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Research Article

Elaboration of Distance Standards Against the Electromagnetic Effects of High-Voltage B Overhead Lines in the Republic of Benin

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Abstract

The high-voltage overhead lines used to transport electrical energy from production plants to distribution stations constitute a very important link in the chain of providing electrical energy to communities. However, they constitute potential sources of emission of electromagnetic waves whose impacts are harmful to human health (thermal electrical stimulation of tissues and in particular those of the brain causing different forms of cancer) if the safety distance between these lines and users is not respected. In recent years, Benin has experienced, in urban areas crossed by transport lines and particularly among populations living in the vicinity of these lines, an explosion in the rate of people suffering from cancer. This study is carried out not only to check whether the minimum distance according to the voltage levels of these lines is respected in order to ensure the safety of people living in their vicinity but also to develop a standard of minimum distances to be respected. By the numerical simulation method based on Maxwell's equations established in a supposedly empty medium, the Bio-Savart law and the Lorentz transformation, the model of wave intensity as a function of distances, is determined. The results obtained respectively give minimum safety distances of 15 meters, 20 meters and 36 meters for the 63 kV, 161 kV and 330 kV high voltage lines Category B. These distances are, by far, respected by the populations. Furthermore, the results clearly show that electric fields are more decisive in defining the minimum distances obtained.

Keywords

Standard, Electromagnetic Effects, Overhead Lines, High Voltage B, Cancer

1. Introduction

Using electrical energy to satisfy needs remains a universal challenge for humankind. Produced in power plants, electrical energy is transported and distributed via power lines. This transport, which takes place by submarine, underground and aerial routes, requires choices to be made for reasons of cost, safety and ease of maintenance [1].

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In developing countries like Benin, overhead transmission lines are the most widely used because of their cost and ease of maintenance [2]. However, it is well known that these lines are potential sources of electromagnetic wave emissions, which are very harmful to human health [3-5].

Electromagnetic fields are essentially reservoirs of energy. This energy is known for its influence on human body tissues in everyday activities. These effects are for the most part harmful, and present risks of numerous types of cancer including: blood cancer or leukemia, lymphoma which weakens the body's immune system in the face of cancerous affections, nervous disorders leading to brain damage such as Alzheimer's disease, and breast cancer, among others [6].

According to the World Health Organization (WHO), prolonged exposure of human tissue to electric waves already constitutes a serious danger to the human body [6]. In order to gain a better understanding of the impact of electromagnetic pollution from high-voltage power lines, a number of research studies have been carried out. In the literature, several methods have been used to estimate electromagnetic field intensities in the neighbourhood of electrical conductors. These include: the method based on a wire code, the method based on a single-point calculation, the method based on the load history of a high-voltage line, and the method based on magnetic field measurements at given locations. These methods focus exclusively on the behavior of the magnetic field, without taking into account the implications of the electric field, the environment and the time of exposure to the waves [7-10].

However, other methods have been used to determine electric fields separately, without going so far as to establish a standard distance to be respected, depending on the environmental parameters in the vicinity of the lines. These include the experimental measurement method, which can only be used to measure fields at a point far from the axis of the support and at high frequencies, due to the non-coupling of magnetic and electric fields; temporal and frequency methods, which are only effective for balanced lines, and are very difficult to use [11-13]. Apart from these methods, there is the method based on Maxwell's equations, which has the advantage of easily decoupling the interaction between electric and magnetic fields at 50 Hz [14, 15].

In Benin, no serious study has been carried out on the subject, despite the fact that climatic and environmental parameters are constantly changing. Since 2016, Benin has been experiencing a revolution in the electrification of its various regions, with the introduction of type B high-voltage transmission networks. In 2022, Adégbola's work addressed this issue with the numerical simulation of the electromagnetic field using the finite element method. But this method turns out to be: imprecise in the case of infinite study domains or thin regions, and in the presence of singularities in the study domain. It is relatively difficult to implement. The construction of an approximate function is almost impossible with this method when the number of line nodes is large [16]. It is in view of all the above that the method based on Maxwell's equations is chosen in this work.

This study fills a gap by defining a standard of distances to be respected according to the voltage levels of high-voltage B lines in the Benin environment, in order to ensure the safety of people living in their proximity. Using a numerical simulation method based on Maxwell's equations established in a medium assumed to be empty, Bio-Savart's law and the Lorentz transformation, the model of wave intensity as a function of distance is determined.

2. Materials and Methods

2.1. Materials

2.1.1. Benin's Transport Network

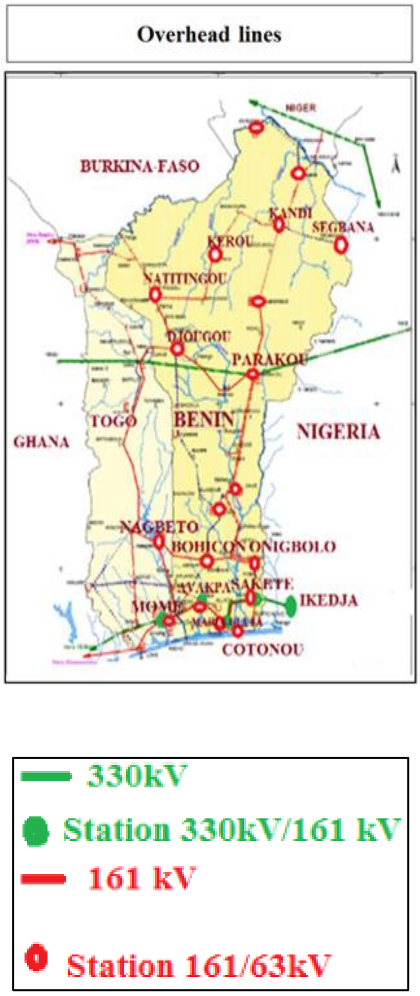

Figure 1. *Configuration of high-voltage B transmission lines in Benin [17].*

2.1.2. Data Used

In order to realize this work, data were collected from the Electrical Community of Benin (CEB). The data concerned the above-ground and phase-to-phase distances of 63 kV, 161 kV and 330 kV lines. In Benin, the above-ground distances are 10 meters, 16 meters and 20 meters respectively. The phase-to-phase distance of the 161 kVA and 330 kVA lines used is 4.6 meters. For 63 kV lines, the distance between phases is 1.5 meters.

2.2. Methods

This study was carried out by numerical simulation of electromagnetic field intensities, in order to determine the separation distances to be observed in accordance with the recommendations of the World Health Organization. These simulations, carried out in the Comsol multiphysics environment, are based on Maxwell's steady-state equations in a medium assumed to be void (1), (2), (3) and (4).

Maxwell-Gauss equation:

$$div\vec{E} = 0 \quad (\rho = 0) \tag{1}$$

Maxwell-Ampère equation:

$$\overrightarrow{rot}\vec{B} = \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t} \quad (j = 0) \tag{2}$$

Magnetic flux equation:

$$div\vec{B} = 0 \tag{3}$$

Maxwell-Faraday equation:

$$\overrightarrow{rot}\vec{E} = -\frac{\partial \vec{B}}{\partial t} \tag{4}$$

ε_0, μ_0 being respectively the permeability and permittivity of the vacuum, have the values:

$$\varepsilon_0 = \frac{1}{36\pi \cdot 10^9} \; [F \cdot m^{-1}] \text{ and } \mu_0 = 4\pi \cdot 10^7 H \cdot m^{-1}$$

2.2.1. Electric Field Model

Applying Gauss's theorem to a conductor of length h and carrying a linear charge density λ [c/m], gives:

$$\oiint \vec{E} \cdot \vec{dS} = 2\pi rh.E(r) = \frac{\lambda h}{\varepsilon_0} \tag{5}$$

Following the radial axis carried by a unit vector, we have:

$$\vec{E} = \frac{\lambda}{2\pi\varepsilon_0} \cdot \frac{1}{r} \vec{u}_r \tag{6}$$

From equation (1), we derive a potential:

$$V(x, y) = -\frac{\lambda}{2\pi\varepsilon_0} \cdot \ln \frac{r(x, y)}{r_0(x, y)} \tag{7}$$

If d is the distance separating the plane perpendicular to the line, we can see from the development of expressions (6) and (7) that the coordinates of the image of the simulation point are (d, -h). The E_x and E_y components of the electric field intensity at (x, y) are expressed as a function of r(x, y) and r_0(x,y), whose expressions are given by equations (8) and (9) in Figure 2.

$$r = \sqrt{(x-d)^2 + (y-h)^2} \tag{8}$$

$$r_0 = \sqrt{(x-d)^2 + (y+h)^2} \tag{9}$$

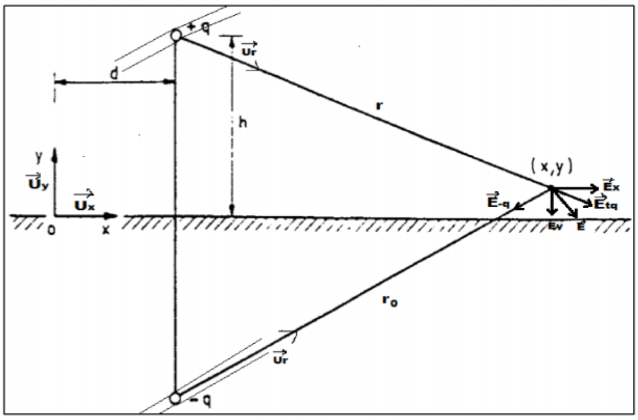

Figure 2. *Projection of the electric field in the cartesian plane [18].*

In two-dimensional coordinates in the Cartesian reference frame, we have:

$$\vec{E} = -\overrightarrow{grad}V(x, y) = \frac{\partial V(x, y)}{\partial x} \cdot \vec{u}_x - \frac{\partial V(x, y)}{\partial y} \cdot \vec{u}_y \tag{10}$$

The combination of expressions (7), (8), (9) and (10) leads to equations (11) and (12).

$$E_x = \frac{\lambda}{2\pi\varepsilon_0} \left[\frac{x-d}{(x-d)^2 + (x-h)^2} - \frac{x-d}{(x-d)^2 + (y+h)^2} \right] \tag{11}$$

$$E_y = \frac{\lambda}{2\pi\varepsilon_0} \left[\frac{y-d}{(x-d)^2 + (y-h)^2} - \frac{y+d}{(x-d)^2 + (y+h)^2} \right] \tag{12}$$

From expressions (11) and (12), the module of the field is determined by equation (13).

$$E = \sqrt{E_x^2 + E_y^2} \quad (13)$$

2.2.2. Magnetic Field Model

Considering the coordinates of the source point and the coordinates of the target point, applying Biot-Savart's law and expressions (2) and (3) to a line of assumed infinite length (very long), gives the expression for the magnetic field.

$$\vec{B} = \frac{\mu_0 I}{2\pi} \cdot \frac{(y - y_s) \cdot \vec{e_x} + (x - x_s) \cdot \vec{e_y}}{(x - x_s)^2 + (y - y_s)^2} \quad (14)$$

On the (ox) axis, we have the component:

$$B_x = \frac{\mu_0 I}{2\pi} \cdot \frac{(y - y_s)}{(x - x_s)^2 + (y - y_s)^2} \quad (15)$$

On the (oy) axis, we have the component:

$$B_y = \frac{\mu_0 I}{2\pi} \cdot \frac{(x - x_s)}{(x - x_s)^2 + (y - y_s)^2} \quad (16)$$

For a three-phase line K, L and M with an assumed infinite (long) length, the magnetic induction is characterized by the equations:

$$B = \sqrt{B_x^2 + B_y^2} \quad (17)$$

With:

$$B_K = \sqrt{B_{Kx}^2 + B_{Ky}^2} \quad (18)$$

$$B_M = \sqrt{B_{Mx}^2 + B_{My}^2} \quad (19)$$

$$B_L = \sqrt{B_{Lx}^2 + B_{Ly}^2} \quad (20)$$

$$B_y = B_{ky} + B_{My} + B_{Ly} \quad (21)$$

$$B_y = B_{ky} + B_{My} + B_{Ly} \quad (22)$$

For simulation purposes, we have assumed that the target point lies on the axis perpendicular to the line support and at a height h from the lines. Thus, y = d = $x_s = 0$ et $y_s = h$.

3. Results and Discussion

The variation in magnetic and electric field strengths as a function of the distance from the vertical axis of the conductor support is shown in Figures 3, 4 and 5.

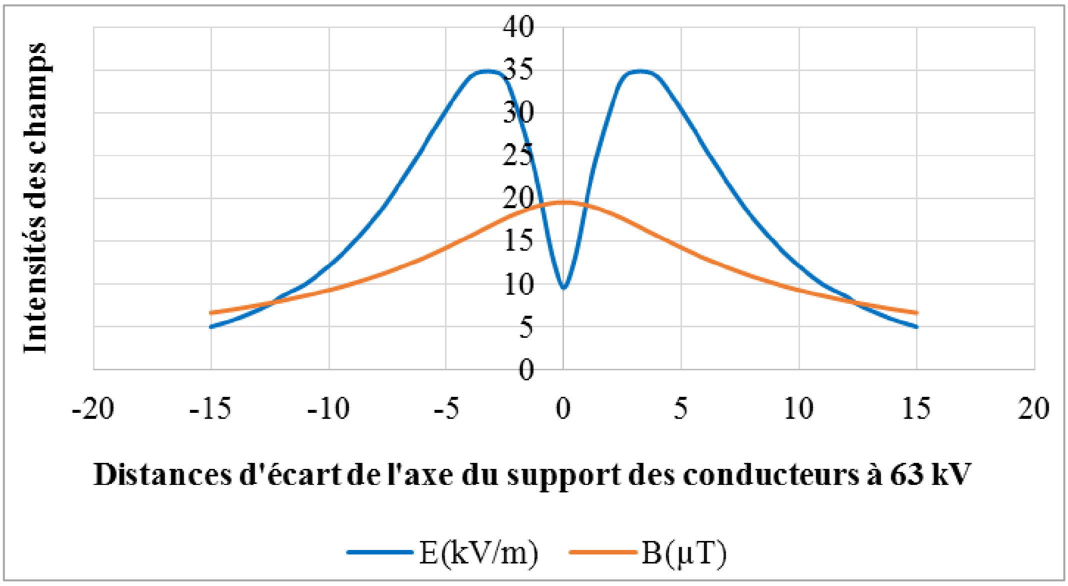

Figure 3. *63 kV field curves.*

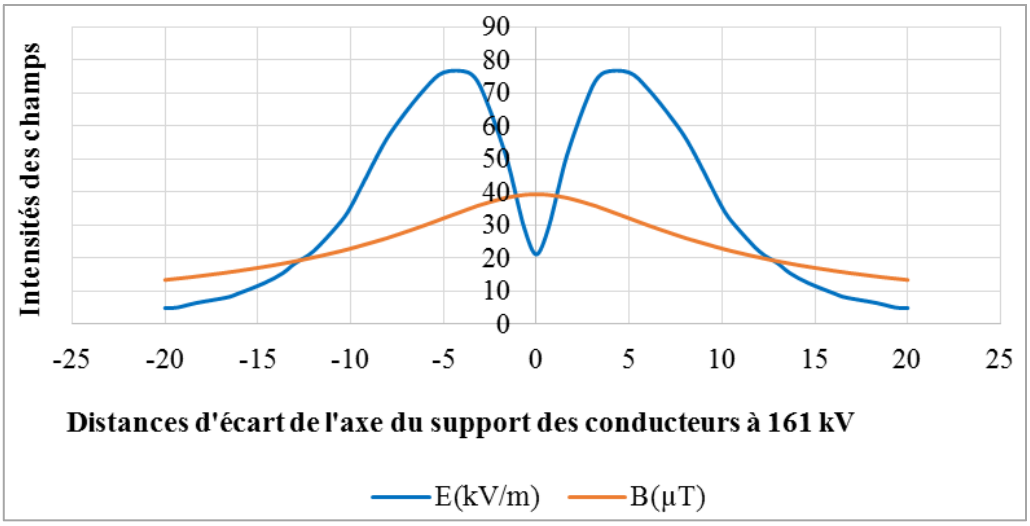

Figure 4. *161 kV field curves.*

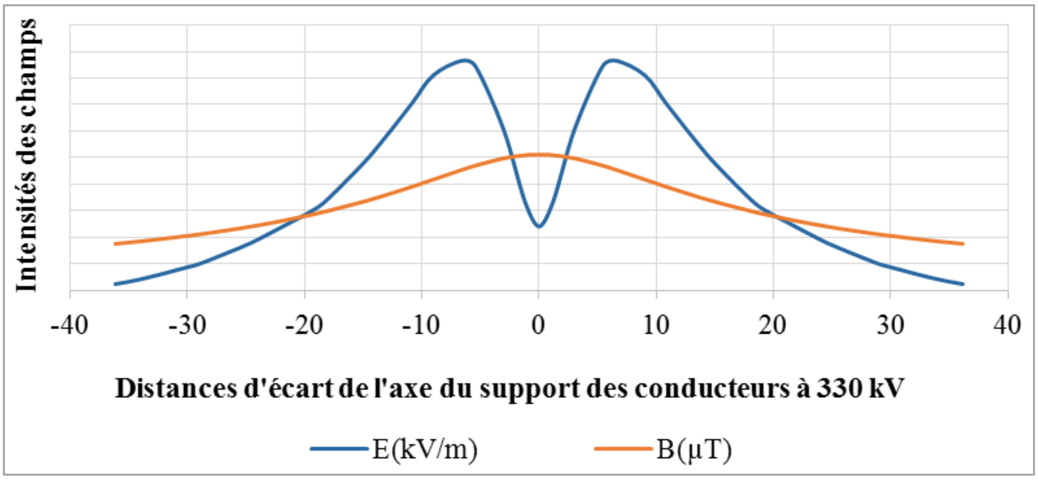

Figure 5. *330 kV field curves.*

The magnetic field is not a hazard at the different voltage levels explored in this study, even though its intensity is close to the limit value of 100 µT [19, 20]. It reaches its maximum intensity at the foot of the support and begins to decrease with distance. The variation in voltage level has a clear influence on the magnetic field intensity. Its maximum value is 20 µT, 40 µT and 99.54 µT respectively for 63 kV, 161 kV and 330 kV lines. In sum, it is clear that magnetic field variation is not too decisive in defining the standard distances to be observed for the voltage levels studied.

The figures show that the electric field reaches a local minimum at the foot of the conductor support. This minimum varies from one voltage level to another. For the three voltages studied, the electric field at the foot of the support is 10 kV/m, 20 kV/m and 50 kV/m respectively for 63 kV, 161 kV and 330 kV lines. It should be noted that all these values are higher than the 5 kV/m value recommended by the standard [19, 20].

Moreover, the electric field reaches its maximum within the first ten meters from the vertical axis of the support, depending on the voltage level. For 63 kV lines, the maximum is reached at around 3 meters from the support, while for 161 kV and 330 kV lines, the maximum is reached at around 5 and 7 meters respectively. This zone is the focal point of the electric and magnetic field in the environment of the lines studied.

Furthermore, this study reveals that after 15 meters from the supports of 63 kV electrical conductors, the field values, particularly that of the electric field, become less than 5 kV/m. So for 63 kV lines, you need to observe at least 15 meters to be spared the harmful impacts of the electromagnetic field. For 161 kV and 330 kV lines, the minimum distances are 20 and 36 meters respectively.

4. Conclusions

The overcrowding of our health centers in recent years with cancer patients of all kinds, and in particular our craftsmen and women who set up in the proximity of transport lines, is the focus of this study. The results obtained provide eloquent evidence of the causes of the repeated and exponential appearance of cancer in society. However, given that the study was carried out under simplifying assumptions relating to the environment, the distance above ground, the distance between conductors and the material used to manufacture the cables, the results may be somewhat inadequate. However, they can be used as a tool for raising awareness among people living in the immediate vicinity of power transmission lines.

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Abbreviations

kV: kilo-Volt
kV/m: kilo-Volt per meter
μT: micro-Tesla
Hz: Hertz
CEB: Electrical Community of Benin
WHO: World Health Organization

Conflicts of Interest

The authors declare no conflicts of interest.

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