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University of M'Sila
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Co-authors: ***CHERIF Bilal Djamal Eddine***

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Analyzing and modeling an insulating surface's leakage current in high voltage

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***Abstract*—This research addresses discontinuous contamination layers developed on the surface of insulators. Two distinct zones are identified: a clean (dry) zone and a contaminated (wetted) zone. The length and position of the dry zone influence the leakage current. These were made on a plane experimental model under AC voltage. Three configurations were studied: pollution deposited near the HV electrode, pollution deposited near the ground electrode and pollution laid out with the centre. This study was made using pollution layers with different conductivities. Based on the experimental results, a theoretical model allowing us to calculate the gap impedance, the transferred (gap) voltage and the leakage current was established. This model enables us to predict the severity of pollution based on the sample's equivalent impedance.**

Keywords— discontinuons pollution, insulte surface pollution Conductivity, equivalent impedance.

I. INTRODUCTION (*HEADING 1*)

Several constraints reside in the insulators of the lines and stations of electrical energy transport. Inter alia, the pollution of the insulators constitutes one of the factors of first importance in the quality and reliability of transport D energy.

Several experimental and theoretical studies have examined the phenomena of conduction and the development of electric breakdown on insulating surfaces uniformly and not uniformly polluted under alternating voltage [1- 8].

This study aims to develop an empirical model based on the impedance of the polluted insulator. We will particularly compare the results obtained from this model with the experimental results relating to the leakage current.

This process aims to identify the insulator's surface quality, i.e., the degree of pollution recovering it, in order to envisage its behavior, some of which is the level of tension that is applied to it.

II. EXPERIMENTAL TECHNIQUE

The equipment of the testing institute in alternating voltage includes primarily:

A transformer of test: 500V/300 Kv, 50 kVA; a capacitive divider of tension; a control panel; a numerical oscilloscope; and additional apparatuses of measurement and protection.

The plane model simulates the insulator 1512 L. This model consists of a plate made of 5 mm-thick glass 50 cm X 50 cm on which two electrodes are posed, one on the ground and the other on high-voltage. These electrodes are carried out with aluminum foil. The dimensions of the electrodes and the distance between them, L (29.2 cm), are kept constant during all the tests.

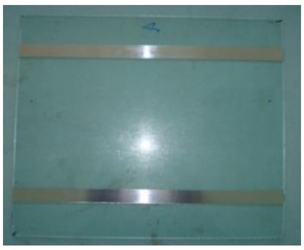

Fig. 1 Studied plane model.

III. LEAKAGE CURRENT

A. Leakage current – conductivity

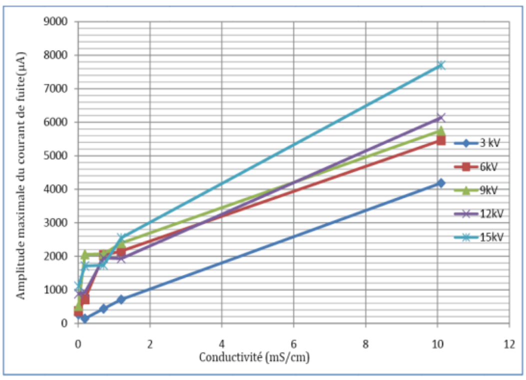

Fig. 2 Variation of the maximum amplitude of the leakage current as a function of conductivity.

From Figure 2, we see that the conductivity affects the leakage current, so the current may believe the increased conductivity of the pollution [9].

In general, the increase of leakage current as a function of conductivity could be explained by:

- The reduction of the equivalent impedance seen between the electrodes.
- The increase of the electric field, especially for high voltage levels, which causes ionization of the polluted layer.

B. Leakage current – applied voltage

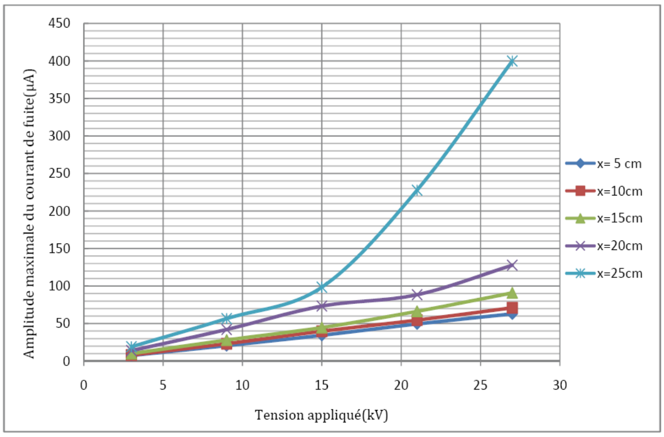

Fig. 3 Variation of the maximum amplitude of the leakage current as a function of the voltage applied high voltage side pollution.

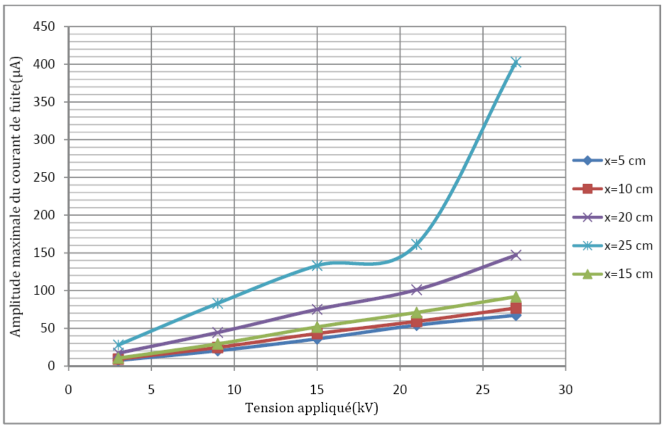

Fig. 4 Variation of the maximum amplitude of the leakage current as a function of the applied voltage pollution earth side.

For cases of possible configurations and arrangements considered, the characteristics showing the variation of the amplitude of the leakage current as a function of the applied voltage indicate that, for all widths of the polluted layer and its position relative to the electrodes, the amplitude of the leakage current increases with the applied voltage [9].

The curves present a linear part of the slope given and another nonlinear:

Thus, the system seems to follow an ohm law where L `total impedance for a given width does not depend on the tension applied, which is logical if one neglects the phenomena of conduction of the dry zone.

By cons for higher voltages, the increase of the leakage current is very sensitive; the system loses its character largely resistive.

On the other hand, for higher tensions, the increase in leakage current is very sensitive; the system thus loses largely its ohmic character.

C. Leakage current – width of the polluted layer

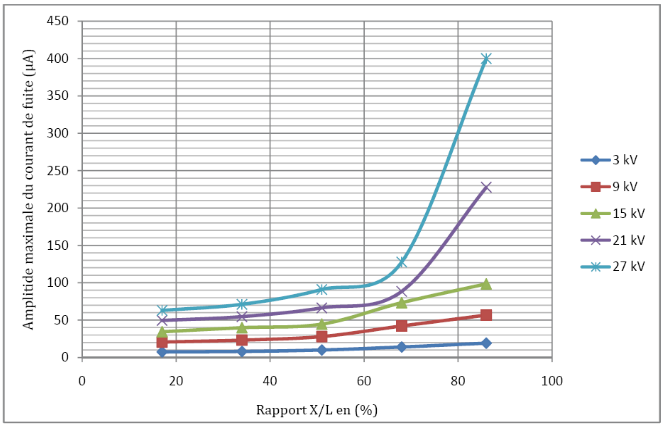

Fig. 5 Variation of the maximum amplitude of the leakage current as a function of X / L (pollution side High Voltage)

Figure 5 shows the evolution of the amplitude of the leakage current as a function of the width of the layer polluting. The increase in the amplitude of the leakage current can be explained by the significant reduction in the total equivalent impedance of the medium in proportion to the expansion of the polluted layer for each voltage level and the three configurations.

We also note that for low voltages, from a certain width of pollution, the current increases quite sharply and then there will be a sudden increase, which is most favorable to the formation of the arc.

D. Leakage current – position of the polluted layer

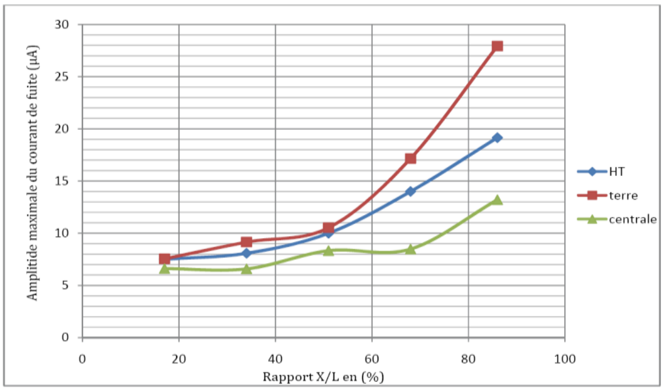

Fig. 6 Variation of the maximum amplitude of the leakage current according to the ratio X / L (applied voltage 3kV).

The experiments show that for small values of the applied voltage (3 and 9kV), the position of the layer does not affect the leakage current for low and that the widths of the polluted layer (Figure 6).

This result shows that the position of the pollution layer does not influence the leakage current until the voltage has not reached a limit, probably corresponding to the breakdown voltage of the air-glass interface for the width considered dry.

That is why we see a large difference in the magnitude of the leakage current at the higher voltage levels; we observe a much higher current when pollution is established on the land side.

It was found that the current amplitude is more intense for the land side than for other configurations where the width of the polluted area is larger. This could be explained by a higher probability of conduction phenomena in the dry zone, corona and arc when the layer pollutes the high-voltage side and central layer [8].

Some researchers [11] have shown that for other configurations of non-uniform pollution, the value of the ratio between the impedance of the polluted layer and the layer of dry land side is actually smaller than that at the high voltage.

I. EMPIRICAL MODEL AND DISCUSSION

The inter-electrode surface in our experimental model is divided into two areas: clean and polluted. Three cases were considered: a polluted area on the side of the high-voltage electrode, a polluted area on the side of the electrode, and a ground-polluted area in the center of the plate.

Determining the empirical expression of the insulator's impedance is necessary for calculating the leakage current.

According to the report, configuration impedances polluted layer-layer clean; it appeared interesting to evaluate, in a completely empirical way, the apparent impedances seen by inserting electrodes on the one hand and the experimental values adopting other simplifying assumptions to introduce a simple empirical model.

In what follows, we determine the impedance of an isolator that covers non-uniform pollution. We first determine the relation, giving the impedances of the two strips dry and humidified according to their width, and subsequently, we deduce the total impedance of the insulator. Determining this impedance allows us to calculate other parameters (voltage postponed leakage current) [8, 10, 11,12].

A. *Empirical impedance*

A.1 Assumptions and data selection

We can consider the impedance of the layer of pollution as a pure resistance [8, 13, 14, 15] based on the fact that the current in such a configuration is resistive.

The value of the impedance of the clean surface is not dependent on the position of the layer. Consider the distribution of pollution to be perfectly linear and even over the entire surface polluted.

We chose a relatively high conductivity (1.2 mS/cm) because the impedance of the polluting layer is negligible compared to that of the dry zone.

- We choose the lowest level of the applied voltage (3 kV) to avoid the nonlinear regime (critical regime) caused by high voltages.

The total impedance of the electrodes is to be considered as the result of the impedance of the clean area (Zc (x)) in series with the impedance of the polluted area (R (x)) [10]. So, knowing that the impedance of the diaper and the resistance of the polluted layer are in series between the electrodes, by taking the sum of the two impedances and after the first hypothesis, we obtain the total impedance Z_T:

$$Z_T(x) = R(x) + Z_C(x) \text{..........(1)}$$

A.2 Impedance Layer clean

By analyzing the current-voltage characteristics of the experimental (for level 3 kV applied voltage), we can deduce the diaper's average impedance Zc according to the width of the polluting layer.

It chooses the function equation corresponding to the quantity (Lx) to always obtain a change in the value of the impedance for different values of the width of the layer polluting. To this end, we propose the following equation (this formula is used by other researchers [8, 10,13]).

$$Z_C(X) = Z_i \left[\frac{(L - X)}{L} \right]^N \text{...........(2)}$$

With:

Zc (X): Impedance empirical diaper according to the width of the polluted layer.

Zi: Measured impedance of the plate; it is completely clean when there is no pollution. It has been estimated as follows:

$$Z_i = 4{,}81 \times 10^8 \Omega$$

L: Distance between electrodes = 29.2 cm (model 1512 L).

X: Width of the pollution layer in cm.

N: empirical exponent, which is the value determined from the graph of the variation of the impedance as a function of the experimental layer width polluting conductivity and voltage data.

The value of N, in this case, is equal to 0.647.

A.3 Impedance polluted layer r (x)

Because the current in such a configuration (i.e., the polluted layer) is more resistive [14,15], we can consider the impedance of the layer of pollution as a resistance R. Thus, we consider a linear distribution of pollution, even distribution over the entire surface polluted, to facilitate the calculations.

Resistance is generally given by the equation

$$dR = \frac{1}{\sigma} \times \frac{dx}{S} \text{........(3)}$$

According to the case of our model and for the three configurations, it has the formula:

$$R(x) = \frac{1}{e} \times \left(\frac{x}{\sigma . L} \right) \text{........(4)}$$

R : The Resistance.
ρ : The resistivity of the layer of pollution.
l : The width of the layer of pollution.
σ : Conductivity of the layer of pollution.
S : Surface of the section considered.
e : thickness average current path.

Where:

$$R(x) = k \times \left(\frac{x}{\sigma.L} \right) ....(5)$$

k is a constant derived from experiments. Indeed, we can obtain from tests of the uniform configuration of pollution (*k = 1 / e*).

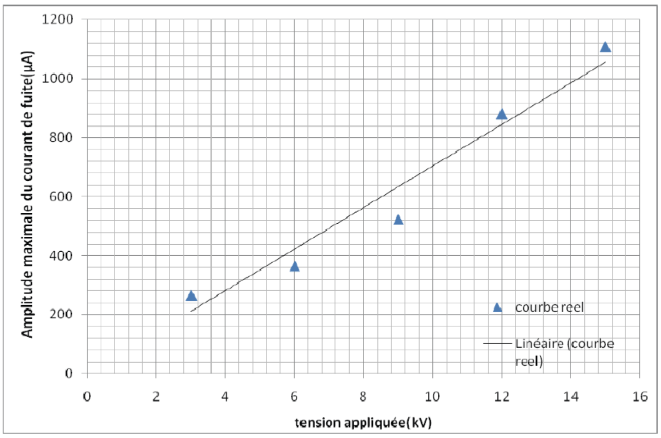

Fig. 7 Current - voltage characteristic applied to the conductivity of 10µs/cm.

The linear curve is approximated.

For conductivity 10 S / cm, we have:
For σ = 10 S / cm → R10 (L = x) = 14 MOhm. R10: resistance of the plate to completely polluted conductivity 10µS/cm.
Conductivity σ for a given:
Rσ (x=L) = R10 (x=L). (10/ σ) =140.106/ σ [Ω].
Where: k=140.106[Ω. (µS/cm)].

Therefore, the total impedance Z_T to the electrodes is considered to be the result of the impedance of the clean area in series with the impedance of the polluted area [10].

Where: $$Z_T(x) = R(x) + Z_C(x)$$

$$Z_T(X) = \frac{k}{\sigma.L} X + Z_i \left[\frac{(L-X)}{L} \right]^{0,647} ....(6)$$

II. LEAKAGE CURRENT EMPIRICAL

One method used to control the degree of pollution of an insulator is a measure of leakage current, which depends on the insulator's apparent overall impedance.

According to our tests, we observe that the model behaves in two different ways because of the stresses applied, where there are two distinct behaviors of the model [8].

- Ohmic regime, where pollution conditions are not yet critical
- Nonlinear regime, no longer obeying the law of Ohm.

To determine the value of the leakage current theory, write: U = ZT .I ⇒ I = U / ZT

Where:

$$I(X) = \frac{U}{\frac{k}{\sigma.L} X + Z_i \left[\frac{(L-X)}{L} \right]^{0,647}} ....(7)$$

A. *Evolution of the empirical leakage current according to the width of the polluted layer*

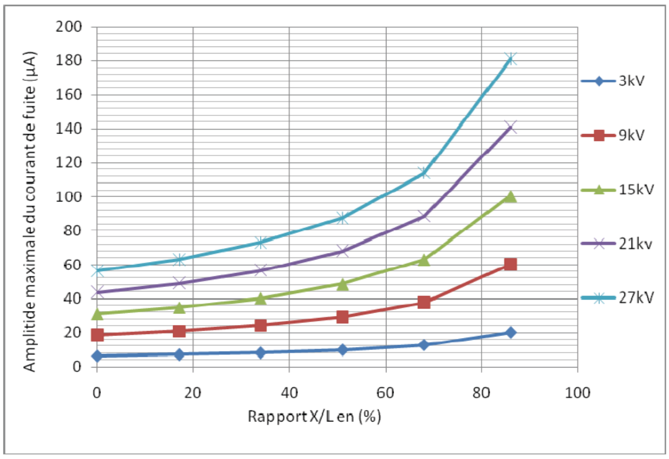

Fig. 8: Variation of the maximum amplitude of the empirical leakage current according to report X/L for various values of the voltage applied (σ=10µS/cm).

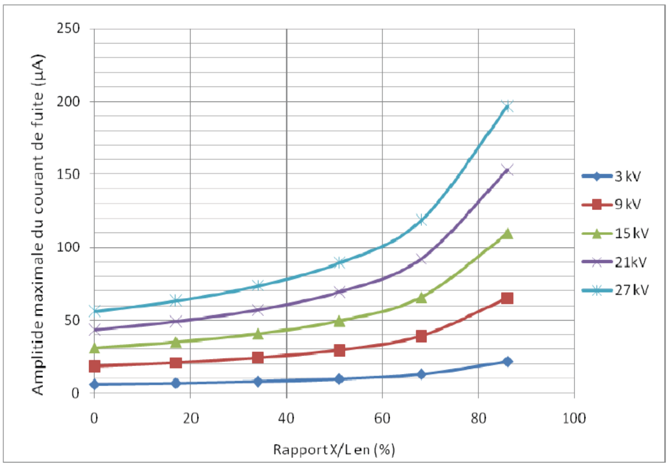

Fig. 9: Variation of the maximum amplitude of the empirical leakage current according to report X/L for various values of the voltage applied (σ=1200µS/cm).

We give graphs (8 and 9) representing the variation of the amplitude of the leakage current according to the width of the polluted layer, with five levels of voltage applied (3, 9, 15, 21, 27 kV).

According to the results obtained, the amplitude of the leakage current increases according to the width of the polluted layer and the level of tension applied. This amplitude presents a maximum for a level of tension equal to 27 Kv and for 85,6% of the distance polluted inter-electrode, which represents the case most favorable to the formation of the electric arc.

The increase in the amplitude of the leakage current can be explained by the significant reduction of the total impedance equivalent of the medium proportionally to L widening of the polluted layer.

B. *Comparison enters the experimental and empirical leakage current*

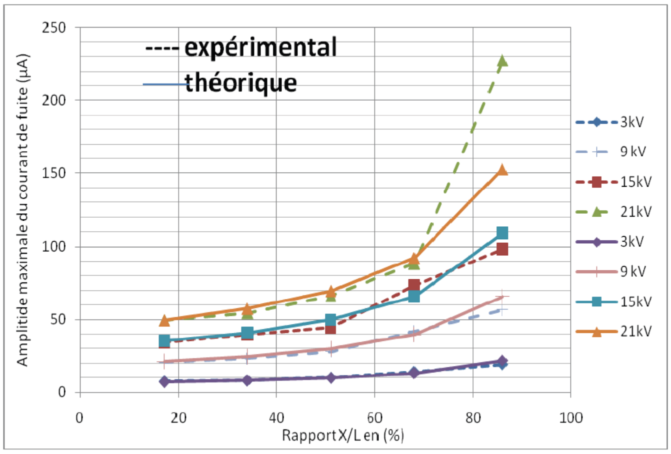

Fig 10. Variation of the maximum amplitude of the empirical and experimental leakage current according to report X/L for various values of the voltage applied (with dimensions high voltage).

Figure 10 shows the variation of the leakage current as a function of the width of the layer polluting. These were plotted for various levels of applied voltage and the conductivity value of 1.2 mS/cm.

The analysis of these curves shows that the empirical model is close to the experimental model.

From Figure 10, we note that the curves are almost confused for low voltage levels 3 and 9 kV, although the conductivity value is high (σ = 1.2 mS/cm).

When the voltage is higher (15 and 21 kV), we have a curve divided into two parts: one part is confused with the experimental curve when the width of the polluted layer does not exceed 70% of the length of the leak total. The other diverges from the second part of the experimental curve from a determined width of pollution (for widths X / L> 70% of the length of total leakage). The latter is estimated at around 75% of the total width for the 15 kV level and 67% for the 21 kV level.

The difference between the two values of leakage current reaches 10 microamps (10%) for the 15 kV voltage level and more than 70 uA (over 46%) for the 21 kV voltage level (Figure 10). This difference in the value of the leakage current is due to a much higher drying of the insulating surface (for experimental purposes) when the applied voltage is high.

III. CONCLUSION

After analyzing the leakage current, we can conclude that the magnitude of the leakage current increases with the applied voltage and the conductivity of the medium. Increasing the width of the polluted layer amplifies the value of the leakage current for the pollution of the HV side and earth.

The theoretical study based on the model impedances showed a good correlation between the theoretical and experimental values. The difference is 0-23% for the three conductivities. This difference can be justified by the fact that the theoretical model diverges when we reach the critical state when the system becomes non-linear and no longer obeys the law of Ohm.

There is, for larger values of conductivity (in our case, 10.1 mS/cm), the value of the impedance of the polluting layer is very low, thus contributing to the phenomenon of conduction in the dry zone. By cons, we get a significant voltage drop across the polluted layer with low conductivity.

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