Effects of ELF Electric and Magnetic Fields on Human Beings and Their Computations

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***Abstract*—Overview of effects of extremely low frequency (ELF) electric and magnetic fields on human beings is presented. Particular attention is given to EHV transmission line fields, with a brief overview of the analytical and numerical methods to quantify the effects of fields. Charge simulation method (CSM) is discussed as one of the methods to evaluate the effects viz., currents induced in human body due to electric fields of transmission lines.**

I. Introduction

ELF refers to the frequency range of 30 Hz to 300 Hz. Above 100 kHz, the fields are called electromagnetic fields because they are essentially coupled in nature and propogate at the speed of light as oscillating bundles or particles of energy. This report eloborates only on the effects of ELF elctric and magnetic fields on human body. Use of electriciy and electric appliances is growing day by day and so is the concern about effect of these artificially generated ELF fields on human being. Electiric signals(stimuli) constitue an important part of nervous system in human beings and hence in the smooth functioning of overall body system. These signals might be affected by artificially produced fields. Further, human beings have no ability to directly detect the electromagnetic radiation.

WHO carried out health risk assessment of ELF fields and the results are reported [7]. The report says that there are little substantive scientific evidences about the effect of ELF fields on humans [7], but there are many unanswered questions which must be answered. And hence **WHO** research agenda demands for research in the this area.

II. ELF fields and humans : an overview

The effect of ELF fields on human body is non-thermal in nature as opposite to that of high frequency(HF) fields [6]. Further, ELF fields by their very nature, belong to the class of non-ionizing fields or non-ionizing radiations; i.e. they cannot ionize the matter due to lack of sufficient energy. Every radiation above X-rays forms ionizing radiation.

It is generally believed that if there is any effect of these fields on human beings it is by the induced currents. As the electric and magnetic fields are not coupled at extremely low frequencies, they are analysed separately. Both the fields are the forms of stored energy. Average conductivity of human body is 0.1 S/m and dielectric constant of 100,000. This differs from the corresponding constants for air which are 0.3333×10^{-8} S/m and 1 respectively. Hence electric field is distorted by the human body to a great extent. Magnetic field on the contrary passes almost unattenuated through human body. This is because the impedance of biological tissue to osclillating magnetic field does not differ from air. Electric fields are shielded by almost any object like tree, windows, wall etc., while magnetic fields are not. The oscillating magnetic field induce electric field which may produce currents. Also electric field at power frequency may induce surface charges and induced currents. Electric field induced spark discharges are noticable. They cause acute sensation of pain that is later accompanied by an exhaustion sensation. Thus electric and magnetic field at power frequency are able to induce current in human body [4].

Also human body is bipedal and upright which makes the problem unique to analyse. Further complexity is involved due to complex geometry of human body and different characteristics of different parts of human body; e.g. conductivity of human body varies from organ to organ [4]. The effect on certain organs are more harmful than on others.

There are short term and long term effects of these fields on humans. Short term effects include nerve and muscle stimulation and change in the nerve cell excitability in central nervous system. Studies in long term effects are mainly concentrated on child leukemia [7], [8]. There are some epidemiological evidences regarding the same.

Various guidelines and regulations regarding the ELF fields quote the limits on electric and magnetic field values in the vicinity of sources of the same. But most of them consider epidimiological studies as their basis [7], [8]. Power lines generate large fields and they are more predictable than any other source e.g. distribution lines, fields due to electric appliances etc. Hence almost all guidelines include the limits imposed on transmission line fields due to their size [9].

III. Classification of ELF fields and methods to quantify the field

ELF fields can be classified as high power fields and low power fields. High power fields are generated by various power system components like alternators at generating station, transmission lines, substations, distribution lines etc. Low/medium power fields are the ones generated by the electrical appliances/machines used at house or at workplace. They include TV, clothes washer, vacuum cleaner copy machines, welding machine etc.

Two types of research are found in the literature regarding the effect of fields on the human beings, epidemiological and reserach aimed at substantiating the effects of the fields by various methods. Below given is a non-exhaustive list of various topics of current research:

1) Calculation of currents electrically and magnetically induced in the human body(due to transmission lines)
2) Design of transmission line configurations to reduce magnetic field
3) Quantification fields in specific organs (e.g. bone marrow) induced due to external ELF fields
4) Study of effect of 'substation-fields' on the civilisation in the vicinity
5) Analysis of protective(shielding) apparatus for ELF fields
6) Development of novel computational methods to calculate the field values

IV. Electrostatic field of transmission line

Only EHV transmission lines are considered here. The largest voltage used for transmission line is 765 kV. The low frequency magnetic field is usually negligible due to balanced nature of three phase currents at fundamental frequency. But if the line carries significant third harmonic current, phase currents do not cancel. The return current can be in the ground circuit such as lighning shield wire and this leads to significant 180 Hz field. Current induced in human body due to magnetic field is considerably less than that induced by electric field [1], [5] if the line currents are balanced and contain no harmonics. Magnetic fields of transmission lines are not discussed anymore.

Classical analytical model of a transmission line considers the line as infinite line charge above the ground as shown in figure 1. Two dimensional approximation is used which agrees with the measured data [3], [4]. Also quasi static approach is used to analyse the fields.

Charge on the line is q_i. (x_i, y_i) are co-ordinates of the line. The electric field at any point T(x, y) can be given as given in equation 1. Subscripts h and v refer to horizontal and vertical component of field respectively.

$$E_t = (E_h^2 + E_v^2)^{1/2} \tag{1}$$

where,

$$E_h = \frac{q_i}{2\pi\epsilon_0} \cdot J \tag{2}$$

$$J = (x - x_i) \cdot \left\{ \frac{1}{D_i^2} - \frac{1}{D_i'^2} \right\} \tag{3}$$

$$E_v = \frac{q_i}{2\pi\epsilon_0} \cdot K \tag{4}$$

$$K = \frac{y - y_i}{D_i^2} - \frac{y + y_i}{D_i'^2} \tag{5}$$

D_i and $D_i^{'}$ are as shown in figure 1. For an 'n' phase line, we shall get 'n' such equations. Hence the total field at any point in that case is,

$$E_{ht} = \sum_{i=1}^{n} E_{hi} \tag{6}$$

$$E_{vt} = \sum_{i=1}^{n} E_{vi} \tag{7}$$

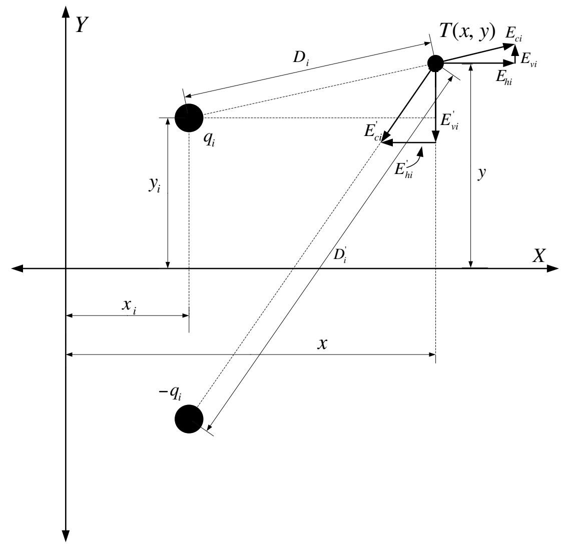

Fig. 1. Calculating electric field near a transmission line by analytical method

Similar procedure can be extended for the lines having multiple circuits and other configurations. For a *balanced single circuit three phase* line, the expressions can be simplified. Hence if V_m is the maximum phase voltage in the system,

$$E_h = J_h \cdot V_m \tag{8}$$

$$E_v = K_v \cdot V_m \tag{9}$$

$$E_t = (E_h^2 + E_v^2)^{1/2} \tag{10}$$

J_h and K_v are derived from J and K above and Maxwell's potential coefficient matrix [3]. Based on these formulae the electrostatic field of a three phase line is calculated using MATLAB(any other programming tool may be used). A simple line configuration as shown in figure 2 is used. Variation of electrostatic field vs distance(from the centre of the tower) of a 750 kV and 400 kV line are shown in figures 3 and 4 respectively. It is clear that the field values are negligible at a distance of five conductor spacings. This result is expected because the fields are defined by inverse square laws. Also, this agrees with the results reported in the literature [3], [4].

It is worth noting that the method above does not consider the sag in the line. There are methods in which a line with sag is modelled by a finite number of finite line charges [6]. The field values calculated by considering sag differ very little from those calculated without considering sag [4].

But these values are not valid when human being is present below the line, because the field gets distorted as found from actual measurements [4]. Further complications are involved when buildings, geographical slopes etc., are in the vicinity of lines. Due to complex geometries involved analytical methods are seldom effective and hence various numerical techniques have been proposed in the literature. Numerical methods can be used prior to planning of new transmission line installations. In each numerical method human body is modelled distinctly.

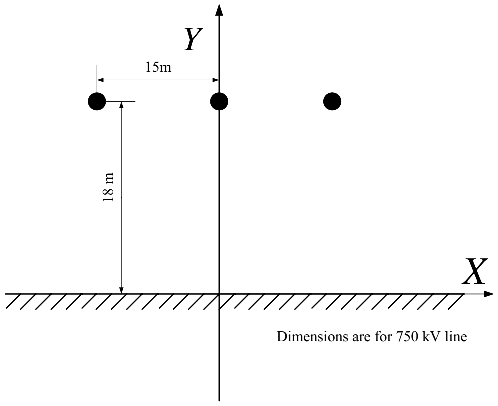

Fig. 2. A single circuit 3 phase 750 kV line

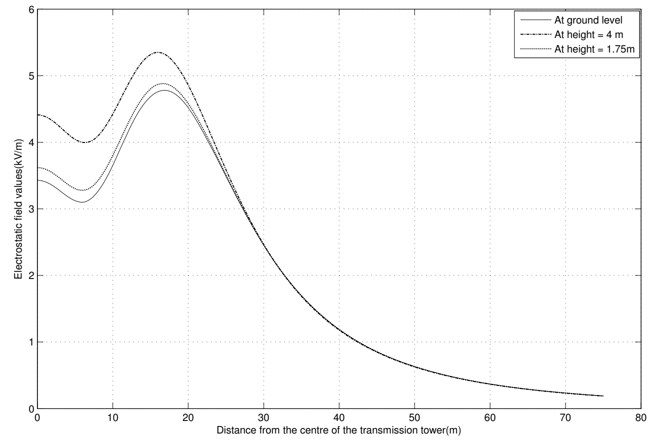

Fig. 4. Electrostatic field Vs distance, line voltage=400 kV

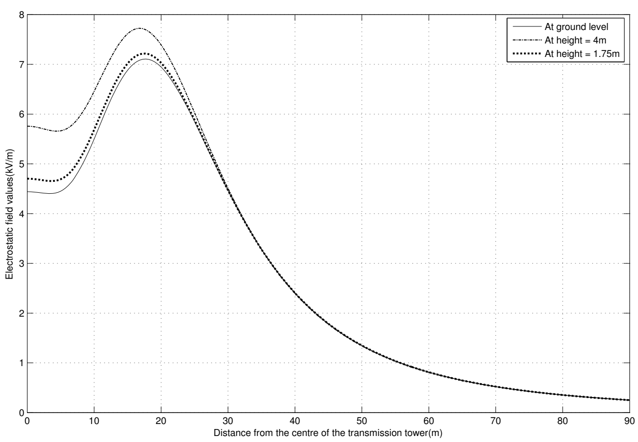

Fig. 3. Electrostatic field Vs distance, line voltage=750 kV

Boundary element method (BEM), charge simulation method (CSM), methods using parasitic antenna model of the body, are some of the examples. Only CSM is discussed here.

V. Charge simulation method

Charge simulation method is used to solve electric field problem including one or more media. Numerical methods are used to solve Laplce's and Poisson's equations. In CSM, potential of fictitious line charges is taken as a particular solution to the Laplace's and Poisson's equations. Existing charge configuration is replaced by 'n' fictitious charges placed outside the space where the field is to be computed. 'n' points on the surface of the conductors are then chosen such that potential at these points is known. Now, that we have removed the original charges present in the problem domain, the the potential at the selected 'n' points (*contour points*) must be produced by the 'n' fictitious line charges. Superposition can be applied in this case which leads to the following equation

$$\sum_{i=1}^{n} P_{ij} \cdot Q_j = V_i \tag{11}$$

Here, $V_i =$ potential at i^{th} contour point due to all charges $P_{ij} =$ 'potential coefficient' which relates potential at i^{th} point due to charge at j^{th} point.
This can be written in the form of a linear system of equations as follows

$$\mathbf{P} \cdot \mathbf{Q} = \mathbf{V} \tag{12}$$

It can be solved and can be checked for the a number of check points. Once the charge values are known, electrostatic field values can be easily calculated by classical method. This method can be used with two dimensional as well as three dimensional fields [2].

VI. Calculation of transmission line electric field in the presence of human body by CSM

The CSM model given in [1] is analysed by the use of MATLAB. The model is described below. Cylindrical co-ordinate system is used.

A. Model of human below transmission line for CSM

The transmission line field without any object below is practically directed vertically downwards. This can be seen from the values of horizontal and vertical components of fields calculated by classical method discussed in section IV. Results are shown in figures 5 and 6. The horizontal and vertical components here correspond to r and z components. Therefore, the field between a stressed horizontal metal plate and the ground plane is considered analogous to the ground-level electric field produced by the overhead transmission lines. In this way, the stressed plate replaces the line conductors. The model is shown in figure 8.

Human body is treated as a perfectly conducting body. It is modelled by a sphere for head, and three cylinders of different dimensions for neck,waist and legs; as shown in figure 7.

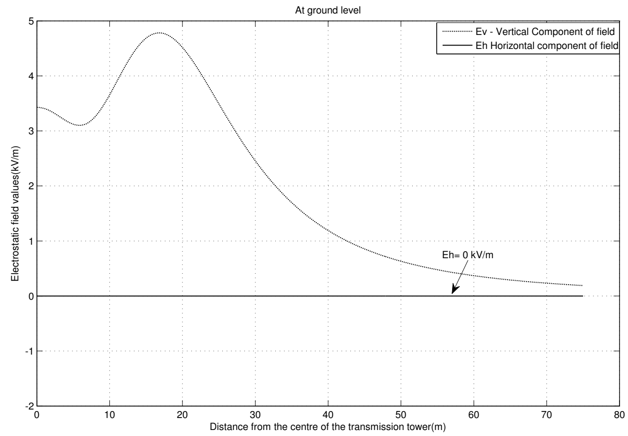

Fig. 5. Comparison of x and y component of electrostatic field (at ground level) due to transmission line

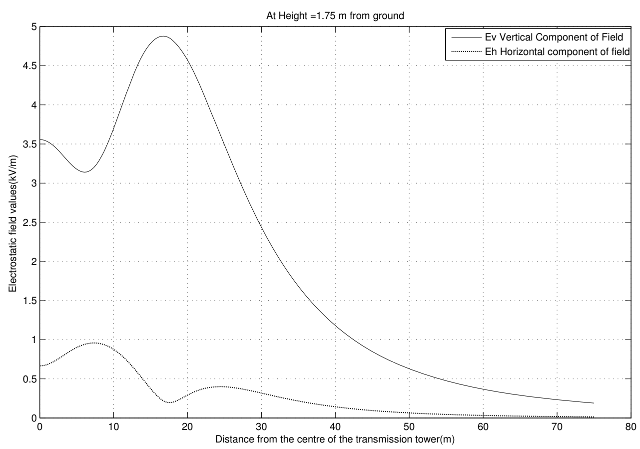

Fig. 6. Comparison of x and y component of electrostatic field (at height = 1.75 m) due to transmission line

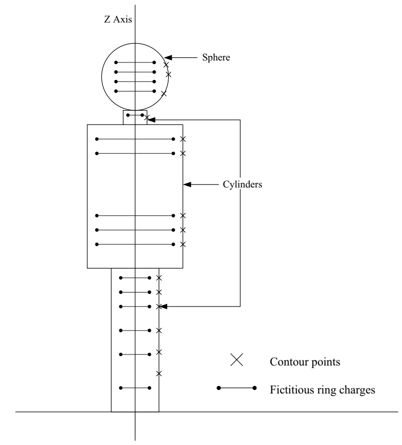

Fig. 7. Charge simulation of a human body

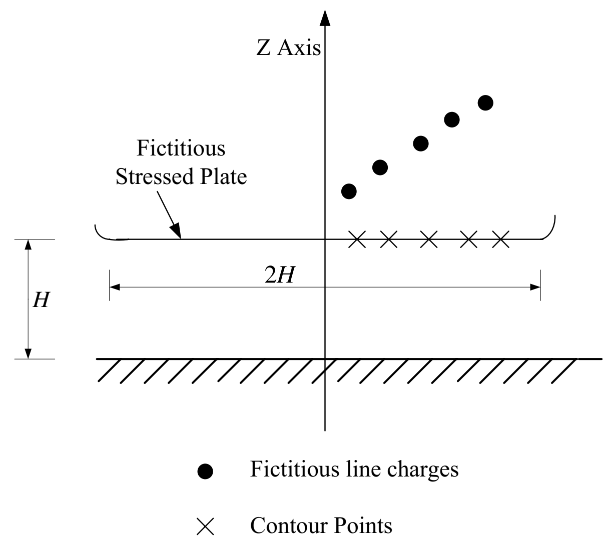

Fig. 8. Charge simulation of a transmission line structure

B. Placement of fictitious chrges

As shown in figure 8, $2 \times N_1$ fictitious charges are placed *above* the (fictitious) conducting metal plate, N_1 charges on each side of the z axis. The surface charge of human is simulated by another set of N_2 ring charges as shown in figure 7. The number of unknowns is $N_1 + N_2$ due to symmetry about Z axis. 'Contour points' for CSM are chosen on the body and on the fictitious metal plate as depicted in figures.

The **boundary conditions** are

1) The potential calculated at the contour points chosen on the metal plate is equal to the applied potential V.
2) For a grounded body the potential at the contour points on the body is zero. The case for the insulated body can also be simulated [1] which is not considered here.

To get a linear system of equations as in equation 12, knowledge of all potential coefficients is necessary. The coefficients are given in [1] Once the values of fictitious line charges are known, the electric field at i^{th} point is given by

$$E_i = \sqrt{E_{r_i}^2 + E_{z_i}^2} \tag{13}$$

where E_{r_i} and E_{z_i} correspond to i^{th} point and are elements of vectors $\mathbf{E_r}$ and $\mathbf{E_z}$ given below

$$\mathbf{E_r} = \mathbf{F_r} \cdot \mathbf{Q} \tag{14}$$

$$\mathbf{E_z} = \mathbf{F_z} \cdot \mathbf{Q} \tag{15}$$

Here $\mathbf{F_r}$ and $\mathbf{F_z}$ are the field coefficient matrices analogous to potential coefficient matrix in equation 12. Components of $\mathbf{F_r}$ and $\mathbf{F_z}$ are functions of geometry and are given in [1]. As human body is treated as a perfectly conducting body, total electric field E_i at any contour points on the human body is normal to the body and hence can be denoted by E_n. By Gauss theorem, charge density σ at a boundary point on the human body is given by

$$\sigma = \epsilon_0 E_n \tag{16}$$

Now if ω is the angular frequency of the voltage applied to the stressed plate, current density J normal to the body and just inside the boundary is

$$J = \omega\sigma = \omega\epsilon_0 E_n \quad (17)$$

The current I_k inside the body part is obtained by integrating J over the surface area of that part. Suppose we consider k^{th} part of the body then,

$$I_k = \int_{S_k} J dS \quad (18)$$

C. Numerical data and simulation results

Following parameters were selected for simulation

1) Height of human body $h = 174$ cm. Dimensions of various parts of the body are tabulated below.
2) Height H of the plate above the ground = 5 $\times h \approx$ 875cm
3) Length of the fictitious conducting plate = 2 $\times H$. This is to make edge effect minor at the human body.
4) Maximum line voltage values= 750 kV and 400 kV

Part of the body	Length (cm)	Radius (cm)
Head	18	9
Neck	6	6
Waist	60	20
Leg	90	15

Electrostatic field values are calculated using the above numerical data by means of a MATLAB program. It is to be noted that the values are different from the ones obtained from undisturbed field calculated by analytical methods. The field is enhanced by the presence of human beings [1] by a factor of 10. This depends on the accuracy of the charge simulation method [2].

VII. Conclusion

There are enough unanswered questions regarding the effect of ELF fields on human beings. These need to be answered by rigourous analysis of fields besides epidemiological studies. This problem is complicated by the fact fields that exhibit a totally different behaviour in the presence of biological entities and other artificial structures. Various computational techniques and approaches are being developed to quantify the field of EHV transmission lines. CSM can be used to quantify the electrostatic field when a human being is present below the transmission line. Model in which the human body is modeled by the ring charges is studied and it agrees with results.

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