Journal of Electrostatics 72 (2014) 387–395

Contents lists available at ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Calculation of electric and magnetic induced fields in humans subjected to electric power lines

M. Talaat

Electrical Power & Machines Department, Faculty of Engineering, Zagazig University, Egypt

ARTICLE INFO

Article history:
Received 11 March 2013
Received in revised form
2 June 2014
Accepted 27 June 2014
Available online 11 July 2014

Keywords:
Magnetic field calculation
Electric field simulation
Induced fields and current
Charge simulation method
Genetic algorithms
Human subject to electric power lines

ABSTRACT

In this work, analysis of the human body exposed to high voltage electric and magnetic fields is presented. 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 magnetic field intensity along the vertical center line of the human is calculated. Exposure to external electric and magnetic fields at power frequency induces electric field, magnetic field and currents inside the human body. The presented model for simulating electric and magnetic fields are 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, electric field, magnetic field and there distribution over the body surface, as estimated in other experimental and computational work.

1. Introduction

The numerical analysis of electromagnetic field plays an important role in the understanding of electrical phenomena such as; flow in electrolytic solutions [1], exposures to high voltage power lines [2], treeing in solids [3], electrification and streamers in liquids [4], streamers in gases [5], and the design of high voltage insulation [6]. Numerical methods, such as finite element method (FEM) [1,6], charge simulation method (CSM) [2,3,7], charge density [8], Monte-Carlo method (MCM) [9], finite difference method (FDM) [10,11], and integral equation methods have been used to simulate the non-uniform electric fields. CSM is one of the most successful numerical methods used for solving electromagnetic field problems [2,3,5,7].

The interaction of electric and magnetic fields with humans has initiated public concern, due to the overlap between the power transmission lines and the settlement areas which lie very near or under the power transmission lines [2,7,12–15]. There has been a growing interest in determining the safe exposure level of humans to power frequency electric and magnetic fields [2,7,12,15]. Therefore, the simulation of electric and magnetic fields, in the space between power lines and ground, is a prerequisite to assess the effect of power lines on human.

The calculation of the induced electric and magnetic fields in human lead to substantial difficulty, due to the complex geometry of the human body. For this reason, several approximate solutions have been derived using CSM [2,7,12,15], MCM [9], FDM [10,11,16], moment method techniques [17], FEM [13], and boundary element method (BEM) [14].

This paper presented a three-dimension electromagnetic field simulation. CSM and the method of image are used for the electric and magnetic fields simulation in the human body. The electric and magnetic fields distribution are obtained from Laplace's equation by treating the human body as a good conducting medium. The surface charges on human body are simulated by a number of charges arranged inside the human body, such as ring charges, finite line charges [2,7]. In this model the simulated electric and magnetic fields is introduced different types of charges such as elliptical charges and segment ring charges [18], taking into consideration the different elementary geometrical shapes of human body.

The optimum number, values, locations, and dimensions of these charges are achieved by using genetic algorithms (GAs) as a search optimization technique [2,4,7,19]. Series of vertical and inclined line charges [4,7,20] especially in the arms and unsymmetrical ring charges [21] especially in the legs. For these inclined and

E-mail addresses: m_mtalaat@eng.zu.edu.eg, m_mtalaat@yahoo.com.

http://dx.doi.org/10.1016/j.elstat.2014.06.008
0304-3886/

unsymmetrical charges, a coordinate transformation is performed. Then, the electric and magnetic fields are calculated in the original coordinate system. The CSM 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.

2. Method of analysis

Description of the electric and magnetic fields emanating from various transmissions line configurations have been adequately presented in many papers and texts [22].

2.1. Charge simulation methods

Analytical solution of Laplace's equation used for calculating electric field, can only be obtained for relatively simple charge distributions and conductor configurations. However, most of the high voltage systems are complex so numerical techniques are used to solve this problems. One of the most efficient end accurate numerical techniques for field computations is the CSM. It consists of replacing the actual continuous surface charge distribution of the conductors by a discrete set of fictitious charge distribution placed inside the volumes occupied by the conductors. The exact positions and values of the simulating charges are found so that the boundary conditions of the particular configurations are satisfied to a certain degree of accuracy.

In this paper the actual electric field is simulated by a number of discrete charges located in, (transmission lines, human body, and earth) [2,4,6,7,12,18–21]. 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 [13] 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 [23]. This is why the human body is treated as a conducting body.

In this model, surface charges on the high voltage line conductors are simulated by infinite line of charges located at each line axis [2,4,6–8].

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 represents the schematic diagram of the engineering drawing of the human body with basic dimensions in centimeters as a three-dimension model; the average dimension of any human part is given by Ref. [24]. The model given by Ref. [2] was used to simulate the human body using CSM, see Appendix A.

Table 1
Tissue conductivity and permittivity values [12].

Tissue	Conductivity $\sigma(\Omega^{-1}\mathrm{m}^{-1})$	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

2.2. Genetic algorithms

Genetic algorithms, (GAs), are a form of evaluation that occurs on a computer. GAs are a search method that can be used for solving problems and modeling evolutionary systems. The basic idea of GAs is very simple. First, a population of individual is created in a computer, and then the population is evolved with use of the principles of variation, selection, crossover and mutation until some termination criteria are reached [25].

In the present paper, GAs are used in the optimization of a variety of variables. These variables include the optimum number of charges, n, used to find the required number of simulated charges for each part of the human body and the transmission lines. Also the optimum location of charges, l , used to obtain the axial location of different types of charges along the human height. Finally the optimum radius of simulated ring charges, f, used for indicating the optimum radius of ring and segment ring of charges, see Appendix C.

2.3. Electric field simulation

The vector of unknown charges Q is computed from the matrix equation:

$$[Q_j] = [P_{ij}]^{-1} \times [V_i] \tag{1}$$

where, P_{ij} is the potential coefficient calculated at the ith boundary point due to the jth simulation charge Q_j and V is the applied voltage of transmission line.

For a given charge distribution, the calculated potential ϕ, at an arbitrary point is a summation of the potentials resulting from the individual charges,

$$\phi_i = \sum_{k=1}^{6} \phi_k \quad i = 1, 2, \ldots M \tag{2}$$

where, k indicates the human part ($k = 1$ for head, $k = 2$ for neck, $k = 3$ for waist, $k = 4$ for arm, $k = 5$ for upper part of leg, $k = 6$ for lower part of leg). The estimated values of ϕ_k are presented in Appendix B.

The simulated charges are distributed uniformly according to shape dimensions except the axial location of the elliptical and ring charges along the z-axis, the optimum location of these charges are determined by GAs, also the optimum radius of any ring charge, see Appendix C.

The used objective function used by GAs is simply the accumulated squared error, which has the form [21]:

$$U = \sum_{i=1}^{M} [V - \phi_i(x, y, z)]^2 \tag{3}$$

where, M is the number of contour points. For an ungrounded human body each of the transmission lines and the human body have an objective function. The ungrounded human body new objective function is simply the summation of factitious simulated charges inside the human body must be equal zero.

$$U = \sum_{i=1}^{M-n} Q_i = 0.0 \tag{4}$$

and for transmission lines the objective function is still the accumulated squared error but with only the simulated line charges.

$$U = \sum_{i=1}^{n} [V - \phi_i(x, y, z)]^2 \tag{5}$$