Interaction of ELF Magnetic Fields with Human Body Organs Model Underneath EHV Transmission Lines

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Abstract

The current densities and the specific absorption rate are important factors to evaluate the biological effects associated with exposure to ELF magnetic fields. These important factors depend on the characteristics of the external magnetic fields and the human organs.

In this paper a standard human model is considered. The important human organs are taken into consideration, wherever the maximum, minimum and average magnetic fields are calculated in these organs under central line conductor, under outermost conductor and at the edge of right-of-way. The maximum and average current densities at the above three situations underneath the line are calculated and discussed. Also, the specific absorption rates are computed and discussed. The magnetic field can be as high as 49.87 μT, the induced current density 615 $\mu A/m^2$, The specific absorption rate $29x10^{-12}$ watt/kg in the human model brain. While in the human model heart the magnetic field can be as high as 47.44 μT, the induced current density 403 $\mu A/m^2$, the specific absorption rate $29x10^{-12}$ watt/kg in the human model heart.

I. Introduction

During the last few decades, there is a growing concern about the health effects on people living in the vicinity of EHV power lines. This concern is mainly based on a presumption that the exposure to extremely low frequency (ELF) magnetic field might cause adverse health effects.

Living bodies do not possess significant ferromagnetic properties, and thus, they do not distort the magnetic field by their presence. In other words, magnetic fields penetrate living body completely. The magnetic fields interact weakly with living bodies by inducing internal current. Many parameters of the exposure field, as well as some characteristics of biological systems influence the interaction between the ELF magnetic fields and living bodies [1,2]. Some of the carefully performed experimental works show that at least some effects depend on the induced electric fields and currents in biological systems. So it is very necessary to compute these induced currents in different sections in the living bodies subjected to these fields. Also, it is necessary to obtain the distributions of the mass-normalized rates of electromagnetic energy absorption (i.e., specific absorption rates, or SAR). Since biological effects depend on currents through important organs such as the brain, the heart, the kidney, the central nervous system, etc., a detailed knowledge of the electric currents due to magnetic fields, should allow one to quantify the hazard and keep the maximum SAR at any location within the ANSI limit.

II. Human Organ Exposure

II.1 Magnetic field assessment

Great lengths of power lines are spread over a wide area at great Cairo zone. These lines varied from distribution power lines, 11 kV lines, to EHV transmission lines, 500 kV lines. The great Cairo zone has densely populated areas. These lines often crossed these areas, such as Alkhousous area, Shoubra Alkhiema area, Bassous area…etc. Some studies are conducted to assess the magnetic field levels at these areas [3,4]. This paper assesses the interaction between the magnetic field induced by EHV Bassous/Cairo line and the human organs.

The human model is placed underneath the Bassous/Cairo 500 kV line, showed in Fig.1. The line is a single circuit line, the phase conductors are 3x500 mm^2 with a subconductor spacing of 45 cm and a minimum clearance to ground of 9 m. The edge of the line right-of-way is 25 m from the central line of the tower as specified by Egyptian standards. The central phase conductor height is 2.35m higher than that of the outermost conductors. The phase-to-phase spacing is 13.2m. The line is fully loaded with 2000 A per phase.

Fig.1 Bassous/Cairo 500 kV transmission line

Magnetic fields were computed in the space surrounding the line. The human body model with standard 175cm length, Fig.2, is placed at different positions underneath the line and the incident magnetic fields on the different human body model organs are computed. The maximum and minimum magnetic fields exposed by some important human organs are computed.

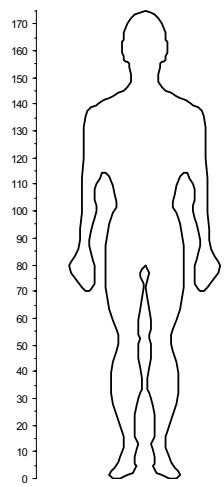

Fig.2 Human body model

The values of the mean volume, the electrical conductivity and the mass density of the different important organs are as shown in Table 1 [5,6]. The human body organs are modeled by a spheroidal model. The equivalent radius of the spheriodal model of the important human organs are calculated and shown in Table1. The paper interested with three very important organs, brain, heart and right and left kidneys, wherever the exposed magnetic fields, induced current densities and the specific absorption rates are computed when the human model is situated under the central line conductor, under the outermost phase conductor and at the edge of the line right-of-way.

Table 1 Data of some important human organs

Organ	Volume In cm^3	Conductivity In S/m	Equivalent Radius (cm)	Mass density Kg/m^3
Lung	3900	0.10	9.76	170
Liver	3200	0.10	9.14	470
Brain	810	0.70	5.78	1700
Heart	280	0.70	4.06	1000
Kidney	175	0.10	3.47	860
Spleen	294	0.03	4.12	680

The magnetic field is computed in human model brain, human model heart and human model kidney. The number of points took are 1400 points distributed inside the brain and 1000 points distributed inside the heart and the kidney models at which the magnetic field values are computed. The maximum, minimum and average magnetic fields under central phase conductor, outermost conductors and at the edge of the right-of-way are shown in Table 2. The maximum magnetic field exposure to the human model brain under the EHV line is computed and its value is about 50 μT, while it is found 48 μT for the human model heart, 47 μT for the human model kidney.

Table 2 exposed magnetic fields in μT of human organs at different situation.

Human location	Magnetic Field	Brain	Heart	Left kidney	Right kidney
Central Line	Bmax	49.544	47.442	46.628	46.628
	Bmin	48.952	47.05	46.301	46.301
	Bav	49.247	47.246	46.464	46.464
Outermost conductor	Bmax	49.87	46.79	45.638	46.016
	Bmin	48.96	46.22	45.163	45.539
	Bav	49.407	46.50	45.400	45.777
Right-of-way	Bmax	17.50	17.16	17.024	17.312
	Bmin	17.31	17.03	16.910	17.201
	Bav	17.404	17.094	16.967	17.260

Under central line conductor the magnetic field is varied from about 49.5 μT to about 48.9 μT along the human model brain, i.e. the magnetic field is varied by about 1% along the human brain at this situation. This small field variation along the brain model is due the small size of the brain and the large distance between the line and the human organ. The magnetic field is varied from about 47.4 μT to about 47 μT along the human heart model. Along the human kidney model the magnetic field is varied from about 46.3 μT to about 46.6 μT.

Under outermost conductor the magnetic field is varied from about 49.9 μT to about 49 μT along the human model brain, i.e. the magnetic field is varied by about 2% along the human brain at this situation. The magnetic field is varied from about 46.8 μT to about 46.2 μT along the human heart model. Along the human left kidney model the magnetic field is varied from about 45.2 μT to about 45.6 μT, while along the human right kidney model the magnetic field is varied from about 45.5 μT to about 46 μT.

At the edge of the line right-of-way the magnetic field is varied from about 17.5 μT to about 17.3 μT along the human model brain, i.e. the magnetic field is varied by about 1% along the human brain at this situation. The magnetic field is varied from about 17.2 μT to about 17 μT along the human heart model. Along the human left kidney model the magnetic field is varied from about 17 μT to about 16.9 μT, while along the human right kidney model the magnetic field is varied from about 17.2 μT to about 17.3 μT.

II.2 Induced current density and SAR

The spheroidal model of the human organ is filled with a homogenous biological tissue. In reality the human body

is not homogeneous and the electrical characteristics of the different organs are different. Therefore, the circulating current within an organ depends of the local induced electric field and on the organ's conductivity.

The internal electric fields vectors in x, y and z-axis resulting from the three orientations of the sinusoidal magnetic fields are expressed as:

$$\vec{E}_{Bx} = \frac{\omega}{2}(z\hat{y} - y\hat{z})\left|\dot{B}_x\right| e^{j(-\pi/2+\varphi_{Bx})} \qquad [1]$$

$$\vec{E}_{By} = \frac{\omega}{2}(x\hat{z} - z\hat{x})\left|\dot{B}_y\right| e^{j(-\pi/2+\varphi_{By})} \qquad [2]$$

$$\vec{E}_{Bz} = \frac{\omega}{2}(y\hat{x} - x\hat{y})\left|\dot{B}_z\right| e^{j(-\pi/2+\varphi_{Bz})} \qquad [3]$$

Where, E_{Bx} is an electric field around x-axis induced by B_x, E_{By} is an electric field around y-axis induced by B_y and E_{Bz} is an electric field around z-axis induced by B_z. Moreover, the angular frequency $\omega=2\pi f$ where f is 50 Hz and φ is the phase angles of B_x, B_y and B_z.

The total induced electric field in the model can be expressed as:

$$\overline{E} = \overline{E}_{Bx} + \overline{E}_{By} + \overline{E}_{Bz} \qquad [4]$$

The total current density induced by magnetic fields is obtained from

$$\overline{J} = \sigma\overline{E} \qquad [5]$$

Table 3 shows the maximum and average induced current densities in the human model brain, heart and kidney. It shows that the current density can be as high as 615 $\mu A/m^2$ in the human model brain under the outermost conductor, while the current density can be as high as 403 $\mu A/m^2$ in the human model heart under the outermost conductor. The current density is about 48 $\mu A/m^2$ in the human model kidney under the outermost conductor, due to its lower conductivity.

Table 3 The induced current density inside human organs at different situation.

Human location	Induced current density ($\mu A/m^2$)	Brain	Heart	Left kidney	Right kidney
Central Line	Jmax	494.798	328.32	39.397	39.395
	Jav	207.740	139.725	17.100	17.099
Outermost conductor	Jmax	614.78	402.88	48.015	48.089
	Jav	297.033	194.992	23.184	23.122
Right-of-way	Jmax	185.83	130.13	15.722	16.070
	Jav	78.940	55.469	6.814	6.971

The specific absorption rate of a magnetic field-exposed human body organ indicates the rate of energy absorption by that organ. So the SAR helps in assessing the environmental impact of the magnetic field. The SAR is given by:

$$SAR = \sigma\,|E|^2/\rho_m \qquad [6]$$

Where, ρ_m is the mass density of the organ tissue

The maximum and average specific absorption rate in the human model brain, heart and kidney are shown in Table 4. The table shows that the specific absorption rate density can be as high as 318×10^{-12} watt/Kg in the human model brain under the outermost conductor, while the specific absorption rate can be as high as 232×10^{-12} watt/Kg in the human model heart under the outermost conductor. The specific absorption rate density is about 23×10^{-12} watt/Kg in the human model kidney under the outermost conductor, due to its lower conductivity.

Table 4 The specific absorption rate (SAR) of human organs at different situation in (watt/Kg$\times10^{-12}$).

Human location	SAR (Watt/kg)x10^{-12}	Brain	Heart	Left kidney	Right kidney
Central Line	SARmax	205.736	153.99	15.521	15.520
	SARav	55.040	41.789	4.428	4.428
Outermost conductor	SARmax	317.61	231.88	23.055	23.126
	SARav	93.261	68.418	6.711	6.736
Right-of-way	SARmax	29.02	24.19	2.472	2.582
	SARav	7.877	6.636	0.711	0.741

II.3 Power Absorbed

Integrating the average power density ($\sigma\,|E|^2/2$) over the spherical organ model volume, gives the total power absorbed by the organ exposed to the incident magnetic field. The power absorbed by the organ model is given by:

$$P = \frac{0.2}{3}\ \sigma\ \pi\ R^5\varpi^2 B^2 \quad \text{watt} \qquad [7]$$

where, ϖ is the angular velocity in radians, B is the average magnetic flux density in T.

Table 5 power absorbed by human organs (watt x 10^{-12})

Human location	Brain	Heart	Left kidney	Right kidney
Central Line	22.639	3.563	0.225	0.225
Outermost conductor	22.786	3.451	0.214	0.218
Right-of-way	2.827	0.466	0.030	0.031

Conclusions

1. The magnetic field is varied only by about 2% along the human model brain and by about 1% along the human model heart, due to small organs dimensions and the relatively greater distance from line phases.
2. Under the outermost conductor the induced current density can be as high as 615 $\mu A/m^2$ in the human model brain, as high as 403 $\mu A/m^2$ in the human model heart and 48 $\mu A/m^2$ in the human model kidney.
3. Under the outermost conductor the specific absorption rat can be as high as 318×10^{-12} watt/Kg in the human model brain, as high as 232×10^{-12} watt/Kg in the human model heart and 23×10^{-12} watt/Kg in the human model kidney.
4. The kidney shows lower values of current density and SAR due to its lower conductivity.
5. The brain absorbed the maximum power under the outermost conductor.

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