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Electric and magnetic field levels generated by AC power systems — Measurement procedures with regard to public exposure

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National foreword

This British Standard is the UK implementation of EN 62110:2009. It is identical to IEC 62110:2009.

The UK participation in its preparation was entrusted to Technical Committee GEL/106, Human exposure to low frequency and high frequency electromagnetic radiation.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Electric and magnetic field levels generated by AC power systems - Measurement procedures with regard to public exposure
(IEC 62110:2009)

Champs électriques et magnétiques générés par les systèmes d'alimentation à courant alternatif - Procédures de mesure des niveaux d'exposition du public
(CEI 62110:2009)

Magnetische Felder, die von Wechselstrom-Energieversorgungssystemen erzeugt werden - Messverfahren im Hinblick auf die Exposition der Allgemeinbevölkerung
(IEC 62110:2009)

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Foreword

The text of document 106/177/FDIS, future edition 1 of IEC 62110, prepared by IEC TC 106, Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 62110 on 2009-11-01.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2010-08-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2012-11-01

Terms defined in Clause 3 appear in *italics* throughout the document.

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 62110:2009 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following note has to be added for the standard indicated:

IEC 61000-2-2	NOTE Harmonized as EN 61000-2-2:2002 (not modified).

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 61786	-[1]	Measurement of low-frequency magnetic and electric fields with regard to exposure of human beings - Special requirements for instruments and guidance for measurement	-	-

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[1] Undated reference.

CONTENTS

INTRODUCTION

All populations of the world are now exposed to electric and magnetic fields and the levels will continue to increase with developing industry and technology. A number of countries have implemented regulations on public exposure to these fields. Therefore, in order to evaluate human exposure levels to these fields adequately, common measurement procedures are required by not only professionals of national authorities and electric power industries, but also the general public.

This standard is applied to the measurement of fields generated by AC power systems in areas accessible to the public. It establishes a common measurement procedure to evaluate the exposure levels of the human body to electric and magnetic fields among the general public.

The values obtained are for use to determine whether the fields comply with exposure limits by comparing them with the field limits for general public exposure such as the reference levels from the ICNIRP (International Commission on Non-Ionizing Radiation Protection) Guidelines [1]1), MPE (maximum permissible exposure) from the IEEE (Institute of Electrical and Electronics Engineers) [2] or in national regulations. If the values obtained are higher than the reference level or MPE, it does not necessarily mean that the basic restriction has been exceeded, in which case other methods must be used to ensure that basic restriction is not exceeded.

The values obtained by using the procedures in this standard are for the load conditions occurring at the time of measurement. Therefore, in the case of magnetic field, in order to check compliance with some exposure guidelines or regulations these values may need to be extrapolated to take account of the maximum load of the circuits.

This standard is not applicable to occupational exposure associated with, for example, the operation and/or maintenance of the power systems. Such exposure may occur when working inside a distribution or transmission substation, a power plant, in a manhole or a tunnel for underground cables, or on an overhead line tower or pole.

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1) Numbers in square brackets refers to the Bibliography.

ELECTRIC AND MAGNETIC FIELD LEVELS GENERATED BY AC POWER SYSTEMS – MEASUREMENT PROCEDURES WITH REGARD TO PUBLIC EXPOSURE

1 Scope

This International Standard establishes measurement procedures for electric and magnetic field levels generated by AC power systems to evaluate the exposure levels of the human body to these fields. This standard is not applicable to DC power transmission systems.

This International Standard is applicable to public exposure in the domestic environment and in areas accessible to the public.

This standard specifies fundamental procedures for the measurement of fields, and, with regard to human exposure, for obtaining a field value that corresponds to a spatial average over the entire human body.

This standard is not applicable to occupational exposure associated with, for example, the operation and/or maintenance of the power systems. Such exposure may occur when working inside a distribution or transmission substation, a power plant, in a manhole or a tunnel for underground cables, or on an overhead line tower or pole.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61786, *Measurement of low-frequency magnetic and electric fields with regard to exposure of human beings – Special requirements for instruments and guidance for measurements*

3 Terms and definitions

For the purposes of this document, the following terms and definitions given below apply. Internationally accepted SI-units are used throughout the standard.

NOTE The distinction between “magnetic flux density” and “magnetic field strength” is only relevant when considering magnetic fields in magnetic materials. In air it is common to use “magnetic fields” as a generic term to cover both of these two quantities.

3.1
single-point measurement
procedure to measure the field level at a specified height, used for uniform fields

NOTE The conditions under which the field can be considered as uniform or non-uniform are given in section 5.1.

3.2
three-point measurement
procedure to measure the field levels at three specified heights at a single location, used for non-uniform fields

3.3
five-point measurement
procedure to measure the field levels at five points at a specified height, used for non-uniform fields generated by field sources below the floor or the ground

3.4
average exposure level
spatial average over the entire human body of fields to which the individual is exposed

3.5
three-point average exposure level
arithmetic mean of the three values obtained from the *three-point measurement* or of the largest three values obtained from the *five-point measurement*

NOTE This arithmetic mean is used as an estimate of the *average exposure level* at a single location.

3.6
maximum exposure level
the maximum of the single-point measurements or *average exposure levels* over the area of interest

3.7
power system
system consisting of overhead lines and underground cables, substations and other power distribution and transmission equipment. Railway systems are covered by a specific standard and therefore are excluded from the present standard.

4 Measurement principle for electric and magnetic fields

4.1 General

Detailed generic information and requirements regarding measurement of electric and magnetic fields are given in IEC 61786 and in other technical documents such as CIGRE technical brochures [6][8] and IEEE guides [7][9].

4.2 Instruments

Instruments for measuring electric and magnetic fields shall meet the requirements regarding calibration and specification given in IEC 61786 or another appropriate national or international standard. These instruments should be used under appropriate conditions, particularly with regard to electromagnetic immunity, temperature, and humidity, recommended by the manufacturer.

A three-axis instrument measures r.m.s. values of resultant field F_r. A single-axis instrument can be used to obtain F_r by measuring F_x, F_y, and F_z, using Equation (1).

$$F_\mathrm{r} = \sqrt{F_x{}^2 + F_y{}^2 + F_z{}^2} \qquad (1)$$

where

F_x, F_y, and F_z are r.m.s. values of the orthogonal three-axis components of electric or magnetic fields.

When the field has no harmonics, F_r can also be obtained by measuring F_max and F_min, and then using Equation (2).

$$F_{\mathrm{r}} = \sqrt{F_{\mathrm{max}}{}^{2} + F_{\mathrm{min}}{}^{2}} \qquad (2)$$

where

F_{max} is the maximum r.m.s. value of the semi-major axis of the field ellipse;

F_{min} is the minimum r.m.s. value of the semi-minor axis of the field ellipse.

4.3 Harmonic content

Harmonics are generally caused by non-linear equipment. Harmonics may be present on transmission lines and on distribution lines. Generally, the total harmonic voltage distortion of AC power distribution systems (see [3][4]) is low enough to not significantly affect the exposure, and so it is normally not necessary to quantify the harmonic content. AC transmission systems have lower harmonic contents.

Where there is significant concern that the harmonic content of fields cannot be ignored, existing methods of assessing the field harmonic content should be used following IEC 61786 for measurement. The assessment of the fields taking account of the harmonic frequencies should be evaluated according to the procedure specified in the safety standard (e.g. [5]) to be applied.

4.4 Record of measurement result

In the measurement report, the following information should be recorded:

- date, time, and weather conditions (e.g. sunny, rain, snow and wind conditions) when the measurement is carried out;
- temperature and humidity (for electric field measurement);
- type (overhead line, cable, substation, etc.) and nominal voltage of the power system, configuration and phase arrangement of overhead conductors and/or underground cables that generate the measured fields, if available;
- information on instruments [instrument manufacturer, model, probe size and geometry, type of probe or meter (free-body meter, ground reference meter, fluxgate meter, coil probe, Hall effect probe), magnitude range, pass bandwidth, latest calibrated date], if available;
- estimation of the uncertainty of measurement;

  NOTE 1 Measurement uncertainty can be estimated using a procedure proposed by, e.g., IEC 61786.
- person/company who performs the measurement;
- height(s) above the ground or the floor where the measurement is performed;
- measurement location related to the power systems of interest;
- measurement location in the room when the measurement is carried out in a building;
- measured field (electric or magnetic) levels;
- clear indication of what field quantity is being reported, for example, resultant field, r.m.s. values of each orthogonal three-axis component of the field or maximum or minimum r.m.s. values of the semi-major or semi-minor axis of the field;
- type, spatial position, and operating condition of other field sources near the measurement point;
- sketch and/or photograph of the measurement site with measurement location and other field sources;
- type, sort of material, dimensions and spatial position of permanent and removable objects for electric field measurement;
- type, sort of material, dimensions and spatial position of permanent and removable objects that contain magnetic materials or non-magnetic conductors for magnetic field measurement;

– current values flowing when magnetic field measurement is carried out, if possible and relevant;

NOTE 2 There might be some cases in which these load values would be difficult to obtain. Moreover, for low voltage distribution systems, the net current can be the more relevant parameter.

NOTE 3 One possible way to survey the variation of the load is to use a second magnetic field meter at a fixed position (see [6]).

– harmonic contents, if significant.

The above information is important when the measurement results are compared with the calculated levels and/or other measurement results.

An example of a measurement report is given in Annex D.

4.5 Measurement considerations

4.5.1 Field orientation

4.5.1.1 Electric field

Electric field measurement instruments are either single-axis or three-axis. The latter is the preferred option.

The electric field adjacent to a conducting surface is normal to the surface, Therefore, the horizontal component of the electric field, particularly where it is generated by overhead lines, can be ignored close to the ground surface. Single-axis measurement (vertical component) is therefore sufficient near the ground. Some examples of calculated electric field levels at a height of 1,0 m above the ground under overhead lines are shown in A.3.3. These demonstrate that at 1,0 m above the ground, the vertical component is similar to the resultant (see Figures A.9 and A.10).

Particular care must be taken in the presence of conducting objects (see 4.5.2.1) or when the clearance of the conductor from the ground is small.

4.5.1.2 Magnetic field

Magnetic field measurements should be made with three-axis instruments and should be of the resultant field, except where there is a particular reason for using single-axis instruments. Reasons for using single-axis instruments include the desire to know the direction of the field and the maximum r.m.s. value of the semi-major axis of the field ellipse, the wish to investigate the orientation and shape of the magnetic field ellipse, and cases when the direction of a linearly polarised field is already known; however, these are not covered by this standard.

When a suitable three-axis instrument is not available, a single-axis instrument may be used to determine the resultant field using Equation (1) or Equation (2), provided that the field level remains stable during the time taken to perform the measurements. In this case, use of a fixture made from non-conducting materials for orienting the probe in three orthogonal directions will expedite the measurement process.

NOTE Three-axis instruments often measure the three components sequentially which should be taken into account when field is changing.

Generally, the r.m.s. value of the semi-minor axis of the field ellipse under transmission lines is significantly smaller than that of the semi-major axis. Single-axis instruments may be used in such a case (see B.3.3).

4.5.2 Measurement locations

4.5.2.1 Electric field

In order to take electric field level measurements representing the unperturbed field at a given location, the area should be free as far as possible from other power lines, towers, trees, fences, tall grass, or other irregularities. It is preferred that the location should be relatively flat. It should be noted that the influence of vegetation on the electric field level can be significant. In general, field enhancement occurs above individual items of vegetation and field attenuation occurs near the sides. Field perturbation can depend markedly on the water content in the vegetation.

All movable objects should be removed when possible. If not, then the distance between the probe and the object should be more than three times the height of the object (non-permanent object) or 1,0 m (permanent object) [6].

If these recommendations cannot be fulfilled, it should be clearly noted on the measurement report.

4.5.2.2 Magnetic field

Non-permanent objects containing magnetic materials or nonmagnetic conductors should be at least three times the largest dimensions of the object away from the point of measurement in order to measure the unperturbed field value. The distance between the probe and permanent magnetic objects should not be less than 1,0 m in order to accurately measure the ambient unperturbed field [7].

If these recommendations cannot be fulfilled, it should be clearly noted on the measurement report.

4.5.3 Perturbing effects of an operator in electric field measurement

To reduce perturbation of a measured electric field, the distance between the electric field measurement instrument and the operator should be at least 1,5 m and 3 m should be recommended [6]. This can be achieved using a fibre optic cable between the monitor and the probe with the latter on a non-conductive support.

4.5.4 Effects from other sources in magnetic field measurement

Magnetic field sources other than power systems near the measurement point should be turned off or removed, if possible, to minimise their influence on the measurement result. If it is difficult to turn off or remove the sources, relevant information about them, for example, type of source, location relative to the measurement point, etc. should be recorded.

4.5.5 Humidity condition in electric field measurement

Electric field measurement may be perturbed if the relative humidity is more than 70 % due to condensation effect on the probe and support [6]. Since the effect of humidity depends on the field meter, the ability of the field meter to work correctly under those conditions should be checked before measurement.

5 Fundamental measurement procedures for electric and magnetic fields

5.1 General procedure

Different procedures are specified here that use single-, three- or five-point measurement. If the values obtained are all below the reference level or MPE, no further processing is necessary for demonstration of compliance.

When measuring field levels under overhead lines, the field near the ground is considered to be uniform (see justification in B.3.2.1); therefore, single-point measurements are sufficient. Other situations such as public areas adjacent to underground cables, indoor substations, etc. are considered to be non-uniform and three- or five- point measurement shall be used as appropriate.

5.2 Single-point measurement

Where the field is considered to be uniform, the electric or magnetic field level at the point of interest should be measured at 1,0 m above the ground or the floor in the building. This measured level is recognised as the *average exposure level* (see Annexes A and B).

If necessary, other heights may be used, in which case the actual measurement height should be explicitly recorded in the measurement report.

5.3 Three-point measurement

Where the field is considered to be non-uniform, the electric and magnetic field level at the position of interest should be measured at the three heights, 0,5 m, 1,0 m, and 1,5 m above the ground or floor level in a building. Beside power equipment or in a building, measurement should be performed at a horizontal distance of 0,2 m from its surface or boundary or a wall.

In situations where the equipment has a height less than 1,5 m, the three-point measurements must be performed at equidistant heights with the highest being at the same height as the top of the equipment (see Figure 1).

If necessary, other heights may be used, in which case the actual measurement heights should be explicitly recorded in the measurement report.

NOTE In the case where the safety standard does not allow spatial averaging (such as [2]), then the maximum of the three measured values should be used.

The *three-point average exposure level* is recognised as the *average exposure level* (see Annex C).

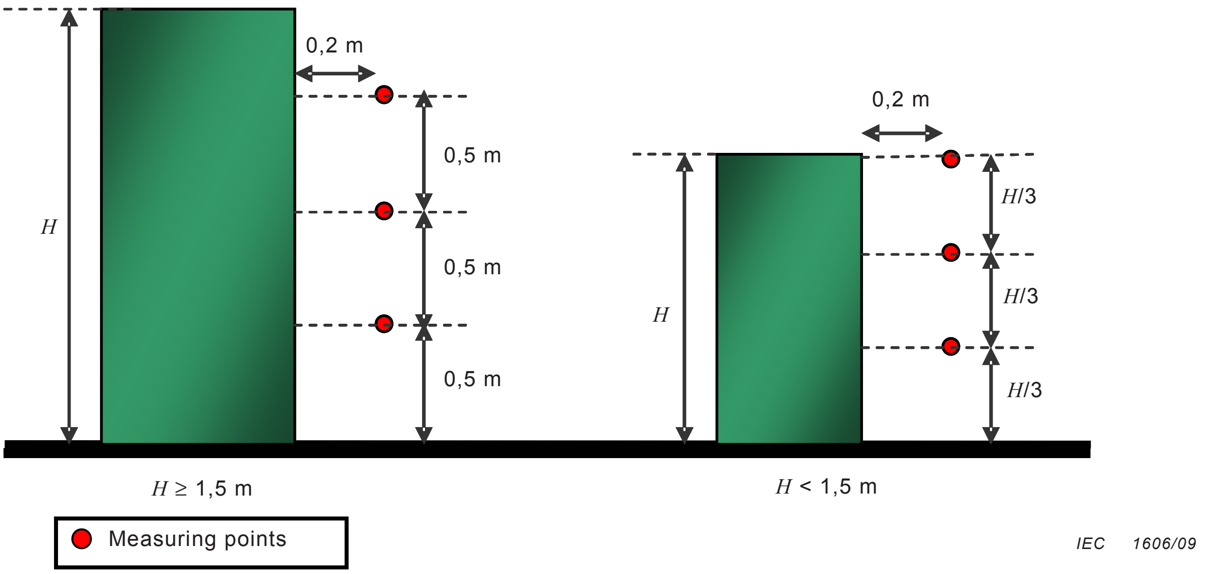


Figure 1 – Heights of *the three-point measurement*

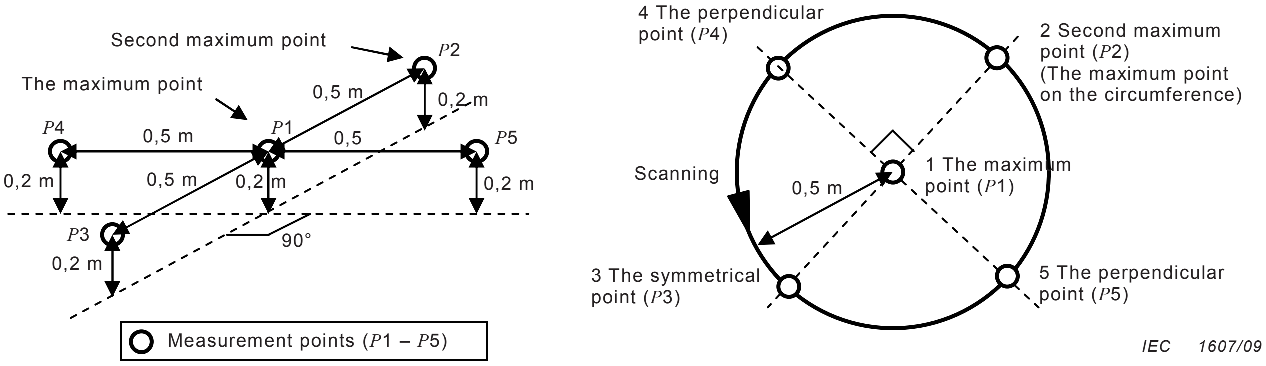
5.4 Five-point measurement

Where there are sources of field below the ground or the floor and there is a reasonable possibility that a person is likely to lie down above it, a five-point measurement should be performed as follows.

The level of magnetic field should be scanned at a height of 0,2 m above the ground or the floor to find the value and the position of the maximum field. The value and the position of the second maximum field should be scanned on a circle with a radius of 0,5 m centred on the maximum position. Another measurement should be made at the point that is symmetric to the second maximum. A further two measurements should be made, along the line perpendicular to the line passing the former three measurement points, at distances of 0,5 m on either side of the position of the maximum (see Figure 2.). The average of the largest three of the five readings shall be calculated. This average is recognised as the *average exposure level*

NOTE In practice, it may be necessary to adapt the procedure to take account of furniture that cannot be removed and walls of the room, etc..

In cases where a person is not likely to lie on the ground or the floor, the normal *three-point measurement* shall be used.



Measuring points	Measured values (index)	Adopted values
$P1$	10 µT	X
$P2$	5 µT	X
$P3$	1 µT	
$P4$	2 µT	
$P5$	3 µT	X

Three-point average exposure level is;

$$\frac{(P1 + P2 + P5)}{3} = 6\ \mu T$$

NOTE Dotted lines represent the floor or ground level.

Figure 2 – Five-point measurement

6 Measurement procedures for finding the maximum exposure level to an electric field

6.1 Overhead lines

The levels of electric field under an overhead line depend on many factors including distance from conductors, their separation and phase arrangement, and the voltage of the line (see Annex A).

The largest electric field level is found under conductors at the point on the span where the conductors are closest to the ground. Therefore, to find the position where the field level is the maximum, the electric field level should first be measured at 1,0 m above the ground along the path parallel to the overhead line under conductors where possible at appropriate intervals (longitudinal profile). Then, to discover whether another peak occurs, measurement should be performed at 1,0 m above the ground along the path perpendicular to the overhead line, at the point of the longitudinal profile maximum (lateral profile).

When the position where the field level is a maximum is already known in the area of interest, a *single-point measurement* should be performed at that position.

If the area of interest is not oversailed by a conductor, then the process for finding the *maximum exposure level* is similar, but the longitudinal profile should be parallel to the line.

There are some references, such as [6] and [7], which give detailed procedures for obtaining the profiles of electric field levels around an overhead line.

6.2 Underground cables

Underground cables do not produce electric fields above the ground, so measurement of electric field is not required.

6.3 Substations and power system equipment

With the exception of overhead lines (see 6.1) and substations with overhead lines connected to the substation, power system equipment does not produce electric fields in areas accessible to the public, so measurements of electric field are not required.

For substations with overhead lines connected to the substation, the level of electric field should be measured at a height of 1 m above the ground and at a distance of 0,2 m from the substation, around substations at appropriate intervals, to find the position where the field level is the maximum in the area of interest.

At the position where the maximum field level is found, a *three-point measurement* should be performed (see 5.3).

When the position of the maximum field within the area of interest is already known, a *three-point measurement* should be performed at that position.

For substations, maximum fields usually occur under overhead lines where they enter the substation. Electric field measurement under these lines should follow the procedure described in 6.1.

7 Measurement procedures for finding the maximum exposure level to a magnetic field

7.1 Overhead lines

The levels of magnetic field level under an overhead line depend on many factors including distance from conductors, their separation and phase arrangement, and the currents in the line (see Annex B).

The largest magnetic field is found under conductors at the point on the span where the conductors are closest to the ground. Therefore, to find the position at which the field level is the maximum, the magnetic field level should first be measured at 1,0 m above the ground along the path parallel to the overhead line under conductors where possible at appropriate intervals (longitudinal profile). Then, to discover whether another peak occurs, measurement should be performed at 1,0 m above the ground along the path perpendicular to the overhead line, at the point of the longitudinal profile maximum (lateral profile).

The magnetic field under an overhead line is considered to be uniform (see 5.1).

When a position where the field level would be the maximum is already known in the area of interest, a *single-point measurement* should be performed at that position.

If the area of interest is not oversailed by a conductor then the process for finding the *maximum exposure level* is similar, but the longitudinal profile should be parallel to the line.

There are some references, such as [6] and [7], which give detailed procedures for obtaining the profiles of magnetic field levels around an overhead line.

7.2 Underground cables

The level of magnetic field should be measured at a height of 1,0 m above the ground, along the path considered to be perpendicular to the underground cables, at appropriate intervals (lateral profile). At the position where the maximum field level is found, a *three-point measurement* should be performed (see 5.3).

The magnetic field is approximately constant along underground cables, except in some special locations such as a splice chamber, joint bay, or change of depth. Such locations can be found by taking measurements along the cable route, seeking the maximum at a height of 1,0 m (longitudinal profile). At the position where the maximum field level is found, the same procedure as that described above (lateral profile) should be performed.

If there are particular areas of interest, a measurement using the same procedure as described above (longitudinal and lateral profile) may be repeated.

When a position where the field level would be the maximum is already known in the area of interest, a *three-point measurement* should be performed at that position.

7.3 Substations and power system equipment

The level of magnetic field should be measured at a height of 1,0 m above the ground, around equipment or substations at a horizontal distance of 0,2 m from its surface or boundary, at appropriate intervals. In situations where the equipment has a height less than 1,5 m, the level of magnetic field should be measured at the top height of the equipment instead of 1,0 m. At the position where the maximum field level is found, a *three-point measurement* should be performed (see 5.3).

When the position of the maximum field within the area of interest is already known, a *three-point measurement* should be performed at that position.

For substations, maximum field levels usually occur under overhead lines or above underground cables where they enter the substation. Magnetic field measurement in these situations should follow the procedures described in 7.1 and 7.2, respectively.

Locally, higher magnetic field levels may be found closer to the surface of the equipment or to the boundary of the substation. However, those levels are not considered as representative of *average exposure level* of the general public in normal situations.

In cases where the area above an indoor substation is occupied and where a person is likely to lie on the floor, a *five-point measurement* should be performed (see 5.4).

In cases where a person is not likely to lie on the floor, the normal *three-point measurement* should be performed.

Annex A
(informative)

Characteristics of electric fields generated by AC overhead lines

A.1 General

In general, it is only higher-voltage overhead lines that produce levels of electric field that need to be considered. Electric field levels are lower near lower-voltage overhead lines, distribution equipment, and around substations. Underground cables are shielded, and therefore produce no external electric field.

This annex shows examples of calculation results of spatial profiles of electric fields generated by overhead transmission and distribution lines.

A.2 General calculation procedure for electric field level

Electric field strength E at distance r from a linear conductor parallel to the ground with charge density λ is expressed as

$$E = \frac{\lambda}{2\pi\varepsilon_0}\frac{1}{r} \tag{A.1}$$

where

ε_0 is permittivity of the vacuum, equal to 8,854 × 10^{-12} F/m.

To take into account conductivity of the ground, the computation of E at a given point (P) can be conducted by using the image charge equivalent to $-\lambda$ at height $-h$ as shown in Figure A.1.

$$E_1 = \frac{\lambda}{2\pi\varepsilon_0}\frac{1}{R_1} \quad \text{and} \quad E_2 = \frac{\lambda}{2\pi\varepsilon_0}\frac{1}{R_2} \tag{A.2}$$

where

E_1 is the electric field strength at point P caused by linear charge λ;

E_2 is the electric field strength at point P caused by image charge $-\lambda$;

R_1 is the distance of point P from linear charge λ;

R_2 is the distance of point P from linear charge $-\lambda$.

$$R_1 = \sqrt{(X_C - X_P)^2 + (h - Y_P)^2} \quad \text{and} \quad R_2 = \sqrt{(X_C - X_P)^2 + (h + Y_P)^2} \tag{A.3}$$

where

Y_P is the height of point P;

X_C is the horizontal location of linear charge λ and $-\lambda$;

X_P is the horizontal location of point P.

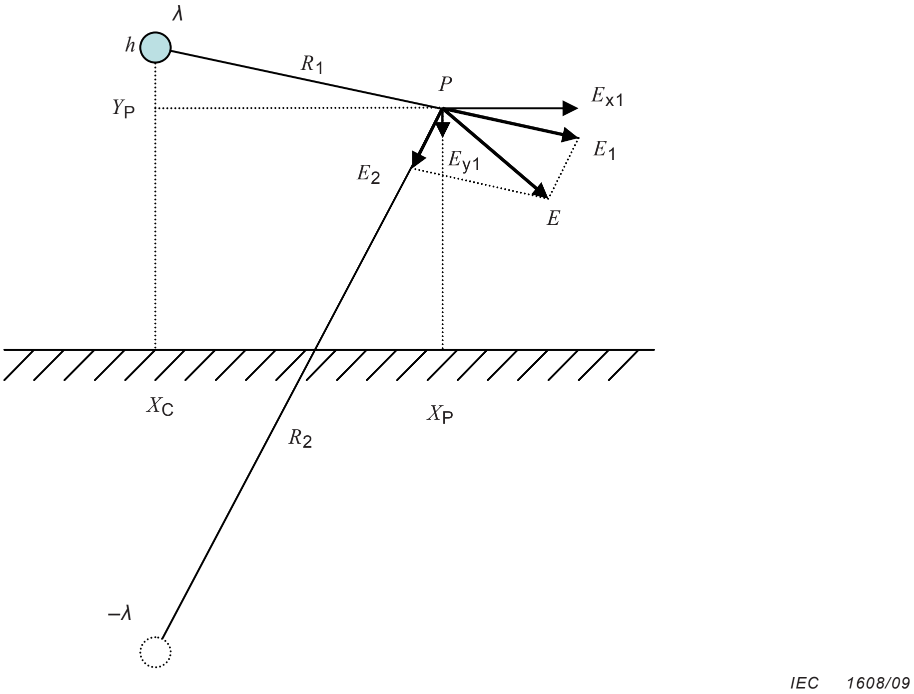


Figure A.1 – Linear charge distribution above ground

Field vectors E_1 and E_2 can be decomposed as orthogonal components.

$$E_{1x} = E_1 \frac{X_P - X_C}{R_1} \text{ and } E_{1y} = -E_1 \frac{h - Y_P}{R_1} \tag{A.4}$$

$$E_{2x} = -E_2 \frac{X_P - X_C}{R_2} \text{ and } E_{2y} = -E_2 \frac{h + Y_P}{R_2} \tag{A.5}$$

Finally, the components of field vector E are

$$E_x = \frac{\lambda}{2\pi\varepsilon_0}\left[\frac{X_P - X_C}{R_1^2} - \frac{X_P - X_C}{R_2^2}\right] \text{ and } E_y = -\frac{\lambda}{2\pi\varepsilon_0}\left[\frac{h - Y_P}{R_1^2} + \frac{h + Y_P}{R_2^2}\right] \tag{A.6}$$

Field strength E at point P is

$$E = \sqrt{E_x^2 + E_y^2} \tag{A.7}$$

Potential V at the conductor surface is given by

$$V = \frac{\lambda}{2\pi\varepsilon_0} \ln \frac{2h}{a} \tag{A.8}$$

Where a is the radius of the conductor.

In the case of multiple conductors as shown in Figure A.2, Equation (A.8) becomes a matrix.

$$[P][\lambda] = [V] \tag{A.9}$$

Matrix $[P]$ is the potential coefficients matrix where

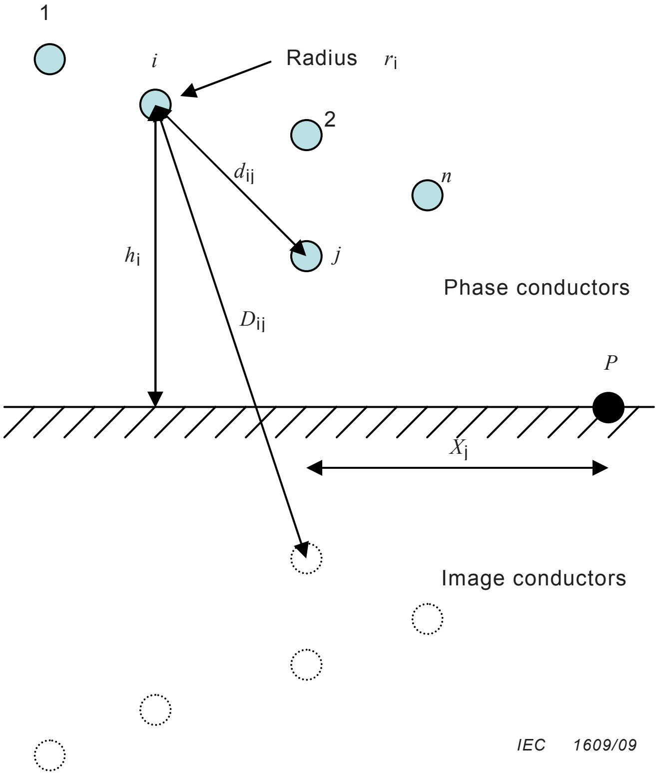


Figure A.2 – General *n*-phase system with ground

$$P_{ii} = \frac{1}{2\pi\varepsilon_0}\ln(\frac{2h_i}{r_i}) \quad \text{for } i = 1 \text{ to } n \tag{A.10}$$

$$P_{ij} = \frac{1}{2\pi\varepsilon_0}\ln(\frac{D_{ij}}{d_{ij}}) \quad \text{for i} \neq \text{j} \qquad \text{A.11)}$$

where

n is the number of conductors;

D_{ij} is the distance between conductor i and the image of the conductor j;

d_{ij} is the distance between the conductors i and j;

r_i is the radius of conductor i.

When calculating electric field levels under an overhead line, this linear charge distribution system can be used. For an AC power line, conductor i corresponds to each phase conductor. When phase conductor i consists of a subconductor bundle, which has the number of subconductors n_b and in which each subconductor is located at each apex of a regular polygon, r_i can be substituted by equivalent geometric radius r_{ei} (see Figure A.4).

$$r_{ei} = \left[n_b \ r_0 \left(\frac{S}{2\sin(\pi/n_b)} \right)^{n_b - 1} \right]^{\frac{1}{n_b}} \tag{A.12}$$

where

n_b is the number of subconductors,

r_0 is the subconductor radius,

S is adjacent subconductors spacing.

Charges λ_i can be determined by solving the linear system of equations (A.9).

Components E_{xi} and E_{yi} of the field vector generated by conductor i at point P are

$$E_{xi} = \frac{\lambda_i}{2\pi\varepsilon_0}\left[\frac{X_P - X_{ci}}{R_{1i}^2} - \frac{X_{ci} - X_P}{R_{2i}^2}\right] \text{ and } E_{yi} = -\frac{\lambda_i}{2\pi\varepsilon_0}\left[\frac{h_i - Y_P}{R_{1i}^2} + \frac{h_i + Y_P}{R_{2i}^2}\right] \qquad \text{(A.13}$$

where

X_{Ci} is the horizontal location of linear charge λ_i and - λ_i;

$$R_{1i} = \sqrt{(X_{ci} - X_P)^2 + (h_i - Y_P)^2} \text{ and } R_{2i} = \sqrt{(X_{ci} - X_P)^2 + (h_i + Y_P)^2} \qquad \text{(A.14)}$$

For the whole overhead lines, the total components at point P are

$$E_x = \sum_{i=1}^{n} E_{xi} \text{ and } E_y = \sum_{i=1}^{n} E_{yi} \qquad \text{(A.15)}$$

A.3 Example of electric fields generated by overhead transmission lines

A.3.1 Spatial profiles of an electric field

Figure A.3 shows an example of the spatial profile of the calculated electric field levels generated by a 77 kV overhead transmission line that has a double-circuit, vertical configuration. Each conductor has a radius of 12,65 mm. Cases of both the untransposed and the transposed phase arrangement are considered (see Figure A.3). Electric field levels are calculated as a function of distance from the centre of the conductors, at a height of 1,0 m above ground.

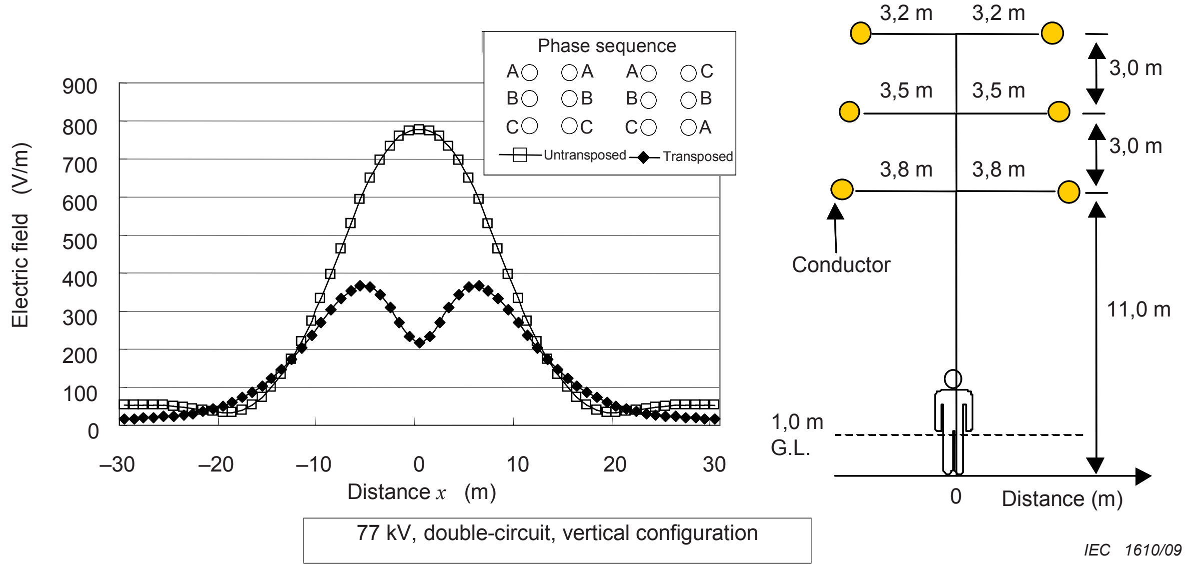


Figure A.3 – Electric field levels under an overhead transmission line

Figure A.4 shows an example of the spatial profile of the calculated electric field levels generated by a 500 kV overhead transmission line that has a single-circuit, horizontal configuration. Each conductor has a radius of 14,25 mm. Electric field levels are calculated as a function of distance from the centre of the conductors, at a height of 1,0 m above the ground. Each phase consists of four bundled conductors with radii of 14,25 mm, and the adjacent conductors spacing of 400 mm. Consequently, the equivalent geometric radius of 189,5 mm, obtained by Equation (A.4) is used for calculation.

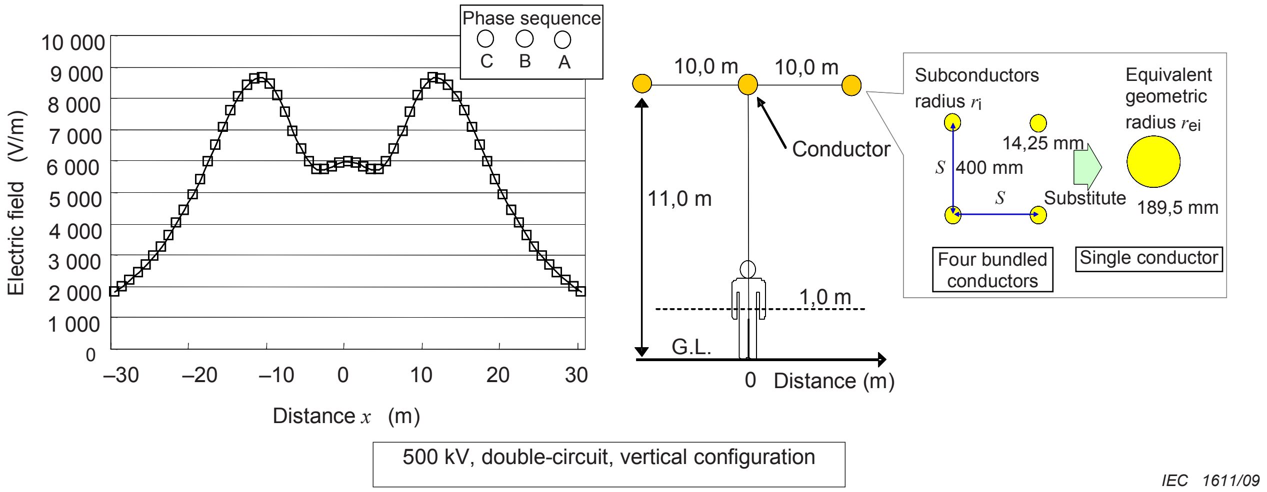


Figure A.4 – Electric field levels under an overhead transmission line with bundled conductors

A.3.2 Factors affecting an electric field

A.3.2.1 Clearance of the lowest conductor from ground

Figure A.5 shows two examples of the spatial profile of the calculated electric field levels generated by a 77 kV overhead transmission line that has a double-circuit, vertical configuration. In one case, the clearance of the lowest conductor from ground is assumed to be 11,0 m, and in the other, 6,0 m. The cases of both the untransposed and the transposed phase arrangement are considered. Electric field levels are calculated as a function of distance from the centre of the conductors, at heights of 0,5 m, 1,0 m, and 1,5 m above ground. Each conductor has a radius of 12,65 mm.

Calculated non-uniformity is also shown in the Figure A.5, which is defined as the maximum value of

$$(\left|E_h - E_{\text{avg}}\right|)/E_{\text{avg}} \times 100\ (\%) \tag{A.16}$$

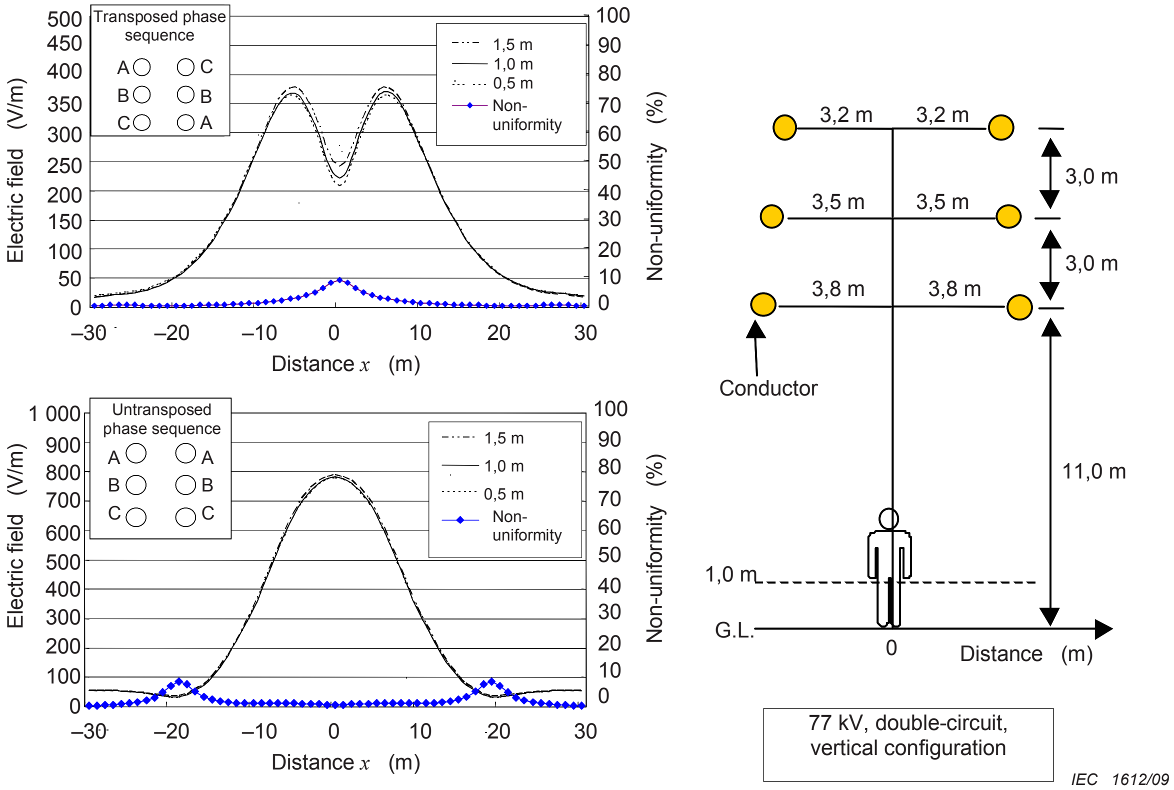
where

E_h is the electric field level at heights of 0,5 m, 1,0 m and 1,5 m above ground;

E_{avg} is the arithmetic mean of the three levels.

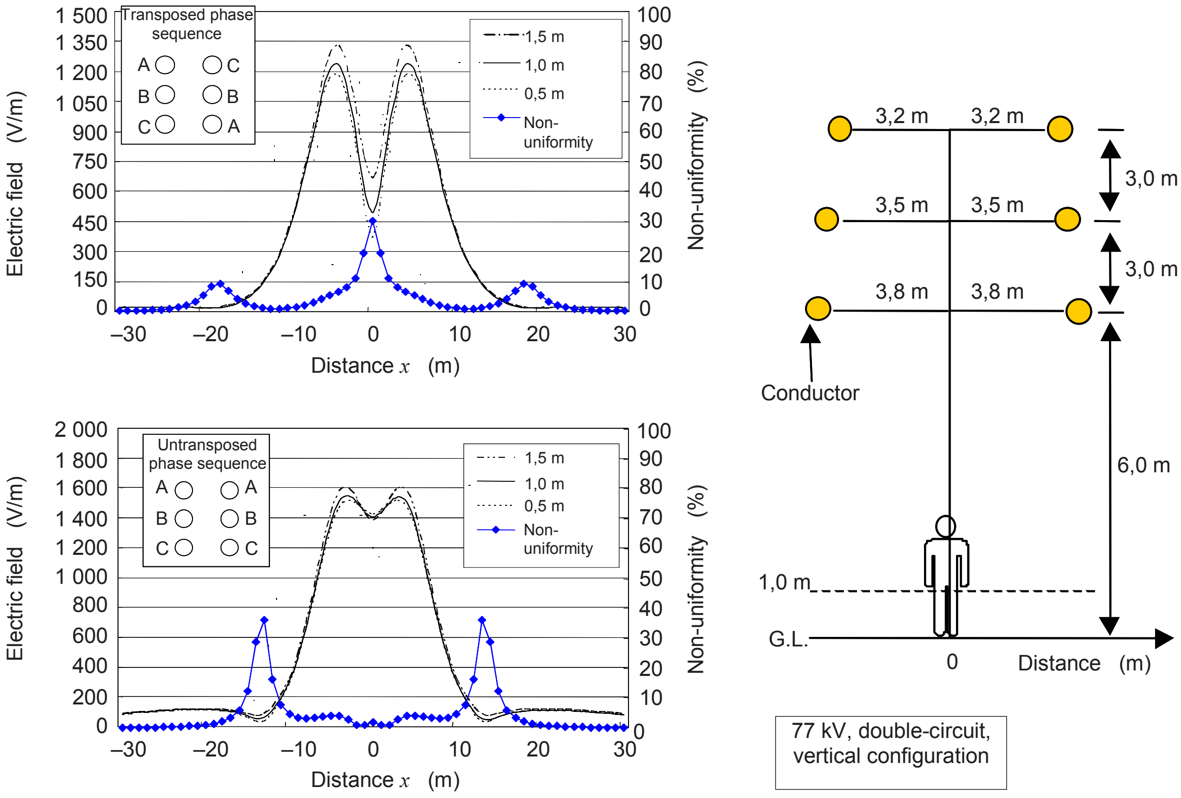
This could be an approximate measure to estimate and to define the non-uniformity of an electric field.

Figure A.6 shows two examples of the spatial profile of the calculated electric field levels generated by a 500 kV overhead transmission line that has a single-circuit, horizontal configuration. Calculated non-uniformity is also shown in the Figure A.6. In one case, the clearance of the lowest conductor from ground is assumed to be 11,0 m, and in the other, 6,0 m. Electric field levels are calculated as a function of distance from the centre of the conductors, at heights of 0,5 m, 1,0 m, and 1,5 m above ground. Each phase consists of four bundled conductors with radii of 14,25 mm, and the adjacent conductors spacing of 400 mm. Consequently, the equivalent geometric radius of 189,5 mm, obtained by Equation (A.12), is used for calculation.



IEC 1612/09

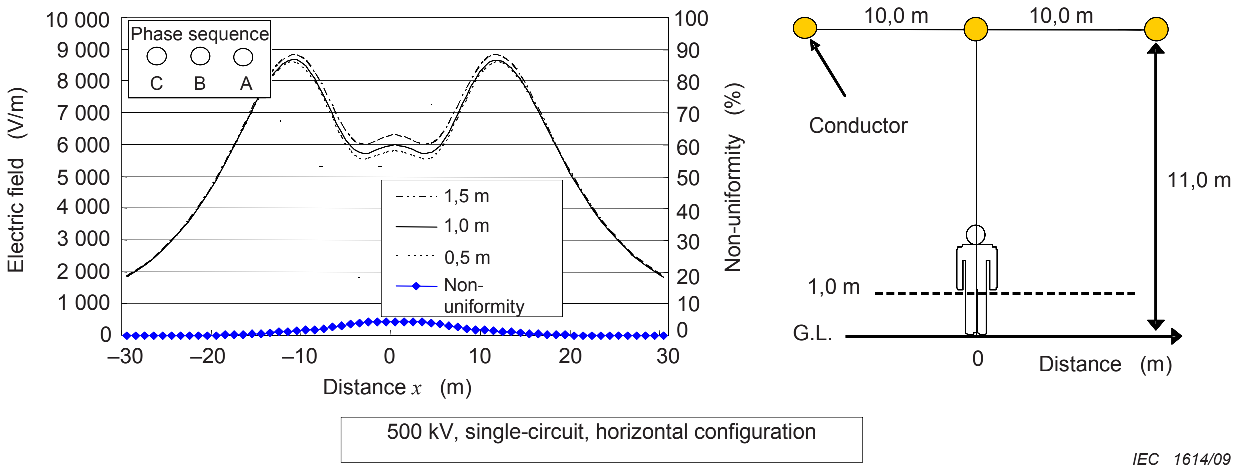
a) Clearance of the lowest conductor from ground is 11,0 m



IEC 1613/09

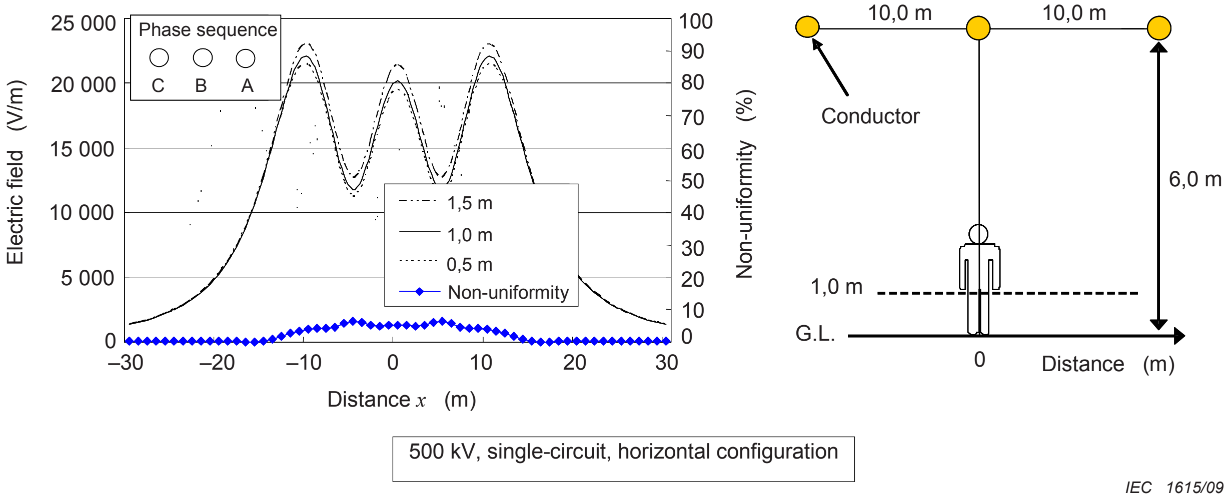
b) Clearance of the lowest conductor from ground is 6,0 m

Figure A.5 – Electric field levels and non-uniformity under a 77 kV overhead transmission line – Effect of heights of conductors



IEC 1614/09

a) **Clearance of the lowest conductor from ground is 11,0 m**



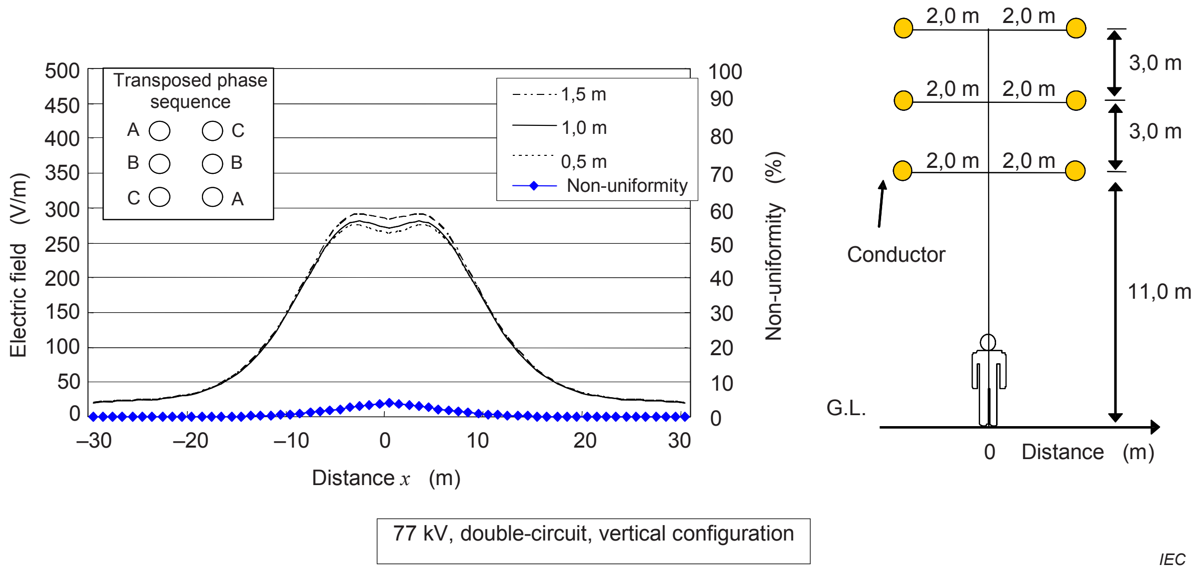
IEC 1615/09

b) **Clearance of the lowest conductor from ground is 6,0 m**

Figure A.6 – Electric field levels and non-uniformity under a 500 kV overhead transmission line – Effects of the heights of conductors

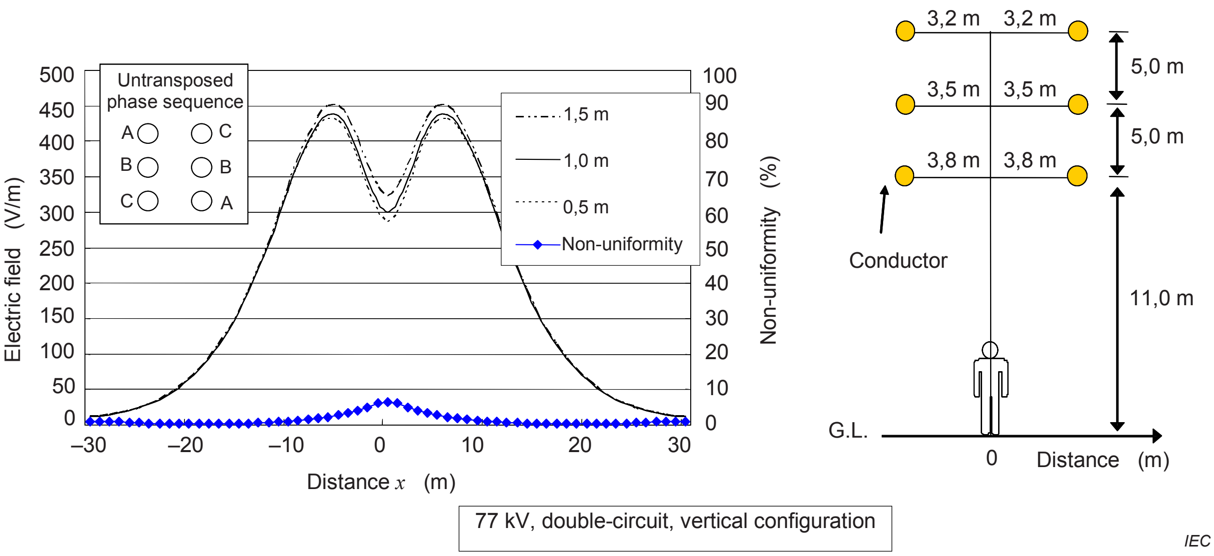
A.3.2.2 Separation of each conductor

Figure A.7 shows two examples of the spatial profile of the calculated electric field levels generated by a 77 kV overhead transmission line that has a double-circuit, vertical configuration. Calculated non-uniformity is also shown in Figure A.7. Two overhead lines with same voltage are assumed, one with smaller conductor separations and the other with larger ones. The phase arrangement is transposed, and each conductor has a radius of 12,65 mm. Electric field levels are calculated as a function of distance from the centre of the conductors, at a height of 1,0 m above ground.



IEC 1616/09

a) Smaller conductor separations

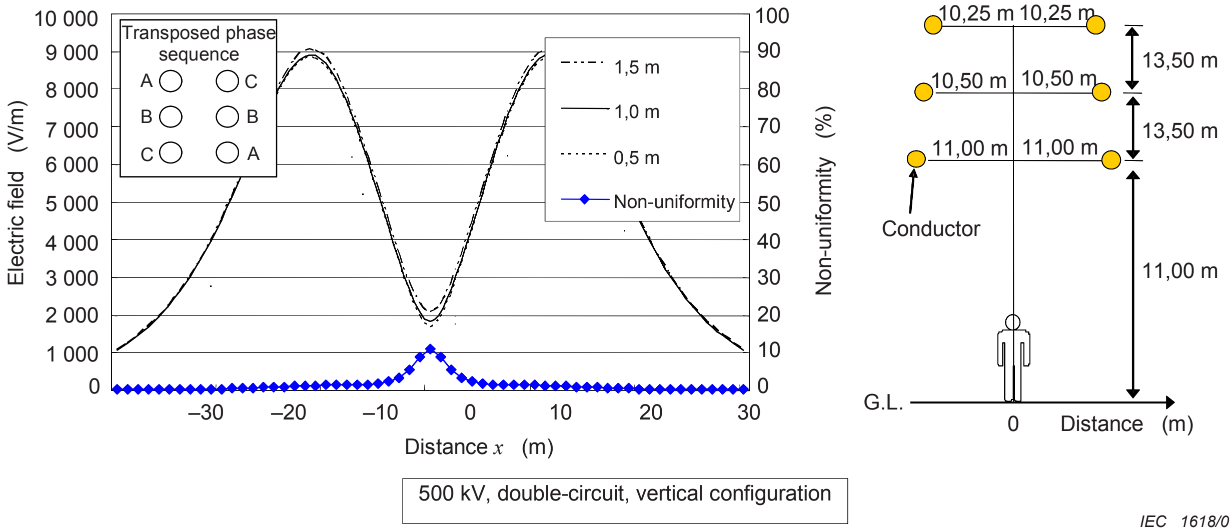


IEC 1617/09

b) Larger conductor separations

Figure A.7 – Electric field levels under a 77 kV overhead transmission line – Effect of separation between conductors

Figure A.8 shows an example of the spatial profile of the calculated electric field levels generated by a 500 kV overhead transmission line that has double-circuit and vertical configuration. Calculated non-uniformity is also shown in Figure A.8. The phase arrangement is transposed. Electric field levels are calculated as a function of distance from the centre of the conductors, at a height of 1,0 m above ground. Each phase consists of four bundled conductors with radii of 14,25 mm and the adjacent conductors spacing of 400 mm. Consequently, the equivalent geometric radius of 189,5 mm, obtained by Equation (A.12), is used for calculation.

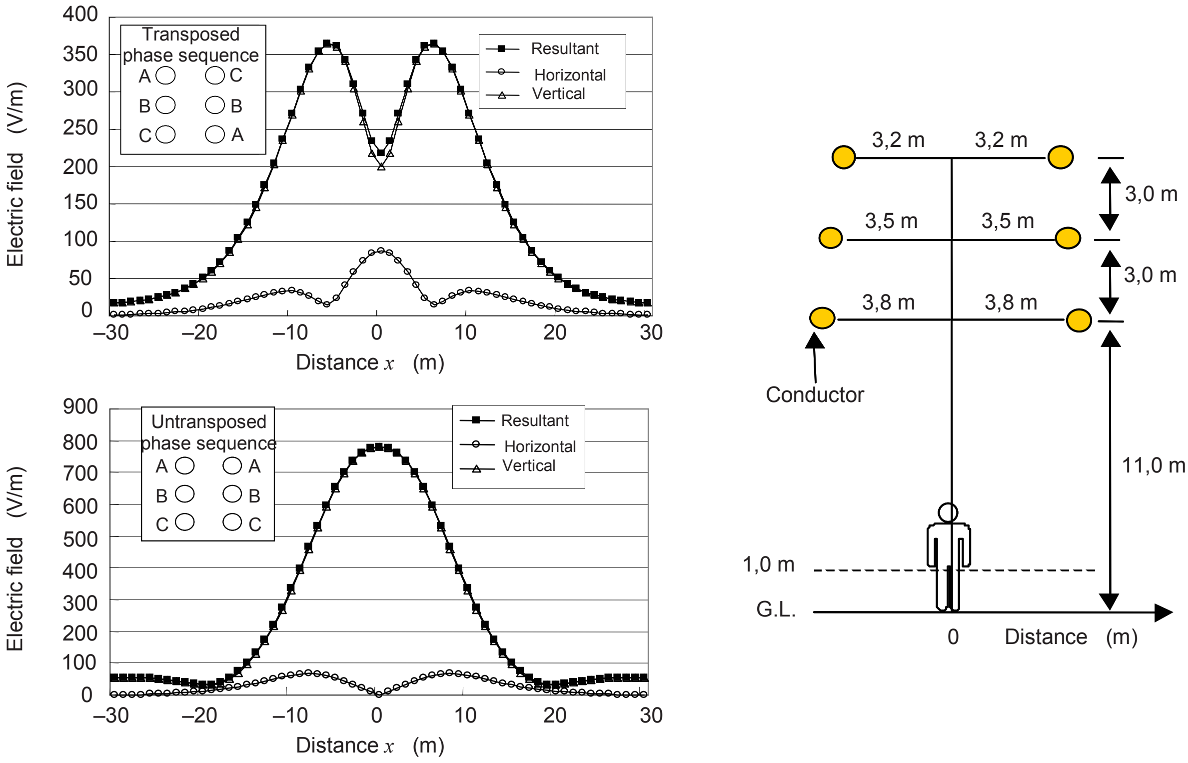


IEC 1618/09

Figure A.8 – Electric field levels and non-uniformity under a 500 kV overhead transmission line – Effect of separation between conductors

A.3.3 Vertical and horizontal components

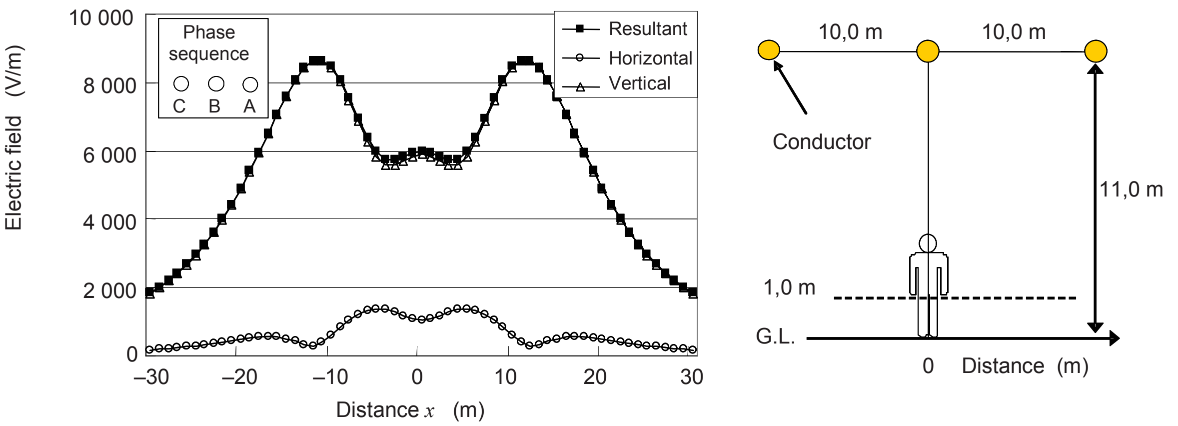
Figure A.9 shows examples of the spatial profile of vertical and horizontal components of the calculated electric field levels generated by a 77 kV overhead transmission line that has double-circuit, vertical configuration. Each conductor has a radius of 12,65 mm. Both transposed and untransposed phase arrangements are considered. Electric field levels are calculated as a function of distance from the centre of the conductors, at a height of 1,0 m above ground. The clearance of the lowest conductor from ground is 11,0 m.



IEC 1619/09

Figure A.9 – Vertical and horizontal components of electric field levels under a 77 kV overhead transmission line

Figure A.10 shows an example of the spatial profile of vertical and horizontal components of the calculated electric field levels generated by a 500 kV overhead transmission line that has a single-circuit, horizontal configuration. Electric field levels are calculated as a function of distance from the centre of the conductors, at a height of 1,0 m above ground. The clearance of the lowest conductor from ground is 11,0 m. Each phase consists of four bundled conductors with a radius of 14,25 mm and the adjacent conductors spacing of 400 mm. Consequently, the equivalent geometric radius of 189,5 mm, obtained by Equation (A.12), is used for calculation.

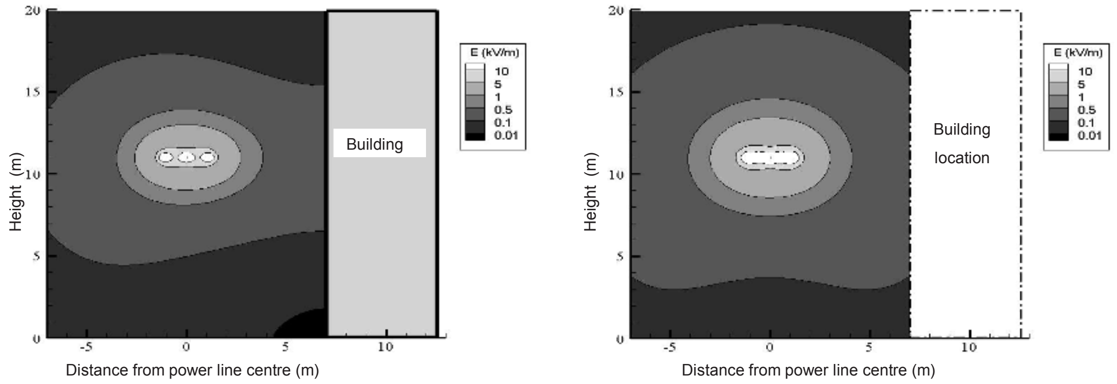


IEC 1620/09

Figure A.10 – Vertical and horizontal components of electric field levels under a 500 kV overhead transmission line

A.3.4 Proximity effect

Figure A.11 shows an example of a calculated contour plot of the electric field levels generated by a 25 kV overhead line close to a tall building. The maximum field on the wall is located at a height close to the conductors. At ground level, the field is reduced by the building (see Figure A.12).



With the effect of the building

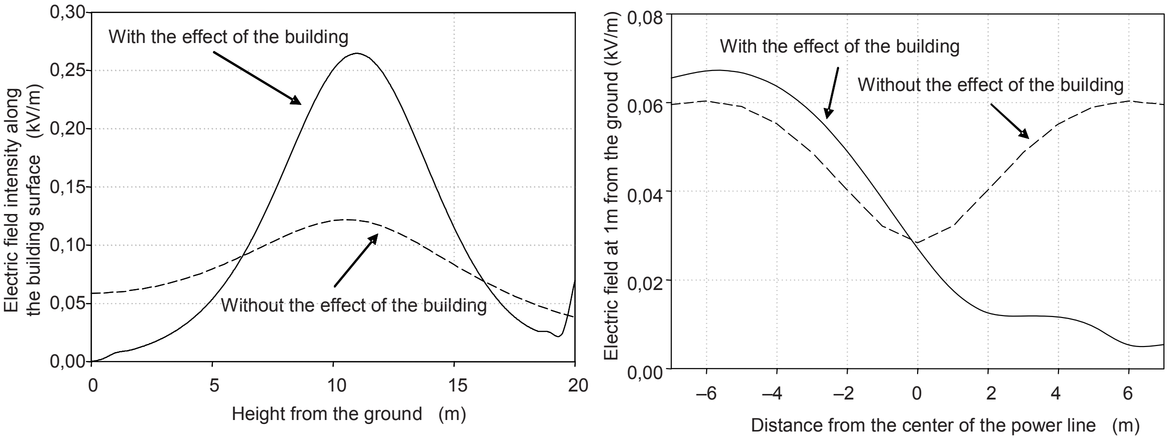
Without the effect of the building

IEC 1621/09

Key

Conductor height	11,0 m
Conductor separation	1,12 m
Building height	20,0 m, located at 7,0 m from the centre of an overhead line

Figure A.11 – Electric field contour of a 25 kV overhead line



IEC 1622/09

Figure A.12 – Electric field profile along the wall of a building and at 1 m above ground level

Annex B
(informative)

Characteristics of magnetic fields generated by AC power systems

B.1 General

When the magnetic field is uniform, the *average exposure level* to the magnetic field can be evaluated by a *single-point measurement*. However, when the magnetic field is non-uniform, an appropriate measurement method is necessary for evaluating the *average exposure level*. For that purpose, we have to understand the spatial distribution of magnetic fields around the power system.

The spatial distribution of magnetic fields can be different depending on the types of source, for example overhead line, underground cable, power distribution equipment and substation. They also differ depending on the circuit configuration of each system.

This annex shows the general calculation procedure and examples of calculated spatial profiles of magnetic fields generated by various power systems.

B.2 General calculation procedure for magnetic field level

B.2.1 Resultant magnetic field

The resultant magnetic flux density B_r is defined as a square root of the mean value over a cycle T of the inner product of magnetic field vector $\boldsymbol{B}$ and $\boldsymbol{B}$, and is expressed by the following formula:

$$\begin{aligned}\boldsymbol{B} &= B_x(t)\,\boldsymbol{i} + B_y(t)\,\boldsymbol{j} + B_z(t)\,\boldsymbol{k} \\ &= \sqrt{2}B_x \sin(\omega t+\alpha)\,\boldsymbol{i} + \sqrt{2}B_y \sin(\omega t+\beta)\,\boldsymbol{j} + \sqrt{2}B_z \sin(\omega t+\gamma)\,\boldsymbol{k}\end{aligned} \tag{B.1}$$

where $\boldsymbol{i}$, $\boldsymbol{j}$ and $\boldsymbol{k}$ are unit vectors of three orthogonal directions.

$$\begin{aligned}B_\mathrm{r} &= \sqrt{\frac{1}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} |\mathbf{B}|^2 \,\mathrm{d}t} = \sqrt{\frac{\omega}{2\pi}\int_{-\frac{\pi}{\omega}}^{\frac{\pi}{\omega}} |\mathbf{B}|^2 \,\mathrm{d}t} \\ &= \sqrt{\frac{\omega}{2\pi}\int_{-\frac{\pi}{\omega}}^{\frac{\pi}{\omega}} \left[2B_x{}^2\sin^2(\omega t+\alpha) + 2B_y{}^2\sin^2(\omega t+\beta) + 2B_z{}^2\sin^2(\omega t+\gamma)\right]\mathrm{d}t}\end{aligned} \tag{B.2}$$

The substitution

$$\int_{-\frac{\pi}{a}}^{\frac{\pi}{\omega}} \sin^2(\omega t+\alpha)\,\mathrm{d}t = \int_{-\frac{\pi}{a}}^{\frac{\pi}{\omega}} \frac{1}{2}\{1-\cos 2(\omega t+\alpha)\}\,\mathrm{d}t = \frac{\pi}{\omega} \tag{B.3}$$

leads to the significant simplification of the formula (B.2):

$$B_\mathrm{r} = \sqrt{B_x{}^2 + B_y{}^2 + B_z{}^2} \tag{B.4}$$

B_r is simply called the resultant magnetic field. It is not influenced by the phase difference between each axial component and is determined only by the r.m.s. value of each axial component of the magnetic field.

B_r should be used to evaluate the exposure of the human body to magnetic fields.

B.2.2 Maximum and minimum r.m.s value of a single-frequency AC magnetic field

The conditions to provide the maximum and minimum magnitude of magnetic field vector $|\boldsymbol{B}|$ are shown below.

$$\frac{\mathrm{d}\left|\boldsymbol{B}\right|}{\mathrm{d}t}=0 \tag{B.5}$$

$|\boldsymbol{B}|$ is expressed by the following formula:

$$\begin{aligned}\left|\boldsymbol{B}\right| &= \sqrt{\boldsymbol{B}\cdot\boldsymbol{B}} \\ &= \sqrt{2{B_x}^2\sin^2(\omega t+\alpha)+2{B_y}^2\sin^2(\omega t+\beta)+2{B_z}^2\sin^2(\omega t+\gamma)}\end{aligned} \tag{B.6}$$

For Equation (B.6), the condition to satisfy formula (B.5) is the following.

$$2\omega t+\delta=\pi \quad \text{or} \quad 2\omega t+\delta=0 \tag{B.7}$$

where

δ is given by

$$\delta=\tan^{-1}\frac{{B_x}^2\sin 2\alpha+{B_y}^2\sin 2\beta+{B_z}^2\sin 2\gamma}{{B_x}^2\cos 2\alpha+{B_y}^2\cos 2\beta+{B_z}^2\cos 2\gamma} \tag{B.8}$$

By substituting (B.7) into Equation(B.6) one can evaluate respective expressions for B_min, the minimum r.m.s. value of $|\boldsymbol{B}|$ and B_max, the maximum r.m.s. value of $|\boldsymbol{B}|$:

$$\left|\boldsymbol{B}\right|=\sqrt{\left({B_x}^2+{B_y}^2+{B_z}^2\right)\pm\left\{{B_x}^2\cos(2\alpha-\delta)+{B_y}^2\cos(2\beta-\delta)+{B_z}^2\cos(2\gamma-\delta)\right\}} \tag{B.9}$$

$$\begin{aligned}B_\mathrm{max} &= \frac{1}{\sqrt{2}}\,\mathrm{Max}\left|\boldsymbol{B}\right| \\ &= \frac{1}{\sqrt{2}}\sqrt{\left({B_x}^2+{B_y}^2+{B_z}^2\right)+\left\{{B_x}^2\cos(2\alpha-\delta)+{B_y}^2\cos(2\beta-\delta)+{B_z}^2\cos(2\gamma-\delta)\right\}}\end{aligned} \tag{B.10}$$

$$\begin{aligned}B_\mathrm{min} &= \frac{1}{\sqrt{2}}\,\mathrm{Min}\left|\boldsymbol{B}\right| \\ &= \frac{1}{\sqrt{2}}\sqrt{\left({B_x}^2+{B_y}^2+{B_z}^2\right)-\left\{{B_x}^2\cos(2\alpha-\delta)+{B_y}^2\cos(2\beta-\delta)+{B_z}^2\cos(2\gamma-\delta)\right\}}\end{aligned} \tag{B.11}$$

B_max and B_min, which are called the maximum and minimum r.m.s. value of magnetic fields, correspond to the major and minor axes of the elliptical magnetic field respectively. The relation of $B_\mathrm{max} \le B_\mathrm{r}$ always holds true, and the equal sign holds true for linear magnetic fields. Furthermore, the following relation holds between B_max, B_min,and B_r.

$$B_r = \sqrt{{B_{max}}^2 + {B_{min}}^2} \qquad (B.12)$$

For fields with harmonics, B_{max} and B_{min} are more difficult to determine, so measurement should rely totally on the determination of B_r by the methods described in 4.3.

B.3 Example of magnetic fields generated by overhead transmission lines

B.3.1 Spatial profiles of a magnetic field

Figure B.1 shows examples of the spatial profile of the calculated magnetic field levels generated by a 77 kV overhead transmission line that has double-circuit, vertical configuration. Cases of both the untransposed and the transposed phase arrangement are considered. Magnetic field levels are calculated as a function of distance from the centre of the line, at a height of 1,0 m above ground. The value of current flowing through each circuit is assumed to be balanced 200 A.

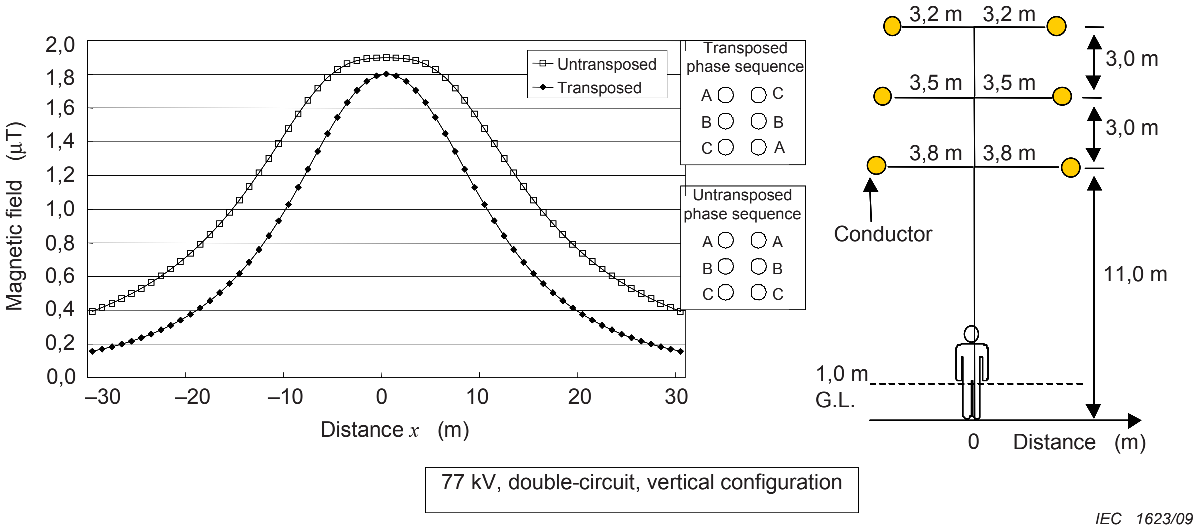
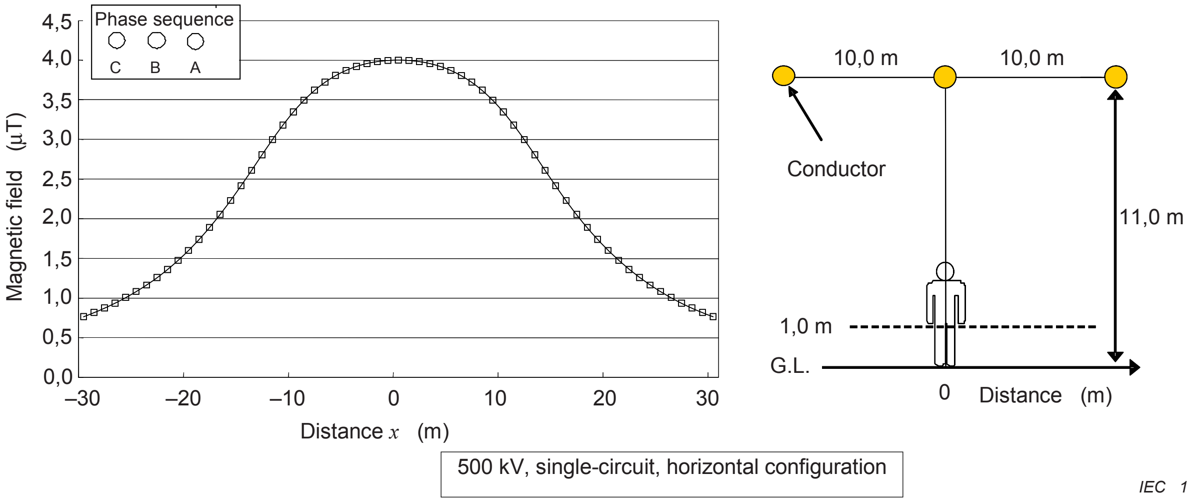


Figure B.1 – Magnetic field levels under a 77 kV overhead transmission line

Figure B.2 shows an example of the spatial profile of the calculated magnetic field levels generated by a 500 kV overhead transmission line that has a single-circuit, horizontal configuration. Magnetic field levels are calculated as a function of distance from the centre of the conductors, at a height of 1,0 m above ground. The value of current flowing through the circuit is assumed to be balanced 200 A.



IEC 1624/09

Figure B.2 – Magnetic field levels under a 500 kV overhead transmission line

B.3.2 Factors affecting magnetic field

B.3.2.1 Clearance of the lowest conductor from ground

Figure B.3 shows two examples of the spatial profile of the calculated magnetic field levels generated by a 77 kV overhead transmission line that has a double-circuit, vertical configuration. In one case, the clearance of the lowest conductor from ground is assumed to be 11,0 m, and in the other, 6,0 m. Cases of both the untransposed and the transposed phase arrangement are considered. Magnetic field levels are calculated as a function of distance from the centre of the conductors, at heights of 0,5 m, 1,0 m and 1,5 m above ground. The value of current flowing through each circuit is assumed to be balanced 200 A.

Figure B.3 also shows the calculated non-uniformity, which is defined as the maximum value of

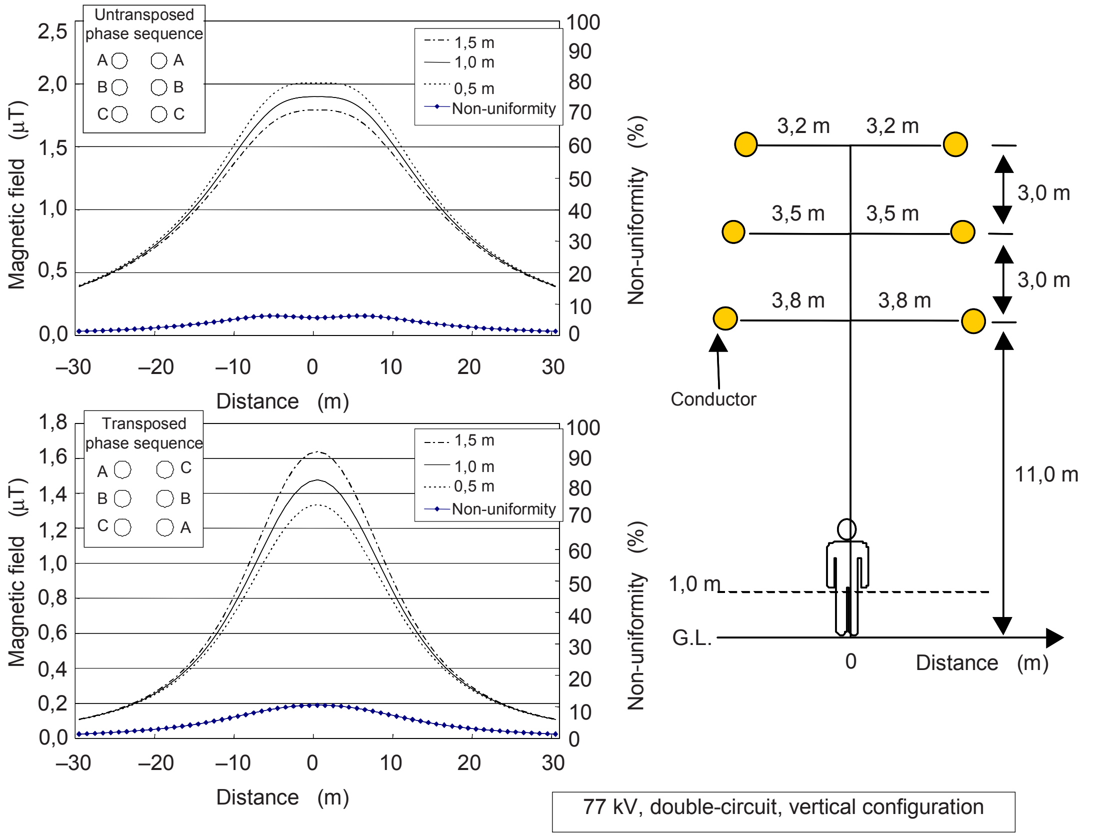
$$(|B_h - B_{\text{avg}}|)/B_{\text{avg}} \times 100 \quad (\%) \qquad \text{(B.13)}$$

where

B_h is the magnetic field level at heights of 0,5 m, 1,0 m and 1,5 m above ground;

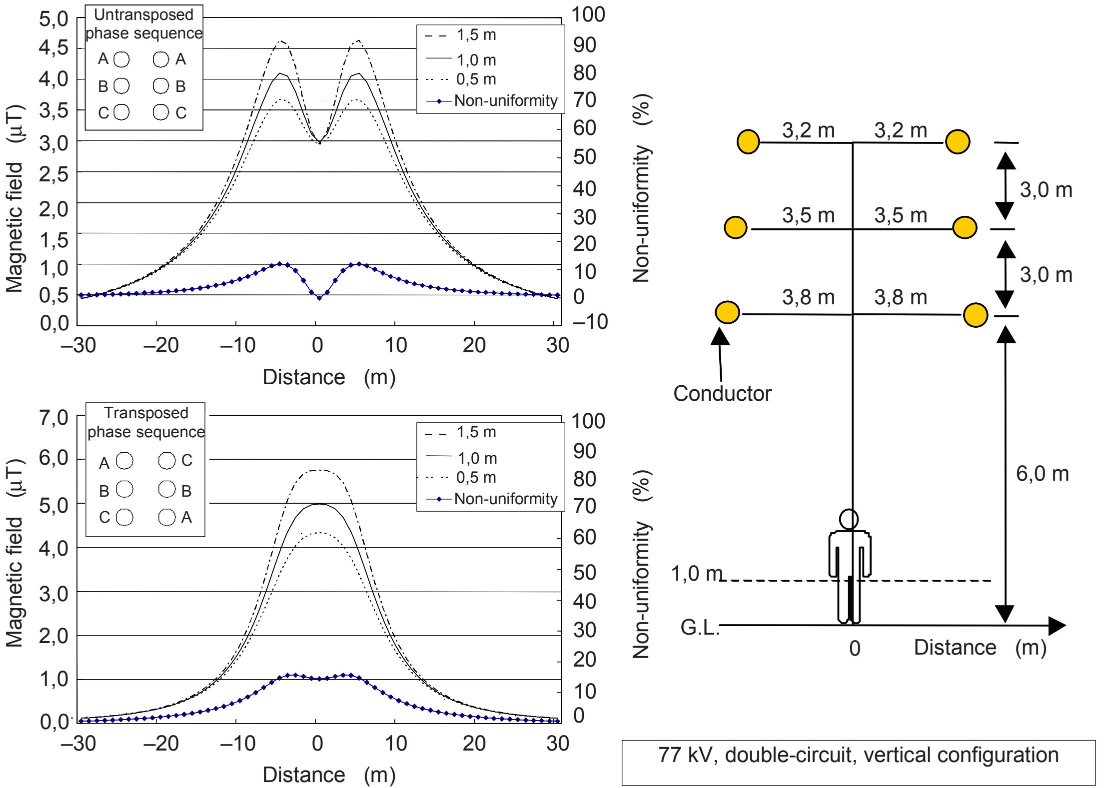
B_{avg} is the arithmetic mean of the three levels.

This could be an approximate measure to estimate and to define the non-uniformity of a magnetic field.



IEC 1625/09

a) Clearance of the lowest conductor from the ground is 11,0 m

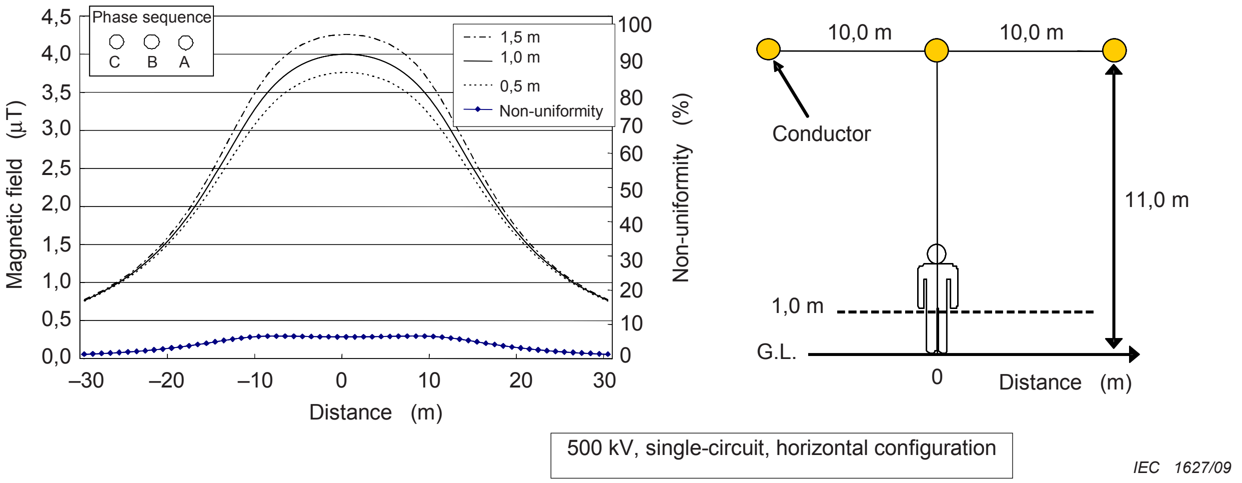


IEC 1626/09

b) Clearance of the lowest conductor from the ground is 6,0 m

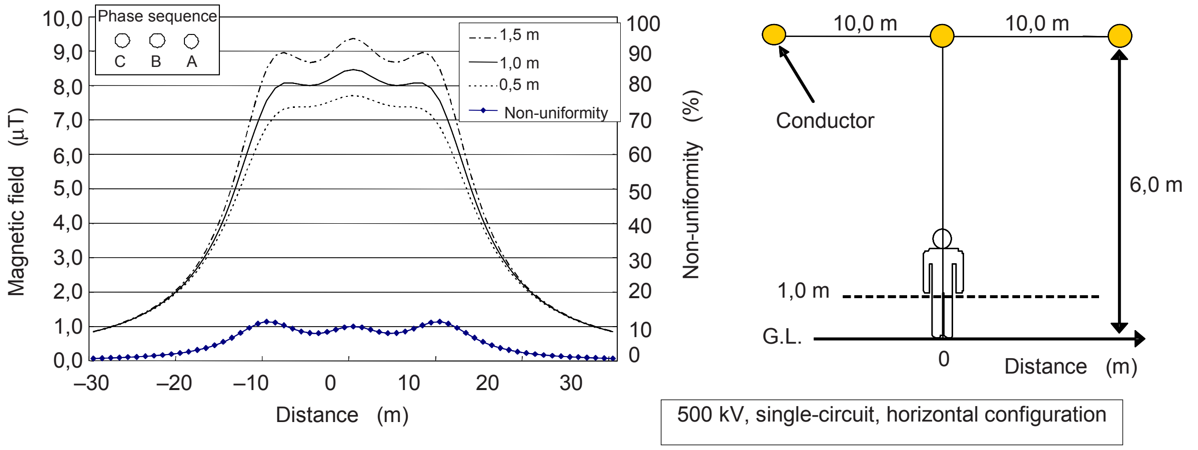
Figure B.3 – Magnetic field levels and non-uniformity under a 77 kV overhead transmission line – Effect of heights of conductors

Figure B.4 shows two examples of the spatial profile of the calculated magnetic field levels generated by a 500 kV overhead transmission line that has a single-circuit, horizontal configuration. Calculated non-uniformity is also shown in Figure B.4. In one case, the clearance of the lowest conductor from ground is assumed to be 11,0 m, and in the other, 6,0 m. Magnetic field levels are calculated as a function of distance from the centre of the conductors, at heights of 0,5 m, 1,0 m and 1,5 m above ground. The value of current flowing through the circuit is assumed to be balanced 200 A.



IEC 1627/09

a) Clearance of the lowest conductor from the ground is 11,0 m



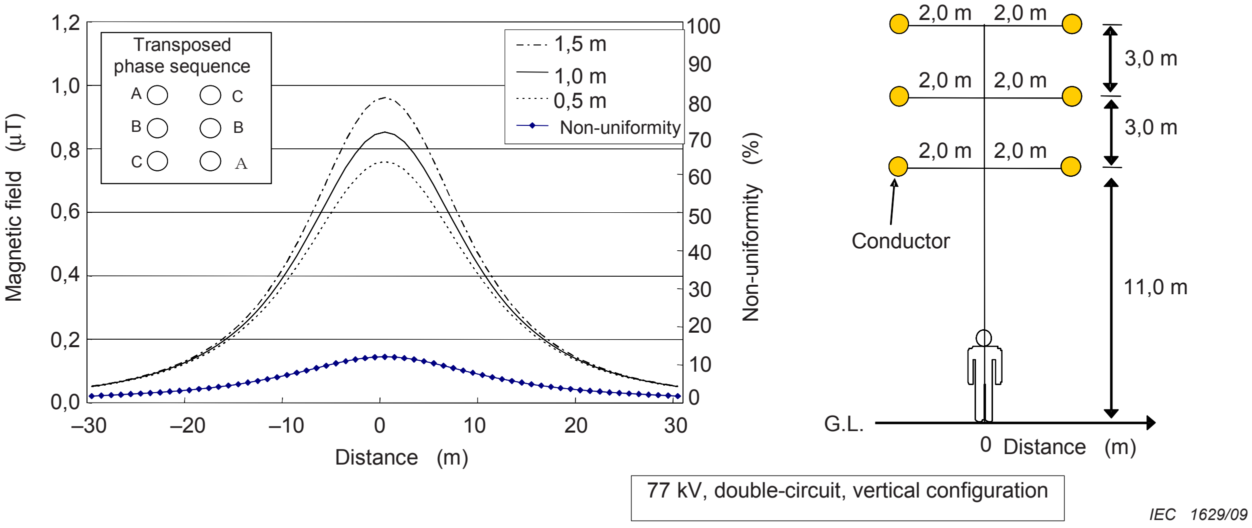
IEC 1628/09

b) Clearance of the lowest conductor from the ground is 6,0m

Figure B.4 – Magnetic field levels and non-uniformity under a 500 kV overhead transmission line – Effect of heights of conductors

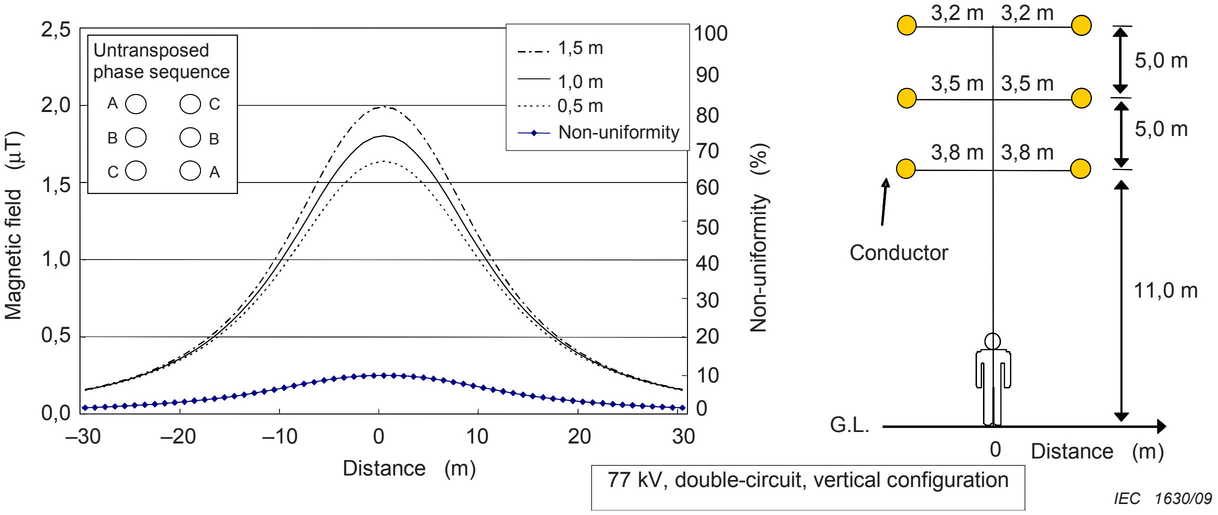
B.3.2.2 Separation of each conductor

Figure B.5 shows two examples of spatial profile of the calculated magnetic field levels generated by a 77 kV overhead transmission line that has a double-circuit, vertical configuration. Calculated non-uniformity is also shown in Figure B.5. Two overhead lines with same voltage are assumed, one with smaller conductor separations and the other with larger ones. Magnetic field levels are calculated as a function of distance from the centre of the conductors, at heights of 0,5 m, 1,0 m and 1,5 m above ground. The value of current flowing through the circuit is assumed to be balanced 200 A, and a transposed phase arrangement is also assumed.



IEC 1629/09

a) Smaller conductor separations



IEC 1630/09

b) Larger conductor separations

Figure B.5 – Magnetic field levels and non-uniformity under a 77 kV overhead transmission line – Effect of separation between conductors

Figure B.6 shows an example of the spatial profile of the calculated magnetic field levels generated by a 500 kV overhead transmission line that has a double-circuit, vertical configuration. Calculated non-uniformity is also shown in Figure B.6. Magnetic field levels are calculated as a function of distance from the centre of the conductors, at heights of 0,5 m, 1,0 m, and 1,5 m above ground. The value of current flowing through the circuit is assumed to be balanced 200 A, and a transposed phase arrangement is also assumed.

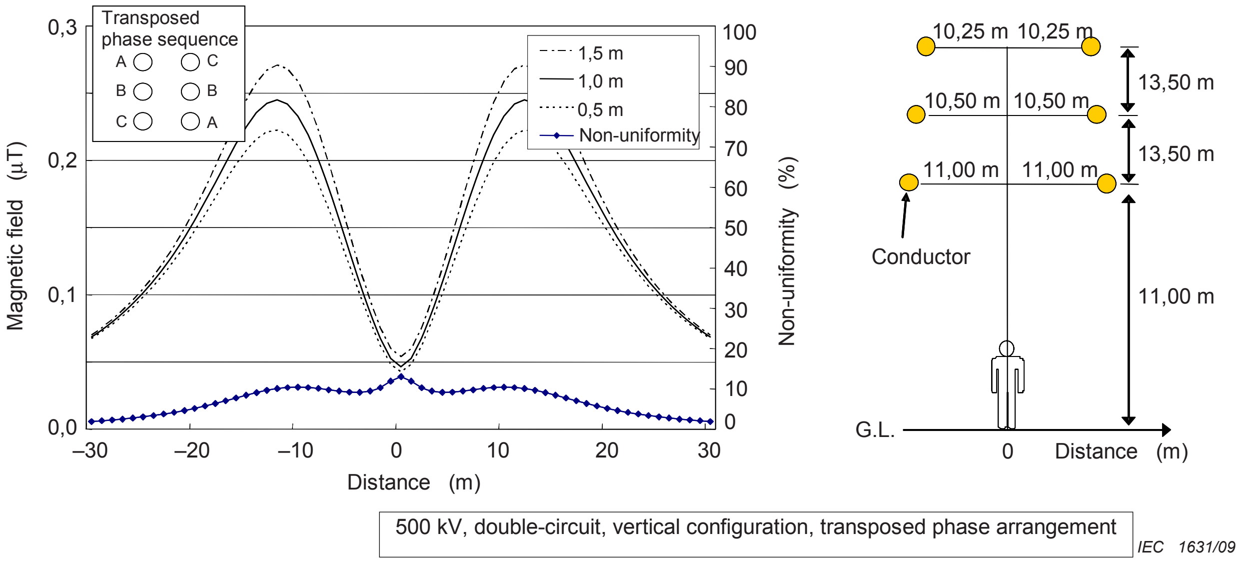
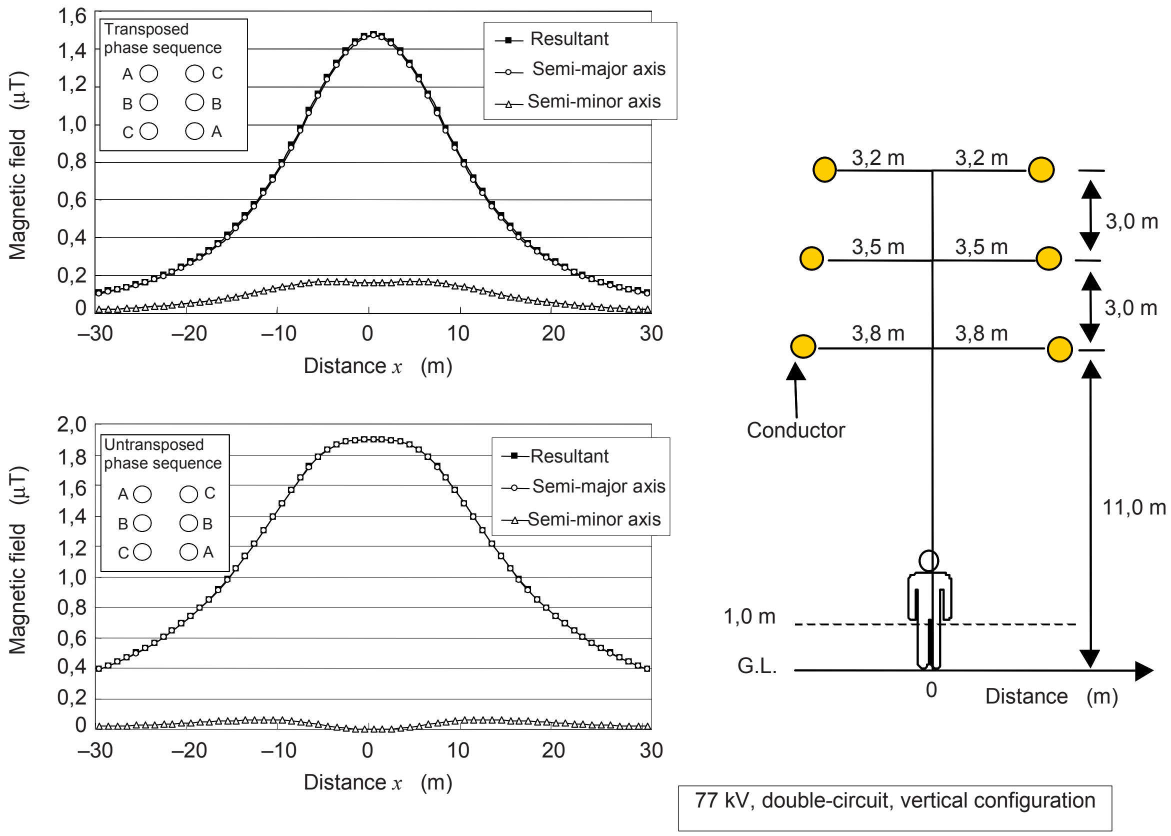


Figure B.6 – Magnetic field levels and non-uniformity under a 500 kV overhead transmission line – Effect of separation between conductors

B.3.3 Semi-major and semi-minor components

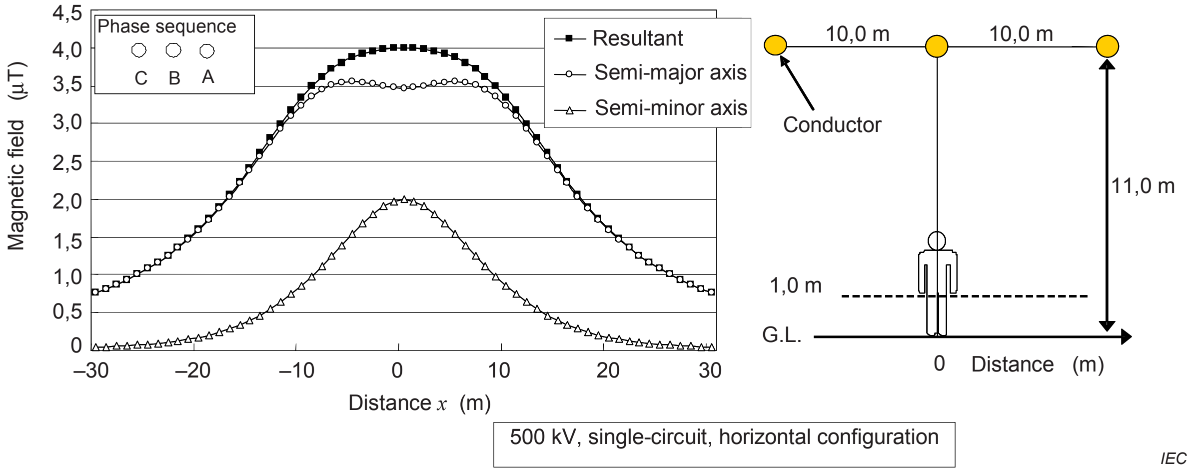
Figure B.7 shows examples of the spatial profile of semi-major and semi-minor components of the calculated magnetic field levels generated by a 77 kV overhead transmission line that has a double-circuit, vertical configuration. Cases of both the untransposed and the transposed phase arrangement are considered. Magnetic field levels are calculated as a function of distance from the centre of the conductors, at a height of 1,0 m above ground. The value of current flowing through each circuit is assumed to be balanced 200 A.



IEC 1632/09

Figure B.7 – Values of semi-major and semi-minor components (r.m.s.) of magnetic field levels under a 77 kV overhead transmission line

Figure B.8 shows an example of the spatial profile of semi-major and semi-minor components of the calculated magnetic field levels generated by a 500 kV overhead transmission line that has a single-circuit, horizontal configuration. Magnetic field levels are calculated as a function of distance from the centre of the conductors, at a height of 1,0 m above ground. The value of current flowing through the circuit is assumed to be balanced 200 A.

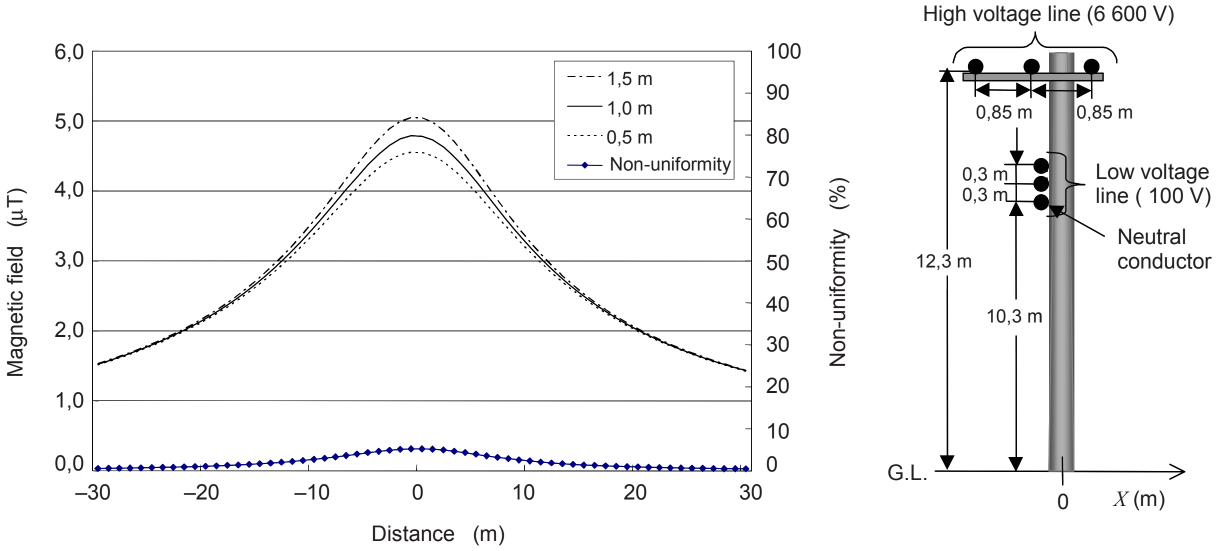


IEC 1633/09

Figure B.8 – Values of semi-major and semi-minor components (r.m.s.) of magnetic field levels under a 500 kV overhead transmission line

B.4 Example of magnetic fields generated by distribution lines

Figure B.9 shows an example of the spatial profile of the calculated magnetic field levels generated by 6 600 V and 100 V overhead distribution lines. Calculated non-uniformity is also shown in Figure B.9. Magnetic field levels are calculated as a function of distance from the centre of the conductors, at heights of 0,5 m, 1,0 m and 1,5 m above ground. The currents flowing through these circuits are assumed to be unbalanced current of 200 A (phase A), 190 A (phase B), and 150 A (phase C) for the 6 600 V line, and to be balanced current of 100 A for 100 V line except for the neutral conductor.

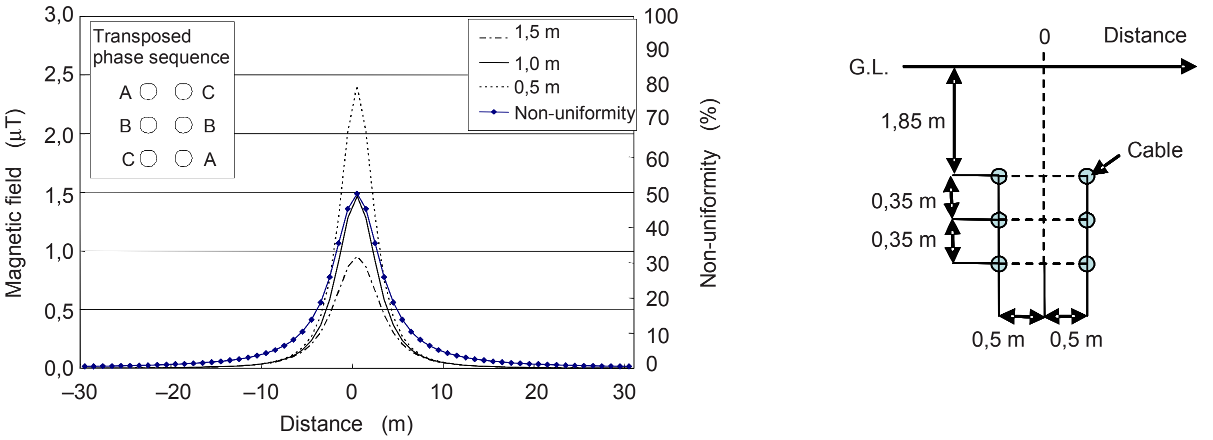


IEC 1634/09

Figure B.9 – Magnetic field levels and non-uniformity under an overhead distribution line (6 600 V / 100 V)

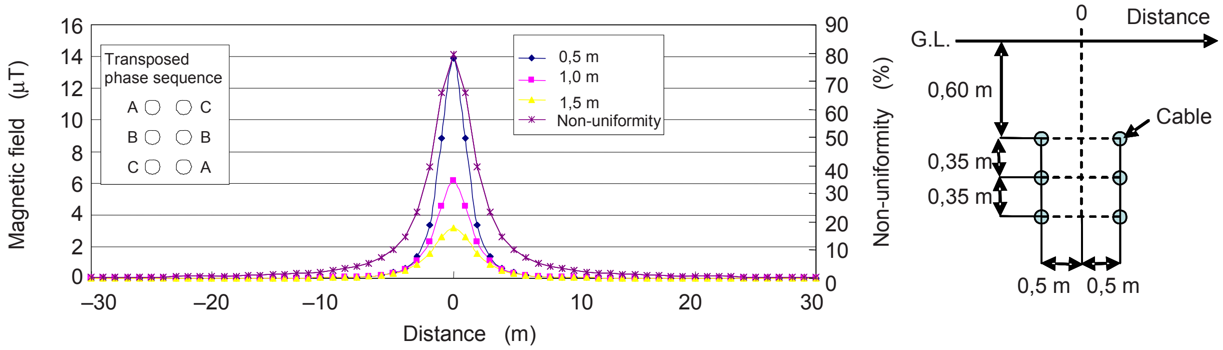
B.5 Example of magnetic fields generated by underground cables

Figure B.10 shows an example of the spatial profile of the calculated magnetic field levels generated by underground cables that have a double circuit, vertical configuration. Calculated non-uniformity is also shown in Figure B.10. Magnetic field levels are calculated as a function of distance from the centre of the cables, at heights of 0,5 m, 1,0 m and 1,5 m above ground. The current flowing through the circuit is assumed to be balanced 200 A, and a transposed phase arrangement is also assumed. Profiles of magnetic field levels and non-uniformity are compared between the cases of deeply buried cables and less deeply buried ones.



IEC 1635/09

a) Deeply buried cables

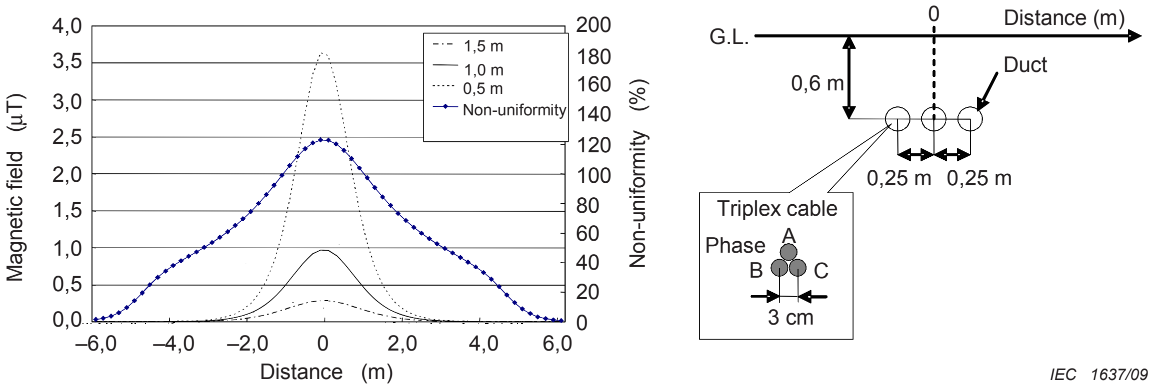


IEC 1636/09

b) Less deeply buried cables

Figure B.10 – Magnetic field levels and non-uniformity above underground cables – Effect of buried depth

Figure B.11 shows an example of the spatial profile of the calculated magnetic field levels generated by underground cables that have a triple circuit consisting of twisted three-wire cables (triplex cable) with a spiral pitch of 3,0 m. Calculated non-uniformity is also shown in Figure B.11. Magnetic field levels are calculated as a function of distance from the centre of the cables, at heights of 0,5 m, 1,0 m and 1,5 m above ground. The current flowing through the circuit is assumed to be balanced 200 A.

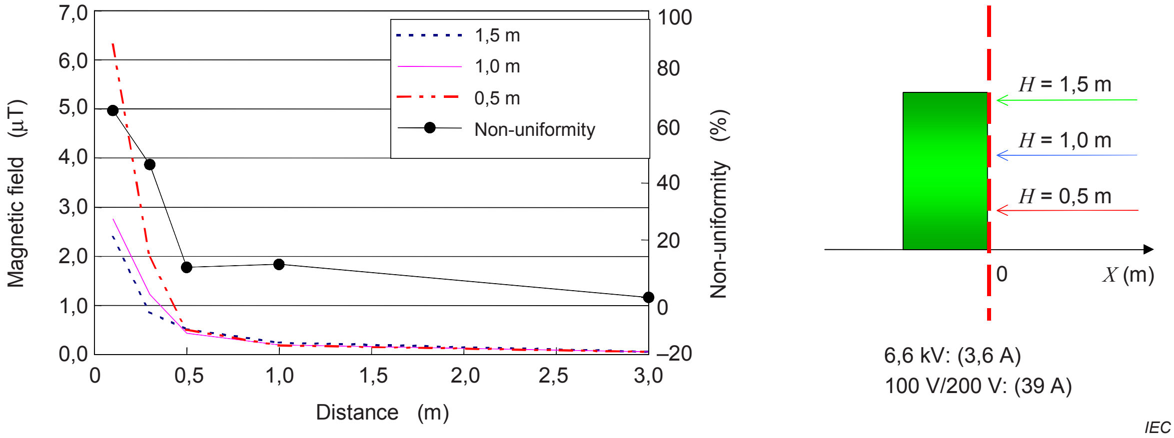


IEC 1637/09

Figure B.11 – Magnetic field levels and non-uniformity above underground cables – Effect of separation between conductors

B.6 Example of magnetic fields generated by power distribution equipment

Figure B.12 shows an example of the spatial profile of the measured magnetic field levels generated by a power distribution equipment (6 600 V pad-mounted transformer). Calculated non-uniformity is also shown in Figure B.12. Magnetic field levels were measured as a function of distance from the surface of the equipment, at heights of 0,5 m, 1,0 m and 1,5 m above ground. The maximum measured point was in front of the LV circuit at 1,5 m height. The measured load current flowing through the primary and secondary circuit was 3,6 A for 6 600 V (primary circuit) and 39 A for 100 V / 200 V (secondary circuit).

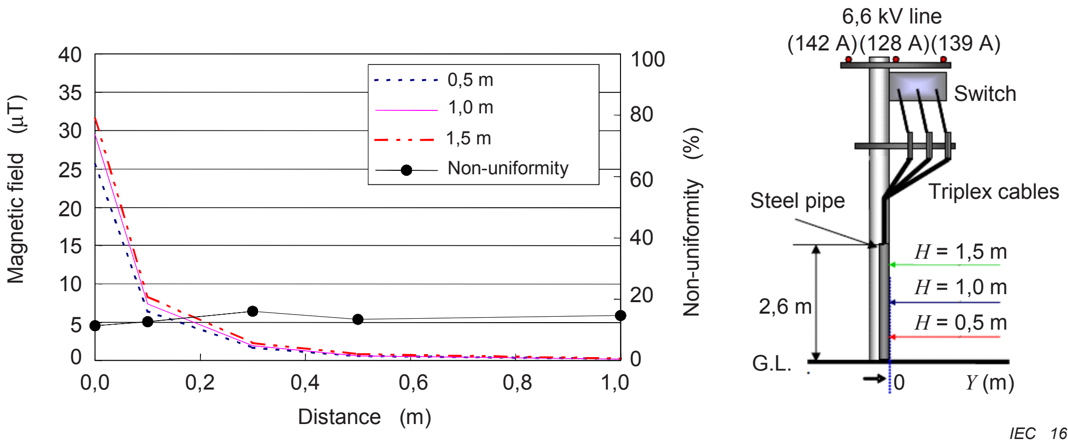


IEC 1638/09

Figure B.12 – Measured magnetic field levels and non-uniformity around a 6 600 V pad-mounted transformer

B.7 Example of magnetic fields generated by vertical cables

Figure B.13 shows an example of the spatial profile of the measured magnetic field levels generated by 6 600 V single-circuit vertical cables that consist of twisted three-wire cables (triplex cable, cross section: 325 mm^2, spiral pitch: 1,35 m, spiral radius: 22,5 mm). Calculated non-uniformity is also shown in Figure B.13. Magnetic field levels were measured as a function of distance from the surface of the cables, at heights of 0,5 m 1,0 m, and 1,5 m above ground. The measured currents flowing through the cables were 142 A, 128 A, and 139 A for each phase.



IEC 1639/09

Figure B.13 – Measured magnetic field levels and non-uniformity around 6 600 V vertical cables

Annex C
(informative)

Concept of the *three-point measurement* with regard to the *average exposure level*

C.1 Concept of the *three-point measurement*

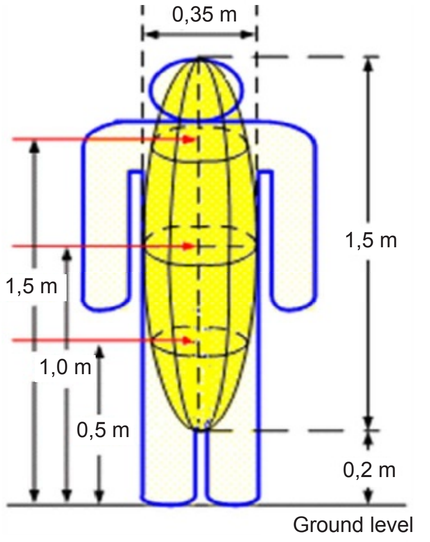
In this standard, for a uniform magnetic field, the field level measured at a height of 1,0 m (a *single-point measurement*) can be recognized as the *average exposure level*. On the other hand, for a non-uniform magnetic field, the *three-point average exposure level* is defined by the arithmetic mean of a *three-point measurement* at heights of 0,5 m, 1,0 m and 1,5 m above ground.

Therefore, it is necessary to demonstrate that the *three-point average exposure level* represents the *average exposure level* over the entire human body. The evaluated values are intended to be compared with reference levels for general public exposure according to the ICNIRP Guidelines. According to the description below, if the consistency of the average exposure level and the three-point average exposure level is explained, comparison with the reference level is possible. But comparison with the basic restriction, which is expressed as a current density in the central nervous system, is impossible because induced current is not considered in this standard. In addition, the three-point measurement cannot evaluate the local maximum such as specified in the IEEE standards.

In this annex, the *average exposure level* is calculated under certain assumptions and is compared with the *three-point average exposure level*.

C.2 Calculation of average exposure level

To simplify the calculation, a human model is assumed. The human body model used is a spheroid whose vertical and horizontal axes are 1,5 m and 0,35 m, located 0,2 m above ground, as shown in Figure C.1 superimposed on a human body shape. The field is calculated on a 0,05 m grid of points within the spheroid, and the average of these values gives the *average exposure level* of the human body.



IEC 1640/09

Figure C.1 – A spheroidal human model

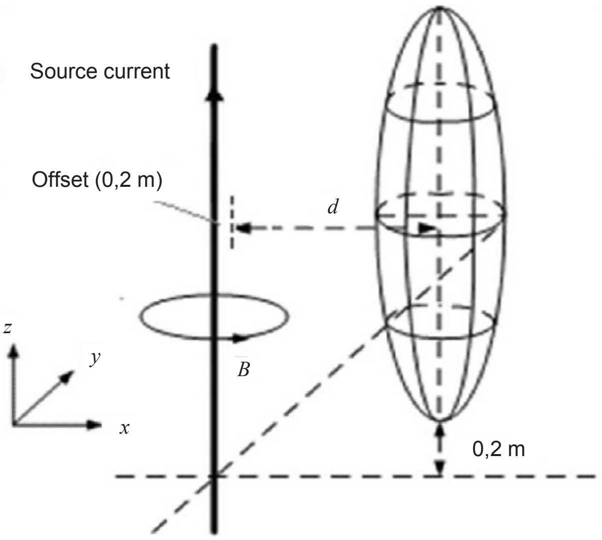
C.3 Comparison between *average exposure level* and *three-point average exposure level*

C.3.1 Calculation of magnetic field levels

Calculation of magnetic field level is performed by using Biot-Savart's law.

C.3.2 Infinite single straight cable

An infinite single straight cable is considered as a field source, in which AC current of 500 A is flowing. The cable is located perpendicular to the ground, at distance d from the centre of the human model (see Figure C.2). The boundary is assumed at 0,2 m from the centre of the cable taking into account the conductor, insulation, space and width of the shield, etc.

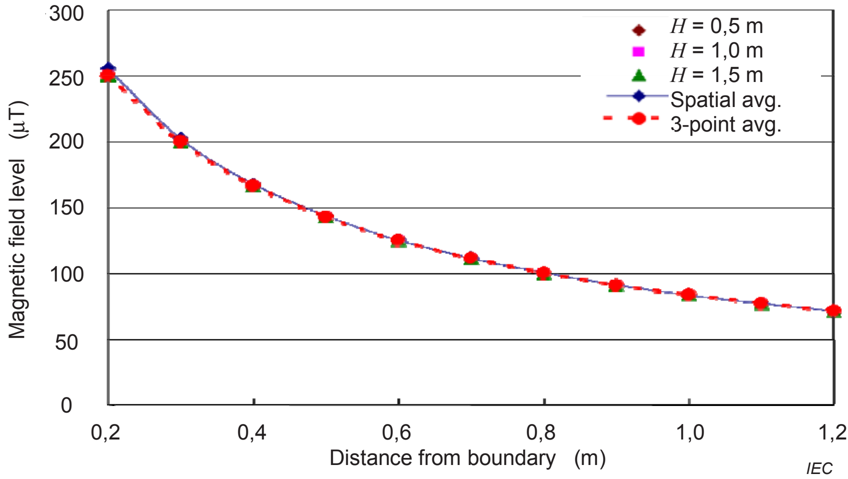


IEC 1641/09

Figure C.2 – The model in the magnetic field generated by a straight cable

The calculated magnetic field distributions are given in Figure C.3.

In this case, the vertical distribution of magnetic fields is uniform, and the *three-point average exposure level* corresponds to the *average exposure level*.

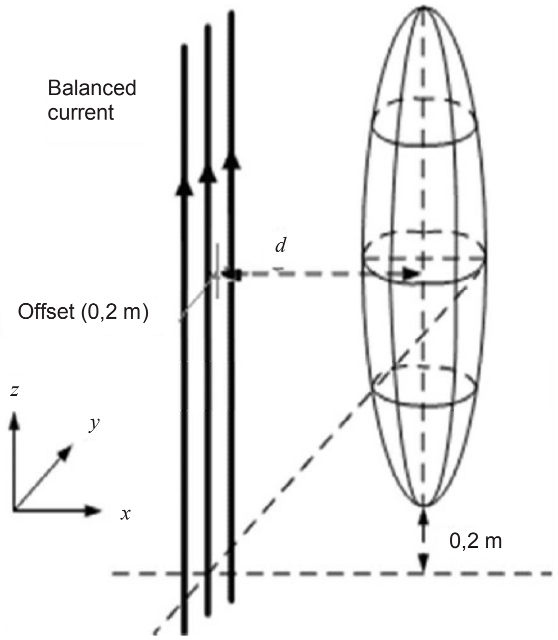


IEC 1642/09

Figure C.3 – Magnetic field levels generated by a straight cable

C.3.3 Three parallel cables with balanced currents

Three infinite straight cables are considered to be a field source, in which three-phase balanced current of 500 A is flowing. The cables are located parallel to each other within the same plane perpendicular to the ground. Three different cable separations, 0,1 m, 0,2 m or 0,3 m, are considered. The human model is located at a distance of d from the centre of the cables (see Figure C.4). The boundary is assumed at 0,2 m from the centre of the cables taking into account the conductor, insulation, space and width of the shield, etc.

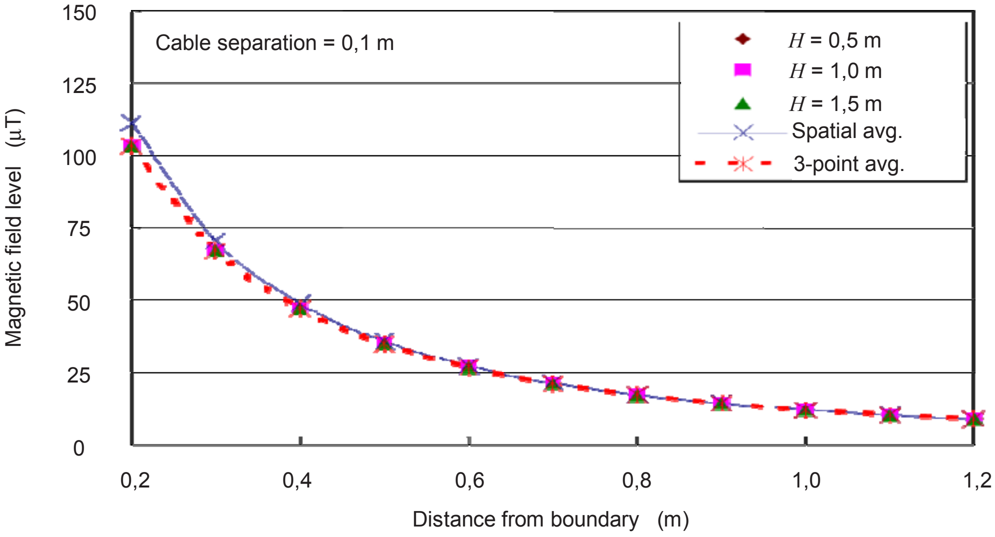


IEC 1643/09

Figure C.4 – The model in the magnetic field generated by three parallel cables

The calculated magnetic field distributions are given in Figure C.5.

In this case, the vertical distribution of magnetic fields is uniform, and the *three-point average exposure level* almost corresponds to the *average exposure level*.



IEC 1644/09

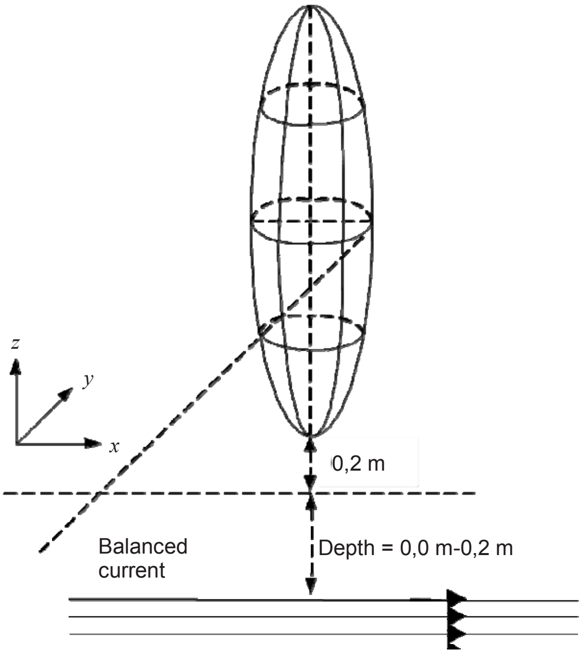
Figure C.5 – Magnetic field levels generated by three balanced parallel cables

C.3.4 Underground cable with balanced currents

An infinite straight cable is considered to be a field source, in which a three-phase balanced current of 500 A is flowing. The cable is located under ground. The cable is a twisted three-phase cable (triplex cable) with a cross section of 325 mm^2, a spiral pitch of 1,35 m, and a spiral radius of 22,5 mm. (see Figure C.6).

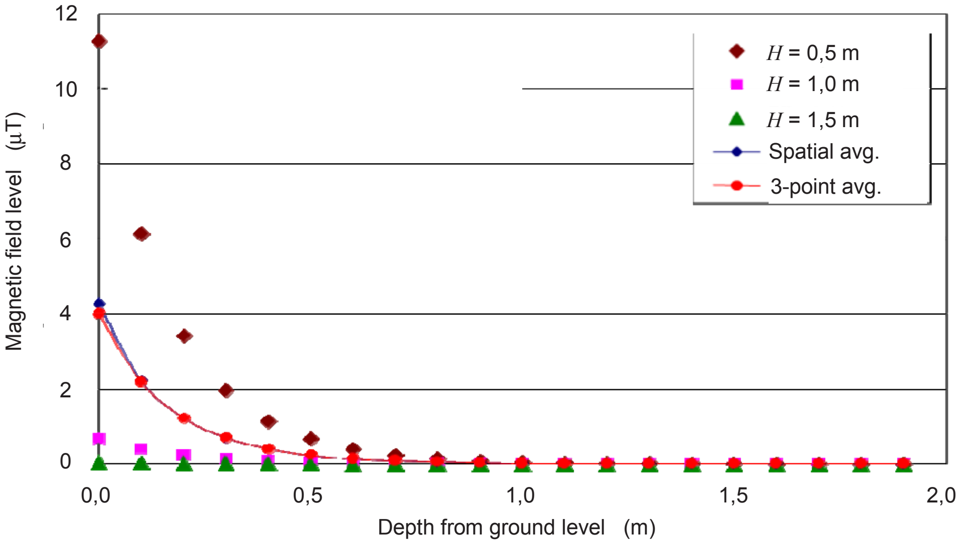
The calculated magnetic field distributions are given in Figure C.7.

In this case, although vertical non-uniformity is high, particularly when the cable is buried near ground level, the *three-point average exposure level* corresponds to the *average exposure level*.



IEC 1645/09

Figure C.6 – The model in the magnetic field generated by underground cables



IEC 1646/09

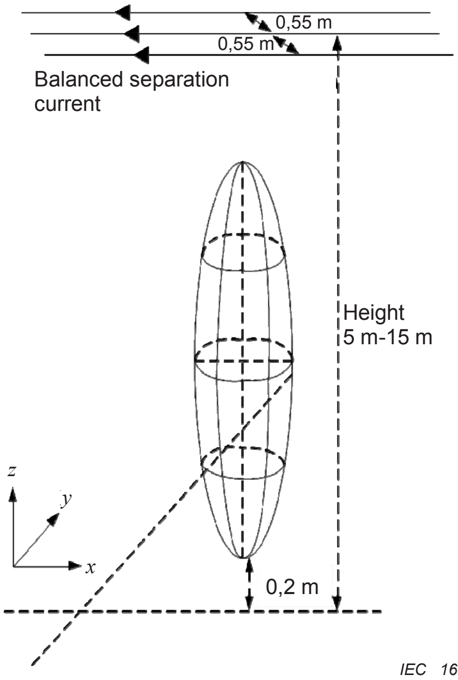
Figure C.7 – Magnetic field levels generated by underground cables

C.3.5 Overhead wires with balanced currents

Three infinite straight wires are considered as a field source, in which three-phase balanced current of 500 A is flowing. The wires are located parallel to each other within the same plane parallel to ground. 0,55 m is considered as the wire separation. The height of three wires is given as H (from 5 m to 15 m) above the ground (see Figure C.8.).

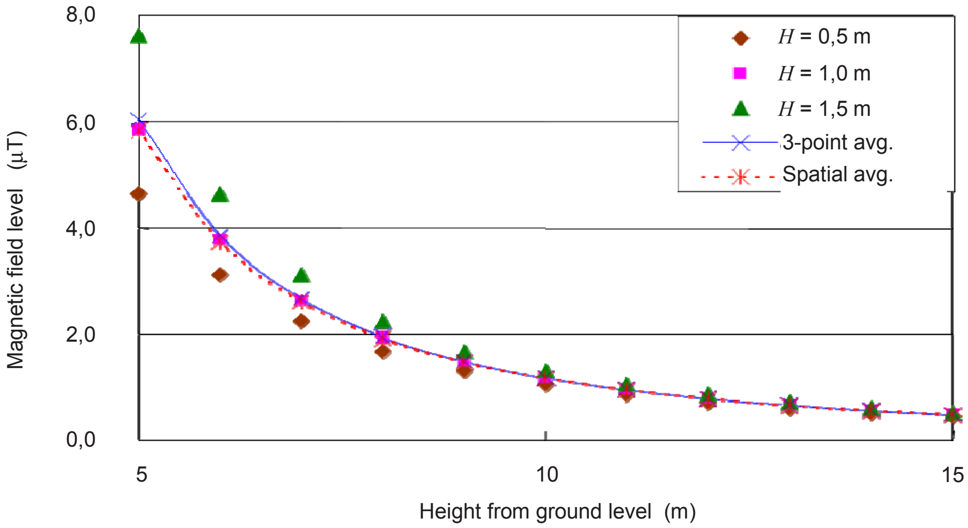
The calculated magnetic field distributions are given in Figure C.9.

In this case, the vertical distribution of magnetic fields is considered to be uniform, and the *three-point average exposure level* and/or the level obtained by a *single-point measurement* at 1,0 m above ground correspond to the *average exposure level*.



IEC 1647/09

Figure C.8 – The model in the magnetic field generated by overhead wires



IEC 1648/09

Figure C.9 – Magnetic field levels generated by balanced overhead wires

Annex D
(informative)

Example of a reporting form for field measurement

An example of a reporting form for field measurement is given below.

Measurement result

1. **Date and time, weather condition, temperature, humidity:**

   27th July 2006, 14:00 ~ 14:15, cloudy, 25 degrees C, 60 %

2. **Type of power system (nominal voltage, load condition during measurement):**

   underground transmission cables (77 kV, 100 A/circuit to 105 A/circuit)

   overhead distribution line (6 600 V / 100 V, load condition not identified)

3. **Location (address)** “address”

4. **Measurement instrument:**

   manufacturer: XXX Co. model: ABC – MF2000

   type of probe: Three-axis air-core coils; diameter of each coil not identified

   magnitude range: 10 nT to 1mT bandwidth: 40 Hz to 800 Hz

   latest calibrated date: 3rd May 2006

5. **Person who performed the measurement:** “name”, “affiliation”

6. **Measurement result:**

Point No.	**Measurement height [m]**	**Field level [μT]**	**Field quantity**
No.1 (outdoor)	0,5 (above ground level)	0,13	resultant magnetic field
	1,0 (above ground level)	0,40	
	1,5 (above ground level)	1,17	
	-	0,57	three-point average exposure level
No.2 (indoor)	0,5 (above floor level)	0,03	resultant magnetic field
	1,0 (above floor level)	0,12	
	1,5 (above floor level)	0,65	
	-	0,27	three-point average exposure level

The measurement points are described in the attached sheet.

7. **Other field sources (in operation):**

No.1: nothing

No.2: an air conditioner (approximately 2,0 m from the measurement point)

a refrigerator (approximately 5,0 m from the measurement point)

8. **Objects to be noted:**

No.1: a car, metallic poles and a carport roof

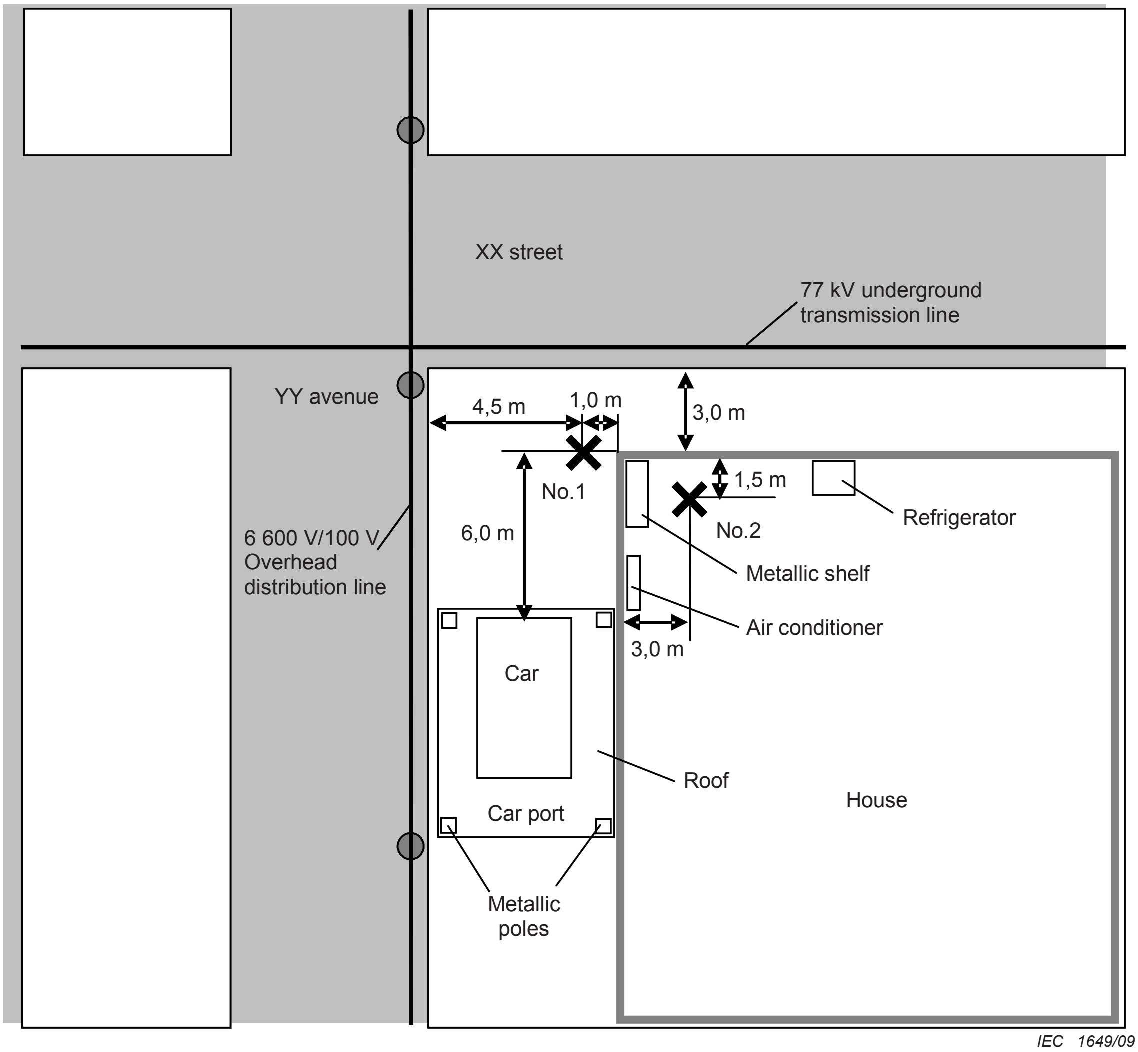
(approximately 6,0 m from the measurement point)

No.2: a metallic shelf (approximately 1,8 m from the measurement point)

9. **Harmonic content:**

It can be ignored.

Plane figure



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