NON LINEAR BEHAVIOR OF LEAKAGE CURRENT ON SILICONE RUBBER HIGH VOLTAGE POST INSULATORS

K. Siderakis(1), D. Agoris(1), E. Pyrgioti(1), E. Thalassinakis(2), J. Stefanakis(2)

(1) High Voltage Laboratory University of Patras
(2) Public Power Corporation of Greece

ABSTRACT

Leakage current measurements can provide plenty of information regarding the surface activity, present due to pollution, in the case of Outdoor Insulation. The advantage of the method is that it can be applied simultaneously for various insulator designs and housing materials. Continuous field measurements are possible, providing the appropriate equipment.
In this paper leakage current measurements on SIR High Voltage Insulators are presented. The measurements took place in the field, at a Substation with intense pollution problems, by a specially designed for this purpose, data acquisition system. The acquired waveforms of leakage current on the SIR insulators are compared to the corresponding waveforms in the case of porcelain insulators. Additionally a Frequency Analysis was performed in order to trace the characteristics of the leakage current in each case. Finally a correlation with the surface mechanisms that result to the recorded leakage current is done.

1. INTRODUCTION

The performance of outdoor insulation is correlated to the interaction of the environment with the material surface. Flashovers are frequent in the case of an insufficient insulation design or due to an intense environmental action (1-3). Many methods have been applied, in order to prevent outages due to pollution. However, the stochastic development of the phenomenon complicates the maintenance procedure and more efficient methods are necessary, in order to achieve a fault free system performance.
Composite materials and especially Silicone Rubber can be used in order to improve the performance of outdoor insulation (4-5). The principal advantage in this case is hydrophobicity, which can provide a wet free surface and thus limited activity (6). However, periods of hydrophobicity loss can be observed due to the influence of the environment and consequently surface activity is due to appear. In this case, migration mechanisms that can impart hydrophobicity to the contaminants layer, (hydrophobicity recovery) determine the overall performance (6-9). It is important to notice that in the case of SIR, the cleaning mechanisms are not as efficient as they are in the case of ceramic materials (10), due to the silicone oil that is found on the surface. As a result larger amounts of contaminants can be found on the surface of a composite insulator.
Furthermore, even in the case of a hydrophobic material, there are periods when wetting of the surface is possible and surface activity can be observed. These periods last in average about 8h to 12h (10), depending on the material condition and the influence of the aging mechanisms (8,9). During these periods, a flashover is probable to occur, since wetting is possible and an amount of contaminants is found on the surface.
Leakage current contains plenty of information, regarding the surface performance and the corresponding electrical activity. Therefore, it can be applied in order to monitor the performance of Outdoor Insulation, including composite materials and Silicone Rubber.
In this paper, leakage current measurements on 150kV SIR Post Insulators are presented analyzed and compared to corresponding measurements on 150kV Porcelain Insulators. The non linear characteristics of the waveforms are evaluated and a correlation with the surface mechanisms responsible is performed. Figure 1 is a photograph of the SIR Insulators under study.

Figure 1 The SIR insulators under study

2. THE MEASUREMENTS SETUP

The insulators monitored are installed in a 150kV Substation, of the Transmission System of Crete, a Greek Island in the Mediterranean. Due to the coastal development of the island, the Transmission System is mainly located near the coast. Consequently, the sea influence is the principal cause for flashovers. It is worth mentioning that since 1969, when the first Transmission Line was energized (at 66kV in the beginning), 43% of the reported power outages are ascribed to pollution.

The selected measurements site is located very close to the coast, in a distance less than 200m. The leakage current measurements are performed by a specially designed data acquisition system, capable to monitor continuously and store the activity data. The measurement is a four stages process starting from the collection of LC until storage, as it can be seen in figure 2.

The collection is possible by a conductive ring installed at the bottom side of the insulator, which is then connected though the sensor to earth. It must be noted that the resistance of the path that is formed from the ring to earth, must be remarkably grater than the resistance of the path through the sensor, in order to force the current to flow to the sensor. This is possible by the appropriate ring installation.

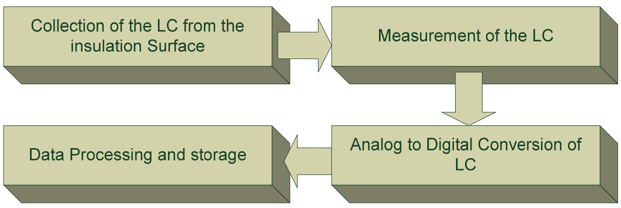

Figure 2 The four stages process in the measurement of LC

For the measurement of the current, many different solutions can be found in the literature. In each case, it is necessary to provide easy installation and sufficient bandwidth. The most common solutions are either the measurement of the voltage across a resistor (3,5) or the use of a Hall Effect sensor. In this case the second solution was selected, since it provides the easiest installation, the necessary bandwidth and additionally the necessary isolation of the electronic system from the high voltage apparatus. The measurement setup is shown in figure 3.

Electromagnetic immunity is also a necessary feature of the measurement system in order to avoid electromagnetic interference. It must be noticed that the operation environment is remarkably EMI polluted.

Finally the study in field conditions requires continuous monitoring for long periods. Thus, sufficient computational power is necessary, for processing the large amount of data and store the important information. In table 1 the data acquisition features of the system are summarized.

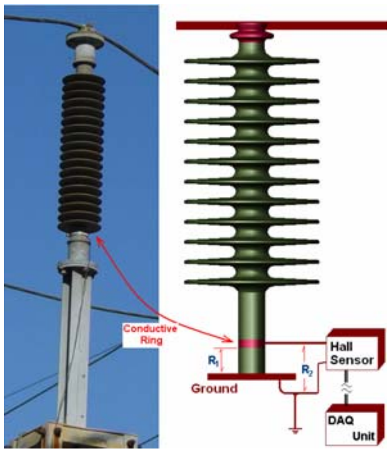

Figure 3 The measurement setup

Table 1: DAQ Features

Resolution	12bit
Accuracy	0.5% of full Scale (25°C)
Sampling Rate	2kHz Continuously
Sensor Isolation	6kV

3. LC ON PORCELAIN INSULATORS

In the case of porcelain insulators, the development of the surface activity may be considered as a three stages procedure.

During the first stage, the observed leakage current is the result of the voltage application across a conductive pollution film. This film is formed due to the accumulation of contaminants and usually requires wetting, in order to become conductive. Further, it can be considered as a surface resistance and consequently the observed leakage current is resistive. In figure 4 a typical LC waveform during the drying period is shown.It can be seen that the current is in phase with voltage (resistive) and sinusoidal. The FFT analysis of the waveform (figure 5) verifies the dominant 50Hz fundamental but also reveals the existence of a very small 150Hz component. The last indicates the presence of weak (but present) non linear components in the current path. This can be seen also in the I-V characteristics of figure 6. Consequently the LC waveform of figure 4 may be considered as the transition from stage 1 to stage 2.

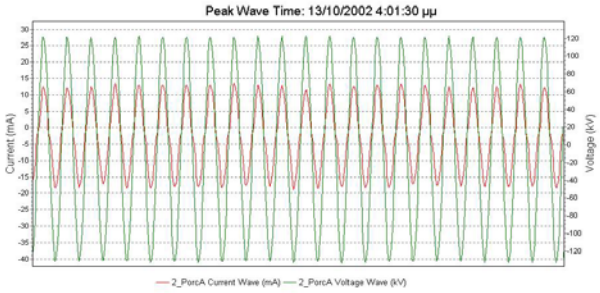

Figure 4. LC at the drying stage

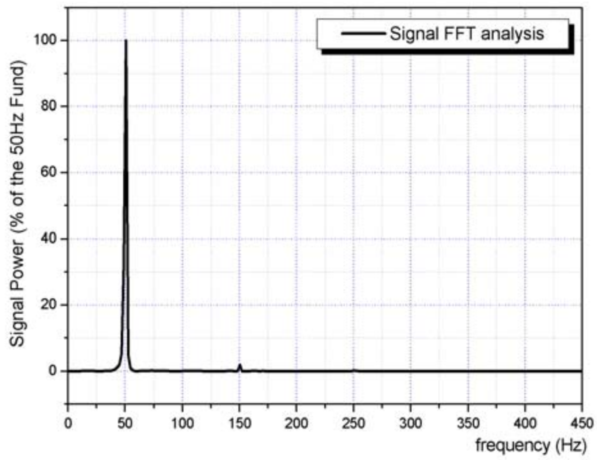

Figure 5 FFT Analysis of the LC in fig. 4

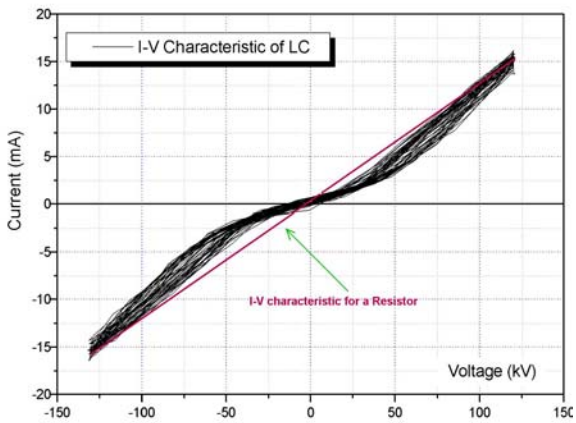

Figure 6 I-V Characteristic for the LC in figure 4

The leakage current during stage 1, although it is small, it can support the drying of areas on the insulation surface, where the current density is increased. These areas obtain higher values of resistance, due to the evaporation of humidity. As a result the voltage distribution is altered, with the higher stress located across these areas (dry bands). Due to the increased voltage stress, arcing takes place (dry band arcing) and under favorable conditions, this activity may expand and lead to a flashover. Figure 7 is a typical waveform during dry band arcing. In comparison to the drying stage, a significant 150Hz harmonic can be traced (figure 8) in the leakage current. The non linearity is due to the participation of an arc in the current path. The hysterisis phenomena included in the arc nature (12) can be seen in the I-V characteristic (figure 9).

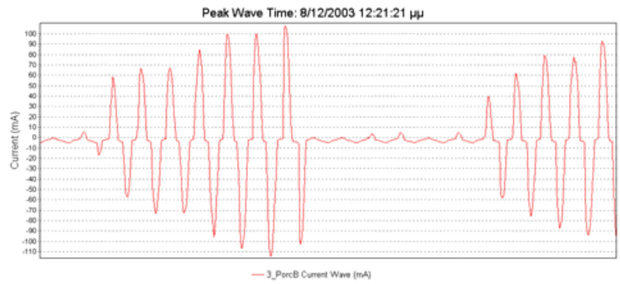

Figure 7 LC during dry band activity

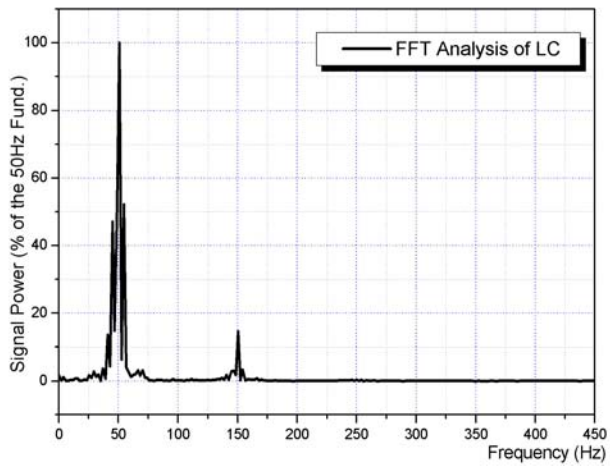

Figure 8 FFT Analysis of the LC in fig. 7

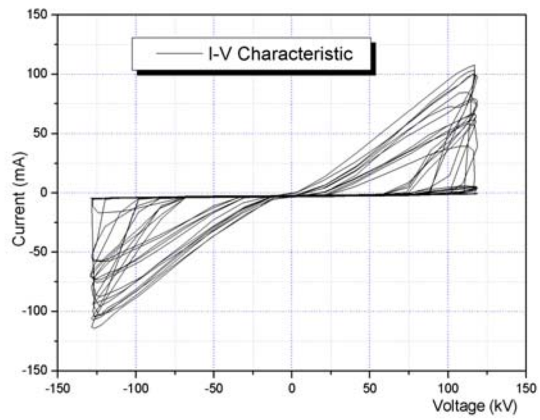

Figure 9 I-V Characteristic for the LC in figure 7

4. LC ON SILICONE RUBBER INSULATORS

In the case of Silicone Rubber, surface hydrophobicity aims to suspend the formation of the conductive surface film, by forcing water to form droplets on the insulation surface. In this case, surface activity, in the form of dry band arcing is suppressed. However the presence of water droplets alters the initial Electrical field distribution and discharges between them can take place. It is worth mentioning that in the literature flashover incidents due to the activity of the water droplets can be found (10). On the other hand, as mentioned before, hydrophobicity loss is also possible to take place. In this case surface activity, similar to the observed on the porcelain insulators can take place.

Usually, in field conditions both hydrophobic and hydrophilic areas can be observed. Thus in the leakage current waveforms both droplet discharges and dry bands can be observed. Figure 10 is the leakage current waveform on a composite insulator at an initial stage of activity. As it can be seen it is composed by a small 50Hz current and a number of oscillations, attributed to surface droplet discharges. Figure 11 is the FFT spectrum of the waveform in figure 10.

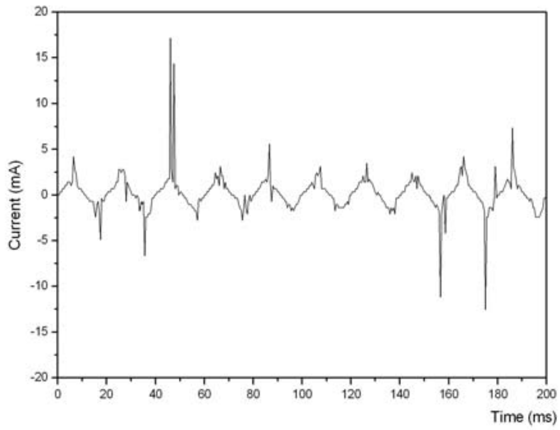

Figure 10 LC during dry band activity and water droplets corona in the case of SIR Insulators

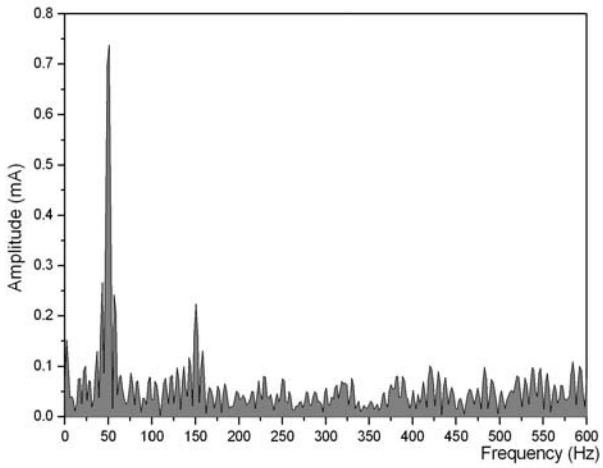

Figure 11 FFT Analysis of the LC in fig. 10

Figure 12 is a LC waveform observed on the same insulator during dry band arcing. Figure 13 is the FFT spectrum of the LC waveform shown in figure 12 and figure 14 is the I-V characteristic.

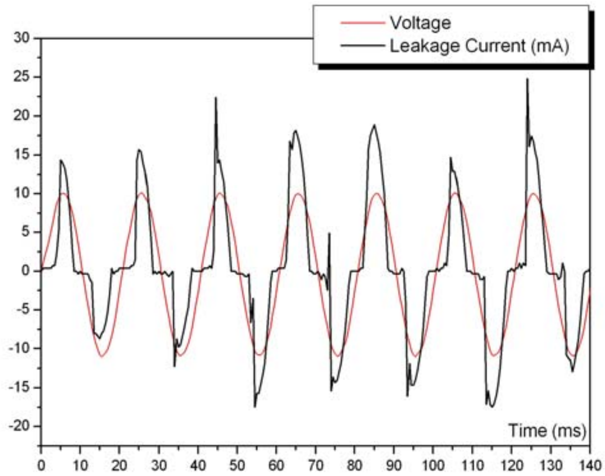

Figure 12 LC during dry band activity in the case of SIR Insulators

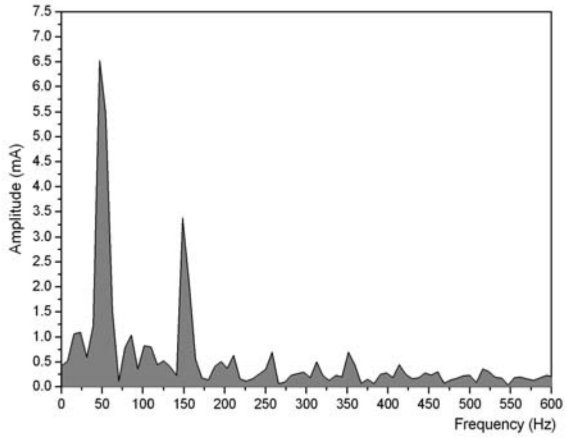

Figure 13 FFT Analysis of the LC in fig. 12

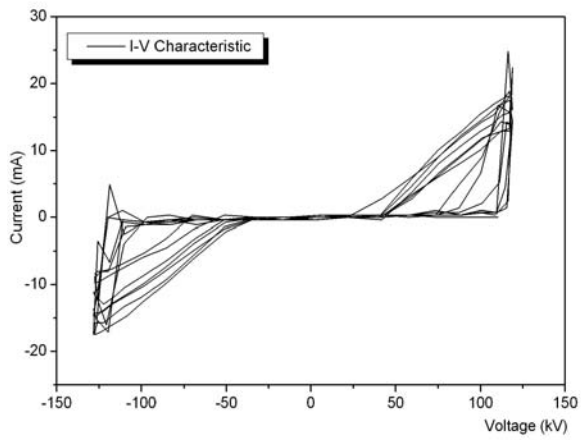

Figure 14 I-V Characteristic for the LC in figure 12

5. DISCUSSION

In the case of the porcelain insulators, leakage current becomes non linear, when dry bands are formed and arcing takes place. The presence of the arc in the current path is indicated from the hysteresis behavior of the I-V characteristic. This behavior is observed since the conduction of current, when a dry band is formed, requires the breakdown of the air surrounding the band (figure 15).

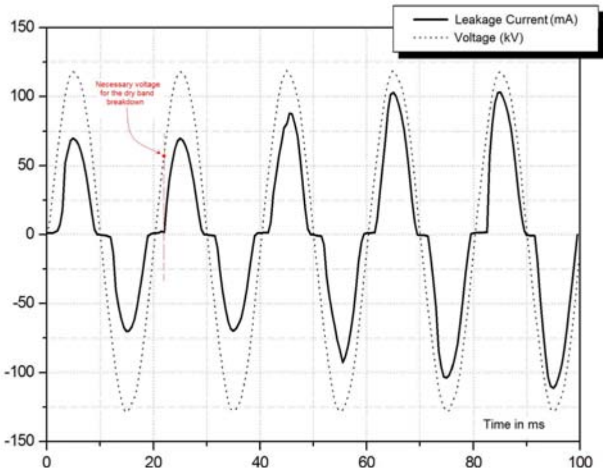

Figure 15 Influence of the dry band to the LC waveform in the case of porcelain insulators

The same behavior can be observed on SIR insulators during a period of hydrophobicity loss. There is a dominant 50Hz component and an enhanced 150Hz harmonic as it can be seen from the FFT analysis. A voltage threshold is observed as it can be seen in figure 14, such as in the case of porcelain.

In addition to the dry band activity the comparison of the LC waveforms indicates the existence of additional mechanisms in the case of SIR. As it can be seen in figures 10 and 12, a number of current peaks is superimposed on the leakage current. These peaks correspond to a sudden and short in duration increase of the surface conductivity. Most of them take place at the current peak, but there are also some at lower values.

The additional feature of the SIR surface is the hydrophobic behavior. Although hydrophobicity is lost during the above waveforms, there are areas on the surface still hydrophobic. In these areas droplets are formed and discharges between them can take place, resulting to an increase of conductivity.

This mechanism stands for the discharges that appear at the peak of the 50Hz fundamental. At that time the applied voltage is also at the highest value and thus the electric field is strong enough for the breakdown.

However there are peaks that take place at lower values, near zero, where the above mechanism cannot be applied. In this case the influence of the wetting mechanism and the insulator geometry must be taken into account. The LC waveform of figure 12 was observed during rain. As it can be seen in figures 1 and 3, the sheds of this insulator are of the same diameter. Consequently a water drip is possible to bridge two or more sheds, resulting to a discharge that can increase the surface conductivity.

6. CONCLUSION

Leakage current measurements can be used in order to monitor, compare and evaluate the pollution performance of insulators, constructed by different housing materials. Field measurements can provide plenty of information, regarding the development of the phenomenon in real conditions. In this case the LC on three 150kV SIR Post insulators was monitored by an on-line measuring system and the non linear characteristics were compared with field measurements on 150kV porcelain insulators.

From the measurements it can be concluded that during a hydrophobicity loss period, phenomena similar to ceramic insulators take place. Leakage current is non linear and a 150Hz component is present. However due to the existence of hydrophobic areas a number of current peaks is also observed and can be attributed to the discharges that can take place between droplets. Additionally a possible influence of the insulator geometry is suggested, in the case of peaks that cannot be assigned to water droplet discharges.

REFERENCES

1. CIGRE, WG33-04, Taskforce 01, 1998, “A Review of current knowledge: Polluted Insulators”
2. Looms J.S.T., “Insulators for High Voltage”, IEE Power Engineering, Series 7
3. Sherif. E.M., 1987, “Performance and aging of HVAC and HVDC overhead line insulators”, Techn. Report No 169, Dept. of Electric Power Engineering, Chalmers University of Technology, Goteborg.
4. Hackam R., 1999, IEEE Transactions on DEIS, No. 5, Vol 6, 557-585
5. Sorqvist T., 1998, “Polymeric Outdoor Insulators – A long term study”, PhD Thesis, Dept. of Electric Power Engineering, Chalmers University of Technology, Goteborg
6. Kim J., Chaudhury M. K., Owen M. J., 1999, IEEE Transactions on DEIS, No. 5, Vol 6, 695-702

7. Hillborg H., Gedde U.W., 1999, IEEE Transactions on DEIS, No. 5, Vol 6, 703-717
8. Reynders J.P., Jandrell I.R., Reynders S. M., 1999, IEEE Transactions on DEIS, No. 5, Vol 6, 620-631
9. Yoshimura N., Kumagai S., Nishimura S.,1999, IEEE Transactions on DEIS, No. 5, Vol 6, 632-650
10. Karady G.G., 1999, IEEE Transactions on DEIS, No. 5, Vol 6, 718-723
11. Fernado M.A.R.M., Gubanski S.M., 1999, IEEE Transactions on DEIS, No. 5, Vol 6, 688-694
12. Hoyaux M. F., 1968, “Arc Physics”, Applied Physics and Engineering, Springer Verlag