Dariusz SZTAFROWSKI, Jacek GUMIELA, Zbigniew WRÓBLEWSKI

Wrocław University of Science and Technology, Department of Electrical Engineering

doi:10.15199/48.2017.03.51

Measuring analysis of the distribution of magnetic field free of errors resulting from fluctuation of currents

***Abstract**. The paper presents a new method for measuring the electromagnetic field distribution under power transmission lines in real field conditions that is free from error brought by fluctuations of voltage, current and/or deviation of the multiphase system. The article analyses these problems for a selected case of the 110 kV line.*

***Streszczenie.** W artykule przedstawiono nową metodę pomiaru rozkładu składowej magnetycznej pola elektromagnetycznego pod liniami elektroenergetycznymi, która jest wolna od błędów wnoszonych przez wahania napięć, prądów i/lub odchyłki symetrii faz układu wielofazowego. W artykule przeanalizowano powyższe problemy dla wybranej linii 110 kV.*

Keywords: ELF, electromagnetic fields, power lines, digital simulations.
Słowa kluczowe: ELF, pole elektromagnetyczne, linie elektroenergetyczne, symulacje cyfrowe.

Introduction

The progress of civilization, along with a steady increase in the demand for electricity is inextricably connected with continuous growth in electricity infrastructure, particularly transformer stations and power lines, which are often adjacent to residential buildings

(Fig. 1). The use of electrical appliances entails the emission of physical and chemical agents into the environment. The former ones include 50Hz electromagnetic fields, noise and vibration. Additionally, high voltage power lines emit ozone. Research into the impact of electromagnetic fields on living organisms reveals that these physical factors are not indifferent to the health of organisms under its influence [1-5]. Scientific papers describing the problem focus on finding the possible applications of electromagnetic fields in medicine for treating certain diseases, for treatment of wounds, faster recovery of broken bones or treatment of depression (using TMS) [6], or describe the potentially negative impact of these fields on the human body. In many publications, authors focus on the risk of cancer, which may potentially be induced by the vicinity of electric power facilities [7-11]. Recent research in this area published in Proceedings of the National Academy of Sciences (PNAS) in April 2009 indicate that the fields of this type can also affect the behavior of animals. It has been shown that the electromagnetic fields produced by power lines interfere, in their immediate vicinity, with the earth's magnetic field lines, causing confusion in animals using the earth's magnetic field for navigation. Some animals are believed to sense magnetic fields similarly to visual stimuli, and perceive and interpret them in the form of "visual" patterns. The study showed that the magnetic field of 50 Hz has a much greater impact on the orientation of animals than other factors such as the position of the sun, wind direction and terrain conditions [12]. In extreme cases, high intensity of such current can be lethal for a human being and cause immediate death. Apart from such extreme situations, there is also a huge number of other situations in which, for professional, health and other reasons, exposure and safe levels of this physical factor require special consideration.

Factors affecting the accuracy of the determination of the distribution of electromagnetic fields around power facilities

Individual countries have introduced restrictions on exposure to electromagnetic fields and waves generated by electrical facilities and equipment. In Poland, the rules in this respect have been defined by the Regulation of the Minister of Environment of 30 October 2003 on permissible levels of electromagnetic fields in the environment and ways of enforcing these levels (Journal of Laws, No. 192, item 1883). The document determines permissible levels of magnetic field intensity H at the frequency of 50 Hz in areas accessible to humans (with time-unlimited exposure) at 60 A/m, and intensity of electrical component of electromagnetic fields as not higher than 1 kV/m in residential areas, and 10 kV/m in other areas accessible to people [13,14].

These values are comparable with permissible intensity levels of electromagnetic fields used by other European countries and presented in many international publications [15-17].

Human habitation is prohibited in areas where field values are higher than the acceptable levels specified in these standards. This puts restrictions on residential construction in the vicinity of such infrastructure. Hence the increased need for precise assessment of the areas around power infrastructure, and power lines in particular, with regard to their usability (Fig.1). The correct designation of the areas suitable for permanent residential construction, in particular objects such as schools, kindergartens, nurseries and hospitals, is a complex issue. Such a task requires a correct determination of electromagnetic field distribution, which can be done by the following method [18]:

- measurement in the vicinity of objects subject to such analysis,
- research using models of real objects,
- computationally.

Fig.1 Example 110kV line configuration next to the residential buildings in Lower Silesia

Fig. 2. An example of an unusual distribution in 110 kV power line in the immediate vicinity of residential buildings

Measurements performed directly around an electric power facility prior to construction of a residential building, or made with the purpose of verification of the position of existing buildings, can pose several problems.

Fig. 2 presents an example of 110 kV line using B2 transmission towers running in the immediate vicinity of residential buildings surrounded by a variety of metal objects like pylons of streetlights, and trees, which have a big impact on the distribution of the individual components of the electromagnetic field. The power line is located in the immediate vicinity of buildings, and branches from a double-circuit system, (viz. the column to the right in Figure 2), to two single-circuit systems, at the angle of about 60 degrees. Determination of electromagnetic field using theoretical methods, in this case, would be very difficult and time consuming. For such a line layout, the best way to determine the distribution of individual components is to use measurement identification, and then introduce measurement adjustments referred to in point 6 of the Annex 2 to the Regulation of the Minister of Environment of 30 October. It allows for the determination of the occurrence of the highest components of electromagnetic field in given points.

This measurement procedure, however, is subject to a number of errors which can include [19]:

- errors introduced by the instruments for the measurement of electromagnetic fields,
- errors in the measurement of the height of high voltage lines (or calculation thereof),
- errors resulting from uneven terrain affecting the determination of changes in height of the line above ground.

The value of measurement, in particular the electric component, is also affected by:

- the presence of the person making the measurements, as well as other objects and plants (eg. shrubs and trees) and dense seasonal vegetation (e.g. crops which skew elevation measurement by 1m), within the area affected by the lines of the electromagnetic field,
- correctness of measurement adjustments,
- wind, affecting the distance between phase conductors,

variability of the current at the time of measurement.

The measurement necessary for the creation of a distribution of individual components of the electromagnetic field can take from several minutes to several hours, depending on the terrain and weather conditions. Measuring the electrical component E shows relatively small fluctuations of voltage in high voltage power lines.

The results vary in the case of measurement of the component H of the magnetic field strength. In this case, measurements can be subject to much larger errors due to possible occurrence of large load differences of the test line and the value of flowing current, which has a direct impact on the value of the measured magnetic field.

A method for the reduction of error in the determination of the time-varying distribution of magnetic field

The following method for the reduction of error in determining distribution of time-varying electromagnetic field around the power generating facilities is based on the use of two independent measuring instruments for this field. As mentioned earlier, measuring the distribution of intensity of electromagnetic field is subject to numerous errors. One of these errors may be associated with random error resulting from the time-varying intensity of power line current and/or concurrent changes of the potential, leading respectively to a change of specific component values of magnetic and/or electric field around the power line under consideration. For these reasons, measurements which taken over an amount of time, measured intensity of the field can vary by up to several tens of percent. It should be stressed that field distribution determined using method described below is corrected for errors resulting from random variation factors discussed above.

Figure 3 shows the changes in the magnetic induction generated by the 110 kV line in Wroclaw on B2 pillars with 300 meter spans (Fig. 2). Measurements under the power lines were performed using ESM-100 Maschek measuring device. With this instrument, magnetic induction B [nT] was measured, and then converted into magnetic field intensity H [A / m]. Height of the line above ground at the point of measurement was 12 meters. The measurement of the magnetic field was carried out over about 2 hours at intervals of 1 second. In this time, changes of magnetic field intensity ranged from a minimum of 86 nT to the maximum value of 368 nT. Such a large change in field intensity during the measurement can cause significant errors in the field distribution.

Minimizing this type of error involves constant monitoring of the variation of magnetic field during the measurement and subsequent use of thus registered changes in determining the correction values for individual measuring points.

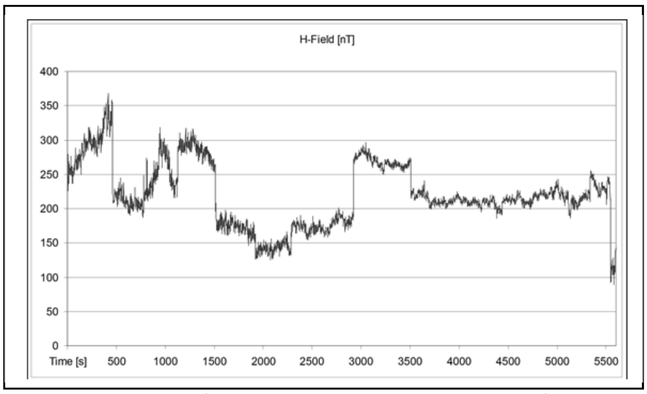

Fig. 3. The course of changes in the measured value of magnetic field under the 110 kV line for B2 pylons in the city of Wroclaw

The method proposed by the authors of the paper assumes measuring the intensity of magnetic field using at least two measuring devices, whereby one (device #1) is placed under the power line at the point where the conductor is closest to the ground (i.e. most preferred location). Its location should remain unchanged in the course of the series of measurements on the line. The purpose of this instrument is constant registration of field intensity (H_{1x}) and its random variation during the measurement. The second measuring instrument (instrument #2) changes position and is used to measure the intensity of magnetic field (H_{2x}) at various points below the power line. Based on the time-varying measurements H_{1x} achieved from device #1, corrections (H_{1X}/H_0) are calculated individually for each measurement H_{2x} made with the measuring device #2, and then, using this information, H_S offset values are achieved at individual points of measurement:

$$Hs = H_{2X} \cdot \frac{H_{1X}}{H_0} \tag{1}$$

where: H_s - the corrected value free of any random changes of the measured current and possible fluctuation of the potential difference, H_0 - value of magnetic field intensity at the start of the measurements, t = 0.

Thus determined values of magnetic field are free of errors related to changes in the amperage of the analysed power line during measurements.

Measurements made without the above adjustments may be prone to errors which, for the case of the line presented in Fig. 2 and field distribution presented in Fig. 3, determined with the changes in current intensity during the measurement, are presented in Fig. 4.

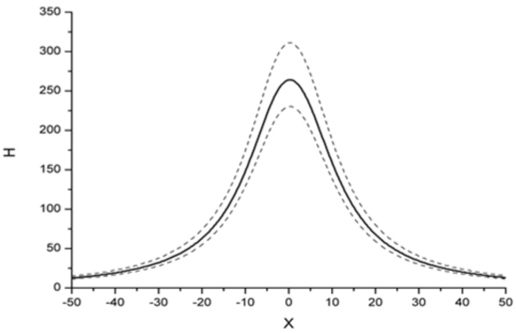

Fig. 4. Distributions of the magnetic field below the line in Fig. 2 corresponding to the constant current during the measurement (continuous line) and its extreme values (dotted lines)

The solid line shows the distribution of the magnetic field in accordance with existing methods, assuming constant current in the power line. Dotted lines define the range of possible changes in the distribution due to changes in current during measurement. These lines were determined by dividing the maximum value (upper line) and minimum (lower line) by the initial value of the field H_0.

Figure 5 shows magnetic field distribution under the line in Fig. 2 determined by measurement (solid line) and by numerical method (broken line) assuming constant current value during the test. Figure 6 shows graphical representation of errors introduced by each class of measuring instruments included in the measurement system and the range of random changes of magnetic induction during the measurements.

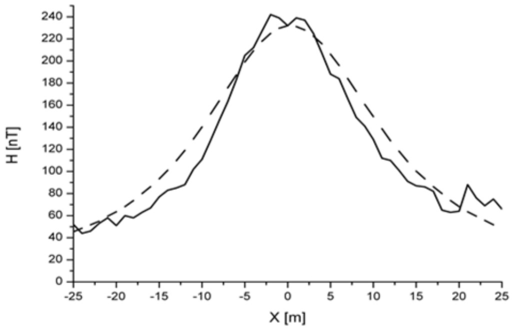

Fig. 5. Magnetic field distribution obtained by the measurement (solid line) and the calculation method (broken line)

In the example above the changes in magnetic induction detected using measuring instrument with fixed position (device #1) fell within the range from 86 nT to 368 nT, wherein the initial value H_0 nT was 232, which means that the measurement error caused by the variability ranged from -62.9% to 58.5% with respect to the initial value H_0.

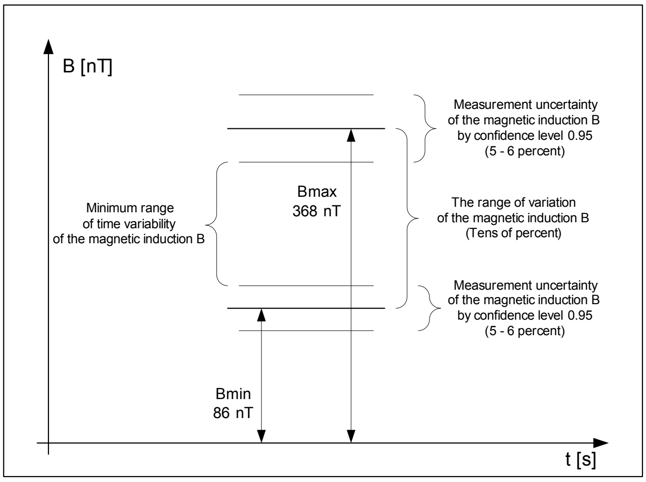

Fig. 6. Graphical presentation of the range of variation of the magnetic induction and measurement uncertainty for a confidence level of 0.95

The uncertainty of measurement in accordance with PN-EN 50413 [20], EA-4/02 M: 2013 [21] and JCGM 100: 2008 GUM 1995 [22] can be expressed using the formula:

$$u_B(\overline{B}) = \frac{1}{\sqrt{3}} \cdot \sqrt{\left(\frac{\delta_g B \cdot \overline{B}}{100}\right)^2 + \left(\frac{\Delta n}{n}\overline{B}\right)^2} \tag{2}$$

where: $\delta_g B$ – error of measuring instrument, expressed as a percentage; $\overline{B}$ – measured value of magnetic induction; Δn – error of measuring instrument expressed in the least significant figures; n – measured value (without the decimal point).

After calculating uncertainty of measurement using the equation (2) it must be applied to the required level of confidence (here: 0.95) for which the coverage factor is k=2

$$U_B(\overline{B}) = k \cdot u_B(\overline{B}) \tag{3}$$

reduces the role of beliefs in moral judgments, *Proc Natl Acad Sci U S A.*; 107(15): 6753–6758; 2010

Measurement uncertainty for the confidence level 0.95 (with k=2) resulting from the class of measuring instruments used (Maschek ESM-100) is relatively low at just +/- 5-6% compared to measurement correction values (tens of percent) which are used to correct the measured values of magnetic induction with the described method for reducing the error.

Conclusions

1. The new method of measurement of distribution of magnetic field around electric power objects enables us to determine the distribution of the field free from errors resulting from changes in current intensity during measurement. This method also allows you to eliminate errors in determining the magnetic and electric fields resulting from voltage fluctuation and phase unbalance of a three-phase electroenergetic system.
2. If needed, the presented measurement method also makes the measurement process faster by allowing the use of multiple probes and simultaneous measurements at several different heights. For each tested plane one fixed position probe and at least one variable position probe should be used.
3. One of the advantages of this method is that in case of substantial changes in current intensity during the measurement and the resulting variations in the field intensity, the errors caused by the use of low-grade measuring instruments to analyze the line are practically negligible.

Authors: Prof. dr hab. inż. Zbigniew Wróblewski, dr Dariusz Sztafrowski, mgr inż. Jacek Gumiela, Politechnika Wrocławska, Katedra Energoelektryki, ul. Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, E-mail: dariusz.sztafrowski@pwr.edu.pl; zbigniew.wroblewski@pwr.edu.pl; jacek.gumiela@pwr.edu.pl

REFERENCES

[1] Halgamuge, Malka N.; Critical time delay of the pineal melatonin rhythm in humans due to weak electromagnetic exposure;*Indian j. Biochem. Biophys.*, VOL. 50; 2013
[2] Sztafrowski Dariusz, Joanna Jakubaszko.; Wpływ zmiennego pola magnetycznego na funkcje narządu wzroku; *Przegląd Elektrotechniczny* nr 4; 2005
[3] Sztafrowski D., Wróblewski Z., Łukaszewicz M.; Survey identification of 50 Hz magnetic field impact on selected biological processes in the model organism Saccharomyces cerevisiae; *Przegląd Elektrotechniczny* nr 1a, R. 89; 2013
[4] Jakubaszko, Juliusz, Dariusz Sztafrowski, and Zbigniew Wróblewski.; Wpływ składowej magnetycznej pola elektromagnetycznego 50 Hz na zmiany hemodynamiki organizmu człowieka.; *Przegląd Elektrotechniczny* 02; 2014
[5] Sztafrowski D., Wróblewski Z., Łukaszewicz M., Sikorski A., Majkowski M.; Magnetic field 50 Hz: its influence on living cells HL-60. W: 2011 10th International Conference on Environment and Electrical Engineering; Rome, Italy, 8-11 / eds. M. Caciotta, Z. Leonowicz; [Piscataway, NJ] : *IEEE*, cop. May 2011; 2011
[6] Liane Young, Joan Albert Camprodon, Marc Hauser, Alvaro Pascual-Leone, and Rebecca Saxe Disruption of the right temporoparietal junction with transcranial magnetic stimulation reduces the role of beliefs in moral judgments, *Proc Natl Acad Sci U S A.*; 107(15): 6753–6758; 2010
[7] McBride M.L. i wsp.: Power-frequency electric and magnetic fields and risk of childhood leukemia in Canada. *Am. J. Epidemiol,* , Vol. 149, pp. 831-842; 1999
[8] Linet M.S. i wsp.: Residential exposure to magnetic fields and acute lymphoblastic leukemia in children. *N Eng. Journ. Med.*, vol. 337, pp.1-7; 1997
[9] Kleinerman R.A. i wsp.: Are children living near high-voltage power lines at increased risk of acute lymphoblastic leukemia? *American Journal Epidemiology*, vol. 151, pp.512-515; 2000
[10] Myers A. i wsp.: Childhood cancer and overhead power lines. A case-control study. Br. J. Cancer; vol. 62, pp. 1008-1011;1990
[11] Ahlbom A.: A pooled analysis of magnetic field and childhood leukaemia. *British Journal of Cancer*, vol. 83, no. 5, pp. 692-698; 2000
[12] Burda H., Begall S., Červený J. Neef J. Němec P. Extremely low-frequency electromagnetic fields disrupt magnetic alignment of ruminants. *PNAS*; 2009
[13] Rozporządzenie Ministra Ochrony Środowiska, w sprawie dopuszczalnych poziomów pól elektromagnetycznych w środowisku oraz sposobów sprawdzania dotrzymania tych poziomów, z dnia 30 października 2003; 2003
[14] Zmyslony, M., Kubacki, R., Aniolczyk, H., Kieliszek, J., Trzaska, H., Bienkowski, P., Krawczyk, A., and Szmigielski, S.; Verification of Polish regulations of maximum permissible intensities in electromagnetic fields by the Commission for Bioelectromagnetic *Issues of the Polish Radiation Research Society. Med Pr* 56; 2005
[15] Vulevic, B. and Osmokrovic, P. Survey of ELF magnetic field levels in households near overhead power lines in Serbia. *Radiat Prot Dosimetry* 145; 385-8; 2011
[16] Vulević, Branislav, and Predrag Osmoković. "Evaluation of uncertainty in the measurement of environmental electromagnetic fields." *Radiation protection dosimetry* 141.2 : 173-177; 2010
[17] IARC, Non-Ionizing Radiation, Part 1: Static and Extremely Low-Frequency (ELF) Electric and Magnetic Fields, IARC *Monographs on the Evaluation of Carcinogenic Risks to Humans* 80; 2002
[18] Habrych M., Wróblewski Z.: Analiza przydatności programu komputerowego MAH w prognozowaniu rozkładu pól elektromagnetycznych pod nowobudowanymi liniami elektroenergetycznymi. *VI Ogólnopolska Konferencja Naukowo-Techniczna Postępy w Elektrotechnice Stosowanej. PES-6*, Kościelisko; 2007
[19] Zeńczak, M. "Analiza pola elektrycznego i magnetycznego wokół linii elektroenergetycznych i wybranych urządzeń elektroenergetycznych." *Napędy i Sterowanie* 13/2011; 150-15; 2011
[20] PN-EN 50413:2009. Metody pomiaru i obliczeń ekspozycji ludzi w polach elektrycznych, magnetycznych i elektromagnetycznych (0 Hz–300 GHz) norma podstawowa. Polski Komitet Normalizacyjny, Warszawa 2009
[21] EA-4/02 M: 2013; Wyznaczanie niepewności pomiaru przy wzorcowaniu - Evaluation of the Uncertainty of Measurement in Calibration; Komitet EA do spraw Laboratoriów; 18.10.2013
[22] JCGM 100: 2008; GUM 1995; Evaluation of measurement data — Guide to the expression of uncertainty in measurement Évaluation des données de mesure — Guide pour l'expression de l'incertitude de mesure; 2008