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Calculation of electrostatically induced field in humans subjected to high voltage transmission lines

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ABSTRACT

A new approach is described for calculating the induced current and field in the human body by high-voltage alternating electric fields. The distribution of the electric field is obtained by using Laplace's equation. This relates the surface charge induced on the body to the potential in a reciprocal Laplace problem, which is then calculated by charge simulation method coupled with genetic algorithms to determine the appropriate arrangement of simulating charges inside the human body. The presented model for simulating electrical field is a three dimensional field problem and introduced different types of charges to simulate the different elementary geometrical shapes of human body. The particular strength of the charge simulation method in this application is its ability to allow a detailed representation of the shape and posture of the human body. The results have been assessed through comparison induced current and its distribution over the body surface, as estimated in other experimental and computational work. The accuracy of the simulated electric field is satisfied for the potential error (less than 0.1%), and the field deviation angle (less than 1°) over the human body.

1. Introduction

The simulation of non-uniform electric field plays an important role in the understanding of electrical phenomena, especially in the composite dielectrics and conducting medium; flow in electrolytic solutions [1], treeing in solids [2,3], streamer and electrification in liquids [4], and streamers in gases [5]. Numerical methods, such as finite element method (FEM) [1], charge simulation method (CSM) [3,6], charge density [7], Monte–Carlo method (MCM) [8], finite difference method (FDM) [9,10], and integral equation methods have been used to simulate the non-uniform electric fields.

An increasing demand to understand and quantify the interaction of electric fields with biological tissue has arisen in public discussion throughout the past years, due to the population increases and the overlap between the power transmission lines and the settlement areas which causes a problem, as in the case of exposure in random, residential, commercial and other areas, which lie very near or under the power transmission lines [6,11–14]. Also due to the development of transmission lines in operation range, which generate very strongly electric field in their near vicinity [11,14], needs to describe accurately the field interaction with life forms in close proximity to the transmission line right-of-way. Therefore, in the vicinity of AC transmission lines, the existence of electric field, in the space between the energized conductors and ground, needs an accurate calculation to simulate the induced electric field as a prerequisite to assess the environmental impact and health implications of transmission line fields on human.

Due to the complex geometry of the human body, the calculation of the induced electric field and current lead to substantial difficulty. For this reason, several approximate solutions have been derived, with the body represented by a parallelepiped, hemisphere, hemispheroid, or cylinder with several methods for numerical calculations. CSM [6,11,14], for example is used with approximation spherical shape for the head and cylindrical shape for the human body. MCM [8], also is used with approximation cylindrical shape for the human body but with more detailed geometrical modeling. FDM [9,10,15], is used but with a large number of grid points. Moment method techniques [16], assume a body made up of a combination of thin cylindrical sections. Finite element method [12], is used for the spatial distributions of the electric fields induced in the human body by switched magnetic field. Boundary element method [13], is used assumed the human body as thin wire, since the ratio of the average body length to its mean radius is enough to satisfy the thin wire approximation.

In this paper, the simulation of the induced field in the human body considered this model as a three-dimension problem. Hence, accurate computation of electric field is a prerequisite for determining the calculating induced field. The charge simulation method (CSM) and the method of image are used for the electric field distribution in the human body. The electric field distribution is obtained from Laplace's equation by treating the human body as conducting

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Table 1
Tissue conductivity and permittivity values [12].

Tissue	Conductivity σ (Ω^{-1} m^{-1})	Relative dielectric constant ε_r
Muscle	0.86	434,930
Bone	0.04	12,320
Skin	0.11	1136
Heart	0.5	352,850
Gland	0.11	56,558
Blood	0.6	5259
Lung	0.04	145,100
Liver	0.13	85,673
Lens	0.11	105,550

medium. The electric field is redistributed during the movement of the human. The charge over the human body is simulated by a set fictitious simulation charges arranged inside the human body, such as ring charges, finite line charges [6], and segment ring charges [17]. The presented model for simulating electrical field is introduced different types of charges used for the first time to simulate the human body, "such as elliptical charges and segment ring charges", taking into consideration the different elementary geometrical shapes of human body.

The optimum arrangement of these charges is achieved by using genetic algorithms (GAs) as a search optimization technique [3,6,18]. Series of vertical and inclined line charges [3,6,19] especially in the arms and unsymmetrical ring charges [20] especially in the legs. For these inclined and unsymmetrical charges, a coordinate transformation is performed. Then, the electric field is calculated in the original coordinate system. The charge simulation method in this application has the ability to allow a detailed representation of the shape and posture of the human body for grounded and an ungrounded case. The surface charges on the high voltage line conductors are simulated by infinite line of charges located at each line axis [3].

2. Method of analysis

Description of the electric field emanating from various transmissions line configurations has been adequately presented in many papers and texts [21]. Less attention has been paid to the magnetic field, probably because of the disparity in magnitude between the electric and magnetic fields.

2.1. Charge simulation methods

High voltage transmission line electric fields can be computed by numerical methods such as FEM, Boundary Element, MCM, FDM and CSM.

In CSM, the actual electric field is simulated by a number of discrete and fictitious simulation charges located in the conductors (transmission lines, human body, and earth) [3,5,6,11,17–20]. Values of simulation charges are determined by satisfying the boundary conditions at a number of contour points selected at the conductor surfaces. Once the values of simulation charges are determined, then the potential and electric field of any point in the region outside the conductor can be calculated using the superposition principle.

The various conductivity and relative equivalent dielectric constant of human Tissue [12] is given in Table 1. From this table the large conductivity and the large relative equivalent dielectric constant of the human body cause the external power frequency electric field near the human body to be perpendicular to the surface [22]. This is why the human body is treated as a conducting body.

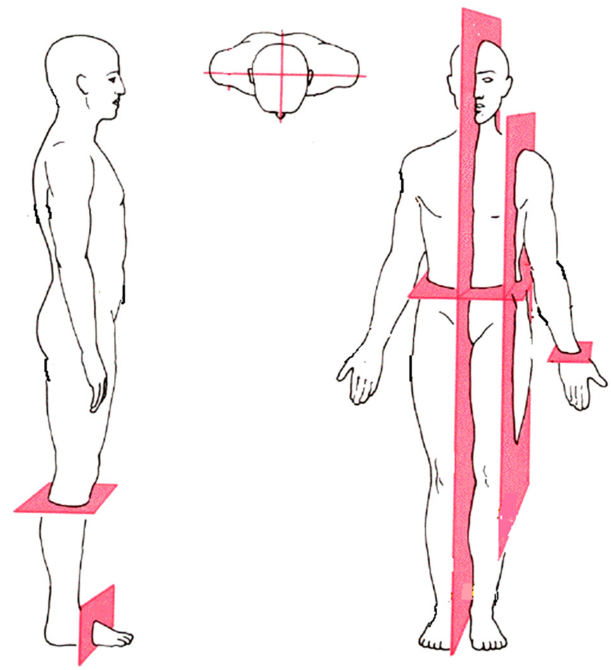

Fig. 1. The main planes of human body anatomy [23].

In this model, surface charges on the high voltage line conductors are simulated by infinite line of charges located at each line axis [3,5–7].

The human body is modeled taking a representation of boundary surface as a combination of certain elementary geometrical shapes: spheres, cylinders, boxes etc. these are juxtaposed or superposed as required.

Fig. 1 shows the main planes in the human body as a three-dimension model, and Fig. 2 represents the schematic diagram of the Engineering drawing of the human body with basic dimensions in centimeters.

The human body can be divided into five parts; head, neck, waist, arms, and legs. The head can be represented by a hemi-elliptical sphere at the top and a cylindrical shape for the remaining of the head. The head can be simulated as elliptical charges [24] at the top part, then as ring charges at the remaining part as shown in Fig. 3.

The neck can be represented by a cylindrical shape with simulated ring charges. While the waist can be represented by cuboid ends with a semi-cylinder at the edges in the direction of y-axis as shown in Fig. 4. This shape simulated by segment ring charges [17] at its semi-cylinder edges and two finite line charges in parallel to y-axis.

The legs are divided into two parts; top part represented as cylindrical shape, and bottom part represented as truncated cone. The top part is simulated with fixed ring charges diameters, and the bottom part is simulated with graduated ring charges diameters, see Fig. 5.

The arm can be represented by inclined cylindrical shape with simulated inclined vertical finite line charges, see Fig. 5.

The ground surface in Fig. 6 was represented by an infinite plane, while the transmission line was represented by infinite line of charge [6,11,25–27].

For each arm, the transformation of representation shape, see Appendix A, and inclines finite line of charges axes is required (Appendix B).

The potential calculated at the contour points chosen on the stressed transmission line is equal to the applied voltage V, while the potential calculated at the contour points chosen on the human body is equal to zero for a *grounded* body and for *ungrounded* body