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# THE EFFECT OF ELECTRIC FIELD ON HUMANS IN THE IMMEDIATE VICINITY OF 110 KV POWER LINES

*UDC 537.8*

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**Abstract**. *The paper presents the effect of the electric component of an electromagnetic field (ELF) of 50 Hz, originating from overground 110 kV power line, on humans in its immediate vicinity. In the paper, the electric field which penetrates the human body was calculated with the help of a human model, containing blocks which represent different human organs or body parts (brain, lungs, digestive organs, etc.) based on their electromagnetic features (conductivity, electric and magnetic permittivity). The distribution of the electric field surrounding humans will be given, as well as the values of the field which penetrates humans. Likewise, comparison has been made between calculated values and the values obtained through the usage of adequate software solutions.*

**Key Words**: *Electromagnetic Field, Power Line, Induced Currents*

## INTRODUCTION

One of the most commonly found sources of non-ionizing radiation to which humans are exposed is, by all means, the electromagnetic (EM) field at industrial frequency. The effect of EM field near high voltage facilities is much greater than its natural effect, which raises the issue of its detrimental effect on human population. Sudden growth in population and technological advancement have led to increasing demands for larger quantities of electric energy, which in turn led to the increase in the EM field level in urban and working environments. Since this phenomenon cannot be avoided, there is the issue of detrimental effect of this field on human health and the need to define safe exposure limits for both professional and general population. That requires legal regulation, definition of parameters for adequate control, and punitive measures for violators.

The paper contains the analysis of only the electric field of the power line Niš III (Niška Banja, Niš 10), its distribution in free space, as well as the values of the field penetrating into humans, with the aid of software operating by the finite-element method.

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## THEORETICAL BACKGROUND

Electric field is generated by electric charges on phase conductors and protective ropes of the power line. Each of the phase conductors and protective ropes is modeled as an infinitely long cylindrical conductor with a cross-section of finite dimensions. As the Earth's surface is at zero potential, the so-called method of "reflection" has to be used during the calculation of such a system.

We shall observe a very long, thin cylindrical conductor, located at a certain height above the Earth's surface (Fig. 1).

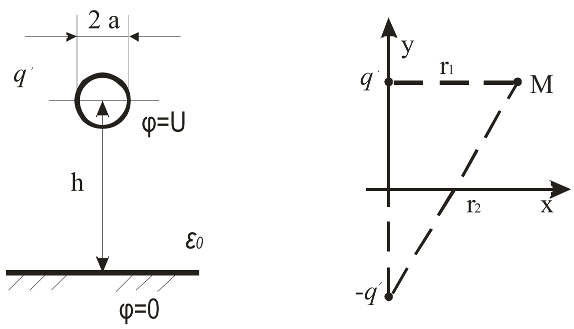


Fig. 1. Thin Cylindrical Conductor Parallel to the Earth's Surface

Complex specific conductivity is

$$\underline{\sigma} = \sigma + j\omega\varepsilon\,, \tag{1}$$

and in the following the complex variables are assumed.

Since the Earth's surface is at zero potential, we get the following expression for the potential in point M:

$$\varphi = \frac{q'}{2\pi\varepsilon}\ln\frac{r_2}{r_1}\,. \tag{2}$$

For $r_1 = a$ it follows $\varphi = U$, thus

$$\varphi = U = \frac{q'}{2\pi\varepsilon}\ln\frac{2h+a}{a} \tag{3}$$

from which it follows

$$q' = \frac{U 2\pi\varepsilon}{\ln\left(\frac{2h+a}{a}\right)} \tag{4}$$

resulting in the final expression for the potential:

$$\varphi = \frac{U}{\ln\left(\frac{2h+a}{a}\right)}\ln\frac{r_2}{r_1} \tag{5}$$

If we introduce concrete numerical values for corresponding parameters, e.g. $a = 8.74$mm, $h = 1[m]$, $U = 110$kV, the value of potential in point M will be $\varphi = 16279$V which is an approximately identical result obtained by using FEMM application, which operates on the principle of the finite-element method [2].

Electric field produced by a single conductor in the polar-cylindrical coordinate system $(r,\theta,z)$ is

$$\vec{E} = E\,\hat{z},\ E_r = 0,\ E_\theta = 0,\ \ E = E(r), \tag{6}$$

The *Helholtz*'s equation

$$\frac{1}{r}\frac{d}{dr}\left(r\frac{dE}{dr}\right) + k^2 E = \mathrm{j}\frac{\omega\mu I}{2\pi r}\delta(r)\,, \tag{7}$$

on the great distance from quasi-linear conductor, that satisfies the conditions of radiation,

$$\frac{\partial E}{\partial r} + E\left(\mathrm{j} + \frac{1}{2kr}\right) = 0,\ \ r \to \infty\,. \tag{8}$$

The solution is

$$E = CH_0^{(2)}(kr), \tag{9}$$

where

$$H_0^{(2)}(kr) = J_0(kr) - \mathrm{j}\,N_0(kr) \tag{10}$$

is *Hankel*'s function on the second kind, $J_0(kr)$ and $N_0(kr)$ are *Bessel*'s functions of the first and the second kind. And $C$ is at temporary unknown constant, that can be determined from the condition that at ELF ($k \to 0$) the intensity of magnetic field have to be stationary

$$H = \mathrm{j}\frac{kC}{\omega\mu}H_1^{(2)}(kr),\ \ \text{i.e}\ \ \lim_{\omega\to 0} H = \frac{I}{2r\pi}\,. \tag{11}$$

However,

$$J_1(kr) \to \frac{kr}{2}\ \ \text{and}\ \ N_1(kr) \to -\frac{2}{\pi k r}\ \ \text{for}\ \ kr \to 0, \tag{12}$$

one can obtain

$$C = -\frac{\omega\mu I}{4}, \tag{13}$$

and finally

$$E = -\frac{\omega\mu I}{4}H_0^{(2)}(kr)\,. \tag{14}$$

For ELF

$$E = E_\mathrm{c} + \mathrm{j}\frac{\omega\mu I}{2\pi}\ln r\ ,\ \text{for}\ \ kr \to 0, \tag{15}$$

because of

$$J_0(kr) \to 1\ \ \text{and}\ \ N_0(kr) \to \frac{2}{\pi}\ln(kr)\,,\ \text{for}\ \ kr \to 0\,, \tag{16}$$

and $E_c$ is an additive constant which is independent of chosen coordinate system.

Table 1 gives the power line dimensions, and the values of voltage and currents flowing through the conductor.

Table 1. Coordinates and radii of phase conductors and protective ropes of 110kV lines

| | Phase 1 | Phase 2 | Phase 3 | Rope 1 | Rope 2 | |
|---|---|---|---|---|---|---|
| $n$ | 1 | 2 | 3 | 4 | 5 | |
| $x$[m] | $-6$ | 0 | 6 | $-4.15$ | 4.15 | |
| $y$[m] | 12 | 12 | 12 | 15 | 15 | $U_f=110/\sqrt{3}$ kV<br>$I_f=50\,\text{A}$<br>$s=2\pi/3$ |
| $U_n$ | $U_f e^{j0}$ | $U_f e^{js}$ | $U_f e^{-js}$ | 0 | 0 | |
| $I_n$ | $I_f e^{j0}$ | $I_f e^{js}$ | $I_f e^{-js}$ | 0 | 0 | |
| $a$[mm] | 8.74 | 8.74 | 8.74 | 5 | 5 | |

A 110kV power line is shown in Fig. 2.

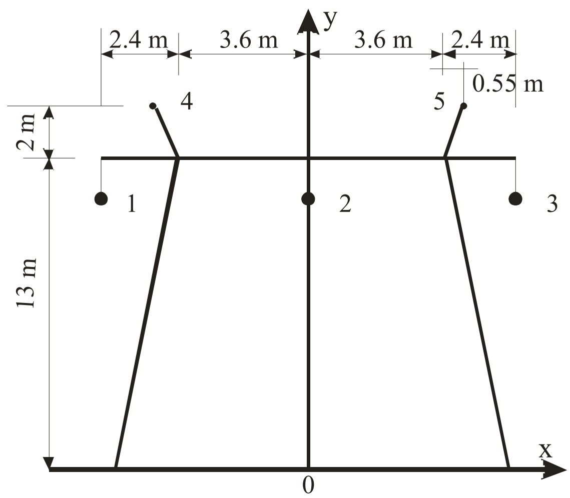


Fig. 2. Cross-section of the conductors of a 110kV power lines in the level of the supporting construction

The values for intensity of electric field vector $E$ [V/m] and electrical scalar potential φ[V] obtained using FEMM [2] program are shown as Fig. 3.

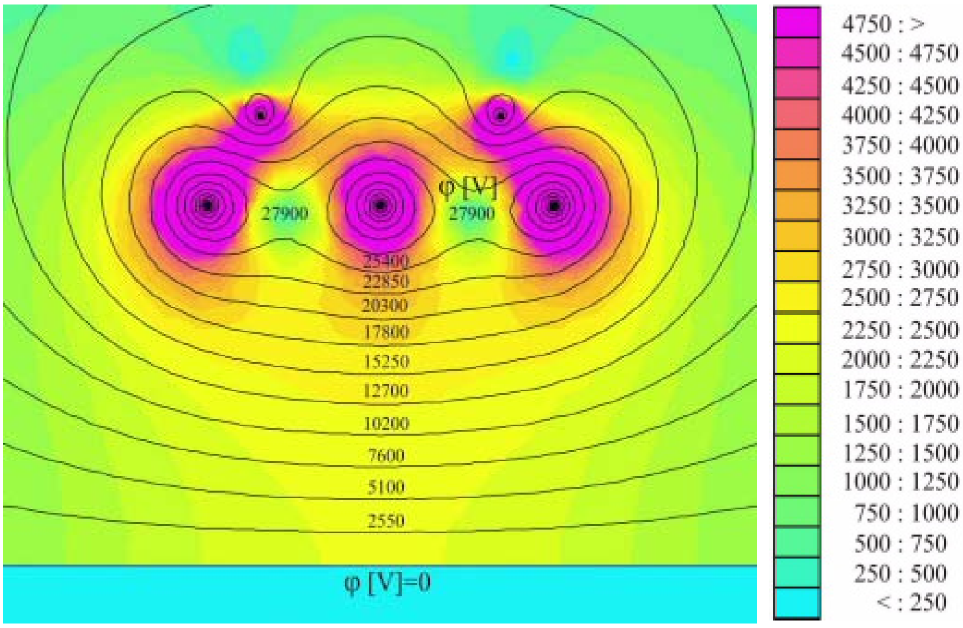


Fig. 3 Distribution of *E*[V/M] and Potential φ[V] in the Vicinity of 110kV Power Lines

## HUMANS IN THE POWER LINES ELECTRIC FIELD

Electromagnetically, human organism is a non-homogenous, diamagnetic, dispersive and conductive medium. Every domain, in electromagnetic sense, is defined by specific electric conductivity, relative dielectric constant, and relative magnetic permittivity ($\sigma,\varepsilon_r,\mu_r$), all of which are frequency-dependent [3]. Since biological material, in electromagnetic sense, consists of several different types of tissue with different electromagnetic features, it is necessary to model it according to the part-by-part principle. The block human model is suitable not only for calculating the strength of electric and magnetic fields in tissues but also for applying finite-element methods. The block model is simplified and reduced to a few distinctive biological tissues (brain, lungs, liver).

The strength of incidental electric field decreases significantly while penetrating tissues, because of electromagnetic properties of biological tissues.

Through the application of the finite-element methods, [2], the distributions are obtained for the electric scalar potential φ, and the electric field strength *E*, in the vicinity of the source (power lines) that includes human presence i.e. tissues.

Serving as an example, an actual case is presented of a man situated directly below the 110 kV power line, where distribution of electric energy is realized by a three-phase line system.

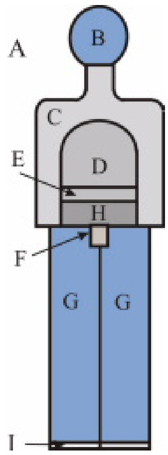


Fig. 4. A block Model of the Human Body

Table 2. Relative Dielectric Constant of Tissues and Materials [8]

| Material | Air | Brain | Other tissues | Lungs | Liver | Testis | Legs | Digestive organs | Rubber |
|---|---|---|---|---|---|---|---|---|---|
| Mark | A | B | C | D | E | F | G | H | I |
| $\varepsilon_r$ | 1.0006 | $1.21\ 10^7$ | $1.11\ 10_7$ | $5.76\ 10^6$ | $1.83\ 10^6$ | $1.64\ 10^6$ | $1.77\ 10^7$ | $1.68\ 10^7$ | 3 |

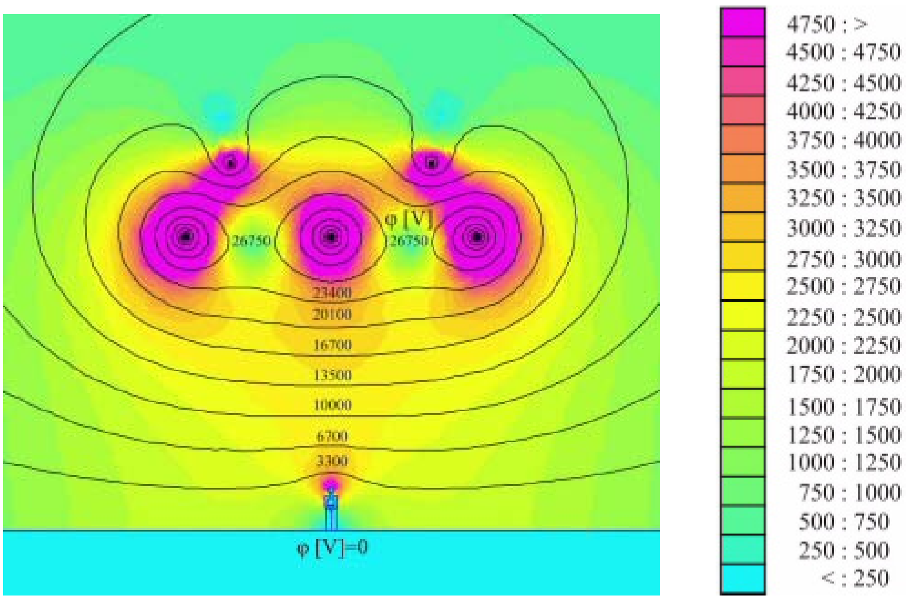


Fig. 5. Distribution of *E*[V/M] and Potential φ[V] in the Vicinity of a 110 kV Power Line with Presence of the Human Body – Global Structure

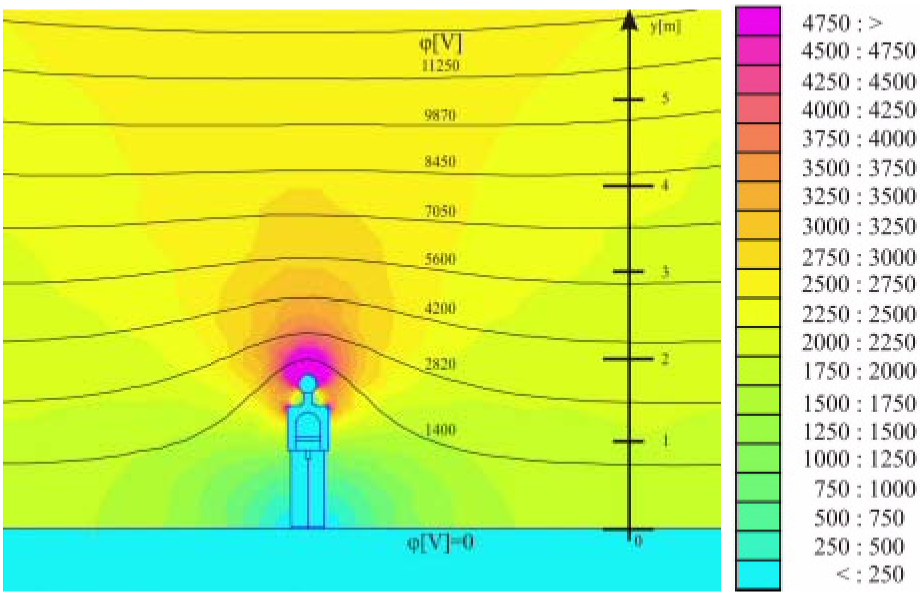


Fig. 6. Distribution of *E*[V/M] and Potential φ[V] of a 110kV Power Line with Human Presence - Details

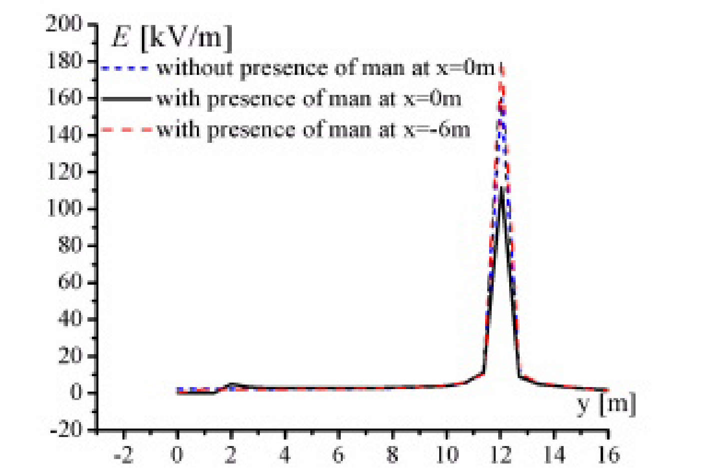


Fig. 7. Distribution of Electric Field Strength along the Vertical Axes

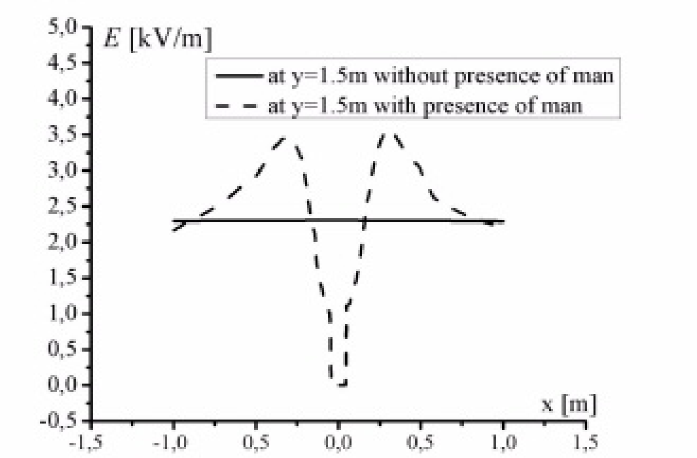


Fig. 8. Distribution of Electric Field Strength along the Horizontal Axes

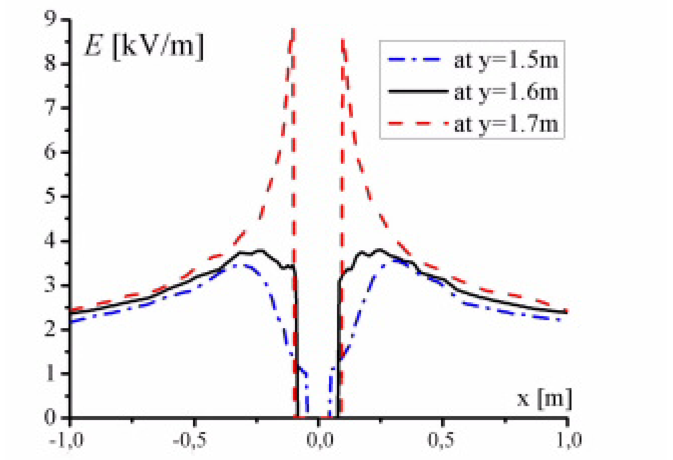


Fig. 9. Distribution of Electric Field Strength along the Horizontal Axes at Human Head Levels

## DAMAGE FACTOR

Human body in electric field is a semi-conducting domain. In that case, the constitutive relation between current density and intensity of electrical field $J = \sigma E$ leads to the previously-established standards (see Table below).

During exposure to EMF industrial frequencies it is important to observe the densities of induced currents in human tissues.

It is fundamental to limit the current density in the body to 10 mA/m$^2$ which is a little above the value normally generated by the body. The following topics are selected from literature:

Table 3. Damage Factor and Current Density

| Damage factor | Current density J [$mA/m^2$] | Description |
|---|---|---|
| a | 1-10 | Minimum biological tissue response. |
| b | 10 - 100 | Disorders in visual and nervous system. |
| c | 100 - 1000 | Stimuli of excitable tissues, which can lead to undesired reactions. Heart disorders, neuro-muscular irritability and disorders of the CNS. |
| d | >1000 | Extrasystoles, cardiac fibrillation. Conditions with high mortality rate. |

Based on these medical findings and specific electric conductivity of certain tissues, the intensity of electric field in tissues were calculated and the results given in Table 4.

Table 4. Intensities of Electric Field Intensity in Tissues Based on Damage Factor

| *E* [V/m] in tissues | | | | |
|---|---|---|---|---|
| Organs | Conductivity $\sigma$[S/m] | Damage factor | | |
| | | a | b | c |
| Brain | 0.7 | 0.014 | 0.142 | 1.428 |
| Lungs and liver | 0.1 | 0.100 | 1.000 | 10.000 |
| Digestive organs | 0.03 | 0.333 | 3.333 | 33.333 |
| Legs (muscles) | 0.1 | 0.100 | 1.000 | 10.000 |
| Other tissues | 0.02 | 0.500 | 5.000 | 50.000 |

## CONCLUSION

The application of the law of electric field line reflection on a splitting surface $\varepsilon >> \varepsilon_0$ results in the expression for the incidental field $E_0 = \varepsilon_r E$, where *E* the intensity of the electric field in the tissue is. From this, it is possible to derive the intensities of incidental electric field which cause biological effects in tissues. This is of paramount importance for defining maximum allowed fields, which represent normative values for any standard of exposure to ELF. The main results are presented on Figures 6 and 9. The head of human body is exposed to the extremely strong electrical field.

Based on the presented investigation, the general conclusion is that the biological tissues in electric field produced by the power lines have the similar properties as the conductor.

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# UTICAJ ELEKTRIČNOG POLJA NA ČOVEKA U NEPOSREDNOJ OKOLINI 110 KV DALEKOVODA

**Dejan M. Petković, Dejan D. Krstić, Vladimir B. Stanković**

*U ovom radu će biti prikazan uticaj električne komponente elektromagnetnog polja industrijske učestanosti, 50 Hz, koje potiče od nadzemnog 110 kV-nog dalekovoda, na čoveka koji se nalazi u njegovoj neposrednoj okolini. Električno polje koje prodire u čoveka računato je modelovanjem čoveka korišćenjem blokova koji predstavljaju neke organe ili delove ljudskog tela (mozak, pluća, organi za varenje, ...) prema njihovim elektromagnetnim karakteristikama (provodnost, električna i magnetna propustljivost). Prikazana je raspodela električnog polja u okolini čoveka kao i vrednosti prodrlog polja u čoveka. Takođe je izvršeno poređenje analitički dobijenih vrednosti sa vrednostima dobijenim numeričkim rešavanjem postavljenog modela.*

Ključne reči: *elektromagnetno polje, dalekovod, indukovane struje*