Investigation of the dry band activity on High Voltage Porcelain insulators based on field leakage current measurements

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Abstract : In this paper the development of surface activity on porcelain high voltage insulators is investigated. Three 150kV porcelain post are monitored for a period that has exceed four years, by a specially designed data acquisition system, capable of continuous monitoring the surface activity. The insulators are installed at a High Voltage Substation, with intense pollution activity, located in a distance of less than 500m from the sea coast, in Greece. Based on these measurements, the characteristics of the recorded waveforms are investigated and correlated to phenomena present on the surface, regarding both the wet part (contaminants film) and the gas conductivity.

Key Words : Outdoor Insulation, porcelain, dry bands, leakage current, field measurements

INTRODUCTION

The performance and lifetime of an insulation system are affected by the service conditions observed. In the case of outdoor applications, the surrounding environment has a crucial role to play, since insulators are exposed to the influence of various ambient parameters. Furthermore there are many degradation mechanisms, originated from the environment and capable of reducing the insulation performance.

Pollution of high voltage insulators is one of the mechanisms, included in the environmental influence [1-3]. In this case the performance degradation occurs due to the formation of a conductive film, which covers the insulator surface and permits the flow of current. Although small (less than 1A) this current is capable to impose the voltage redistribution along the creepage distance and conclude to a flashover under the nominal voltage stress. Such flashovers are often in many transmission networks worldwide, especially when ceramic insulators are used, resulting to long duration power outages and additional financial cost for the corresponding utilities [4-8].

Many methods have been applied in order to minimize the possibility of a flashover. The selection of the appropriate in each application depends on the efficiency and the relevant cost. However knowledge of the phenomenon development is usually required for the method selection and application. A typical example is insulator washing, where the crucial point that usually determines the method efficiency is the selection of the appropriate application time.

Usually pollution is considered as a six stages process, shown in figure 1 [1,3]. Four of them are correlated to electrical surface phenomena (3 to 6). Therefore leakage current, which can be considered as a projection image of the surface activity, can provide much information about the process development. Also stages 3 to 5 are more frequently observed in service than the process outcome, stage 6, which occurs under favorable conditions. The transition observed from the ordinary surface activity to the flashover will determine the outage possibility and therefore is crucial for the phenomenon investigation.

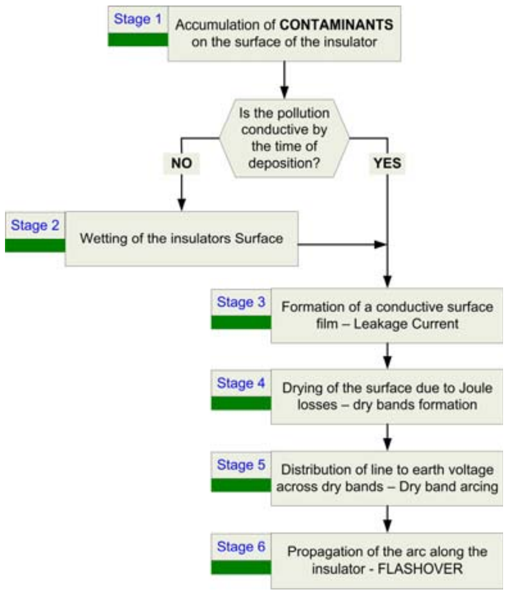

Fig.1 The pollution phenomenon in stages

In this paper field measurements of leakage current on porcelain insulators are used in order to investigate the pollution development and especially stages 3 to 5. The measurements took place at a 150kV high Voltage Substation, located in Crete, a Greek island in the Mediterranean with intense pollution problems.

MEASUREMENT OF LEAKAGE CURRENT

The measurement of leakage current is a method usually applied for the investigation of the pollution phenomenon[1,4,8]. The principal advantage is the capability of monitoring simultaneously various insulators, from the onset of the current flow until a possible flashover, regardless the substrate material and the geometrical design. The measurements can be

continuous without interfering with the surface condition (E.S.D.D.) and the applied stress (flashover stress). Further field and laboratory measurements are possible providing the appropriate equipment.
On the other hand no information regarding the non electrical stages is provided, since the monitoring capability corresponds to the flow of current. Also the financial cost and the sophistication required for the necessary equipment are considerable.
In this case a specially designed data acquisition system, capable to operate under actual substation conditions was installed at a 150kV High Voltage Substation located in a small distance from the coast (less than 1km). The installation site is shown in figure 2a and the measurements setup in figure 2b.

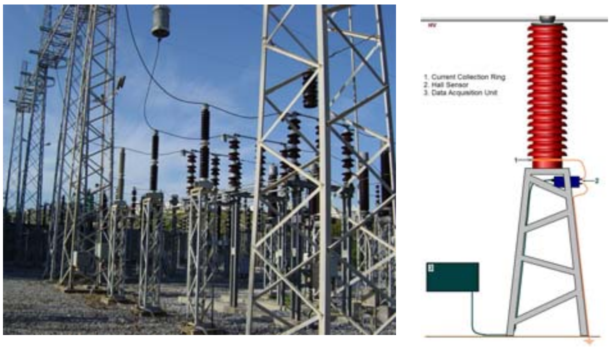

Fig.2 (a) The test site and (b) the measurements setup

The measurement of leakage current is possible by inserting in the LC path a collection ring and a Hall sensor (Figure 2b). Due to the low input impedance, the current is forced to go through the sensor on the way to earth and thus the measurement is accomplished. Then the data are transmitted to the central unit where it is processed and stored. Simultaneous recordings of 9 LC and 3 voltage channels are possible, at a sampling frequency of 2 kHz (each channel simultaneously sampled).

TYPICAL LC WAVEFORMS

Field leakage current measurements in Crete started in year 2000 and continue until today. The measurements presented in this paper are typical waveforms for stages 3 to 5. In figure 3a the waveform of leakage current during stage 3, thus before the appearance of surface discharges. The frequency analysis performed indicates that the principal frequency component present is the 50Hz fundamental (figure 3b). Being sinusoidal the phase difference can be seen in a I-V diagram, which in this case is shown in figure 3c. The observed linearity corresponds to either 0^{o} or 180^{o} phase difference thus in this case 0^{o}. The change of the I-V diagram with the phase difference is shown in figure 3d. Consequently the waveform reveals a resistive behavior for the measured current,
During dry band activity higher values of leakage current can be observed. This is due to the discharges that appear on the surface, that result to higher surface conductivity. However the presence of a discharge influences the leakage current waveform, due to the non linear characteristics of the arc [6].
A typical waveform of LC during dry band activity is shown and analyzed in figures 4a and 4b. The duration of the discharge exceeds the time of 10 voltage periods and the peak current is 25mA. In figure 4b the frequency analysis of the leakage current in figure 4a is shown. The non linear behavior is indicated by the presence of components, primary at 150Hz and also at 250Hz and 350Hz. It is worth mentioning that the fundamental and the 150Hz components are the dominant in this case.

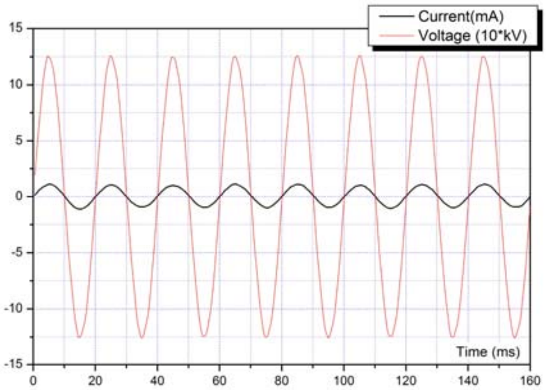

Fig. 3a LC at the drying stage

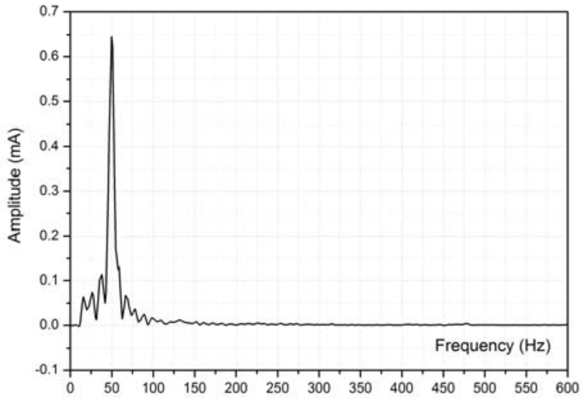

Fig. 3b FFT Analysis of the LC in fig. 3a

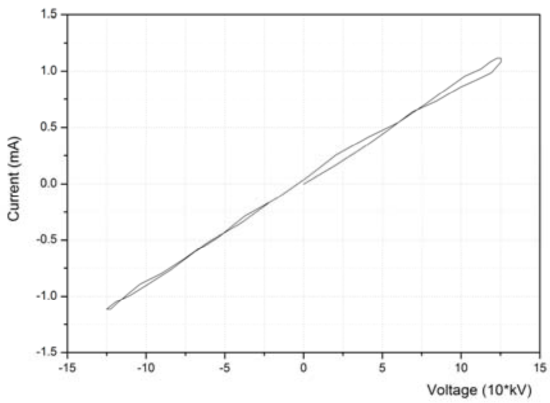

Fig. 3c I-V diagram (one voltage period)
of the LC in fig. 3a

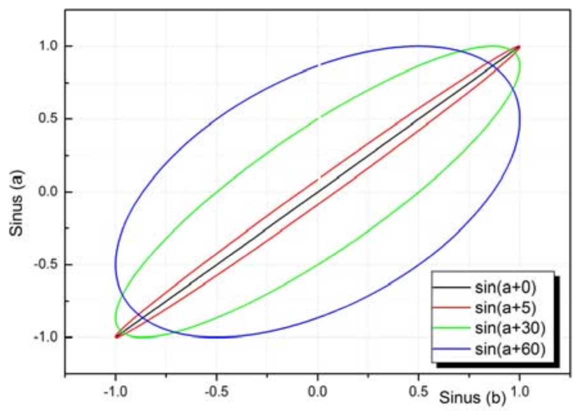

Fig. 3d Influence of phase difference to the I-V diagram

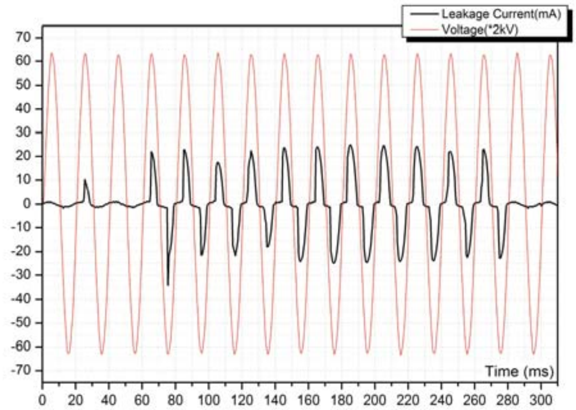

Fig. 4a LC in the case of a dry-band discharge (early stage)

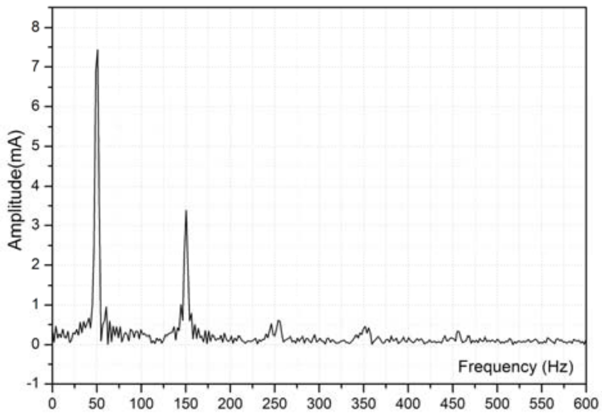

Figure 4b: FFT Analysis of the LC waveform in fig. 4a

Under favorable for the phenomenon conditions more intense activity can be observed. The waveform in figure 5a is such a case. As it can be seen, subsequent discharges of the same or multiple dry bands have been recorded. It is important to notice that the duration of each discharge is about seven voltage periods and the peak value of LC reaches 100mA. In figure 5b the frequency analysis in this case is shown. The 50Hz fundamental and the 150Hz component appear dominant in this case also.

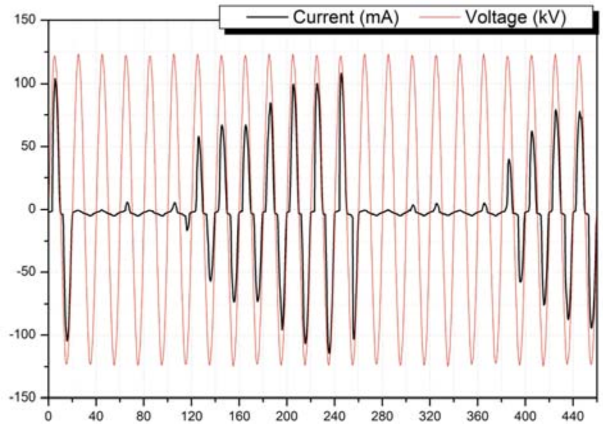

Fig. 5a: LC waveform in the case of intense activity

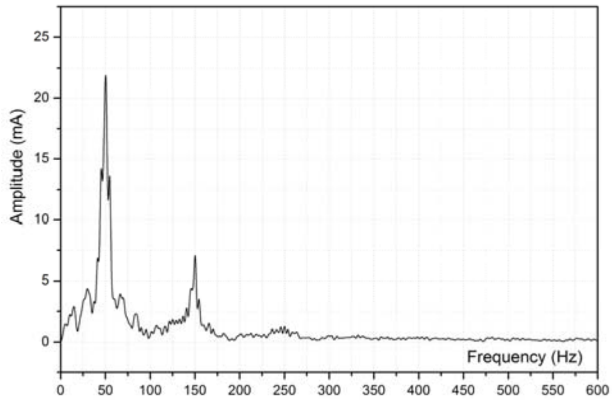

Fig. 5b: FFT Analysis of the LC waveform in fig. 5a

STAGES OF SURFACE ACTIVITY

The leakage current in figure 3a is sinusoidal, at a frequency of 50Hz (FFT analysis, figure 3b), indicating linear behavior at this stage. In addition, the phase difference between the current and the applied voltage is negligible (figure 3c). Therefore the surface conductivity formed demonstrates a resistive behavior, which corresponds to the loss of energy due to the current flow (Joule losses).

The dissipation observed is not uniform along the creepage distance, due to the insulator geometry, but areas of increased activity appear. Even if uniform contamination build up is assumed the current density increases as the axial radius decreases. This can be easily calculated assuming the insulator geometry as a synthesis of small cylinders and a uniform contamination film. Thus the surface resistance per unit length and film resistivity is given in equation 1.

$$dR = \rho \frac{dl}{\pi k(2r+k)} \tag{1}$$

where

dR is the resistance for the length dl
k is the pollution thickness
r is the axial radius
ρ is the surface resistivity

Furthermore the localized dissipation of energy corresponds to the change of the conductivity value achieved. Ordinary contamination usually contains substances that can become conductive after dissolution in water. A typical example is marine contamination, composed mainly by salts. Therefore the onset of surface activity is often correlated with the appearance of a wetting mechanism capable to provide the required amount of water on the surface and the value of the conductivity formed is consequently a function of the contamination accumulated and the amount of water. Considering contamination unchangeable, thus limited cleaning capability of the wetting mechanism (typical case condensation), the onset conductivity depends on the wetting condition, thus the amount of water on the surface.
Consequently two counterbalancing mechanisms appear on the insulator surface, the action of the wetting mechanism which corresponds to an increment of the surface water and the drying capability of the flowing current, which is enhanced along certain parts of the leakage distance. Of course other parameters should also be considered, such as the exact type of contamination, dissolution time available, inert material present, solution temperature etc.
Further where current density is increased, areas of higher resistance are formed (dry bands) and consequently the voltage distribution along the insulator is altered. As a result increased stress along the dry bands is observed and discharges appear (dry band discharges).
The waveform in figure 4a corresponds to the appearance of a dry band discharge on the insulator surface.
In this case the current waveform is enriched with higher frequency components, especially at 150Hz. The linearity observed before, doesn't exist in this case, due to the resistive barriers set by the dry bands and the occurring surface discharges. A closer look (figure 6) at the current and voltage waveforms reveals the influence mechanism.

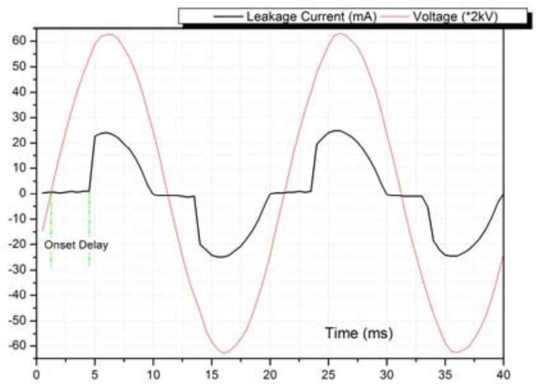

Fig. 6 Leakage current and voltage, a closer look to figure 4a

The presence of the dry part suppresses the flow of current and additional voltage stress is required for the barrier overcome [9]. This is evident by the onset delay shown in figure 6. The value of the required voltage depends on the voltage distribution. Further the participation of a gaseous conductor to the total surface conductivity developed also enhances the already existing non linearity.
The reason underlying is the relation that exists between the conductivity value of the discharge and the temperature of the participating air (gaseous conductor) [10]. This influence can be seen in the I-V diagram shown in figure 7, where a typical for a gas discharge waveform is shown. Comparing the values of current for the same voltage stress, before and after the current peak, as shown in figure 7, higher conductivity is assigned for the later.

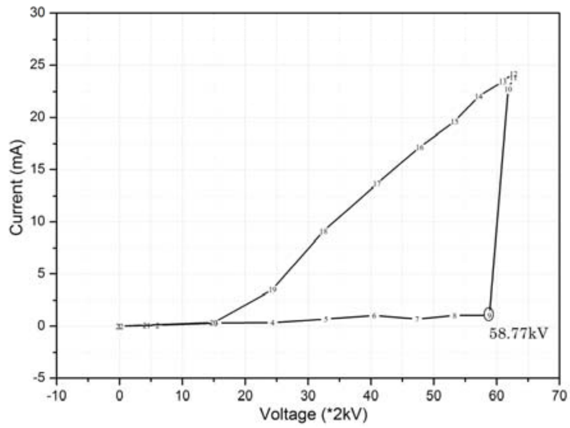

Fig. 7 I-V Diagram for the leakage current and voltage, in figure 4a

The same behavior is observed for the current and voltage of figure 5. In this case the measured activity is more intense and sequential discharges appear. The onset delay for the current flow is also observed, indicating that a dielectric breakdown is required for the dry band arc to develop. However when comparing the I-V diagrams (figures 7 and 8), it is evident that the non conducting gap is less in this case. Considering that the surface conductivity is composed by the series connection of the arc the remaining wet part, this corresponds to an increased conductivity value for the wet part. Thus the voltage applied along the dry band is increased and the onset is observed earlier. It is worth mentioning that the measured voltage shown in the above figures is the total applied stress, along both the discharge and the wet part.

CONCLUSIONS

The surface activity observed on 150kV porcelain insulators is investigated by field leakage current measurements. The measurements took place in actual field conditions at a 150kV/20kV High Voltage Substation, in Crete, a Greek Mediterranean island.

Leakage current can provide plenty of information regarding the electrical stages of the phenomenon development, allowing continuous monitoring of the surface activity without interfering with the surface conditions.

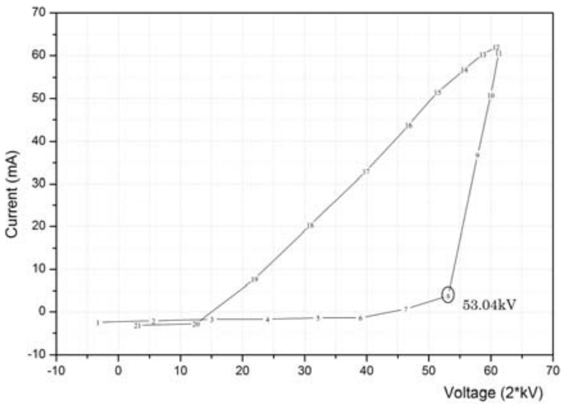

Fig. 8 I-V Diagram for the leakage current and voltage, in figure 5a

The measurements shown in this case indicate that the initial surface activity corresponds to a pure sinusoidal leakage current, which although small is capable of drying the insulator surface, considering of course the localized range of the drying action. Further discharges develop on the surface, which distort the current waveform. Components at higher frequency appear, mainly at 150Hz.

The underlying reason for this distortion is the discharge conductivity value which changes during a voltage half period. At first the onset of current flow occurs over a certain voltage level, since the breakdown of the air surrounding the dry band is required and then the gas conductivity value changes due to the energy supplied from the current in the gap.

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