Electric Field Distribution Resulting from a Mobile-Phone-Human Interfacing With an Overhead Power Transmission Line

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Abstract: - This paper presents exploitation of the finite difference method (FDM) to estimate electric fields resulting from an overhead power transmission line. The proposed analysis not only investigates the electric field intensity of the power line, but also examines interference caused by a mobile phone operation, sending an outgoing call. By using the FDM, electric field distribution around a human and his/her mobile phone can be graphically presented. This could reveal comprehensive effects of using the mobile phone underneath the power line on the mobile phone user. For demonstration, A 69-kV, 50-Hz overhead power transmission line supported by a H-frame tower is employed for a case study. Area of 8×12 m^2 underneath the power line is discretized as a simulation domain. As a result, electric flux lines around a human with sending outgoing call is very steep sloped and have a descent direction towards the human who is using the mobile phone.

Key-Words: - Electric Field, Finite Difference Method (FDM), Permittivity, Overhead Power Transmission Line, Boundary Conditions, Mobile Phone Operation

1 Introduction

The computation of electric fields is complex and difficult to find an exact solution [1]. Several numerical techniques have been increasingly employed to solve such problems since availability of high performance computers. Among these, finite difference method (FDM), finite element method (FEM) and boundary element method (BEM) are very popular [2]. Although they are simple and useful to estimate electromagnetic fields, it typically consumes substantial execution time when high accuracy of obtained solutions is required or especially when time-varying field is involved. The prediction of electric field intensity is very important in many aspects nowadays. Due to difficulty and time consuming of electric field measurement, numerical calculation can be applied to evaluate electric field distribution. In addition, since serious effects on health risk caused by electric field strength have been reported [3,4,5], recommendation and guidelines of electric-field-related tasks such as an overhead power transmission line are released to prevent a careless activity that might be performed close to the restricted area around the live conductor.

Nowadays, advanced communication technology has been rapidly developed. It results in low cost and wide access to communication network via wireless mobile phones. In most parts of the world, it might say that people, especially adults, has at least one mobile phone in their pocket. It is ready to use anywhere at anytime. We can use a mobile phone almost everywhere, even area under an overhead high voltage power transmission line. Of course, the transmission line itself carries load currents that can serve the entire demand of a major city. With high voltage potentials at the naked conductor surfaces, high level of electric field distributes to free spaces around the power lines. When human uses a mobile phone to send outgoing call under the power lines, electric field resulting from the mobile operation interferes with the electric field distributed by the transmission lines. This may cause some serious interaction acting on the mobile phone user [4,5].

In this paper, investigation of electric field interference caused by a power transmission line and mobile phone operation is carried out. A 69-kV, 50-Hz overhead power transmission line supported by a H-frame tower is employed for a case study. Area of 8×12 m^2 underneath the power line is discretized as a simulation domain. Section 2 provides information of analytical methods for electric field calculation. Also, the FDM is briefed to estimate electric field distribution of this interference. Section 3 gives detail of the test system and interfacing between human-mobile-phone interaction system and the electric field of the power transmission line. Simulation results and discussion are presented in section 4, while section 5 gives the conclusion and future work related to this paper.

2 Electric Field Calculation

Fig. 1 shows a single conductor system in 2D. Points 1 and 1′ in the figure represent the live conductor with potential V_1 and its image potential, respectively.

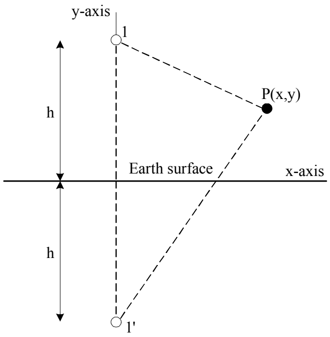


Fig.1 A single conductor system

2.1 Analytical method

From Maxwell's equations, in case of a point charge located sufficiently far from a measure point P(x,y), electric potentials at P can be expressed [5] as follows.

$$V_P = \frac{\lambda}{2\pi\varepsilon_0} \ln\left(\frac{\sqrt{x^2+(h+y)^2}}{\sqrt{x^2+(h-y)^2}} \right) \tag{1}$$

Also, self electric potentials inside a conductor can be computed by using Equation 2.

$$V = \frac{\lambda}{2\pi\varepsilon_0} \ln\left(\frac{2h}{r} \right) \tag{2}$$

From Equation 1 and 2, Equation 3 can be formed

$$V_P = \frac{V}{\ln\left(\frac{2h}{r}\right)} \ln\left(\frac{\sqrt{x^2+(h+y)^2}}{\sqrt{x^2+(h-y)^2}} \right) \tag{3}$$

To calculate electric field distribution, electric potentials at all related points must be obtained. It is simple to apply the relation of E=-∇V to a boundary of a region. Therefore, with Equation 4, the electric field at a given point can be calculated according to knowing the electric potential.

$$E = \sqrt{\left|\frac{\partial V_P}{\partial x}\right|^2 + \left|\frac{\partial V_P}{\partial y}\right|^2} \tag{4}$$

where,

r is a conductor radius

h is a distance between the conductor and the earth surface underneath

V is a conductor potential

λ is line charge density

ε_0 is the permittivity of a free-space

2.2 Field Solutions by the Finite Difference Methods (FDM)

Solutions of partial differential equations such as Laplace or Poison equations can be obtained numerically by using the FDM. These methods divide a domain into many small discrete elements to formulate a set of algebraic difference equations characterizing electric flux of the domain. With given boundary conditions on the solution region, an approximate solution is simply obtained by solving such algebraic equations. In 2D problems, rectangular grid as shown in Fig. 2 are the most commonly used domain discretization [2,4] for the FDM.

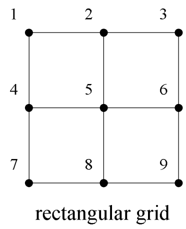


Fig.2 Domain discretization of the FDM

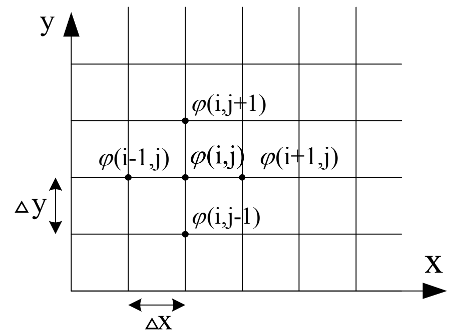


Fig.3 Discretization of 2D domain

2.2.1 Two-Dimensional FDM

Two-dimension domain in xy-plane is considered as shown in Fig. 3. The domain is assumed to be source-free and if the boundary conditions in terms of potential and its normal derivative are pre-specified, the static problem can be formulated by Laplace equation [2]:

$$\nabla^2\varphi = 0 \tag{5}$$

Where φ stands for the unknown potential within the domain of interest. For two-dimension problems in rectangular coordinates become Equation 6.

$$\frac{\partial^2 \varphi}{\partial x^2} + \frac{\partial^2 \varphi}{\partial y^2} = 0 \qquad (6)$$

Utilizing the central difference formula, the second order derivatives of the unknown field are obtained as follows.

$$\frac{\partial^2 \varphi}{\partial x^2} = \frac{\varphi(i+1,j) - 2\varphi(i,j) + \varphi(i-1,j)}{(\Delta x)^2} \qquad (7)$$

$$\frac{\partial^2 \varphi}{\partial y^2} = \frac{\varphi(i,j+1) - 2\varphi(i,j) + \varphi(i,j-1)}{(\Delta y)^2} \qquad (8)$$

Finally, substituting Equations 7 and 8 in Equation 6 results in the following formula

$$\varphi(i,j) = \frac{1}{4}\left[\varphi(i+1,j) + \varphi(i-1,j) + \varphi(i,j+1) + \varphi(i,j-1)\right] \qquad (9)$$

2.2.2 Interface between media of dielectric permittivities ε_1 and ε_2

On the dielectric boundary, the boundary condition ($D_{1n} = D_{2n}$) must be imposed. This condition is based on Gauss's law for the electric field as Equation 10 [2].

$$\oint_l D \times dl = \oint_l \varepsilon E \times dl = 0 \qquad (10)$$

As can be seen in Fig. 4, Equation 10 is rewritten into Equation 11 that is simpler and ready for use by the FDM.

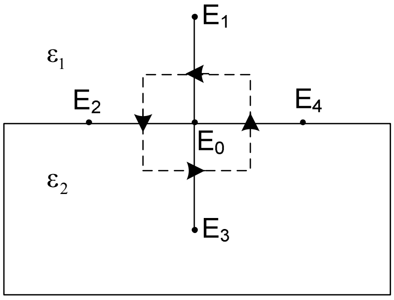


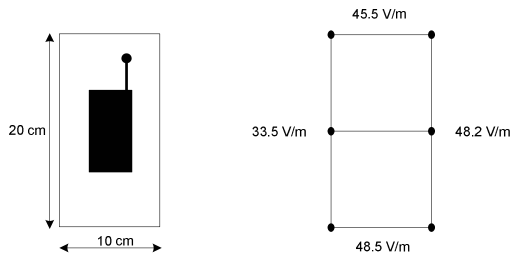
Fig.4 Interface between media of dielectric permittivities ε_1 and ε_2

$$E_0 = \frac{\varepsilon_1}{2(\varepsilon_1+\varepsilon_2)} E_1 + \frac{\varepsilon_2}{2(\varepsilon_1+\varepsilon_2)} E_3 + \frac{1}{4} E_2 + \frac{1}{4} E_4 \qquad (11)$$

After all node equations or all element equations are successfully derived, they must be assembled altogether to represent the unified characteristic of the entire domain. The entire system is expressed in matrix form as [C][V] = [F], where [C] is a coefficient matrix, [V] is a vector of unknowns and [F] is a vector of external forces [2]. Its solutions can be obtained with many efficient techniques of handling a set of linear equations, e.g. Gaussian elimination, matrix factorization, conjugate gradient method, etc.

3 Mobile phone and human interface model

The simplest way to model a mobile phone interfacing with human is to define a small rectangular domain. Its size is given to fit a mobile phone size, typically rectangle-like shape as shown in Fig. 5-a. In this paper, Nokia3210 of 5×10 cm^2 is used. By taking field measurement around the mobile phone [6], the rectangle domain of 5×10 cm^2 with fixed electric field intensity at the boundary is characterized as shown in Fig. 5-b.



a) b)

Fig.5 Mobile phone discretization for FDM

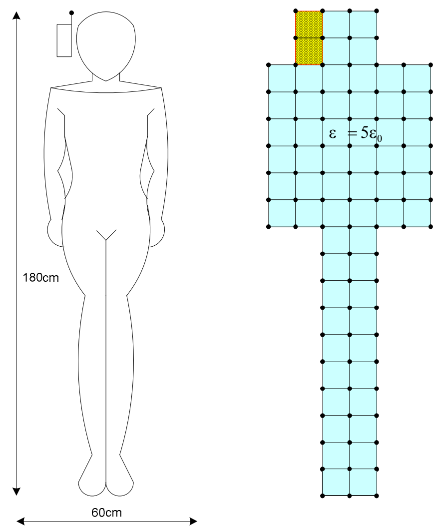


Fig.6 Mobile phone and human interface model

Human body model of 180-cm height with a given of $5\varepsilon_0$ for body kin permittivity is set. Neglecting any effects from environment, air surrounding the human body has a constant permittivity of ε_0 as shown in Fig. 6. This model can be simply added together with the domain defined for the power transmission line conductors and formulate the entire system matrix coefficient for the FDM.

4 Numerical Results

A $8\times12m^2$ area underneath an overhead power transmission line as shown in Fig. 7 is situated as the test system. The high voltage level of 69-kV, 50-Hz is applied as the surface conductor potentials. The discretization domain for the FDM can be depicted as shown in Fig. 8.

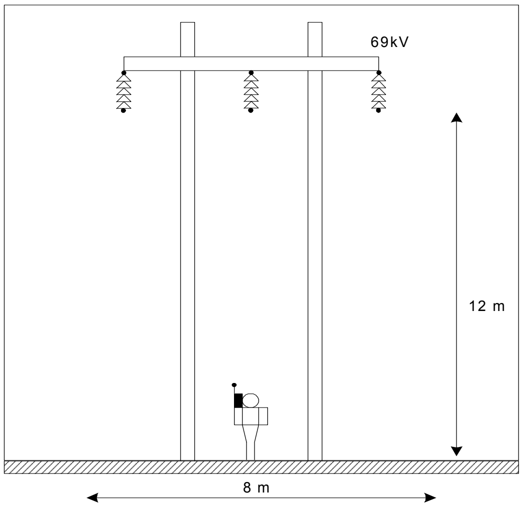
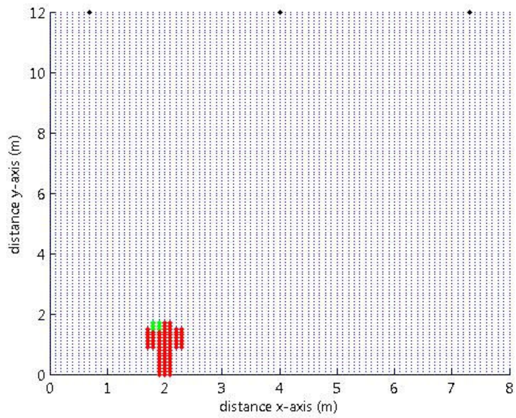
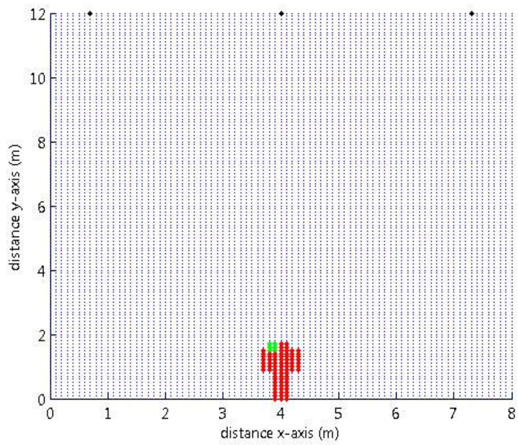


Fig.7 Test domain for mobile-phone-human interfacing with an overhead HV power transmission line

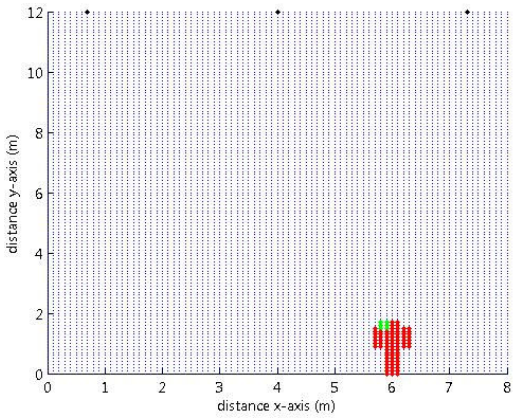
The test carries out 3 main test cases, the human located at x = 2 m, x = 4 m and x = 6 m as shown in Fig. 8-a, 8-b and 8-c, respectively. Each case consists of two test case scenarios, i) mobile phone operating in the standby mode and ii) mobile phone operating in the mode of sending an outgoing call. With performing the electric field simulation via computer programs coded in MATLAB [7,8], the electric field distribution for each case can be shown in Figs 9 – 11. Fig. 12 illustrates the electric flux contour surrounding the human body. This result can be further developed to identify the ability of electric field absorption to diagnose health risk of the human body or sudden occurrence of electric shock that might be induced due to high different electric potential acting on the human body.



a) x = 2-m case

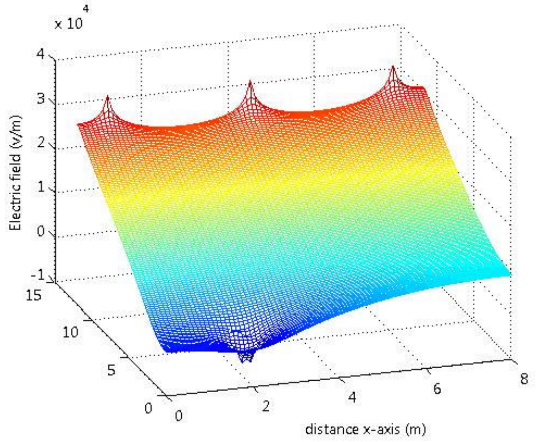


b) x = 4-m case

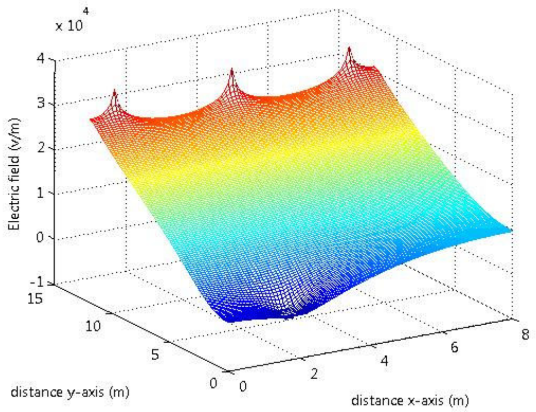


c) x = 6-m case

Fig.8 Test cases for mobile-phone-human interfacing with an overhead HV power transmission line based on the FDM

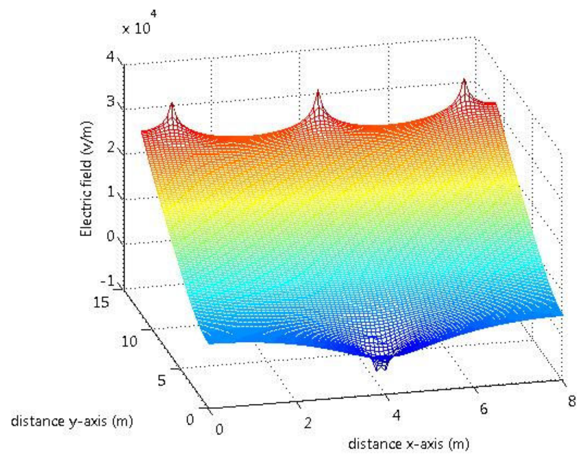


a) Sending outgoing call

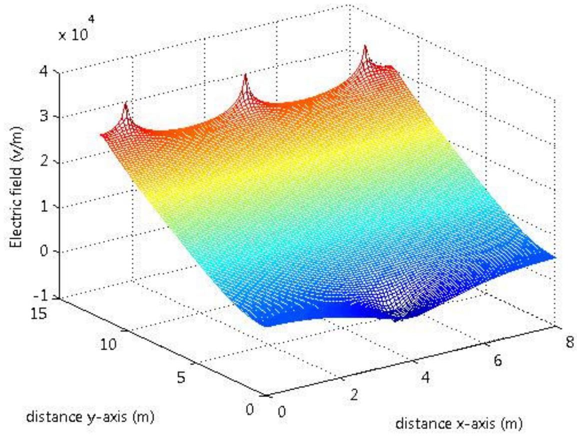


b) Standby mode of operation

Fig.9 Human interfacing with the mobile phone located at x = 2 m

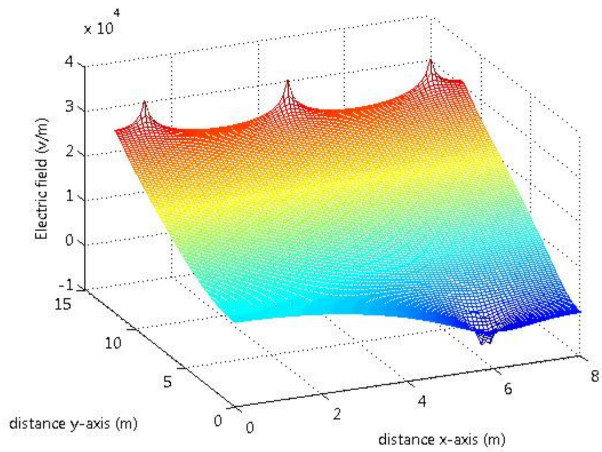


a) Sending outgoing call

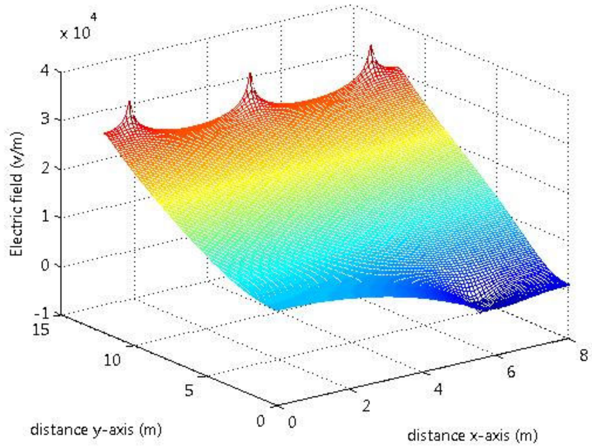


b) Standby mode of operation

Fig.10 Human interfacing with the mobile phone located at x = 4 m



a) Sending outgoing call



b) Standby mode of operation

Fig.11 Human interfacing with the mobile phone located at x = 6 m

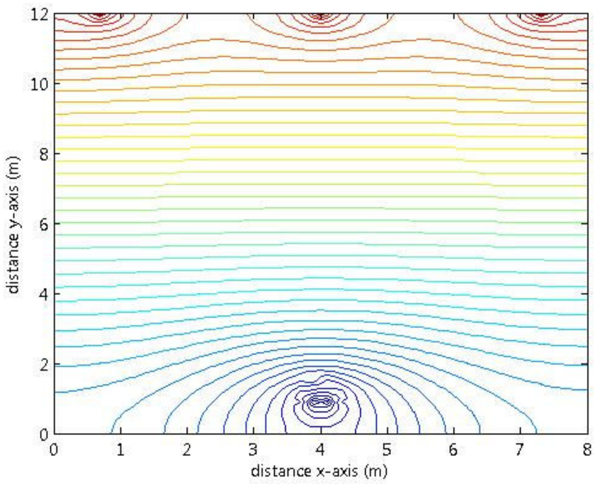


Fig.12 Contour of electric flux lines

As can be seen, by using the FDM to solve for electric field distribution, some complex electrostatic field problems can be estimated. This leads to investigate advanced and comprehensive situations related to the power transmission system.

Taking a close look into the computational procedure, the FDM is based on numerical computing that means it formulates a numerical coefficient system matrix to form a linear system of equations. In this situation, a total of 9801 nodes was generated. It results in a very large matrix size, 9801×9801, and therefore consumes very slow execution time. However, to speed up the calculation, sparse matrix storage and computation are exploited. Hence, the overall execution time can be reduced to about 20% of the original consumed. Fig. 13 shows the sparsity (using spy plot command in MATLAB [7]) of the system coefficient matrix of the FDM problem in this paper.

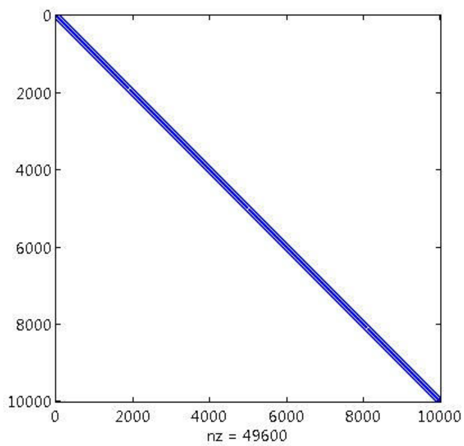


Fig.13 Sparsity of the system coefficient matrix

5 Conclusion

Estimation of electric field distribution can be performed by using the FDM. In this paper, an overhead 69-kV power transmission line interfacing with mobile-phone-human system is used for test. It consists of 9801 nodes for the FDM domain. As a result, difference electric flux distribution between cases of sending outgoing call and standby-mode of the mobile phone operation is characterized.

Utilization of the FDM is simple but time-consuming process. To enhance the computational speed, sparse matrix computation may be exploited. However, as can be seen in Fig. 13, all non-zero elements are packed around the diagonal with a certain matrix band, therefore applying a structured sparse matrix like band diagonal matrix can lead to maximize the computational time reduction.

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