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A NEW EXPERIMENTAL STUDY OF MAGNETIC FIELD CONFIGURATION IN THE VICINITY OF THE MEDIUM-VOLTAGE ELECTRIC LINES

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Abstract

The limit of the magnetic field produced by the distribution power lines is calculated and measured in an urban area, and consideration of risk perception on the environment, recommends several analysis of this field. In this paper, the level of magnetic field is presented for three configurations of the medium-voltage electric lines (30 kV). The proposed computational method is based on the symmetrical configuration of these lines, applied to the three current-carrying conductor's vectors. This approach leads to a simple formula involving the distance *Ri* from the conductor to the point of interest P in space. This theoretical and experimental study takes on consideration the real situations and was done at a 50 m as maximum distance from the tower at the height of 1m , 5m and 9m respectively from the ground. The measured and simulated results of magnetic field were assessed to verify the recommended limits and the possible hazard from exposure of the magnetic field configurations on the environment.

Keywords: Magnetic field, Electric field, Electric power distribution, High-and medium-voltage power lines, Biot-Savart law.

1. Introduction

The problems of distribution line and its associated equipments, has been known for well over 40 years. However, these lines produce the magnetic field which is likely to have dangerous effects on their environment, when the level exceeds indicated limits [1-3]. The problem has gained widespread recognition only in the last 10 years due to improvements in environments and the increased tendency to locate solutions in order to decrease this field near medium-voltage electric lines.

Nomenclatures

B_i	The magnetic flux density, µT
Ci	Conductor i (Fig. 2).
d	distance between two phase conductors (Fig. 2), m
hm	The height between the ground and the measuring point p, m
hp $\bar{I}_i$	The height between the conductor and the measuring point p, m
Mi	Current, A
Ri	Measuring situation. The normalized distance from the conductor to the point of Interest P (Fig. 1), m
xm	Measuring point (Fig. 1), m

Greek Symbols

μ_0	Permeability, H/m

Abbreviations

EHV	Extra-High-Voltage
ELF	Extremely Low Frequency
FFT	Fast Fourier Transform
RMS	Root Mean Square
STEG	Society of Electricity and Gaz of Tunisia
UHV	Ultra-High-Voltage

Several studies have been developed and made by many contributors in order to establish a formula of the magnetic fields produced by the power lines and on their environment. To establish this relationship, many works of literature have defined and analyzed the source by theoretical and experimental calculation of this field near to the power line [1-20].

This one, these sources, it is produced by electric power line such as the single circuit lines (in flat, vertical, or delta configurations), as well as for another considered such as double circuit lines as given in [4]. The calculation of the magnetic field in the vicinity of distribution and transmission lines is presented by [4-5]. Several hypothetical cases have been developed. It results from it a theoretical formulation which shows its dependencies on the various parameters of the line configurations. The derived expression is valid at any point close to or far from the line. In [6], the artificial tower displacements are modelled and the analysis of the magnetic field distribution is conducted. The effect of the tower displacement, on the magnetic field distribution is extensively studied. In [7] and [8], a simple formula for the analytic calculation of the produced magnetic fields “near and far from the line” was presented. This field produced by these lines at relatively large distances in comparison to their phase spacing was analyzed.

The basic principles of transmission and distribution line magnetic field generation are addressed in order to enhance understanding when designing for low fields, in [9]. These theoretical studies are supported by several experimental works. Misakian in [10] gives a survey of the standards and the measurement methods that can be used to characterize the magnetic field near the medium-voltage lines and the associated equipments.

The results of measurements were carried out, in [11], to determine the levels of electric and magnetic field in various environments (substations, power transmission lines, power cables) associated with residential and occupational exposure. In [12], the electric and magnetic fields with a frequency of 50 Hz, caused by the operation of indoor power distribution substations, are examined.

The International Commission on Non-Ionizing Radiation Protection presented several study results of research for safe general public and occupational exposure. The result of the electric and magnetic-field measurements in indoor power distribution substations of all the standardized nominal power ratings is discussed. In [13], the analyses of the magnetic fields measured in the vicinity of separate overhead distribution lines are summarized. The results and data obtained, and the correlation between the magnetic field and the phase currents at various distances from the line are presented. In [14], the effects of the multi-conductor transmission line in the Magnetic Field distribution are given. The experiments take in consideration the real situations of the power line equipments. To investigate these effects under and around these lines, experimental measurements have been done and the results show the effect of tower configuration in the characteristic of the electromagnetic fields at different distances from the power line. In [15], a simple model is developed to estimate the value of the extremely low frequency magnetic field of the overhead power line. The model is based on the Biot-Savart law, considering the actual geometry and the conductor mutual position as well as their centenary shape. The accuracy of the model is verified by measuring the magnetic field of the overhead power line, it is shown that the influence of the catenary on the sag maxima location can be neglected.

The perturbation source is analyzed by these theoretical and experimental studies. Several contributions are supported by these works to determinate the effects of this source on their environment.

Nowadays, with increasing rate of power consumption, extremely low frequency magnetic fields from power distribution lines known as "electromagnetic pollution" is increasing [16], different studies have been carried out to determine the ELF-magnetic field flux densities in urban areas and others have been focused on inhabitants in close vicinity to overhead power lines. With the advent of EHV transmission lines and the almost certain possibility of UHV lines, it becomes increasingly important to describe accurately the transmission line electromagnetic field interaction with life forms. This paper [17], develops a numerical method for predicting current and normal electric field distributions induced on humans situated in the near vicinity of lines.

The international organizations have proposed by laws that put limits value for the generated magnetic field by the electric power line on the environments. The relationship between magnetic fields and the health of people is increasingly studied. In this work [18], the measures of the magnetic field created by electrical high voltage lines are presented, the degree of compliance with European regulation are analyzed. The simulation result of these fields generated by these lines is similar to the measured values. For simulating the behaviour of the lines under given conditions one simple model is used, and an FFT analysis of the magnetic field waveform was performed to study the amplitude and frequency of the induced currents. In [19], an experimental characterization of electromagnetic environment near of electric substation is presented. Within a very highly populated area, the method applied in this case is progressive; it can initially study the behaviour of the magnetic field produced by these lines and these different couplings between its equipments that will be used later as a source of disturbance. However, most researchers did not study the correlation of the magnetic fields for several scenarios, and different designs of distribution lines at the same time, which will be used later as a source of disturbance in a very high populated zone. To overcome this limitation, we developed different configuration models, in order to determine the limit possible hazard from exposure of the field on the environment. In our theoretical and experimental study, which is intended to study the limit and the level of magnetic field generated by medium-voltage lines in our immediate electrical network the society of electricity and gaz of tunisia (STEG) , has elaborated these electromagnetic fields in the vicinity of these lines (30 kV).

The organization of this paper is, in Section 2, a computational model of the magnetic field configuration of the medium-voltage electric lines is given. In Section 3, the theoretical and experimental results of this field are presented; Section 4 summarizes all the results of this study by giving some recommendations for further research.

2. Computational Models for Lines

The various methods presented in the literature for the calculation of the magnetic field in the vicinity of the power line often require different models to determine the possible hazard of exposure of this field to the environment.

To verify the limits recommended of this field, we have used different configurations of power line model 30 kV.

2.1. Magnetic field formulation

The magnetic flux density B_i created by various configurations in the conductor i is given by the Biot-Savart's law (Fig. 1).

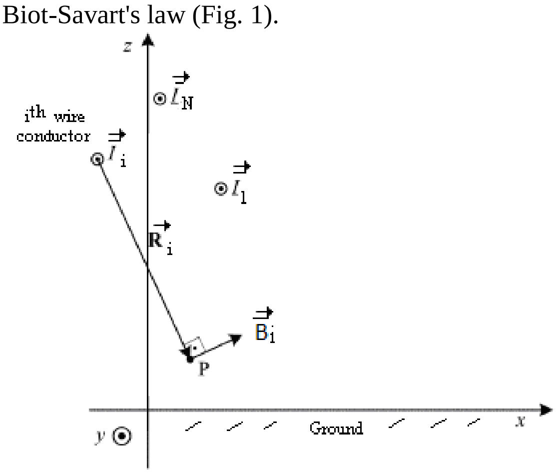

Fig. 1. Transverse section of the power line model.

The magnetic field, produced by different conductors *i* (*i*=1,2 and 3) carrying current $\bar{I}_i$, is represented in the general case using the superposition theorem [4,7,19];

$$\vec{\bar{B}}_i = \mu_0 \sum_{i=1}^{3} \frac{\vec{\bar{I}}_i \times \vec{R}_i}{2\pi R_i^2} \quad (1)$$

where the vector $\vec{\bar{I}}_i = \bar{I}_i \vec{e}_y$ denotes the current phasor $\vec{\bar{I}}_i$ and $\vec{e}_y$ is the unit vector in the direction of y axis, $\vec{R}_i$ is the vector distance from the conductor to the point of interest P, and the symbol $\times$ denotes the cross product of the vectors $\vec{e}_y$ with $\vec{R}_i$.

Figures 2 to 4 present three towers of the power line with different real dimensions; and in order to simulate and measure the total magnetic field *B*, we considered a vector superposition of the fields created from the different single straight currents.

In this paper, we have proposed three configurations of the distribution power line 30 kV, vertical power line, flat power line and delta power line. This different geometry is given to model the magnetic fields produced by these lines. The normalized distance from the conductor to the point of interest P is usually characterized by its resultant value *Ri*.

2.2. Configuration of the models

Figures 2-4 show, respectively, a vertical, flat and delta power line configuration. These lines consist of three distances from the conductor to the point of interest P. we can write *Ri* for each configuration as follows:

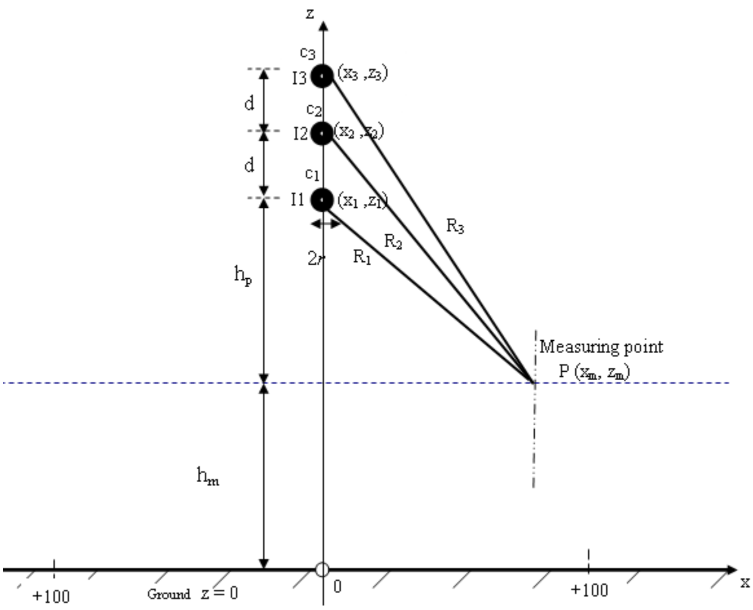

Fig. 2. Traverse section of a vertical power line.

The general expression term of the magnetic field, is usually characterized by its resultant value B, and was presented by [4].

Considering a three-phase system with straight parallel conductors of infinite length (see Fig. 2), the resulting distance from the conductor to the point of interest P can be expressed as:

$$R_1^2 = x_m^2 + h_p{}^2$$
$$R_2^2 = x_m^2 + (h_p + d)^2 \quad (2)$$
$$R_3^2 = x_m^2 + (h_p + 2d)^2$$

In this paper a different approach is adopted, based on the application of the symmetrical components method to the geometrical vectors *Ri*, considered as a triplet:

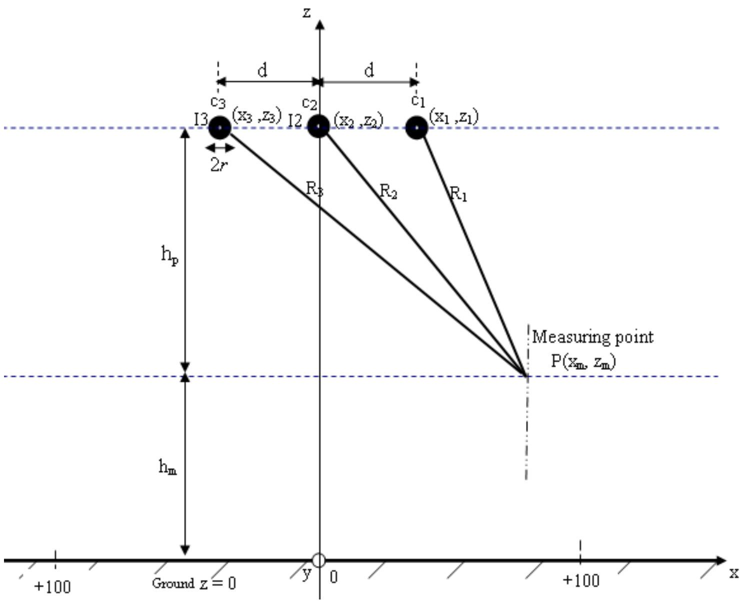

Fig. 3. Traverse section of a flat power line

With distribution line present in Fig. 3, the geometrical vectors distance can be represented as

$$R_1^2 = (x_m - d)^2 + h_p{}^2$$
$$R_2^2 = x_m^2 + h_p{}^2 \quad (3)$$
$$R_3^2 = (x_m + d)^2 + h_p{}^2$$

In (3) the distance *R1*, *R2*, and *R3* represent the zero, the positive, and the negative symmetrical sequence components of the geometrical vectors *Ri*.

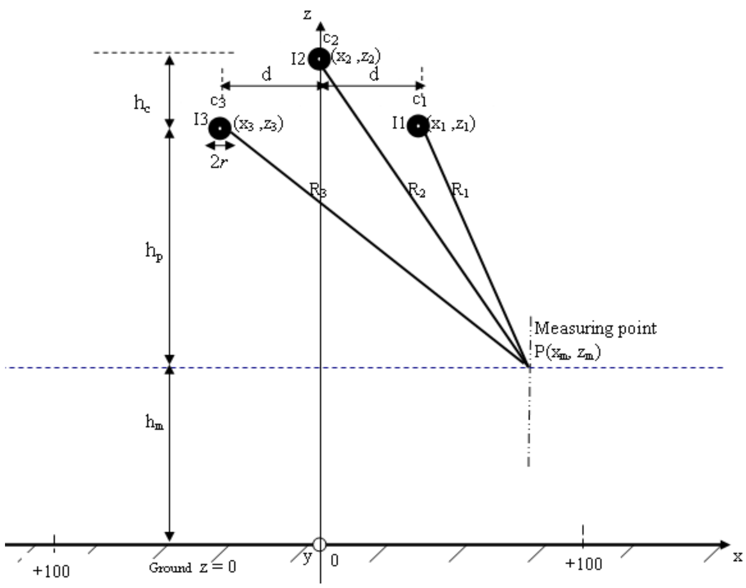

Fig. 4. Traverse section of a delta power line.

The distance from the conductor to the point of interest P presented in the Fig. 4 can be expressed by

$$R_1^2 = (x_m - d)^2 + {h_p}^2$$
$$R_2^2 = x_m^2 + (h_p + h_c)^2 \quad (4)$$
$$R_3^2 = (x_m + d)^2 + {h_p}^2$$

The RMS spacing d between the phase conductors is defined as

$$d = \sqrt{\frac{d_{12}^2 + d_{13}^2 + d_{23}^2}{3}} \quad (5)$$

By introducing Eq. (5) in Eqs. (3) and (4), we found the resultant value of the magnetic field *B*, for three distribution line 30 kV.

Using these equations, the simulation process of this field can be calculated more accurately with the Biot-Savart method because the magnetic concept is more important when we consider the measuring points near away from the line.

3. Results and Discussion

The theoretical results of the magnetic field were made under Matlab environment, using the Biot-Savart law, Eq. (1).

The distribution line parameters of the “vertical”, symmetrical “delta” and “flat” line configurations are considered, having the same RMS wire spacings *dij* = 1m (Figs. 2 to 4, respectively). The corresponding line heights are given, having the *hp*+*hm*=10 m and *hc*=1 m respectively.

The comparison is made between the results obtained by the traditional approach, i.e., assuming the current carrying power line conductors as straight parallel horizontal wires and calculating the magnetic field by Eq. (1), and the proposed approach, i.e., the approximated RMS field is given by introducing the Eqs. (2), (3), (4) into Eq. (1).

3.1. Simulation results

The simulation results present the distribution of the magnetic field around three configuration towers of the medium-voltage electric lines (30 kV) according to the distance *xm.*

Figures 5-7 show the variation of magnetic fields for different height relative to the ground, and when we see in near to the tower, there is a significant difference in the flat configuration which reaches a maximum value and the vertical configuration reaches a minimum value. Indeed, this remarkable difference in Fig. 7, when it is near to the tower. But, there is no difference between the configurations far to the tower when compared to power line, and level of this field converges for all settings to the same point.

3.2. Measurement results

Measurements of magnetic field were obtained by the measuring apparatus «HI-3604 ELF Field Strength Measurement System» associated with 50/60Hz power lines, and made at various hours for the three considered geometrical configurations from Figs. 2 to 4.

The direction (-xOx) was used to measure the magnetic field; and we took measurements in three different situations; the first measured situation (*M1*) is around the first tower which is in the proximity of the power station, the second measured situation (*M2*) is around the second tower, and the third measured situation (*M3*) is between $(N-1)^{th}$ and N^{th} tower of the line.

The magnetic field dependency with the distance is shown in Fig. 8 to Fig.10 respectively, for three scenarios which are: scenario 1 to scenario 3 for the power line 30 kV.

In Figure 8, we see that the level of the field of delta configuration is more important compared to other configurations. Indeed, the measurement result is not similar to the simulation result due to the influence of the power station of the line 30 kV, which can affect the calculated fields, and produces a resultant magnetic intensity generated by the power transformer and line.

The vertical configuration always reaches a minimum intensity of the magnetic field. The theoretical calculation based on the Biot-Savart law is made for power lines infinement long, and it does not correspond to scenario *M1*.

In Figs. 9 and 10, when we are near from the flat line configuration, the intensity reaches a maximum magnetic field, the measurement result and was similar to the simulation result.

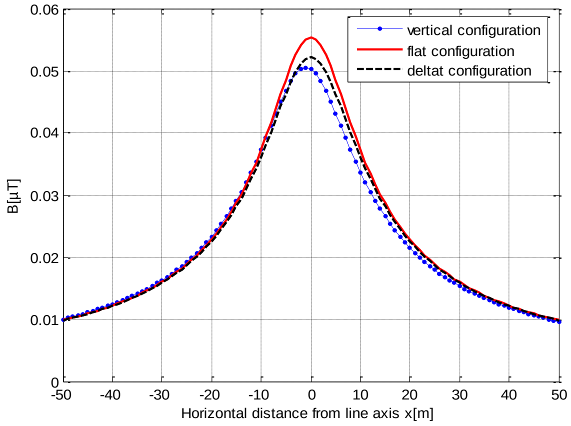

Fig. 5. Comparison of the magnetic field intensity generated by different distribution power lines at the height of 1m from the ground.

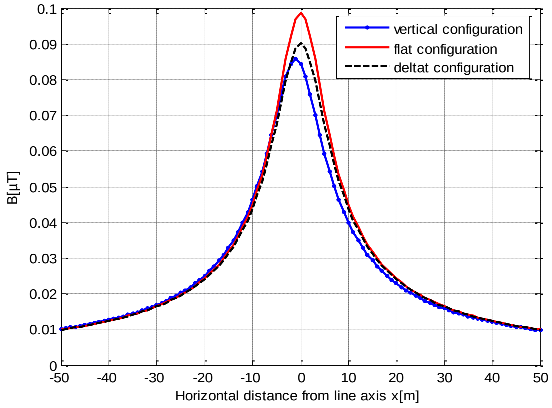

Fig. 6. Comparison of the magnetic field intensity generated by different distribution power lines at the height of 5m from the ground.

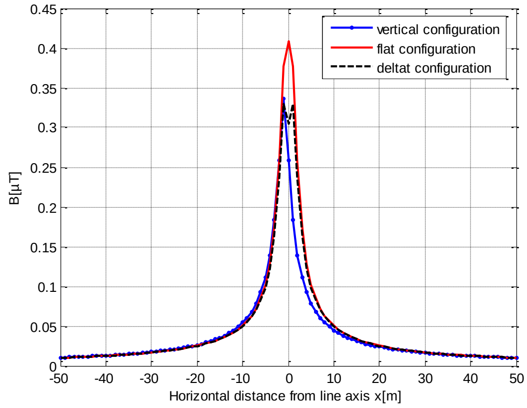

Fig. 7. Comparison of the magnetic field intensity generated by different distribution power lines at the height of 9m from the ground.

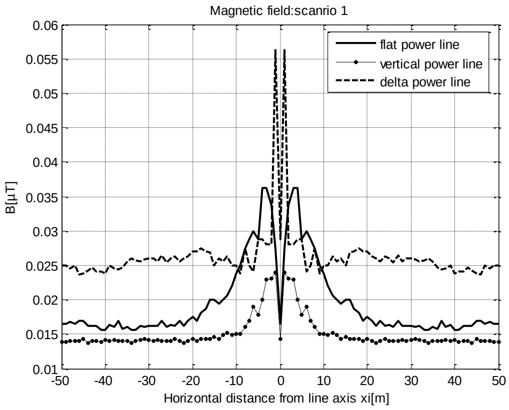

Fig.8. The distribution of the magnetic field intensity generated by a single distribution power line at the measuring situation *M1*.

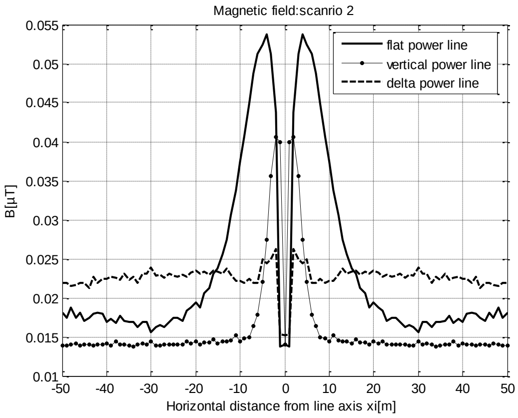

Fig. 9. The distribution of the magnetic field intensity generated by a single distribution power line at the measuring situation *M2*.

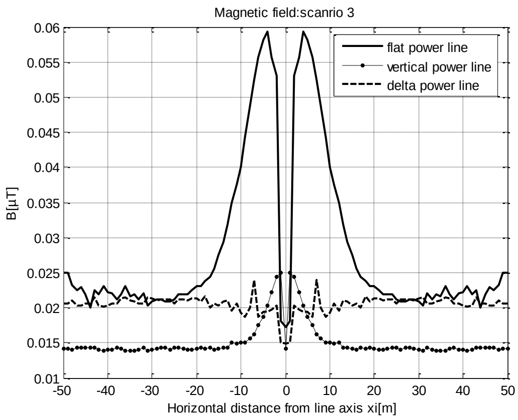

Fig.10. The distribution of the magnetic field intensity generated by a single distribution power line at the measuring situation *M3*.

When we are far away from the line, In Fig. 9, the magnetic field variation in the intervals [-50, -15] and [15, 50] increase for maximal value in the measured point *M2* for the delta configuration, then this field at *M3* in Fig. 10, decreases for in a minimum value for the same interval relative at the flat configuration, which explain that the effect of the transformer in the calculation of the magnetic fields .

When we are far away from the line, In Fig. 9, the magnetic field variation in the intervals [-50, -15] and [15, 50] increased, in its maximal value at the measured point M2 for the delta configuration, then this field at *M3* in Fig. 10, decreases for its minimum value for the same relative interval at the flat configuration, which explain that the effect of the power transformer in the calculation of the magnetic fields.

Concerning the magnetic field B depicted in Fig. 9, it is shown that at the distance far from the power station (*M2*) and near to the distribution power lines, the magnetic field of the flat configuration becomes more intensified compared to that of another's configuration, which explain that the magnetic field is depending on the geometry of conductor wires. In figure 10, it is shown that in the distance far away from the power station (*M3*), and far away with the power lines, the measurement results of magnetic field are similar to the simulation results.

4. Conclusions

In this work the theoretical and experimental results of produced magnetic field by the 30 kV distribution power line configurations (vertical power line, flat power line, and triangle power line) are presented, these lines are integrated in the network of Electricity and Gaz Company of Tunisian.

- The simulation results obtained by the proposed model have been discussed and compared to the corresponding ones obtained by experimental methods. It has been shown that the degree of approximation is lower than to scenario *M1*, because Biot-Savart law is made for power lines infinement long and it does not correspond to this scenario. But, for the scenarios *M2* and *M3*, the measurement result is similar to the simulation result.
- The characterization of the magnetic field was verified by measurements for three configurations in order to establish the degree of compliance with international regulation, and for each measuring situation, we can deduce different characteristics of magnetic field, which can be employed like support in the planning of electrical systems.
- On the base of this study, i recommend at least 30 m away far from the line to avoid the influence of this field on environment.

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