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Numerical Analyze of Corona Discharge on HVDC Transmission Lines

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***Abstract*—**This study and the field test comparisons were carried out on the Algerian Derguna – Setif transmission systems. The transmission line of normal voltage 225 kV is 65 km long, transported and uses twin bundle conductors protected with two shield wires of transposed galvanized steel.

An iterative finite-element method is used to solve Poisons equation. Two algorithms are proposed for satisfying the current continuity condition and updating the space-charge density.

A new approach to the problem of corona discharge in transmission system has been described in this paper. The effect of varying the configurations and wires number is also investigated. The analysis of this steady is important in the design of HVDC transmission lines. The potential and electric field have been calculating in locations singular points of the system.

***Keywords*—**Corona discharge, Electric field, Finite element method, HVDC.

I. Introduction

THE process of corona generation in the air at atmospheric conditions requires a nonuniform electrical field, which can be obtained by the use of a small diameter wire electrode and a plate or cylinder as the other electrode.

Many studies and research have been done on the electrical discharge phenomena; this is for more than one century. Early studies describing their evolution have proposed discharge mechanisms dating back from the early twentieth century [1]–[5]. In fact, the first publications on the corona dated back to 1915 when F.W. Peek has established by experimental tests an empirical law expressing the appearance of the corona threshold field [6]. From that time an impressive number of research concerning the corona effect on overhead lines of electric energy were performed and published. Thus, the first experiments on thin wire conductors carried at sufficiently high voltages showed that it forms around them a bright sheath, blue-purple color, whose thickness increases with the voltage. It is the presence of this glow which has resulted in the expression universally employed which is the corona discharge. Since the Last fifty years, several studies have been conducted to understand the mechanisms of corona and guarding tools for the prediction of this phenomenon and its influence on the overvoltage of high voltage lines. The results of these multiple studies have allowed to developed models giving the characteristics of corona discharges operating on the surface of conductors and the surrounding air. The main parameter governing the amplitude of the corona phenomenon is the electric field at the conductor surface which depends on the diameter of the surface state of the conductor, the density of the surrounding air, rain, pollution, etc. However, it should be specified that most of these models are empirical or semi-empirical. Nowadays, other numerical models are available. In addition to the phenomenon of corona, the problem of overvoltage in the lines has always been an issue of passionate controversy, due to several phenomena of different origins, so it is necessary to protect the installations and equipment connected to the network including elements constituting the electrical network. This overvoltage can be affected and deformed by the corona and the effect of surface (skin effect), which complicates the process.

One of the consequences of the transport of electrical energy at high voltage levels is the appearance of corona effect around the transport lines. This effect is at the origin of radio and television interference, telephone, audible noise, significant electrical losses and mechanical vibration. There has been controversy recently concerning the effect that electric and magnetic fields, emitted by high voltage overhead lines, might have on human beings both psychologically and physically. Thus, there is a need to determine the magnitude and distribution of these fields and if necessary to reduce them [7]. Thus, the first experiments on thin wire conductors carried at sufficiently high voltages showed that it forms around them a bright sheath, blue-purple color, whose thickness increases with the voltage. It is the presence of this glow which has resulted in the expression universally employed which is the corona discharge.

The objective of this work is to calculate the electric field distribution in the vicinity of high voltage lines. The selected line to be studied is the line linking the hydroelectric station of Derguina (Bejaia) to the center of Elhassi (Setif) which has amplitude of 220KV. For the calculation phase, a Comsol Multiphysics code has been used to solve the system of equations governing the corona discharge. This code uses the finite element method [8]–[10].

II. Mathematical Modeling

There are many mathematical models adapted to different types of electric discharge. They all make use a coupling between the evolution equations of particles and the electromagnetic field. Problems of physics of discharge are categorized among the most difficult to solve numerically

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because of the great number of equations and degrees of freedom. Electromagnetic can be described by the equations of Maxwell and the constitutive relations. Maxwell's equations are a set of partial differential equations in space and time applied to electromagnetic quantities. When they interact with material, the equations can assume nonlinear forms [11].

A. Geometric Description of the Problem

Fig. 1 shows the geometric model of the system to be studied. It consists of the conductor wire with a radius r0 and brought to a potential U (high-voltage electrode). The wires are attached using pylons parallel to the electrode plane (earth) with a height H. This geometric model is deducted from a real case. The used data in the calculation and analysis of the results are in accordance with the dimensioning and climatic conditions.

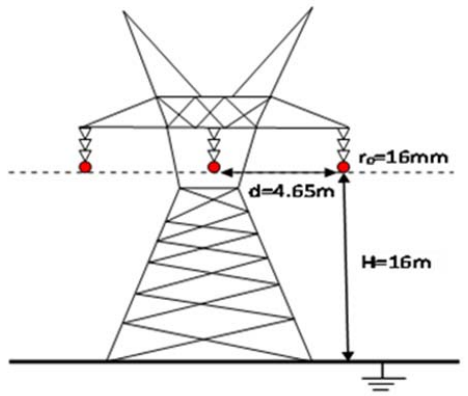


Fig. 1 Geometric model

B. Governing Equations

If the basic equations governing the phenomenon of corona discharge are brought back to the Maxwell equations of electrostatics to which are added equations of the considered milieu (air is used in our case) [12]–[14]. These equations are:

$$\nabla . \vec{E} = \pm \frac{\rho}{\varepsilon_0} . \quad (1)$$

$$\nabla . \vec{J} = 0 \quad (2)$$

$$\vec{J} = \pm \rho . \mu . \vec{E} \quad (3)$$

$$\vec{E} = -\nabla \phi \quad (4)$$

$$\nabla^2 \phi . = \mp \frac{\rho}{\varepsilon_0} . \quad (5)$$

where E is the electric field (V / m). ϕ is the electric potential (V). ρ is the density of the space charge (C/m^3). J is the current density (A/m^2). μ is the mobility of positive or negative ions depending on the polarity of the active electrode (m^2/V.s) and ε_0 is the air permittivity.

Equation (5) is the Poisson equation. It is obtained by replacing the expression of the field given by (4) in (1). Equation (3) is the equation of the current density. Equation (2) is the current equation of continuity. In reality, it is extremely difficult to find an exact solution to these equations due to their non-linear nature, which is how simplifying approaches based on hypothetical models have been developed.

To solve equations governing the corona discharge in the field of study, several solutions can be given; however, only one of them is the real solution of the problem. To find this solution, we need to know the conditions associated with the domain boundaries for the electric potential and space charge density [15], [16]. These conditions are:

- ✓ The value of the potential on the active electrode is equal to the applied voltage U;
- ✓ The potential at the plane surface is zero;
- ✓ The electric field on the conductor is equal to the field threshold Es (Peek criterion);
- ✓ The values of the potential to the points situated on the artificial boundaries are identified and subsequently used in the finite element formulation.

IV. Results and Discussion

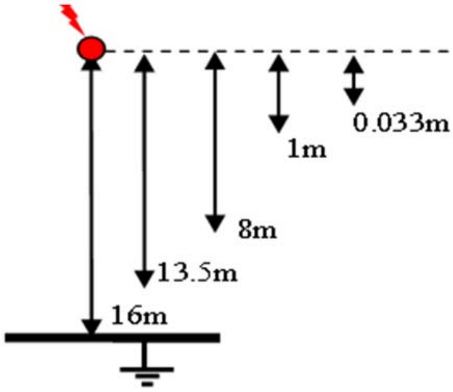
The simulation is performed by Comsol Multiphysics software, using finite element numerical method. We proposed the introduction of a potential corresponding to the critical minimum ionization field directly in the finite element formulation as a Dirichlet condition. We used the model which separates the corona in two distinct regions. The ionization region radius and the electric field at the ionization-region/drift-region interface, which corresponds to a zero net ionization coefficient of the ambient air.

Two cases have been taken into consideration (Fig. 2): Wire-earth and three wires – earth in order to analyze various parameters that influence the discharge phenomenon.

The measurements are carried out for various parameters such as: the number of the active wires, the air flow velocity, the polarity and the strength of the applied voltage.

The overhead line to be studied has the following characteristics:

- Applied voltage: 220 kV;
- Current: 138 A;
- Active power: 52 MW;
- Reactive Power: 13 kVAR:
- Section of the conductor: 411 mm²;
- Conductor Material: Aluminum (ε_r = 1; σ = 4.88×10^7 s/m);
- Distance between wires: D = 4.65 m;
- Line Length: 64 km;
- Height of the line: 16 m;
- Arrow of the conductor: Hmin = 7.65 m;
- Characteristic of soil: $\mathcal{E}_r$ = 10; σ =10^{-2} s/m.



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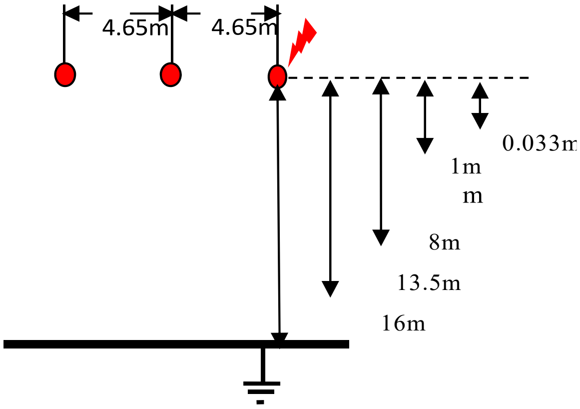


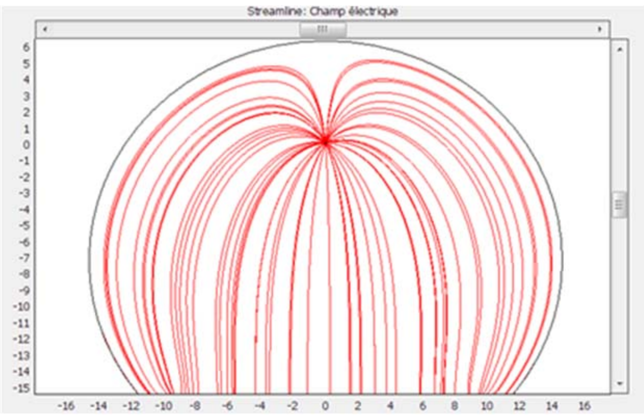
(b)

Fig. 2 Studied configurations: (a) 1Wire-Earth, (b) 3Wires-Earth

B. Numerical Determination of the Field Lines

The representation of the field lines is shown in Fig. 3. A field line is a tangent curve at each point to the vector field.

The line of field is oriented in the direction of the vector field. It is found that the field lines arise on the surface of the electrode and end at the artificial border or on the grounded plane. Each of them are each located in a well defined angle.



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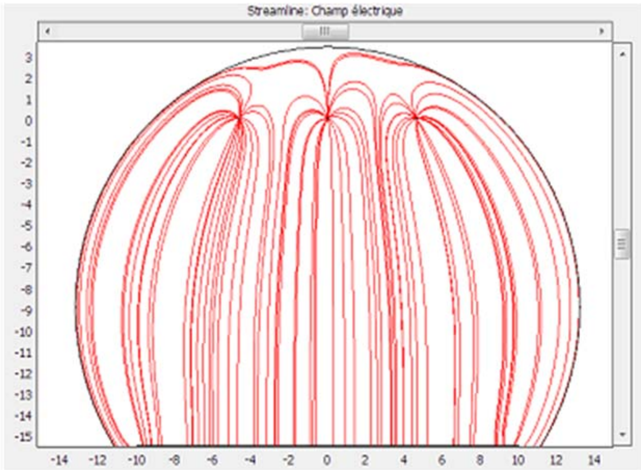

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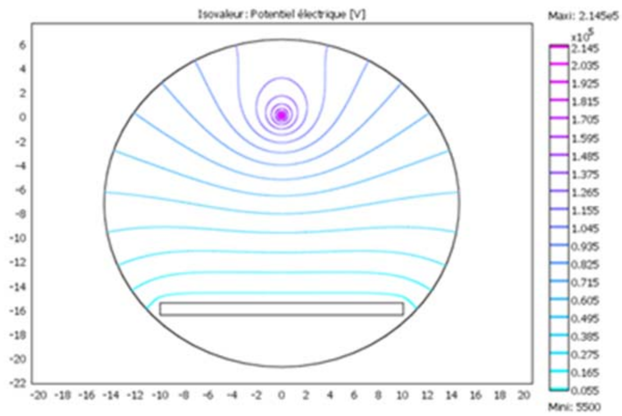
Fig. 3 The field lines: (a) 1Wire-Earth, (b) 3Wires-Earth

C. Numerical Determination of the Equipotential Contour

The equipotential contour variations are shown in Fig. 4. An equipotential surface is the site of points of the space where the potential has a given value. It is obvious that two equipotential surfaces never intersect.



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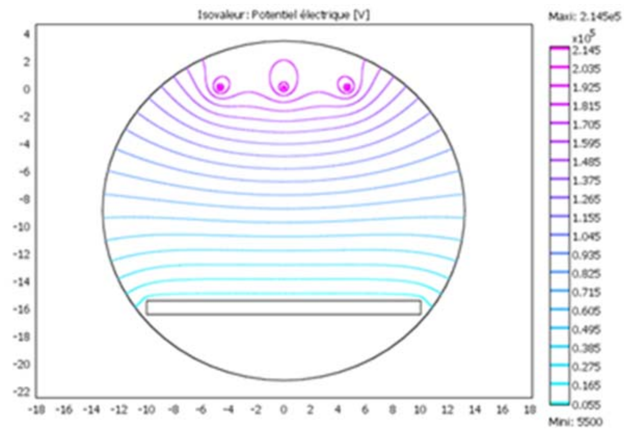


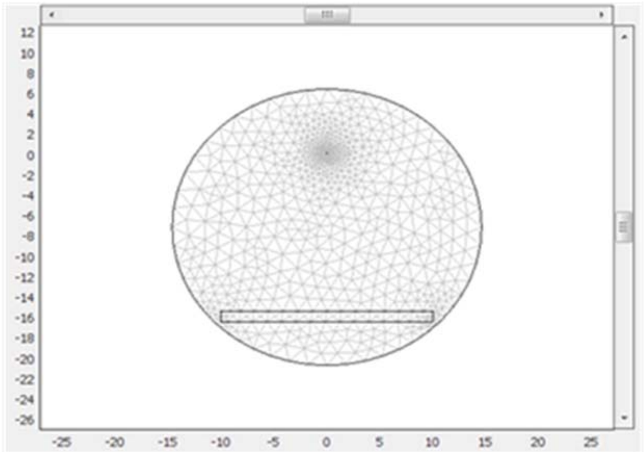
(b)

Fig. 4 Equipotential contours: (a) 1Wire-Earth, (b) 3Wires-Earth

An equipotential surface is orthogonal at each point to the field line passing through this point. It is found that the contours are centered on the conductor when the voltage is at its maximum.

D.Numerical Determination of the Mesh Grid

Fig. 5 shows examples of finite element of a studied mesh configurations. The node (*i*, *j*) is obtained by the intersection of the line with the contour. The mesh size is finer as one approaches the wire. In the drift region, the areas of the triangular elements increase with displacement along *X* and *Y*. FEM consists in subdividing the field of study into elementary domains, it enables us a certain freedom by cutting the field of study, while avoiding a subdivision where the domain borders do not coincide with the borders of the subdomains.



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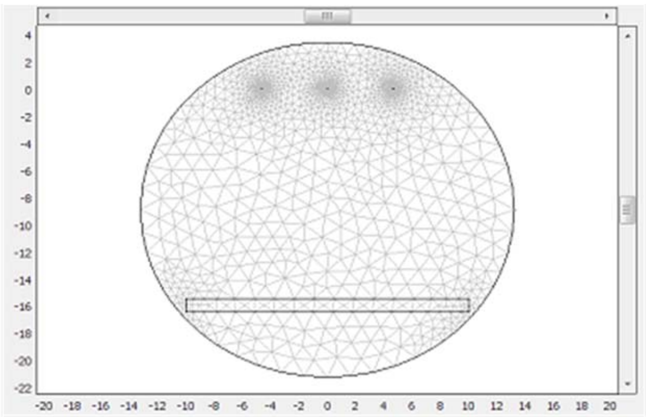
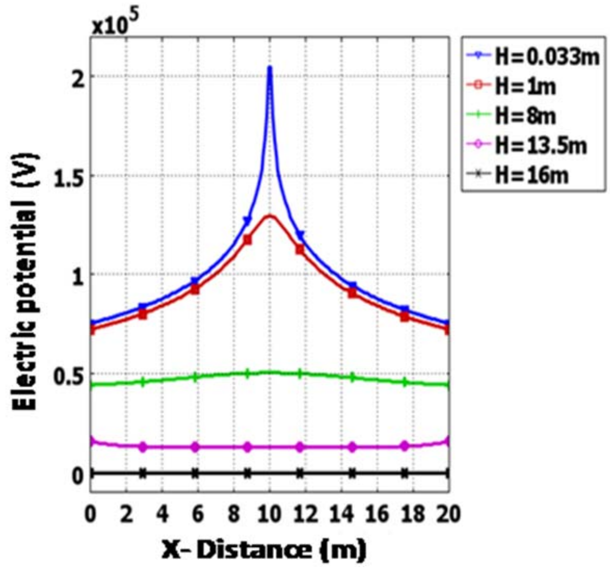


(b)

Fig. 5 The mesh used: (a) 1Wire-earth, (b) 3Wires-earth

D. Electric Potential

The potential distributions are shown in Fig. 6. It is noted that the electric potential has a maximum value at the vicinity of the conductor (H = 0.033m, U = 220 kV) while it has a minimum value at vicinity of the ground (H = 16m below the conductor, U = 0 kV).



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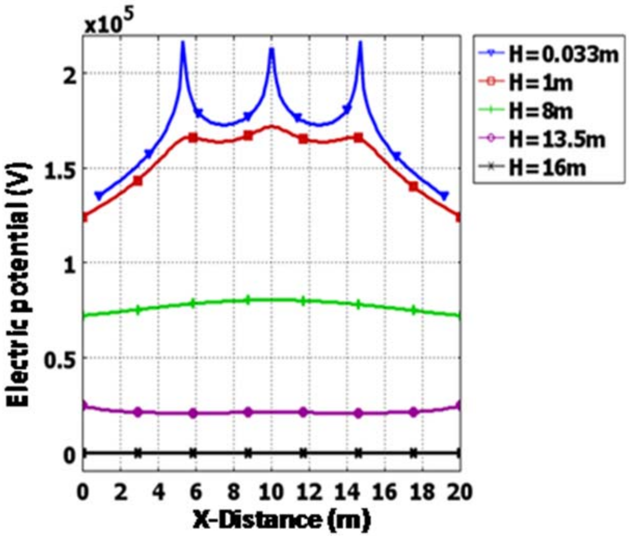
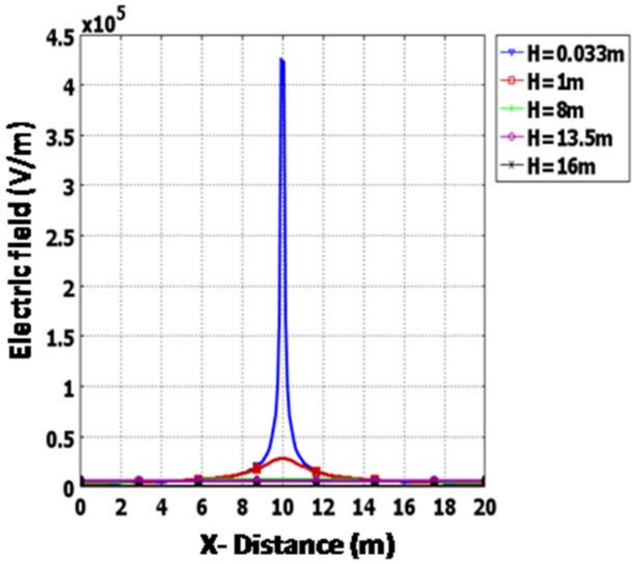


(b)

Fig. 6 Potential distribution: (a) 1Wire-earth, (b) 3Wires-earth

E. Electric Field

The electric field distributions of the system for various cases are shown in Fig. 7. It is found that the electric field around the wires is at its maximum and decreases rapidly approaching the earth. The electric field vector is the sum of the field due to the voltage applied at the transmission line plus the field contribution of the continuous space charge distribution. It will be appreciated from this fundamental approach that the operation of an electrostatic discharge is dependent on having a voltage high enough to produce an electric field in order to precipitate the particles and have sufficient current capability to satisfy ion production for the initial charging of the particles.



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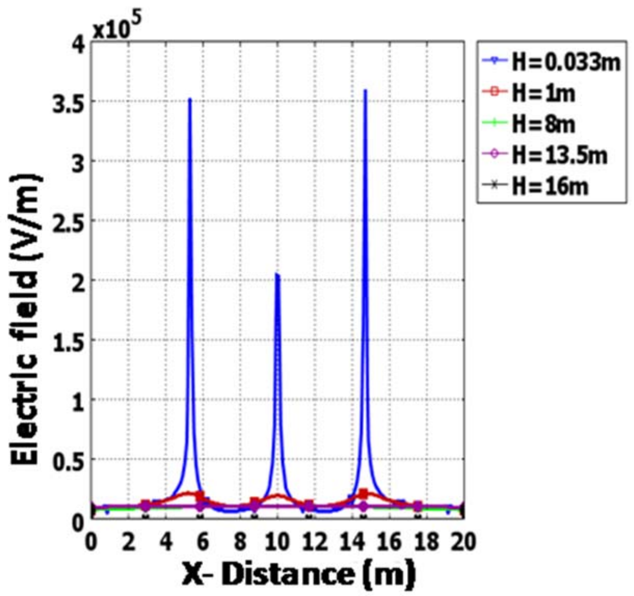

(b)

Fig. 7 Variation of electric field: (a) 1Wire-earth, (b) 3Wires-earth.

III. Conclusion

The study shows how this type of investigation can be done using the finite-element method. For a three-phase line, the electric field distribution is symmetric in the horizontal napped configuration. The influence of the height of the voltage on the field distribution below each phase has also been studied. The determination of the field distribution of electric potential for any high voltage system is a complex calculation problem, this is not because of the simplicity of partial differential equations that describe them, but because of the irregular shape of the dielectric, because of the metal proximity surfaces with complex forms, transmission lines, and in some cases, the presence of a conductive layer.

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