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May 06-07th, 2025

University of M'Sila
Faculty of Technology
Electrical Engineering Laboratory (LGE)

جامعة محمد بوضياف - المسيلة
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Mohammed BOUDIAF University of M'Sila

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Maintenance voltage of the electric arc on a discontinuous polluted insulating surface at high voltage

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***Abstract*—In this paper, we present results dealing with the non-uniform pollution carried out under 50 Hz applied voltage on a plane model simulating the 1512 L outdoor insulator largely used by the Algerian Company of Gas and Electric Power (SONELGAZ). Many configurations in non-uniform pollution are studied in the ENP's High Voltage Laboratory in order to analyze the impact of polluted layer distribution on the insulator dielectric performances. In this paper, we deliberated the phase angle measurements indicate that the equivalent impedance of the insulator behaves like RC circuit with a high capacitive effect engendered by the pre-established clean band. This effect decreases when electric discharges occur at a particular voltage level.**

Keywords— electric arc, insulter surface, discontinuous pollution, conductivity, high voltage, plane model.

I. Introduction

The insulators of electricity transmission lines and substations are subject to a number of constraints. Insulator pollution is one of the most important factors in the quality and reliability of power transmission.

On-site observations have shown that the distribution of pollution along insulators is not very uniform [1, 2, 3]. This pollution distribution depends mainly on the insulator profile, the nature and level of the applied voltage, and the position of the insulator in relation to the high-voltage conductor [2, 3].

Given the complexity of electrical discharge phenomena on polluted insulating surfaces, a number of theoretical and experimental studies have been undertaken to investigate their behavior under pollution. Various parameters have been adopted, namely the nature of the pollutant deposit [1, 4], the non-uniformity of the pollution [5], the surface conductivity of the pollutant layer [6], and the profile and diameter of the insulator [6, 7, 8].

In this work, we are interested in determining the minimum arc maintenance voltage and the number of electric discharges as a function of the applied voltage. To this end, we apply a given dry width to the model, either on the ground electrode side or on the high-voltage electrode side. Several pollutant conductivities were used: 10, 190, 710, 1200 and 10100 µS/cm. During our various tests, we determined the phase shift between the leakage current and the voltage applied to each voltage level.

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.

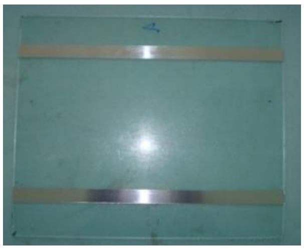

Fig. 1 Studied plane model.

III. STUDY OF PARALLEL LANDFILLS

For the uniform case, the length of the parallel discharges developing on the surface of the polluted plane model is measured using a digital camcorder, enabling them to be viewed as a function of the applied voltage. The number of parallel discharges was determined for both cases of pollution distribution, pollution on the ground electrode side and pollution on the live electrode side. The critical discharge length is measured for each pollutant's conductivity. The filmed sequences are processed using KM

Player image processing software, enabling us to follow the evolution of parallel discharges as a function of the voltage applied to the polluted plane.

A. *Relationship: Critical Length - Conductivity*

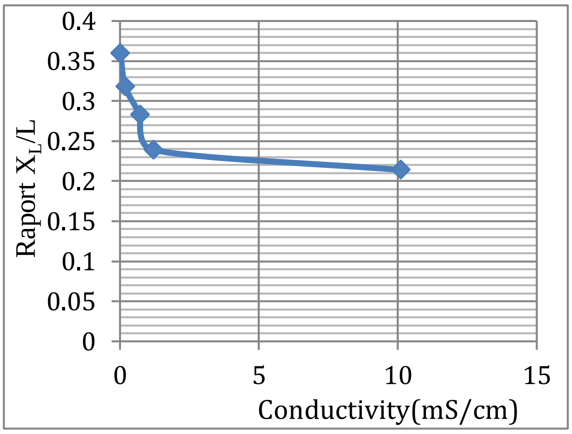

Fig. 2 Critical length of parallel discharge for each conductivity.

From Figure 2, we see that the maximum critical length of parallel discharge is 36% of the total leakage length for the lowest conductivity, 0.01 mS/cm and 31.8% for 0.19 mS/cm. For high conductivities, the critical length of parallel discharge is 23.9% for 1.2 mS/cm and 21.4% for 10.1 mS/cm of the total leakage length.

This leads us to say that the critical length of the discharge decreases nonlinearly with the increase in conductivity of the polluted layer due to the decrease in the resistive effect of the insulator resistance. This decrease is caused by the appearance of arcs all over the polluted surface, which, at low voltages, favours the creation of an ionized channel along which the final discharge will progress. The appearance of arcs can be interpreted as a considerable drop in the equivalent impedance of the polluted insulator, which favours the creation of dry zones.

B. *Relationship: Arc Length – Applied Voltage*

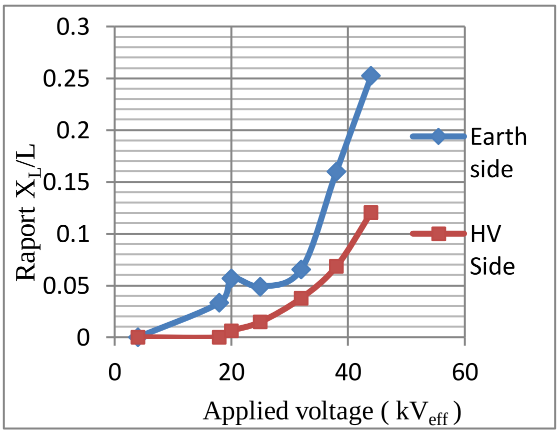

Fig. 3 Variation Ratio of the maximum length of the parallel discharge to the total leakage length as a function of the applied voltage, for the HV and earth side (σ=10µS/cm).

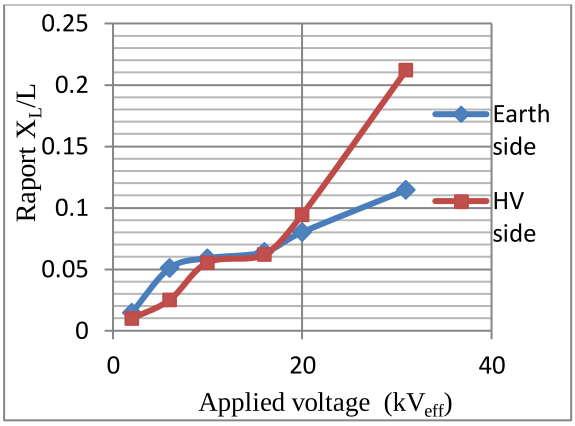

Fig. 4 Ratio of maximum parallel discharge length to total leakage length as a function of applied voltage, for HV and earth side (σ=1200µS/cm).

Figures 3 and 4 illustrate the variation in the ratio of maximum parallel discharge length to voltage for the two conductivities.

We can see that applying a voltage of a few kilovolts between the electrodes for a uniform layer of pollution causes parallel discharges to appear. Figures (3) and (4) show a steady increase in arc length as a function of applied voltage. This result is to be expected since increasing the voltage causes the polluted layer to dry out considerably. The voltage transferred to the dry zone must be high enough, and the arcs are extinguished to feed the main arc, which grows until it causes a total short-circuit. Indeed, the increase in voltage leads to an increase in the electrical energy appearing in the arc, causing it to lengthen [2].

We see the same pattern for both configurations (ground side and high voltage side)

C. *Relationship: Number Of Arcs - Applied Voltage*

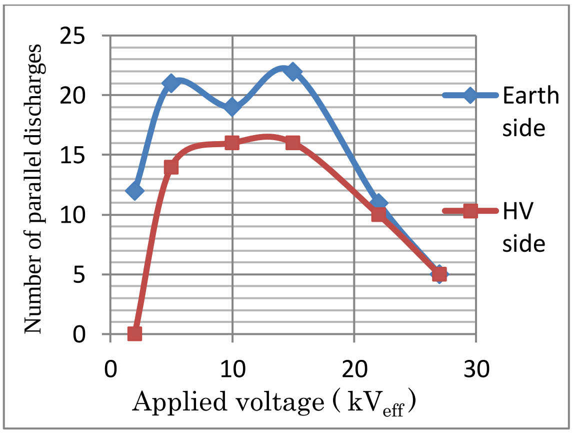

Fig. 5 Number of parallel discharges as a function of applied voltage (σ=710µS/cm).

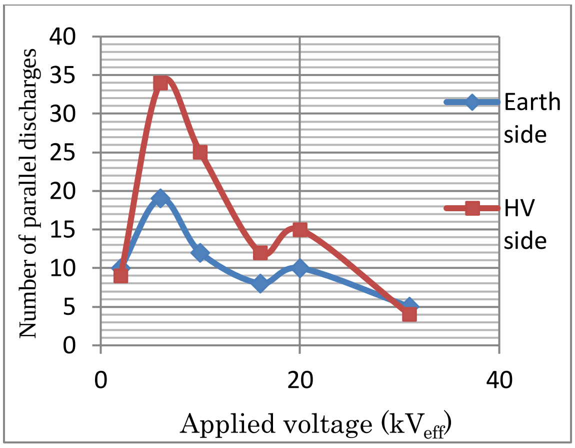

Fig. 6 Number of parallel discharges as a function of applied voltage (σ=1200µS/cm).

The number of discharges progressing across the insulating surface increases as the applied voltage increases. The number of discharges gradually decreases, and the arcs are extinguished to feed the main arc. As the electric field increases, the main arc becomes thicker and longer until it reaches its critical length, causing the insulator to be completely bypassed.

IV. STUDY PHASE SHIFT BETWEEN LEAKAGE CURRENT AND APPLIED VOLTAGE

The measurement of the leakage current-applied voltage phase shift is determined using the discrete Fourier transform based on the FFT, thanks to a MATLAB program that calculates the phase shift between the fundamentals of the leakage current and that of the applied voltage.

This measurement is carried out for uniform pollution and for different configurations concerning non-uniform pollution. The calculation aims to determine the insulator's surface condition and understand the effect of the physical phenomena (drying and evaporation) generated by discharges parallel to the surface of the plane model. This measurement can be seen as a tool for diagnosing changes to the surface condition by varying conductivities and voltage levels on the 1512 L insulator's planar pattern.

A. *Dry Cas*

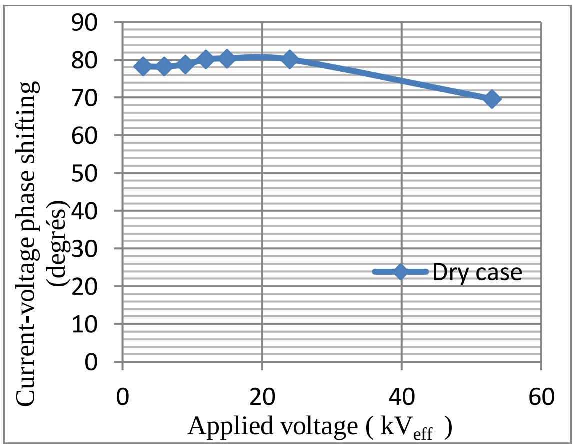

Fig. 7 Evolution of the current-voltage phase shift as a function of the applied voltage for the dry case.

We note that the current-voltage phase shift increases slightly for low voltage levels (< 24 kV_{eff}), indicating that the insulator's behaviour is practically capacitive with a slight resistive effect. However, the value of the phase shift decreases for a voltage level of 53 kVeff, which shows us that, for high voltage levels, the resistive effect tends to increase compared with the capacitive effect. This may be due to the increase in the plate temperature, which favours thermal agitation of the electrons on the surface of the plane and, therefore, increases the resistive effect of the plane insulator.

B. *Uniform Pollution*

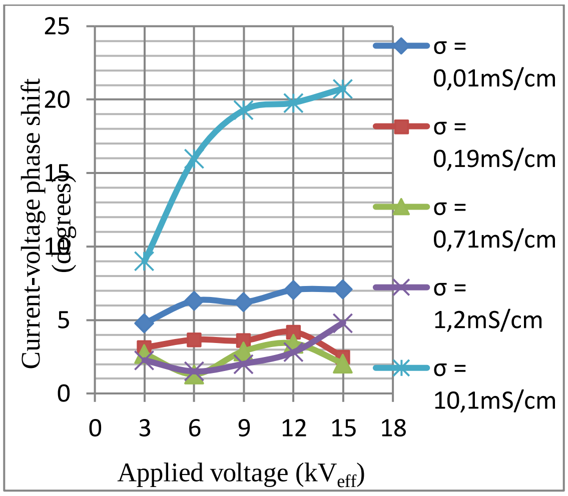

Fig. 8 Variation in current-voltage phase shift as a function of applied voltage for different conductivities.of parallel discharges as a function of applied voltage (σ=1200µS/cm).

Figure 8 shows that the current-voltage phase shift tends to decrease as the conductivity of the medium increases, for 0.01 mS/cm, 0.19 mS/cm and 0.71 mS/cm, whatever the applied voltage. This indicates that the insulator's behaviour is largely resistive with a very slight capacitive effect. For the 1.2 mS/cm conductivity, we note that there is an increase in the current-voltage phase shift from the 9 kV_{eff} voltage onwards, but it remains less than that obtained for the 0.01 µS/cm conductivity.

This increase in phase shift is justified by the drying out of certain areas of the plane, which increases the capacitive effect of the insulator.

For the 10.1 mS/cm conductivity, the value of the current-voltage phase shift is greater than for the other conductivities. This shows that at voltages above 3 kV_{eff}, discharge activity is already high, causing an increase in dry zones as a result of the rise in temperature. This activity increases as the applied voltage rises, creating drier zones that increase the capacitive effect and, therefore, reduce the resistive effect of the polluted layer.

C. *Pollution Non-Uniform Pollution*

C.1 Polluted layer on the high-voltage side

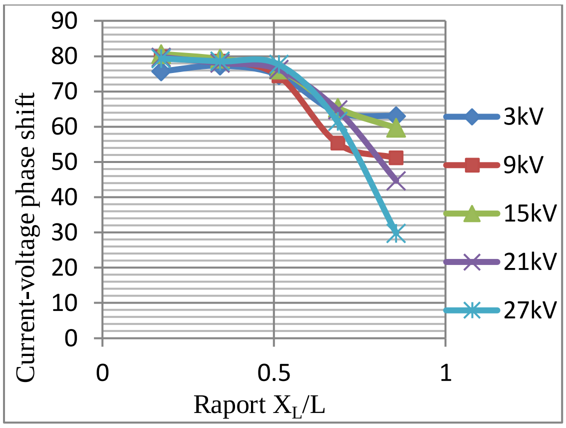

Fig. 9 Variation in the current-voltage phase shift as a function of the ratio of the width of the polluted layer to the total leakage length for high-voltage-side pollution (σ =1.2 mS/cm).

We note that for all the applied voltage levels, the phase shift decreases as the width of the polluted layer increases; this shows that the insulator behaves more resistively than capacitively as the width increases.

For polluted layers 5, 10 and 15 cm, the applied voltage has no influence on the current-voltage phase shift, which is between 76° and 80°. This indicates that the insulator behaves in a highly capacitive manner with a slight resistive effect.

For a polluted layer width greater than 15 cm, the current-voltage phase shift tends to decrease with the increase in applied voltage, giving the insulator a more resistive behaviour.

We also note that the current-voltage phase shift is smallest for layers 20 and 25 cm and voltages 21 and 27 kV_{eff}. This indicates highly resistive behaviour justified by the appearance of parallel discharges, which tend to short-circuit the air gaps, reducing the insulator's capacitive effect, which is not the case for uniform pollution.

C.2 Polluted layer on the land side

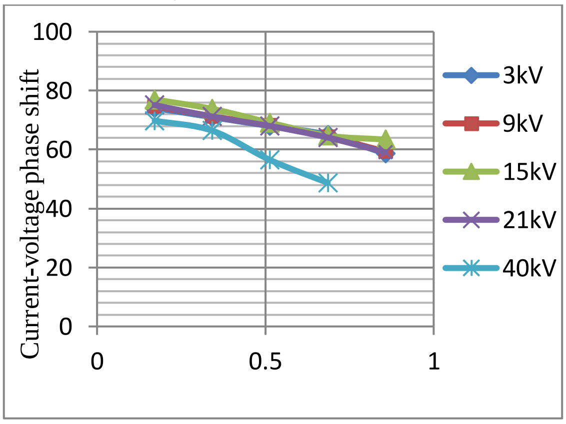

Fig.10 Variation in the current-voltage phase shift as a function of the ratio of the width of the polluted layer to the total leakage length for pollution on the ground side (σ =1.2 mS/cm).

The results obtained for this configuration show, in the same way, that the current-voltage phase shift decreases as the width of the polluted layer increases; the phase shift also decreases with an increase in the applied voltage, which clearly appears from the 15 cm layer onwards. However, this value of the phase shift remains lower in relation to the pollution on the HV side, which means that the insulator is much more resistive when the pollution is on the earth side.

Parallel discharges for the 25 cm layer at a voltage level of 27 kV_{eff} cause a remarkable drop in the phase shift, which again shows that the discharges increase the insulator's resistive effect and reduce its capacitive effect.

C.3 Polluted central layer

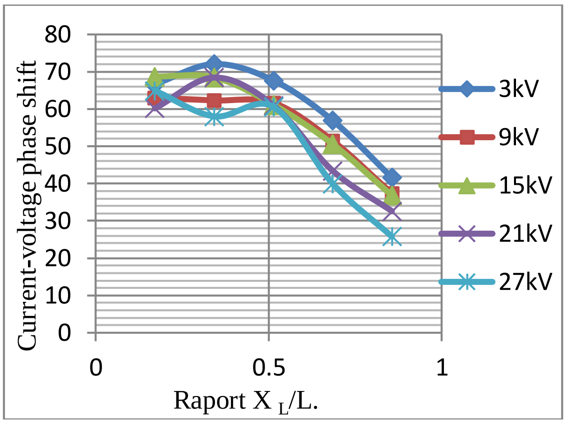

Fig. 11 Variation in the current-voltage phase shift as a function of the ratio of the width of the polluted layer to the total leakage length, for central pollution (σ =1.2 mS/cm).

In this case, the current-voltage phase shift decreases as the width of the polluted central layer increases, indicating an increase in the resistive effect compared with the capacitive effect.

For voltage levels less than or equal to 21 kVeff, the increase in applied voltage has practically no effect on the current-voltage phase shift.

For voltage levels of 40 kVeff, the value of the phase shift decreases considerably due to thermal agitation, which increases the resistive effect compared with the capacitive effect of the planar model.

V. CONCLUSION

We conclude from our study that :

We observe an increase in the arc length as a function of the applied voltage, which is due to the reduction in the number of arcs feeding the main arc.

The study of the leakage current-applied voltage phase shift shows that the planar model is characterised by a dominant capacitive effect and a weak resistive effect for voltages below 24 kveff in the dry case.

For uniform pollution, the value of the phase shift decreases as the conductivity of the medium increases, indicating that the insulator behaves in an increasingly resistive manner. For high conductivities (1.2 and 10.1 ms/cm), the occurrence of parallel discharges creates dry zones that increase the insulator's capacitive effect. This increase is more noticeable as the level of applied voltage increases.

In the case of non-uniform pollution, increasing the width of the polluted layer, whatever its location, reduces the capacitive effect and increases the resistive effect of the insulator.

The decrease in the current-voltage phase shift is less pronounced in the case of pollution at the centre of the plane, which indicates a highly capacitive behaviour of the model and, therefore, greater dielectric rigidity compared with pollution on the HV side and the earth side. The case of pollution on the earth side represents a critical case because this model is the least rigid, given the low value of its total equivalent impedance.

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