University of Biskra

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Journal of Applied Engineering Science & Technology

An Interdisciplinary Journal in Sciences & Technology

Journal home page: https://journals.univ-biskra.dz/index.php/jaest

https://doi.org/10.69717/jaest.v6.i3.172 Research Article

Influence of Creepage Distance and Pollution Severity on Flashover Voltage and Parallel Discharge Mechanisms in Glass Insulators

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ABSTRACT

This study investigates the impact of creepage distance and insulator geometry on the AC flashover voltage (FOV) and parallel-discharge characteristics of flat-glass insulator models under uniform pollution conditions. Experimental tests were conducted using a plane-plane electrode configuration with pollution conductivities ranging from 17 µS/cm to 10 mS/cm. The results demonstrate that increasing the creepage distance consistently elevates the flashover voltage by forming multiple distinct dry bands, thereby increasing overall dielectric resistance. Furthermore, while an increased insulator diameter reduces total surface resistance, it does not lead to a proportional decrease in FOV. High-speed video analysis reveals that this phenomenon is driven by the simultaneous initiation of multiple parallel arcs across a single dry band, resulting in a higher cumulative electrode voltage drop. Finally, a critical effective width of approximately 8 cm was identified as a baseline threshold required for steady partial discharge propagation. These findings offer valuable insights for optimizing the profile design of high-voltage outdoor insulators.

KEYWORDS

Discharges
Voltage
Glass
Plane
Creepage distance
Insulator

ARTICLE HISTORY	Received	Revised	Accepted	Published
	12 Apr 2026	09 Jul 2026	11 Aug 2026	19 Sept 2026

1 Introduction

The While in use, line insulators must withstand a wide range of voltage magnitude under normal operating conditions, as well as surge transients imposed by lightning strikes and switching operations. Ceramic insulation systems, such as glass and porcelain insulators, have been in use for more than 100 years [1, 2].

In polluted environments with high moisture levels, electrical discharges will develop on the insulator surfaces, coupled with the high electric field, trigger electrical discharges. The discharges may elongate over many dry bands and, consequently, may lead to complete flashover [3].

The insulator perimeter considered one of the dominant factors involved in the development of discharges on its surface. That is, in the case of small diameter insulator the flashover occurs just after the formation and the propagation of a discharge on its surface. However, for the large insulators when contaminated uniformly, several parallel partial arcs can observed [4]. These arcs can grow and may develop to a full flashover. Therefore, this parameter will dictate the insulator flashover performance [5].

This paper, in continuation with the previous researches on the electrical characteristic of polluted insulator [6,7], presents findings of experiments which allow quantifying the effects of the pollution on glass insulation, the degree of its contamination and the electrode system configuration (plane- plane) on the development of the parallel and independent discharges until the full flashover of the insulator when an AC voltage is applied [8]. The results of this experimental investigation described in this paper and the main parameter considered is the flashover voltage.

2 Experimental Setup and Test Procedure

The experimental model, illustrated in Figure 1, is a plane-plane electrodes system, the electrodes are made up of iron have the shape of a half cylinder of 4 cm diameter and are of different lengths. The inter-electrodes distance (l_f) is kept constant during the tests and is equal to 10 cm.

The insulating specimens are made of 5 mm thick glass and are of rectangular shape, the dimensions of which are 20 cm x 32 cm.

The composition of a glass insulator depends on the desired properties. It is manufactured by melting a mixture of sand, lime, and sodium carbonate in crucibles heated to a red-hot temperature of 900°C, the characterization of the flat insulator performance was carried in Table 1.

The resulting liquid, which is not very fluid, is poured into steel molds shaped to match the insulators. Chemically, glass is a mixture of alkali silicate and calcium or lead.

A suspension is prepared using the following composition consisting of: distilled or tap water, 20 g of kaolin per liter and a suitable amount of NaCl of commercial purity. The desired volume conductivity is reached by adjusting the amount of salt in the solution [9]. The obtained electrical conductivity of the prepared solution was measured and found between 17 µS/cm and 10 mS / cm. The application of the pollution layer on the hydrophilic sample is carried out according to the international standards (Tests performed under artificial pollution conditions based on the solid layer method of IEC 60507). The polluted bandwidth is varied between 4 and 32 cm.

During the laboratory tests, the maximum dispersion affecting the measurement of the flashover voltage between each value of the 25 tests and the average value is kept

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within 5% margin. Moreover, the disruptive discharge voltage measured in given test conditions (temperature (T), pressure (P), humidity (H)) is converted to the equivalent value under the standard reference atmospheric conditions (T0=20 °C, P0=101.3 kPa, H0=11 g/m^3) [10].

Table 1. Glass characteristics.

Characteristics	Value
Dielectric strength	50 to 100 kV/mm et 0.5 until 1 kV/mm to 400° C
Relative permittivity	5 to 8
Resistivity at 20° C	10^{10} to 10^{16} Ω·cm

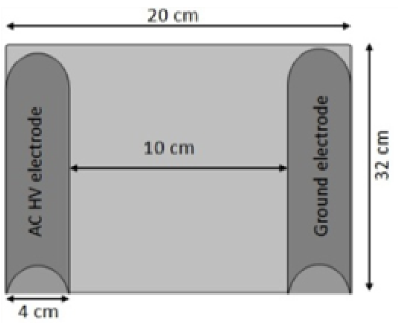


Fig.1. View of the studied configurations.

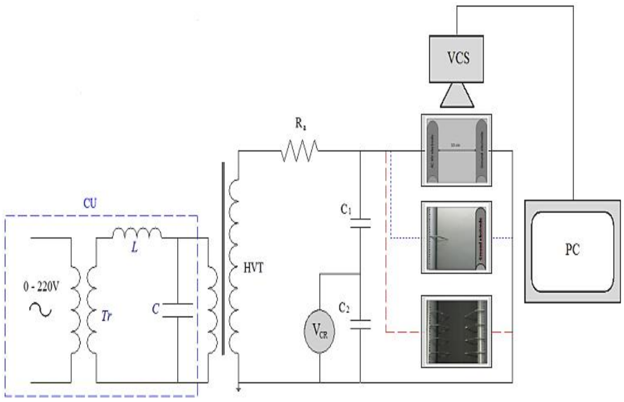


Fig. 2. Laboratory test setup.

The AC test circuit, used in this study Figure 2, consists of a 135 kV ; 8 kVA HV transformer (Tr) connected to the autotransformer integrated in SG and which allows the voltage to be adjusted to the desired value. A maximum allowed secondary voltage is 135 kV. A control unit (CU) for adjusting the speed ramp. A peak voltmeter (Vcr) across the low voltage arm of the capacitive divider (C1, C2) to measure the flashover voltage. A protection resistance (Ra) of about 106 kΩ was connected in series with test object (To). A video camera system was then used to visualize and record the development of the electrical discharge along the sample surface from inception to full flashover.

For a given contamination severity, it might be thought that flashover voltage would decrease indefinitely with increasing diameter of insulator because the overall resistance [11], which limits the arc current, would also decrease similarly and hence the Lf required for any profile has to be increased. However, an increase in diameter does not reduce the FOV correspondingly. This may be due to the fact that more than one arc can initiate across a single dry band, causing a higher electrode voltage drop that partially compensates for the decrease in the FOV.

As mentioned before, the work focus on the behavior of parallel discharges developed on the polluted plane model during the flashover process and on the critical discharge width just before the insulator flashover. A uniformly deposited layer with different conductivities and widths covers the insulator. In the same time, obtaining an equivalence between multi rods-rods and plane-plane configurations. To understand clearly the flashover mechanism from the beginning of the discharge phenomena until the final electric arc it is necessary to consider both the important parameters namely the bandwidth and the number of parallel discharges [12].

3 Results and Discussion

To this end, we have chosen two conductivity values of the pollution solution. The first is taken as $\sigma_{v1} = 17\ \mu S/cm$ and the second is equal to $\sigma_{v2} = 10\ mS/cm$.

3.1 Effect of creepage distance on flashover voltage

The interest of this study is the importance of variation of the creepage distance on the flashover voltage of the glass insulator. In the case of a clean and polluted insulating surface, we found that the higher of the leakage length, the greater of the insulation flashover voltage regardless of the configuration of the electrodes studied, which is logical since the flashover of a large area requires a longer duration than that of a small area [10, 13].

It is interesting to note in Figure 3 that for the creepage distance (l_{f1} =5cm), the formation of two dry zones, one at the level of the high voltage electrode and the other in the vicinity of the earth electrode. However, for (l_{f2} =10 cm) the presence of three dry zones was noted, the first at the high voltage electrode, the second within the mass electrode and the third in the middle of the inter-electrode surface. According to Erler [14], the more the number of dry zones increases, the greater the value of the flashover voltage.

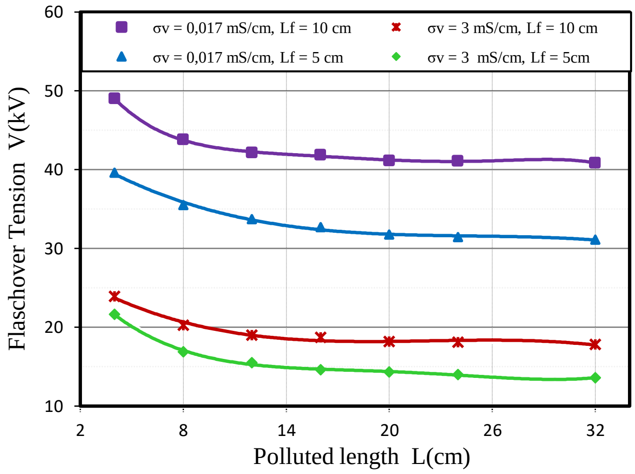
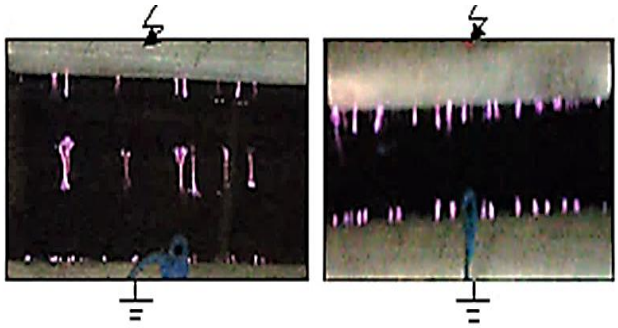


Fig.3. Flashover voltage versus creepage distance length.

The critical length of the arc just before the flashover; this is the limiting length of the partial arc beyond which the arc will lead to total flashover. The critical lengths of the parallel arcs for each conductivity are shown in Figure 4.



a) l_{f1} = 10 cm, three dry zones b) l_{f2} = 5 cm, two dry zones

Fig.4. Configuration of dry zones for two different distance values.

3.2 Identification of the electrods system formed by the plane model

To identify the electrode system, the flashover tests for inter-electrode distances l_{f1}=10 cm, which corresponds to the dry flashover distance, and l_{f2} = 5 cm, which corresponds to the leakage distance under polluted conditions.

The expression (1) for the flashover voltage is:

$$V_c = 3.16 * l_f + 14 \quad (1)$$

l_f : inter-electrode distance.

Table 2. Flashover voltage values.

Test		Average (by expression (1))	Average (experimentally)
Voltage (kV)	l_{f1} = 5 cm	29.8	29.9
	l_{f2} = 10 cm	45.6	47

It is found from formula 1 that the flashover voltage is 29.8 kV for l_{f1} and 45.6 kV for l_{f2}. These values are relatively close to the results obtained experimentally as illustred in Table 2.

3.3 Study of critical length

The maximum critical length of the parallel discharge is 56% of the total leakage length and for the lowest conductivity 17 µS/cm is 47 % as shown in Figure 5. For high conductivities, the critical length of the parallel discharge is 25% for 10 mS/cm. This leads us to say that the critical length of the discharge decreases non-linearly with the increase in conductivity which is due to the decrease in the resistive effect of the width. This reduction is caused by the appearance of arcs over the entire polluted surface which favors, at low voltages, the creation of an ionized channel along which the final discharge will progress [10].

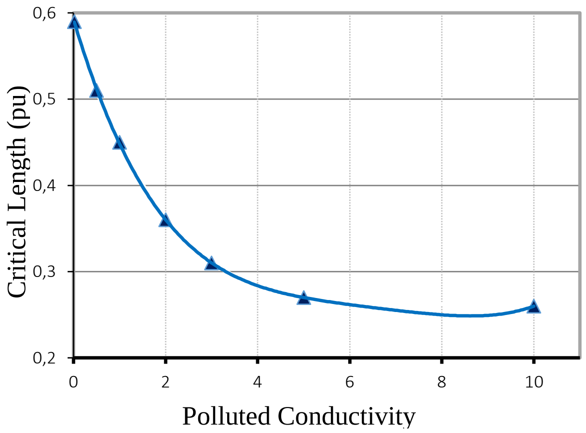
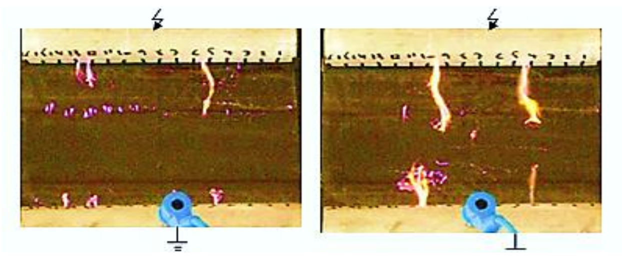


Fig.5. Critical length of parallel discharges.



a) σ_{v1} = 10 mS/cm b) σ_{v2} = 17 µS/cm

Fig.6. Critical lengths.

The reduction of the critical discharge length is explained by the increase in dry bands on the polluted surface formed by the discharges.

These gaps result in an increase in the resistance of the dielectric insulation and, therefore, a decrease in the critical discharge length before flashover as the conductivity increases. For the highest conductivity (10 mS/cm), the reduction in the critical discharge length caused by electric arcs appearing on the polluted surface [15].

These arcs begin to appear and participate in the formation of an ionized channel through which the parallel discharge extends to its critical length and causes total bypass as shown in Figure 6.

4 Conclusion

In this work, extensive tests carried out characterizing the effective width of partial parallel electric discharges evolving independently on a large insulating surface under AC voltage. Tests performed under artificial pollution conditions based on the solid layer method of IEC 60507 taking into account the influence of several parameters such as the polluted width, the length of the leakage path, the conductivity and the electrode system configurations.

This study is interesting to shows the importance of variation in the creepage distance on the flashover voltage of the glass insulator. In the case of a clean and polluted insulating surface, we found that the greater the creepage length, the greater the flashover voltage of the insulation, regardless of the configuration of the electrodes studied, which is logical since flashover a large surface requires a longer time than flashover a small surface.

From the data collected from tests presented in this work, it can concluded that the insulator periphery plays a significant role in contributing to the development of discharges on its surface and greatly affect the flashover voltage and the number of parallel arcs. These results showed that only a single electric arc propagates until flashover for small insulator when contaminated uniformly. However, several parallel partial arcs observed for large insulators.

The critical length of the discharge decreases non-linearly with the increase in conductivity, which is due to the decrease in the resistive effect of the width. This reduction is caused by the appearance of arcs over the entire polluted surface which favors, at low voltages, the creation of an ionized channel along which the final discharge will progress.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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