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EXPERIMENTAL STUDY OF HIGH VOLTAGE INSULATOR UNDER DISCONTINUOUS POLLUTION AND IMPULSE VOLTAGE

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ABSTRACT

In this paper, we study the behavior of high voltage insulator model, which is submitted to the same critical surface state as 1512L cap and pin insulator, under impulse voltage and various electro-geometrical parameters. These latter consist of discontinuous pollution layer made of aluminum paper deposited on the insulator surface, the pollution width, the active electrode polarity and the time between two successive impulses. The experimental results concern the $U_{50\%}$ flashover voltage and the leakage current (LC) are evaluated and discussed. Overall, these results indicate that the behavior of the insulators can be influenced by The HV electrode polarity and pollution layers width deposed on their surface.

Keywords: insulator model; impulse voltage; pollution; leakage current; flashover; $U_{50\%}$ voltage.

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1. INTRODUCTION

To ensure good operational performance of the High voltage transmission line, the design concept of these lines seeks to avoid insulators with poor reliability [1]. They are necessary in a power system network to offer isolation between power line phases and ground tower and provide mechanical hold [2, 3]. Aside from the electric field stress, the insulators are subjected to surface contamination and environmental condition. They can easily considerably increase the insulators surface conductivity, which will gets a great stream of leakage current along the insulator surface, and then the partial discharge will be taking place between the dry bands [4]. During critical weather conditions and manly in lightning time the impulse leakage current on the surface of insulator will have a large magnitudes and they provoke damage of the outdoor insulators surface [5-8]. As a result, all these critical factors leads to surface flashover of insulators, and consequently the blackout in power system will be occurs for long time [9, 10].

The efficiency of distribution system is influenced considerably by the destroyed insulators in various ways. With extensive development in the power system network, the classic techniques of investigating to examine the lines in close area by the rise of electric tower are not practicable. The different methods of high voltage insulators monitoring seeks at forecasting the suitable outages just before they in fact take place [5, 11, 12].

Recently, the electromagnetic transient simulation of lightning-induced overvoltage has produced satisfactory improvement, and such due to the fast development of electromagnetic transient computation approaches [13]. There are a large numbers of published researches that focus on the electromagnetic coupling model [14-17] mainly associated to physical procedure of the return stroke. These approaches models clearly demonstrate the features and processes of lightning-induced overvoltage in outdoor electrical transmission lines.

A recent study by Qing *et al* [13] suggests a lightning-induced overvoltage monitoring gadget utilizing a ceramic capacitor insulator which supplied by the overhead line and incorporates wireless communication device. This sensing and monitoring device is examined in HV laboratory under 10 kV of impulse voltage. A results of case studies for long time of sensing revealed a good performance of device.

Most previous research for remote outdoor insulators monitoring have a positive impact on improving its performance in the transmission lines and reduced the occurrence of power outages and maintenance time. Indeed, many researchers have used the leakage current parameters as guide to insulators situation [18-20]. Furthermore, using the Fast Fourier Transform (FFT) method of leakage currents signal offer beneficial insight for insulators pollution levels context and flashover phenomenon prediction. This will be regarded as estimating technique of the insulation efficiency, the same as the liquid and gases, in which researchers [21, 22] attempt to get most effective prospect as for another solution.

Roman *et al* [23] have examined the leakage current performances of polluted HV insulators. In fact, they proved that the higher LC magnitude are detected on HVDC glass insulators, whereas HVDC composite insulators illustrate less LC magnitude under beginning rain precipitations and with high level of humidity (90%).

A recent study by Chaou *et al* [12] offers probably the most comprehensive performance of polluted insulators monitor based on Recurrence Quantification Analysis (RQA) and Recurrent Plot (RP) methods. All these approaches are applied on LC temporal waveform. RP diagrams indicate specific illustrations and morphologies for diverse value of pollution conductivity. Therefore, during contamination conditions the RP tracks perfectly enough the insulator performance. RP appears as an excellent package to monitor the insulator state. To analyze LC waveforms according to several pollution conductivities; deposed on the insulators surface; 8 RQA indicators are provided.

The pollution represents a major factor in the deterioration of high voltage insulators performances. Indeed, it is necessary to examine their behavior under heavily polluted conditions. Such insulators can undergo, during their working, an accidental over-voltages. To reproduce the lightning voltage wave in laboratories, we use the impulse generators of Marx giving a bi exponential form [24, 25].

The present investigation relates to discontinuous pollution layer placed on the insulator surface. For the first time, we study and monitors the behavior of an experimental model, under impulse voltage. This model is submitted to the same critical surface state as 1512L cap and pin insulator, largely used in the high voltage transmission lines installed in Hassi-R'mel electrical region (Algerian Sahara) [26-29]. The behavior of the laboratory model is examined by analyzing the flashover process, the $U_{50\%}$ flashover voltage, the leakage current and the voltage/current ration. Different electro-geometrical constraints are applied on the laboratory model, such as the pollution width, the HV electrode polarity, the applied tension and the time between two successive impulses.

2. EXPERIMENTAL SETUP

The power source consists of an impulse generator of Marx (8 floors, 640kV and 4 kJ). The used laboratory model is constituted by a glass plate (500x500x6 mm) having the property to resist the heat due to the electrical discharges. Made up of aluminum film, two electrodes having a thickness of 2 μm are used. The first is circular (25 mm of radius) connected to the high voltage. The second is rectangular (400x50 mm) connected to the earth. The pollution layer distribution of the 1512L insulator used in the Hassi R'mel electrical region is reproduced on the laboratory model (Fig.1). The distance between electrodes of this experimental model is maintained constant (d=292 mm). It corresponds to the leakage path of the real insulator. The longitudinal dimensions for clean and polluted bands are shown in table 1. To simulate perfectly conducting layers, the pollution is realized by aluminum paper.

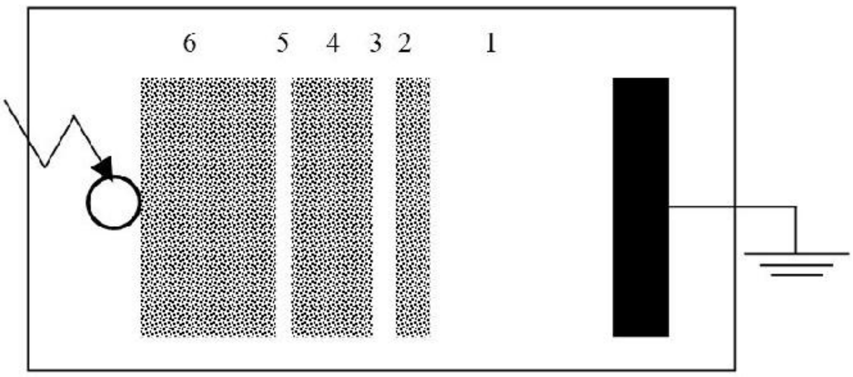

Fig.1. Experimental model

Table 1. Dimension of clean and polluted bands

	Band i	Length (mm)	Percentage with respect to the leakage path (%)	
Equivalent clean band	1	106	36.30	42.12
	3	13	4.45	
	5	04	1.37	
Equivalent polluted band	2	30	10.27	57.88
	4	52	17.81	
	6	87	29.80	

The flashover voltage is measured for both positive and negative polarities of the HV electrode and for different pollution width (1, 2, 4, 6, 8, 16, 24, 32 and 40 cm). The leakage current is carried out using electrical circuit constituted by two resistances and an operational amplifier (UA74) [30]. In order to record all current signal, we have used an adapter at the entry of the oscilloscope (Tektronix SDR 340A 100MH).

For a given pollution width and HV electrode polarity, the leakage current is recorded for the following voltage levels: $0.5U_{0\%}$, $0.6U_{0\%}$, $0.7U_{0\%}$ and $0.8U_{0\%}$, $U_{0\%}$ is the voltage with null discharge probability were determined by using the “multiple-level tests” method based on IEC 60060-1 [31-33].

3. EXPERIMENTAL RESULTS

3.1 $U_{50\%}$ flashover voltage

Laboratory observations show that the flashover occurs directly without apparition of preliminary partial arcs. With the increase of the applied voltage, and from a threshold representing the critical voltage, a rapid electrical discharge short-circuits the distance between electrodes, leading to flashover of the insulating surface. This phenomenon, characterized by the absence of the partial discharges, is due to the nature of used pollution deposit and also to the fact that the equivalent clean band length exceeds the critical value from which no steady partial arc propagates [34-36]. This critical length has been estimated in a previous study [36, 37] to the third (≈ 33 %) of the distance between electrodes. In our case, longitudinal dimension of the total equivalent clean band represents 42.12 % of total leakage path.

3.1.1 Pollution width effect

Figure 2 (a) and (b) show the variation of the $U_{50\%}$ flashover voltage according to the pollution width, for different times between two shocks and for the two polarities. With the increase of the pollution width, $U_{50\%}$ flashover voltage decreases quickly for the widths between 0 and 4 cm, increase slightly between 4 and 8 cm, and remain practically invariant elsewhere.

We explain the abrupt diminution of the $U_{50\%}$ flashover voltage, by the fact that these pollution layers of aluminium paper are considered as floats electrodes of weak widths. In these conditions, the electrical field becomes intense engendering a reduction of the dielectric rigidity of the system.

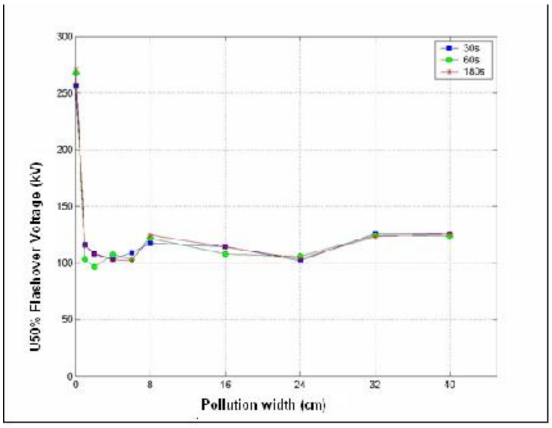

Fig.2.(a) $U_{50\%}$ flashover voltage as function of pollution width, for different time between two shocks and for positive polarity

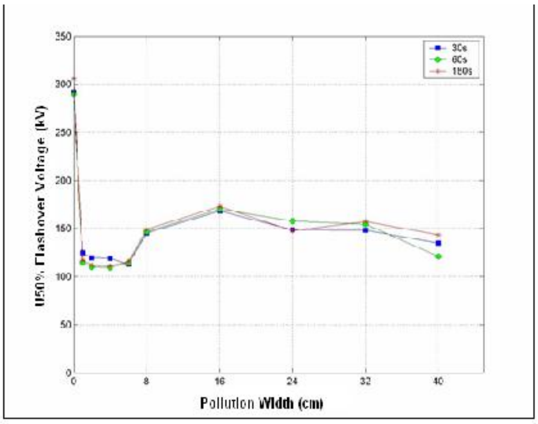

Fig.2.(b) $U_{50\%}$ flashover voltage as function of pollution width, for different time between two shocks and for negative polarity

3.1.2 HV electrode polarity effect

The HV electrode polarity has non negligible role in the behavior of the insulators. Some researchers [38] have showed that the dielectric strength in positive polarity constitutes the severe constraint for the HV electrical networks. However, other authors have obtained the opposite [39]. The same result has been obtained in the case of insulators covered by ice [38].

For a same pollution width inferior at 40 cm and whatever the time between two shocks, Figure (3) shows that the $U_{50\%}$ flashover voltage obtained in the case of negative polarity is higher. However, for the highest width (40 cm) of the pollution layers, the voltages obtained in the case of the two polarities are, in general, close.

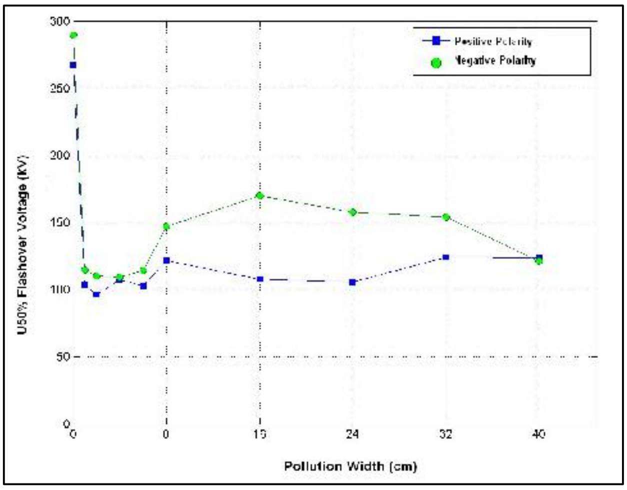

Fig.3. $U_{50\%}$ flashover voltage as function of pollution width, for two polarities

3.2 Leakage current

Concerning the leakage current, we have interested to the crest value obtained for the following applied voltage levels: 0.5, 0.6, 0.7 and 0.8 of $U_{0\%}$.

3.2.1 Applied voltage effect

The characteristics giving the leakage current as function of the applied voltage are presented at in figures 4 (a) and (b). For the two polarities and whatever the pollution width, the leakage current increases with the applied tension.

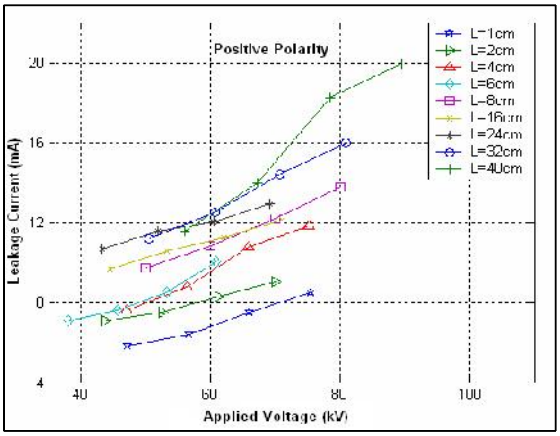

Fig.4.(a) Leakage current as function of applied voltage, for positive polarity

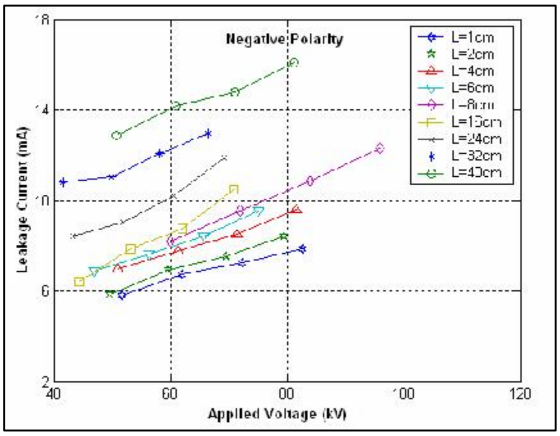

Fig.4.(b) Leakage current as function of applied voltage, for negative polarity

3.2.1 Pollution width effect

For the adopted applied voltage levels and the two polarities, the variation of the leakage current according to the pollution width is presented in figures 5 (a) and (b).

With the increase of the pollution width the leakage current decreases suddenly for widths varying from 0 to 1 cm, reaches a minimum at 1 cm and increases thereafter. From 24 cm, the leakage current augmentation is accentuated, notably for the higher voltages. This brutal increase of the leakage current is explained by the diminution of the total equivalent impedance between electrodes.

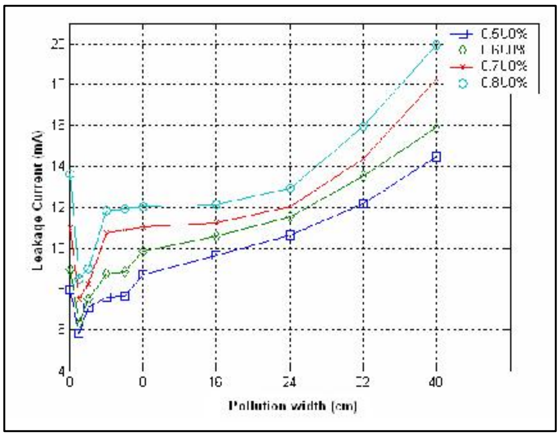

Fig. 5.(a) Leakage current as function of pollution width, for positive polarity

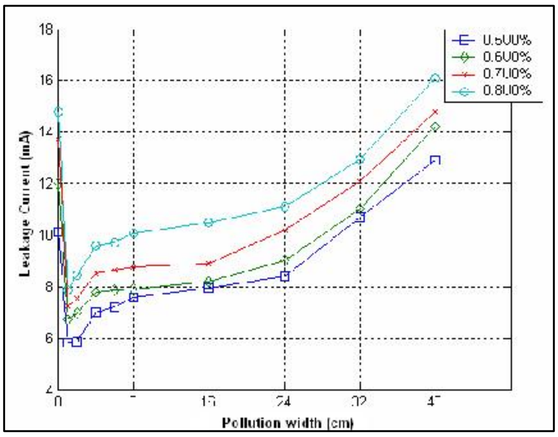

Fig. 5.(b) Leakage current as function of pollution width, for negative polarity

3.2.2 HV electrode polarity effect

Figures 6 and 7 present respectively the variations of the leakage current according to pollution width and according to the applied voltage, for the two electrode polarity. These characteristics show that leakage current is more important in the positive polarity.

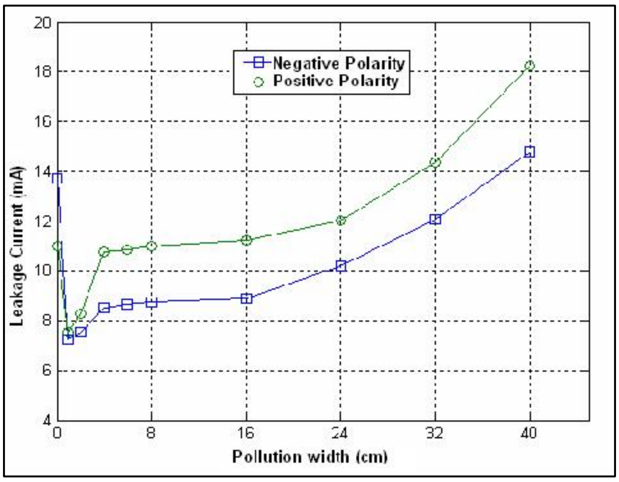

Fig.6. Leakage current as function of pollution width for two polarities and a voltage of $0.8U_{0\%}$

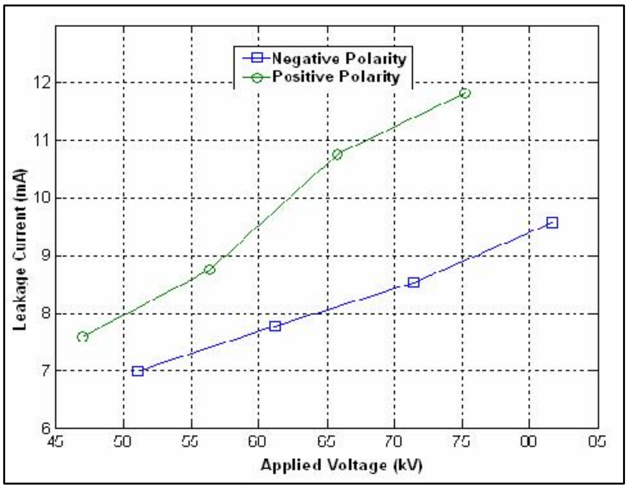

Fig.7. Leakage current as function of applied voltage for two polarities and at a pollution width of 4 cm

3.3 Voltage/current ratio

Since the leakage current magnitude increases practically linearly with the applied voltage, we can determine, in the limits of the used voltages, the voltage/current ration representing the slope of each characteristic. In figure (8), we present this ratio according to pollution width.

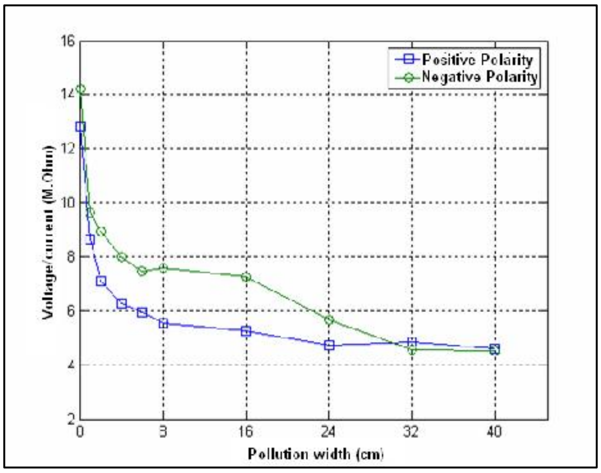

Fig.8. Voltage/current ration as function of pollution width, for two polarities

For a given polarity, when the pollution width increases, the voltage/current ratio decreases rapidly for widths between 0 and 8 cm and slowly elsewhere. On other hand and for the widths inferior to 32 cm, the voltage/current ratio obtained in the negative polarity case is superior to the one obtained in the positive polarity case. Also, these characteristics show that the polarity hasn't practically any effect on the voltage/current ratio, for the widths up than 32 cm.

4. CONCLUSION

Due to the pollution deposit nature and to the important longitudinal dimension of the total equivalent clean band with respect to the distance between electrodes, the flashover occurs directly without partial discharge appearance.

The pollution width increase leads to a diminution of the $U_{50\%}$ flashover voltage. This later is practically insensible to the variation of the time between two shocks. On other hand, the system is more rigid in the negative polarity case.

The magnitude of leakage current increases with the applied voltage. When the pollution width increases, the leakage current decreases at first, reaches a minimum, and increases then after. On other hand, the leakage currents recorded in the positive polarity case are more important than those obtained in the negative polarity one.

The increase of the pollution width leads to a diminution of the voltage/current ratio. This later is more important in the negative polarity case.

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