of, and the size of insulators can be reduced, as can the weight also, the manufacturing cycle of the insulators can be improved significantly, and insulators made to good dimensional tolerances. It is certain that polymeric insulators are no overall replacement for porcelain and glass insulators, but where the disadvantages of porcelain and glass are evident, significant improvements can be achieved.

Tracking:

A track is defined as a permanent conducting path formed on the surface of an insulator [4]. During the operation of insulators in polluted areas, contamination will take place on them, and as time continues and with the presence of moisture a surface leakage current will flow. This current will make the surface dry out ending with dry band formation which will be bridged by a very small electrical discharge, which will in turn produce a heat. The heat may be sufficient to decompose the insulation and form short conducting paths, which are called tracks. These tracks will propagate in a tree-like manner after a period all of the distance between the electrodes is bridged, causing failure of the insulation [5].

There are four types of tracking, the first type is simply as a result of the presence of an arc burning near to the surface of a material which produces a patch of pyrolised resin which is conducting, if the arc was passing between two electrodes fixed on the surfaces of a material a good conducting path will remain between them after the arc is switched off. This type of track is the one to which arc-chutes must be resistant. This kind of track is normally as a result of a flashover, or of wrong choice of material exposed to conditions, or close to a hot component [6]. The second type of track occurs as a result of a small current at high voltage passing between two electrodes fixed on the surfaces of an insulating material.(i.e . polymer) in the form of spark dishrags. If the material is clean and dry, it will not suffer for a considerable time, but if it is sprayed with water, one or more thin wavy track of char will form, as the discharge and wetting continue a complex tree pattern causes bridging of the electrodes [6]. The third type of track gives a good background for the previous one. A solution in water of any salt is spread in the form of a continuous film between two electrodes and a supply of 200 - 300 V applied to the electrodes. The film is evaporated by the heating of the current, the thinnest region gets heated the most and rapidly thins down to the a narrow neck which breaks with a tiny bright discharge like a miniature arc, but, it need only be carrying a few mille-amperes [6]. A small spot of charred material is left where the discharge occurred. If the liquid then flows back or is replenished the process repeats, and with repetition the spot becomes extended into lines more or less along the direction of the field. The fourth type of track takes place in oil containing droplets of water. These are drawn into strong fields on the surface and form a layer on the surface which behaves in the manner explained above [6].

Pollution Flashover:

Pollution flashover of an insulator occurs when an insulator surface is covered with a layer which has low resistively. The contaminant should be wet to be dangerous. As the moisture film builds up on a polluted surface, a thin film of conducting liquid is formed. The conductivity of this film will depend upon the amount of moisture and the chemical composition of the contaminant [7]. This surface film will cause the leakage current to increase several times. When the insulator surface is contaminated and wet, the voltage distribution is no longer determined by the capacitive effect between each unit. This is due to the conductivity of the electrolytic film with a high leakage current. As the polluted surface gets wet, the leakage current starts to increase slightly. Non-uniform heating of the pollution layer occurs and dry areas appear around the narrowest section of the insulator. The dry areas rapidly widen to form dry bands [7]. The whole insulator voltage appears across these areas and air breakdown occurs. The process leading to the breakdown of a contaminated insulator usually starts with the surface discharge. The development of the surface discharge can be separated into three basic stages [8, 9]:

- Electrolyte formation
- Formation of dry band
- Discharge in dry band

The effect of the surface discharges would alter the electric stress and the current flow field on the electrolyte surface. Under certain conditions these discharges will move and bridge an appreciable fraction of the creep age length. Flashover will occur if the discharge elongation continues.

Tracking Tests:

For long time ago there have been many attempts to develop a suitable laboratory test to give an accurate guide to the liability of a material to track when stressed in a polluted environment, although it is impossible to reproduce all the possible conditions that can happen in reality [10]. However, the requirements of good test method are:

- reasonably high acceleration.
- good correlation with known service experience.
- good reproducibility and repeatability.

The first laboratory tracking tests were started in Europe 60years ago [10]. Since that time, many investigators have studied tracking of insulation, and numerous test methods have been published. Three of these test methods have been widely used and, although limited in scope, have provided valuable tracking information on many insulating materials [6]. It is of course, impractical for manufactures of materials to develop them using complete insulators as test specimens and many different kinds of tracking tests exist to compare and evaluate materials in sheet or rod form. The differential wet tracking test and dust -fog test have served well and although they have their attraction are less used now than the drop tracking test and the inclined plane test which are the only ones graced with IEC status [4].

Inclined Plane Test :

In fact, the Inclined Plane Test (IPT) was developed in 1961 as a result of hard work by Mathes and McGowan. It was adopted as an ASTM Tentative Standard in 1964 [4]. It is considered the most comprehensive test for tracking and erosion, in that its scope covers two tracking and one erosion test procedures. In its simplest form, the IPT is simply drops of solution of ammonium chloride arranged to run down the surface of the test sample to wet the space between two chisel electrodes between which an adjustable test voltage is set. Figure 1 shows the IPT electrode arrangement.

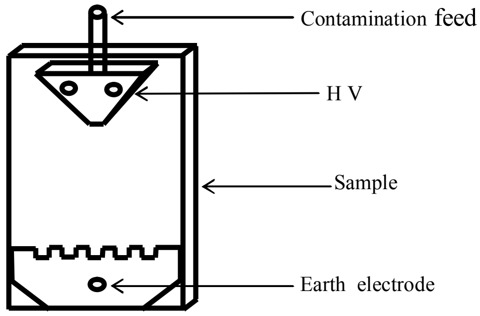

Figure 1: Inclined Plane Test electrode arrangement

Dust-Fog Test:

For many years ago researchers have attempted to develop a reliable method to investigate the insulation materials, one of these methods which was developed and considered a suitable method is called the dust-fog test (DFT). In this test, the specimen is sprinkled with a specified dust, wet by water from a fine spray, and a voltage increasing from 500V applied between two electrodes [10]. The subsequent control of voltage is complicated, the condition which causes conduction or , failing this, the final degree of erosion is noted [11]. Figure 2 shows the arrangement of the DFT electrodes, whilst tables 1 and 2 show in general the advantages and disadvantages encountered in the application of some available tests for both the materials and components test methods.

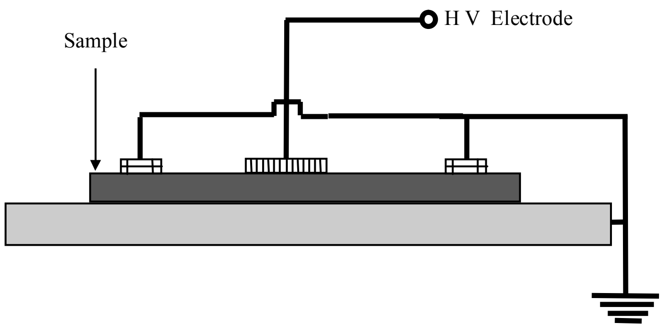

Figure 2: Dust-Fog Test Electrode Arrangement

Test Rig arrangement:

In this paper some brief details are given for the test method used, the equipments and test procedures which were used to test two different materials.

Summary of Test Method :

The following is an attempt to develop a new test method differs from the methods that already explained in the previous chapter (and other have not been explained in this dissertation), to evaluate the tracking performance on the surface of an insulating materials under polluted environment.

Contrary to the methods of the preceding, where the electrodes fixed on one surface side only [12], in this method the electrodes were fixed on both sides of the polluted sample, in addition, the method of preparing the pollution enabled it to be considered to remain wet as long as possible, by using the silicate material. This was a trail to represent the real pollution which occurs on outdoor insulators specially in the presence of dust combined with moisture, mist or drizzle. This method was used to determine the initial tracking voltage.

Samples Arrangement and Preparation:

The samples which were tested been taken from actual insulators, each sample has different diameter of the others, but, all of them have the same shape (circular). The dimensions and type of the samples as shown in table 1.

Sample No	Sample type	Outer Diameter (mm)
A	EPDM	235 mm
B	EPDM	210 mm
C	EPDM	190 mm
D	EPDM	175 mm
E	S R	112 mm
F	S R	110 mm
G	EPDM	225 mm
H	EPDM	220 mm
I	EPDM	200 mm
J	EPDM	180 mm
K	S R	112 mm
L	S R	110 mm

Table 1: Dimensions of the samples

To avoid the presence of wax and oil on the surfaces of the samples, they were cleaned with isopropyl alcohol, then rinsed with distilled water and were left to dry [13].

Pollution Preparation:

The used pollution consists of about 100 g of silicate melted in a litre of water containing 30 g of sodium chloride. The mixture was stirred until it became sticky, then was left two days to complete the chemical reactions.

Silicate was chosen due to its ability to remain wet for long time once it is melted in water.

Test circuit:

Generally, the electrical circuit used in the test consisted of a variable ratio auto transformer fed from a 240 V, 50 Hz supply, connected to a 240V/10KV high voltage transformer, the high voltage side of the transformer was connected to a series set of current limiting resistors then in series with the sample, the sample is connected in series with 60mA fuse as shown in figure 3.

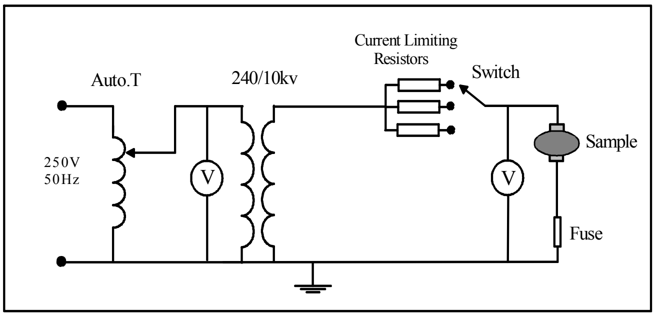

Figure 3 : AC Test Circuit

For the purpose of the DC test a full bridge rectifier was connected on the high voltage side of the high voltage transformer to produce a DC voltage as shown in figure 4. Two voltmeters were connected at both sides; low voltage and high voltage of the circuit to measure primary and secondary voltages.

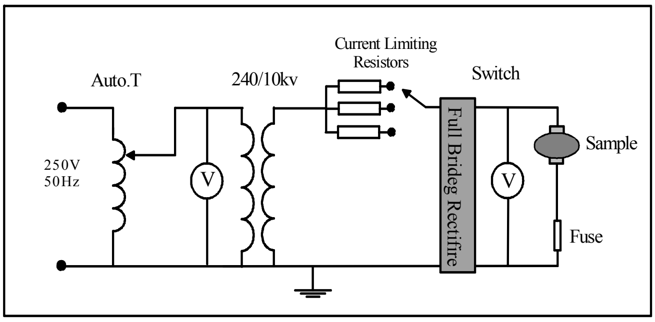

Figure 4: DC Test Circuit

For safety purposes the high voltage components as well as the sample were surrounded with a cage which has a gate interlocked in such away that power was disconnected as long as it was open. Figure 5 show photographic pictures of the
test rig.

Figure 5: Photographic pictures of the test rig.

Experimental Work:

Initial Tracking Voltage Test:

To determine the initial tracking voltage, the circuit was arranged as described above, with the sample coated on both sides with the prepared pollution by a soft brush, then the electrodes were fixed on both sides of the sample [7]. The supply was switched on, and the voltage increased gradually with steps of 500V, holding each step for an hour unless failure occurs before increasing to the next step, starting test voltage must be determined so that tracking failure does not occur sooner than the third step, if there was no failure occurring the voltage is increased to the next step until discharging with yellow to white arcs occurs, then the voltage was slowly increased until progressive tracking starts to extend on one of the sample sides. This is considered as the initial tracking voltage.

AC Test:

In this test six samples of organic polymer, four of EPDM type, and two of SR were tested under AC voltage to evaluate the tracking performance on their surfaces by using liquid pollution. They were actual insulator sheds having different disc diameters. The obtained results are listed in tables 2 and 3, while figure 6 shows the photographic picture of the six samples before and after testing.

Sample	Disk diameter (mm)	Start voltage (KV)	Initial tracking voltage (KV)
A	235	4	5.5
B	210	4	5.20
C	190	4	5
D	175	4	4.80

Table 2 : First AC Test Results (EPDM Samples)

Sample	Disk diameter (mm)	Start voltage (KV)	Initial tracking voltage(KV)
E	112	4.25	5.25
F	110	4.25	5.10

Table 3: Second AC Test Results (SR Samples)

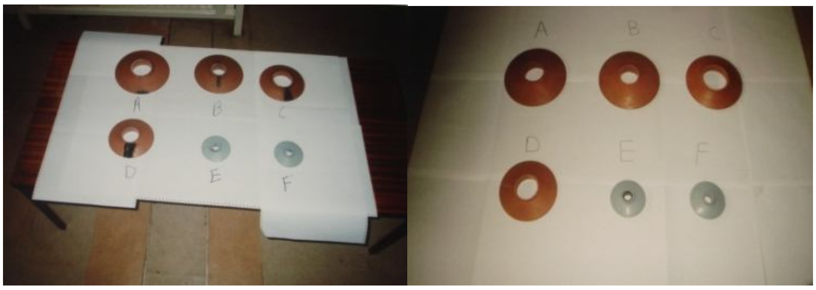

Figure 6: Photographic picture of the six samples before and after testing

DC Test:

In this test four samples of organic polymer EPDM type, and two SR type were tested under DC voltage to evaluate the tracking performance on their surfaces by using liquid pollution. They were actual insulator sheds having different disc diameters. The obtained results are tabulated in tables 4 and 5, while figure 7 shows the photographic picture of the six samples before and after testing.

sample	Disk diameter (mm)	Start voltage (KV)	Initial tracking voltage (KV)
G	225	3	4.15
H	220	3	3.85
I	200	3	3.50
J	180	3	3.20

Table 5: First DC Test Results (EPDM Samples)

Sample	Disk diameter (mm)	Start voltage (KV)	Initial tracking voltage (KV)
K	112	3.5	5.20
L	110	3.5	5

Table 6: Second DC Test Results (SR Samples)

Figure 7: Photographic picture of the six samples before and after testing

Results :

Figures 8 and 9 show the effect of insulator diameter on the initial tracking voltage for two types of polymeric materials. It is clear that in both types of voltage the initial tracking voltage increases linearly with the diameter of the disc. But in comparing the results from the material type point of view it can be said that the tracking performance of the SR samples exhibited better characteristics compared to the performance of the EPDM samples. It is obvious from tables 2, 3, 4 and 5, the initial tracking voltage for the SR samples is larger than that for EPDM samples, although the earlier have smaller sizes than the latter.

It is known that the flashover of polluted insulators is still a serious threat to the safe operation of a power transmission system [14]. It is generally considered that pollution flashover is becoming ever more important in the design of EHV and UHV transmission lines, especially under DC voltage [15].

It was observed from the experimental results that the type of the voltage plays an important role in the tracking performance of polluted insulators, whereas, the polluted samples which were tested under AC voltage show better characteristics compared to those which were tested under DC voltage. It can be seen that the initial tracking voltage in the AC test is larger than that in the DC voltage test.

The relation between the initial tracking voltage and the diameter of the disc was obtained.

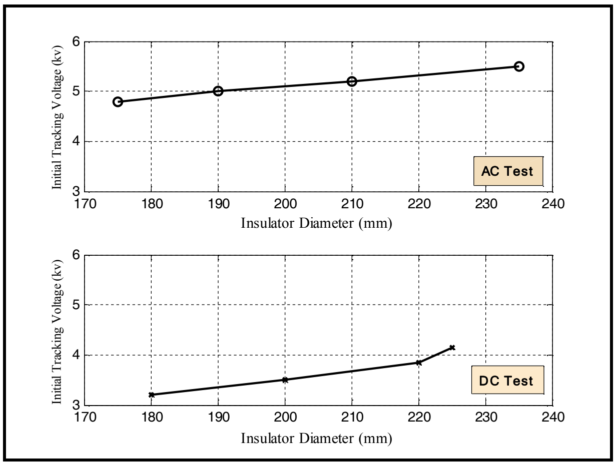

Figure 8:

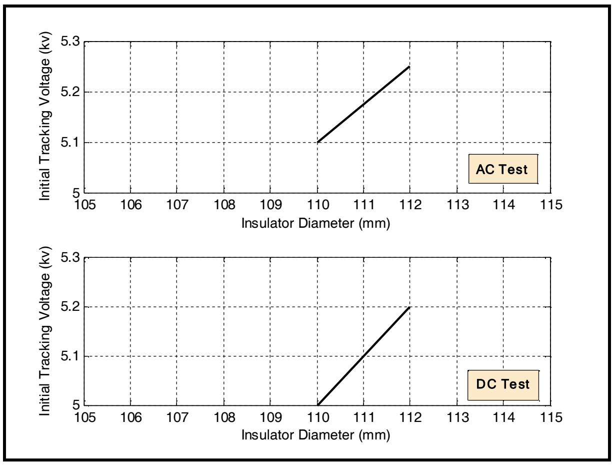

Figure 9:

Conclusion:

The tendency of an insulating material to track is principally due to various factors, which, frequently, occur simultaneously. However, breakdown mechanism of polymers is determined by the contents of the polymer. All polymers based on aromatic compounds will be tracking material. This is because all aromatic compounds contain an inherently mobile electronic structure which tends to form free radicals easily during thermal degradation.

The objective of this work was to test two types of polymeric materials in the form of actual round shape sheds and different diameters, by tracking their surfaces using liquid pollution under AC and DC voltage. The conclusions can be summarised in three main points:

- The chemical structure of the polymer is of primary importance in determining the tendency to surface tracking under small electrical discharges. So, the SR samples exhibited better characteristics compared to the EPDM samples.
- The pollution problem is more serious for DC insulators than for AC ones. This may be due to the difference in the arc characteristics for AC and DC, the current passing through a DC arc is constant, but alternates for AC.
- The initial tracking voltage increases linearly with increasing the disc diameter.

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