Factors affecting the breakdown of air gap between a discharge and ice-plane or wet-plane surfaces

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***Abstract* - The main objective of the present study is to further our understanding about elongation mechanism of flashover discharge and breakdown mechanism in the vicinity of an electric discharge. Breakdown tests on an air gap between an electrical discharge and an ice surface or an electrolyte one were carried out. The critical breakdown length of the air gap was determined under constant DC- positive and negative polarity of 10 kV, using a discharge of 3mm length and a variable discharge current intensity ranging from 10 to 400mA for the conductivities 400µs.cm^{-1} and 50µs.cm^{-1} of the freezing water and wet- pollution. The critical maximum field strength in the vicinity of the discharge was calculated and compared with the disruptive field strength. A new mechanism of air breakdown in the vicinity of the discharge is proposed.**

I. INTRODUCTION

The elongation mechanism of flashover was the subject of several works, various assumptions concerning the responsible mechanism were proposed. Wilkins and Albaghdadi [1] have proposed the mechanism of the elongation by discontinuous ionization and displacement of the foot of the discharge. The assumption of Jolly [2] is practically the same one as the preceding one; he regards flashover as being primarily a process of electric breakdown of the air. Rahal [3] proposes the mechanism of the electrostatic force which is exerted on the discharge and which may cause its elongation. All these assumptions consider that the discharge propagates while keeping its tubular form. Contrary to this dynamic tubular aspect of the discharge, the author [4]-[5] proved that it resembles an extended foot.

In spite of the presence of all these assumptions, the mechanism of the discharge evolution did not provide a convincing explanation. To explain this mechanism, given that this evolution is an air breakdown between the discharge and pollution started in the vicinity of the discharge, several studies [6]-[7]-[8] were made at the high voltage laboratory at the university of sciences and technology of Oran concerning air breakdown in the vicinity of an electric discharge.

The conclusion of these studies is as follows:

- The presence of the discharge weakens the dielectric rigidity of the air gap.
- The breakdown in negative polarity is easier than in positive polarity.
- The conductivity or the nature of the ground electrode has practically, no influence on the dielectric rigidity of the air gap.

Unfortunately the mechanism of the air breakdown in the vicinity of the discharge and that of flashover remains unspecified. To better understand, this mechanism, we studied in this work the factors affecting the air breakdown between an electric discharge and an electrolytic surface (Na Cl + H2O) in liquid state and ice state.

II. EXPERIMENTAL SET

The experimental set is represented in the Fig. 1. The discharge is started between two pointed copper electrodes of 8 mm diameter. The distance between electrodes is maintained constant and equal to 3 mm. Resistances R1and R2 are used to limit the discharge current and the breakdown current respectively.

The electrolyte or freezing water is filled in an insulating square vat of 100 cm^2 surface; ground electrode is put at the lower part of the square vat.

The applied voltage is fixed at 10 kV; the value of the discharge current used varies from 10 mA to 400 mA and the two values of electrolyte conductivities used were: 400µs.cm^{-1} and 50µs.cm^{-1}.

We used the set described previously to study the influence of discharge current, applied voltage polarity, electrolyte conductivity and its states (liquid or ice) on the dielectric rigidity of the air gap represented by its critical distance (dc) of breakdown.

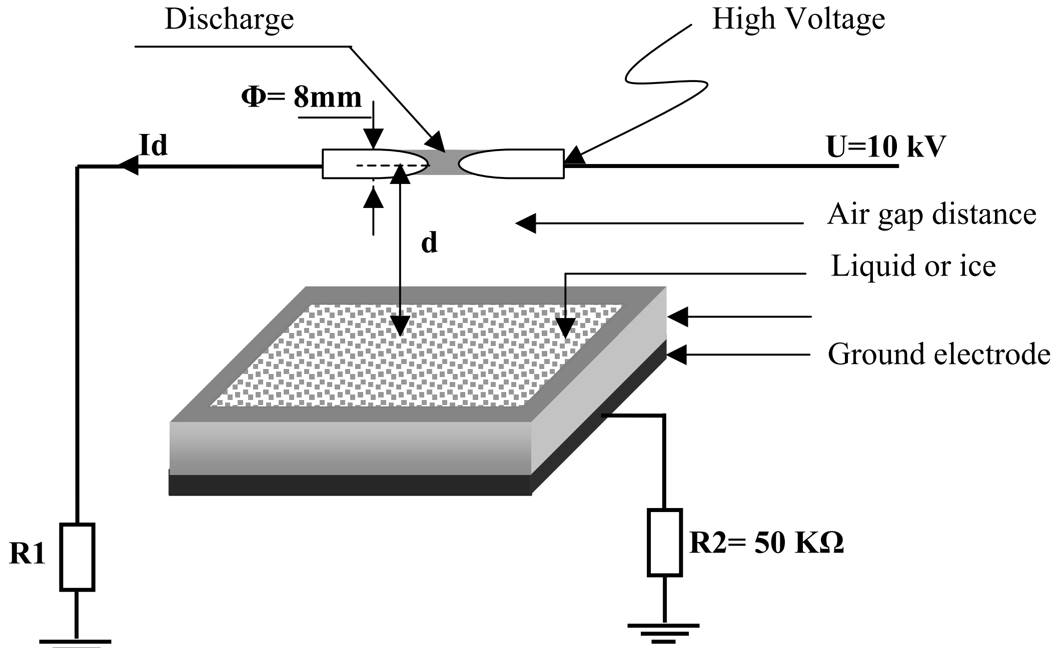

Fig. 1. Experimental set to study the influence of the electric discharge on the dielectric rigidity of the air.

III. EXPERIMENTAL RESULTS WITH LIQUID ELECTROLYTE

Fig. 2 shows the variation of the critical distance of breakdown as function of the discharge current for both polarities and the two conductivities.

It is noticed that: the critical distance in positive polarity increases with the increase in the discharge current for both conductivities of the electrolyte. In negative polarity it increases quickly with the increase in the discharge current up to a certain value, in the vicinity of 100 mA where it becomes constant. It is also noticed that the critical distance increases, imperceptibly, with the decrease in the electrolyte conductivity.

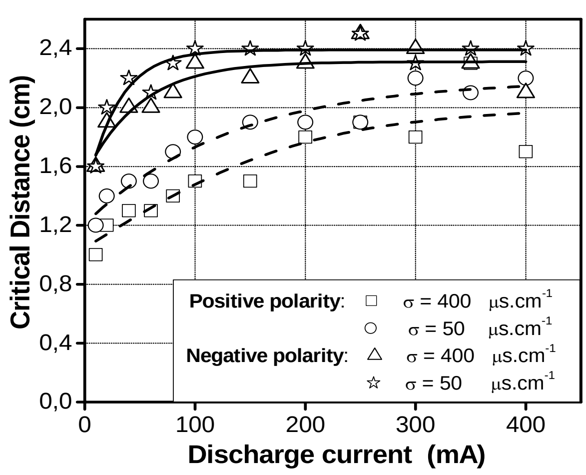

Fig. 2. The critical distance according to the discharge current for liquid electrolyte

The critical strength of electric field in the vicinity of the discharge was calculated for various critical cases to compare it with the disruptive field strength of the air in atmospheric pressure, which is about 30 kV. cm^{-1}.

It can be considered that the distribution of the electric field between the discharge and the electrolyte is roughly the same as that between a circular wire and a plane electrode. The maximum field strength in the vicinity of the discharge in critical conditions is thus calculated by the formula (1):

$$E\max c = \frac{U}{r_d \,.\ln\left(\frac{2.dc - r_d}{r_d}\right)} \qquad (1)$$

U: applied voltage (DC ±10 kV).
dc: Measured critical distance (cm)
rd: the ray of the discharge calculated by the formula (2) as a function of discharge current I_d.

$$r_d^{\,2} = \frac{I_d}{D\,.\pi} \qquad (2)$$

D: current density (A.cm^{-2})

In D.C. and atmospheric pressure the current density in the positive column of the discharge is equal to 1A.cm $^{-2}$ [3]-[9], in the foot of the discharge, it depends on the polarity and the nature of propagation surface. We recapitulated in Table I the values of current density which determined by a number of researchers.

In our case the most suited value is 1A.cm^{-2} because the discharge is between two metallic electrodes.

TABLE I
RECAPITULATION OF THE VALUES OF CURRENT DENSITY D ($A.cm^{-2}$) IN THE DISCHARGE

Positive column [3]-[9]		
1		
Polluted surface		
Wilkins [1]	Näche [10]	Pissolato [11]
1.45	1.27	1.5
Ice surface		
Positive polarity [12]		Negative polarity [12]
0.648		0.624

Fig. 3 shows the variation of the maximum field strength in critical conditions calculated by formula (1) according to the discharge current for both polarities and the two conductivities: σ =400 µs.cm^{-1} and σ = 50µs.cm^{-1}. It is noticed that the maximum critical field strength decreases with the increase of discharge current for both polarities and that in positive polarity it is slightly bigger than in negative polarity for σ =400 µs.cm^{-1} and indifferent for σ=50µs.cm^{-1}. The conductivity of electrolyte has a very small influence on the critical field strength, it is slightly bigger for σ=400µs.cm^{-1} then for σ=50 µs.cm^{-1}.

As per formula 1, the effect of arc diameter (rd) on the maximum strength of electric field Emaxc is much more significant than that of distance (dc). This is the reason why the critical distances are very different but the maximum strength of electric field calculated is very similar.

It is also noticed that for the values of discharge current greater than 50 mA, the value of the maximum critical field strength is smaller than 30 kV.cm^{-1} for both polarities, it reaches 11 kV.cm^{-1} for Id = 400 mA. It is a very weak value in comparison with the disruptive field value.

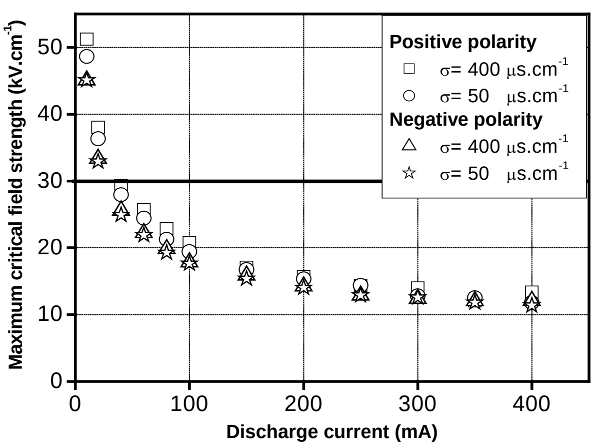

Fig. 3. The maximum critical field strength according to the discharge current for liquid electrolyte

IV. EXPERIMENTAL RESULTS WITH ICE

Fig. 4 shows the variation of the critical distance according to the discharge current for both polarities and the two conductivities. It is noticed that: for a conductivity of the freezing water equal to 400 µs.cm^{-1} in positive polarity, the critical distance increases with the increase of the discharge current up to a certain value where it becomes constant, in negative polarity the critical distance presents a very important peak for Id = 200 mA.

For a conductivity of the freezing water of 50µs.cm^{-1} in positive polarity the critical distance increases slightly with the increase of discharge current. In negative polarity one notices an abrupt increase followed by a reduction in the distance according to the discharge current. The peak value is very important for Id=200 mA.

In both polarities we noticed a difference in the critical distances according to the freezing water conductivity; the most elevated distance corresponds to smaller conductivity. A difference also exists between the two polarities; the biggest distances correspond to the negative polarity.

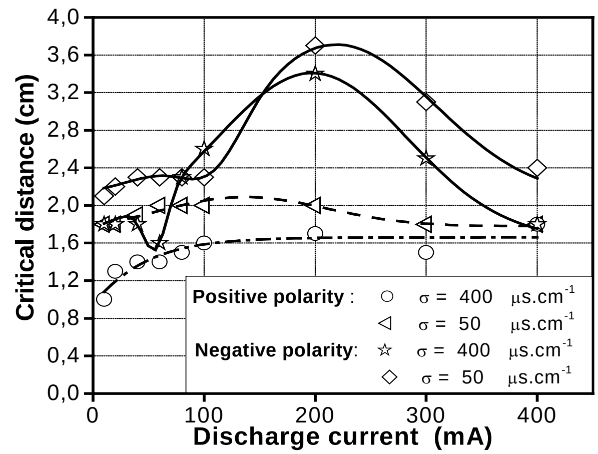

Fig. 4: The critical distance according to the discharge current for ice case

Fig. 5 shows the variation of the maximum field strength in critical conditions calculated by formula (1) according to the discharge current for both polarities and the two conductivities of freezing water.

It is noticed that the maximum critical field strength decreases with the increase of the discharge current for both polarities. In positive polarity it is slightly bigger than in negative polarity for σ=400µs.cm^{-1}, but indifferent for σ=50µs.cm^{-1}. The conductivity of the freezing water has very small influence in positive polarity and indifferent in negative polarity.

It is also noticed that for the values of discharge current greater than 50 mA, the value of the maximum critical field

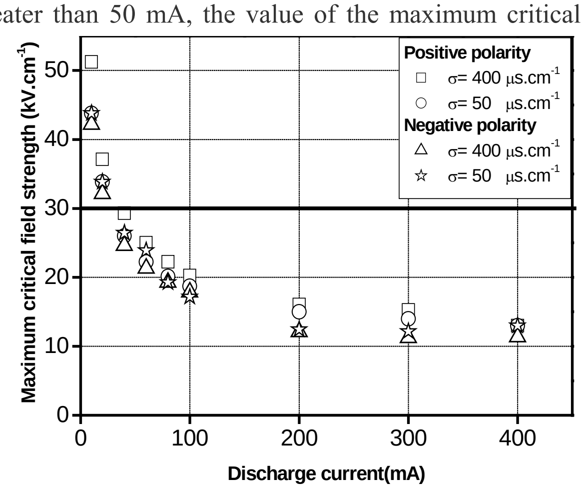

Fig. 5. The maximum critical field strength according to the discharge current for ice

strength is smaller than 30 kV.cm^{-1} for both polarities reaching 11 kV.cm^{-1} for Id = 400 mA. It is a very weak value in comparison with the disruptive field value.

V. COMPARISON BETWEEN LIQUID AND ICE

Fig. 6 and 7 show the variation in the maximum field strength in critical conditions according to the discharge current for both polarities and for the two conductivities: σ=400µs.cm^{-1} and σ=50µs.cm^{-1} respectively.

The maximum critical field strength is indifferent for the cases of positive polarity with σ=50µs.cm^{-1} and negative polarity with σ=400µs.cm^{-1}, for another cases it is slightly greater in liquid case than in the ice case.

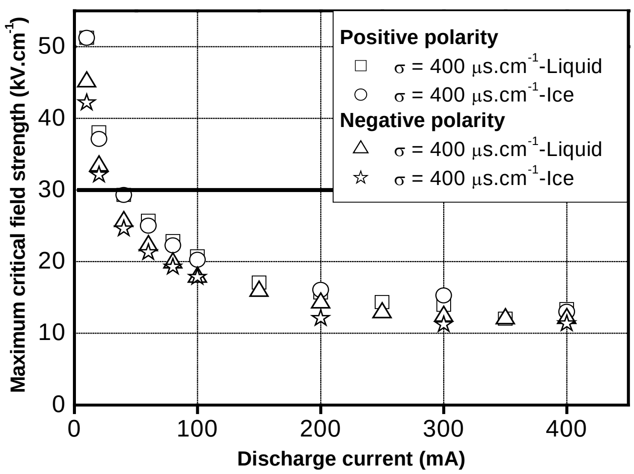

Fig. 6. The maximum critical field strength according to the discharge current for the two cases and for the both polarities with σ = 400µs.cm^{-1}

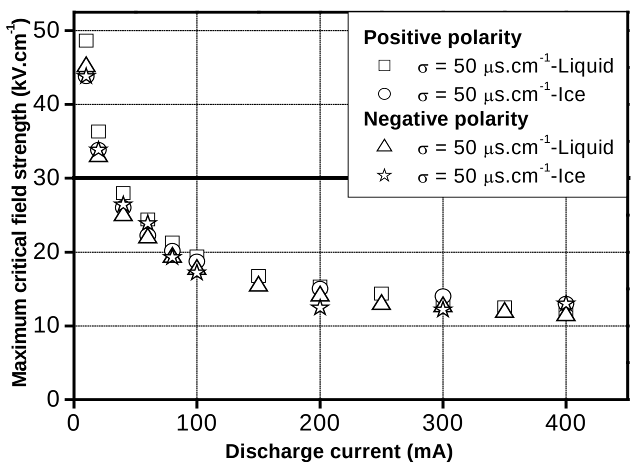

Fig.7. The maximum critical field strength according to the discharge current for the two cases and for the both polarities with σ = 50 µs.cm^{-1}

VI. RESULTS INTERPRETATION AND ANALYSIS

We saw that: The breakdown of an air gap between an electrical discharge and an ice surface or an electrolyte one occurs, even at values of the maximum field strength that are much lower than the disruptive field strength. These results are unexplainable by the mechanism of Townsend or streamer. Our explanation or our mechanism proposed is that the critical field tears off the plasma of the discharge thus creating a channel strongly ionized along the air gap. This channel becomes the discharge of the air gap breakdown.

VII. CONCLUSION

- The presence of the discharge weakens the dielectric rigidity of the air gap, it breakdown occurs even at values of the maximum field strength that are much lower than the disruptive field strength. This conclusion is valid not only for the value of current density of 1A.cm^{-2} but also for all the values in Table I. The mechanism of Townsend or streamer can't explain this breakdown since the value of the maximum strength of electric field is much smaller than the disruptive field strength. Our proposed explanation or mechanism is that: in the critical conditions the external field tears off the plasma of the discharge thus creating an ionized channel along the air gap between the discharge and electrolyte, this channel becomes the discharge of the air gap breakdown.
- The maximum critical field strength decrease with the increase of discharge current for both polarities, the two conductivities and for the two cases, liquid and ice.
- In positive polarity and in the two cases, liquid and ice, the maximum critical field strength is slightly greater than in negative polarity for σ=400µs.cm^{-1}, for σ=50µs.cm^{-1} it is indifferent.
- For σ=400µs.cm^{-1} the maximum critical field strength is slightly greater than for σ=50µs.cm^{-1} for both polarities in liquid case and for negative polarity in ice case.

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