The profile of the electric field on the earth discontinuity with a lightning conductor

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Abstract: *In this paper, we present some results of investigations carried out in the electric field distribution of both horizontal and vertical lightning conductors in the case of discontinuous earth. The conductors may be situated as well as in the upper or the lower earth part. The electric field distribution was determined in the case of lightning conductor situated between the high voltage rod and the discontinuity (interface) and also in the case of high voltage rod situated between the lightning conductor and the discontinuity. In some situations the electric field distribution on the plan are smaller than defined by the electro-geometrical model. We attribute this result to the great field intensity at the discontinuity, which reduce the lightning conductor discharge capture effect. This is in concordance with the results concerning the electrical strength of such air gaps without lightning conductors.*

Keywords: *the electric field, Discontinuous earth Electrogeometrical model, Vertical lightning conductor, Horizontal lightning conductor.*

Nomenclature

H: height
D : distance between its axis and the interface
$U_{0\%}$: applied voltage

1. Introduction

The electrogeometrical model represents a widely used method for the determination of the electric field distribution of a lightning conductor. This method does not take in amount the ground nature. The earth electrogeological properties are in fact very important in the predetermination of the lightning impact points. To examine the influence of these properties, some investigations have been carried out to determine the capture zones of horizontal and vertical earthed rods in the case of the heterogeneous or homogeneous and bad conducting earths [1, 2]. It has been found that the capture zones of a lightning conductor could be, in general, greater than defined by the classical electrogeometrical model [1, 2].

To explain the variations of electric field distribution, it has been studied the electric strength of rod-plane air gaps under negative lightning impulse voltage. Both heterogeneous and discontinuous earths were studied. It has been observed that the discharge phenomena are different as found in the case of air gaps with conducting homogeneous earth [3, 4]. This led us to do experiments to determent the electric field distribution on the discontinuous earth with a vertical and a horizontal lightning conductor [5, 6].

In this paper, we present a comparison between the different results obtained with and without lightning conductor on the discontinuous earth. The electric field distribution was determined experimentally, using a laboratory experimental model.

2   EXPERIMENTAL SET UP

The studied earth called "discontinuous earth" is made up of a square metallic sheet with 4 mm thickness and having two different levels of respective surface 1x1 m^2 (figure 1a or lb). The lightning discharge at its final jump is simulated by an iron rod, whose diameter equals 4.8 mm. This electrode is connected to a lightning pulse generator of 600 kV, 4 kJ.

The position of the rod is determined by its height (h) compared to the earth and the distance (D) between its axis and the interface. This distance is considered positive when the rod is located above the high and negative part in the other case. The distances h are the same one as in homogeneous system, but the distances d and D is selected so that the tests are carried out for d/h ratio and respectively identical D/h for various values of h. The applied voltage level to use is 0.3$U_{0\%}$ of the rod-plane corresponding system, at each selected distance h. For a given height h, we as well apply the same applied voltage level for the rod located above the high part as above the low part of the discontinuous plane.

Thus it is the same level of applied voltage $U_{0\%}$ which is taken into account for a given height h and the corresponding height h+e when the rod is located above the low part of the discontinuous plan. We are interesting to the $U_{0\%}$ voltage of disruptive discharge in order to determine the voltage level of selected test equal to 0.3$U_{0\%}$. This applied voltage level allow to avoid the disruptive discharges on the level of the probe because of its sensitivity to the high currents [7, 8].

During tests, the $U_{0\%}$ breakdown voltage is determined by the constant multiple steps method. To find this voltage we have used a Gaussian arithmetic scale paper.

In this work, we have studied all possible configurations according to the lightning conductor position upon the higher or the lower part of the discontinuous earth. We present in this paper results concerning both cases of horizontal and vertical lightning conductors [9, 10].
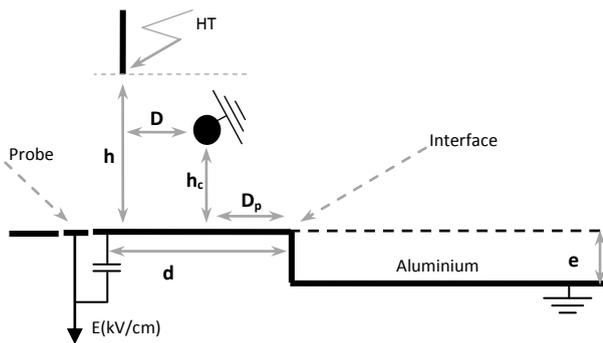

Fig.1a .Configuration with discontinuous earth for a horizontal lightning conductor
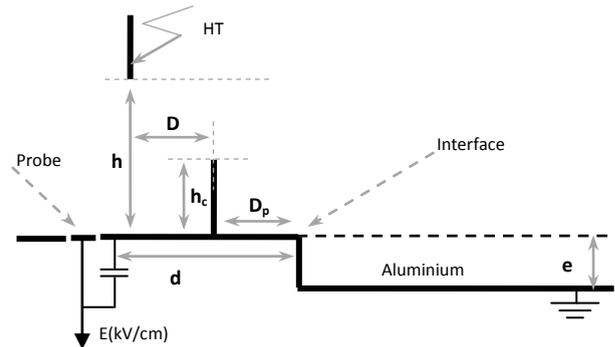

Fig. 1b. Configuration with discontinuous earth for a vertical lightning conductor

The electric field distributions obtained with the different configuration of discontinuous earth are compared to that defined by homogeneous system.

The configuration of the experimental model used is constituted of a flat metallic earthed sheet (figure 2)
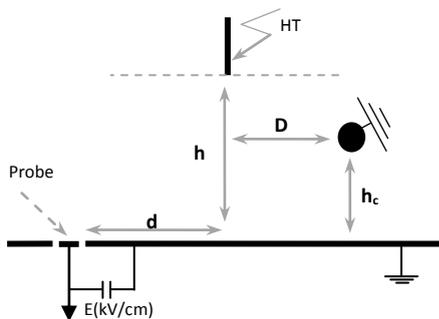

Fig.2a. System with homogeneous conducting earth for a horizontal lightning conductor
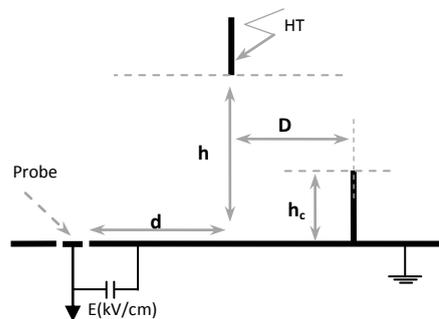

Fig.2b. System with homogeneous conducting earth for a vertical lightning conductor

1. RESULTS AND DISCUSSION

3.1 Electric Field Distribution on the Homogeneous Conductor Earth

In order to obtain a reference for the comparison between the results of experimental with discontinuous system, we initially determine the distribution of the field in the case of the homogeneous system with vertical and horizontal lightning conductor, according to the height h of the stem under high voltage in the case of the selected voltage level $0.3U_{0\%}$.

With the applied voltage level $0.3U_{0\%}$, we notice that, the intensity of the electric field tends towards a constant value, as the lightning conductor moves away from the rod under voltage starting from a relative position D/h_c higher or equalizes to 2. When the lightning conductor approaches to the axis of the rod for D/h_c lower than 2, the intensity of the field decrease considerably and takes a minimum value for $D/h_c = 0$ (Fig.3). [10, 11]
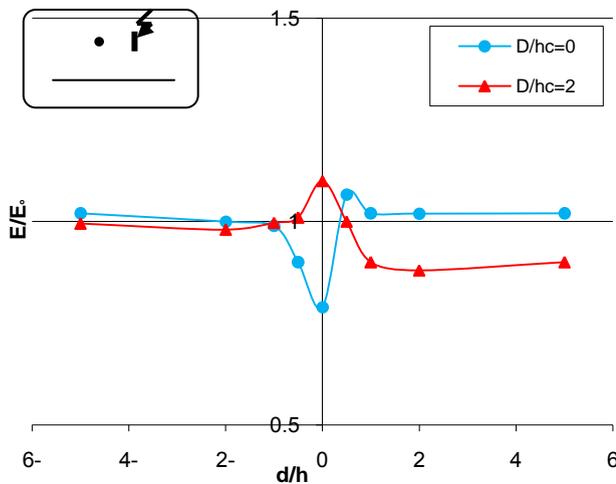

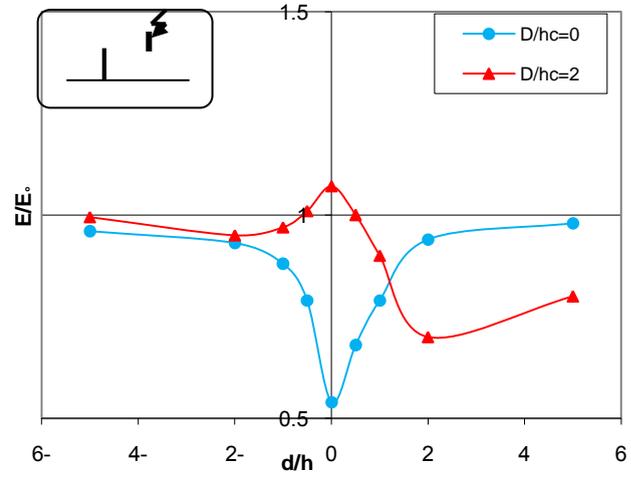*Fig.3a. Electric field distribution with homogeneous conducting earth for a horizontal lightning conductor*

Fig.3. Electric field distribution with homogeneous conducting earth for a vertical lightning conductor

3.2 Electric Field Distribution on the Discontinuous Conductor Earth
3.2.1 Lightning Conductor Situated on the Upper Part of Discontinuous Earth

We have determined the electric field distribution for different values of the D/h_c ratio, in to possible configuration.

The first configuration corresponds to the vertical (figure 4a) or the horizontal (figure 4b) lightning conductor situated between the earth discontinuity and the axis of the discharge.

For the applied voltage level $0.3U_{0\%}$ and for the positions of the probe far from the interface *(d/h > 2)*, we notice that the intensity of the field measured on the high part of the discontinuous earth is practically equal to that corresponding to the case of the system with homogeneous earth of the same length. Near the interface (*d/h<2*), the results obtained show a kind of discontinuity in the evolution of the electric field. This discontinuity is due to the role of the lightning conductor which would have the same effect as a point, transforming the system rod-plan into system rod-rod. This fact explains the abrupt decrease in the field below the lightning conductor and the increase in the rigidity of the interval rod-plane and the phenomena of discharge observed in preceding research tasks [03, 04]. Indeed, even for relatively large D/h distances, electric discharges can occur between the rod and the lightning conductor and not between the rod and the plan according to the path the shortest correspondent with the height h. [11, 12]

We notice that the air interval rod-lightning conductor constitutes preferable path for the lines of electric field. Indeed, the system rod- lightning conductor which behaves as a system point-point is less rigid than the system point-plan. This justifies, the reason why, we sometimes obtain disruptive discharges on the lightning conductor, for the low values of the D/h_c ratio.
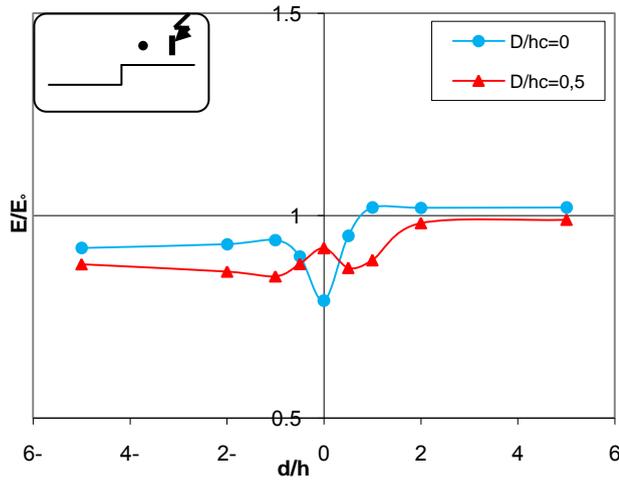
Fig.4a. Electric field distribution with discontinuous conducting earth for a horizontal lightning conductor
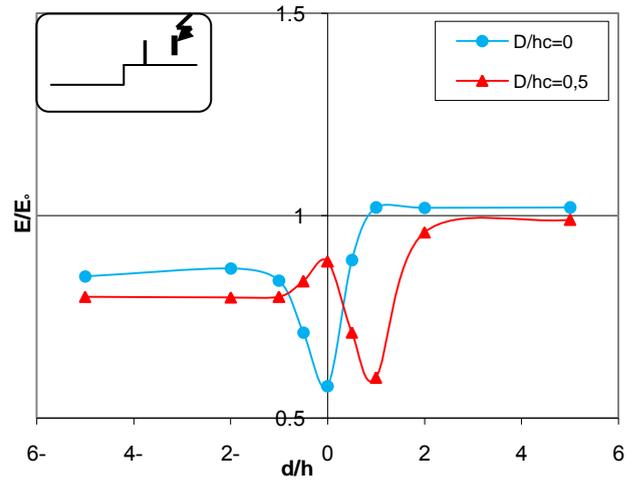

Fig.4b. Electric field distribution with discontinuous conducting earth for a vertical lightning conductor

The second configuration consists of a lightning discharge evolving between the vertical (figure 5a) or the horizontal (figure 5b) lightning conductor and the earth discontinuity. The results show that when the lightning conductor is relatively near of the earth discontinuity (D/hc=1.5), the distribution of electric field is decrease than defined by the same model without rod lightning. but when the D/hc ratio becomes superior or equal to 3.5 the electric field intensity is confounded to the model without rod lightning, how has no effect on the attract of discharges by the interface
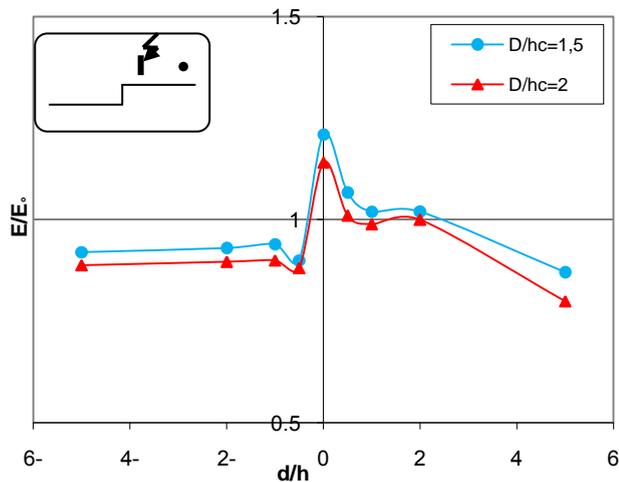

Fig.5a. Electric field distribution with discontinuous conducting earth for a horizontal lightning conductor
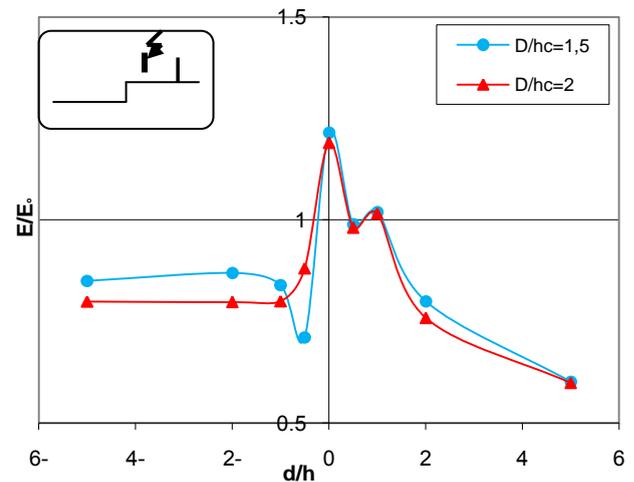

Fig.5b. Electric field distribution with discontinuous conducting earth for a vertical lightning conductor

3.2.2 Lightning Conductor Situated on the Lower Part of Discontinuous Earth

In the theirs configuration, the lightning conductor is placed in the lower part of the earth and the high voltage lightning rod is situated between the earth discontinuity and the lightning conductor (figure 6a and 6b). With regard to the field on the low part of the discontinuous earth, the results show that the field intensity is lower than that of the high part. That is due to the increase in the distance rod-probe. In the vicinity of the interface, the field takes the lowest value on the plan. The results show that when the vertical (figure 6a) or the horizontal (figure 6b) lightning conductor is relatively near of the earth discontinuity (D/hc =1.5), the electric field distribution increase. But when the D/hc ratio becomes superior or equal to 2.5 the electric field intensity is confounded to the model without rod lightning. On the level of the interface, where the system rod-interface behaves as a system rod-rod which is less rigid than the system rod-plan, the relationship between the two systems takes the value maximum ($E/E_0=1.25$) which corresponds to the value where there is a great probability of having disruptive discharges direct on the interface. [11, 13]
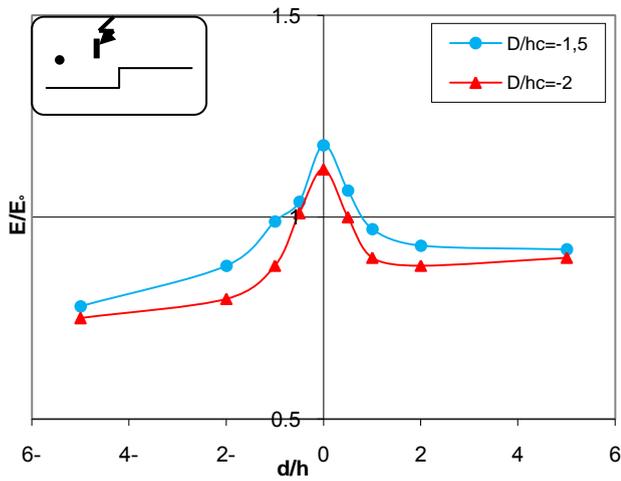
Fig.6a. Electric field distribution with discontinuous conducting earth for a horizontal lightning conductor
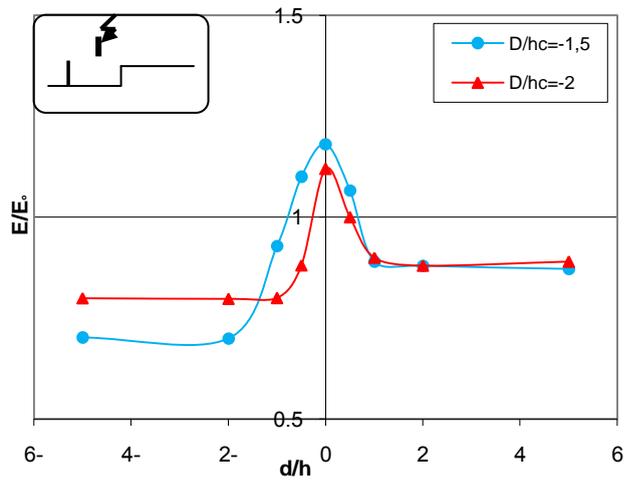

Fig.6b. Electric field distribution with discontinuous conducting earth for a vertical lightning conductor

The last studied configuration corresponds to the lightning conductor situated in the lower part of the discontinuous earth, between the lightning high voltage rod and the earth discontinuity (figure 7a and 7b). We observe that the electric field intensity of the vertical (figure 7a) or the horizontal (figure 7b) lightning conductor correspond in this case to that give by second configuration [12, 14]
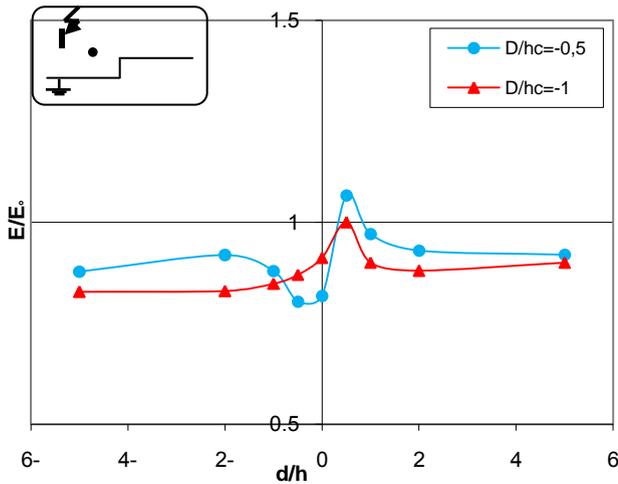

Fig. 7a. Electric field distribution with discontinuous conducting earth for a horizontal lightning conductor
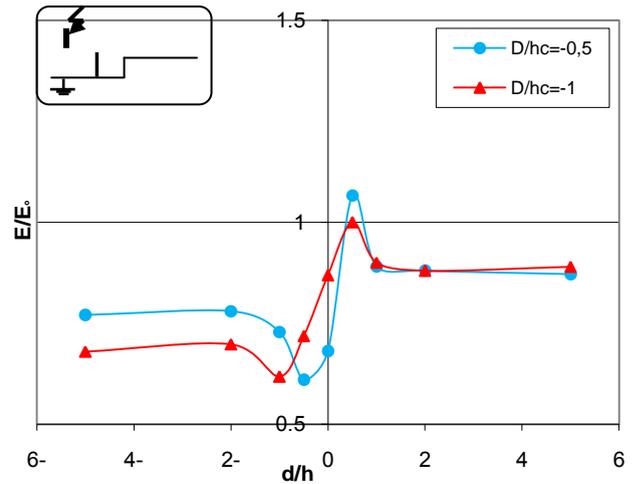

Fig.7b. Electric field distribution with discontinuous conducting earth for a vertical lightning conductor

3. CONCLUSION

The influence of the earth discontinuity on the electric field distribution with presence of a vertical or a horizontal lightning conductor depends essentially on the discharge axis position with regard to the lightning conductor and to earth discontinuity. This influence is more marked when the lightning conductor is situated very near of the earth discontinuity. It would be owed to the relatively intense electric field in this part of the earth.

In the case of vertical or horizontal lightning conductor situated on the high part of the discontinuous earth between the discharge axis and the earth discontinuity, the electric field intensity is smaller that defined by the same model without lightning conductor. This wideness depends on the lightning conductor horizontal position. On the other hand, when the discharge evolves on the same part of the earth between the interface and the lightning conductor, the electric field intensity is smaller or equal that defined by the same model without lightning conductor.

When the vertical, or horizontal, lightning conductor is placed on the low part of the earth, and the high voltage rod situated between it and the earth discontinuity, the electric field distribution depend on the position D/hc of the lightning conductor with regard to the earth discontinuity. More this relative size is small; more the electric

field intensity would be reduced. In the other cases, the intensity is confounded that defined by the same model without lightning conductor.

When lightning conductor is placed on the lower part of the earth, and it situated between the high voltage rod and the earth discontinuity, the electric field intensity reduced on the interface. This is also available for a vertical or a horizontal lightning conductor.

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