Journal of Fundamental and Applied Sciences

ISSN 1112-9867

Available online at http://www.jfas.info

Research Article

EXPERIMENTAL INVESTIGATION AND MODELING OF THE ELECTRIC FIELD DISTRIBUTION IN LIGHTNING PROTECTION SYSTEM

A. Khechekhouche*, T. Guia, A. Hima

University of El Oued, Fac. Technology, 39000 El Oued, Algeria

Received: 25 December 2018 / Accepted: 19 May 2019 / Published online: 01 September 2019

ABSTRACT

The study presented in this paper highlights the electric field distribution of mutually horizontal and vertical lightning conductors with discontinuous earth. The conductors may be located in both higher or lower earth part. The electric field distribution was resolved in the case of lightning conductor placed between the high voltage rod and the discontinuity (interface). For this aim, we have used different results obtained by a numerical method for computation and an experimental model tested the efficacy of the finite elements methods (FEM). In some configurations the electric field distribution on the plan are less significant than definite by the electro-geometrical configuration. We suggested that effect to the grand field strength at the discontinuity part, which decrease the lightning conductor capture consequence. The results of this study are in harmony with the study relating to the electrical stress of such air gaps devoid of lightning conductors.

Keywords: Electrogeometrical model; Vertical lightning conductor; Discontinuous earth; Horizontal lightning conductor; the finite elements methods (FEM).

Author Correspondence, e-mail: khechali@yahoo.fr

doi: http://dx.doi.org/10.4314/jfas.v11i3.5

1. INTRODUCTION

The electrogeometrical model present an extensively technique resolve of the electric field distribution of lightning conductor. This process neglected the ground nature. The electrogeological properties are very significant in the determination of the lightning impact points. To study the impact of these properties, some search have been approved to resolve the capture zones of horizontal and vertical earthed rods in the heterogeneous or homogeneous configurations. In this study, the capture zones of a lightning conductor can be, in general, superior than distinct by the classical electrogeometrical model [1,2].

To explain the variations of electric field allocation, it has been calculated the electric power of rod-plane air gaps below negative lightning impulse voltage. Both heterogeneous and discontinuous earths were considered. It is thought that the discharge phenomena are different from the configuration of air gaps with conducting homogeneous earth [3,4]. This led us to determent the electric field sharing on top of the discontinuous earth with a horizontal and a vertical lightning rod, with experimental and numerical model [4-6].

Electric field problems in high voltage engineering are frequently electrostatic field difficulty. The computation of electrostatic fields need the resolution of Poisson’s and Laplace’s equations with boundary situation satisfied. Finite element method FEM is one of the majority winning mathematical methods for resolution electrostatic field problems. FEM can be used effectively for the calculation of an electric field between electrodes with different dielectrics is concerned. Solution of the electric field model by FEM can vary depending on the fact, known from variational determiner, that Laplace’s equation is satisfied when the total energy functional is minimum [5-7]. The calculated of electric field configuration are compare to measured ones approved on laboratory model of rod-plane air gap arrangement. Therefore, the aim of our work is to validate a numerical model and to show that modeling of electric field under lightning impulse voltage can successfully be performed using finite element method [5-8].

2. EXPERIMENTAL SET UP

The considered earth call "discontinuous earth" is consist of a square metallic sheet with 4 mm depth and having different levels of respective surface 1x1 m2 (figure 1a or lb). The lightning discharge supply at its final jump is replicated by an iron rod, with 4.8 mm diameter. This rod is related to a lightning pulse generator of 600 kV, 4 kJ. The situation of the bar is resolute by its altitude (h) compared to the earth and the space (D) linking its axis and the interface. This position is considered positive when this bar is situated on top of the high and negative piece in the other case. The position h are the identical as in homogeneous configuration, but the position d and D is chosen so that the tests are agreed for d/h ratio and respectively indistinguishable D/h for different values of h. The useful voltage intensity to use is $0.3U_{0\%}$ of the rod-plane equivalent arrangement, at every selected position h. For a specified altitude h, we as well apply the similar voltage intensity for the rod situated on top of the high element as above the low element of the plane. So, it is the similar level of applied voltage $U_{0\%}$ which is taken into explanation for a specified height h and the equivalent elevation h+e when the rod is situated on peak of the low element of the plan. We are motivating to the $U_{0\%}$ voltage of disruptive discharge in order to resolve the voltage level of selected test equal to $0.3U_{0\%}$. This practical voltage intensity permits to avoid the disrupting discharges on the point of the probe as its sensitivity to the elevated charges [1-4].

Through tests, the $U_{0\%}$ discharge voltage is calculated by the constant multiple steps method. To find this level we have used a Gaussian arithmetic scale paper. In our research, we have considered every probable arrangements according to the lightning rod location upon the superior or the inferior piece of the discontinuous earth. Our research present, the consequences about both cases of horizontal and vertical lightning conductors [7-10].

The electric field distributions determinate with the diverse arrangement of discontinuous earth are compared to that distinct by homogeneous earth. The arrangement of the investigational model used is constituted of a flat metallic earthed sheet (figure 2)

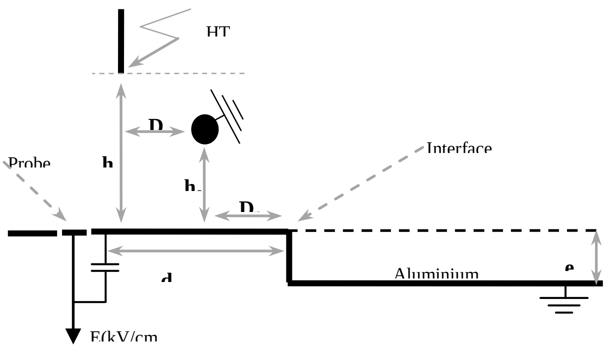


Fig.1.a) Configuration with discontinuous earth for a horizontal lightning conductor

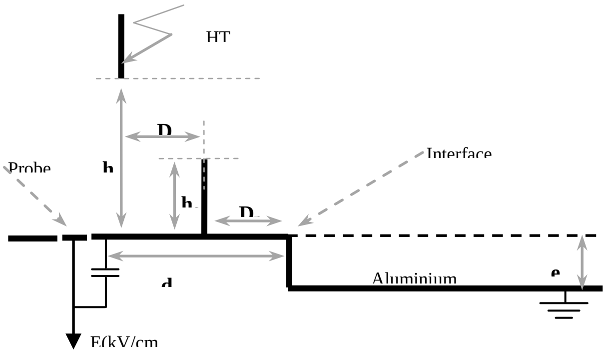


Fig.1.b) Configuration with discontinuous earth for a vertical lightning conductor

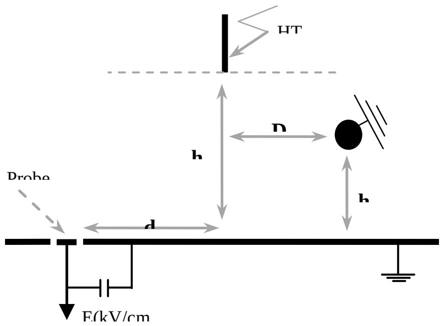


Fig.2.a) : configuration with homogeneous conducting earth for a horizontal lightning rod

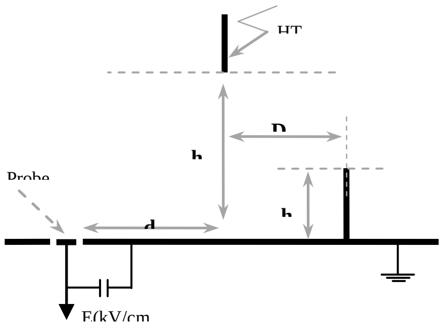


Fig.2.b) : configuration with homogeneous conducting earth for a vertical lightning rod

3. RESULTS

3.1 Electric field distribution on the homogeneous conductor earth

In order to get indications for the evaluation connecting the consequences of experimental with discontinuous arrangement; we firstly fined the distribution of the field in the case of the homogeneous structure by means of vertical and horizontal lightning conductor, according to the altitude h of the stem below elevated voltage in the case of the special voltage intensity $0.3U_{0\%}$. With the useful voltage intensity $0.3U_{0\%}$, we observe that, the strength of the electric field tends towards an invariable significance, as the lightning conductor moves away from the rod below voltage initial from a relative situation D/hc upper or equalizes to 2. When the lightning conductor in the vicinity of the axis of the rod for D/hc inferior than 2, the strength of the field reduce significantly and takes a smallest value for D/hc = 0 (Fig.3). [8-11]

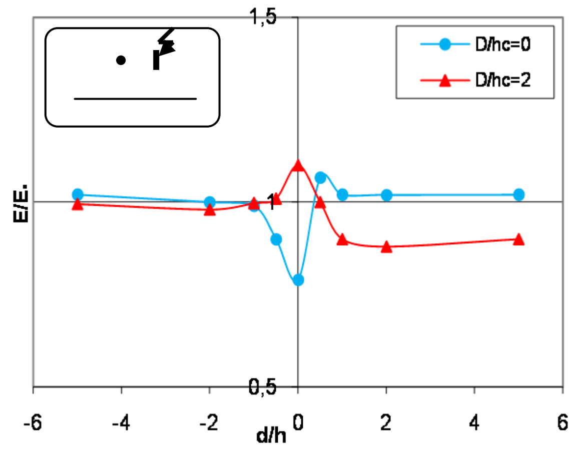


Fig.3.a) Electric field distribution with homogeneous conducting earth for a horizontal lightning rod

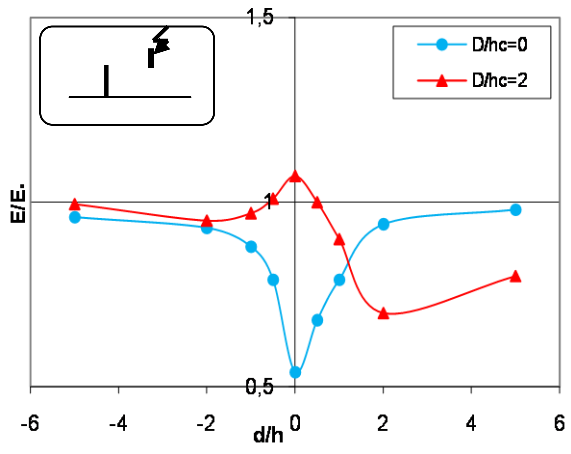


Fig.3.b) Electric field distribution with homogeneous conducting earth for a vertical lightning rod

The results obtained from the preliminary analysis to FEM illustrate that the equipotential lines are condensed approximately the lightning rod and the field distribution in the gap is non-uniform. The electric field on the rod surface reaches its greatest charge at the position face the grounded plane.

3.2 electric field distribution on the discontinuous conductor earth

3.2.1 Lightning rod located on the higher part of discontinuous earth

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

The first design corresponds to the vertical (figure 4a) or the horizontal (figure 4b) lightning conductor positioned between the earth discontinuity and the axis of the discharge. For the practical voltage intensity $0.3U_{0\%}$ and for the distance of the probe distant from the interface (d/h > 2), we observe that the strength of the field measured on the high division of the discontinuous earth is almost identical to that equivalent to the case of the arrangement without conductor earth of the similar length. Approximate the interface (d/h<2), the results obtained show a sort of discontinuity in the progress of the electric field. This kind of discontinuity is appropriate to the task of the lightning conductor which would have the similar result as a point, transforming the arrangement rod-plan into structure rod-rod. This reality explains the sudden decrease in the electric field under the lightning conductor and the augment in the rigidity of the interval rod-plane and the phenomena of discharge observed in previous research tasks [03-04]. in reality, even for reasonably large D/h distances, the electric discharges can happen between the rod and the lightning conductor and not between the rod and the plan joining to the path direct correspondent with the height h. [1-4]

We observe that the air space rod-lightning conductor create preferable path for the lines of electric field. Certainly, the structure rod- lightning conductor which behaves as a arrangement point-point is less rigid than the arrangement point-plan. This justifies, the reason why, we occasionally obtain disruptive discharges on the lightning conductor, for the small ratio of the D/hc.

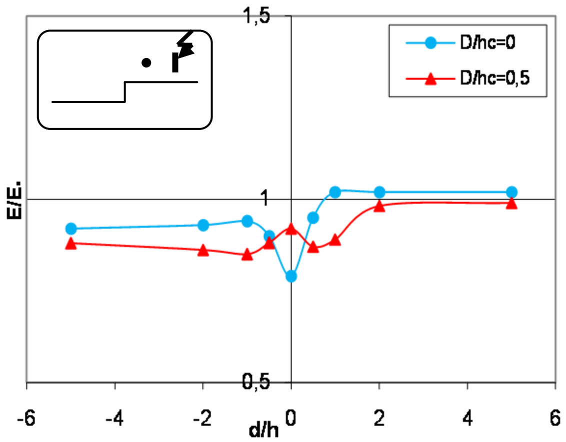


Fig.4.a) Electric field distribution with discontinuous conducting earth for a horizontal lightning conductor

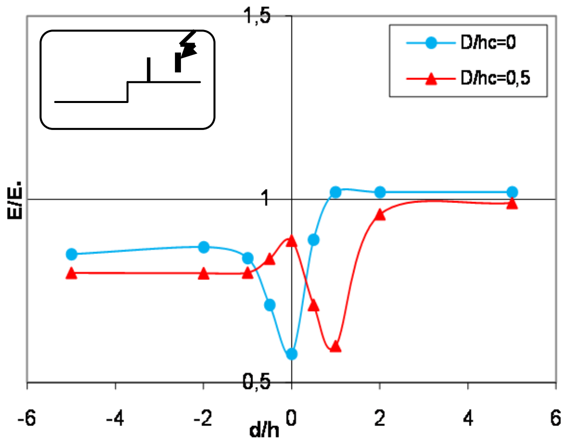


Fig.4.b) Electric field distribution with discontinuous conducting earth for a vertical lightning conductor

These results suggest that, numerical computations are display by using FEM technique.

Electric field of the rod-plane gap (Figure 5) is approved by applying the initial and boundary conditions. Initial condition applies when no charge in the gap before application voltage. It can therefore be assumed that the practical voltage is 1 Volt across 16 cm gap space in air at atmospheric pressure. Figures 5 illustrate the computed electric field distribution on the discontinuous plane when the rod is on the high piece of the discontinuous plane.

Electric field calculations are approved for diverse distances between a rod and interface (Fig 5). For each computation maximum field value was simply read on surface plot produced by the FEM technique for electric field distribution, at the end.

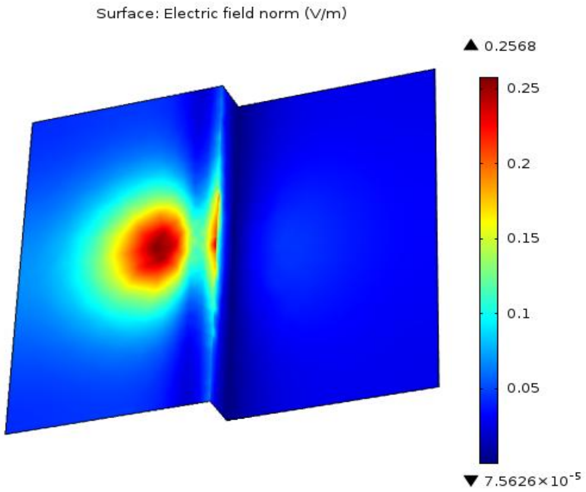


Fig.5.a) the computed electric field distribution on the discontinuous plane for a horizontal lightning conductor

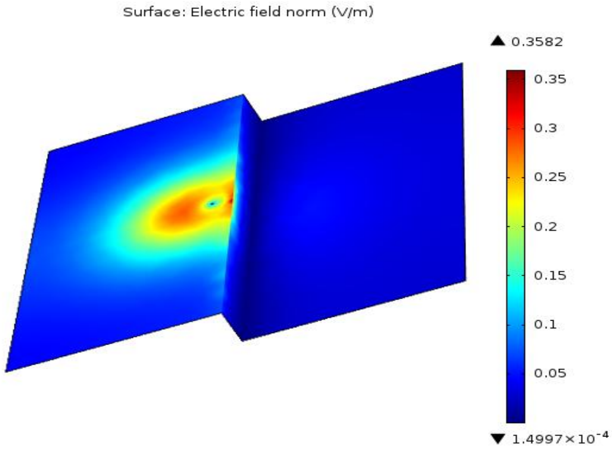


Fig.5.b) the computed electric field distribution on the discontinuous plane for a vertical lightning conductor

The next arrangement consists of a lightning discharge developing between the vertical (figure 6a) or the horizontal (figure 6b) lightning rod and the plane discontinuity. The results illustrate after the lightning rod is comparatively in the vicinity of the earth discontinuity (D/hc=1.5), the distribution of electric field is reduce than defined by the identical model without rod lightning. but when the D/hc ratio becomes greater or equal to 3.5 the electric field strength is confused to the model without rod lightning, how has no effect on the attract of discharges by the interface

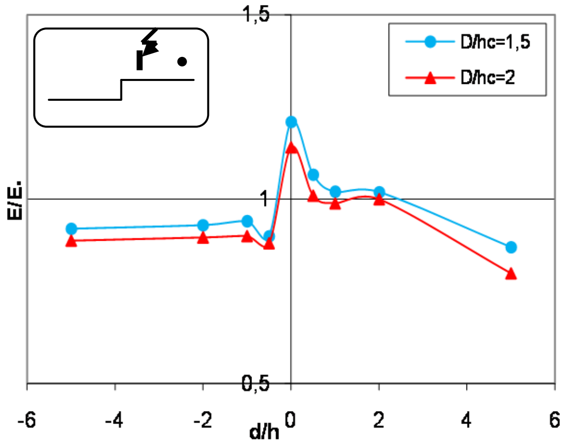


Fig.6.a) Electric field distribution with discontinuous conducting plane for a horizontal lightning rod

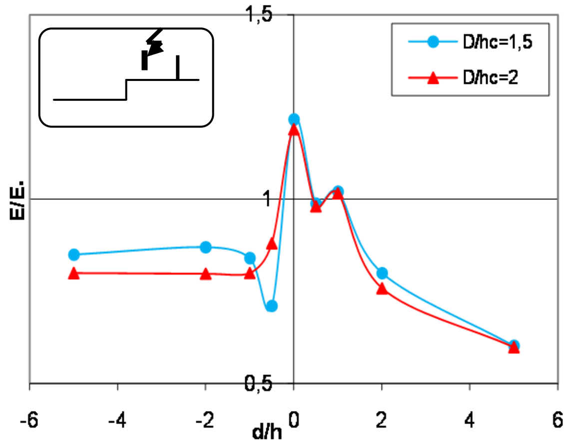


Fig.6.b) Electric field distribution with discontinuous conducting plane for a vertical

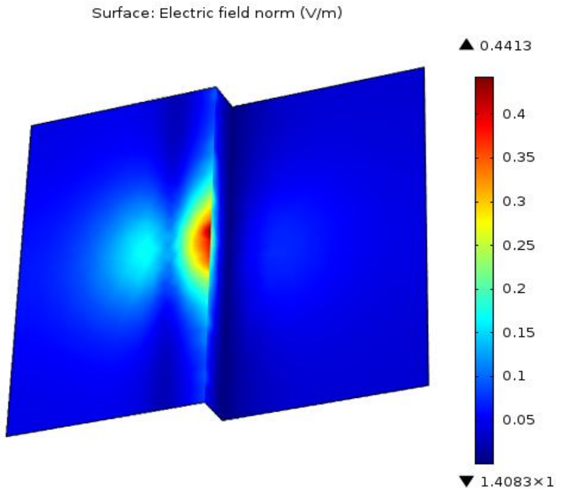


Fig.7.a) The computed electric field distribution on the discontinuous plane for a horizontal lightning conductor

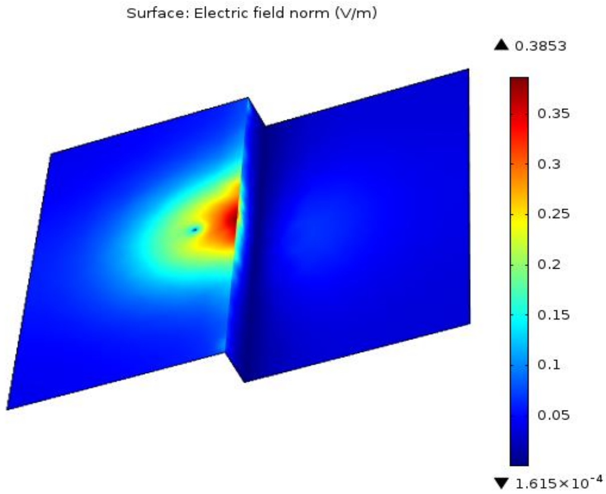


Fig.7.b) The computed electric field distribution on the discontinuous plane for a vertical lightning conductor

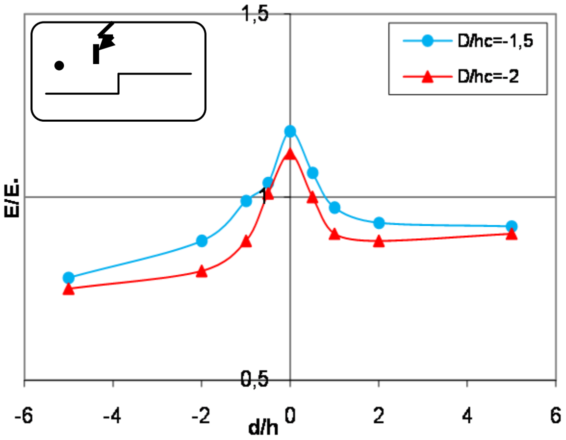
The results obtained from the preliminary analysis of FEM set out that the equipotential lines are strong approximately on the interface and the electric field distribution in the gap is non-uniform. The field at the interface surface reaches its highest rate. This method was experienced with several investigational measurements and it was detected that the field strength considered are inferior to the measurements. This provides a conservative value, that can be used to develop targeted interventions aimed at design protection model.

3.2.2 Lightning rod located on the lower part of discontinuous earth

In the theirs arrangement, the lightning rod is positioned in the inferior division of the plane and the high voltage lightning rod is located between the earth discontinuity and the lightning conductor (figures 8). With consider to the electric field on the inferior division of the discontinuous plane, These analytical procedures and the results obtained illustrate that the field strength is inferior to that of the high division. That is owing to the augment between rod and probe. In the surrounding area of the interface, the field takes the lowly value on the plan.

The results confirm that when the vertical (figure 8a) or the horizontal (figure 8b) lightning rod is moderately the earth discontinuity (D/hc =1.5), the electric field distribution amplify. But when the D/hc ratio becomes greater or equal to 2.5 the electric field strength is confused to the model without rod lightning. on top of the interface, where the arrangement rod-interface perform as a system rod-rod that is fewer rigid than the system rod-plan, Previous studies have demonstrate a consistent association between the two systems takes the greatest ratio (E/E0=1.25) that be similar to the great value produced disruptive discharges direct on the interface. [09-11]

The final considered arrangement be identical to the lightning rod located in the inferior division of the discontinuous plane, linking the lightning high voltage conductor and the earth discontinuity (figure 10). We observe that the electric field strength of the vertical (figure 10a) or the horizontal (figure 10b) lightning rod be the same in this situation to that give by second configuration [10,11]



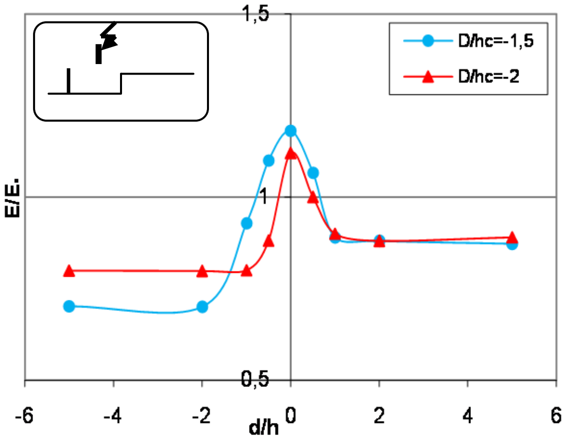
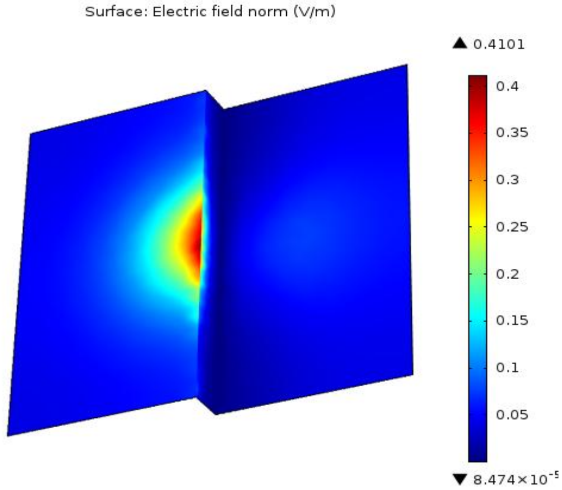


Fig.8.a) Electric field distribution with discontinuous conducting plane for a horizontal lightning rod

Fig.8.b) Electric field distribution with discontinuous conducting plane for a vertical lightning rod



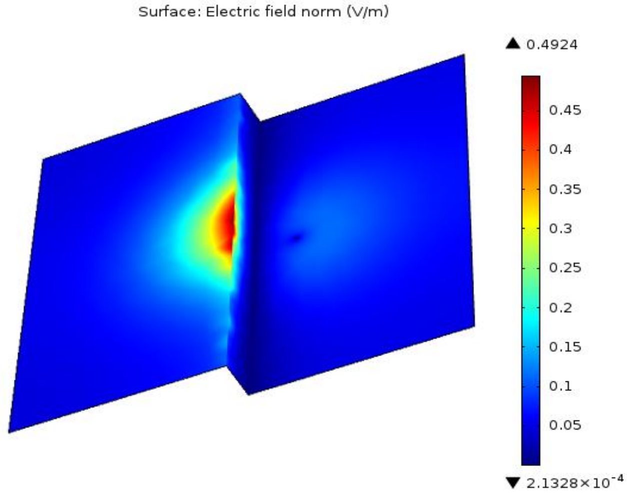


Fig.9.a) The computed electric field distribution on the discontinuous plane for a horizontal lightning conductor

Fig.9.b) The computed electric field distribution on the discontinuous plane for a vertical lightning conductor

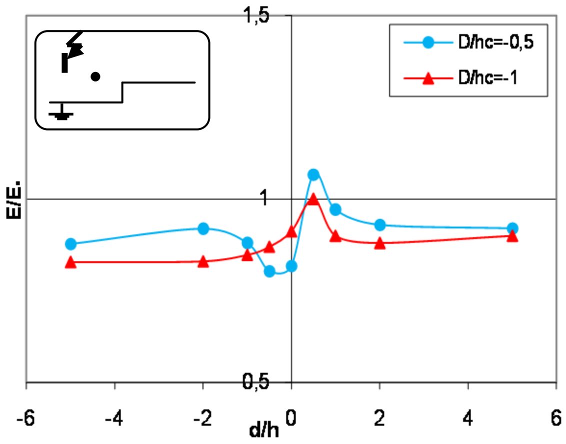


Fig.10.a) Electric field distribution with discontinuous conducting plane for a horizontal lightning rod

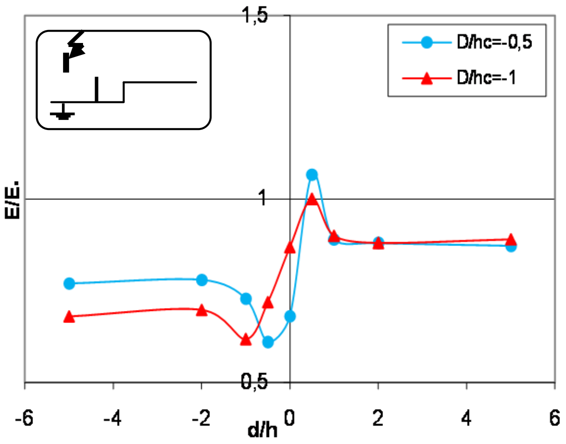


Fig.10.b) Electric field distribution with discontinuous conducting plane for a vertical lightning rod

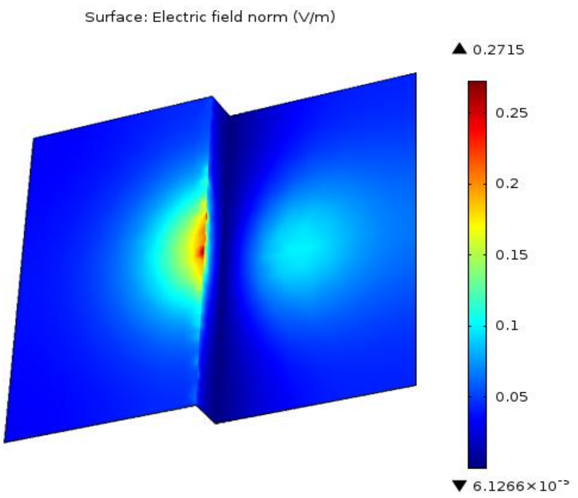


Fig.11.a) The computed electric field distribution on the discontinuous plane for a horizontal lightning conductor

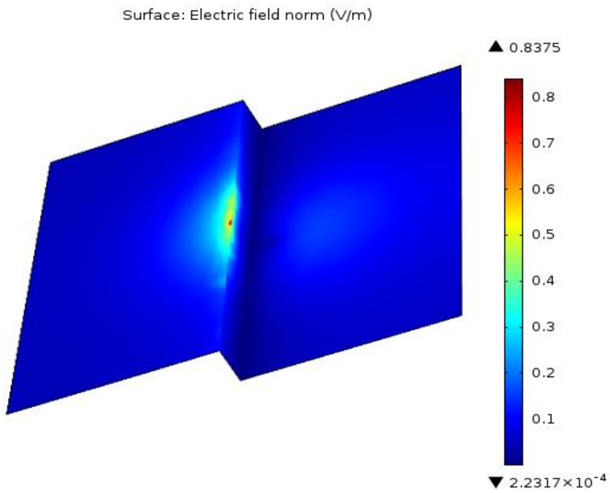


Fig.11.b) The computed electric field distribution on the discontinuous plane for a vertical lightning conductor

4. CONCLUSION

This study set out to investigate impact of the earth discontinuity on the electric field distribution by means of a vertical or a horizontal lightning rod be determined essentially by the discharge axis place by look upon to the lightning rod and earth discontinuity.

This impact is the most interesting whenever the lightning rod is neighboring of the earth discontinuity. It would be interesting to assess the effects of the electric field intensity in this part of the plane. On the question of vertical or horizontal lightning rod positioned on the high division of the discontinuous plane linking the discharge axis and the earth discontinuity, the electric field strength is less important that defined by the similar model without lightning conductor. This broadness be predicted on the lightning rod horizontal place.

In addition, it is important to ask when the discharge change on the same division of the plane among the interface and the lightning rod, the electric field strength is lesser or equal that defined by the identical model without lightning conductor. When the vertical, or horizontal, lightning conductor is located on the low division of the plane, and the high voltage rod located surrounded by it and the earth discontinuity, the electric field distribution depend on the position D/hc of the lightning rod with respect to the earth discontinuity. More this relative size is small; more the electric field strength would be reduced. In the other cases, the strength is confused that defined by the similar model without lightning conductor. When lightning conductor is located on the lower division of the plane, and it located among the high voltage rod and the earth discontinuity, the electric field intensity concentrated on the interface. This is also obtainable for a vertical or a horizontal lightning rod.

5. REFERENCES

[1] A. Khechekhouche, D. Benattous: J. Fundam. Appl. Sci. vol. 8 (2016), p. 1054

[2] A. Khechekhouche. D.Benattous Mekhaldi and A. Boubakeur: J Fundam App Sci. vol. 6 (2014), p. 1

[3] A. Rahmani, A. Khechekhouche, A. Mekhaldi and A. Boubakeur: Electrical Strength of Rod-Discontinuous Plane Air Gap Under Lightning Impulse Applied Voltage Using a

Distributed Capacity Probe ” IEEE-CEIDP, October 14-17, 2012, Montréal CANADA, pp 379-382.

[4] A. Khechekhouche: Energetica vol. 1 (2016), p. 30

[5] A. Beroual, J. Rakotonandrasana and I. Fofana: IEEE Trans. Dielectr. Electr. Insul. Vol. 17 (2010), p. 1551

[6] A. Boubakeur, S. A. A. Boumaza, R. Belaicha and R. Boudissa: Influence of earth heterogeneity on negative lightning breakdown of rod-plane air-gaps, 24th ICLP, Birmingham, 1998, pp : 473-477.

[7] A . Rahmani, A. Boubakeur and H. Brouri: Model of an horizontal lightning conductor protection in the case of earth discontinuity, International Symposium on Electromagnetic Compatibility EMC EUROPE 2002, (Sorrento) Italy 2002, pp 267-270.

[8] S. Cristina, G. Denelli and M. Feliziani: IEEE Trans. Ind. Appl.Vol. 27 (1991), p. 147

[9] A. Kara, E. Onal, O. Kalenderli and K. Mardikyan: The Effect of Insulating Barriers on AC Breakdown Voltage in Inhomogeneous Field, IEEE MELECON 2006 Mediterranean Electrotechnical Conference, Benalmádena (Málaga), Spain, 16-19 May 2006, pp. 1206-1208.

[10] K. Adamiak and P. Atten: J. Electrostat. Vol. 61 (2004), p. 85

[11] J. Anagnostopulos and G. Bergeles: J. Electrostat. Vol. 54 (2002), p. 129

How to cite this article:
Khechekhouche A, Guia T, Hima A. Experimental investigation and modeling of the electric field distribution in lightning protection system. J. Fundam. Appl. Sci., 2019, *11(3), 1122-1134*.