Experience with Aging Tests for Testing of Non-Ceramic Insulators

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***Abstract* — Non-ceramic outdoor insulators are increasingly being used in both distribution and transmission lines. One of the major problems that is still facing polymer insulators is aging which leads either to tracking/erosion or to flashover under contaminated conditions at normal operating voltage. To study aging, different laboratory tests have been adapted. Salt-fog, tracking wheel and inclined plane tests are some examples of these tests. It is extremely important to have the required experience while conducting aging tests as easily misleading results can be obtained. This paper reviews and explores different aspects of both salt-fog and inclined-plane tracking and erosion of insulating materials tests. The following points are reviewed: fog/electrolyte conductivity, fog/electrolyte distribution, applied voltage and leakage current measurements.**

***Index Terms* — Outdoor non-ceramic insulators, aging, leakage current.**

I. INTRODUCTION

Aging, which leads either to tracking/erosion or to flashover under contaminated conditions at normal operating voltages, is still the main cause of registered failures for non-ceramic insulators. Consequently, it is extremely important to understand the aging mechanism of non-ceramic insulators as well as the factors affecting the aging performance. The best way to understand the aging of non-ceramic insulators is to watch their performance under real field conditions. However, one disadvantage of field monitoring is the time factor, as it requires long time for non-ceramic insulators to begin the aging process. For this reason, several accelerated aging tests have been developed to accelerate the aging process.

Aging tests consist of two key types of tests: aging tests for polymeric insulators and aging tests for polymeric materials. Salt-fog and rotating wheel tests are examples of both the first and second categories, and inclined plane tracking and erosion of insulating materials (IPT) test is an example of the second category only. Regardless of the aging test type, the main challenge to the industry is to correlate the natural aging process with the accelerated one. Also, understanding the aging process of each test is very important to correctly evaluate the tested insulator/material.

The ability of non-ceramic insulators to prevent the beginning of leakage current (hydrophobicity) and to resist the degradation process after the development of dry-band arcing (erosion resistance) is the two most important characteristics of non-ceramic insulators. So it is important to evaluate the performance of non-ceramic insulators based on these two characteristics using accelerated aging tests. In this article, a brief description about both IEC 61109 (salt-fog test) and IEC 60587 (IPT test) will be given with some emphasis about what can be measured by each test. Also, the practical difficulties using these two tests will be addressed with some proposed solutions.

II. AGING TEST

A. Salt-Fog Test:

The salt-fog test is considered to be one of the most popular aging tests for the following reasons [1]:

- It is easy to perform.
- It has low costs.
- It can be used to test both material samples and real insulators.
- It is a standardized test.

Both the IEC 61109 [2] and IEEE 1024 [3] are available as standard aging tests for non-ceramic insulators. Two different aging tests are defined in the IEC 61109 standard: a 1000 h salt-fog test and a 5000 h cycle test. Of these two tests, the 1000 h salt-fog test is preferred because it is simpler and shorter.

The basic principle of the salt-fog test is the generation of continuous discharges by exposing the energized insulator to salt water spray. A typical salt-fog chamber is demonstrated in Figure 1.

The main requirements for both the IEC 61109 and IEEE 1024 can be summarized as follows:

- Water flow rate: 0.4 ± 0.1 l/m^3 .h;
- Salinity: 10 ± 0.5 kg/m^3 (1.6 S/m);
- Duration: 1000 h;
- Maximum chamber volume: 10 m3;
- Specific creepage: 20 mm/kV;
- Test voltage: 14 to 20 kV;

• Maximum voltage drop: 5% for 250 mA;
• Current protection level: 1 A;
• Nozzle type; turbo spray or humidifier;
• Size of droplets: 5 to 10 μm.

The insulator is considered to pass the test if it meets the following criteria:

• The number of flashovers is not more than three over the current trip-outs for each specimen tested.
• The visual degradation does not show any tracking.
• The erosion does not reach the glass fibre core.
• The sheds are not punctured.

The heat, UV-radiation, and gases generated from the discharge activities influence the insulator performance in two ways:

• Due to the high salinity during the fog test, the dielectric strength of the insulator can be reduced. As a result, a flashover may occur even without any visible damage to the insulator surface. As such, the test is considered as a pollution test.
• Different types of insulator surface damages can occur during the test like tracking, erosion, cracks, and shed puncture. As such, the test is considered as an aging test.

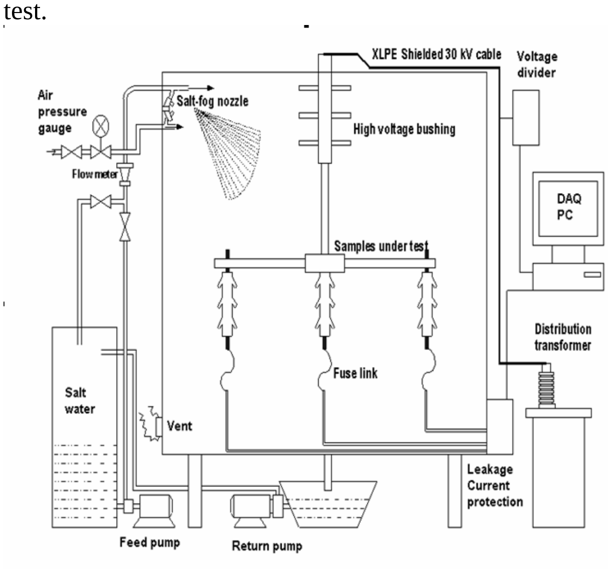


Fig. 1: Experimental Setup for Salt-Fog Test

B. Inclined-Plane Tracking and Erosion of Insulating Materials Test:

The Inclined Plane Tracking and Erosion of Insulating Materials (IPT) test is one of the most common testing methods for evaluating the tracking and erosion resistance of non-ceramic materials. It is recommended by both the IEC 60587 [4] and ASTM D 2303 [5] standards and considered to be a quick technique to rank different materials. Slabs of materials with the dimensions of 50 mm by 127 mm are subjected to high voltage (1 to 6 kV) while salty water is allowed to flow on the material surface. Two different test procedures are used in the IPT test. In the first one, the high voltage is applied in steps of 250 V. Each step lasts for one hour and the voltage is increased till the sample fails. The voltage, at which the material fails, is recorded. In the second test procedure, a constant voltage is applied until material fails. The time at which the material fails is recorded. A schematic showing the experimental setup for IPT test is depicted in Figure 2.

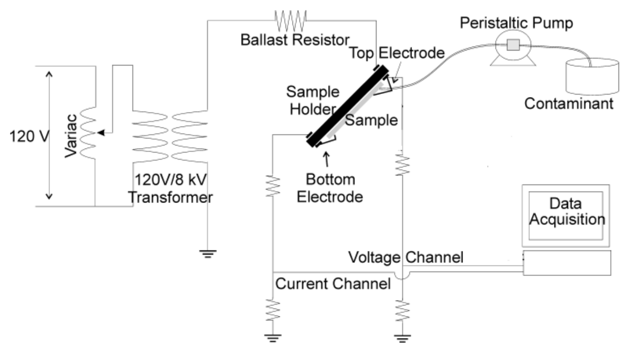


Fig. 2: Experimental Setup for IPT Test

III. RESULTS and DISCUSSION

A. Test Parameters

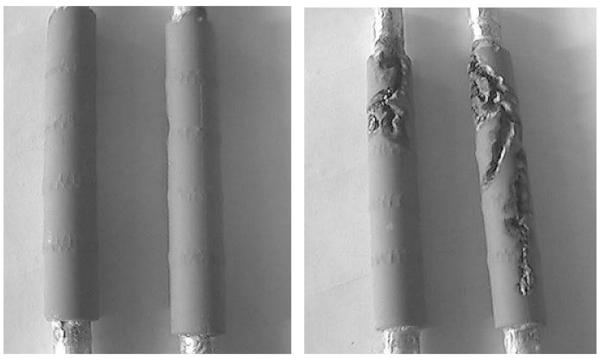
The effects of different test parameters on the accuracy of salt-fog and IPT tests has been investigated and summarized in the following subsections.

A.1) Water conductivity:

One main criticism to both IEC 61109 and IEEE 1024 is their requirement for highly conductive fog (1.6 S/m). As a result, both these tests behave more like a flashover test than an aging test [1]. This occurs because such high conductive fog can produce a large current that can cause flashover by bridging the whole insulator; as a result, no tracking or erosion can take place on the insulator surface. Tracking and erosion occur when dry-band arcing is close to the surface of the polymer insulator, which is obtained for the LC in the range of 15-50 mA (peak). Water conductivity in the range of 0.025 – 0.2 S/m can produce this range of LC [6]. Therefore, different salt-fog conductivity levels needed to be chosen such that the increase in the LC is due to the changes in the surface conditions, rather than by the low resistance offered by a highly conductive spray or fog.

Such concern is not applicable in IPT since the water conductivity used in the test is 0.2 S/m. Such relatively low conductivity will guarantee that the arcing will be on the insulator surface and no flashover is usually noticed.

A.2) Applied voltage:
The applied voltage is very critical to have the salt-fog test as an aging test or as a flashover test. Two different samples were tested at 6 and 9.5 kV. The degree of erosion on the tested samples surface at 6 kV is much more significant than the erosion on the surface of the samples tested at 9.5 kV as shown in Figure 3. At higher applied voltage (9.5 kV) the arcing was bridging the two electrodes and despite the measurement of higher current, little arcing was on the insulator surface. However, the arcing was on the insulator surface when the samples were tested at 6 kV and hence clear erosion was noticed.



(a) (b)

Fig. 3: Surface condition of tested samples in Salt-Fog test; (a) Tested at 9.5 kV, (b) tested at 6 kV.

The applied voltage during IPT test is between 1-6 kV with a suitable flow rate of the electrolyte according the voltage level. It has been noticed that at low voltage levels (1-1.5 kV) no significant erosion is usually noticed on silicone rubber based materials. On the other hand, at high voltages (5-6 kV) significant tested materials will usually suffer from severe tracking and erosion to the extend that it will be very hard to compare between different materials. Optimum values of applied voltages have been found to be between 2-3 kV.

A.3) Fog/electrolyte Distribution:
It is very important and challenging to have a uniform distribution for the salt fog inside the fog chamber. To solve this problem two solutions were investigated:

a) Rotation of the samples during the test so each sample will be subjected to the same amount of fog during the whole test. The major concern with this approach is that the level of leakage current measured during the test will be changing from one position to another and as a result it will be hard to tell if the change in the LC is due to the fog distribution or samples' aging. Typical Leakage current behaviour for a rotated sample every 40 hours is depicted in Figure 4.

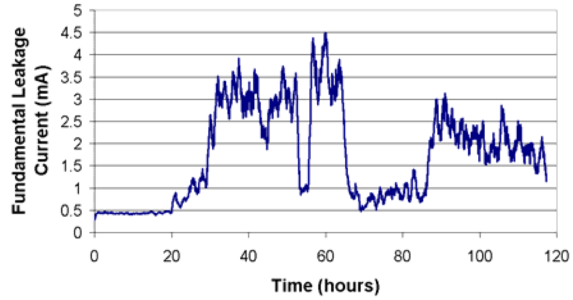


Fig. 4: Leakage current measurement for a sample rotated during a 120 hours salt-fog test.

b) Adjusting nozzle orientation, air pressure and water flow to have a uniform fog distribution during the test. To compare 2-3 different designs, at least three samples of each design is required and hence 6-9 positions with uniform for distribution need to be allocated inside the fog chamber. However, it is extremely difficult to have such number of positions inside the fog chamber that receives uniform fog distribution.

To overcome this difficulty, testing one design at a time, could be a solution to this problem, however, this approach is time consuming.

The flow of electrolyte is better controlled during IPT test. Before starting the test the flow of the electrolyte on the material samples should be continuous from the high voltage to the ground electrode. This goal can be achieved by destroying the surface hydrophobicity of the samples using special grade sand paper without destroying the insulating material itself.

B. Measured parameters:
Different parameters are measured during and after aging tests. The most common parameter that is usually measured during the aging tests is the Leakage Current (LC). After the aging tests several physiochemical properties are measured using different techniques like contact angle, scanning electron microscopy (SEM), atomic force microscopy (AFM), transmission electron microscopy (TEM) and Fourier Transform Infra-Red (FT-IR). In this section the focus will be on LC measurement.

Usually, the maximum peak of LC and the number of pulses have been measured during different aging tests for non-ceramic insulators. These measurements were carried out over various fog conductivity levels ranging from 2000 to 16000 μS/cm. Vazquez and Chavez discovered that the maximum peak with an applied field of 0.25 kV/cm was registered at the highest conductivity level; however, no correlation was found between the number of peaks of the LC and the damage on the insulator surface [7]. The cumulative number of LC pulses during multi-environment stress tests for two different materials have been counted while the insulators were stressed at 0.25 kV/cm [8]. Although both insulators passed the tests, no correlation was found between the cumulative counts of LC pulses and the surface conditions of the tested insulators. Liang et al. [9] counted the number of LC pulses for two different insulators stressed at 0.28 kV/cm in salt-fog test. Despite a large difference in the number of pulses counted, about eight times more than the other, no clear difference between the two insulators in terms of surface damage was found.

It has been reported that arcing is correlated with the harmonics in LC. Fernando and Gubanski conducted a detailed LC analysis during clean fog tests for non-ceramic insulators [10]. The measured LCs produced a deformed sinusoidal shape, although their levels were much lower than the level of LC that preceded flashover. These deformed waveforms contained a large number of third and fifth harmonic components, and their content increased with the applied voltage.

It can be concluded that although the peak values of LC have been used to study the aging mechanism, no correlation has been found between the LC peak values and the damage on the insulator's surface. Despite identifying the relation between the low frequency harmonic components and dry-band arcing, no attempt has been made to correlate the harmonics with the aging of non-ceramic insulators. Both the fundamental and low frequency component of leakage current has been measured during both salt-fog and IPT tests and correlated with aging in non-ceramic insulators.

It has been noticed that the fundamental component is not a good indication of aging during both IPT test. Three different samples of silicone rubber material filled with silica at 10, 30 and 50% by weight were tested in IPT test. The eroded volume of the three samples were measured and shown in Figure 4. It is evident from Figure 5 that as the percentage of filler increases, the erosion resistance improves.

However, it is evident from Figure 6-a that the fundamental component of leakage current does not show any difference between the tested samples regardless of the eroded volume. Also, the average value of fundamental component saturates around 6 mA. This could be attributed to the controlled flow of contaminant on the material surface in the IPT test, which results in a controlled surface resistance and hence constant LC.

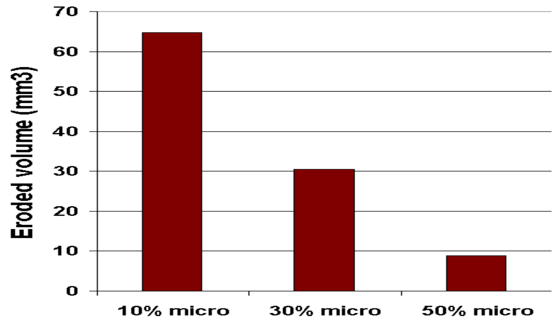
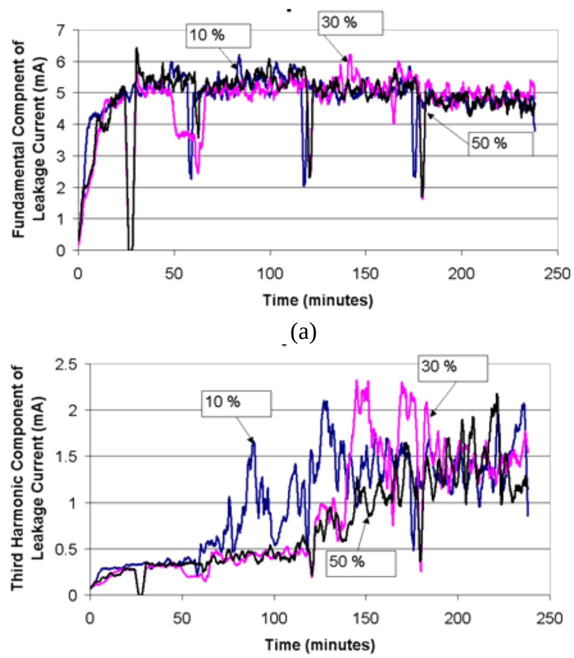


Fig. 5: Comparison between micro-size silica filled composites in terms of eroded volume.



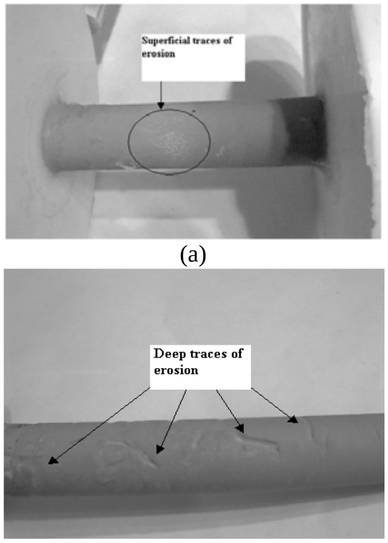
(a)

(b)

Fig 6: Fundamental component of leakage current during the IPT test.

On the other hand, the third harmonic component of the LC shows a better correlation with the eroded volume, Figure 6-b. This is because dry band arcing is well correlated to both surface damage and the third harmonic of the LC as previously discussed.

On the other hand, both LC fundamental and harmonics components are well correlated with aging during salt-fog test. A correlation was noticed between the average value of LC harmonic components, and two different forms of degradation. These two forms of degradation are defined as type-1 and type-2 based on the level of erosion on the insulator surface as depicted in Figure 7.



(b)

Fig. 7: Damage observed on insulator surfaces: (a) superficial traces of erosion of an insulator, type-1 degradation; and (b) deep traces of erosion of an insulator, type-2 degradation

Merely the average level of both the fundamental and third harmonic components of LC is enough to distinguish between type-1 and type-2 degradation as depicted in Figure 8 where the average value of LC fundamental and third harmonic components were plotted for several insulators suffered from type-1 and type-2 degradation. It is evident from Figure 8 that there exist a threshold value after which there is a transfer from type-1 degradation to type-2 which appears to be around 1 mA for the fundamental component and 0.5 mA for the third harmonic component.

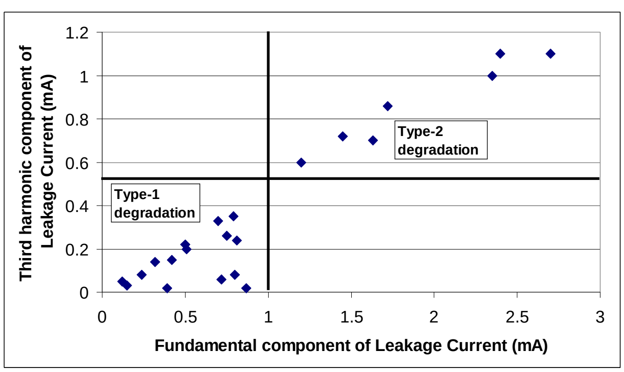


Fig. 8: Fundamental component of leakage current vs. third harmonic component of leakage current

IV. CONCLUSION

From the presented results, the following conclusions can be made:

- The following factors affect the results of both the salt-fog and IPT tests:
    - o Fog conductivity (only salt-fog).
    - o Fog distribution (only salt-fog).
    - o Applied voltage.
- Leakage current harmonics is a better parameter to measure the aging performance of non-ceramic insulators than peak values during aging tests.

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