AIR BREAKDOWN IN THE VICINITY OF FLASHOVER DISCHARGE

A.OUIS S.FLAZI H.HADI
University of Science and Technology of Oran Mohamed Boudiaf,
Faculty of Electrical Engineering, Electrical Engineering Laboratory of Oran (LGEO)
BP 1505 EL M'naouer Oran 31000, Algeria, Tel/Fax: +213-41-560341
E-mails: oameldz@yahoo.fr flazis@yahoo.fr hadihocine@yahoo.com

Abstract: *The study of flashover phenomenon of the outdoors insulators showed that the flashover evolution is a progressive breakdown of the air, between the electric discharge and the wet pollution deposit on the insulator surface. To understand the mechanism of this evolution, an experimental study was carried out, in positive and negative polarity, in order to measure the dielectric rigidity represented by the critical distance of an air interval between the discharge and wet pollution, according to the following parameters: Electrolyte resistivity, nature of the electrode opposite to the discharge and initial discharge current. Next to that, a simulation study was then carried out to assess the electric-field distribution in the interval between the electric discharge and the electrolyte surface, and to determine the maximum field value in the vicinity of the discharge that corresponds to the experimental breakdown conditions.*

The obtained results show that the discharge current acts directly on the breakdown voltage, with a relatively weak electric field strength and a significant time lag to breakdown. We found that the initiation and the evolution of the streamer to the vicinity of the discharge compared to a metal electrode necessitate a feebler field strength, which is explained by the means of heat near the discharge, of photo-ionization and space charge caused by the discharge.

Key words: *Outdoors insulators, pollution, electrical discharge, flashover, air breakdown, electrical field, dielectric rigidity, Streamer.*

1. Introduction

To be able to study the flashover phenomenon, i.e. the phenomenon of the discharge elongation on the pollution surface of outdoor insulator, several experimental models were used having a simple geometry [1-13] which represent the discharge in series with the pollution resistance as it is shown in figure1, where by the insulator pollution is simulated using the resistance of electrolyte solution or the ice [14-15].

The experimental results obtained, from these simple models and / or those of the theoretical studies carried out on their equivalent electrical circuits, showed that the flashover evolution is a progressive breakdown of the air between the electric discharge and the layer of wet pollution deposited on the insulator surface [16-18] as it shows on figure1.

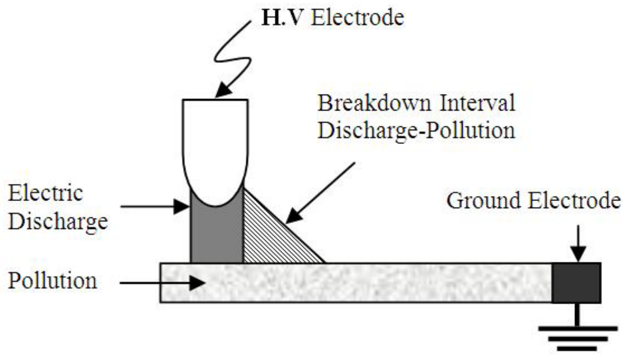

Fig. 1. Interval between flashover discharge and pollution

But the mechanism of this breakdown is not yet well defined; more precisely, the influence of the discharge on the dielectric rigidity of the air in its vicinity is not yet well known. The objective of the present work is to study this influence.

For that, we performed an experimental study on an interval between an electric discharge and a surface of wet pollution (figure 2).

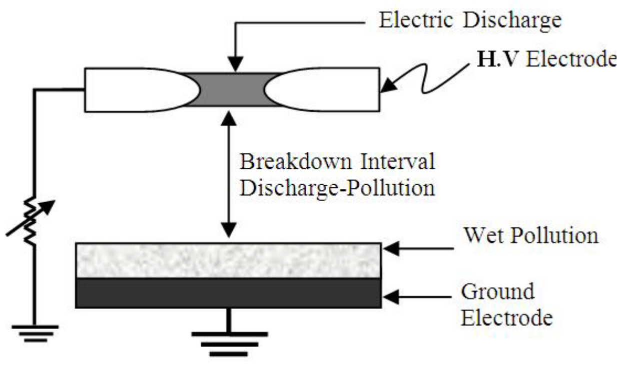

Fig. 2. Interval between the discharge and the pollution

We measured the dielectric rigidity of the studied interval under constant voltage in positive and negative polarity. This rigidity is represented by the distance (dc) of breakdown between the surface of the discharge and the surface of the pollution.
Next to that, a simulation study was then carried out to assess the electric-field distribution in the interval between the electric discharge and the electrolyte surface, and to determine the maximum field value in the vicinity of the discharge that corresponds to the experimental breakdown conditions. The calculation of the electrical field was performed using calculation software called FEMLAB version 3.5 Multip Physics (Implementing the FEM).

2. Experimental Study

Several experiments were made, in positive and negative polarity, in order to measure the dielectric rigidity of the air represented by the critical distance (dc) under the influence of the following parameters:

- Electrolyte resistivity;
- Nature of the electrode opposite to the discharge;
- Initial current of the discharge.

2.1. Description of the experimental set

The experimental set [10] is represented on figure 3; it is composed mainly of an electric discharge and a cylindrical tube.

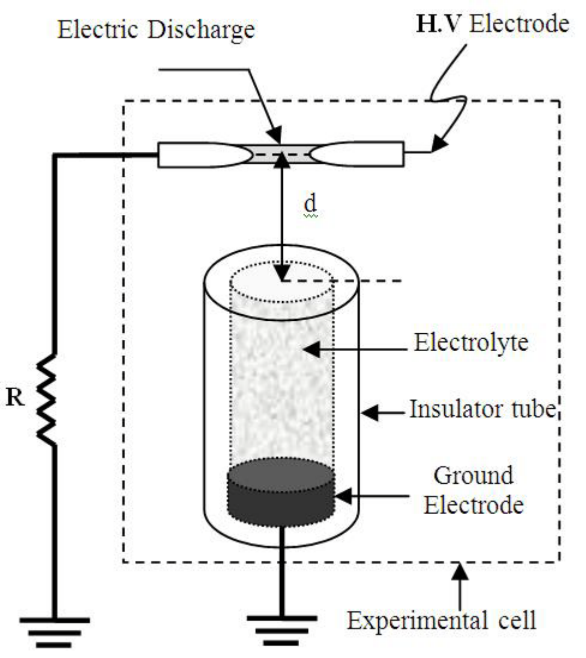

Fig. 3. Experimental set

The electric discharge is created between two pointed copper electrodes 8mm in diameter. The distance between the electrodes is maintained constant and equal to 3mm. One of these electrodes is connected to the high voltage (H.V) and the other is connected to the ground by a variable resistance R to control the current (I_{d1}) of the electric discharge.

The cylindrical tube is made of plexiglas, has an interior radius of 6mm, a height of 5cm, filled by an electrolyte (Nacl+ H_2O) of a given resistivity. A ground metal electrode was placed at the bottom of the tube.

2.2. Experimental conditions and procedure

The HVDC-generator (DC high voltage generator) used is a battery of HV-condensers (30kV) of 16.7µF, charged by a small current HV-generator of I_{max}=150mA and V_{max}=30kV.

The diagnostics tools used were: HV probe of Tektronix type P6015 – 1000 X-3 pF 1000 MΩ - 20 kV DC, LV probe type BNC 1X and digital storage oscilloscope of LEADER type LBO-5825- 0.2µs to 0.5s/ div.

The atmospheric conditions at the time of the experiments were as follows: The pressure was between 998 and 1022hPa; the temperature was between 17° and 20°C and the relative humidity between 62 and 80%.

A constant DC voltage of 11kV is applied to the high voltage electrode. The first electric discharge starts between the two copper electrodes with the desired current I_{d1} regulated by the resistance R.

We gradually decrease the distance (d) between the axis of the discharge and the electrolyte surface until breakdown, a second discharge appears between the first discharge and the electrolyte surface after a time lag (t).

The critical distance (d_c) between the surface of the first discharge and the surface of the electrolyte can be deduced from the relationship (1):

$$d_c = d - r_d \quad (1)$$

Where
r_d is the radius of the discharge calculated by the relationship (2) as a function of the discharge current I_{d1} [16, 20].

$$r_d = \sqrt{\frac{I_d}{D.\pi}} \quad (2)$$

Where
D is current density ($A.cm^{-2}$)

In the case of direct current and one atmospheric pressure the current density in the positive column of the discharge is equal to $1.45A.cm^{-2}$, as it determined experimentally by Wilkins [16].

2.3. Experimental results

2.3.1. Influence of the electrolyte resistivity

The electrolyte resistivity is a very significant parameter in the determination of the flashover critical conditions; it's directly related to the critical voltage [9, 21-23]. Does it influence the breakdown of the air in the vicinity of the discharge, or not? To answer this question, we used six values of resistivity ρ = 1, 2, 5, 10, 20 and 40kΩ.cm. In order to obtain an initial electric current of 300mA in the discharge, the resistance R (figure 3) was set at 30kΩ.

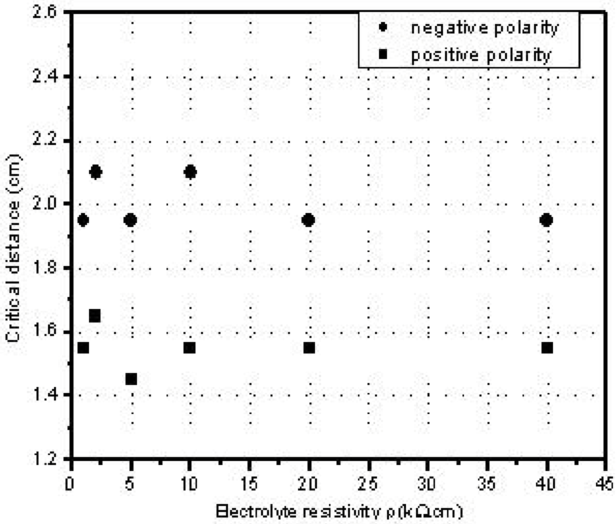

Fig. 4. Critical distance according to the electrolyte resistivity

Figure 4 shows the measured values of the critical distance (d_c) according to the electrolyte resistivity for positive and negative polarity, it may be observed that:

- The electrolyte resistivity does not have a significant influence on the critical distance (d_c).
- The critical distance (d_c) is longer for negative polarity than for positive one, it is around 2cm and 1.5cm respectively, i.e. the breakdown is easier for negative polarity than positive one.

2.3.2. Influence of the nature of the electrode opposite to the discharge

Having discovered that the resistivity of the electrolyte does not influence the breakdown, we proposed to check if the nature of the electrode opposite to the discharge influences the breakdown or not. We covered the electrolytic surface with a metal plate of 2cm wide on side. The initial current of the first discharge is maintained at 300mA.

Figure 5 shows the measured values of the critical distance (d_c) according to electrolyte resistivity for positive and negative polarities, it may be observed that the results obtained are practically the same results obtained without the metal plate as shown in figure 4.

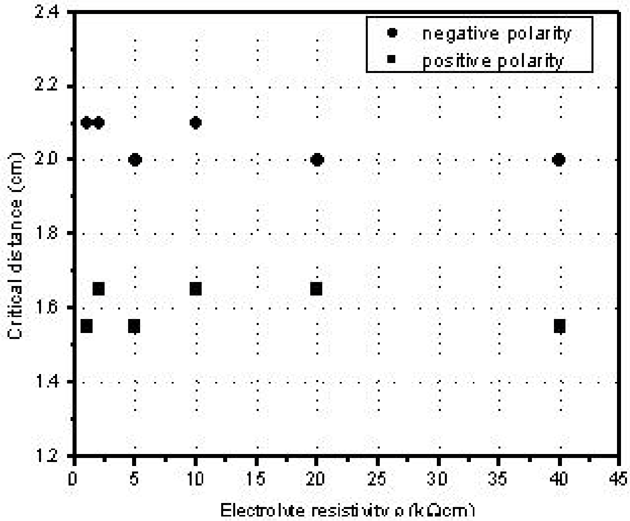

Fig. 5. Critical distance according to the resistivity of the electrolyte under the metal plate

2.3.3. Influence of initial discharge current

The values used for the initial current (I_{d1}) of the first discharge are: 10, 50, 100, 200, 300, 500 and 800mA, the electrolyte resistivity used is 5kΩ.cm.

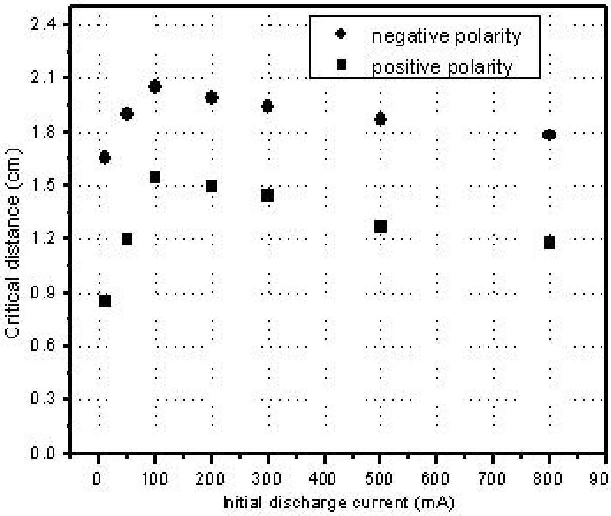

Fig. 6. Critical distance (dc) according to the initial current in the first discharge

Figure 6 presents the measured values of the critical distance (d_c) according to the initial current in the first discharge, it may be observed that:

- The dielectric rigidity of the air in the case of negative polarity is lower than that in the case of positive one for all current values.
- The critical distance (d_c) for both polarities

increases quickly with the discharge current, up to a certain value - about 100mA - where it starts to decrease slowly.

2.3.4. Time lag of formation of the second discharge

Figure 7 shows the current's waveforms of the first (I_{d1}) and second (I_{d2}) discharges. The initial current of the first discharge is fixed by R at 300mA.

The current of the second discharge appears after a time lag (t) between the start of the first discharge and the start of second discharge which represent the breakdown of the air interval. It is observed that the value of the measured time (t) is equal to 35ms, it's a very long time compared to the time of the appearance of a discharge given by the mechanism of Townsend which is about 10^{-5}s, or by the mechanism of Streamer which is about 10^{-7} –10^{-8} s [24].

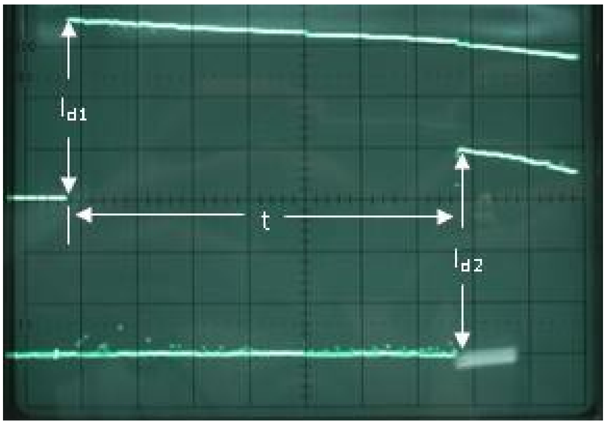

Fig. 7. Time lag of formation of the second discharge

I_{d1}: the initial current of the first discharge;
I_{d2}: the initial current of the second discharge;
t: time lag of the second discharge formation.

2.4. Analyses of the experimental results

The above results may be summarized as follows:

-The presence of an electric discharge weakened the dielectric rigidity of the air for both polarities.

-The air breakdown in the vicinity of the discharge is easier in negative polarity than it is in positive one, contrary to the breakdown conditions between metallic electrodes [25-27].This results confirms that found by the following references [28-30].

-The time lag of the formation of the second discharge (the time to breakdown) is very large compared to the time given by the mechanism of Townsend or Streamer.

-Between the studied parameters, only the initial current of the discharge has a remarkable influence on the breakdown of the air in its vicinity, this result confirms the work published in reference [31-34].

We know now that the electric discharge has a big influence on the rigidity of the air but we don't know the mechanism of this influence, we don't know how a discharge weakens the dielectric rigidity of the air, and how it influences the mechanism of breakdown.

Knowing that the electric field is the first actor in the breakdown process, we thought it would be useful to study the distribution of the electric field in the studied interval while subjected to the breakdown conditions.

3. Simulation study

The calculation of the electric-field distribution in the air gap between the discharge and the electrolyte surface was performed using calculation software called FEMLAB version 3.5 (multidisciplinary computer code based on the finite elements method and operating under MATLAB).

3.1. Simulation procedures

The algorithm of electric field calculation by using FEMLAB is shown on figure 8.

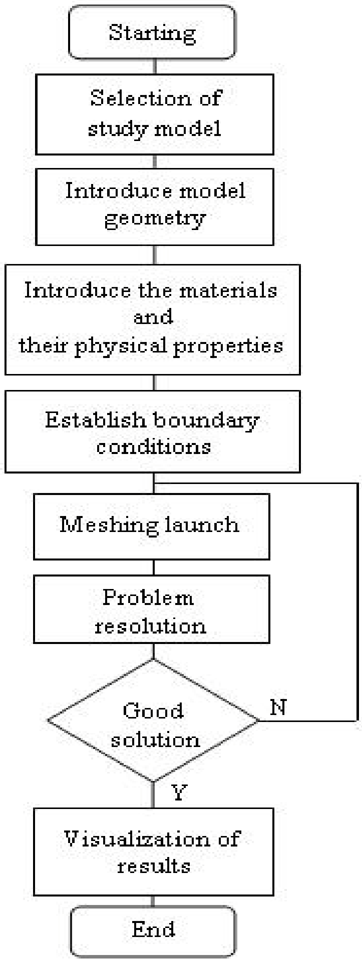

Fig. 8. The stages of electric field calculation

- The selection of the study model: The problem was solved out under an electrostatic model 2D. by using the following operations under FEMLAB (multidisciplinary computer code based on the method: finite elements, operating under MATLAB):
- Introduce the geometry model of the experimental cell:

-The geometry of the cell is introduced by using the dimensions corresponding to each experimental point (d_c and r_d), the diameter of the discharge (r_d) is calculated by equation (2).

-The artificial boundary is defined to be three to five times the diameter dimension of the tube. At this boundary, it is assumed that the electric field dies down to zero. Figure 9 shows the model with the artificial boundary.

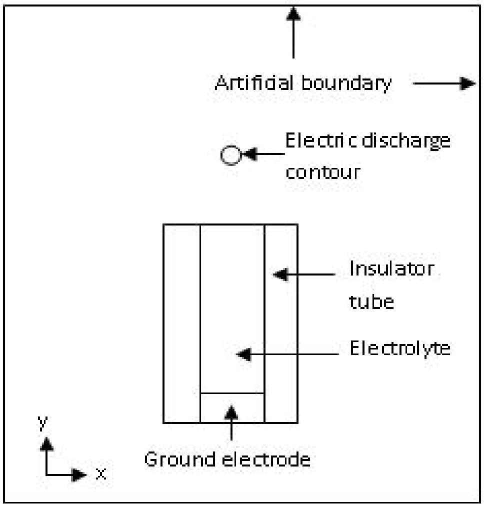

Fig. 9. The model of experimental set with artificial boundary

- Define the different materials and their physical properties introduced in the model:

-The conductivity and the permittivity of the electric discharge, the electrolyte, the insulator tube and the metallic ground electrode are defined in table 1.

Table 1
Conductivity and permittivity adopted for the simulation

Model	Materials	Permittivity (εr)	Conductivity (S/m)
Electrostatic	Electric discharge	1	0.0051
	Insulator tube	3.3	10^{-10}
	Electrolyte	1	1 ;0.5 ;0.2 ;0.1 0.05 ;0.025
	Gound electrode	1	$5.8x10^{7}$

- Establish the boundary conditions:

The boundary conditions are preset in the graphical interface; it must only select the conditions which are appropriate.

- A constant DC voltage (11kV) was applied to the discharge contour.

- Zero volts were applied to the electrolyte surface, the metallic electrode is considered as ground.

- Launch the meshing:

The meshing through the graphical interface (GUI) of FEMLAB is an automatic operation which remains only to ensure that the mesh is fine enough so that the result is the most precise possible.

- Solve the system of equations:

Finally the last stage is the launching of the automatic resolution of the problem through the graphical interface.

- Visualization of results.

3.2 Simulation results

3.2.1. Distribution of the electric field in the interval

An example of the electric field distribution along the principal axis between the surface of the discharge and the electrolyte is shown in figure 10.

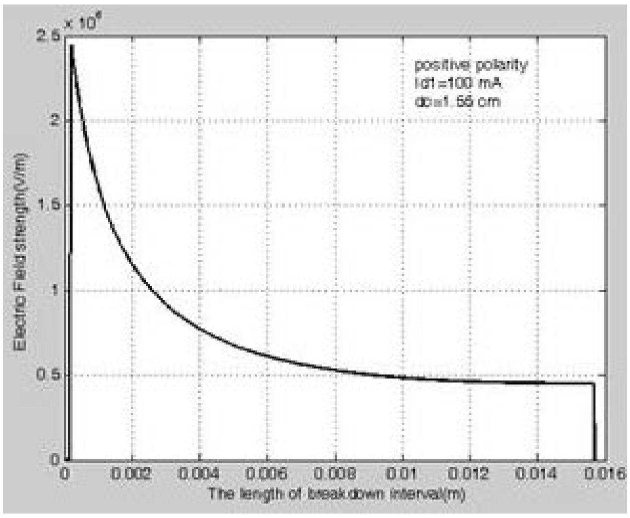

Fig. 10. Electric field distribution along the principal axis between the discharge surface and the electrolyte

It is noticed that the maximum value of the electric field (24.8kV/cm) is in the vicinity of the discharge surface.

The field value decreases gradually along the principal axis between the discharge and the electrolyte down to 5kV/cm near the electrolyte surface.

The maximum field value is lower than the disruptive field strength of the air in one atmospheric pressure (about 30kV/cm), which is necessary to carry out ionizing collisions.

For the next step, the critical strength of electric field in the vicinity of the discharge was calculated for various currents of the discharge to compare it with the disruptive field strength (30kV/cm).

3.2.2. Maximum field value according to the discharge current

By using the experimental results for positive and negative polarities of figure 6, we obtained figure 11 which shows the variation of the electric field value in the vicinity of the discharge in relation to its current.

It is clearly observed that, for the two polarities, the electric field decreases by increasing the intensity of the discharge current.

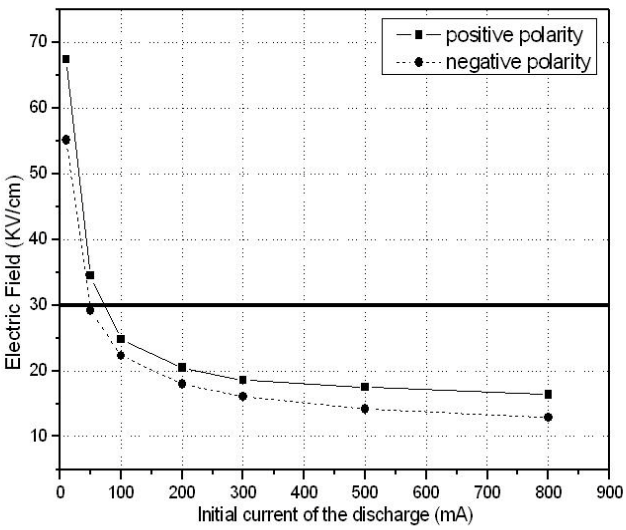

Fig. 11. Maximum field value according to the discharge current

Figure 11 also shows that the critical strength of the electric field for current values lower than 100mA is higher than the disruptive one, but it is lower for current values higher than 100mA.

3.3. Results and discussion

The easiness of the air breakdown in the interval discharge-electrolyte compared to the interval between two metal electrodes (point–plan) can be due to the influence of the electrical discharge on the air in its vicinity, by means of heat, of photo-ionization and space charge. The presence of these factors weakened the disruptive electrical field necessary for Streamer starting from the discharge to breakdown.

For that, the increase of electrical current values which increases the effect of weakening factors decreases the critical strength of electric field necessary for breakdown, like it's shown on the figure11.

The remarkable time lag of formation of the second discharge can be explained by the time necessary to the heat, photo-ionization and the space charge to take place.

The easiness of breakdown in the case of negative polarity compared to the positive one can be due to the easiness of electron emission from the discharge in the case of negative polarity. In this case the discharge is bombarded by positive ions but in other case the discharge is bombarded by electrons.

4. Conclusion

The study of the air breakdown in the vicinity of an electric discharge yielded three main results:

- The breakdown of the air in front of a discharge can be triggered by a low electric field strength which can reach values lower than 20kV/cm.
- Breakdown in the case of negative polarity occurs with an electric field strength less than that in the case of positive polarity and the breakdown time lag is a some tens of ms.

These results may be explained as follows:

- The facility of Streamer starting from the discharge to interval breakdown can be due to the influence of the discharge on the air in its vicinity, by heating, photo ionisation and space charge formation during the important time lag.
- The facility of breakdown in the case of negative polarity compared to the positive one can be due to the facility of electron emission in the case of negative polarity.

The results obtained in this work clarify the physical phenomenon responsible for the discharge propagation. But to confirm that the same mechanism is reproduced in the flashover phenomenon of the outdoors insulators, we proposed to carried out an experimental and theoretical studies, about the air breakdown between an electric discharge in series with pollution surface, as it shows on figure1, by taking into account the anatomy of the discharge (anode region, cathode region and the positive column).

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