Measuring the Electric and Magnetic Fields

A. Malfait K. Hameyer R. Belmans
Katholieke Universiteit Leuven, Faculteit Toegepaste Wetenschappen
Departement Elektrotechniek (ESAT), Onderzoeksgroep ELEN
Kardinaal Mercierlaan 94, B-3001 Heverlee, Belgium
Phone (+)32.16.32.10.30 Fax (+)32.16.32.19.85
E - mail: An.Malfait@esat.kuleuven.ac.be

Abstract - **The paper describes different methods that may be used to measure the electric and the magnetic field in an industrial environment as well as in domestic applications. The aim is to show how these fields can be measured, and to give some ideas of specific values.**

I. INTRODUCTION.

During recent years there is a large pressure on nature and environmental issues. Many papers have been devoted to problems dealing with various aspects of nature and environment, its disturbance and its protection. One of the very often treated topics is the eventual biological and medical implications of extra low frequency electric and magnetic fields caused by high voltage overhead lines, substations, domestic equipment, etc.

This paper describes several methods used many times by the electric energy division of the electrical engineering department to measure the electric and the magnetic field in an industrial environment as well as in domestic applications. At the one hand experience is gathered on measuring the electric and magnetic fields of high voltage overhead lines in general and substations in industrial plants. At the other hand a whole new house fully equipped with the highest and newest technology on household machines and domotics is analysed. The aim of these last measurements is to have some representative values of the electric and mag-netic fields in places where the general population may be exposed to in future during a large part of the day.

II. NATURAL AND TECHNICAL ELECTRIC AND MAGNETIC FIELDS

Since ages people already lived in a natural electric and magnetic field. These fields find their origin in the earth, the atmosphere and the cosmos. The value of the natural electric field is time dependent and reaches from 100 V/m to 500 V/m in good weather conditions and from 3000 V/m to 20000 V/m during thunderstorms. The earth magnetic field has a value of 35 µT to 40 µT depending on the place on the globe and is time independent too [3]. Figure 1 shows the na-tural electric and magnetic field values at the earth surface.

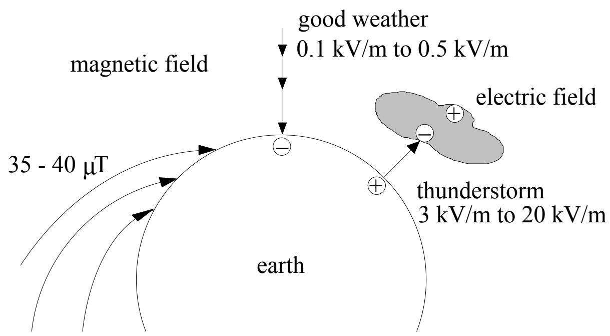

Fig. 1. Natural electric and magnetic field values at the earth surface.

Apart from these natural, continuously existing electric and magnetic fields, there exist also technically generated fields. These technical fields exist already from the day man invented electricity. To obtain a technical electric field a voltage is required and to get a technical magnetic field a current or a permanent magnet is needed. These technical fields are often alternating in time, a sinusoidal time dependency being the most common. Their value depends on the absolute value of the excitation source and on the distance from the source. The larger the distance, the smaller the field value.

The main difference between natural magnetic fields and technical, artificial magnetic fields is that the natural field is continuously present while the technical field only occurs if currents are flowing. Therefore, if nor currents nor induced currents are possible there may not be any magnetic field except by using permanent magnets.

In the case of the electric field this distinction is not possible because both the natural and the technical electric field can be present all the time.

Due to the continuously existing electric and magnetic field of the earth, it is very important to be able to measure correctly the technically artificial added values of the electric and the magnetic field.

III. MEASURING EQUIPMENT

The measuring equipment used is the field meter model HI-3604 of the firm Holaday Industries. It measures the RMS-value of the component perpendicular to the disc-shaped measuring probe. The apparatus is very easy to handle. There is also a remote control available in the measuring kit in order to measure the electric field from a distance avoiding the disturbance of the field by the operator. There exists a special tripod in non-dielectric material in the measuring kit to be able to measure the different components of the field at exact the same point. An interface is available to register the measured values immediately by a personal computer so the processing afterwards, if any, can be done more easily and the measurement are represented accurate. Figure 2 shows a picture of the measuring kit used.

Fig. 2. Measuring kit.

Electric fields are detected by a displacement current sensor consisting of two very close conductive disks connected electrically. When immersed in an electric field, charges are redistributed among the two parallel disks in such a way that the electric field between both disks remains zero. The distribution of charges is reflected as a displacement current that can be measured and subsequently, related to the external electric field strength. This type of transducer possesses a flat frequency response and permits accurate measurements of fields having significant harmonic content at frequencies above the fundamental 50 or 60 Hz.

Surrounding the circular displacement current sensing disks, a coil consisting of several hundred turns of a fine gage wire is found. When placed in an alternating magnetic field, a current is induced in the coil proportional to the flux density of the applied magnetic field. The magnetic field strength or the flux density is then determined by measuring the voltage developed across the terminals of the coil. The equipment can be used in environments having significant harmonic content and yield accurate results of the resultant fields. Broad band response is required when measuring fields having harmonic distortion such as may occur with electrical machines supplied by power electronic converters.

The outputs of both field transducers are measured with a true RMS-detector. True RMS-detection offers accurate evaluation of fields having a variety of wave forms, including non-sinusoidal wave forms.

IV. Different Measuring Situations.

A. Overhead High Voltage Lines

In Belgium nowadays high voltage overhead lines are a point of discussion. Because the department of electrical engineering got a lot of questions from the general public on this topic, a measuring campaign was set up. Measurements were done in different situations and on different locations. In this paper only one situation is discussed with respect to measuring set up, measuring situation and measuring results.

1) Measuring set up: To get good measurements in the case of a high voltage line one has to follow the "IEEE Standard Procedure for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines"[1]. This means that measuring places should be on a line perpendicular to and in the middle of the high voltage line span. Here the distance from the ground to the high voltage line is the smallest, yielding the highest field values. The first point is taken right under the high voltage line, the other points are taken 2 m apart from each other, symmetrically to the left and to the right of the high voltage overhead line. In the here mentioned case ten points are taken on the left as well as on the right. Figure 3 shows the measuring points for a high voltage overhead line.

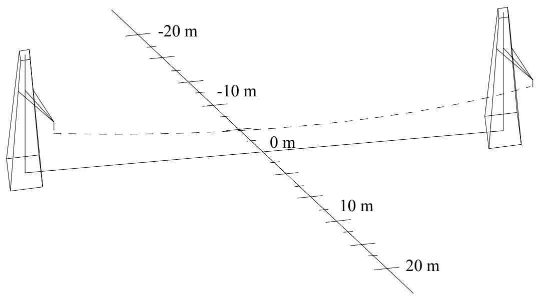

Fig. 3. Measuring points of the high voltage overhead line.

The measuring equipment should be placed in each measuring point. The different field components are registered at 1 m above the earth surface. In the case of a high voltage overhead line, it is only necessary to measure the two components of the field perpendicular to the high voltage overhead line because the third component, parallel to the high voltage line is negligible. When measuring the electric field, the operator should be at a distance of minimum twice his length from the measuring equipment, and he should bent his knees.

2) Measuring situation: The situation discussed here is a high voltage overhead line leading from Verbrande Brug to Wilsele with a rated voltage of 150 kV. The measuring spot is sited in Kampenhout between tower poles number P238 and P239. The towers are 446 m away from each other and the heights of the lines on the measuring instant are given in table I. The current was 266 A on that very same moment. Figure 4 shows the configuration of the high voltage overhead line.

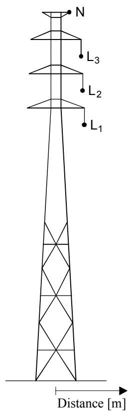

Fig. 4. Configuration of the considered high voltage overhead line

TABLE I
HEIGHT OF THE LINES OF THE HIGH VOLTAGE OVERHEAD LINE

Line	Height [m]
L1	22.81
L2	27.81
L3	32.81
N	39.38

3) Measuring results: Table II shows the values of the electric and the magnetic field of the 150 kV overhead high voltage line. The x-component is the component perpendicular to the high voltage line but parallel to the earth, the y-component is the component perpendicular to the high voltage line and the earth.

B. Substations

Apart from the high voltage overhead lines often questions are asked dealing with the electric and the magnetic field values in industrial installations. One project handled the measurements of the magnetic field outside a substation in an industrial plant.

1) Measuring set up: The measurements are done again at a height of 1 m above ground level. The measurements are performed in such a way that the three components (x,y,z) of the magnetic field are obtained in different points of interest. The x-component of the field is parallel to the door of the substation and parallel to the ground, the y-component is parallel to the door and perpendicular to the ground and the z-component is perpendicular to the door and parallel to the ground. Because only the magnetic field is measured, no special precautions have to be taken with regard to interference by the operator.

TABLE II
MEASUREMENT RESULTS IN THE CASE OF A HIGH VOLTAGE LINE

distance [m]	x-comp. E-field [V/m]	y-comp. E-field [V/m]	x-comp. M-field [µT]	y-comp. M-field [µT]
-20	95	88	0.097	0.336
-18	117	111	0.127	0.348
-16	143	128	0.146	0.371
-14	170	166	0.205	0.398
-12	212	196	0.243	0.402
-10	229	240	0.295	0.387
-8	276	268	0.368	0.372
-6	319	309	0.435	0.356
-4	352	361	0.481	0.296
-2	400	387	0.527	0.245
0	380	388	0.555	0.149
2	396	418	0.605	0.073
4	408	426	0.604	0.017
6	396	421	0.588	0.082
8	372	403	0.570	0.156
10	364	373	0.532	0.228
12	303	334	0.463	0.292
14	290	296	0.435	0.337
16	240	265	0.368	0.341
18	185	226	0.282	0.356
20	169	186	0.256	0.368

2) Measuring situation: The substation under consideration here has a rated voltage of 36 kV. At the instant of the measurements, the current in the substation is 910 A.

Fig. 5. View of the substation

TABLE III
THREE COMPONENTS AND RMS-VALUES IN DIFFERENT POINTS

(x,y,z) [m]	x-comp. M-field [µT]	y-comp. M-field [µT]	z-comp. M-field [µT]	RMS [µT]
0.4, 1, 0	18.1	0.6	13.5	22.59
1.2, 1, 0	12.9	1.1	4.8	13.81
0.4, 1, 0.61	22.9	3.1	10.7	25.47
1.2, 1, 0.61	16.4	2.0	1.9	16.63
0.4, 1, 1.04	33.4	4.3	10.2	35.19
1.2, 1, 1.04	17.2	2.2	6.0	18.35

3) Measuring results: Table III shows some values of the three components and of the RMS-values in the different points of interest. The location of the points is also indicated.

C. Domestic situations

In the light of the opening an entire new house fully equipped with the highest and newest technology on domestic machines and domotics, measurements were performed on the electric and magnetic field inside this new house.

1) Measuring set up: The measurements were performed in such a way that the three components of the electric and the magnetic field are measured at a height of 1 m above ground level in the different places of the house, every time in the middle of the room or just in front of the heating systems. The values of the magnetic field are measured as a maximum RMS-value. For the values of the electric field, the three components of the electric field are measured and the total RMS-value is calculated. These measurements are performed using the remote control. In some cases only two field components may be measured, because there is not enough space to measure the third component.

2) Measuring situation and results: The house the measurements were performed in has two different systems for the electric heating of the total house. The first heating method is based on heath accumulation and the second way is direct heating. Out of the measurements of the electric and magnetic fields (see table IV) it is clear that in the situation studied here and with the heating equipment used, the accumulation based heating system shows higher values of the magnetic field than the direct heating based system. When the electric field is considered the opposite is shown.

The values of the magnetic field in the kitchen was measured without any household equipment working. If one uses the furnace the magnetic field in front of the grill is 2 μT. When using the electric cooking equipment based on the induction principle, the value of the magnetic field depends on the amount of plates used. When using only one plate the magnetic field in front of the plate is 0.35 μT and above the pot the field goes from 0.9 μT for smaller plates to 3.3 μT for larger ones. If one uses two plates with the same characteristics, the value of the magnetic field in front of the plates remains the same, but above the pots the field becomes smaller. Out of experiments with electric hot-plates based on the induction principle, it may be concluded that the magnetic field value depends also on the material of the pot used to cook. If one uses specially designed pots for induction cooking the magnetic field values are higher than with ordinary cooking pots. If efficiency is concerned, the special pots filled with water boil quicker than the water in ordinary pots. Some other places measured in the house are in table IV.

TABLE IV
MEASURING RESULTS IN DOMESTIC SITUATIONS

place or apparatus	RMS-value M-field [μT]	x-value of the E-field [V/m]	y-value of the E-field [V/m]	z-value of the E-field [V/m]
Accumulation heating system	1.3	1.54	1.74	
Direct heating system	0.0280	134	228	
Kitchen	0.0165	9.60	2.0	4.8
Bathroom with heated mirror	0.88	54	8	73.7
Switching board	0.5	8.2	19.5	22.8
Bedroom	0.0165	1.62	1.62	1.77
Living room	0.165	1.65	1.64	1.65

V. CONCLUSIONS.

Out of the experiments it can be concluded that the values of the magnetic field measured in the case of the high voltage overhead line and in the domestic situations are in the same order of magnitude. It should also be mentioned that none of the measured values was higher than the limits recommended by IRPA and WHO [7].

VI. ACKNOWLEDGEMENT.

The authors wish to thank the council of Belgian National Science Foundation for granting a project sponsoring the research. Furthermore, they wish to acknowledge the personnel of the Power Generating Board Electrabel for supplying the data of the overhead line lay-out and for giving the opportunity to measure in their model house. They wish to thank also the personnel of BASF, Antwerpen for giving the opportunity to measure in their plant.

VII. REFERENCES.

[1] American National Standards Institute / Institute of Electrical and Electronics Engineers, ANSI / IEEE Std. 644-1987: “IEEE Standard Procedure for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines”.

[2] Holaday Industries - 3604; ELF Field Strength Measurement System: User Manual.

[3] R.Thäle, "Elektrische und magnetische Felder im Wohnungsbereich", Elektrowärme International 52 (1994) A 2 June, pp. 76 - 81.

[4] W.Koopmans, “Berekening en meting van het elektrisch en magnetisch veld onder een hoogspanningslijn”, Master thesis 1991/1992.

[5] R.Mertens, “Elektrisch en magnetisch veld van een hoogspanningslijn”, Master thesis 1992/1993.

[6] M.Prinzie, “Magnetisch veld rond een schakelcel in een schakelpost”, Master thesis 1993/1994.

[7] International Radiation Protection Association (IRPA): "Interim guidelines on limits of exposure to 50/60 Hz electric and magnetic fields", Health Physics Vol.58, No.1 (January), pp. 113-112, 1990.

8. REFERENCES

[1] Ministerial regulation dated 20.04.88 appeared in the Belgian Staatsblad dated 06.05.88 on pp.6528.

[2] Silvester, P.P., Ferrari, R.L.: 'Finite Elements for Electrical Engineers", Cambridge University Press, 2nd edition, 1990.

[3] Freeman, E.M., Lowther, D.A.: "A novel mapping technique for open boundary finite element solutions to poissons equation", IEEE Transactions on magnetics, Vol. 24, No. 6, pp.2934-2936, November 1988.

[4] Freeman, E.M., Lowther, D.A.: "Further aspects of the Kelvin transformation method for dealing with open boundaries", IEEE Transactions on magnetics, Vol. 28, No. 2, pp.1667-1670, March 1992.

[5]