Student report

BIOLOGICAL EFFECTS OF LOW-FREQUENCY ELECTROMAGNETIC FIELDS PRODUCED BY POWER LINES

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Abstract: Electric and magnetic fields produced by high-voltage transmission lines have recently been added to the list of potential threats to public health. It is a purpose of this paper to look for scientific facts of this problem, like determining the electromagnetic field at all points near high-voltage transmission line in analytical form, the electric and magnetic field and current and power densities in the interior of a human body. Account will be taken of the presence of the earth below the three-wire, three-phase power line. Based on these facts it will be determined the eventual adverse effects on human health.

Keywords: electromagnetic field of three-phase transmission line, current density and electromagnetic field in interior of human body, thermal effects, electric field in cells, induced currents in cells

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 lossiness in power transmission. Particularly, EHV lines carry electric power with lower energy losses and with smaller land usage than lower-voltage lines with the same power-delivery capacity. 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 adverse effect on human health appeared, it served to stimulate public concern. Since than journalist try to increase their concern with their non-technical articles, and physical and biomedical science try to solve this problem using scientific facts [1].

In this paper it will be determined all six components of the electromagnetic fields at all points near power line over the earth with conductivity $\sigma_1 = 0.04$ S/m. From these, it will be calculated induced currents and electric and magnetic field in the interior of the human body. Possible adverse effects of extremely low-frequency fields will depend on these values.

In following analysis, use is made of derived formulas for the complete electromagnetic field at any height *z* in the air over an imperfectly conducting or dielectric earth when source is a horizontal electric dipole at any height *d* [2] [3]. This set of formulas satisfies Maxwell's equations and all boundary conditions on the air-earth boundary, and it is experimentally verified at frequencies $f = 1-10$ Hz, $f = 25-100$ Hz and $f = 0.9-1.8$ Hz [4], [5], [6]. It is obviously that it can be use for calculating field produced by power lines at $f = 50$ Hz.

HIGH VOLTAGE TRANSMISSION LINES

Configuration

There are several configurations of power lines. Typical three phase, three wire power lines can be arranged horizontally, vertically or equilaterally. Here will be discussed horizontal configuration, like typical type of long distance power lines in Republic of Srpska, Bosnia and Herzegovina. This type is given on Fig.1 [7].

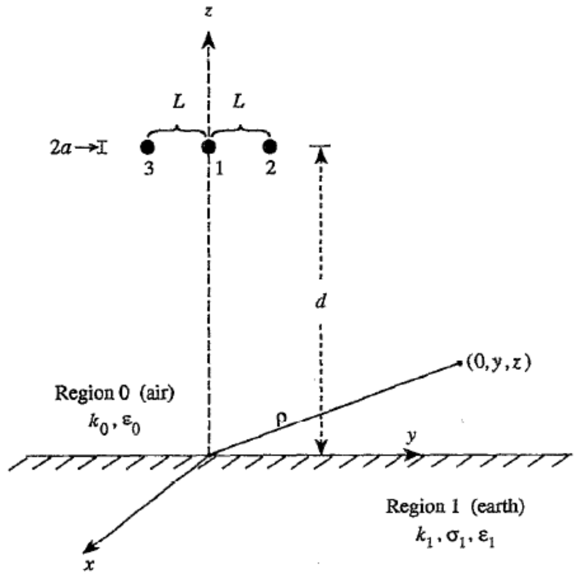

Fig.1 – Cross section of three wires of power line at height d over earth

The amplitudes of the three currents are the same [7]

$$|I_1(x)| = |I_2(x)| = |I_3(x)|, \quad (1)$$

and they differ in phase according to [7]

$$I_2(x) = I_1(x)e^{j2\pi/3}; I_3(x) = I_1(x)e^{-j2\pi/3}. \quad (2)$$

Electric and magnetic field

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The complete three components of electric field produced by horizontal type of power lines are calculated and given in [4]. The corresponding formulas in rectangular coordinates are derived and given in [7]. In this paper, for special appliance of power lines with 220 kV, 600 A, 50 Hz, d=15m and L=3m, using these formulas there are obtained values of the magnitudes for three components of electric field. In table I are given values of magnitudes for component $E_{0z}(0,y,z)$ since this component is the largest and it is parallel to the longest dimension of standing body, so it induces the largest field and current density in the body.

Table I

$\left|E_{0z}(0,y,z)\right|$ *in V/m*

	z [m]										
y [m]	0	2	4	6	8	10	12	14	16	18	20
0	184,62	203,97	272,66	434,29	824,21	1926,32	6016,26	32413,14	32389,23	5991,06	1898,38
1	271,60	298,43	392,29	605,94	1089,23	2292,14	5685,50	14065,57	14034,46	5648,15	2250,12
2	430,88	471,04	609,73	916,59	1575,95	3078,99	6771,81	14630,74	14581,30	6711,07	3010,63
3	591,77	643,60	820,63	1203,29	1997,65	3755,33	8451,65	33824,39	33762,09	8371,30	3660,58
4	735,05	794,53	994,93	1416,11	2252,13	3986,83	8062,78	16672,35	16586,59	7961,00	3866,71
5	853,08	915,52	1122,41	1541,86	2323,49	3764,89	6237,55	6333,01	6222,11	6112,85	3620,22
6	942,76	1003,75	1201,89	1586,35	2246,97	3282,82	4420,91	3004,93	2869,66	4273,35	3114,71
7	1003,85	1059,87	1237,79	1565,91	2077,99	2736,55	3098,11	1697,19	1539,21	2928,79	2546,55
8	1038,16	1086,84	1237,62	1500,29	1867,50	2237,37	2218,09	1083,95	905,37	2028,73	2027,46
9	1048,85	1089,00	1209,97	1407,75	1651,06	1823,71	1639,96	758,68	561,79	1432,64	1596,18
10	1039,81	1071,23	1163,01	1302,56	1448,59	1496,07	1254,32	570,28	357,53	1031,32	1253,39
11	1015,16	1038,36	1103,75	1194,58	1268,71	1241,21	990,67	453,70	227,58	754,33	985,92
12	978,83	994,79	1037,70	1089,89	1113,35	1043,59	805,52	377,64	140,76	558,19	778,20
13	934,36	944,25	968,94	991,82	981,03	889,57	671,96	325,72	80,99	415,91	616,49
14	884,73	889,76	900,29	901,84	868,95	768,34	573,10	288,83	40,54	310,48	489,85
15	832,38	833,68	833,64	820,28	774,00	671,74	498,09	261,59	22,26	230,92	389,91
16	779,19	777,74	770,15	746,86	693,26	593,68	439,80	240,72	31,67	169,96	310,41
17	726,57	723,18	710,44	681,01	624,23	529,72	393,48	224,17	46,45	122,67	246,68
18	675,50	670,83	654,83	622,01	564,80	476,55	355,87	210,57	58,92	85,66	195,22
19	626,68	621,22	603,37	569,13	513,29	431,76	324,73	199,05	68,66	56,58	153,40
20	580,50	574,63	555,97	521,69	468,31	393,55	298,46	189,02	76,05	33,94	119,24

To determine components of the magnetic field use is made of the Maxwell equation [7]

$$j\omega\mathbf{B}(x,y,z)=\nabla\times\mathbf{E}(x,y,z), \quad (3)$$

where $\mathbf{E}(x,y,z)=\mathbf{E}(0,y,z)e^{jk_0x}$ so that [7]

$$\partial\mathbf{E}(x,y,z)/\partial x=jk_0\mathbf{E}(0,y,z)e^{jk_0x}. \quad (4)$$

The components are [7]

$$j\omega B_{0x}(0,y,z)=\frac{\partial}{\partial y}E_{0z}(0,y,z)-\frac{\partial}{\partial z}E_{0y}(0,y,z), \quad (5)$$

$$j\omega B_{0y}(0,y,z)=\frac{\partial}{\partial z}E_{0x}(0,y,z)-jk_0E_{0z}(0,y,z), \quad (6)$$

$$j\omega B_{0z}(0,y,z)=jk_0E_{0y}(0,y,z)-\frac{\partial}{\partial y}E_{0x}(0,y,z). \quad (7)$$

The complete formulas for three components of magnetic field are given in [7].

CURRENT AND ELECTROMAGNETIC FIELD IN MAN ON THE EARTH UNDER AND NEAR A POWER LINE

When a person is under or near a power line the body acts as an isolated electrically very short parasitic antenna excited by the component of the electric field parallel to its length [7]. The equivalent cylindrical model of man is given on Fig.2 [9]. As there can be seen on Fig.2 and preceding calculation of values of the magnitudes for electric field, the component $E_{0z}(0,y,z)$ has the largest influence on human body.

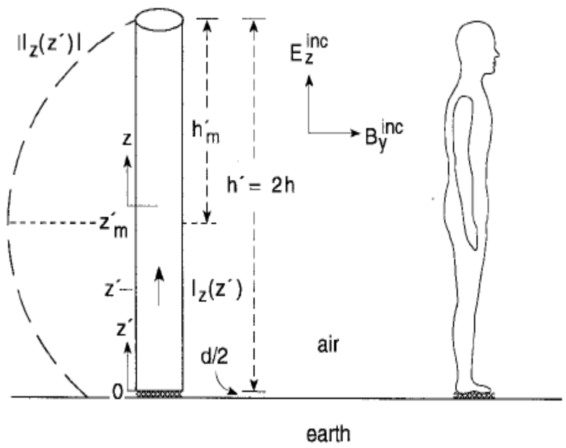

Fig.2 – Equivalent cylindrical model of human body

Here E_{0z}^{inc} is the part of the axial field that is constant in amplitude over any transverse cross section of the body. The associated magnetic field is $B_{0y}(0, y, z)$.

If the earth is treated as perfect conductor it follows $\left[B_{0y}(0, y, z)\right] \sim c^{-1}\left[E_{0z}(0, y, z)\right]$ [7].

Since neither the electric nor magnetic field is constant over a cross section of the man's body, the field across the approximately circular cross section of the body can be presented as traveling wave of the form [7] $E_{0z}^{inc}(x', y', z) = E_{0z}^{inc}(0, y', z)e^{jk_0x'}$, where x' and y' are measured from the center of the body , and $k_0 = \omega / c$ is wave number of the air. Since $k_0a_1 \ll 1$, where a_1 is radius of cylinder, $e^{jk_0x'} \sim 1 + jk_0x'$ so that [7],

$$E_{0z}^{inc}(x', y', z) \sim (1 + jk_0x')E_{0z}^{inc}(0, y', z), \tag{8}$$

$$B_{0y}^{inc}(x', y', z) \sim (1 + jk_0x')B_{0y}^{inc}(0, y', z). \tag{9}$$

It is obviously that the electric and magnetic fields acting on the body can be separated into a constant and variable part. Using Maxwell equations it can be shown that variable part of electric field is associated with constant part of magnetic field and vice versa [7].

There will be two types of induced currents in the human body. The axial current will be induced due to $E_{0z}^{inc}(0, y', z)$ and $jk_0x'B_{0y}^{inc}(0, y', z)$, and circulating current will be induced due to $B_{0y}^{inc}(0, y', z)$ and $jk_0x'E_{0z}^{inc}(0, y', z)$. It is given on the Fig.3 [9]

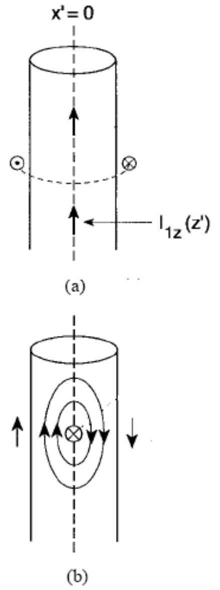

Fig.3 – Axial and circulating currents induced in the body

Axial current in the body

A man standing on the surface of the earth has a collinear image in the earth. Two different situations were considered in the following analyses. First it is calculated the values of current density and field in the body in the case when man is standing on moist earth with rubber soles 1 cm thick, with a capacitive impedance $Z_L = -j / \omega C$ between man and his image, and then for the barefooted man, with $Z_L \sim 0$.

The current in the body in the general case is given by [8]

$$I_z(z') = \frac{j2\pi k_0 h'^2 E_z^{inc}}{\zeta_0 \psi}\left[1 - \frac{z'^2}{h'^2} - \frac{Z_L}{Z_0 + Z_L}\left(1 - \frac{z'}{h'}\right)\right], \tag{10}$$

where [7],

$$Z_0 = \frac{j\zeta_0\psi}{2\pi k_0 h_m'^2}, \quad \psi = 2\ln\frac{2h'_m}{a_m} - 3. \tag{11}$$

In (11), $\zeta_0 = 120\pi\ \Omega$, h_m is the distance from the top of the head at $z' = h'$ to the point of the maximum current at $z' = z'_m$, and a_m is the equivalent radius [7] $a_m = (A/\pi)^{1/2}$ where A is the area of the cross section at z'_m (Fig.2). Formula (10) is appropriate when $|Z_L| \le |Z_0|$. The location of the maximum of current is [7]

$$z'_m = \frac{h'}{2}\frac{Z_L}{Z_0 + Z_L}. \tag{12}$$

1. First case

For the man standing on moist earth with rubber soles 1 cm thick and for $h^{'} = 1.75\ m$, (10) gives

$$I_z(z^{'}) = j1.725\times10^{-8} E_z^{inc}\left[1-\frac{z^{'2}}{h^{'2}}-0.33\left(1-\frac{z^{'}}{h^{'}}\right)\right],$$

$$0 \le z^{'} \le h^{'}. \tag{13}$$

The maximum amplitude at $z^{'} = z_m^{'} = 0.289\ m$ is

$$I_z(0.289) = j1.203\times10^{-8} E_z^{inc}. \tag{14}$$

For the incident field of $E_z^{inc} = 1050\ V/m$ at $z = 1$ maximum current is

$$I_z(0.289) = j12{,}6\ \mu A, \tag{15}$$

and the corresponding current density and electric field with $\sigma = 0.5\ S/m$ are

$$J_z(0.289) = j210\ \mu A/m^2, \tag{16}$$

$$E_z(0.283) = j420\ \mu V/m. \tag{17}$$

The power density is

$$p(0.283) = \sigma\left|E_z(0.283)\right|^2 = 35.28\times10^{-8}\ W/m^2. \tag{18}$$

2. Second case

For the barefooted man with $Z_L \sim 0$, (10) gives

$$I_z(z^{'}) = j1.542\times10^{-8} E_z^{inc}\left(1-\frac{z^{'2}}{h^{'2}}\right);\ 0 \le z^{'} \le h^{'}. \tag{19}$$

The maximum current is at $z^{'} = 0$ in the feet. For the incident field of $E_z^{inc} = 1050\ V/m$ current density and electric field are

$$J_z(0) = \frac{j1.524\times10^{-8}}{0.06} E_z^{inc} = j266.7\ \mu A/m^2, \tag{20}$$

$$E_z(0) = j533.4\ \mu V/m. \tag{21}$$

The power density is

$$p(0) = \sigma\left|E_z(0)\right|^2 = 14.6\times10^{-8}\ W/m^2. \tag{22}$$

Circulating current in body

The current induced in the body due to differential part, $jk_0 x^{'} E_{0z}^{inc}(0, y^{'}, z)$, of electric field and constant part, $B_{0y}^{inc}(0, y^{'}, z)$, of magnetic field is circulating. Formulas for current density and total circulating current induced in the body are derived and given in [7]. At two points where $x^{'} = \pm a_1$, current density at the surface on the opposites sides of the body is [7],

$$J_{1\theta}(\pm a_1, y^{'}, z) = \pm\frac{jk_0 a_1 \sigma_1}{2} E_{0z}^{inc}(0, y^{'}, z). \tag{23}$$

The total circulating current in the body is [7],

$$I_{1z}(y^{'}, z) = \frac{jk_0 a_1^3 \sigma_1}{3} E_{0z}^{inc}(0, y^{'}, z). \tag{24}$$

With $a_1 = 0.14\ m$ and $\sigma_1 = 0.5\ S/m$,

$$I_{1z}(y^{'}, z) = j4.8\times10^{-10} E_{0z}^{inc}(0, y^{'}, z). \tag{25}$$

For the incident field of $E_{0z}^{inc} = 1050\ V/m$ it follows that,

$$I_{1z}(y^{'}, z) = j0.504\ \mu A, \tag{26}$$

and

$$J_{1\theta}(a_1, y^{'}, z) = j38.5\ \mu A/m^2. \tag{27}$$

CONCLUSION

From calculated values of current density and electromagnetic field in the body it is obvious that there are no thermal effects of low-frequency electromagnetic fields produced by power lines. There have been analyzed two cases for man standing on the ground and values of current density, (16), (20), are too small to cause thermal effects. Influence on functioning of cells and propagation of impulses along nerves has not been analyzed, so possibility of adverse influence on these has not been ruled out.

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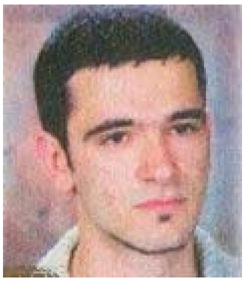

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