INDUCED CURRENT CALCULATION IN EMBRYO DUE TO HIGH VOLTAGE TRANSMISSION LINE

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Abstract: *This paper investigates the induced electric field and current in the embryo body when exposed to an incident extremely low frequency electromagnetic field. The one of the sources that produces this kind of electromagnetic fields is high-voltage (HV) overhead transmission line. This electromagnetic field has lately been added to the list of potential threats to public health. It is a goal of this paper to search for scientific facts of this problem, like determining the electromagnetic field at all points near a HV overhead transmission line and the induced electric field and current in the embryo body. For reaching this purpose, a cylindrical human body model has been used in simulation.*

Keywords: *Electromagnetic field, human body, transmission line, induced current.*

1. INTRODUCTION

In late 1960s, increased need for electrical energy caused that power companies turned increasingly to Extra High Voltage (EHV) transmission lines. Transition was necessary in order to handle with large losses in high-voltage (HV) overhead transmission lines. Specifically, EHV lines carry electric power with lower energy losses and with smaller land usage than lower-voltage lines with the same power-delivery capacity [1]

Public attention to EHV transmission lines focused first on their ecological impact of their rights-of-way, and the adverse effects by their strong fields, like audible noise and TV/radio interference, which are direct consequence of "corona" effect. When first evidence that power frequency fields might have opposed effect on human health appeared, it served to stimulate public concern. Since then journalist try to increase their concern with their non-technical articles, and physical and biomedical science try to solve this problem using scientific facts [2].

Electric and magnetic fields (EMF) are present everywhere that electricity flows. Electrical appliances, household wiring and electrical power lines all produce electric and magnetic fields. These fields are part of a broad range of waves called the electromagnetic spectrum, which includes other waveforms such as radio waves, microwaves, infrared rays and x-rays. Different forms of electromagnetic energy are distinguished by their frequency, measured in hertz (Hz). Power frequency EMF has a frequency of 50 or 60 Hz. EMF from electricity is classified as "Extremely Low Frequency" (50 or 60 Hz), producing much less energy than other waveforms in the spectrum. The increasing use of distribution and transmission of electrical energy between randomly occurring causes concerns regarding the risks of human exposure to near-field radiation from the HV overhead transmission lines and electric power substations. The studies into the health effects of long-term exposure have been progressing on several fronts [3]-[6].

In this paper we will model and calculate the induced current in embryo inside mother body.

2. EMBRYO MODELING FOR INDUCED CURRENT CALCULATION

In this analysis the following configuration (Figure 1) is considered [7]. In this model a pregnant woman is stand near to a HV transmission line (figure 1(a)). Figure 1 (b) shows a human embryo. Figure 1(c) shows spherical model of embryo, in this model 5 region is considered as follows:

1- $r<a$ Embryo pole
2- $a<r<b = a + \delta_2$ Embryo membrane
3- $b<r<c$ Embryo membrane to uterus wall
4- $b<r<d = c + \delta_4$ Uterus membrane
5- $d<r$ Outside of uterus

E_{2z} is induced electrical field in mother body in z direction.
Above parameters for embryo are shown in table 1.
Boundary conditions are:

$$r=a \qquad E_{1r}=\varepsilon_2 E_{2r} \qquad \varphi_1=\varphi_2$$
$$r=b \qquad \varepsilon_2 E_{2r}=E_{3r} \qquad \varphi_2=\varphi_3$$
$$r=c \qquad E_{3r}=\varepsilon_4 E_{4r} \qquad \varphi_3=\varphi_4$$
$$r=d \qquad \varepsilon_4 E_{4r}=\varepsilon E_{5r} \qquad \varphi_4=\varphi_5$$

Due to spherical symmetry of embryo and this fact that induced electrical field in mother body in z direction is constant, we have following equation (equation 1) for scalar potential:

$$\varphi \equiv \varphi(r,\theta) = f(r)\cos(\theta) \qquad (1)$$

By using the following equation:

$$\nabla^2 \varphi(r,\theta) = 0 \qquad (2)$$

We have:

$$\nabla^2 \varphi(r,\theta) = \cos(\theta)\left(\frac{\partial^2 f}{\partial r^2} + \frac{2}{r}\frac{\partial f}{\partial r} - \frac{2}{r}\right) = 0 \qquad (3)$$

By solving the above equation we have:

$$f = f(r) = C_1 r + C_2 / r^2 \qquad (4)$$

In equation (4) C_1 and C_2 are constants and can be obtained from boundary conditions.

r<d so:

$$f(r) \to -rE_{2z}^{inc} \qquad (5)$$

By obtaining the general solution of the equation (3) we can find the solution in specific regions of fig. 1, therefore we define the *f(r)* for different regions as follows:

$$f_1(r) = A_1 r \qquad r < a \qquad (6)$$

$$f_2(r) = A_2' r + A_2'' / r^2 \qquad a < r < b \qquad (7)$$

$$f_3(r) = A_3' r + A_3'' / r^2 \qquad b < r < c \qquad (8)$$

$$f_4(r) = A_4' r + A_4'' / r^2 \qquad c < r < d \qquad (9)$$

$$f_5(r) = -rE_{2z} + A_5'' / r^2 \qquad r > d \qquad (10)$$

These are 8 constants in the above mentioned equations (6 to 10). These constants can be obtained from equations 1 to 5.

$$f_1(a) = f_2(a) \ (11\text{-a}) \qquad \frac{\partial f_1(r)}{\partial r} = \varepsilon_2 \left[\frac{\partial f_2(r)}{\partial r} \right] \ (11\text{-b})$$

$$f_2(b) = f_3(b) \ (12\text{-a}) \qquad \varepsilon_2 \left[\frac{\partial f_2(r)}{\partial r} \right] = \frac{\partial f_3(r)}{\partial r} \ (12\text{-b})$$

$$f_3(c) = f_4(c) \ (13\text{-a}) \qquad \frac{\partial f_3(r)}{\partial r} = \varepsilon_4 \left[\frac{\partial f_4(r)}{\partial r} \right] \ (13\text{-b})$$

$$f_4(d) = f_5(d) \ (14\text{-a}) \qquad \varepsilon_4 \left[\frac{\partial f_4(r)}{\partial r} \right] = \frac{\partial f_5(r)}{\partial r} \ (14\text{-b})$$

With aid of equations 6 to 14 we have equations 15 to 18 for computing the constants.

For r = a:

$$A_1 - A_2' - \frac{A_2''}{a^3} = 0 \qquad (15\text{-a})$$

$$A_1 - \varepsilon_2 \left[A_2' - 2\frac{A_2''}{a^3} \right] = 0 \qquad (15\text{-b})$$

For r = b:

$$A_2' + \frac{A_2''}{b^3} - A_3' - \frac{A_3''}{b^3} = 0 \qquad (16\text{-a})$$

$$\varepsilon_2 \left[A_2' - 2\frac{A_2''}{b^3} \right] - A_3' + 2\frac{A_3''}{b^3} = 0 \qquad (16\text{-b})$$

TABLE 1.
EMBRYO MODEL PARAMETERS [7].

Parameters	Pregnancy Duration (Weeks)		
	Six	Seven	Eight
a (mm)	2	4.5	6.5
b (mm)	2.1	4.6	6.6
c (mm)	50	50	50
d (mm)	51.1	51.1	51.1
δ_2 (S/m)	0.1	0.11	0.12
δ_4 (S/m)	0.1	0.1	0.1

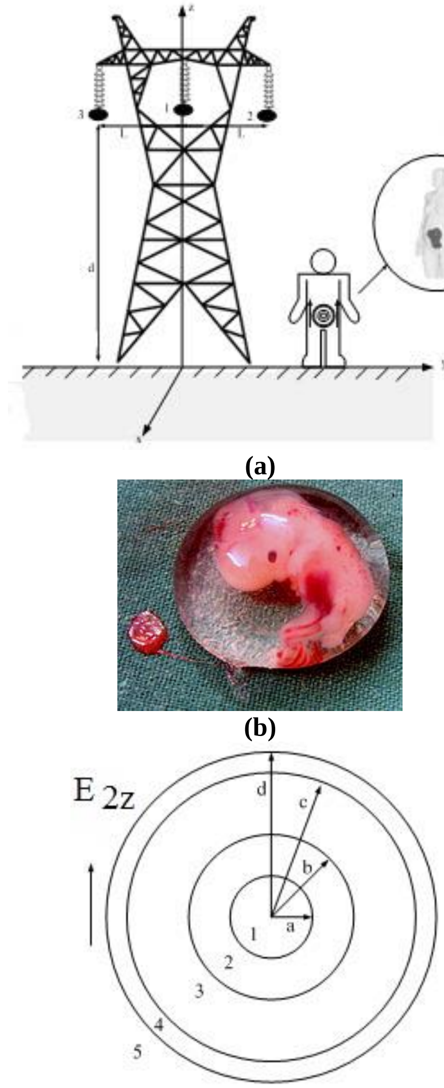


Figure. 1. (a): System configuration, (b): Embryo, (c): Embryo spherical model.

For r = c:

$$A_3' + \frac{A_3''}{c^3} - A_4' - \frac{A_4''}{c^3} = 0 \qquad (17\text{-a})$$

$$A_3' - 2\frac{A_3''}{c^3} - \varepsilon_4 \left[A_4' - 2\frac{A_4''}{c^3} \right] = 0 \qquad (17\text{-b})$$

For r = d:

$$A_4' + \frac{A_4''}{d^3} - \frac{A_5}{d^3} = -E_{2z} \qquad (18\text{-a})$$

$$\varepsilon_4 \left[A_4' - 2\frac{A_4''}{d^3} \right] + 2\frac{A_5}{d^3} = -E_{2z} \qquad (18\text{-b})$$

By sequential analysis and solving couple of equations together the constants are resulted.

$$A_1 = -\frac{3\varepsilon_3}{1-\varepsilon_2}\frac{1}{a^3}A_2'' \qquad (19)$$

$$A_2' = \frac{1+2\varepsilon_2}{3\varepsilon_2} A_3' - \frac{2(1-\varepsilon_2)}{3\varepsilon_2} \frac{1}{b^3} A_3'' \quad (20)$$

$$A_2'' = -\frac{1-\varepsilon_2}{3\varepsilon_2} b^3 A_3' + \frac{2+\varepsilon_2}{3\varepsilon_2} A_3'' \quad (21)$$

$$A_3' = \frac{2+\varepsilon_4}{3} A_4' + \frac{2(1-\varepsilon_4)}{3} A_4'' \quad (22)$$

$$A_3'' = -\frac{1-\varepsilon_4}{3} c^3 A_4' + \frac{1+2\varepsilon_4}{3} A_4'' \quad (23)$$

$$A_4' = -\frac{1+2\varepsilon_4}{3\varepsilon_4} E_{2z} - \frac{2(1-\varepsilon_4)}{3\varepsilon_4} \frac{1}{d^3} A_5 \quad (24)$$

$$A_4'' = -\frac{1-\varepsilon_4}{3\varepsilon_4} d^3 E_{2z} + \frac{2+\varepsilon_4}{3\varepsilon_4} A_5 \quad (25)$$

By starting from equation (25) and solving above mentioned equations in a sequential order we have:

$$A_1 = 3^4 \varepsilon_2 \varepsilon_4 D^{-1} E_{2z} \quad (26)$$

$$A_2' = 3^3 \varepsilon_4 (1+2\varepsilon_2) D^{-1} E_{2z} \quad (27)$$

$$A_2'' = -3^3 \varepsilon_4 (1-\varepsilon_2) D^{-1} a^3 E_{2z} \quad (28)$$

$$A_3' = 3^3 \varepsilon_4 [(1+2\varepsilon_2)(2+\varepsilon_2) - 2(1-\varepsilon_2)^2 a^3 / b^3] D^{-1} E_{2z} \quad (29)$$

$$A_3'' = 3^3 \varepsilon_4 (1+2\varepsilon_2)(1-\varepsilon_2) b^3 (1 - a^3/b^3)^2 D^{-1} E_{2z} \quad (30)$$

$$A_4' = -\frac{1+2\varepsilon_4 + 2(1-\varepsilon_4) N D^{-1} / d^3}{3\varepsilon_4} E_{2z} \quad (31)$$

$$A_4'' = -\frac{1-\varepsilon_4 + (2+\varepsilon_4) N D^{-1} / d^3}{3\varepsilon_4} d^3 E_{2z} \quad (32)$$

$$A_5 = N D^{-1} E_{2z} \quad (33)$$

$$\begin{aligned} D = & -[(1+2\varepsilon_2)(2+\varepsilon_2) - 2(1-\varepsilon_2)^2 a^3/b^3] \times \\ & [(1+2\varepsilon_4)(2+\varepsilon_4) - 2(1-\varepsilon_4)^2 c^3/d^3] + \\ & 2(b^3/c^3)(1+2\varepsilon_2)(1-\varepsilon_2) \times \\ & (2+\varepsilon_4)(1-\varepsilon_4)(1-a^3/b^3)(1-c^3/d^3) \end{aligned} \quad (34)$$

$$\begin{aligned} N = & -d^3[(1+2\varepsilon_2)(2+\varepsilon_2) - 2(1-\varepsilon_2) a^3/b^3] \times \\ & [(1+2\varepsilon_4)(1-\varepsilon_4) - (1-c^3/d^3)] - \\ & b^3[2(1-\varepsilon_4)^2 d^3/c^3 - (1+2\varepsilon_4)(2+\varepsilon_4)] \times \\ & (1+2\varepsilon_2)(1-\varepsilon_2)(1-a^3/b^3) \end{aligned} \quad (35)$$

3. ELECTRIC FIELD INSIDE AND NEAR THE EMBRYO POLE

Electric field at r<a:

$$E_1 = (1-n^3)^{-1} \beta \Delta E_{2z} (\hat{r} \cos(\theta) - \hat{\theta} \sin(\theta)) \quad (36)$$

where,

$$n = \frac{b}{c}$$

$$\Delta = \frac{3\varepsilon_4 d}{2\delta_4}$$

$$\beta = \frac{3\varepsilon_2 b}{2\delta_2}$$

Electric field at b<r<c:

$$E_3 = -\left[\hat{r}(A_3' - 2A_3''/r^3)\cos(\theta) - \hat{\theta}(A_3' + A''/r^3)\sin(\theta)\right] \approx$$
$$E_{2z} \Delta (1-n^3)^{-1} \left[\hat{r}\left(1+\beta - \frac{b^3}{r^3}\right)\cos(\theta) - \hat{\theta}\left(1 + \frac{b^3}{2r^3}\right)\sin(\theta)\right] \quad (37)$$

Electric field at d<r:

$$E_5 = \hat{r}\left[E_{2z} + \frac{2}{r^2} A_5\right]\cos(\theta) - \hat{\theta}\left[E_{2z}^{inc} - \frac{1}{r^3} A_5\right]\sin(\theta) \quad (38)$$

4. INDUCED CURRENT DENSITY IN THE EMBRYO AT DIFFERENT REGION

$$J_{2z}^{inc} = \sigma E_{2z}^{inc} \quad (39)$$

$$J_{5\theta}(d) \approx -\sigma\left(E_{2z}^{inc} - \frac{1}{d^3} A_5\right)\sin(\theta) \quad (40)$$

$$J_{5r}(d) \approx \sigma\left(E_{2z}^{inc} + \frac{2}{d^3} A_5\right)\cos(\theta) \quad (41)$$

$$J_3(r) \approx -\sigma\left[\hat{r}\left(A_3' - 2\frac{A''}{r^3}\right)\cos(\theta) - \hat{\theta}\left(A_3' + \frac{A_3''}{r^3}\right)\sin(\theta)\right] \quad (42)$$

$$J_{3r}(r) \approx -\sigma\left(\left(A_3' - 2\frac{A''}{r^3}\right)\cos(\theta)\right)\hat{r} \quad (43)$$

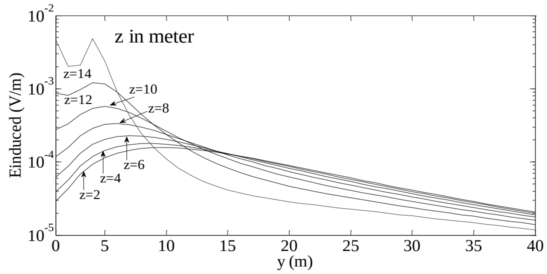
$$J_{3\theta}(r) \approx \sigma\left(\left(A_3' + \frac{A_3''}{r^3}\right)\sin(\theta)\right)\hat{\theta} \quad (44)$$

By replacing r with b or c the induced current at r = b or r = c will be obtained.

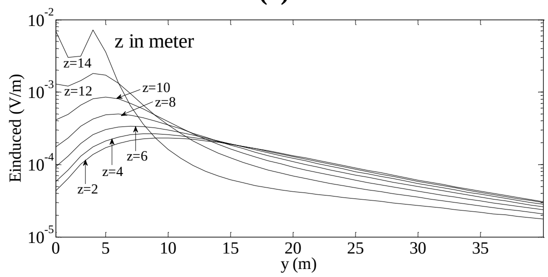
5. SIMULATION

5.1. Pregnant Woman Is Isolated From the Ground

Induced electric fields in embryo under 220 kV transmission line for $0 \le y \le 40$, $2 \le z \le 14$ when mothers' hands angle with respect to her body is Θ degree and x = 0 are shown in figure 2, where x, y and z are coordination of embryo's position in x, y, z axes.



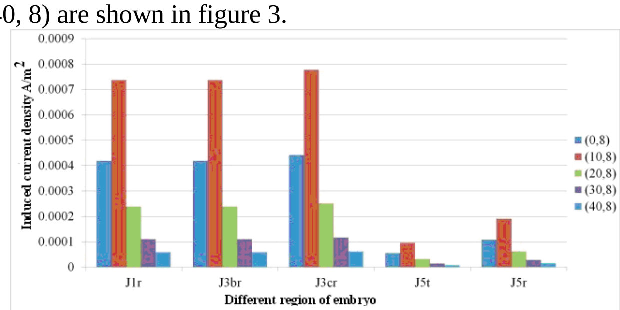
(a)



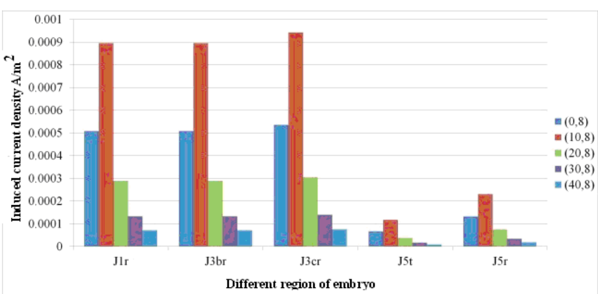
(b)

Figure. 2. Induced electric fields: a) Θ = 30, b) Θ = 180.

Induced currents in embryo under 220 kV transmission line when mothers' hands angle with respect to her body is Θ degree for (x, y, z) = (0,0,8), (0,10,8), (0,20,8), (0,30,8), (0, 40, 8) are shown in figure 3.



(a)



(b)

Figure. 3. Induced current density: a) Θ = 30, b) Θ = 180.

5.2. Pregnant Woman Is Not Isolated From the Ground

Induced electric fields and currents in embryo under 220 kV transmission line when mothers' hands angle with respect to her body is Θ = 0 degree for x = 0 and (y, z) = (0,1), (10, 1), (20,1), (30,1), (40, 1) are shown in figures 4 and 5.

The simulation is conducted for deferent values of impedances between mother's feet and ground such as:

$$ZL1 = -j7.24\times10^{8}\,\Omega$$

$$ZL2 = -j0.50\times10^{8}\,\Omega$$

$$ZL3 = 0\,\Omega$$

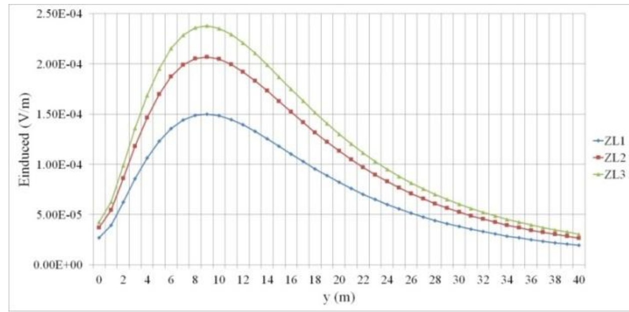
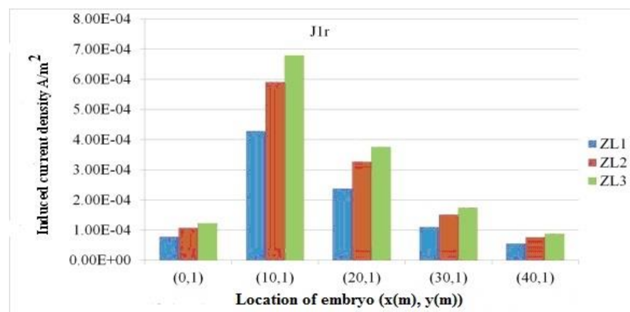


Figure. 4. Induced electric field in pregnant woman in embryo region for z = 1.

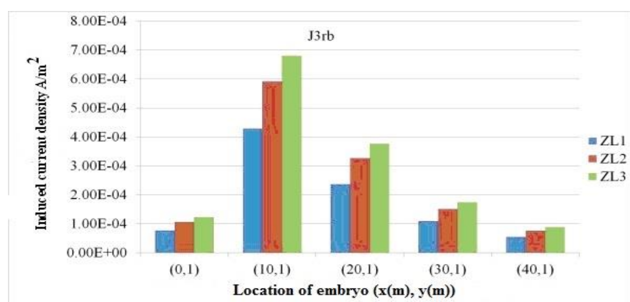
6. CONCLUSION

In this paper induced electric field and current in embryo due to the transmission line field is calculate when the pregnant mother is stand near the transmission line.

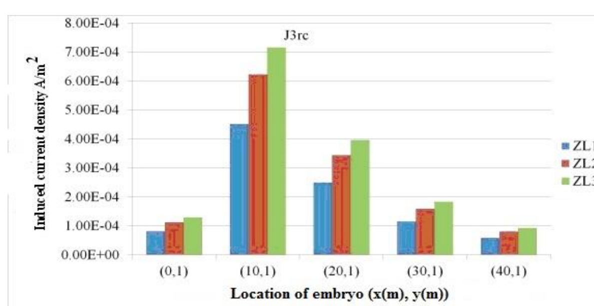
From simulation results can conclude that for different location of pregnant mother current can be calculate and compare with permitted threshold values.



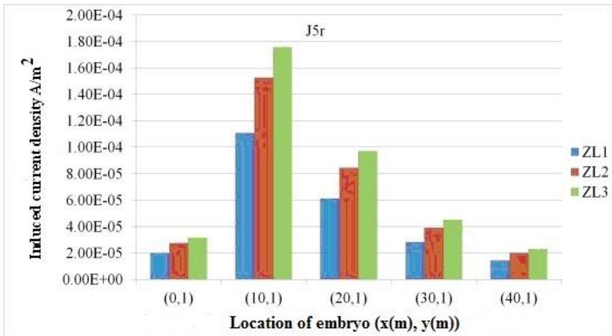
(a)



(b)



(c)



(d)

Figure. 5. Current induced in embryo, (a): in region 1 at r direction, (b): in region 3 at r direction for r = b, (c): in region 3 at r direction for r = c, (d): in region 5 at r direction.

REFERENCES

[1] Amer, G. M. et al, "Computational aspects of electromagnetic fields near H.V. transmission lines", *Energy and Power Eng.*, **1**(2): 65-71 (2009).

[2] Florig, H. K. et al, "Biological effects of power frequency electric and magnetic fields", *U.S. Congress Office of Technology Assessment*, OTA-BP-E-53 ~U.S. Government Printing Office, Washington, DC, (1989).

[3] Hauf, R. "Non-ionizing radiation protection", Copenhagen, *World Health Organization Regional Office for Europe*, WHO Regional Publications, European Series, 10 (1982).

[4] King, R. W. P. "Lateral electromagnetic waves", Springer, New York, (1992).

[5] Barnes, F. Greenebaum, B. "Bioengineering and biophysical aspects of electromagnetic fields", FL, *CRC press*, (2006).

[6] Fereidouni, A. Vahidi, B. Shishehgar, F. Hosseini Mehr, T. Tahmasbi, M. "Human body modeling in the vicinity of high voltage transmission lines", *Science International (Lahore)*, **26**(3): 1017-1031 (2014).

[7] Fereidouni, A. "Analysis of effects of electromagnetic field of HV transmission lines on human body", M.Sc. Thesis, Amirkabir University of Technology, Tehran, Iran, (2011).