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Performance of Polymeric Insulators under Accelerated Ageing under AC & DC Voltages

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The performance of insulator for AC and DC voltages is of great practical importance as the insulators can be used with both types of voltages. In view of the many advantages of composite (polymeric) insulators, extensive experimental and analytical investigations have been carried out in the present study on the ageing characteristics of these insulators. Inclined plane tracking and erosion tests, as well as the long term ageing tests, were conducted on samples of polymeric insulator materials. It has been possible to conclude from the above experiments that positive polarity DC is more severe for polymeric material compared to negative polarity DC and AC voltages. The surface degradation of the material was diagonised by hydrophobicity measurement and leakage current analysis. Analytical techniques such as x-ray Diffraction, Energy Dispersion x-ray have been used to analyze the material deterioration. Thermo graviometric analysis and Differential scanning calorimeter tests were also used to study the filler material content in the polymer.

1. INTRODUCTION

Composite insulators are in use for outdoor insulation for more than three decades. The long term performance of these insulators were fairly good for AC transmission. The experience and utilization of these insulators under DC voltages are less. Research work on composite insulators for DC voltages are limited. The use of composite insulators in DC system is of high importance, especially to developing country like India where a significant development of high voltage DC system is foreseen.

In the present study, the behavior of composite insulator material under inclined plane tracking and erosion studies and its performance under accelerated ageing studies for AC and DC voltages are investigated. Based on the test results full length insulators were subjected to accelerated ageing tests. The effect of droplet size on the performance of composite insulators were also investigated.

2. TEST METHOD TO INVESTIGATE FOG CONDITIONS

The accelerated ageing tests on composite insulator simulate the long-term performance within a short period. Under this, the varied weather conditions which are available in the field are simulated and the results obtained in the test will be a realistic one. Although CIGRE committee specified the test chamber size, test cycle duration of the test etc., it has not clearly specified the size of the fog droplets, fog rate, fog density, volume of the salt water injected in to the chamber.

The electrical properties of the insulator like surface hydrophobicity, surface conductance, withstand and flashover characteristics etc., are effected by the droplet size and plays decisive role in the fog chamber. Usually larger sized fog droplets will take the bubble shape and runs off from the hydrophobic surface but the smaller sized droplets may wet the insulator surface or move away without any impact

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on the surface of the insulator. Therefore, to investigate the fog droplet size, which is suitable for pollution aging studies, the pressure variation technique was adopted with different pollution severities.

2.1 Effect of Fog Droplet Size on the Surface Conductance

The surface conductance was measured at three different severities of pollution representing light, medium and heavy pollution. A test specimen of silicone rubber insulator of 25 kV only was used to evaluate the effect of fog condition. The test was performed in a pollution chamber of 8 m × 8 m × 9 m having the salt fog generation nozzles as per IEC60507. A test source of 10 kV, 100 mA, DC source was used for the conductance measurement study. Silicone rubber insulator was mounted in the testing chamber in the vertical position at the center of the chamber. The fog generation is as per IEC-60507. The volume of salt water injected through the nozzle was 0.5 l/min. A test voltage of 1 kV DC was applied momentarily at every five minutes intervals and the leakage current was monitored. The variation in the fog droplet size is obtained from different input air pressures of 3 kg/cm^2, 5 kg/cm^2, 7 kg/cm^2 and 8 kg/cm^2. The salinities used were 10 kg/m^3, 40 kg/m^3 and 80 kg/m^3.

2.2 Effect of Fog Particle Size on Flashover Voltage of the Composite Insulator

The flashover voltage tests were carried out on the same insulator in the same fog chamber to characterize the flashover strength of the insulator for different sized fog particles. The DC source used for the test is of rating 150 kV, 1 A. The flashover voltage of the insulator was determined by means of rapid test method[1]. The insulator was tested for varied air pressure of 3.5, 5, 7 kg/cm^2.

3. INCLINED PLANE TRACKING AND EROSION TEST

The inclined plane tracking and erosion resistance of the polymeric material have been studied using a specially designed inclined plane tracking and erosion test set apparatus under AC and DC voltages. ASTM D 2303 & IEC 60587 document test procedures have been used for the study. Tests were carried out on Silicone Rubber and EPDM material at a voltage of 1.5 kV at salinities varying from 200 micro Siemens/cm to a maximum of 80grams/lit. The duration of the test was 10 hours. DC positive voltage was found to be more severe for polymeric material during the tests.

4. AGEING TEST ON SAMPLE INSULATING MATERIAL

Pollution aging studies were carried out to obtain information needed for the insulator designers and utilities about the behavior of composite insulators exposed to extreme service conditions and to evaluate their expected life in service. Ageing of sample polymeric insulator material was conducted in a fog chamber of dimension 2 m × 2 m × 2.5 m and the fog was generated by using IEC nozzle. The specimen used were rectangular in shape of 10-centimeter length and 5 centimeter breadth and 5 millimeter thick. Stainless steel electrodes were fitted on both the sides of the specimen. The samples were positioned vertically in the fog chamber. A test source of 10 kV, 100 milli ampere AC source was used for ageing study under AC voltage and a 10 kV, 100 milli ampere DC source was used for the ageing study under DC voltage. Ageing tests were performed at both the polarities of DC voltages. The aging cycle consisted of 8 hours of fog and rest of the period dry with the application of voltage throughout the aging. This method of aging was followed in order to see whether the recovery of hydrophobicity of the material can take place after a prolonged dry band arcing during the salt fog period. A voltage of 7 kV was applied to the specimen with specific creepage distance of 10 mm/kV. The severity of fog used were 590 micro Siemens/cm, 7 kg/m^3 and 80 kg/m^3. The duration of the aging was about 1500 hours.

DC positive polarity was found to be more severe for polymeric insulator material both under inclined plane tracking and erosion test as well as material ageing test at lower severity of pollution.

5. AGING STUDIES OF FULL LENGTH INSULATORS AT HIGH CONDUCTIVITY FOG (80 grams/litre)

The composite insulators of silicone rubber and EPDM were subjected to accelerated aging by the repetition of a weekly cycle. The test reproduces the service conditions such as the applied voltage with relevant electric fields and the weathering agents such as humidity, rain, pollution, solar radiation and relevant heating and drying periods that can influence the life duration of polymeric materials. This cycle is similar to CIGRE cycle except the severity of pollution is 80 g/l instead of 7 g/l .This work was carried out at CESI laboratories under CESI -CPRI research cooperation[2].

The DC voltage was chosen taking into account the results of the research carried out on cap and pin insulators indicating that under the same surface contamination, the DC flashover voltage is lower than the corresponding AC flashover voltage. The DC-AC voltage ratio decreases when the pollution degree is increased and is about 0.7 at 80 g/l severity level. Thus a voltage of 70 kV negative polarity was chosen. Negative polarity was chosen because the pollution flashover under DC negative is severe. The duration of the aging was about 2000 hours. Visual inspections were made on the insulators before and after the aging tests by the degree of degradation observed on the insulators such as erosions, change in color, chalking, and incrustation. Before and after aging, tests to evaluate the average flashover voltage in salt fog were carried out on the insulators by using rapid test procedure[1]

5.1 Ageing of Full Length Insulator under Low Conductivity Fog

Insulators of Silicone Rubber and EPDM were subjected to accelerated ageing after obtaining the results from the tracking and erosion studies and accelerated ageing studies on the polymer materials. The ageing cycle consisted of fog at lower severity for eight hours and rest of the period dry with continuous voltage application to the insulators. The applied voltage remained same for ageing study for low conductivity as well as high conductivity ageing tests.

6. ANALYTICAL STUDIES OF THE POLYMERIC INSULATOR MATERIAL BEFORE AND AFTER AGEING TEST

EDX and X-ray diffraction studies were carried out on virgin and aged samples of the insulator material to assess the material ageing. This technique indicates the filler concentration as the ratio between aluminum and silicon. To understand the physical processes involved in the failure of the insulator, studies were carried out using EDX analysis at critical locations of the insulator. The virgin and the aged samples were cut and subjected to EDX analysis to study the processes which have degraded the material. Energy dispersion X-ray analysis on the sample material cut from the virgin and aged samples of the composite insulator material was carried out using Scanning electron micro- scope with EDAX facility. Samples of silicone rubber and EPDM, 1 cm × 1 cm, cut from the virgin and the aged composite insulator material were subjected to EDX analysis. X ray diffraction studies were performed on the sample material in order to find out the degree of crystalanity. Thermo gravimetric analysis and differential calorimeter were used to study the filler concentration of the each sample of insulator material used.

7. RESULTS AND DISCUSSIONS

7.1 Results of Surface Conductance Measurements

A 25 kV Silicone rubber Insulator which was subjected to surface conductance measurement as described in section 2.1 revealed the following results. The variation of surface conductance with respect to time for different pressures is shown in figure 1. It is seen from the results that surface conductance increases with increase in pressure up to a pressure of 7 kg/cm^2 and then decreases there after. At 8 kg/cm^2 the flashover voltage increase is due to lower leakage currents obtained due to drying of the fog, thus increasing the flashover voltages. The increase in surface conductance is due to variation in droplet size of the fog. At lower pressure the size of the fog particle is lower and the velocity of throw is lower and the droplet on the surface of insulator runoff due to gravity and the surface conductance value becomes lower up to a pressure of 5 kg/cm^2. The rapid flashover performed on the insulator also showed lowest flashover voltage at a pressure of 7 kg/cm^2. Fig. 2 shows the variation of flashover voltage at different air pressures by rapid flashover technique.

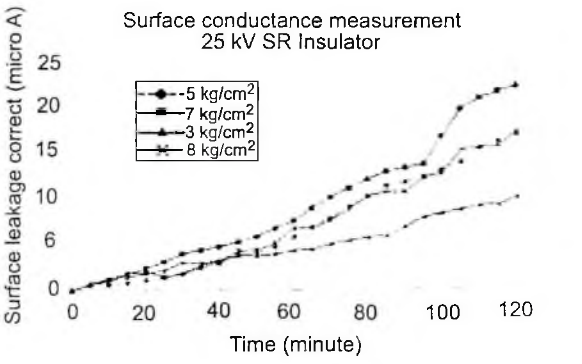

FIG. 1. VARIATION OF SURFACE CONDUCTANCE AT DIFFERENT AIR PRESSURE

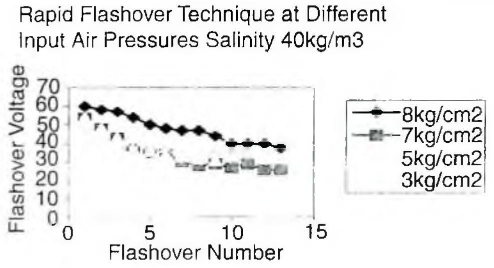

FIG. 2. SHOWS THE RAPID FLASHOVER VOLTAGES OBTAINED AT DIFFERENT PRESSURES OF FOG GENERATION

7.2 Results of Tracking and Erosion Test on Sample Material

Tracking and erosion test under AC voltages revealed no failure of Silicone and EPDM material at higher severity of pollution (80 g/l). At lower severity (590 micro Siemens/cm) traces of carbonates seen adhering to the surface and thus surface becoming slightly crystalline. From the results obtained under various severities of pollution under both polarities of DC voltages and AC voltages it is worth pointing out that the samples subjected to positive polarity represented the worst case of degradation of polymer material. Fig. 3 shows the degradation of material under lower conductivity tracking and erosion test carried out on material under AC and DC positive voltages.

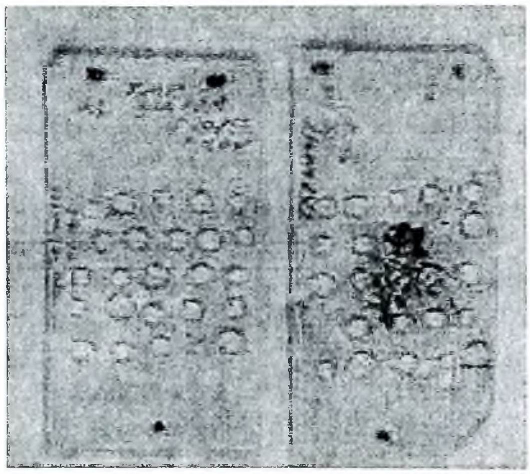

FIG. 3. PHOTOGRAPH SHOWING DEGRADATION OF MATERIAL AT LOWER SEVERITY OF POLLUTION UNDER AC AND DC POSITIVE POLARITY

7.3 Results of Ageing Studies on Sample Material

The ageing tests on sample polymeric insulator material revealed no degradation of material for higher conductivity fog both under AC and DC voltages. Lower conductivity ageing showed slight degradation of material particularly for DC positive polarity voltage.

7.4 Results of Ageing Studies on Full Length Insulators under Low and High Conductivity Fog under AC and DC Voltage

The performance of polymeric insulators aged under AC voltages performed better during the entire ageing duration. No tracking or erosions were seen after the ageing.

No tracking or erosions were seen on Silicone rubber and EPDM insulators which were subjected to high conductivity ageing under DC negative polarity. The average flashover tests conducted before and after ageing tests showed 10 percent reduction in average flashover at high conductivity fog ageing studies and 20% reduction in average flashover for insulators aged at low conductivity fog. EPDM insulator failed in ageing subjected to low conductivity fog ageing under positive DC voltages. Silicone rubber insulators performed better compare to EPDM insulators. Fig. 4 shows the degradation of insulator after ageing test performed under lower conductivity fog. Analytical studies performed on the samples of virgin and aged insulators before and after ageing studies showed deficiency of Al and Si filler material. XRD analysis showed higher degree of crystalanity for lower conductivity fog ageing test validating lower severity is more severe for polymer insulators.

FIG. 4. CAT SCRATCH AND SURFACE EROSION ON THE SURFACE OF THE INSULATOR AFTER LOW CONDUCTIVITY AGEING TEST

8. CONCLUSIONS

- Droplet size on the polymer material play important role on its performance under fog conditions. Fog produced at 7 kg/cm^2 gives lowest flashover voltage and higher surface conductivity.
- Tracking and erosion on polymeric material is more under lower severity pollution compared to higher severity pollution both under AC and DC voltages.
- Positive polarity DC voltage causes severe damages to polymer material compared to negative polarity since the arc moves closer to the surface of the material.
- The performance of silicone rubber and EPDM insulator material were good under AC voltages.
- The performance of the Silicone and EPDM polymeric material under DC negative polarity were good under all severity of pollution.
- The performance of Silicone Rubber and EPDM material were good at higher severity of pollution.

Slight degradation of the material was observed at lower severity of pollution on Silicone Rubber and EPDM insulator material under negative DC voltages.

- No tracking or erosion were observed on the material when subjected to accelerated ageing at negative polarity DC voltages of pollution. Severities studied.
- During sample material ageing erosion of material were seen under positive DC voltage on both Silicone and EPDM material at lower severity of pollution. These results were similar to those observed during tracking and erosion tests.
- No tracking or erosion on the weathersheds were seen both on Silicone Rubber and EPDM insulators under high conductivity ageing studies.
- Analytical studies on material before and after ageing test revealed that the higher severity pollution does not degrade the polymer material.
- Positive polarity DC is more severe under pollution ageing for the composite insulators for EPDM while Silicone rubber showed better performance.

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