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Basic standard for the evaluation of workers' exposure to electric and magnetic fields from equipment and installations for the production, transmission and distribution of electricity

National foreword

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English Version

Basic standard for the evaluation of workers' exposure to electric and magnetic fields from equipment and installations for the production, transmission and distribution of electricity

Norme fondamentale pour l'évaluation de l'exposition des travailleurs aux champs électriques et magnétiques produits par les équipements et installations de production, transport et distribution d'électricité

Basisnorm für die Evaluierung der beruflichen Exposition gegenüber elektrischen und magnetischen Feldern ausgehend von Komponenten und Anlagen zur Erzeugung, Übertragung und Verteilung elektrischer Energie

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European foreword

This document [EN 50647:2017] has been prepared by CLC/TC 106X “Electromagnetic fields in the human environment”.

The following dates are fixed:

- latest date by which this document has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2018-04-10
- latest date by which the national standards conflicting with this document have to be withdrawn (dow) 2020-04-10

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1 Scope

This European Standard provides a general procedure to assess workers' exposure to electric and magnetic fields (EMF) in work places associated with the production, transmission and distribution of electric energy, and to demonstrate compliance with exposure limit values and action levels as stated in the Council and European Parliament "EMF" Directive 2013/35/EU [11].

NOTE 1 The Council and European Parliament Directive 2013/35/EU will be transposed into national legislation in all the EU member countries. It is important that users of this standard consult the national legislation related to this transposition in order to identify the national regulations and requirements. These national regulations and requirements may have additional requirements that are not covered by this standard

It has the role of a specific workplace standard. It takes into account the non-binding application guide for implementing the EMF Directive [10] and it defines the assessment procedures and compliance criteria applicable to the electric industry.

The frequency range of this standard covers from DC to 20 kHz, which is sufficient to include the power frequency used for electric power supply systems throughout Europe (50 Hz) and the various harmonics and inter-harmonics occurring in the supply system. In this extremely low frequency range, electric and magnetic fields are independent and, therefore, they both have to be addressed in the exposure assessment.

NOTE 2 Electrical companies also use radio frequency transmissions to operate and maintain their networks and power plants. Similarly, other exposures to EMF may occur during maintenance operations, for instance, due to the use of hand-held electrical tools. All these EMF sources are outside the scope of this standard.

NOTE 3 Regarding EMF in the low frequency range, the scientific basis of the EMF directive is the ICNIRP health guidelines published in 2010 [13]. Reference is made to this scientific basis when necessary for justifying or clarifying some of the technical statements of the present document.

2 Normative references

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

EN 61786-1, *Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings - Part 1: Requirements for measuring instruments (IEC 61786-1)*

EN 50527-1, *Procedure for the assessment of the exposure to electromagnetic fields of workers bearing active implantable medical devices - Part 1: General*

EN 50527-2-1, *Procedure for the assessment of the exposure to electromagnetic fields of workers bearing active implantable medical devices - Part 2-1: Specific assessment for workers with cardiac pacemakers*

IEC 61786-2, *Measurement of DC magnetic, AC magnetic and AC electric fields from 1 Hz to 100 kHz with regard to exposure of human beings - Part 2: Basic standard for measurements*

3 Terms, definitions, physical quantities, units and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1

action level

AL

operational level established for the purpose of simplifying the process of demonstrating compliance with the relevant exposure limit value or, where appropriate, to take relevant protection or prevention measures

Note 1 to entry: “Reference levels” as defined in the European Recommendation 1999/519/EC [3] for limiting the exposure of the public and in ICNIRP Health Guidelines [13] are based on the same approach as Action Levels and the two terms are defined to achieve the same objective.

Note 2 to entry: For electric fields, “Low ALs” and “High ALs” are levels which relate to the specific protection or prevention measures specified in the EMF Directive [11].

Note 3 to entry: The Low AL for external electric field is based both on limiting the internal electric field below ELVs and on limiting spark discharges in the working environment. Below the High AL, the internal electric field does not exceed ELVs and annoying spark discharges are prevented, provided that the relevant protection measures are taken.

Note 4 to entry: For magnetic fields, “Low ALs” are levels which relate to the sensory effects ELVs and “High ALs” to the health effects ELVs.

Note 5 to entry: Compliance with the ALs will ensure compliance with the relevant ELVs. If the assessed exposure values are higher than the ALs, it does not necessarily follow that the ELVs have been exceeded, but a more detailed analysis is necessary to demonstrate compliance with the ELVs.

Note 6 to entry: ALs may not provide adequate protection to workers at particular risks, for whom a particular risk assessment shall be performed.

3.1.2

compliance distance

distance from a source of field that ensures respect of the relevant exposure limit values or action levels

Note 1 to entry: Working at distances smaller than compliance distances requires a specific assessment.

3.1.3

contact current

current between a person in established contact with a conductive object, resulting from the inductive or capacitive coupling between the field and the person and/or object, and expressed in amperes (A)

Note 1 to entry: The EMF directive [11] specifies limits for the steady-state value of the contact current.

3.1.4

electric field

constituent of an electromagnetic field which is characterized by the electric field strength E together with the electric flux density D

Note 1 to entry: In French, the term “champ électrique” is also used for the quantity electric field strength.

[SOURCE: IEV, ref 121-11-67]

3.1.5

exposure index

EI

assessed exposure divided by the relevant action level or exposure limit value

3.1.6**exposure-limit-equivalent field****LEF**

magnitude of uniform external electric or magnetic field that exposes the person to the sensory or health effects ELV

Note 1 to entry: The numerical values of LEFs are derived from dosimetry.

3.1.7**exposure limit value****ELV**

limit which is based directly on established health effects and biological considerations

Note 1 to entry: In the frequency range covered by the present standard, ELVs are expressed in terms of induced electric fields except between 0 Hz and 1 Hz where the ELV is given in terms of external magnetic field.

Note 2 to entry: “Basic restrictions” as defined in the European Recommendation 1999/519/EC [3] for limiting the exposure of the public and in ICNIRP Health Guidelines [13] are based on the same approach as Exposure Limit Values and the two terms are defined to achieve the same objective.

3.1.8**exposure limit values for sensory effects (sensory effects ELVs)**

ELVs above which workers might be subject to transiently disturbed sensory perceptions, i.e. retinal phosphenes and minor changes in brain functions

Note 1 to entry: The sensory effects relate only to the central nervous system of the head. Exceeding sensory effects ELVs is allowed under controlled conditions for informed workers.

3.1.9**exposure limit values for health effects (health effects ELVs)**

ELVs above which workers might be subject to adverse health effects, such as stimulation of nerve and muscle tissue

Note 1 to entry: Compliance with health effects ELVs will ensure that workers exposed to electric and magnetic fields are protected against all established adverse health effects.

Note 2 to entry: The threshold for muscle excitation is far higher than for nerve excitation, and therefore the directive [11], consistently with its scientific basis [13], considers limits to prevent only nerve excitation, as they are conservative with regard to muscle excitation. As a result, the health effects relate to the peripheral nervous system, i.e. the whole body.

3.1.10**induced electric field**

electric field inside a human body resulting directly from an exposure to an external source of electric or magnetic field

3.1.11**magnetic field**

constituent of an electromagnetic field which is characterized by the magnetic field strength H together with the magnetic flux density B

Note 1 to entry: In French, the term “champ magnétique” is also used for the quantity magnetic field strength.

Note 2 to entry: In this document, the term magnetic field is used for magnetic flux density.

[SOURCE: IEV ref 121-11-69]

3.1.12

total exposure index

TEI

sum of all exposure indexes (e.g. at different frequencies, or from different sources) of either electric or magnetic field

Note 1 to entry: If the total exposure index is less than one, the exposure is compliant.

Note 2 to entry: Using the arithmetic sum makes the TEI a conservative assessment of exposure.

3.1.13

unperturbed field

field at a point that would exist in the absence of persons or in the absence of movable objects which are not necessary for the work progress

Note 1 to entry: All limits expressed in terms of fields external to the human body refer to the unperturbed field.

[SOURCE: EN 61786-1:2014, 3.3.1]

3.2 Physical quantities and units

For the purposes of this document, the physical quantities and units given in Table 1 apply.

Table 1 — Physical quantities and units

Quantity	Symbol	Unit	Comments
Electric field strength	E	V/m	
Magnetic flux density	B	T	μT is more usually used at 50 Hz
Contact current	I_c	A	

3.3 Abbreviations

AL	action level
CNS	central nervous system
DC	direct current
EI	exposure index
ELV	exposure limit value
GIS	gas insulated substation
HV	high voltage
LEF	exposure limit equivalent field
PNS	peripheral nervous system
TEI	total exposure index
WPR	worker at particular risk
rms	root mean square

4 Assessment procedure

According to Article 4 of EU Directive 2013/35/EU [11] “...the employer shall assess all risks for workers arising from electromagnetic fields at the workplace and, if necessary, measure or calculate the levels of electromagnetic fields to which workers are exposed.....In workplaces open to the public it is not necessary for the exposure assessment to be carried out if an evaluation has already been undertaken in accordance with the provisions on the limitation of exposure of the general public to electromagnetic fields, if the restrictions specified in those provisions are respected for workers and if the health and safety risks are excluded. Where equipment intended for the public use is used as intended and complies with Union law on products that establishes stricter safety levels than those provided for by this Directive, and no other equipment is used, these conditions are deemed to be met.”

Electrical equipment for the production, transmission and distribution of electricity is highly standardized and a few general assessments may cover many sites which have similar equipment and work positions. Therefore, a systematic and thorough assessment of every site containing electrical equipment is not necessary. For a given site, the risk assessment should be limited to any specific equipment or work positions not covered by the general assessments.

The exposure assessment shall be updated if any modification to the installation, the working environment or the work practice significantly affects the EMF exposure conditions.

In electrical companies, many workplaces are exposed simultaneously to electric and magnetic fields. The internal electric fields induced simultaneously by external electric and magnetic fields are vectors, which most often are neither collinear in space nor coincident in phase. ICNIRP's position [13] is that situations where these field vectors are collinear and in phase “*are judged to be very infrequent taking into account the great difference in the distribution of the electrically and magnetically induced electric fields*”.

Therefore, when assessing compliance with the Directive according to the present standard, exposure to low frequency electric and magnetic fields shall be considered separately and not additively.

This clause gives a general procedure for the exposure assessment of a work place, which is presented in Figure 1 as a flowchart. It shows all the possible methods to demonstrate compliance with the EMF directive [11]. The different steps of this flowchart are developed in Clauses 5, 7, 8, 9, 10 and 13.

Compliance can be demonstrated using any of the possible methods. For example, in some cases it might be more simple and efficient to demonstrate compliance using measurements (e.g. subclause 8.3) rather than identifying all the electrical equipment and checking whether it meets the criteria for simplified assessment (e.g. subclause 8.2).

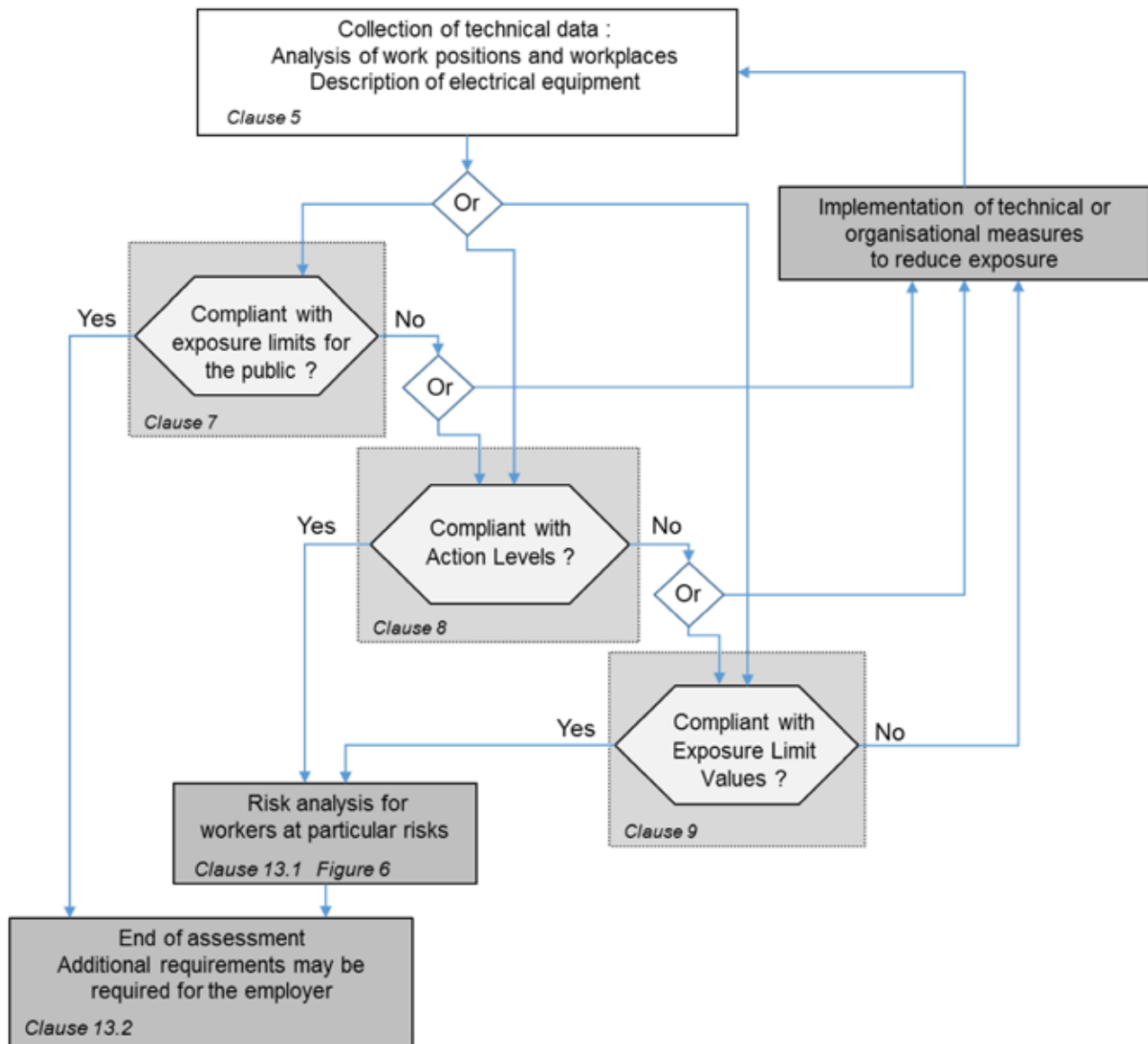


Figure 1 — General flowchart of the compliance assessment procedure

5 Collection of technical data

For assessing compliance, it is necessary to characterize the workplace in terms of EMF sources and of work positions in relation to them, and of the work practices involved. In terms of the scope of this standard, relevant field sources are energized electrical conductors and electrical equipment for producing and distributing electricity.

A simple identification is sufficient for the equipment covered by simplified procedures and general assessments (see Clause 7 and 8.2).

For the specific electrical equipment which may need a particular assessment, the following technical data may be useful to characterize the workplaces being assessed:

- type of equipment;
- rated characteristics (e.g. voltage, current);
- whether the equipment is insulated or not;

- whether any screens or shields are present;
- extent of any harmonics;
- distance of the energized parts of the equipment to workers;
- etc.

6 Methods for assessing exposure of workers

6.1 General

When assessing exposure in a particular area, it is normally sufficient to identify only the main EMF sources that affect that area. If the workers are very close to - or in contact with - one EMF source, any other sources located further away can generally be neglected (examples: HV live-line working, GIS inspection, etc.).

For working environments where different sources are at comparable distances to the workers (examples: low voltage environments, where the three phases are close to each other), the simultaneous contribution of all such sources should be considered.

The worst case exposure of workers shall be determined. As the exposure may vary as a function of the operating conditions, it may be necessary to extrapolate the exposure to worst case exposure conditions. Magnetic fields are generated by currents in electric equipment, such as lines, cables, coils and windings. The current may vary significantly over time and thus so will the magnetic field. This means that extrapolations of measured or calculated values will often be relevant when considering magnetic fields. Electric fields are generated by non-shielded electric equipment, such as overhead lines or busbars in substations. The voltage does not vary significantly over time and neither does the electric field at a given point, provided it remains unperturbed i.e. not affected by any moving object. Therefore, extrapolations of measured or calculated values are not normally relevant when considering power frequency electric fields, except under special circumstances such as a change in maximum operating voltage.

Waveforms of electric and magnetic fields at 50 Hz are not always purely sinusoidal but may contain significant harmonic components, which have to be taken into account in the exposure assessment when relevant. See 6.2.2 and 6.2.3.

6.2 Exposure assessment regarding external fields

6.2.1 General

External fields may be assessed by measurements and/or calculations.

Field meters shall be compliant with EN 61786-1.

This standard does not specify any specific measurement protocol, because of the diversity of the exposure situations experienced by workers. The measurement protocol shall be compliant with IEC 61786-2.

For small distances to a magnetic field source, where the magnetic field is highly non uniform, the size of the measuring probe may introduce an averaging bias and therefore may underestimate the actual field. Therefore the size of the probe shall be appropriate to the spatial variation of the field. Guidance is given in the measurement standard IEC 61786-2.

Magnetic field measurements should not be performed for assessing compliance for distances to field sources smaller than the measuring probe.

Measurements and calculations of electric fields are much more complex than for magnetic fields, as the electric field is perturbed by all conducting objects, even poorly conducting objects, and particularly by metallic structures. This is known as the “peak effect” and it results in strong local enhancements of the electric field. The strongly non-uniform field resulting from the peak effect is not representative of the exposure of a worker. That is why, in order to measure the unperturbed field, IEC 61786-2 recommends:

- a minimum distance of 2 m between the operator and the E field probe;

- to remove movable objects if possible;
- a minimum distance of 1 m to permanent objects if possible.

To overcome this effect, it is recommended to remove any movable object not necessary for the work in progress that might disturb the measurements during electric fields measurements.

Similarly, the peak effect also affects E-fields measurements close to fixed metallic structures, and a minimum distance to such structures should be respected in order to perform reliable and reproducible measurements. IEC 61786-2 recommends a minimum distance of 1 m when possible. However, a measuring distance of 1 m is not applicable to many work situations which involve contact to metallic structures, such as workers climbing in lattice steel electrical towers. In this case, a minimum distance of 20 cm shall be maintained between conducting objects and the measurement probe to reduce the peak effect measurement bias.

6.2.2 Harmonics of magnetic field

For transmission and distribution systems it is acceptable to perform a simplified assessment of harmonics, except around supplies for industry operating high power converters and rectifiers. Annex A proposes different approaches for assessing harmonics.

For simplified assessment of harmonics, the total exposure index is allocated partly to the exposure index for 50 Hz and partly to the sum of exposure indexes of harmonics. A total exposure index, including the fundamental and all harmonics, below 1 demonstrates compliance. Criteria for the 50 Hz exposure index, depending on the nominal voltage, are given in order to demonstrate that the total exposure index remains lower than 1. Alternative values may be used if based on specific assessment of harmonics.

— **Criterion for voltage range ≥ 60 kV**

Based on available field measurements and current measurements, the harmonics of magnetic field at voltage levels higher than 60 kV can be neglected because the maximum harmonic content of currents in transmission and distribution systems is limited during normal operations.

NOTE Circumstances where significant harmonics can occur, such as resulting from saturation of transformers during energizing or during geomagnetic storms, are too rare to need considering further.

— **Criterion for voltage range 1 kV to 60 kV**

Based on available field measurements and current measurements from medium voltage distribution and transmission systems, the harmonics up to the 50th might be relevant, but the exposure is compliant if the exposure index for 50 Hz is below 0,8 (see Annex A). The same criterion can be applied for broadband measurements.

— **Criterion for low voltages (<1 kV)**

Based on available field measurements and current measurements from low voltage distribution systems, the harmonics up to the 50th might be relevant, but the exposure is compliant if the exposure index for 50 Hz is below 0,7 (see Annex A). The same criterion can be applied for broadband measurements.

For power plants, assessment of harmonics may be limited to the excitation unit.

6.2.3 Harmonics of electric field

The harmonics of electric field at any voltage level can be neglected because the maximum harmonic content of voltage in transmission and distribution systems, which is limited by voltage quality requirements, usually increases the total exposure index only within the range of the expected uncertainty of assessment.

6.3 Numerical calculation of induced electric fields inside the human body

Numerical computations of induced electric fields inside the human body can be performed using different numerical methods, such as Finite Elements Method, Finite Integration Technique, Finite Difference Time Domain, and Scalar Potential Finite Difference. (See [7] and [8]).

Sophisticated models for calculating induced currents in the body have been used and are the subject of a number of scientific publications. These models use numerical 3D electromagnetic field computation codes and detailed models of the internal structure with specific electrical characteristics of each tissue within the body. Such scientific models can be used to assess compliance to ELVs.

7 Assessment against exposure limits for the public

At many workplaces, EMF levels will remain below the reference levels or basic restrictions for the public, such as those established in the Council Recommendation 1999/519/EC [3]. For such workplaces, when compliance to these values has already been demonstrated, no further assessment is needed.

The Application Guide [10] of the EMF Directive [11] gives a non-exhaustive list of workplaces where it should not be necessary to carry out a specific assessment as there is expected to be no risk from EMFs. The corresponding sources (Table 2) are not expected to give rise to exposures in excess of the reference levels of the Council Recommendation [3] under any conditions of normal operations.

Table 2 — Equipment or work places deemed to comply with reference levels for public exposure, i.e. 100 μ T or 5 kV/m at 50 Hz (from Table 3.2 of the application guide [10])

Type of equipment or workplace	Type of exposure
Overhead bare conductors of any voltage	Magnetic fields
Electrical installations or electrical circuits within an installation, with a phase current rating of 100 A or less for the individual circuit (includes wiring, switchgear, transformers, etc.)	Magnetic fields
Any underground or insulated cable circuit, rated at any voltage	Electric fields
Any overhead bare circuit in substations above the work place rated at a voltage up to 110 kV	Electric fields
Any overhead bare circuit in substations with a grounded shield, rated at any voltage	Electric fields
Any overhead line above the work place rated at a voltage up to 150 kV	Electric fields
Any overhead lines at any voltage over-sailing the workplace building where the workplace is indoors	Electric fields

8 Assessment against Action Levels

8.1 General

Action Levels may not provide sufficient protection for workers at particular risk, as defined in the EMF directive [11], and a separate assessment is required for those categories of workers (see 13.1).

The rms values for Low and High ALs are given in Figure 2 (magnetic field) and Figure 3 (electric field). At 50 Hz the corresponding values are given in Table 3.

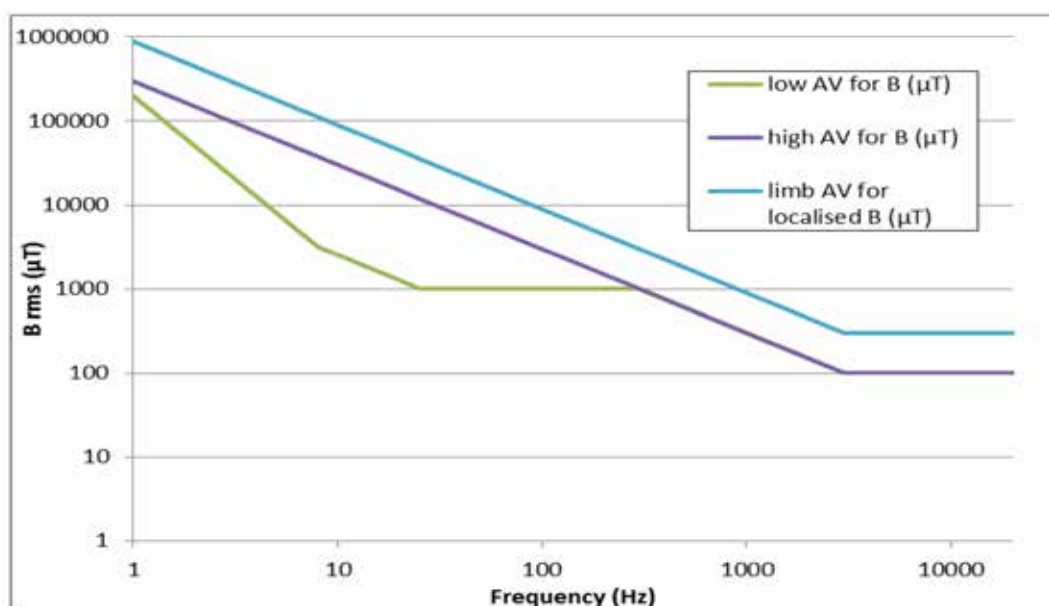


Figure 2 — Low and High Action Levels for magnetic fields in the frequency range from 1 to 20 kHz

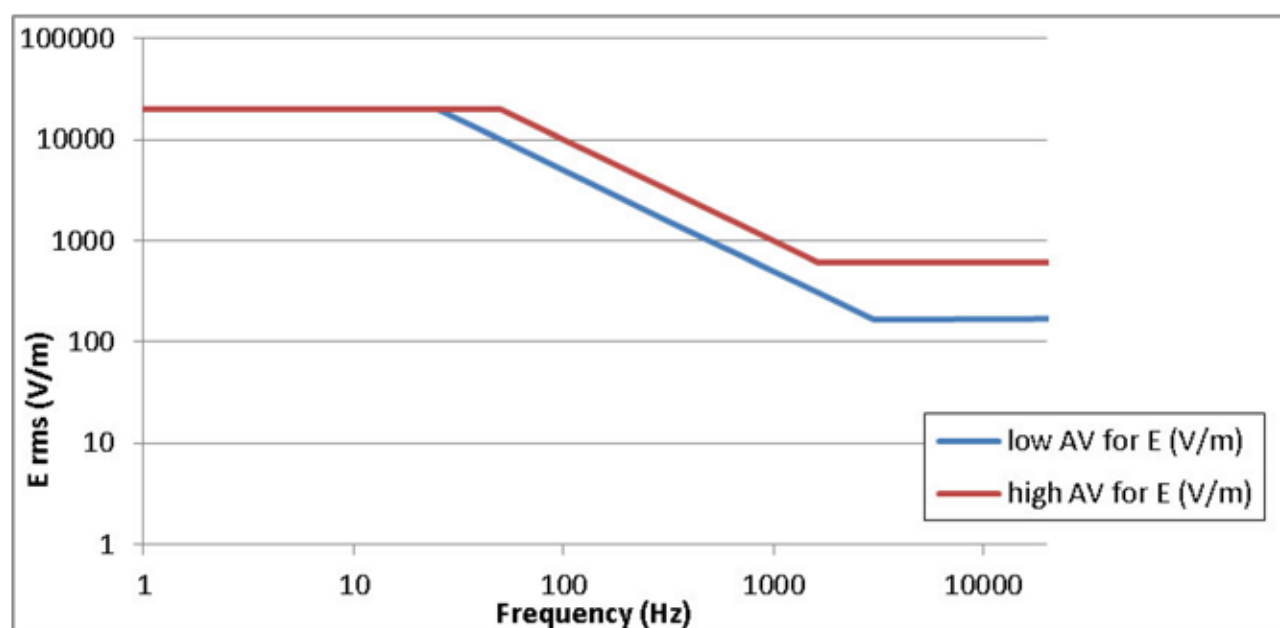


Figure 3 — Low and High Action Levels for electric fields in the frequency range from 1 to 20 kHz

Table 3 — Action Levels at 50 Hz

	Low AL	High AL	AL for limbs exposure to a localized field
Electric field	10 kV/m	20 kV/m	-
Magnetic field	1 000 μ T	6 000 μ T	18 000 μ T
Contact current	1 mA		

For magnetic fields up to 400 Hz, the Low and High ALs refer to different biophysical effects and different organs of the human body. In practice, the Low ALs are related to sensory effects on the central nervous system and are only applicable to the head. The High ALs are related to health effects on the peripheral nervous system and therefore apply to the whole body.

Therefore, when the magnetic field is non uniform over the body, compliance with the Low ALs at the position of the head may not necessarily imply compliance with the High ALs over the remainder of the body. On the other hand, when the magnetic field can be considered as uniform over the body, compliance with the Low AL always ensures compliance with the High AL.

Regarding electric fields, the Low and High AL are based upon the same biophysical effects, and therefore compliance with the Low AL for electric fields always ensures compliance with the High AL.

8.2 Simplified criteria for compliance with action levels

8.2.1 General

This section gives non-exhaustive lists of electrical equipment and operating conditions under which the equipment is deemed to be compliant with the ALs. For other equipment or different operating conditions further assessment is needed (see 8.3).

Some electrical equipment is compliant with the ALs provided that a compliance distance to the magnetic field source is respected. A workplace containing only this kind of equipment is deemed to be compliant with the EMF Directive [11] regardless the number of instances of such equipment. Such workplaces will require no further assessment. There may be additional requirements for the employer (see Clause 13).

8.2.2 Magnetic fields

For electrical circuits, this compliance distance depends directly on the current flowing in the circuit. A rationale for the compliance distance applicable to electrical circuits is given in Annex B (Table B.1).

The list of equipment given in Table 4 is compliant with the Low AL for 50 Hz magnetic fields without further assessment.

**Table 4 — Equipment or work places deemed to comply with the Low AL for 50 Hz magnetic field
(live-line situations not considered)**

Type of electrical equipment	Remark
Overhead bare conductors of any voltage	Provided that electrical safety distances are respected
Any electricity installation or circuit in the workplace with a phase-current rating of 250 A or less (includes wiring, switchgear, transformers, etc.)	Justification for 250 A is given in Annex B For currents exceeding 250 A, a compliance distance can be calculated using Formula (2) or Table B.1 of Annex B Exceptions listed below in Table 5
Any iron-cored transformer (with metallic enclosure) or motor or generator	Excluding the connections to these equipment and the end-windings of high-power turbogenerators
IPB (Isolated Phase Busbars) and GIS/GIC/GIL (Gas Insulated Substations/Cables/Lines) of any rating	Excluding parts outside the regions where the metal enclosures of the different phases are bonded together

Other situations may exceed the ALs for magnetic field and require further assessment for demonstrating compliance with the ELVs of the EMF Directive [11]. Based either on measurements or computation, a possible method is to determine the distance which guarantees that the magnetic field strength falls below the ALs (subclause 8.3 assessment) or below the exposure-limit-equivalent-field (subclause 9.2 assessment). Some examples are given in Table 5:

Table 5 — Examples of equipment or workplace requiring further assessment with regard to 50 Hz magnetic field

Type of electrical equipment	Remark
Air-cored reactors	Manufacturers are able to provide information (calculated or measured values) on the magnetic fields levels in the vicinity of the reactors. This can be used to define the distance from the reactors at which ALs are met, and to determine whether safety measures are necessary to protect workers. A simplified method for calculating the maximum magnetic field produced by a single air-core reactor is given in C.1. This maximum calculated value is conservative with regard to a 3-phase system of reactors. Such a calculation can be used to check the need for limiting access to the reactors (e.g. using fences) or to determine a conservative safe distance to the reactors.
Connections to transformers, motors and generators, where the current rating exceeds 250 A.	
In the vicinity of the busbars of power generators	

8.2.3 Electric fields

Electric fields are generated by non-shielded electrical equipment, such as overhead lines or busbars in substations. Non-shielded equipment is not directly accessible and electrical security requires respecting a minimum safety clearance, depending on the voltage level.

The list of equipment given in Table 6 is compliant with the Low AL for 50 Hz electric fields without further assessment.

Table 6 — Equipment or work places deemed to comply with the Low Action Level for 50 Hz electric field (10 kV/m)

Type of electrical equipment	Remark
Any low voltage (up to 1 kV) wiring and associated components	
Any cabling with a conducting sheath at any voltage	Conducting sheaths are normal on insulated cables for use at 1 kV or more
Any underground cable	
Any overhead line up to 400 kV, for a person standing at ground level	See note
In substations, any overhead unshielded conductor up to 200 kV, for a person standing at ground level	
In substations outside HV compounds	Where clearance to ground is higher to allow circulation of vehicles
Inside any building, with energised conductors of any voltage located outside the building	

NOTE Some designs of 400 kV lines can theoretically produce fields above 10 kV/m (up to 12 kV/m) when operating at minimum clearance. Such instances are deemed to be rare in practice and only temporary and it is not necessary to include them in assessments.