Behavior of AC High Voltage Polyamide Insulators: Evolution of Leakage Current in Different Surface Conditions

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Abstract. *This paper is aimed at a systematic study of the leakage current of high voltage polyamide insulator string under different conditions of pollution for possible application in the electric locomotive systems. It is shown that in the case of clean/dry and clean/wetted insulators, the leakage current and applied voltage are linear. While in the case of pollution with saline spray, the leakage current and the applied voltage are not linear; the leakage current changes from a linear regime to a nonlinear regime up to total flashover of the insulators sting. Traces of erosion and tracking of insulators resulting of partial discharges are observed.*

Keywords

Dielectric, electrical arc, flashover, humidity, insulator, leakage current, partial discharges, pollution, polyamide.

1. Introduction

The knowledge of the performance of high voltage outdoor insulation is very important regarding to the stability of power system grids and locomotive networks. And it is well known that when the pollutant deposits covering the insulator are wetted, a leakage current that can lead to local heating, takes place. This heating engenders dry bands which interrupt the flow of the leakage current. At this instant, local discharges occur at these regions provoking then the total flashover of insulator.

The initiation and the evolution of discharges at the surface of polluted insulators on laboratory models or real insulator profiles have been the subject of numerous investigations [1], [2], [3], [4], [5]. Many researches focus on insulating materials that present optimal performances under humid and polluted conditions [2], [6], [7], [8], [9], [10], [11], [12]. At present, synthetics and composite insulators are used; their most important advantage is the hydrophobic characteristic that they present [2], [5], [11], [12]. However, this hydrophobicity is lost under some conditions [7], [9], [13], [14], [15] such as corona discharge, chemical atmospheric attack, UV, etc. On the other hand, the insulator surface must be stable as longer as possible and does not present erosion and tracking traces. This aspect is considered as a criterion of acceptability for further application of the chosen dielectric material.

The leakage current at the insulator surface is the most important parameter that gives information on the behaviour of the dielectric material [7], [8], [9], [13], [14], [16], [18], [19], [20]. This current is the superposition of three components: polarisation current, ionisation current and conduction current. The first one is a result of the intrinsic dielectric response to the applied electric field. The second one is created by the corona and unstable partial discharges that appear at the dielectric surface. The last one is due to the conductive pollution layer at the dielectric surface. This conductive pollution layer consists of ionic salts, insoluble matters and moisture. In practice, the conduction current is higher than the other ones; and it was found that it presents a resistive behaviour in the case of continuous pollution layer [1], [5]. When the pollution layer is discontinuous, the pollution layer behaves as impedance constituted by a resistor and a capacitance [3], [4], [16], [17], [21].

In this paper, we present a systematic study of ac leakage current of polyamide sting insulators in different conditions of pollution: dry, wet and polluted insulator surfaces. We also analyse the influence of partial discharges that can occur at the insulators surfaces and their consequences on the possible use of such insulators in HV networks.

2. Experimental Setup

Figure 1 presents the used scheme of experimental setup. It consists of a 200 kV – 60 kVA - 50 Hz high voltage transformer (HIPOTRONICS type), the insulators sting with a mechanical device reproducing the real mechanical stress and a resistive divider connected to an oscilloscope (Tektronix DSA601A). The Data are transferred to a personal computer and treated with WaveStar software package.

The insulators string we tested is made of polyamide. It consists of two sealed parts connected through a cable. Table 1 presents the geometrical parameters of the used insulators.

Three different surface conditions namely clean and dry, clean and wet and polluted are tested. In the case of wetted test, we used demineralised water. For the polluted test, we used an electrolytic solution ($NaCl+H_2O$) with different conductivities: 100 μS·cm^{-3}, 250 μS·cm^{-3}, 500 μS·cm^{-3}, 1000 μS·cm^{-3} and 6000 μS·cm^{-3}. The wetting (clean water or polluted water) of the insulators is realised by manually spraying of all the insulator surfaces except the mechanical cable connexion. The applied voltage is increased progressively with a step of 5 kV. The values of current and voltages are given in rms.

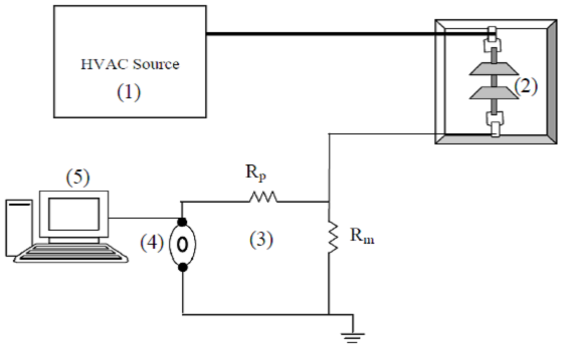


Fig. 1: Experimental setup: (1) HVAC transformer, (2) Insulators string, (3) Measurement and Protection Resistances, (4) Oscilloscope and (5) Personal Computer for Data Acquisition.

Tab. 1: Geometrical parameters.

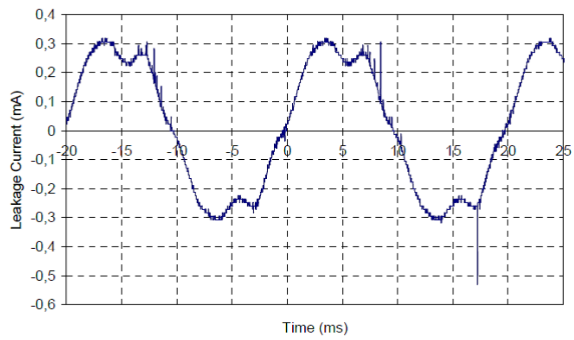
Unit leakage distance (mm)	Unit diameter (mm)	Unit spacing (mm)	Dry distance (mm)	Distance between insulator (mm)
240	131	85	290	65

3. Results and Discussion

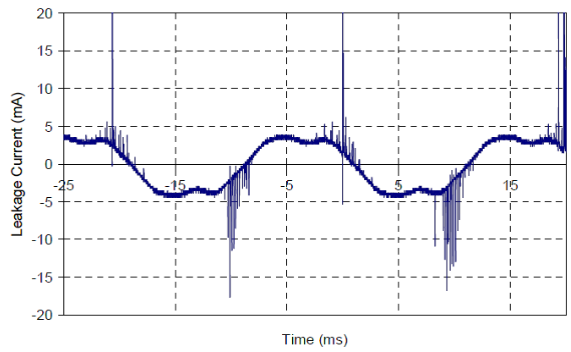
3.1. Clean Dry and Clean Wet Tests

Figures 2 illustrates the instantaneous variation of the leakage current respectively for clean dry test and clean wet tests. We observe that the leakage current (LC) presents a sinusoidal form on which are superposed current pulses (CP). The amplitude of these pulses increases with the voltage and is higher than the sinusoidal peak value of LC. They represent the corona discharge activity appearing at the insulators surface. The density and the amplitude of these CP increase with insulators surface wetting. They are higher for wetted insulators than those in case of dry insulators as reported by Waluyo [18]. We observe that CP corona onset for wetted insulators is less than in the dry test case.

The peak values of LC increase linearly with the applied voltage, as shown Fig. 3. This indicates that there is no apparition of dry band arcs at the insulator surface. On the other hand, we note that the peak values of LC do not present a significant change as the state surface insulator variation.



(a) Clean and dry test



(b) Clean and wet test

Fig. 2: Instantaneous variation of leakage current in dry and clean test with an applied voltage of 30 kV.

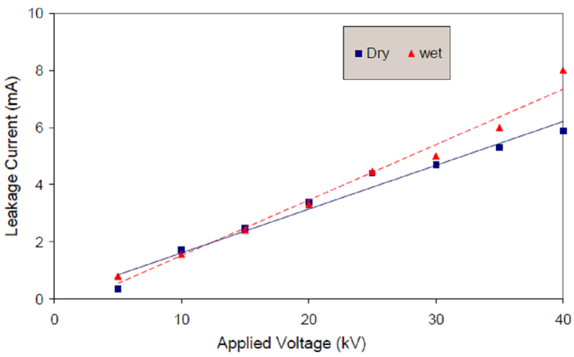
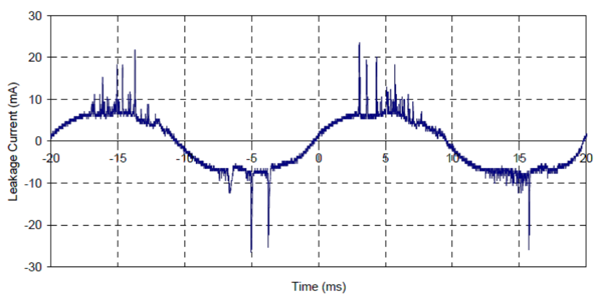


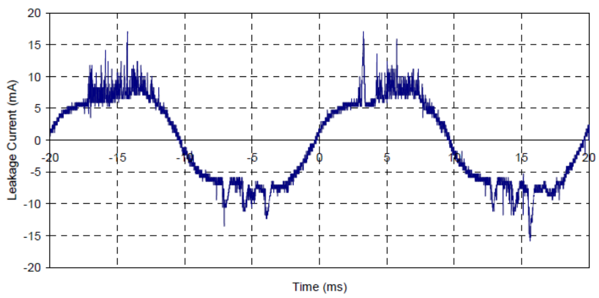
Fig. 3: Variation of leakage current versus the applied in clean dry test and clean wet test.

3.2. Pollution Tests

In this case the partial discharges (PD) activity is more important than the corona activity for the dry and wet clean insulators surface. The onset voltage of PD pulses is linked to the conductivity of the pollution and the applied voltage. Indeed, for the same applied voltage, the onset voltage of PD pulses decreases with the increase of pollution conductivity. Figure 4 illustrates the instantaneous variations of the leakage current for pollution conductivities of 100 µS·cm^{-3} (Fig. 4(a)) and 500 µS·cm^{-3} (Fig. 4(b)) for an applied voltage of 30 kV.



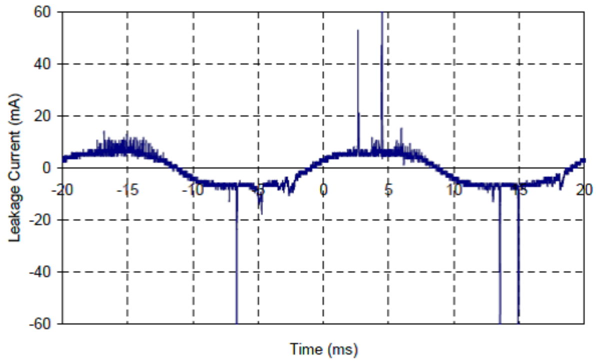
(a) 100 µS·cm^{-3}



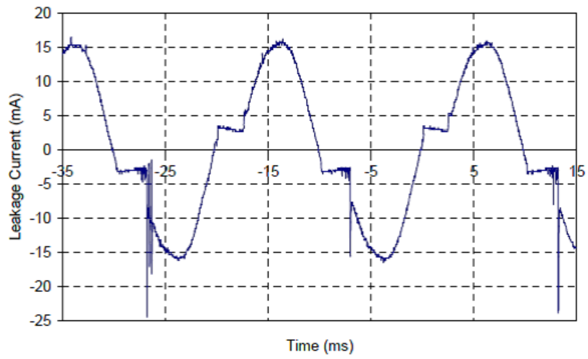
(b) 500 µS·cm^{-3}

Fig. 4: Instantaneous variation of leakage current in pollution test with an applied voltage of 30 kV and conductivities 100 µS·cm^{-3} and 500 µS·cm^{-3}.

Figure 5(a) and Fig. 5(b) depicts the activity of LC for pollution conductivity of 1000 µS·cm^{-3} and 6000 µS·cm^{-3} for an applied voltage of 25 kV. The density and the amplitude of CP are very important indicating the apparition of unstable low current arc discharges on the insulators surface (Fig. 5(a)). This result is similar to the observations reported by references [19] and [20]. These unstable arc discharges caused erosion at the insulator surface (Fig. 6). In Fig. 5(b), the LC is typical of dry band arc one and reflects the presence of arc discharge that produces total flashover of the insulator string as depicted in Fig. 7.



(a) 1000 µS·cm^{-3}

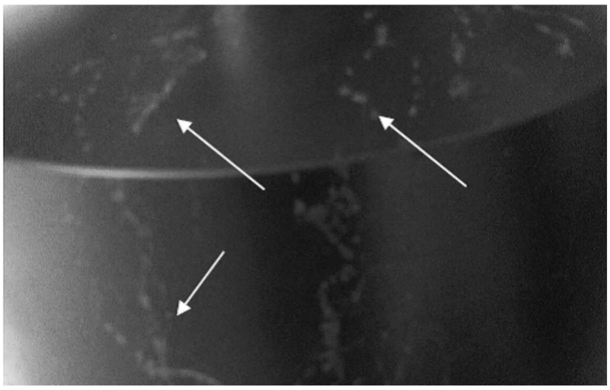


(b) 6000 µS·cm^{-3}

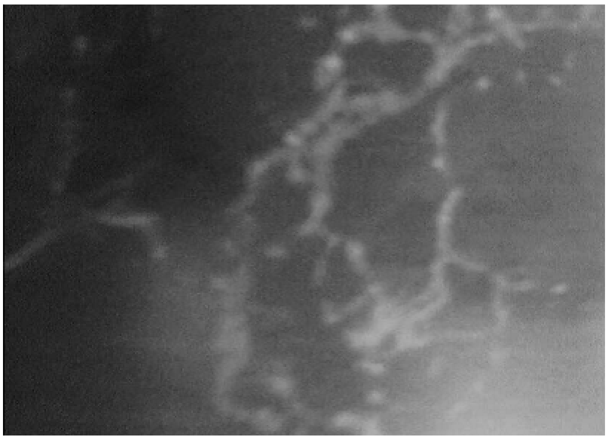
Fig. 5: Instantaneous variation of leakage current in pollution test with an applied voltage of 30kV and conductivities 1000 µS·cm^{-3} and 6000 µS·cm^{-3}.

Figure 8 presents the variation of the peak values of LC versus the applied voltage for different pollution conductivities. We observe that LC is not linear. This result shows that most of partial discharges evolve in partial arcs when increasing the pollution conductivity and the applied voltage. For example, for a pollution conductivity of 1000 µS·cm^{-3}, the non-linearity begins from an applied voltage of 20 kV while for a pollution conductivity of 6000 µS·cm^{-3} it starts from an applied voltage of 15 kV. For the rest of pollution conductivities, the non-linearity starts from an applied voltage of 25 kV.

Figure 9 and Fig. 10 present a comparison of the LC versus the applied voltage between the clean/dry test, clean/wetted test and pollution test. For clean/dry test, clean/wetted test and pollution test with a con-



(a) Global view of erosion insulator



(b) Zoom view

Fig. 6: Erosion caused by partial discharge.

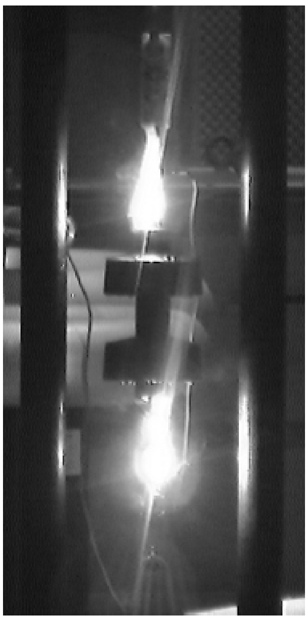


Fig. 7: Flashover of tested insulator in pollution test.

ductivity of 100 µS·cm^{-3}, with an applied voltage up to 20 kV, LC is practically the same. Over this voltage, LC for polluted insulator increases because of the

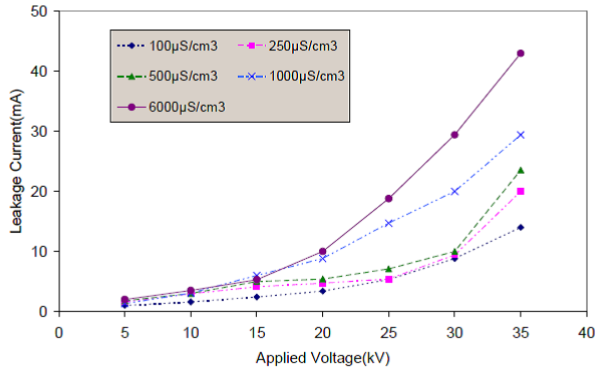


Fig. 8: Variation of LC versus applied voltage in pollution test.

apparition of unstable PD. In case of pollution conductivities of 250 µS·cm^{-3} and 500 µS·cm^{-3}, LC for pollution test is always higher than that for the clean/dry test and clean/wetted test.

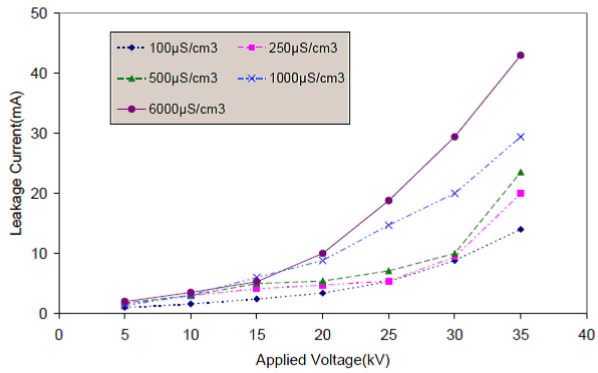


Fig. 9: Comparison of the LC versus applied voltage for clean dry test, wetted test and pollution test with conductivities 100 µS·cm^{-3} to 500 µS·cm^{-3}.

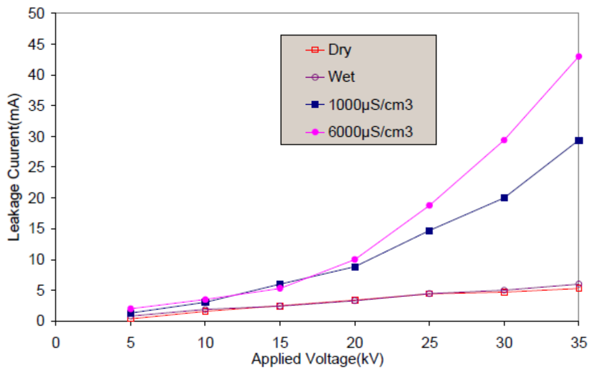


Fig. 10: Comparison of the LC versus applied voltage for clean dry test, wetted test and pollution test with conductivities 1000 µS·cm^{-3} to 6000 µS·cm^{-3}.

The LC of pollution test with conductivities of 1000 µS·cm^{-3} and 6000 µS·cm^{-3} is always higher than that of the clean/dry test and clean/wetted test (Fig. 10). This is due to the high conductivity of pollution layer that engenders thermal unstable partial arcs over the insulators surface and that leads to flashover.

4. Conclusion

This work focus on the leakage current flowing through the surface of insulators string submitted to HVAC under different environment conditions. It appears that:

- in clean/dry test and clean wet test:
  - the corona current pulses onset for wetted insulator is less than the dry test case,
  - the peak values of the leakage current increase linearly with the applied voltage. This result indicates that there is no apparition of dry arcs at the insulator surface,
  - the peak values of the leakage current don't present a significant change as the state surface insulator variation,
- in pollution test:
  - the partial discharge activity is more important than the corona activity for the dry and wet clean tests,
  - most of partial discharges evolve into partial arcs when increasing the pollution conductivity and the applied voltage,
  - the onset voltage of the PD pulses is linked to the conductivity of the pollution and the applied voltage
  - an unstable arc discharges causes erosion at the insulator surface,
  - the leakage current for pollution conductivities higher than 1000 $\mu S \cdot cm^{-3}$ is typical of the dry band arc one evidencing the presence of arc discharge that leads to total flashover of the insulator string.

The observed traces of erosion and tracking on the insulators surface resulting of partial discharges could be an obstacle for the use of such insulating material (namely polyamide) in pollution conditions.

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