Different Characteristics of Artificially Polluted High Voltage Composite Insulators

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Abstract: Characteristics of leakage current, electrical field and surface resistivity of artificially polluted high voltage composite insulators for different composite materials in their structure, equivalent salt deposit density, electrolyte flow-rate and hydrophobicity are discussed, analyzed and presented in this paper. All these parameters are compared with conventional non composite insulators, too. Relativity of leakage current, applied electric field, electrolyte flow-rate and electrolyte conductivity to the environmental conditions are presented by the results of artificial pollution tests. Waveform, frequency spectrum and magnitude-phase diagram of leakage current of polluted insulators with different pollution densities and durations and applied voltages are presented. Surface resistivity of different insulators is compared regarding different kinds and densities of pollution. Electrical field causing flashover for polluted insulators as a function of the insulators' surface hydrophobicity and salt deposit density is also presented. Through the study, investigating the life time of being used insulators is achieved by measuring their leakage current, salt deposit density and surface resistivity and comparing with the test results.

Key Words: Composite Insulator, Surface Resistivity, Leakage Current, Hydrophobicity, Pollution, Equivalent Salt Deposit Density.

INTRODUCTION

The use of nonceramic or composite insulators for outdoor high voltage insulation which started in 1960s, is increasing greatly especially for polluted areas [1-4]. Different tests are done for proving the electrical and mechanical properties of these insulators in various environmental conditions by almost all of the manufacturers and research laboratories, each considering and pointing out some special and partial differences between composite and non composite insulators or composite insulators with different materials in their structure [5-7]. So gathering and analyzing the results of all these tests as a paper for studying the whole characteristics of composite insulators in comparison with porcelain or glass insulators is done in this paper.

This paper is a review of about forty papers since 1990s each reporting the results of artificial pollution tests for insulators, which have been all gathered and mentioned as a routine paper. Studying the characteristics of leakage current (LC) of artificially polluted composite and non composite insulators as their waveform, frequency spectrum and Bode diagram with various densities and durations of pollution and the applied voltage are presented. Also their electrical field and surface resistivity (SR) for different materials in their structure, equivalent salt deposit density (ESDD), electrolyte flow-rate and hydrophobicity characteristic (HC) are discussed and analyzed. The relativity of LC, applied electric field, electrolyte flow-rate and electrolyte conductivity to the environmental conditions are also presented. SR of different insulators is compared regarding different kinds and densities of pollution. Electrical field causing flashover for polluted insulators as a function of the insulators' surface HC and ESDD is presented when pollution causing short circuit on the surface. Through the whole study, an investigating method is achieved for determining the life time of HV composite insulators already in use by measuring their LC, ESDD and SR and comparing them with the test results.

SURFACE LEAKAGE CURRENT

Surface leakage current (I) of insulators is dependent on several parameters such as the applied electric field (E), electrolyte flow-rate (q), electrolyte conductivity (σ), environmental humidity (h) and environmental pressure (p), so the relationship is presented as follow:

$$I=f(E,q,\sigma,p,h) \tag{1}$$

In [8,9] it is proved that the relativity of surface LC and applied electric filed to the other parameters are as follow:

$$I=f_1(q,\sigma)=A.(q^3\sigma^{-2}) \tag{2}$$
$$E=f_2(q,\sigma)=B.(q^{-1}\sigma^{-2})^{0.25}+E_0 \tag{3}$$

Results of the tests prove that the LC levels of similarly polluted composite insulators for several times are the same. The waveforms of composite insulators are disturbed because of non linearity characteristics of insulator surface resistance, which becomes stronger by increasing the applied voltage and for short time laps of pollution duration while the waveforms are almost sinusoidal for porcelains. The waveforms of three porcelain, EPDM and silicone rubber insulators after a one hour, one day and one week time lapse of pollution are simulated through the test results in Fig. 1.

The frequency domain studies of the surface LC of composite insulators prove an increase in the first, fifth and seventh harmonics of the LC and the disturbance of the waveforms become stronger. The results of the tests also prove that for a specific applied voltage, the pollution duration does not affect the level of the LC and its harmonics but the level of harmonics in composite insulators increases with an increase in the applied voltage [10]. This is shown in Fig. 2 for a composite insulator with constant pollution duration and different voltages.

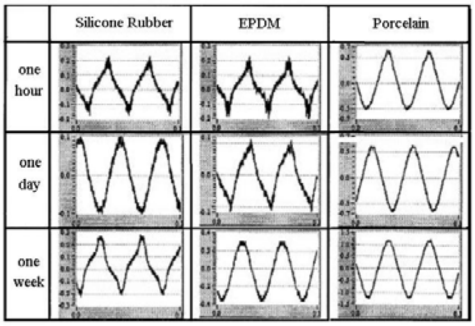

Fig. 1. LC waveform of three different insulators for different time lapses after contamination for applied constant 5 kV

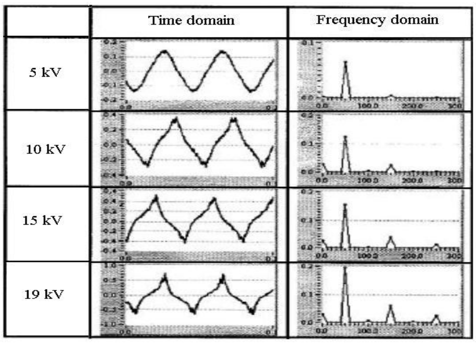

Fig. 2. LC waveforms of silicone rubber insulator in time and frequency domains one day lapse after contamination for different applied voltages

The LC of porcelain insulators decreases with voltage increase because of their surface drying but for voltages higher than a limit, the LC saturates for a constant level. The LC disturbed characteristic is probably because of reduction in HC of the tested insulators surface. The LC can affect the pollution drying on the surface of insulators to be non uniformed under strong electrical fields and though causing dry-band in narrowest parts of the surface in which the density of LC is high. In the case of presence of dry-bands on the surface of porcelain insulators, LC level can differ from one point to the other points around the surface of insulator because of the difference in SR. The changes in LC level and production of dry-bands result in dynamic changes of electrical filed density around the insulator.

LC level also depends on the density of pollution and electrolyte flow-rate on the surface. Fig. 3 shows the relation between LC and electrolyte flow-rate and conductivity, which proves LC level increases almost linearly with an increase in electrolyte flow-rate or conductivity. Fig. 4 shows the relation between electrolyte flow-rate and conductivity for different LC levels and proves for a constant electrolyte flow-rate, LC level increases with an increase in electrolyte conductivity and for a constant electrolyte conductivity, LC level increases with an increase in electrolyte flow-rate and also, LC level increases for higher electrolyte flow-rate and conductivity [8,9]. It is also shown for a constant LC on the insulator surface, with an increase in electrolyte conductivity, electrolyte flow-rate level decreases and with an increase in electrolyte flow-rate, electrolyte conductivity level decreases.

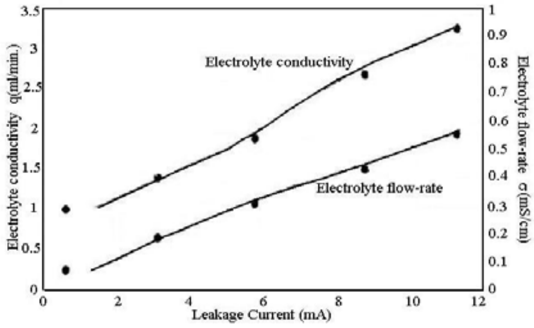

Fig. 3. LC relativity to electrolyte flow-rate and conductivity

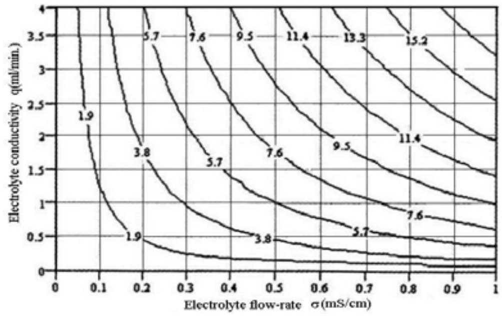

Fig. 4: Electrolyte flow-rate and conductivity relations for different LC levels

The electrical field of the insulator decreases with an increase in electrolyte flow-rate and conductivity so higher electrical field of insulator is shown for lower electrolyte flow-rate and conductivity on the surface see Fig. 5.

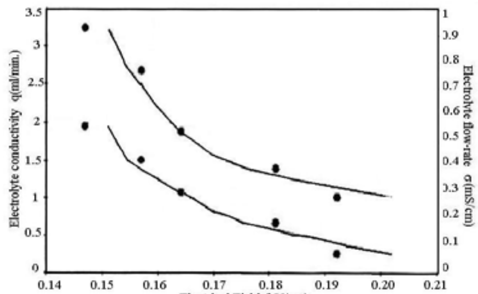

Fig. 5: Electrical field relativity to electrolyte flow-rate and conductivity

In a specific test [11], the magnitude and phase of the LC of glass and silicone rubber insulators are measured for artificial spray wetting. The results of the test show that LC was capacitive at the beginning but with pollution continue, LC magnitude increases but its phase decreases until the glass and silicone rubber LC changes completely to resistive respectively about 15 and 30 minutes after the test start. This shows that the surface of non composite insulators becomes wet easier and faster than composites. Although SR of both of them decreases with pollution time, but still surface resistivity of composite insulators are higher than non composites. The Bode diagram of the tests is shown in Fig. 6.

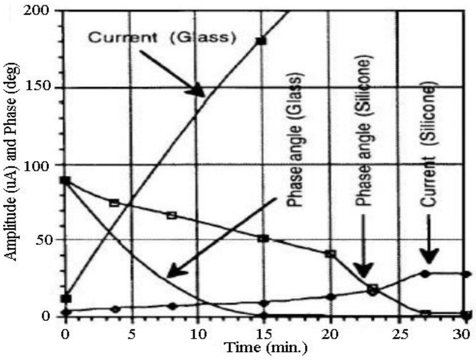

Fig. 6. Bode diagram of LC of two different insulators

SURFACE RESISTIVITY

ESDD is a parameter for determination of surface pollution of insulators. Polluted environments cause contamination of insulators surface that results in insulator aging. Aging is a complicated process which results in increase of LC level, flashover in wet conditions and mechanical break-down of insulators. Because of the relativity of LC increase to aging and SR can be measured according to characteristics of aging or ESDD on the insulators surface. SR measurement test results are different for various tests because of non uniform contamination on the surface. The results of these test prove that SR of composite insulators with contaminated surfaces are much less than their clean surface but still it is much higher in comparison with non composite insulators. Fig. 7a shows SR of three silicon rubber, EPDM and porcelain insulators for the same polluted conditions for one hour of artificial spray wetting. SR decrease is obvious at the beginning of the test but it is shown that silicone rubber insulators are much better than other composite and non composite insulators for polluted areas. The results of SR measurement of artificial fog test for silicone rubber and EPDM composite insulators are shown in Fig. 7b, proving the reduction of SR for both of them but still showing the better characteristics of silicone rubber insulators [12].

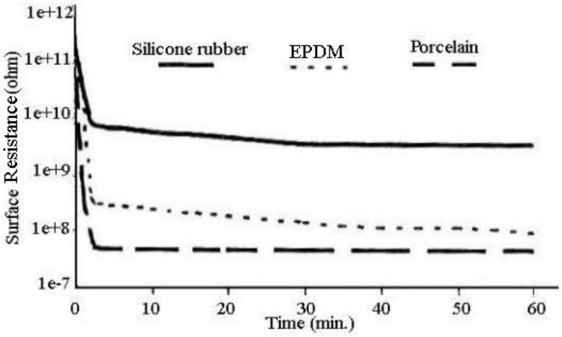

Fig. 7a. SR measurement of three different insulators for spray wetting test

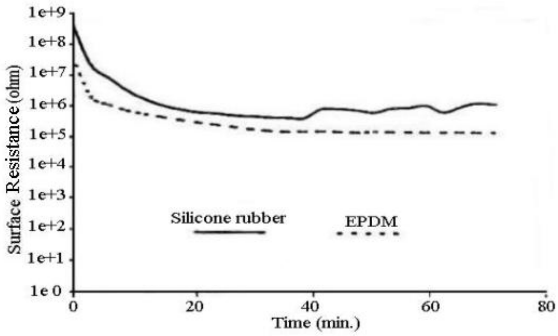

Fig. 7b. SR measurement of two different insulators for fog wetting test

Surface resistivities of silicone rubber composite insulators for different ESDD are almost the same after a long period of contamination but it is completely different at the beginning of the pollution test, shown in Fig. 8.

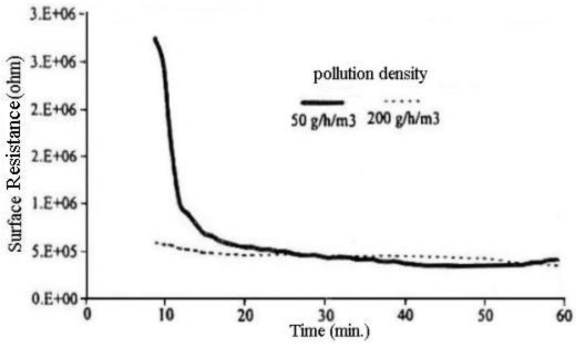

Fig. 8. SR measurement of two different insulators for fog wetting test with different pollution densities

ELECTRICAL FILED

One of the tests on artificially polluted insulators is measuring the electrical field causing flashover for different applied voltages and studying the characteristics of insulators under such conditions. The test results prove that composite insulators are stronger against flashovers and the mechanical strength is still enough but flashovers can lead to mechanical break-down of non composite insulators.

The surface of composite insulators looses its HC after being contaminated in accordance with the pollution density. HC of silicone rubber insulators is shown in Fig. 9 for different pollution densities. It is proved that for lower values of ESDD, HC level can increase and retransfer back to its clean time value as fast as about 4 days but for higher ESDD values, HC level cannot retransfer to its clean time value even after 7 days of pollution [13].

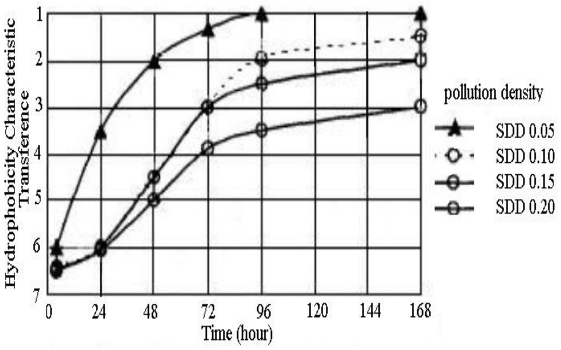

Fig. 9. HC transference of polluted silicone rubber insulators for different pollution densities vs. time lapse after contamination

The test results show that with pollution density increase, lower electrical fields can cause flashover and also, with an increase in HC, required electrical filed causing flashover increases, too. This is shown in Fig. 10 as the results of required electrical field for flashover according to the HC transference and ESDD. Transference of HC after the pollution continues slowly with time, i.e. the slope of electrical field change immediately after the pollution from HC7 to HC6 is higher than later times from HC2 to HC1 that the electrical filed value saturates to a constant value. It is also shown that at the pollution time, lower values of electrical field can cause flashover than a long time after pollution that higher values are required for flashover.

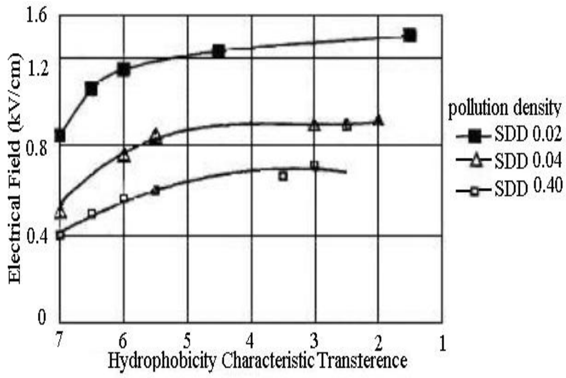

Fig. 10. Electrical filed causing flashover for different pollution densities vs. HC levels

In Fig. 11, the required electrical filed for flashover is shown according to ESDD changes with different HC level curves. It is shown that for lower pollution densities, higher electrical field values are required for flashover. And also, for a constant pollution density, with an increase in HC level, higher electrical field values can cause flashover.

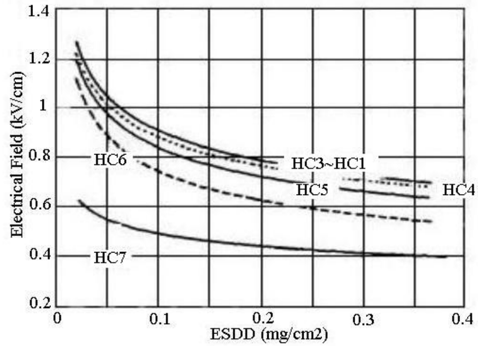

Fig. 11. Electrical filed causing flashover for different ESDD on the surface for different HC levels

The laboratory tests indicate that silicone rubber composite insulators still possess excellent electrical performance under clean fog conditions [14]; therefore, the flashover voltage still has low chance to happen in these insulators a long time after being in service, even though their HC is less than new ones. Fig. 12 shows the electrical field variations of a composite insulator in a polluted area from the higher curvature to the lower one.

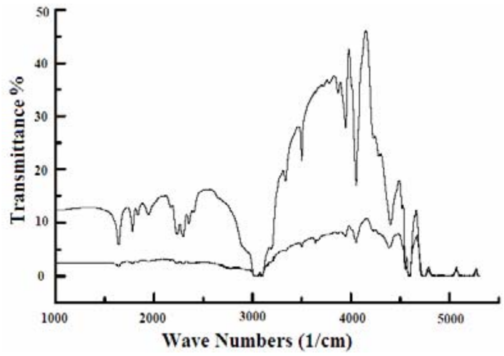

Fig. 12. Electrical field variation around the composite insulator in a polluted area.

The electrical field of composite insulators also depends on shed diameter and the space between the sheds. The results of tests for electric field causing flashover for composite insulators according to the equivalent diameter of the insulator sheds are shown in Fig. 13. It is shown that the required electric field causing flashover in composite insulators increases with a decrease in equivalent diameter of sheds but still the electric field causing flashover for higher values of ESDD is less than the lower ESDD values.

The pollution in the surface of the insulators can lead to short circuit between the high voltage and earth electrodes of the insulator [15,16]. The electrical field strength near the high voltage electrode is the highest and for the middle ones is the lowest as shown in Fig. 14a. But pollutions can cause this field distribution to be modified as shown in Fig 14b.

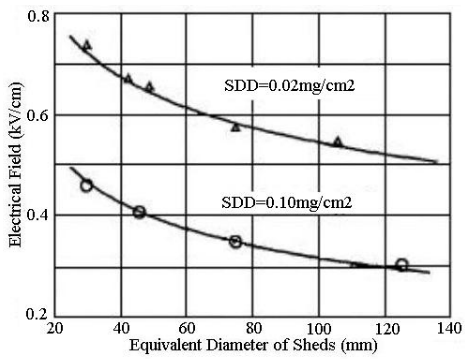

Fig. 13. Electrical filed causing flashover for different pollution densities vs. shed diameters of composite insulator

When the moisture of pollutions make a conductive path for the leakage current to continue on the surface of the insulator from high voltage to earth electrode; one, two or more sheds are short circuited and the electrical filed distribution is modified and the most electrical strength is on the short circuited sheds as shown in Fig 15 for one and two sheds being short circuited. It is also proved that the electrical filed level on the short circuited sheds increases with an increase in the number of short circuited sheds. Through the tests, it is also proved that modification is more affected by spray wetting than fog.

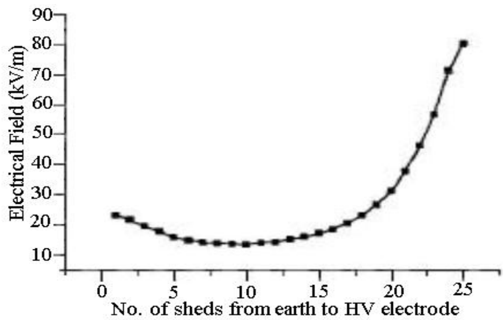

Fig. 14a. Electrical field distribution of clean insulator

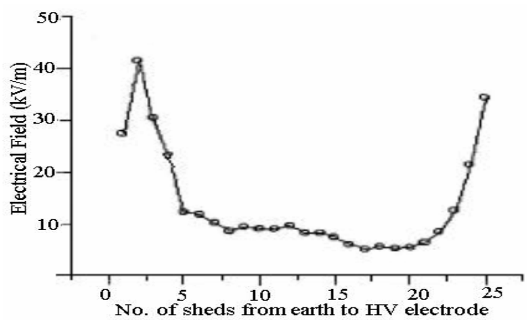

Fig. 14b. Electrical field distribution of contaminated insulator

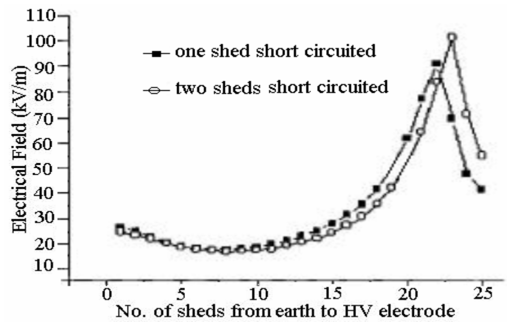

Fig. 15. Electrical field distribution of contaminated insulator with one or two sheds short circuited

CONCLUSION

In this paper, characteristics of LC, electrical field and SR of artificially polluted high voltage composite insulators were presented for different ESDD level, electrolyte flow-rate and hydrophobicity of the insulator. LC and electrical field relativity to electrolyte flow-rate and conductivity were presented. LC waveforms in time and frequency domains for different pollution densities, time laps after pollution and applied voltages were studied. SR of different insulators for different kinds and densities of pollution and electrical field causing flashover for polluted insulators as a function of the insulators' surface HC and ESDD were discussed. Through the study, investigating the life time of being used insulators can be achieved by measuring their LC, ESDD and SR and comparing with the test results.

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