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Study and measurement of magnetic emission generated by underground 400kV power cables

***Abstract**. Over the past few years, the use of very high-voltage underground electrical cables has gradually increased for the transmission of electricity in densely populated areas. This article presents a two-dimensional simulation based on the magnetostatic formulation to assess the magnetic field generated by a 400 kV underground high-voltage cable using the finite element method. An experimental study is conducted to evaluate magnetic pollution according to position and 2D coordinates for a variable load. The novelty lies in conducting this study in two scenarios: underground in the duct and the second case at the tunnel exit or aerial. In general, both the numerical simulation results and experimental findings are compared to demonstrate the efficiency of our model. The comparison of the two results shows a strong resemblance; they are very close with minimal errors, which ensures the validity of the adopted method.*

***Streszczenie.** W ciągu ostatnich kilku lat stopniowo wzrosło wykorzystanie podziemnych kabli elektrycznych bardzo wysokiego napięcia do przesyłu energii elektrycznej na obszarach gęsto zaludnionych. W artykule przedstawiono dwuwymiarową symulację opartą na sformułowaniu magnetostatycznym, mającą na celu ocenę pola magnetycznego generowanego przez podziemny kabel wysokiego napięcia 400 kV metodą elementów skończonych. Przeprowadzono badanie eksperymentalne w celu oceny zanieczyszczenia magnetycznego na podstawie położenia i współrzędnych 2D dla zmiennego obciążenia. Nowością jest przeprowadzenie badań w dwóch scenariuszach: pod ziemią w kanale oraz w drugim przypadku na wyjściu z tunelu lub w powietrzu. Ogólnie rzecz biorąc, porównuje się zarówno wyniki symulacji numerycznych, jak i ustalenia eksperymentalne, aby wykazać skuteczność naszego modelu. Porównanie obu wyników wykazuje duże podobieństwo; są one bardzo zbliżone przy minimalnych błędach, co gwarantuje słuszność przyjętej metody. (**Badanie i pomiar emisji magnetycznej generowanej przez podziemne kable elektroenergetyczne 400kV**)*

Keywords: Power Cable, Finite Element Method, Underground Line, Magnetic Field, Comsol, Teslameter.
Słowa kluczowe: : Kabel zasilający, Metoda elementów skończonych, Linia metra, Pole magnetyczne, Comsol, Teslametr.

1.Introduction

The demand for electrical energy worldwide is rapidly increasing due to industrial and technological development and the growth in the world's population [1,2]. Transportation and distribution of energy pose significant challenges in the electrical grid [1,3]. Effective management and control of electrical installations play a crucial role in ensuring continuity, electricity quality, and sustainable economic growth [1,3].

The expansion of the electrical grid through the extension of substations and electrical transmission and distribution lines, such as aerial, underground, and submarine power lines with Very High Voltage (VHV) levels, is essential [4,5].

The transportation of energy through Very High-Voltage underground electrical cables in specific areas such as substations and power plants can potentially lead to electromagnetic interference with electrical devices, control and electrical measurement cables, or maintenance personnel [1-3].

In recent years, several research studies have investigated electromagnetic pollution generated by underground cables, focusing primarily on simulation, experimental testing, and measurements on both humans and equipment [1,6,7,8].

In this context, several studies have been carried out to assessment the potential hazards and the impact of electric and magnetic fields generated by VHV electrical networks have led to numerous research efforts aimed at demonstrating their harmful effects on the environment, human health, and sensitive equipment [1,9,10].

Many research projects aim to accurately assess the levels of these radiated and induced fields in pipelines and explore technical solutions for minimizing electromagnetic pollution through passive, active, or hybrid shielding [1,9].

The limits and restrictions on exposure to electromagnetic fields (based on numerous experimental studies and scientific data) have been established by several international commissions to protect both professionals and the general public in general terms [11-13].

Underground 400kV electrical cables are a source of magnetic fields due to the very high current passing through them. In this regard, the purpose of this article is to assess magnetic fields, which will be done through two methods: firstly, simulation, and secondly, experimental tests.

In this article, the study of the 400kV underground cable is conducted in two scenarios: the first within the duct and the second outside the duct (aerial). These scenarios are analyzed to estimate the level of magnetic induction in both cases.

In this study, the development of a mathematical model is necessary to simulate all the cables in the aforementioned scenarios with different conditions.

Generally, numerical simulation is a powerful, efficient, and highly accurate tool. Therefore, we will conduct a finite element analysis. This analysis aims to demonstrate and calculate the magnetic distribution and pollution as a function of distance and current load. Simultaneously, the development of this study involves conducting on-site experimental tests to obtain precise data at various locations near the underground electrical cable. This will be achieved using a Teslameter with a magnetic probe. Finally, the experimental results and those obtained from simulation will be compared to demonstrate the reliability and compliance of both methods used."

The study and experimental measurements were conducted in Sonelgaz company, more precisely at GRTE - SPA 220/400 KV substation in Hassi Messaoud power plant, Ouargla Algeria. The underground electrical cables of 400 kV are located between the electrical transformers that ensure simultaneous conversion between 220 kV and 400 kV, and between 400 kV and 220 kV. The measurements of the electrical currents in the underground cables are provided by the control room located in the substation.

2. Presentation of Underground Transmission Cables

The underground VHV electrical cable of 400 kV is characterized by a structure and geometry represented in the figure 1. Table 1 show the geometric dimensions and shape of the 400 kV cable. Table .2 represents the electrical properties of the materials used in the 400 kV underground cable that we have studied.

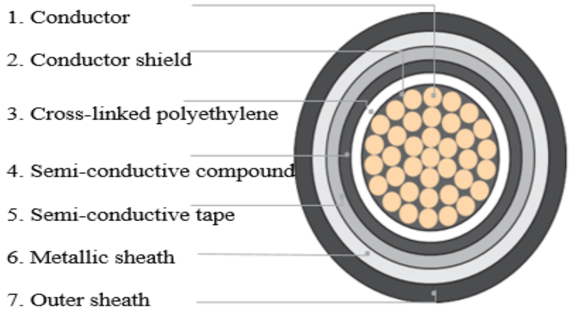


Fig .1. The shape of the underground VHV (400 KV) ILJIN brand electrical cable [14].

Table 1. Geometrical characteristics of the underground VHV (400 KV) electrical cable [14,15].

Parameter and Cable Size	Values
Conductor Section	800mm2
Conductor Diameter	34.3 mm
Conductor Screen Thickness	2.0 mm
Insulation Thickness	30.0 mm
Insulation Screen Thickness	1.5 mm
Metallic Sheath Thickness	1.8 mm
Outer Sheath Thickness	6.0 mm
Cable Outer Diameter	124 mm
Rated Current in Aerial Case	1099 A
Rated Current in Underground Case	836 A

Table 2. Characteristics of the materials of the 400 kV VHV Underground Cables [15,16].

Materials	Conductivity	Relative Permittivity
Air	10^{-14}	1
Soil	1	28
Polyethylene	10^{-18}	2.25
Cross-linked Polyethylene (XLPE)	10^{-18}	2.5
Semi conductive compound	2	2.25
Semiconductor tapes	2	2.25
Smooth aluminum	3.53810^{7}	2.2
Copper	5.99810^{7}	1

3. Geometric Characteristics of Electrical Lines:

The horizontal distance between the three underground phases at the exit of the tunnel is approximately 5m, but for underground case it's around 0.5m (table 3).

Table 3. Distances of burial and aerial Underground Cables.

Underground Distance		Aerial Distance
H(mm)	D(mm)	D (mm)
1000	500	5000

Underground electrical lines are characterized by distances between each phase according to international standards. Table.3 shows the geometric shapes of the electrical line.

Figure .2 represents the geometric characteristics of the electrical lines, where D represents the horizontal distance between the cables, and H represents the depth of the cables in the ground.

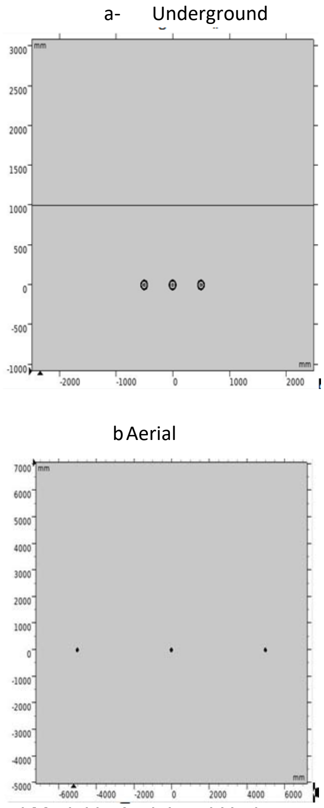


Fig .2. Dimensional Model in Aerial and Underground Cases.

Underground electrical lines are characterized by distances between each phase according to international standards. Table.3 shows the geometric shapes of the electrical line.

Figure .2 represents the geometric characteristics of the electrical lines, where D represents the horizontal distance between the cables, and H represents the depth of the cables in the ground.

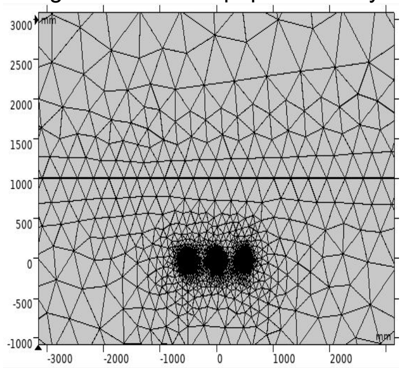
3.2 Mesh of underground 400Kv threes phases electric cables:

In this stage, the cable's geometry and the model's representation in a graphical interface (the study area is illustrated in Figure .3) using numeric software for the 2D underground cable model under consideration [17,18].

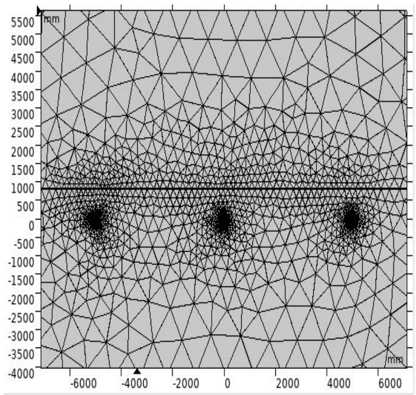
Electromagnetic model and simulation of underground electrical cables: Magnetostatic model. This model is characterized by non-zero electric currents. We then have the equation [18,19]:

$$\text{rot}\left(\frac{1}{u}\text{rot}\left(\vec{A}\right)\right) = \vec{J} + \text{rot}\left(\frac{1}{u}\,\text{Br}\right)) \quad (1)$$

where, J: is the surface current density A: vector magnetic potential Br: magnetic induction μ: permeability.



a- Underground



b- Aerial

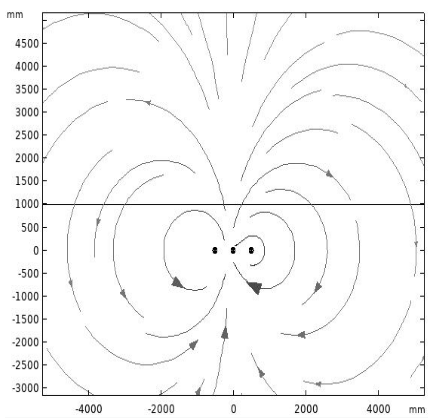
Fig .3. Meshing of VHV underground electrical cables in aerial and underground cases.

This step displays the geometry of the cable and the representation of the model in a graphical interface (the study domain can be seen), using the finite element analysis in two cases underground and aerial.

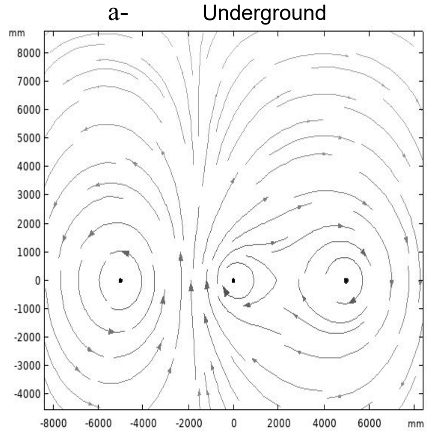
4. Simulation results of VHV Underground 400 kV three phase cables

4.1 Results of magnetic field simulations:

For this section, we used the magneto-static module to model magnetic phenomena and calculate the magnetic field generated near transmission lines.



a- Underground



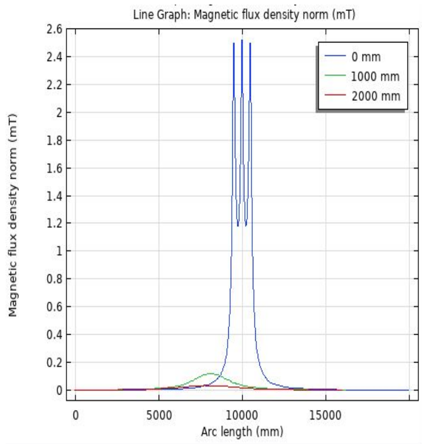
b- Aerial

Fig .4. The distribution of the magnetic field in underground and aerial VHV electrical cables.

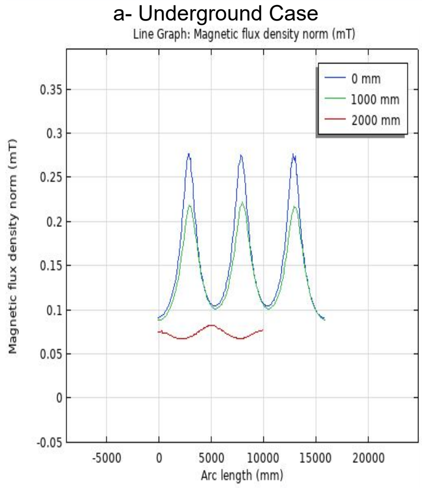
Based on the results in Figure .4, it can be observed that the distribution of the field is significant due to the high current intensity flowing through the three cables of each line. The magnetic field lines emerge from the ground into the air. There are always electromagnetic interactions between the electrical lines, both inductive and capacitive effects, which are represented by the field lines between the phases.

4.2 Measurement of the Magnetic Field Near Underground Electrical Lines:

The simulation results show the horizontal and vertical distribution (along both the x and y axes) of magnetic flux density at various levels above the underground electrical lines, as seen in Figures 5-a and 5-b. Measurements along the x-axis are taken relative to the cables' position as the zero reference point. We conducted a simulation of the cable in both the air and underground, under regular conditions, while varying the current intensity flowing through the electrical cable. The three curves represent the magnetic field value on the cables, then at a distance of 1 meter, and finally at a distance of 2 meters. See the following figures 5:



a- Underground Case



b- Aerial case

Fig .5. Magnetic Flux Density in the vicinity of and around underground electrical cables in the underground case. (Value of current 900A.)

Through the simulation results in figures 5-a and .5-b, which depict the value and shape of the magnetic field in terms of distances, it can be observed that in all the results, the magnetic field increases near the three electrical cables, specifically on the cable itself. This magnetic field is weaker and less significant as one moves away from the three electrical cables. Additionally, it is noted that the magnetic field is related to the electric current intensity.

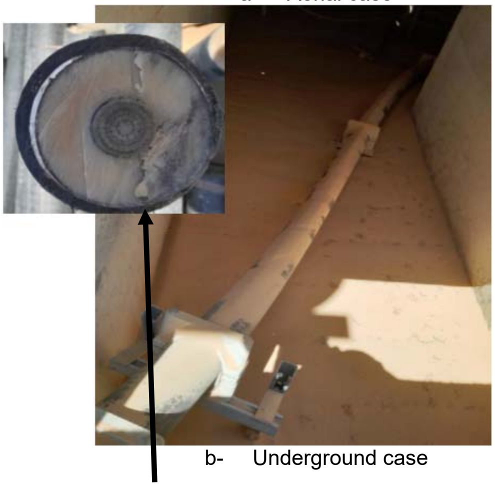
By analyzing the magnetic field results for underground cables in both aerial and underground scenarios with the same current intensity value, it is observed that the magnetic field in the aerial case is lower than in the underground case in the extremity (0m). But in 2 meter the magnetic induction is important in aerial case than underground case.

The maximum current intensity value supported in these cables is 1099 A when in the aerial case and 836 A when underground.

5. Experimental measurements in a gas power plant Study of in two cases:

The photo represents a 400 kV cable in cross-section, as it consists of: Underground position and aerial position (at the tunnel exit) of 400 kV Cable Section, ILJIN Quality.

a- Aerial case



b- Underground case

Fig .6. Measurement of the magnetic field of a 400 kV underground cable using a Tesla meter.

The figures 6. describe the installation of an underground cable at the opening (Exit) of a tunnel, which has a depth of 1.2 meters. The cable is secured in a way that it does not come into contact with the ground. The tunnel has a length of 1.62 meters and a width of 1.46 meters. Using a Tesla meter, we assessed the magnetic field of the underground cable based on variations in the electrical current The results of this measurement were recorded on the device's screen and expressed in mT units. The electrical current variation over 24 hours in Group 03, we obtained them from the substation administrator controller. These current results will be used in the step as a measurement reference for comparison and simulation using numeric method.

In this case, we measured the magnetic field using a Tesla Meter at different times and positions in aerial case in the exit of tunnel. We will focus more on the aerial case because:

- The underground case is distant and located far from the substation (buried).
- The aerial cable is at the tunnel exit.
- A significant magnetic field will be directly and closely exposed.
- The distance between the cable and maintenance personnel or equipment, as well as control and measurement cables, is short.
- The measurements for the underground cable (buried) are less significant compared to the aerial case.

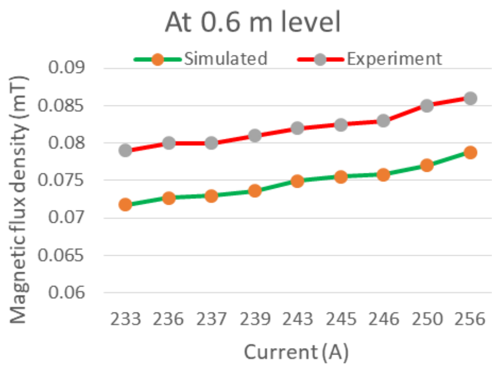
The results obtained are presented in the following, Table 4:

Table 4. Experiment results of the magnetic field at different times and positions.

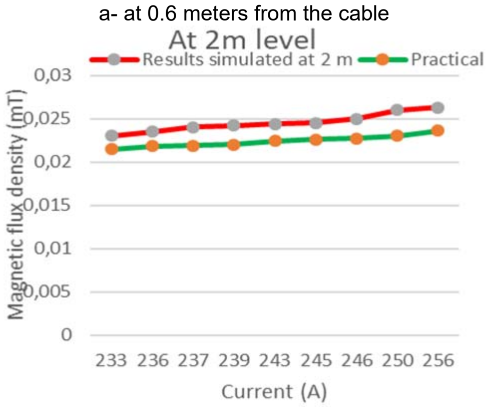
GROUPE (03)			Magnetic flux density (mT)	
Times (H)	Current (A)	0.6 m	1 m	2 m
09H00	256.63	0.086	0.07	0.0263
09H30	239.55	0.081	0.063	0.0242
10H00	233.21	0.079	0.06	0.023
10H30	236.47	0.080	0.0615	0.0235
11H00	246.83	0.083	0.068	0.0245
12H00	250.75	0.085	0.069	0.026
13H00	237.74	0.08	0.062	0.024
14H00	243.38	0.082	0.066	0.0244
15H00	245.5	0.0825	0.0675	0.0245

The table .4. represents measurements of the magnetic field in terms of changes in current intensity at different moments, using a tesla meter. Through the obtained results, it can be observed that the magnetic field increases as one approaches the cable and also increases as the current intensity increases.

5.1 Comparison of simulated and experiment magnetic field measurements:



a- at 0.6 meters from the cable



b- at 2 meters from the cable

Fig .7. Comparison of experimental and simulation results magnetic flux density.

The figures 7-a and 7-b illustrate the variations in the magnetic field obtained from experimental results and simulation, in terms of changes in current intensity at a distance of 2 meters as well as at the cable level. We can observe that the results in both cases are very similar. Furthermore, we notice that in both situations, the results are in compliance with international standards governing acceptable values of the magnetic field (near the limit of 100µT in 1 and 2 meter) but high of limit near and around the underground power cable. This confirms the reliability of the simulation and its ability to accurately predict the magnetic characteristics of the system at 1 and 2 meters. However, these amplitudes can create interferences or inaccurate measurements, especially in the circuits and control cables or sensors.

6. Conclusion:

In this paper, the first part content the computation of magnetic field of VHV underground electrical transmission cables of 400 kV at a frequency of 50 Hz using the finite element analysis software. The study was implemented in two different cases: the first case underground cable (tunnel) and the second case in the aerial position (the exit of underground tunnel) with different horizontal position. From results we can conclude that the magnetic field intensities change according to the electric current transmission intensity, vertical distance from cable and aerial and underground positions. The magnetic field is more significant in an aerial case compared to an underground case because it is directly exposed to the open air, making it potentially hazardous. The experiment results confirm the simulation results values of magnetic flux density with great agreement and fit. Finally, the results can be used to predict the magnetic pollution of underground cable at different positions in the environment.

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