



Assessment of magnetic field induced by overhead power transmission lines in Algerian National Grid

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Abstract

This paper presents a systematic investigation about the extremely low-frequency magnetic fields generated in the vicinity of high voltage overhead power transmission lines constituting the Algerian national electricity power transmission grid. The influences of loading current on the magnetic field as well as the variation of tower configuration and conductor section are investigated. Simulations are made by COMSOL software and experimental measurements of magnetic field near overhead power transmission lines are performed by Chauvin Arnoux C.A 40 gaussmeter. Both Simulation results and measurements are compared to safety exposure limits given by International Commission on Non-Ionizing Radiation Protection ICNIRP. Well agreements are found between simulations and experiments overall the three considered voltage levels 60/220/400 kV and for all shapes of lines and towers.

Keywords Magnetic field · Extremely low frequency · Algerian national electricity power transmission grid · Current flow · Transmissions lines configurations · Conductors sections

1 Introduction

The biological effects of electromagnetic fields (EMF) on humans, animals and plants have become an interesting topic for researchers. Numerous studies have been conducted through the past decades in order to find the existence of any relationship between the electromagnetic field emitted from high voltage transmission lines and major impacts on health such as cancer and other diseases. Most of performed researches and studies concluded that no relationship exists between chronic diseases and the electromagnetic fields emitted from transmission lines [1]. A study conducted by the National Institute of Environmental Health Sciences (NIEHS) stated that through experiments in laboratories, the probability of the exposure to the electromagnetic field (EMF) from transmission lines causing health hazard is

currently small [2]. Another study conducted by the World Health Organization (WHO) declared that the evidence of an association between EMF exposure and childhood leukemia is not strong enough to be considered causal, but sufficiently strong to remain a concern [3]. In addition, an experiment performed in Canada showed the uncertainty of having a causal relationship between the magnetic fields developed by transmission lines as well as that around the homes and the risk of having leukemia [4].

Therefore, high voltage overhead transmission lines (HVOHTL) impact the environment in several ways:

landscape, biodiversity, land use, proximity effect and indirect emissions.

The proximity effect on human beings in the vicinity of HVOHTL encompasses a fear of the adverse health effects of electromagnetic field, annoyance and noise. While there is no definitive scientific study which establishes that 50 Hz electromagnetic fields within the recommended range of WHO present a danger for human health, many countries place restrictions on distance to human habitation as a precaution [5, 6].

A particularity of the extremely low-frequency (ELF) fields, compared to the high-frequency fields is that the electric field or the magnetic field can exist in isolated form

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from each other unlike the high-frequency fields where they are related, justifying their qualifier electromagnetic [7, 8].

Extremely low-frequency (ELF) radiations are positioned at the low-energy end of the electromagnetic spectrum and are a type of non-ionizing radiations. This particular non-ionizing radiation has sufficient energy only to move atoms in a molecule around and cause them to vibrate, but not enough energy to remove charged particles such as electrons and damage the DNA directly. ELF radiation has even lower energy than other types of non-ionizing radiations like radio frequency radiation, visible light, and infrared [9]. In order to characterize ELF fields, the magnitude, frequency and orientation of the electric and magnetic fields have to be determined. Under high voltage transmission lines, the electric field has its major component oriented vertically (perpendicular to the earth's surface), while the main magnetic field component is horizontal (parallel to the earth's surface).

Several researches focused on the evaluation of magnetic field at extremely low frequency (ELF) near overhead power transmission lines (OHTLs) to insure human health safety and equipment immunity [10]. According to international commission for Non-ionizing radiation protection (ICNIRP), the safety limits exposure to magnetic field in extremely low frequency is $200\mu\text{T}$ for people and $500\mu\text{T}$ for professional workers [11]. These values are adopted in Algerian legislation. In this regard, it will be very interesting to know about the level of magnetic field induced by extremely high voltage (EHV) power transmission lines 400 kV with 4200 km consistency which are recently introduced and used in Algerian national electricity transmission power grid, and compare the results with magnetic field values generated by classical and usual power transmission lines 60 kV with consistency 10,800 km and 220 kV with consistency 15,000 km [12, 13].

GRTE is a crown corporation responsible for Algerian national transmission grid, so it is responsible to build new transmission lines or making changes to existing transmission lines.

Originally, Algerian transmission grid is optimized for regional self-sufficiency and developed for a more centralized generation, and interconnections between regions are created for mutual support.

Also, the Algerian National Grid is interconnected at the Westside to ENTSO (European Network of Transmission System Operators) via Morocco National Grid ONEE (National office of electricity and water) and Tunisian National Grid STEG (Tunisian Electricity and Gas Company) at Eastside.

The Algerian national power transmission grid has actually more than 30,000 km consistency and the Ten-Year Network Development Plan at year 2030 introduces 20,000 km of additional transmission lines. Firstly, this project contributes to energy sector development. Secondly, it was

important to interconnect the isolated south grid with the North Algerian interconnected transmission grid. Another major factor contributing to the importance of this project is the interconnection of renewable energy system projected in the region of Adrar in South to the North Algeria [14].

Therefore, by 2030, the GRTE Company will manage more than 50,000 kms of high voltage overhead transmission lines (HVOHL).

GRTE is frequently asked about transmission lines. Many of these questions relate to the effect that transmission lines may have on the environment and on people. In particular, we often hear from citizens who want to know more about the effects of construction, operation and maintenance of transmission lines related.

In this order, serious public concerns are expressed about negative effects on human health as a consequence of exposure to electromagnetic fields generated by high voltage overhead transmission lines (HVOHL).

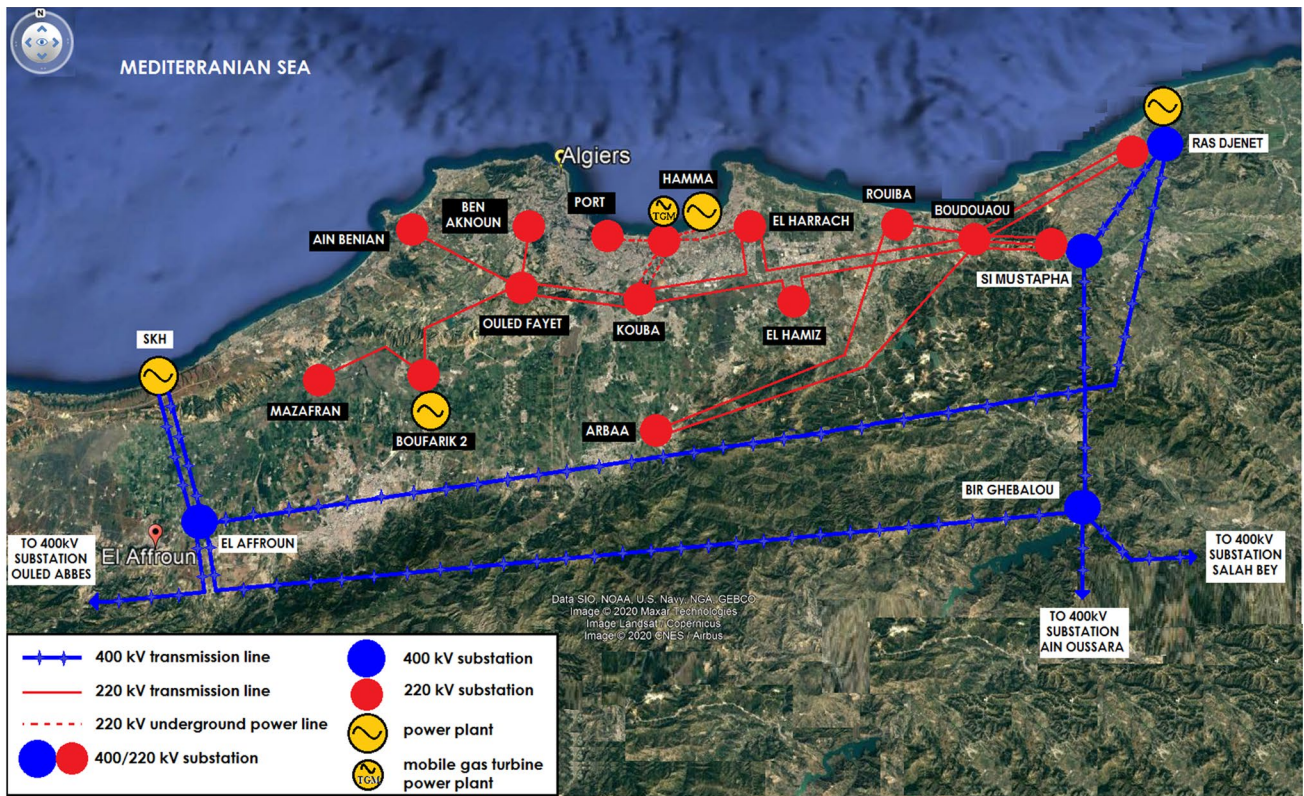
Due to public anxieties and concern, a study has been conducted to assess the extremely low-frequency magnetic field (MF) radiations from the 60 kV, 220 kV and 400 kV transmission lines used in Algerian National Grid (Fig. 1a, b), specifically on a vacant land near the transmission line and the area directly under the transmission line.

The aim of the study is to determine the MF levels emitted by the transmission lines and compare the results with the international recommendations of standards and guidelines issued by the International Commission on.

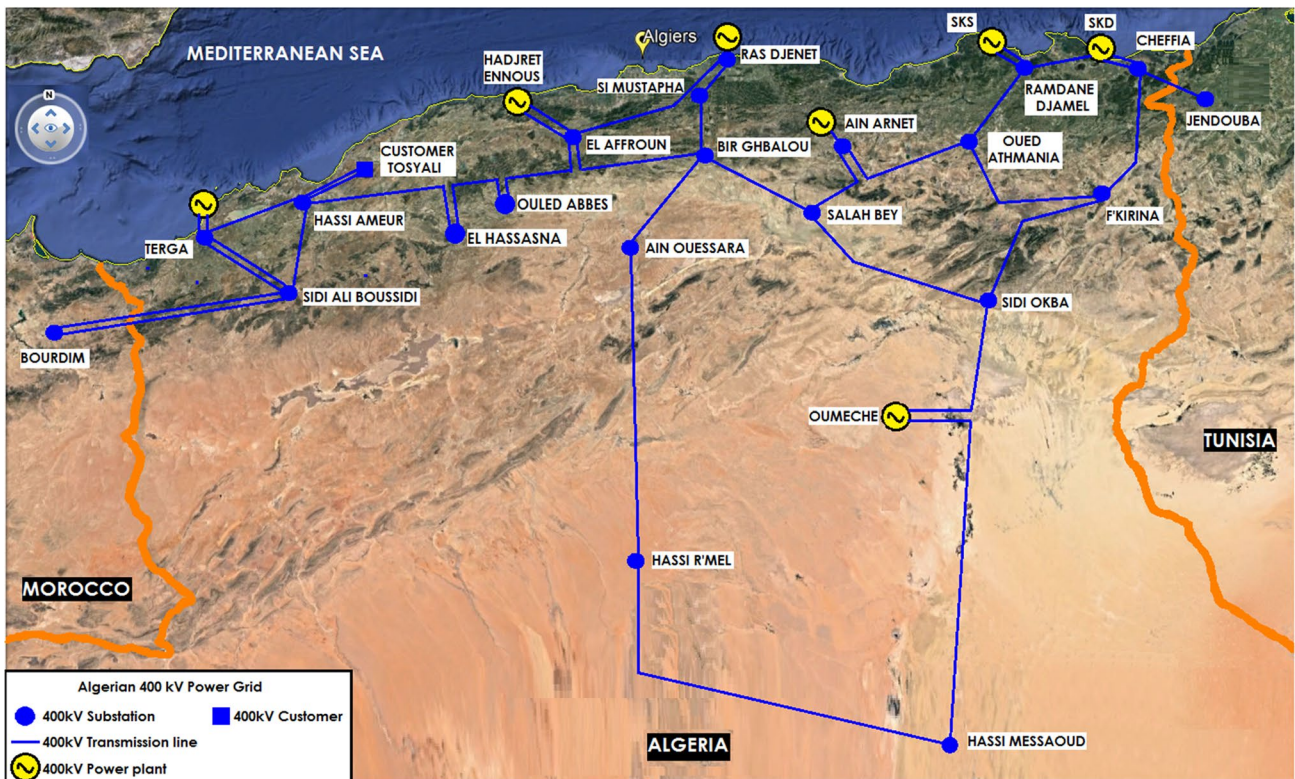
Non-Ionizing Radiation Protection (ICNIRP). In addition, the study is intended to identify other factors like current flow, tower configuration and cable size that influence the magnetic field strength in the different cases.

Numerical computations have been done for several towers configurations: horizontal, vertical and delta, for various voltage levels, especially 60 kV and 220 kV at 50 Hz with one and two conductors per phase. The magnetic field was simulated at 2 m above the ground. Therefore, we will try to evaluate the influence of different configurations and conductors section on the magnetic induction B. We considered the most used conductors in Algerian network which is the 570 mm^2 All Aluminum Alloy Conductor (AAAC) and 288 mm^2 Aluminum Steel Reinforced Conductor (ACSR) [15].

As such, we took as an example of study the 400 kV interconnecting lines Ras Djenet—Si Mustapha which is an important power plant evacuation and Ras Djenet—El Affroun which ensures the interconnection between North and West. For 220 kV levels, we have considered the interconnecting line between Boudouaou 220/60 kV substation and the 220/60/30/10 kV substation located at El Harrach city in the East of Algiers [12, 13]. For the 60 kV voltage level, El Harrach—Bab Ezzouar line is taken as an example, it is a strategic distribution line the fact that it supplies an important area in the East of Capital city.



(a)



(b)

Fig. 1 a 400 kV and 220 kV transmission grid around Algiers City. b Algerian 400 kV power transmission grid

For the present work, the magnetostatic model of COMSOL software was used to simulate and calculate the magnetic field at the vicinity of HV and EHV power transmission lines at 2 m height above the ground with using a real value of current measured in the substation at different days. A typical daily power flow is depicted in Fig. 2a for the 400 kV and Fig. 2b for the 220 and 60 kV transmission lines. The calculated results are compared with those obtained by on site measurements using C.A 40 Gaussmeter device [16].

2 Magnetic field generated by power transmission lines

The phases conductors are assumed of infinite length which are crossed by current, the close loops of magnetic field are created around. The magnetic field intensity **H** induced at a distance *r* by the current *I* flowing through the conductor can be calculated by using Ampere’s law (1).

$$\mathbf{H} = \frac{I}{2\pi r} \tag{1}$$

The magnetic induction *B* is linked to the magnetic field by:

$$\mathbf{B} = \mu\mathbf{H} \tag{2}$$

where $\mu = \mu_0\mu_r$; μ_r the relative permeability ($\mu_r = 1$ for air); μ_0 the void permeability ($\mu_0 = 4\pi 10^{-7}$ A/m). So

$$\mathbf{B} = \frac{\mu_0 I}{2\pi r} \tag{3}$$

where *I* is the line current and *r* the distance between the conductor and the considered point P [17].

3 Electromagnetic models

All electromagnetic phenomena are described by J.C Maxwell laws, and according to devices studies certain phenomena are neglected rendering the laws uncoupled, so simple models are obtained [18].

For the present work, a magnetostatic model has been chosen, where the current source is quasi-static and the magnetic induction was created by induced currents. Knowing that the potential vector **A** gives more knowledge of all physical parameters, its expression is given by the combination of Eqs. (4) and (5):

$$\text{Rot}\mathbf{H} = \mathbf{J} \tag{4}$$

$$\mathbf{B} = \text{Rot}\mathbf{A} \tag{5}$$

2D spatial evolution of electromagnetic phenomenon was given by magnetostatic law:

$$\text{Rot} [1/\mu \text{Rot}\mathbf{A}] = \mathbf{J} \tag{6}$$

Equation (6) describes the magnetostatic behavior of rectilinear conductor crossed by current [17, 18]. Therefore, in this work, we will try to study the magnetic field overhead power transmission lines for different tower configurations. The influence of load current *I* and the conductors section on the magnetic induction **B** will be investigated.

4 Geometric models

The towers geometries of single circuit 60 kV, 220 kV with one conductor per phase and two conductors per phase are those represented in Figs. 3 and 4. The 400 kV line with twin bundle conductors per phase interconnecting the North and West of Algeria is represented in Fig. 5. We assume that the overhead phase bundle is replaced by an equivalent single conductor. For 400 kV, two cases are treated, in the first case the phase conductors are at 11.50 m from the ground and in the second case, the phase’s conductors are at 50 m from the ground.

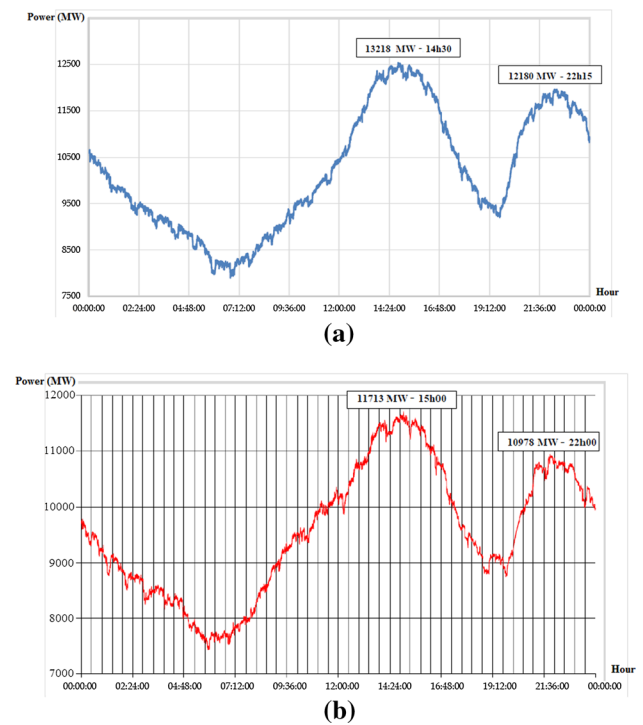


Fig. 2 a Algerian load curve of the day considered for 400 kV transmission lines measurement. b Algerian load curve of the day considered for 220 kV and 60 kV transmission lines measurement

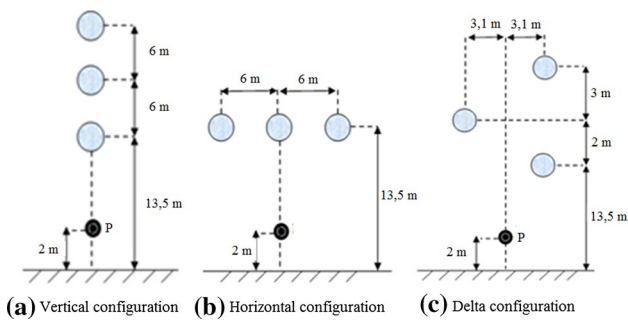
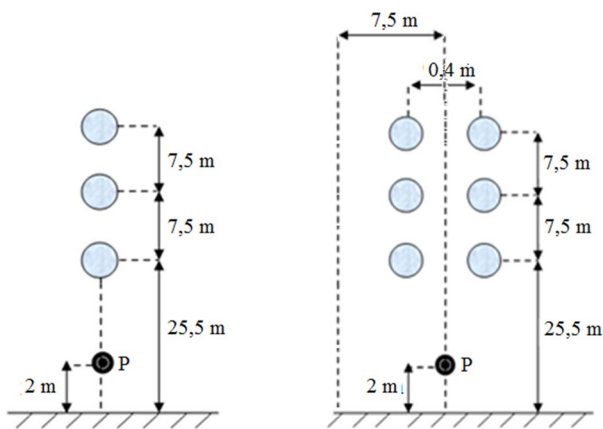


Fig. 3 Different configurations for 60 kV single circuit



(a) 1 Conductor per phase (b) 2 Conductors per phase

Fig. 4 Different configurations for 220 kV single circuit

5 Measurement procedures

The measurement of electric and magnetic fields is an often-complex operation, which requires appropriate measuring equipments [19, 20]. We used a digital apparatus "C. A 40 Gaussmeter device" which displays the magnetic component in μT and the electrical component in V/m [21]. The magnetic field was measured at 2 m above the ground.

"Suparule Cable Height Meter" is a digital device that uses ultrasonic technology to measure distances between conductors and the ground [22]. The measurements were taken at different days and times. Figures 6 and 7 depict the used apparatus and the investigated tower.

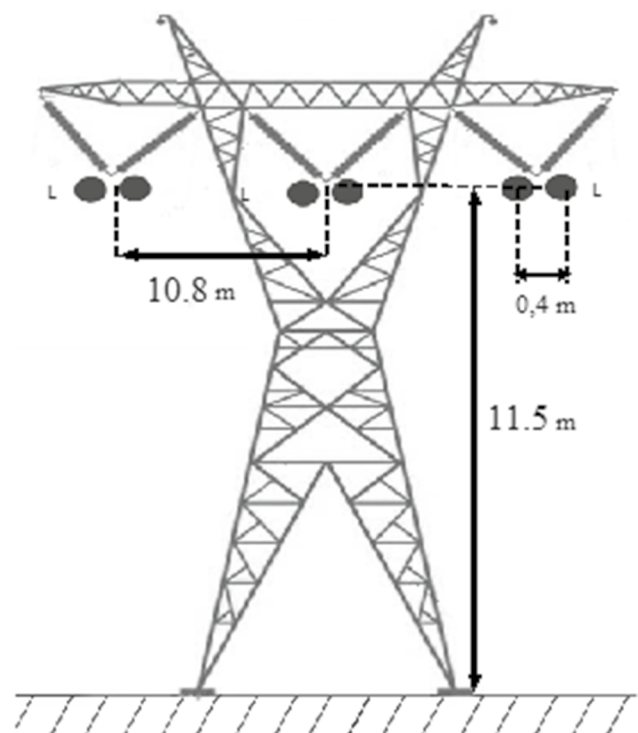


Fig. 5 Tower for 400 kV single circuit line



Fig. 6 400 kV Ras Djenet—Si Mustapha line



Fig. 7 Height measurement between ground and conductor

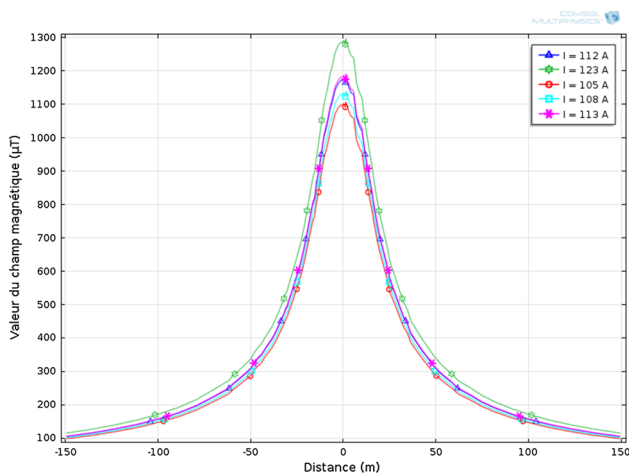


Fig. 8 Magnetic induction for 60 kV horizontal single circuit line

6 Results and discussions

6.1 Magnetic induction at 2 m above the ground at various load current and various configurations for 60 kV single circuit line

Figures 8, 9 and 10 show that the magnetic induction for 60 kV line increases with increased current flow. Table 1 shows the magnetic induction comparison between

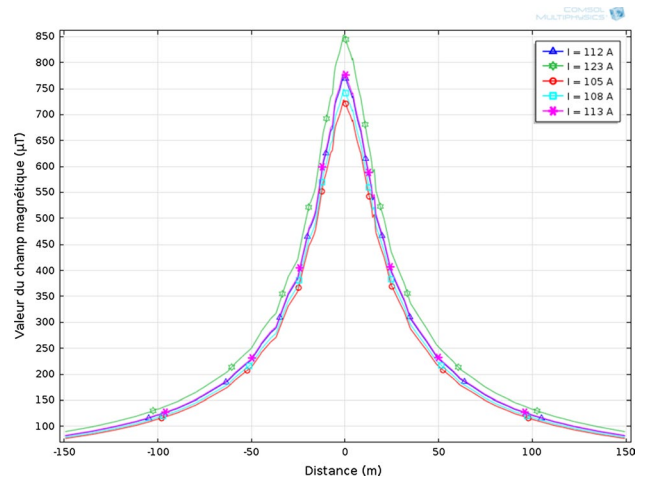


Fig. 9 Magnetic induction for 60 kV vertical single circuit line

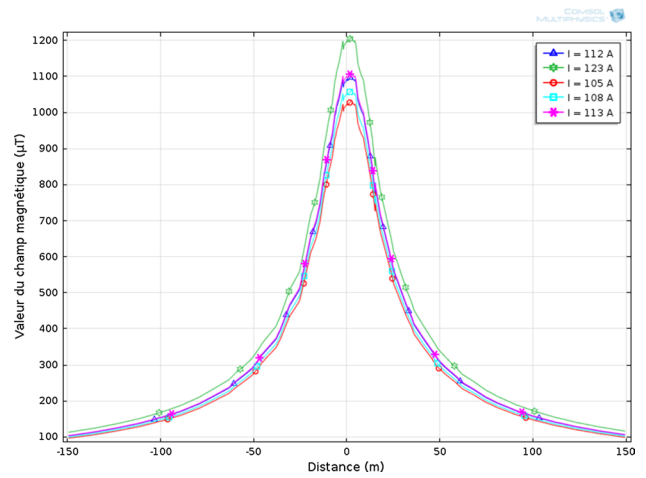


Fig. 10 Magnetic induction for 60 kV triangular single circuit line

calculation and measurement at 2 m above the ground for different configurations of a 60 kV single circuit line. It is observed that the magnetic induction generated by the horizontal configuration is higher than the magnetic induction generated by vertical and triangular configurations. Also, the magnetic induction generated by delta configuration is higher than that of the vertical configuration.

6.2 Magnetic induction at 2 m above the ground at various load current and different conductor's section for 220 kV single circuit line

Figures 11 and 12 show that the magnetic induction increases as the load current level increases for 220 kV single line. Table 2 shows the magnetic induction comparison at 2 m above the ground for 220 kV single circuit line with

Table 1 Magnetic field for different configurations and various load current levels at 2 m above the ground for 60 kV single circuit

Configurations	Load current I (A)	Magnetic induction calculated B (μT)	Magnetic induction measured B (μT)
Horizontal	105	1100	1100.15
	108	1130	1130.28
	112	1170	1170.19
	113	1180	1180.21
	123	1290	1290.28
Triangular	105	1020	1020.17
	108	1050	1050.27
	112	1090	1090.19
	113	1100	1100.24
	123	1200	1200.18
Vertical	105	725.92	726.21
	108	746.67	746.95
	112	774.31	774.52
	113	781.23	781.44
	123	850.37	850.62

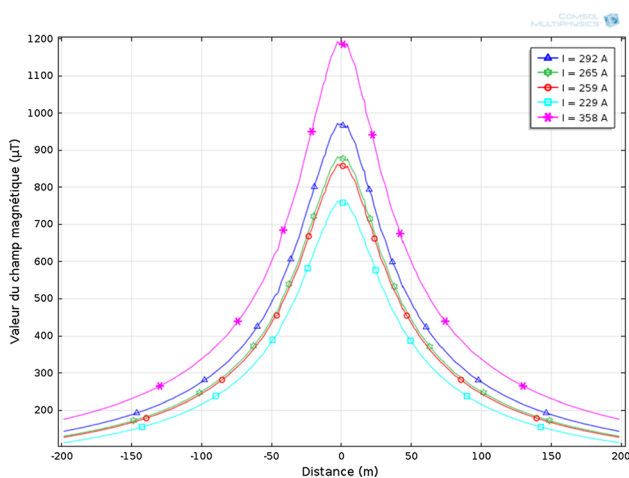


Fig. 11 Magnetic induction with conductor section $S=570 \text{ mm}^2$ for 220 kV vertical single circuit line

different conductor sections. It is observed that the magnetic induction generated by 220 kV line with twin bundle conductors per phase $2 \times 570 \text{ mm}^2$ is lower than the one generated by 220 kV single circuit line with one conductor per phase of conductor Sect. 570 mm^2 . This is due to the current density J that changes with conductor section variation and constant value of current loading. So, current density decreases with bigger section of conductors. It is clearly observed for 220 kV line that the values of magnetic induction for twin bundle conductors per phase slightly exceed $200 \mu\text{T}$ limit exposure given by ICNIRP for the very large

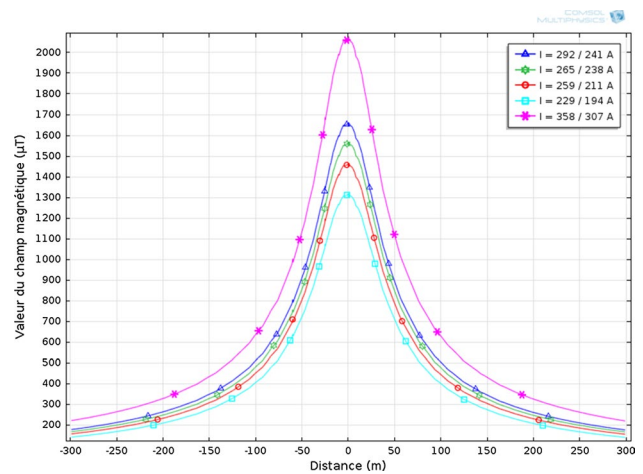


Fig. 12 Magnetic induction with conductor section $S=2 \times 577 \text{ mm}^2$ for 220 kV vertical single circuit line

Table 2 Magnetic induction for different conductor sections and various load current for 220 kV single circuit

Sections of conductors S (mm^2)	Load current I (A)	Magnetic induction B (μT)
2×570	229	131.41
	259	148.62
	265	152.06
	292	167.56
	358	205.44
570	229	761.43
	259	861.18
	265	881.12
	292	970.91
	358	1190.00

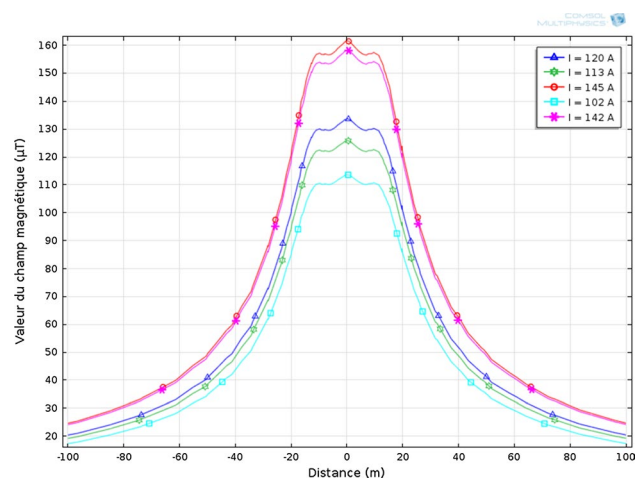


Fig. 13 Magnetic induction for 400 kV single circuit line 11.50 m height between ground and conductor Ras Djenet-El Affroun

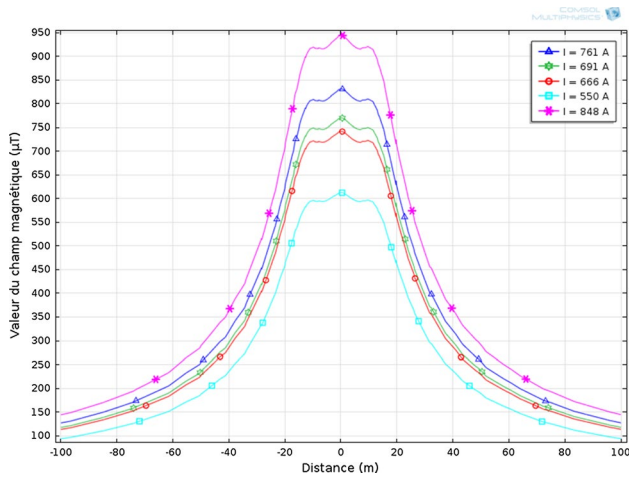


Fig. 14 Magnetic induction for 400 kV single circuit line 11.50 m height between ground and conductor Ras Djenet—Si Mustapha

Table 3 Magnetic induction for different levels of load current and 11.50 m height between ground and 400 kV line Ras Djenet—El Affroun

Load current I (A)	Magnetic induction calculated B (μT)	Magnetic induction measured B (μT)
102	113.58	115.50
113	125.82	128.12
120	133.62	135.62
142	158.11	159.95
145	161.46	163.26

Table 4 Magnetic induction for different levels of load current and 11.50 m height between ground and 400 kV line Ras Djenet—Si Mustapha

Load current I (A)	Magnetic induction calculated B (μT)	Magnetic induction measured B (μT)
550	612.21	614.13
666	741.35	743.65
691	769.17	771.17
746	830.22	832.06
848	943.94	945.74

value of current and it is largest exceed for single circuit line with one conductor per phase [11].

6.3 Magnetic induction at 2 m above the ground for various current loading for 400 kV single circuit Ras Djenet—El Affroun and Ras Djenet—Si Mustapha

The magnetic induction variations presented in Figs. 13 and 14 exhibit high values for increasing load currents.

Table 5 Magnetic induction for different levels of load current and 50 m height between ground and 400 kV line Ras Djenet—El Affroun

Load current I (A)	Magnetic induction calculated B (μT)	Magnetic induction measured B (μT)
102	34.84	35.99
113	38.59	39.70
120	40.98	42.16
142	48.50	50.04
145	49.52	50.70

Table 6 Magnetic induction for different levels of load current and 50 m height between ground and 400 kV line Ras Djenet—Si Mustapha

Load current I (A)	Magnetic induction calculated B (μT)	Magnetic induction measured (μT)
550	187.84	188.61
666	227.46	228.57
691	236.00	237.18
746	254.78	256.32
848	289.61	290.79

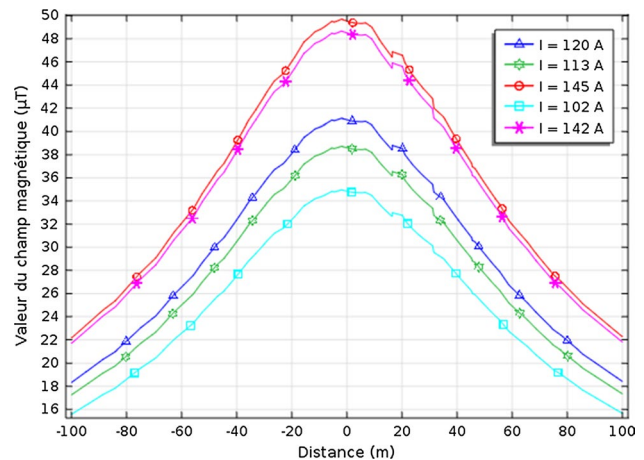


Fig. 15 Magnetic induction for 400 kV single circuit line 50 m height between ground and conductor Ras Djenet—El Affroun

Also, Tables 3 and 4 show clearly that the safety limit of 200 μT is not exceeded for Ras Djenet—El Affroun line. But, for Ras Djenet—Si Mustapha line which is an evacuate power plant line the safety limit is largely exceeded for 11.50 m height between ground and conductor. Fortunately, this type of tower cross agricultural and hill areas, so population is not exposed to such fields. However, according to Table 5, the values of magnetic induction

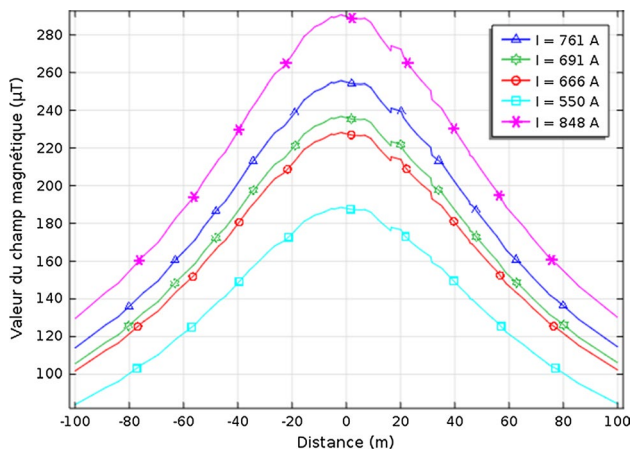


Fig. 16 Magnetic induction for 400 kV single circuit line 50 m height between ground and conductor Ras Djenet—Si Mustapha

B are lower even than safety limit value 200 μT given by ICNIRP, Table 6 shows clearly that the safety limit of 200 μT is also exceeded for various load currents when the line to ground distance is 50 m, especially for high currents reaching 848 A. More the line is close to the ground, more is the magnetic flux density, because magnetic field decreases as one goes away from the source of its creation, which is the circulating current in the conductor (Figs. 15, 16).

7 Conclusion

This work allowed us to obtain the values of the magnetic fields induced by the different power transmission lines in Algerian Grid. Several cases were used in such validation and the obtained results were compared with those measured by using C. A 40 Gaussmeter. They are found in good agreement.

So at normal operating conditions, the magnetic field density varies with the distance from the center phase for different percentage of current flow and conductor's sections. Also, the decrease in the load capacity decreases the magnetic field density. The ground level magnetic field density has its maximum value when the clearance between the conductors and the ground level has its minimum value. But directly under tower height, the ground level magnetic field density has its minimum value due to the maximum clearance between the conductors and the ground level.

Also, we can conclude that for very large currents it is better to use more bundled conductors per each phase and for less currents it is more economical to install lines with only one conductor per phase.

The magnetic field induced values vary at different times of the day depending on the transit on the lines considered according to the daily load curve of Algerian national grid.

Finally, for people standing under power transmission lines, the safety limits for magnetic field depends on the tower silhouette, height, spacing of the overhead conductors, the number and nature of conductor and load current values, which in turn varies at different times of the same day.

From the results it is noticeable that with choice and selecting the appropriate section and adequate number of conductors and the line configuration combined with increase of the height of the towers will allow a significant reduction of the magnetic field. In this regard steps must be taken by Algerian National Power Transmission Company before the construction of new transmissions lines in order to keep the magnetic field within the limits permitted.

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