Journal of Electrical and Electronic Engineering
2014; 2(1): 1-8
Published online February 20, 2014 (http://www.sciencepublishinggroup.com/j/jeee)
doi: 10.11648/j.jeee.20140201.11

Study of the influence high-voltage power lines on environment and human health (case study: The electromagnetic pollution in Tebessa city, Algeria)

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To cite this article:
DIB Djalel, MORDJAOUI Mourad. Study of the Influence High-voltage Power Lines on Environment and Human Health (Case Study: The Electromagnetic Pollution in Tebessa City, Algeria). *Journal of Electrical and Electronic Engineering.* Vol. 2, No. 1, 2014, pp. 1-8. doi: 10.11648/j.jeee.20140201.11

Abstract: In this paper we present a modeling and simulation, the methodology for calculating the electromagnetic field radiated by the high voltage (HV) lines and for selection of analytical models that interpret the electric and magnetic fields as a function of the distance to the target object. The results were compared with measurements carried out on site where the HV lines are present through a neighborhood of a large agglomeration in the city of Tebessa, for over 50 years. Following published standards establishing the human to HV power line distances for professional exposure or in the case of low frequency field exposure the results obtained by calculations /simulation and measurement in this work, enable us to recommend possible solutions for the electromagnetic pollution issues in the town of Tebessa and thus to reduce the permanent danger to the public considering also the legislative vacuum and the poor preoccupation of official authorities.

Keywords: Electromagnetic Pollution, Low Frequency, Human Health, Aggression, Leukimia, Power Lines, Electric and Magnetic Field

1. Introduction

The potential health effects of the very low frequency electromagnetic fields surrounding power lines and electrical devices are the subject of ongoing research. While electrical and electromagnetic fields in certain frequency bands have fully beneficial effects for medicine, radar and mobile telephony, they appear to have more or less potentially harmful, non-thermal, biological effects on plants, insects and animals, as well as the human body when exposed to levels that are below the standardized threshold values. One must respect the precautionary principle and revise the current threshold values that have become inefficient and not aligned in different countries. Asbestos, leaded petrol and tobacco that are polluting and aggressive to human health are currently managed by the laws of strict precaution after several sessions of legislative revisions. Nowadays, people is highly concerned about the effects of high voltage transmission lines on health. Probable risks for leukemia, breast cancer, neuropsychological disorders and reproductive outcomes have been reported.

A noticeable source of extremely low frequency radiation is the high voltage electrical transmission lines, which in some instances produce such high losses that they bend the earth's ionosphere. Power lines are dangerous because they are constantly losing energy. Because we can't see electricity, and we don't use to have a detector, we can't see it oozing.

If we have an extremely low frequency spectrum analyzer, we could find that extremely low frequency fields propagate very far, even at long distances, and the intensity will be quite significant from biological viewpoint for long term exposures.

Figure 1. *HV electric power line 400kV doubly- three phases lines*

Even for people living at distance from power lines, long term exposure may be dangerous. Often it was found that secondary transmission lines, like in the streets, are much worse polluters than the huge power lines. The human body is a living antenna that can absorb and re-emit [1]-[13]-[14] power line energy, in the environment. Animals also could contribute to re-enforcing environment electromagnetic loading. So a school full of children and teachers near a power line, can become a tremendous new source of electrical energy and a major polluter, not only to the children in the school, but even to people living nearby

2. Living by Power Lines

Both high-voltage transmission lines and also power lines vicinity constitute a radiation hazard. The size of the power line is not the issue. The strength of the electromagnetic field (especially the magnetic component) where you live is what is important.

The configuration of power transmission lines greatly affects the electromagnetic field (EMF) bio-effects. It is common for high-voltage, high-current-carrying power transmission lines to generate a magnetic field whose strength is well above normal household ambient levels, at distances up to 400 meters. But it is also common for a neighborhood power line to create a similar EMF at a distance of 30 meters, and for the wiring inside the walls of your house to create a dangerous EMF at 1.0 meters. In each case, much depends on the configuration of the wires and the amount of current they carry.

2.1. Effects of the Electromagnetic Fields (EMF) on Human Health

The following health outcomes have been conclusively linked with EMF exposure in the scholarly literature: a variety of cancers, leukemia, tumor growth, skin damage, abnormal cell activity, sleep and daily rhythm disturbances, perception and memory changes, genetic defects and impairment of hormone regulation and production; also gland deficiencies, mental and behavioral problems, immune system deficiencies, nervous system disorders, fetal development problems, miscarriages, birth defects, and blood and circulatory problems (Wagner 2006 [15])

2.2. Several Effects on Human Health

The U.K. Stakeholder Advisory Group on Extremely Low Frequency EMFs (2007) cited links between EMFs and the following adverse effects; childhood and adult leukemia, adult brain cancer, Alzheimer's disease, Lou Gehrig's disease, breast cancer, childhood cancers, depression, electrical sensitivity symptoms, certain types of heart disease, miscarriage and suicide.

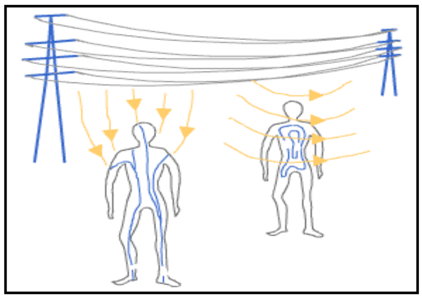


Figure 2. *Low frequency electric and magnetic fields induce weak electric currents in humans and animals [5]*

Many occupational, epidemiological (population health and illness), animal and cell studies reported in the peer reviewed literature by the Colchester School Parents' Association (1988) show major increases in the occurrences of many diseases and other health problems in children and adults exposed to EMFs.

These include: leukemia, non-Hodgkins lymphoma, intestinal cancer, myeloid leukemia, brain tumors, brain cancer, immune system deficiencies, DNA uncoiling, retardation of fertilization, increased infant mortality, embryo abnormality and stunting of growth. A comprehensive review of recorded EMF effects on human health and behavior conducted by Rubtsova [16] included those effects recorded elsewhere in the literature as well as the following: fatigue, decrease in visual and motor reaction time, attention and memory deterioration, persistent mental disorders, headache, nausea, male sexual dysfunction, changes in cardio-respiratory functions, nervous system changes, and embryonic death.

2.3. Risk of Cancers and Leukemia in Children

Epidemiological studies show an increased risk of cancer and leukemia in children exposed to low frequency electromagnetic-field and beyond the 5 kV / m and 0.4 T. In his study, published in the journal Bio electromagnetic in 2001, Daniel Wartenberg [17] considers that the 2200 from all cases of child leukemia (under 15 years) listed in the U.S., 11% of cases will be attributable to domestic exposure to magnetic fields of 60 Hertz. Involving more than 29,000 children with cancer, including 9,700 with leukemia, in the study, published in June 2005 by Oxford University researchers it was found that the risk of leukemia increased by 69% for children whose home is located within 200 meters of high voltage lines at birth and by 23% for those living at a distance between 200 and 599 meters, compared to those born at more than 600 meters.

From these studies confirmed in several publications [1]-[2]-[3]-[0] one may deduce that people living near the power line, the risk for Leukemia increases. In the landscape, high voltage line placement (90, 110, 230 and 400 kV) is strongly criticized by organizations of environmental protection and The media.

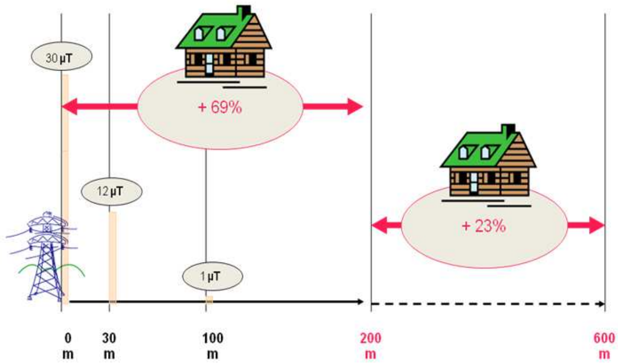


Figure 3. Percentage of additional risk of developing childhood leukemia by a line HV [*Draper* June 4, 2005*]*

3. Computation of Electromagnetic Field Radiated by an HV Overhead Line

The transfer of energy in aerial power lines is a high voltage for technical and economic reasons such as: the discount of joule losses, discount section of drivers and the consideration of the voltage drop in long lines for transport electric power.

The electromagnetic field mainly responsible for the transfer of energy depends essentially on:

- The nominal line voltage which generates an electric field E [kV/m] whose intensity is directly related to the high voltage and the distance to the measuring point.
- The electric current in the line that generate a magnetic field H[A/m].

The mutual interaction between the electric and magnetic fields gives rise to low-frequency electromagnetic field radiated by the line and meant as a source of electromagnetic pollution harmful to human health.

3.1. Computation of the Low Frequency Electric Field

The existence of electric charge into and around the phase conductors lines, in electric substations produce electric fields in their vicinity. These charges are due to the voltage with respect to ground.

The principal idea to calculate the matrix of potential coefficients is deduced from the load quantity around the conductor is solely capacitive and linear according to the applied voltage:

$$q(t) = C_g.V(t)$$

V: is the corresponding voltage of one conductor

Cg: is the geometric capacity of the line

To calculate the radiated electric field at low frequency, the concept of surface charges is generally used. For three phase structure, the surface charges Q are expressed by:

$$[V] = [P][Q]$$

$$[Q] = [P]^{-1}[V] \qquad (1)$$

[P]: matrix whose elements are coefficients of potential $_{ij}$ of three phase lines,

[V] is the single matrix of voltages of each phase.

For the influence coefficients computation, we are going to use the images theory method of conductors with regard to the soil (show fig.4)

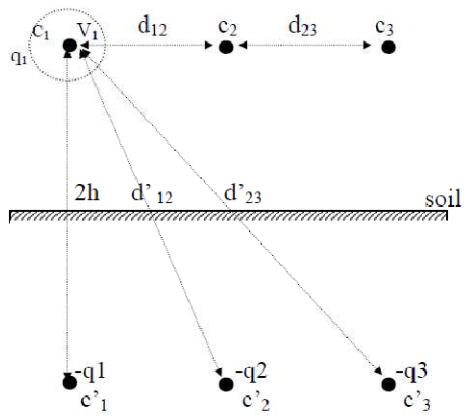


Figure 4. *Three phase line geometry according to the image theory*

The conductors potentials of a three phase line are bound with loads amounts that carry and surround them by electrostatic influences coefficients or potential coefficients $_{ij}$ and expressed by a linear equations system:

$$V_1 = \alpha_{11}q_1 + \alpha_{12}q_2 + \alpha_{13}q_3$$

$$V_2 = \alpha_{21}q_1 + \alpha_{22}q_2 + \alpha_{23}q_3$$

$$V_3 = \alpha_{31}q_1 + \alpha_{32}q_2 + \alpha_{33}q_3$$

The nature of the electric field emitted by a low frequency loaded line is given by the quasi-static electric field components in a the cylindrical coordinate system [3]:

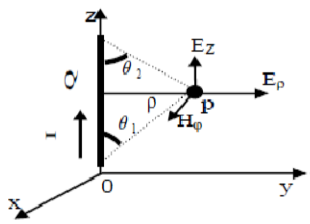


Figure 5. *Model for computing of the electric and magnetic fields*

$$\left\{E_\rho = \frac{Q}{4\pi\epsilon_o\rho}(cos\theta_1 + cos\theta_2) \qquad (2)\right.$$

$$\left\{E_z = \frac{Q}{4\pi\epsilon_o\rho}(sin\theta_1 + sin\theta_2) \qquad (3)\right.$$

E_ρ is the horizontal electric field and E_z is the vertical electric field

Q is the surface charge

ε_o is the permittivity

$\theta_{1,2}$ is the position angle

3.2. Computation of the Magnetic Field Radiated by a HV Power Line

Computing analytically the magnetic field at low frequencies is based on the calculation of the currents in the three phases (A, B, C) of the line [4]. In quasi-static conditions, the density of the magnetic field B (r) generated at a distance r in the point M in the space above the ground by the line current I into a wire structure can be evaluated by the relationship of Biot-Savart:

$$\vec{B} = \frac{\mu_0 \mu_r I}{4\pi} \oint \frac{d\vec{s} \wedge \vec{r}}{r^3} = \mu_0 \mu \vec{H} \quad (4)$$

where μ_0 and μ_r are the magnetic permeability in the vacuum and area

Otherwise the magnetic field strength created by a line of finite length l can be expressed in cylindrical coordinates by:

$$H_\varphi = \frac{Q}{4\pi r}(cos\theta_1 + cos\theta_2)\vec{U}\varphi \quad (5)$$

where Uφ is the unit vector

3.2.1. Modeling of the Magnetic Field Radiated by a Three Phases Line

Let us take that in the modern Cartesian coordinate system the coordinates of wires A, B and C with currents running are x_A, y_A, x_B, y_B, x_C, y_C (Fig.6 shows only x_A and y_A). The coordinates of point M, at which the magnetic field emitted by currents running along the line wires is measured are x_M and y_M. The wire radius r_o is much less than the other transverse linear measurements. A symmetric current system i_A, i_B, i_C is running along the wires.

The current system:

$$i_A = I_m sin\omega t$$

$$i_B = I_m \sin(\omega t - 2\pi/3)$$

$$i_C = I_m \sin(\omega t + 2\pi/3)$$

I_m : maximum current [A]

ω : pulsation [rad/s]

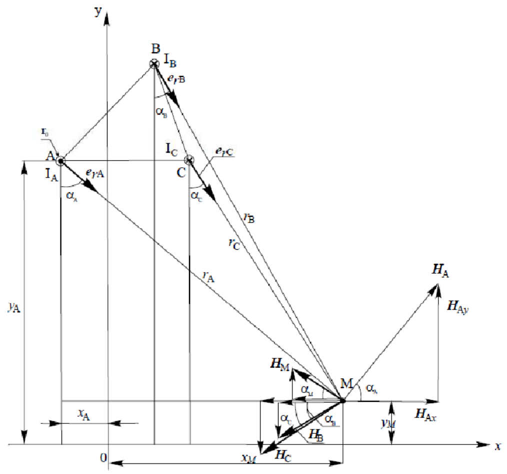


Figure 6. *Scheme of magnetic fields emitted by three-phase power line*

A, B, C – phase wires of aerial power lines;

I_A, I_B, I_C – phase currents;

x_M – distance between pylon and measurement point M;

x_A – distance between phase A wire and y axis;

y_A – distance between phase A wire and x axis;

Suppose that the positive current direction is towards the observer and the negative one from the observer. The strength of the magnetic field emitted by a three-phase aerial line is a vectorial sum of magnetic field strengths emitted by all three currents:

$$\vec{H}M = \vec{H}A + \vec{H}B + \vec{H}C \quad (8)$$

The magnetic field of a straight endless wire with the current I running at the point far from the wire at a distance r is expressed by Biot-Savart equation (4):

$$H = \frac{I}{2\pi r}$$

$$H_M = \frac{I}{2\pi}\left(\frac{I_A}{r_A} e_{rA} + \frac{I_B}{r_B} e_{rB} + \frac{I_C}{r_C} e_{rC}\right) \quad (9)$$

r_A, r_B,,r_C – are the distances of point M to wires A, B and C

e_{rA}, e_{rB}, e_{rC} – are the unit vectors corresponding to these distances.

Summarized by :

$$r_i = \sqrt{(x_M - x_i)^2 + (x_M - y_i)^2} \quad (10)$$

Where:

r_i – wire distance from the point;

x_i, y_i – coordinates of this wire centre.

i: indices of phases line

Angles α formed by unit vectors $\boldsymbol{e}_{rA}$, $\boldsymbol{e}_{rB}$, $\boldsymbol{e}_{rC}$ with axis y (Fig.6) are found by using the formulas:

$$\alpha_i = arctg \frac{x_M - x_i}{y_M - y_i} \quad (11)$$

As the cosine is an even function, projections of vectors ***H*** on to the coordinates are calculated according to the following formulas in two cases:

a) $y_M - y_i < 0$

$$\begin{cases} H_{ix} = -H_i cos\alpha_i \\ H_{iy} = H_i sin\alpha_i \end{cases} \quad (12)$$

b) $y_M - y_i > 0$

$$\begin{cases} H_{ix} = -H_i cos\alpha_i \\ H_{iy} = H_i sin\alpha_i \end{cases} \quad (13)$$

Thus projections of the magnetic field strength vector onto the coordinates will be found as follows:

$$H_x = H_{Ax} + H_{Bx} + H_{Cx}$$

$$H_y = H_{Ay} + H_{By} + H_{Cy} \quad (14)$$

The module of vector $\vec{H}$ and the angle $_M$ (with the x axis) is calculated as follows:

$$H_M = \sqrt{\left(H^2{}_x + H^2{}_y\right)} \tag{15}$$

$$\alpha_M = \frac{H_y}{H_x} \tag{16}$$

Magnetic flow density B is calculated as follows:

$$B = \mu_r \mu_o H \tag{16}$$

Where:

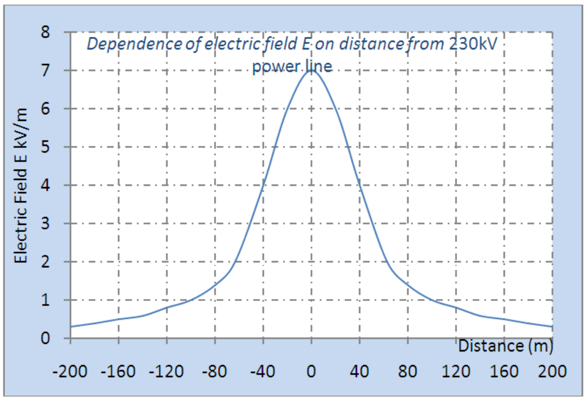
μr – relative magnetic permittivity

$\mu 0$ – vacuum magnetic permittivity ($\mu_0 = 4\pi \times 10^{-7}$ H/m).

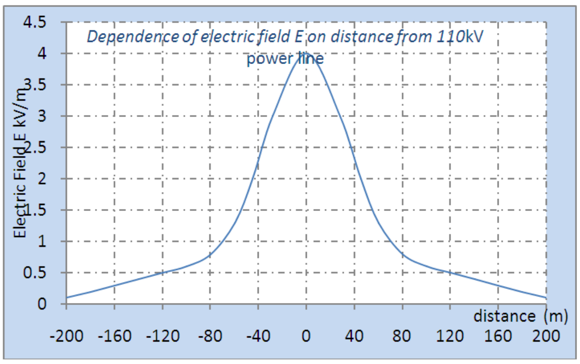
Based on the proposed mathematical model of magnetic fields, an analytic way was used to establish the calculated value of magnetic flow density (B) of 230 kV and 110 kV voltage power line aerial at different currents running along the wires.

4. Simulation Study

To analyze the behavior of the electromagnetic field radiated by the HV lines, we simulate in Matlab the models of E (r) and B (r) (show fig.7 and fig.8) developed above. The results obtained will be compared to those already published by other authors and those measured on site by our team in Tebessa at a line of 220 kV.



(a)



(b)

Figure 7. Dependence of electric field E on distance from (a) 230kV, (b)110kV aerial power line

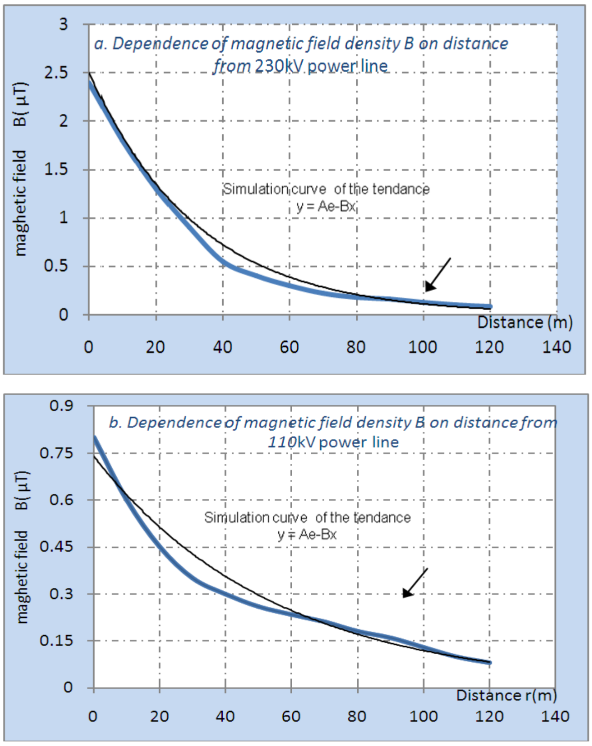


Figure 8. Dependence of magnetic flux density B on distance from: (a) 230kV, (b)110kV aerial power line

The geometric profile of simulation results implies a decreasing of electromagnetic field components with the distance to the measuring point. For enriching this work, we propose an analytical modeling of the field components (regression curves approaching the measured data series), with software version ORIGIN7 and approximate method of numerical interpolation Least-Squares, we obtained the following models:

- *Electric field* of *230 kV power line*:

General model: polynomial function:

$$Y= ax^{n}+bx^{n-1}+cx^{n-2}+ \ldots +K \tag{18}$$

approximate model by LSM:

$Y = ax^6 + bx^4 + cx^2 + dx$

$Y=-5.10^{-13}x^6 + 4.10^{-08}x^4 + 1.10^{-11}x + 5,7$

- *Magnetic field of a 230 kV power line*:

General Model: polynomial function type:

$$Y=A.e^{-Bx} \tag{19}$$

Approximate model by LSM:

$Y= 2e^{-0,02x}$

LSM : Least Squares Model

5. Case Study: Tebessa Town in Algeria

The wilaya of Tebessa comes from the Algerian administrative division of 1974. It extends over an area of 13,878 km² with an estimated population in 2012 to over 700,000 inhabitants and an average population density of 50 inhabitants per km². Located at an altitude (between 700 m and 1000 m), Wilaya of Tebessa currently has 28 communes grouped into 12 province.

The Tebessa is located south-east of Algeria on the highlands, it is limited by (fig.9).

The longitude and latitude of Tebessa city are:

- Latitude : 35°24′15″ North
- Longitude : 8°07′27″ East
- The altitude above sea level: 856 m

In the power grid map of the Wilaya of Tebessa established by the national electricity company SONELGAZ (fig.10) one can find more sources of electromagnetic radiation in the low frequency (50 Hz) such as HV power lines (30 kV, 90 kV and 220 kV).

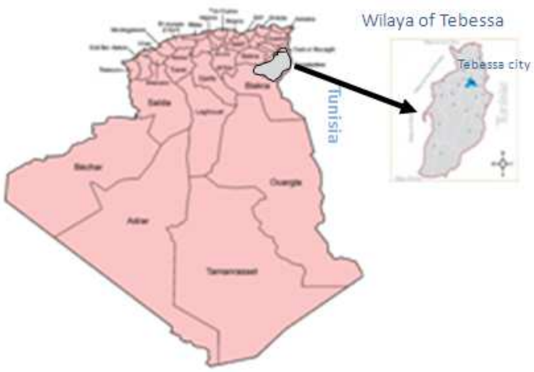


Figure 9. Geographical location of Tebessa Town[19]

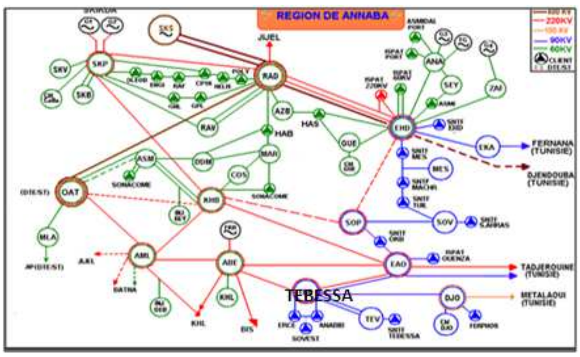


Figure 10. Sonelgaz *Electrical network;* Region EAST, Annaba

SOV, ANA, TEB are the Electric abbreviated designations for Algerian city established by the state society Sonelgaz (producer and supplier of electric energy in Algeria).

5.1. Experimental Study

The measurements are performed in the vicinity of high-voltage power line that crosses the site OuedNagueus in Tebessa city coming from the substation of Annaba town to supply the wilaya of Tebessa by electrical energy.

In the first part, we choice the good conditions for these measurements as the climatic, atmospheric and electric parameters.

The measures are realized in the strictest of environmental conditions in the winter and a humidity of 70% and a maximum power demand rate, which promotes the conductivity in the atmosphere.

The second phase of our experimental study was to take measurements of electrical and magnetic fields near the line and on several points of different distances. The measuring instrument (fig.11) is the model: ME3830B 5 Hz to 100 kHz, highly sensitive and specific for the electric and magnetic fields.

Figure 11. *Instrument model: ME3830B used in main measurements The following table summarizes the main measurements:*

Table 1. *Measurement of electric and magnetic fields near 220kV overhead line in OuedNagueus in Tebessa Town, Algeria*

Distance (m)	E (V/m)	B (T)
Beneath	8000	7
10	4000	4
20	1500	2.5
30	800	2
40	600	5
50	400	4
60	200	3
70	80	2.3

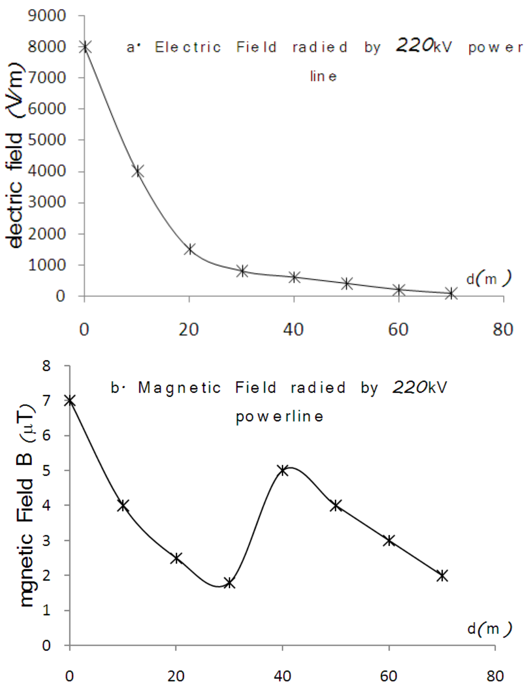


Figure 12. *Experimental measurement of electric (a) and magnetic (b) field of 220kV power line in Oued-Nagueus in Tebessa, Algeria*

5.2. Results and Discussion

For the electric field, simulation, the results of modeling and measurements coincide and give satisfaction. The difference found between theory and measurement at a distance of 35-40 m where the B field rebounds (fluctuation), could be generated by external parameters such as electric permittivity ε and magnetic permeability μ of the soil varying from one location to another, also by climatic and atmospheric conditions such as humidity and environmental temperature gradients. The measures are realized in the strictest of environmental conditions in the winter with a humidity of 70% and a maximum power demand rate, which promotes the conductivity in the atmosphere. The measurements were repeated 3 times for each distance in favorable conditions mentioned above with uncertainties very weak and have no effect on the mean value. The maximum exposure to electric and magnetic field at 50 Hz according to standardized limits [11] are respectively:

- For professional exposure: 10 kV / m and 1 μ T
- For the general population: 5 kV / m and 0.4 μ T

According to studies and research work published by several authors [10]-[11]-[13]-[14] and aiming to establish a platform for regulatory exposure limits of living beings while putting human health of priority we propose the reassuring limits in the following table 2.

Table 2. *Regulatory exposure limits of living beings to electric and magnetic fields radiated by the HV lines*

Voltage of power line	recommended distances
90 kV	45 meters
130 kV	65 meters
225 kV	112,5 meters
400 kV	200 meters

5.3. Photos of Electromagnetic Pollution by 220kV Power Lines in Tebessa Town, Algeria

During our companion measures for the electromagnetic fields on the site at issue, we have taken photos (fig 13) to show of collective offenses committed by the authorities, companies and people by their participation in a direct or indirect manner in electromagnetic pollution and his aggressions to human health.

Figure 13. *Photographs on the aggression Electromagnetic HV lines on the environment in the several zones in Tebessa town (2013)*

6. Conclusion

Although the science is far from conclusive, a substantial base of data exists from years of research which is highly suggestive of an association between exposure to electromagnetic fields and the development of certain health problems. Identification of these groups aggressed of people would be impractical given our current state of knowledge, but their risk would be greater than the general population. The HV power lines are a source of pollution to the environment through its direct assault on the landscape, land use in the city or agricultural land and its impact on human and animal health by its electromagnetic radiation.

The conclusion of our study is summarized in:

- ✓ Computing of electric field and magnetic field following the proposed mathematical model.
- ✓ Simulation under Matlab10 and Origin7 of the electromagnetic field according the distance target.
- ✓ Experimental measurement of electric and magnetic fields of 220kV power lines by our team research in Dhraalimam area in Tebessa Town in Algeria;
- ✓ Good satisfaction between all results given by modeling, simulation and measurement.
- ✓ Confirmation of non-standards compliance to the limits of human exposure to ELF fields in the case of the town of Tebessa and approving the aggression on human health.
- ✓ Lack of specific standards for Algeria which set the terms and distances for any exposure to Electromagnetic fields as is the case in Europe and USA.
- ✓ The establishment of a monitoring study of medical diagnosis on those residents near HV power lines and telephone transmission antennas for the different operators.
- ✓ Proposing to used a diverse sources of renewable energy to avoid the centralized production and promote the proximity between production sites and places of energy consumption

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