Electric Field Distribution in Air: Examples for Various Energized and Grounded Electrode Configurations

ABSTRACT

In this paper, distributions of the electric field and potential in air of two practical cases are presented. The first case is the examination of sphere gaps. The second case is the examination of power line conductors in the vicinity of a tower. Two-dimensional contours of the three-dimensional equipotential and equigradient contours are presented in selected vertical planes. (Gradient here means the potential gradient, i.e., the electric field strength.)

Electric Field Distribution in Air: Examples for Various Energized and Grounded Electrode Configurations

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Abstract

In this paper, distributions of the electric field and potential in air of two practical cases are presented. The first case is the examination of sphere gaps. The second case is the examination of power line conductors in the vicinity of a tower. Two-dimensional contours of the three-dimensional equipotential and equigradient contours are presented in selected vertical planes. (Gradient here means the potential gradient, i.e., the electric field strength.)

Introduction

Understanding the electric field and potential distribution is very important for the design and development of high voltage equipment and electrical insulation. Partial discharges and their effects can be reduced if the distribution of the electric field is known. The primary purpose of this paper is to study the electric field distribution in two practical cases.

- The first case is the examination of various sphere gaps in a Faraday cage.
- The second case is the examination of three-phase power line conductors without and with the presence of their supporting tower.

Consideration of the presence of insulators is not a subject of this paper.

IEEE defines the voltage as the dot product line integral of the electric field strength along a specified path in an electric field. The voltage is a scalar quantity, and therefore has no spatial direction. As here defined, voltage is synonymous with potential difference only in an electrostatic field. The electric potential is the potential difference between the point and some equipotential surface, usually the surface of the earth, which is arbitrarily chosen as having zero potential (remote earth). The definition of an equipotential line or contour is: the locus of points having the same potential at a given time [1].

IEEE also defines the electric field strength as the magnitude of the electric field at a point in the field. The electric field is a vector field of electric field strength or of electric flux density. Its synonyms used are gradient, voltage gradient, potential gradient. The potential gradient is a vector of which the direction is normal to the equipotential surface, in the direction of decreasing potential, and of which the magnitude gives the rate of variation of the potential [1]. The definition of an equigradient line or contour is: the locus of points having the same potential gradient (or electric field strength) magnitude at a given time.

Calculation methods include analytical and numerical methods. Analytical methods solve the Laplace equation for simple geometry and charge distribution. However, it is difficult to use an analytical method for the practical arrangements of energized and grounded electrodes. With the help of modern computers, numerical methods are more and more attractive for solving practical problems [2].

Numerical methods can be divided into two groups. The first group is to discretize the underlying integral equations. These are the charge simulation method and boundary element method (BEM). These two methods are preferable for open boundary problems, such as insulators or transmission lines. The second group is to solve the governing differential equations. These are the finite element method and finite difference method. These two methods are commonly used in the field analysis of problems with limited boundary conditions, such as rotating machines or transformers [3].

Software Used

For the studies in this paper the commercially available program COULOMB, developed by Integrated Engineering Software, has been applied. The COULOMB program is based on the BEM method, which is preferable for the open boundary problems. It has a "geometry modeler" to allow the user to enter the complex three-dimensional geometry of a practical system. It is easy to assign properties of the material (permittivity, conductivity) to appropriate regions of the model examined. COULOMB can provide the potential and electric field strength values at any location throughout the entire model domain.

Preparation of the Models

For the case of the sphere gaps, the diameter of the sphere electrodes is 25cm. The distance between the spheres is 10 cm. The spheres are positioned symmetrically over the center of the ground plane of a $4\times4\times4$ m^3 Faraday cage. Three alternatives are studied:

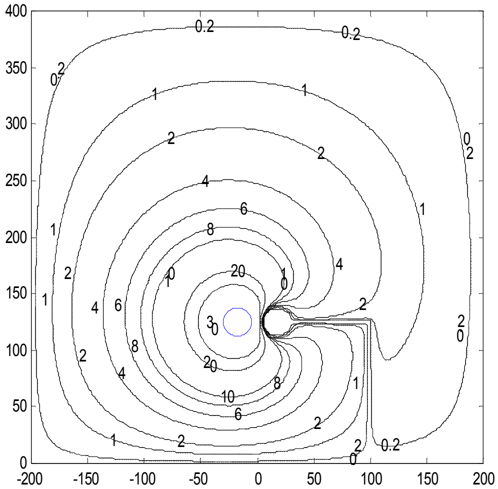
1. Horizontal sphere gap, asymmetrically energized: the spheres are aligned and positioned horizontally. The center line is 125 cm above the ground plane. The left sphere is energized at +100 V. The right sphere is grounded with a 2 cm diameter lead connected to the ground plane.
2. Horizontal sphere gap, symmetrically energized: similar to the arrangement above, except that the left sphere is energized at +50 V and the right one at –50 V.
3. Vertical sphere gap, asymmetrically energized: the spheres are aligned and positioned vertically. The center of the lower sphere is 81.5 cm above the ground plane. The upper sphere is energized at +100 V and the lower one is grounded with a 2 cm diameter lead connected to the ground plane.

For the case of the three phase power line conductors (with four-subconductor bundles), a typical three phase 765 kV transmission tower is utilized in the calculation.

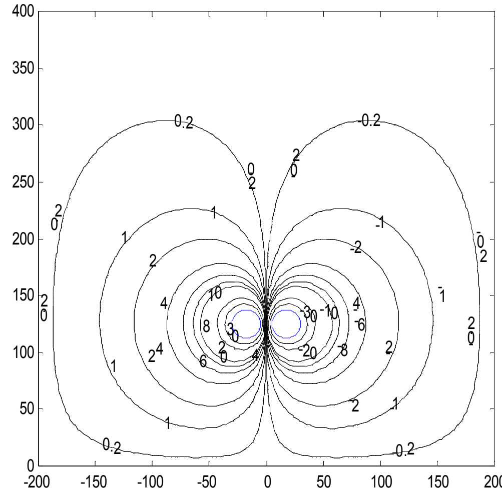
Analysis of the Electric Field of Sphere Gaps

Each sphere gap was modeled three dimensionally. The surface of each sphere was modeled using 864 four-sided elements. The average area of a typical element is about 2.3 cm^2. The discrepancies between the voltage calculated at any point on the surface of the spheres and the actual voltage were less than 0.5%. That shows that the calculation results gave sufficient accuracy. Typical computation time for each case was about 1.5 hours.

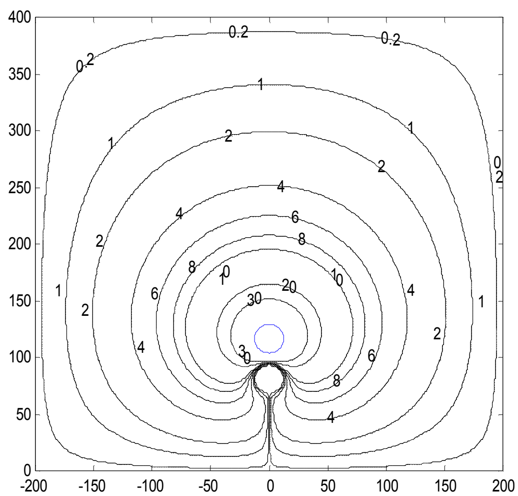
The equipotential contours in the vertical plane going through the centers of the two spheres are shown in Figure 1. The numbers shown in Figure 1, e.g., 0.2, 1, 2, 4, 6, 8, 10, 20, 30, are in volts. Figure 1 shows that the equipotential contours are distorted by the presence of the walls of the Faraday cage and of the grounding lead. (Similar to the grounding lead, the source - to - sphere connection would also change the electric field distribution inside the Faraday cage.) The horizontal or vertical orientation of the sphere gap has no significant effects on the electric field distribution between the two spheres. The electric field is not symmetrical in the vertical plane since the spheres are close to the ground plane.



(a) Equipotential contours of horizontal sphere gap, V_{left} = +100 V, V_{right} = 0 V.



(b) Equipotential contours of horizontal sphere gap, V_{left} = +50 V, V_{right} = -50 V.



(c) Equipotential contours of vertical sphere gap, V_{up} = +100 V, V_{down} = 0 V.

Figure 1.
Equipotential contours of sphere gaps.

Analysis of the Electric Field of Power Line Conductors

The simplified geometry and major dimensions of the tower and conductors are shown in Figure 2.

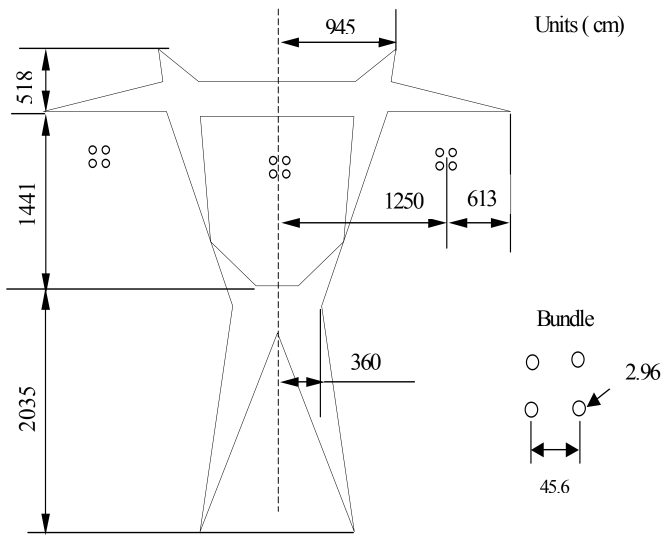


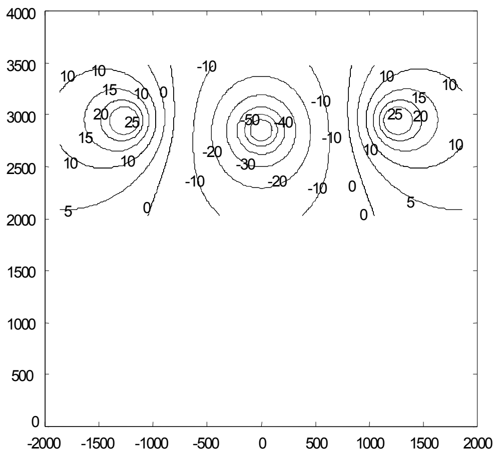
Figure 2.
Simplified geometry and major dimensions of the power line tower and conductors.

The power line conductors and tower were modeled three dimensionally. The conductors were modeled as smooth conductors, positioned parallel to the ground. The length of the conductors considered was 60m. The two ground wires were ignored in the calculation. Each of the three four-subconductor bundle sections was assumed to be 60 meters in length. Each bundle section was modeled using 1580 elements. The tower body was modeled using 3281 elements. The ground plane was modeled using 425 elements. The computation time of the transmission line and tower model using 8446 elements on a Pentium Celeron 400 MHz computer was about 6 hours.

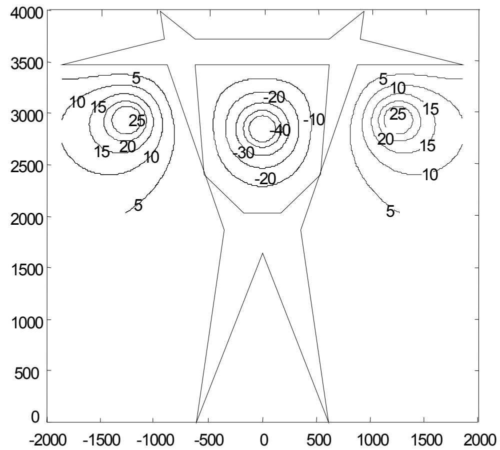
In order to evaluate the tower effects on the electric field distribution of the four-subconductor bundles, two cases were considered. In the first case, the tower is not present, similar to the conductors at midspan. In the second case, the tower is present.

Since the center phase is inside the tower window, one can study the worst case for the center phase conductors. The instantaneous voltages applied to the three phase conductor system are: V_{left} = +50 V, V_{center} = -100 V, V_{right} = +50 V. The resulting equipotential contours for these instantaneous voltages are shown in Figure 3. Of course, these contours are different for each instantaneous voltage system.

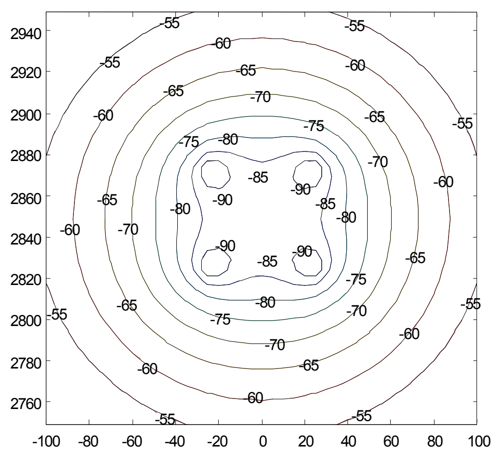
Figure 3 shows that the electric field is changed by the presence of the tower. The grounded tower body enhances the electric field strength around the four-subconductor bundles, which may result in the increase of the corona loss and radio noise.



(a) Equipotential contours of conductors w/o tower;
V_{left} = +50 V, V_{center} = -100 V, V_{right} = +50 V.



(b) Equipotential contours of conductors with tower;
V_{left} = +50 V, V_{center} = -100 V, V_{right} = +50 V.

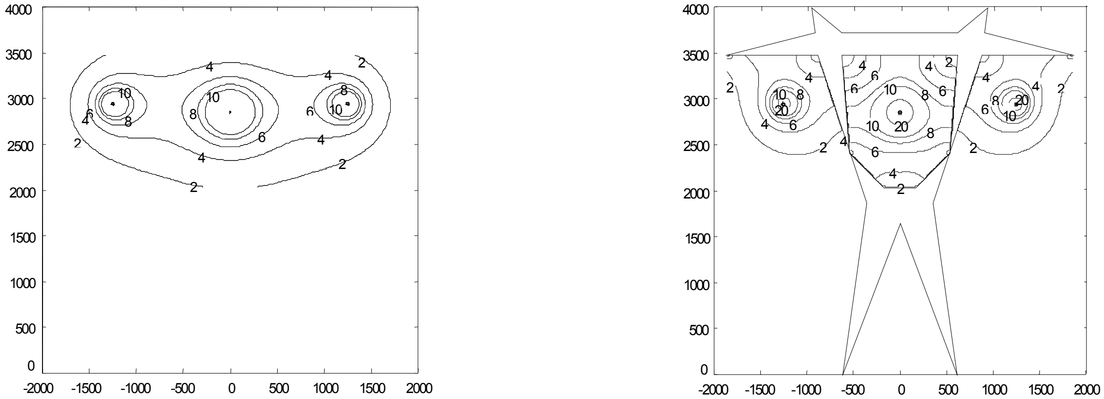


(c) The enlarged view of the equipotential contours around the center phase conductors in the tower window;
V_{left} = +50 V, V_{center} = -100 V, V_{right} = +50 V.

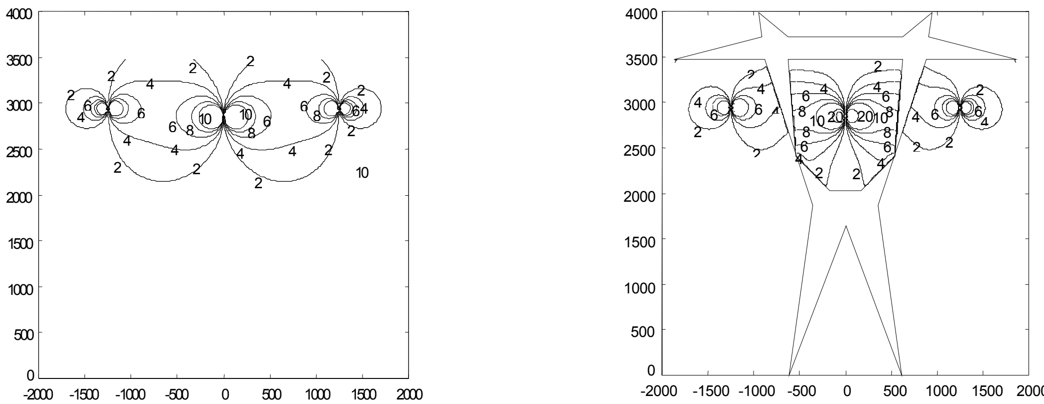
Figure 3.
Equipotential contours of power line conductors without and with the presence of the tower.

The electric field strength distributions around the conductors were also calculated for the two cases without and with the tower. The equigradient contours of the electric field strength (magnitude, horizontal and vertical components) are shown in Figure 4. Numbers shown on the equigradient contours (e.g., 2, 4, 6, 8, 10, 20, 30, 40) are in V/cm units.

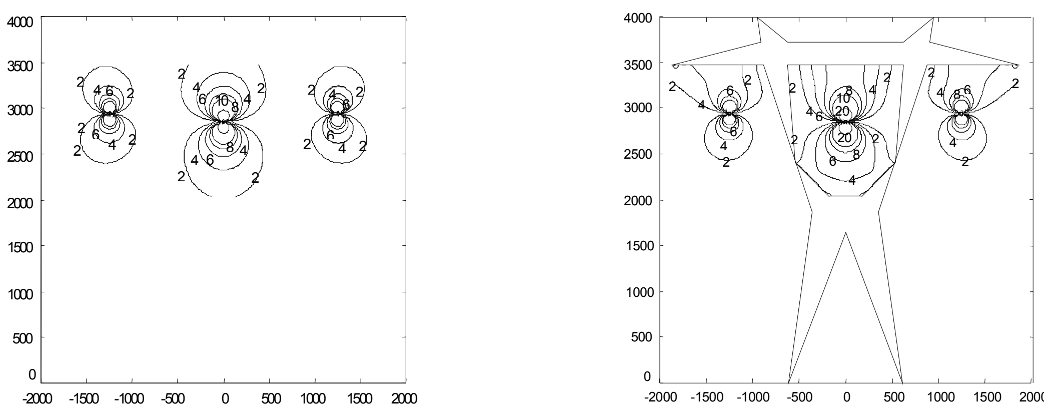
Figure 4 shows the effects of the presence of the tower on the electric field distribution around the four-conductor bundles for the instantaneous values of the three-phase energizing voltage system considered.



(a) Equigradient contours (magnitude) without tower and with tower;
V_{left} = +50 V, V_{center} = -100 V, V_{right} = +50 V.



(b) Equigradient contours (horizontal component) without tower and with tower;
V_{left} = +50 V, V_{center} = -100 V, V_{right} = +50 V.



(c) Equigradient contours (vertical component) without tower and with tower;
V_{left} = +50 V, V_{center} = -100 V, V_{right} = +50 V.

Figure 4.
Equigradient contours of power line conductors without and with the presence of the tower.

Conclusions

The electric field strength and potential distributions of various sphere gap arrangements, and a practical three-phase power line were studied using the COULOMB software.

- For the sphere gaps studied, the energizing and ground leads distort the electric field distribution inside the Faraday cage around the spheres. If the spheres are positioned too close to the ground plane of the Faraday cage, the electric field between the spheres will be modified slightly. The effect of the orientation of the sphere gap (horizontal or vertical) on the electric field in the sphere gap seems to be insignificant.
- For the power line, the effects of the presence of the tower on the electric field around the conductors, especially the center phase conductor, is significant. As a result, the local corona effects around the conductor sections in the vicinity of the tower are higher compared to those of at midspan.

Acknowledgment

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