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Electromagnetic compatibility (EMC) –
Part 2-4: Environment – Compatibility levels in power distribution systems in industrial ~~plants~~ locations for low-frequency conducted disturbances

IEC 61000-2-4:2024-07 RLV(en)

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IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 2-4: Environment – Compatibility levels in power distribution systems in industrial ~~plants~~ locations for low-frequency conducted disturbances

FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC 61000-2-4:2002. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

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IEC 61000-2-4 has been prepared by subcommittee 77A: EMC – Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility. It is an International Standard.

This third edition cancels and replaces the second edition published in 2002. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) introduction of new classes 2a, 2b and 2L (former class 2);
b) modification of existing compatibility levels for class 3;
c) addition of compatibility levels in the frequency range 2 kHz to 150 kHz;
d) addition of compatibility levels using a new quantity: partial weighted harmonic distortion (PWHD).

The text of this International Standard is based on the following documents:

Draft	Report on voting
77A/1215/FDIS	77A/1221/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 61000 series, published under the general title *Electromagnetic compatibility (EMC)*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

IEC 61000 is published in separate parts according to the following structure:

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

Immunity limits (in so far as they do not fall under the responsibility of the product committees)

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

Each part is further subdivided into several parts, published either as International Standards, technical specifications or technical reports, some of which have already been published as sections. Others will be published with the part number followed by a dash and a second number identifying the subdivision (example: IEC 61000-3-11).

Detailed information on the various types of disturbances that can be expected on public power supply systems can be found in IEC 61000-2-1 and IEC 61000-2-12.

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ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 2-4: Environment – Compatibility levels in power distribution systems in industrial ~~plants~~ locations for low-frequency conducted disturbances

1 Scope

This part of IEC 61000 is related to conducted disturbances in the frequency range from 0 kHz to ~~9~~ 150 kHz. It gives ~~numerical~~ compatibility levels in differential mode (L-L and L-N) for industrial locations ~~and non-public power distribution systems~~, with a nominal voltage up to 35 kV and a nominal frequency of 50 Hz or 60 Hz.

NOTE 1 Industrial locations are defined in 3.1.8.

Power ~~supply~~ distribution systems on ships, aircraft, offshore platforms and railways are not included.

~~The compatibility levels specified in this standard apply at the in-plant point of coupling. At the power input terminals of equipment receiving its supply from the above systems, the severity levels of the disturbances can, for the most part, be taken to be the same as the levels at the in-plant point of coupling. In some situations this is not so, particularly in the case of a long feeder dedicated to the supply of a particular load, or in the case of a disturbance generated or amplified within the installation of which the equipment forms a part.~~

NOTE 2 See also Annex E. The compatibility levels specified in this document apply at the in-plant point of coupling (IPC). The level of the low-frequency disturbances at the terminals of equipment receiving its supply from the IPC is generally assumed to be similar to the disturbance level at the IPC itself. However, in some situations this is not the case, particularly when a long feeder is dedicated to the supply of a particular load, or when a disturbance is generated or amplified within the installation of which the equipment forms a part.

Compatibility levels are specified for the types of low-frequency electromagnetic disturbances ~~of the types which can be~~ expected at any in-plant point of coupling (IPC) within industrial ~~plants or other non-public networks~~ locations, for guidance in the definition of:

a) limits for disturbance emissions in industrial power ~~supply~~ distribution systems (including the planning levels defined in 3.1.5);

NOTE 3 A very wide range of conditions is possible in the electromagnetic environments of industrial ~~and other non-public~~ networks. These are approximated in this document by the three classes described in Clause 4. However, it is the responsibility of the operator of such a network to take account of the particular electromagnetic and economic conditions, including equipment characteristics, in setting the above-mentioned limits.

b) ~~the choice of~~ immunity levels for the equipment within these systems.

The disturbance phenomena considered are:

- voltage deviations;
- voltage dips and short interruptions;
- voltage ~~unbalance~~ imbalance;
- power-frequency variations;
- harmonics up to order ~~50~~ 40;
- interharmonics up to the ~~50~~ 40th harmonic;
- voltage components ~~at higher frequencies (above 50th harmonic)~~ above the 40th harmonic up to 150 kHz;
- DC component;

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– transient overvoltages.

The compatibility levels are given for different classes of ~~the electromagnetic~~ environment determined by the characteristics of the supply network and loads.

NOTE 4 Compatibility levels at the point of common coupling (PCC) on public networks are specified in IEC 61000-2-2 for low-voltage networks and IEC 61000-2-12 for medium-voltage networks. IEC TR 61000-3-6 and IEC TR 61000-3-7 describe the approach of ~~supply authorities~~ power distribution system operators to the limitation of emissions from installations and large loads.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60050-101, *International Electrotechnical Vocabulary (IEV) – Part 101: Mathematics*~~

~~IEC 60050-161, *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*~~

~~IEC 60050-551, *International Electrotechnical Vocabulary (IEV) – Part 551: Power electronics*~~

IEC 61000-2-2:2002, *Electromagnetic compatibility (EMC) – Part 2-2: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems*
IEC 61000-2-2:2002/AMD1:2017
IEC 61000-2-2:2002/AMD2:2018

IEC 61000-2-12, *Electromagnetic compatibility (EMC) – Part 2-12: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public medium-voltage power supply systems* ~~[1]~~

IEC 61000-4-7, *Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto*

CISPR 16-1-1, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus*

CISPR 16-2-1, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-1: Methods of measurement of disturbances and immunity – Conducted disturbance measurements*

3 Terms, definitions and abbreviated terms

~~For the purposes of this part of IEC 61000, the definitions given in chapter 161 and parts 101 and 551 of IEC 60050 (IEV) as well as the following apply.~~

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

~~[1] To be published.~~

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ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1 General definitions

3.1.1
~~(~~electromagnetic~~)~~ disturbance

~~any electromagnetic phenomenon which, by being present in the electromagnetic environment, can cause electrical equipment to depart from its intended performance~~

~~[IEV 161-01-05, modified]~~

electromagnetic phenomenon that can degrade the performance of a device, equipment or system

[SOURCE: IEC 60050-161:2018, 161-01-05, modified – in the definition the words "or adversely affect living or inert matter" have been deleted and Note 1, Note 2, and Note 3 have been deleted.]

3.1.2
disturbance level

amount or magnitude of an electromagnetic disturbance, measured and evaluated in a specified way

~~[IEV 161-03-01, modified]~~

3.1.3
electromagnetic compatibility
EMC

ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

Note 1 to entry: Electromagnetic compatibility is a condition of the electromagnetic environment such that, for every phenomenon, the disturbance emission level is sufficiently low and immunity levels are sufficiently high so that all devices, equipment and systems operate as intended.

Note 2 to entry: Electromagnetic compatibility is achieved only if emission and immunity levels are controlled such that the immunity level of devices, equipment and systems, at any location, are not exceeded by the disturbance level at that location, resulting from the cumulative emission of all sources and other factors such as circuit impedances. Conventionally, compatibility is said to exist if the probability of the departure from intended performance or of the adverse effect is sufficiently low. See IEC 61000-2-1:1990, Clause 4.

Note 3 to entry: Where the context requires it, compatibility ~~may be understood~~ is intended to refer to a single disturbance or class of disturbances.

Note 4 to entry: Electromagnetic compatibility is a term used also to describe the field of study of the adverse electromagnetic effect which devices, equipment and systems undergo from each other or from electromagnetic phenomena.

[SOURCE: IEC 60050-161:2018, 161-01-07, modified – Note 1 to Note 4 have been added.]

3.1.4
(electromagnetic) compatibility level

specified electromagnetic disturbance level used as a reference level in a specified environment for coordination in the setting of emission and immunity limits

Note 1 to entry: By convention, the compatibility level is chosen so that there is only a small probability that it will be exceeded by the actual disturbance level.

[SOURCE: IEC 60050-161:1990, 161-03-10, modified – the last sentence of Note 1 is deleted because it is less relevant in industrial locations compared to public locations.]

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3.1.5
planning level
level of a particular disturbance in a particular environment, adopted as a reference value for the limits to be set for the emission of large loads and installations, in order to coordinate those limits with all the limits adopted for equipment intended to be connected to the power supply system

Note 1 to entry: The planning level is locally specific and is adopted by those responsible for planning and operating the power supply network in the relevant area. (For further explanation, see IEC 61000-2-2:2002, Annex A and IEC 61000-1-2.)

3.1.6
industrial and private power distribution system
distribution network that is separated by at least one separation transformer from the public power supply system to which other customer installations are connected

3.1.7
point of common coupling
PCC
point on a public power supply network, electrically nearest to a particular load, at which other loads are, or could be, connected

Note 1 to entry: The PCC is usually the point for which electromagnetic compatibility in public networks is to be considered.

[SOURCE: IEC 60050-161:1990, 161-07-15, modified – the two notes have been deleted, the content of Note 2 is integrated in the definition and a new note has been added.]

3.1.8
industrial location
location characterized by an installation consisting of a separate power distribution network, supplied by a high- or medium-voltage transformer, dedicated for the supply of this installation

Note 1 to entry: Industrial locations can generally be described by the existence of an installation with one or more of the following characteristics:

- significant amount of electrical power generated, transmitted and/or consumed;
- frequent switching of heavy inductive or capacitive loads;
- high currents and associated magnetic fields;
- presence of industrial, high power scientific and medical (ISM) equipment (for example, welding machines).

The electromagnetic environment at an industrial location is predominantly produced by the equipment and installation present at the location. There are types of industrial locations where some of the electromagnetic phenomena appear in a more severe degree than in other installations.

Example locations include metalworking, pulp and paper, chemical plants, car production, farm building, high voltage areas of airports.

Note 2 to entry: The connection between location and electromagnetic environment is given in 3.1.8.

[SOURCE: IEC 61000-6-4:2018, 3.1.12, modified – in the definition, “an installation consisting of” has been added, and the term reference in Note 2 has been updated.]

3.1.9
electromagnetic environment
totality of electromagnetic phenomena existing at a given location

Note 1 to entry: In general, the electromagnetic environment is time-dependent and its description can be better described with a statistical approach.

Note 2 to entry: It is very important not to confuse the concept of electromagnetic environment with the surrounding location.

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[SOURCE: IEC 61000-6-4:2018, 3.1.13.]

3.1.10
in-plant point of coupling
IPC
point ~~on a network inside a system or an installation, electrically nearest to a particular load, at which other loads~~ inside a non-public power distribution system, electrically nearest to a given load, at which loads from other branches are, or could be, connected

Note 1 to entry: The IPC is usually the point for which electromagnetic compatibility in industrial networks is to be considered.

3.2 Phenomena-related definitions

NOTE 1 The definitions below that relate to harmonics are based on the analysis of system voltages or currents by the discrete Fourier transform method (DFT). This is the practical application of the Fourier transform as defined in IEV 101-13-09. See Annex A.

NOTE 2 The Fourier transform of a function of time, whether periodic or non-periodic, is a function in the frequency domain and is referred to as the frequency spectrum of the time function, or simply spectrum. If the time function is periodic the spectrum is constituted of discrete lines (or components). If the time function is not periodic, the spectrum is a continuous function indicating components at all frequencies.

NOTE 3 Other definitions related to harmonics or interharmonics are given in IEC 60050 (all parts) and other standards. Some of those other definitions, although not used in this document, are discussed in Annex A.

3.2.1
fundamental frequency
frequency, in the spectrum obtained from a Fourier transform of a time function, to which all the frequencies of the spectrum are referred~~. For the purposes of this standard, the fundamental frequency is the same as the power supply frequency~~

~~[IEV 101-14-50, modified]~~

Note 1 to entry: In the case of a periodic function, the fundamental frequency is generally equal to the frequency of the function itself (see Clause A.1.). For the purposes of this document, the fundamental frequency is also the same as the power supply frequency.

~~NOTE 2 In case of any remaining risk of ambiguity, the power supply frequency should be referred to the polarity and speed of rotation of the synchronous generator(s) feeding the system.~~

~~NOTE 3 This definition may be applied to any industrial power supply network, without regard to the load it supplies (a single load or a combination of loads, rotating machines or other loads), and even if the generator feeding the network is a semiconductor converter.~~

3.2.2
fundamental component
fundamental
spectral component of a periodic time function whose frequency is equal to the fundamental frequency

3.2.3
harmonic frequency
frequency which is an integer multiple of the fundamental frequency~~. The ratio of the harmonic frequency to the fundamental frequency is named harmonic order. (Recommended notation "*h*")~~

3.2.4
harmonic order
ratio of the harmonic frequency to the fundamental frequency

Note 1 to entry: The recommended notation for harmonic order is "*h*".

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3.2.5
harmonic component
~~any of the components having a harmonic frequency. Its value is normally expressed as an r.m.s. value~~

~~For brevity, such a component may be referred to simply as a harmonic~~

spectral component of a periodic time function whose frequency is a harmonic frequency

Note 1 to entry: Harmonic components are often referred to as harmonics.

Note 2 to entry: See IEC 61000-4-7 for measuring conditions.

3.2.6
interharmonic frequency
~~any frequency which is not an integer multiple of the fundamental frequency~~

~~NOTE 1 By extension from harmonic order, the interharmonic order is the ratio of interharmonic frequency to the fundamental frequency. This ratio is not an integer. (Recommended notation "*m*")~~

~~NOTE 2 In the case where *m* < 1, the term sub-harmonic frequency may also be used.~~

any frequency between two consecutive harmonic frequencies

3.2.7
interharmonic order
ratio of an interharmonic frequency to the fundamental frequency

Note 1 to entry: This ratio is not an integer and can be indicated with "m".

3.2.8
interharmonic component
~~component having an interharmonic frequency. Its value is normally expressed as an r.m.s. value.~~

~~For brevity, such a component may be referred to simply as an interharmonic~~

~~NOTE For the purpose of this standard, and as stated in IEC 61000-4-7, the time window has a width of 10 fundamental periods (for 50 Hz systems) or 12 fundamental periods (for 60 Hz systems), i.e. approximately 200 ms. The difference in frequency between two consecutive interharmonic components is, therefore, approximately 5 Hz.~~

spectral component having an interharmonic frequency

Note 1 to entry: For brevity, such a component can be referred to simply as an interharmonic.

3.2.9
total harmonic distortion
THD
~~ratio of the r.m.s. value of the sum of all the harmonic components up to a specified order (recommended notation "*H*") to the r.m.s. value of the fundamental component~~

$$\cancel{THD = \sqrt{\sum_{h=2}^{h=H} \left(\frac{Q_h}{Q_1} \right)^2}}$$

~~where:~~

~~Q represents either current or voltage;~~

~~Q_1 is the r.m.s. value of the fundamental component;~~

~~h is the harmonic order;~~

~~Q_h is the r.m.s. value of the harmonic component of order h;~~

~~H is 50 for the purpose of the compatibility levels in this standard.~~

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~~NOTE *THD* takes account of harmonics only. For the case where interharmonics are to be included, see A.3.1.~~

ratio of the RMS value of the sum of all the harmonic components to the RMS value of the fundamental component

$$\mathrm{THD} = \sqrt{\sum_{h=2}^{40}\left(\frac{Q_\mathrm{h}}{Q_1}\right)^2} \tag{1}$$

where:

Q represents either current or voltage

Q_1 is the RMS value of the fundamental component

h is the harmonic order

Q_h is the RMS value of the harmonic component of order h

3.2.10
partial weighted harmonic distortion
PWHD

ratio of the weighted sum of the squared harmonic components from order 14 to order 40, to the RMS value of the nominal component n

$$\mathrm{PWHD} = \sqrt{\sum_{h=14}^{40} h\cdot\left(\frac{Q_\mathrm{h}}{Q_\mathrm{n}}\right)^2} \tag{2}$$

where:

Q_n is the nominal value of the quantity (e.g. voltage)

h is the harmonic order

Q_h is the RMS value of the quantity harmonic component of order h

3.2.11
voltage unbalance
voltage imbalance

~~condition in a polyphase system in which the r.m.s. values of the line-to line voltages (fundamental component), or the phase angle between consecutive line-to line voltages, are not all equal. The degree of the inequality is usually expressed as the ratios of the negative and zero sequence components to the positive sequence component~~

~~[IEV 161-08-09, modified]~~

~~NOTE 1 Generally voltage unbalance, in relation to three-phase systems, is considered through its negative phase sequence only. However, in some circumstances, the zero sequence component should also be considered.~~

~~NOTE 2 Several approximations give reasonably accurate results for the levels of unbalance normally encountered (ratio of negative to positive sequence components):~~

$$\cancel{\text{e.g. voltage unbalance} = \sqrt{6 \times \frac{U_{12}^2 + U_{23}^2 + U_{31}^2}{(U_{12} + U_{23} + U_{31})^2} - 2}}$$

~~where U_{12}, U_{23}, U_{31} are the three fundamental line-to-line voltages.~~

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condition in a polyphase system in which the r.m.s. values of the fundamental component of the line-to-line voltages, or the phase angle between consecutive line-to-line voltages, are not all equal

Note 1 to entry: Generally, in relation to three-phase systems, the amount of voltage imbalance is quantified by the ratio between the negative sequence components and the positive sequence components. However, in some circumstances, it is more appropriate to use the ratio between zero sequence and positive sequence components.

Note 2 to entry: Several approximations give reasonably accurate results for the levels of imbalance normally encountered (ratio of negative to positive sequence components), for example:

$$\text{voltage unbalance (imbalance)} = \sqrt{6 \times \frac{U_{12}^2 + U_{23}^2 + U_{31}^2}{(U_{12} + U_{23} + U_{31})^2} - 2} \quad (3)$$

where

U_{12}, U_{23}, U_{31} are the three fundamental line-to-line voltages

[SOURCE: IEC 60050-161:1990, 161-08-09, modified – the definition was simplified and the reference to the “zero sequence component” was moved from the core of the definition to Note 1.]

3.2.12
voltage deviation
~~increase or decrease of the r.m.s. supply voltage normally due to the variation of the load on the supply network or a part of it, or a rapid voltage change repeated, or not, due to a rapid change of load (see the first paragraph of 4.2 of IEC 61000-2-2); the part of transients with no remaining effects is excluded~~

~~NOTE Some voltage deviations may be fast changes due to adaptation of the voltage network to the load conditions (example: voltage taps changes of transformers, permanent effect of capacitor bank switching). Voltage fluctuation, which may cause flicker is a different phenomenon (series of voltage changes or cyclical voltage changes). Voltage variations and voltage fluctuations are the major types of voltage changes.~~

increase or decrease of the power supply RMS voltage, excluding transients with no remaining effects

Note 1 to entry: Voltage variations and voltage fluctuations are the major types of voltage deviations. Some voltage variations are fast due to the supply voltage adapting to different load conditions (for example, voltage taps changes of transformers, permanent effect of capacitor bank switching). Voltage fluctuations, which can cause flicker, are a different phenomenon (series of voltage deviations or cyclical voltage deviations, see IEC 61000-2-2:2002 and IEC 61000-2-2:2002/AMD2:2019, 4.2).

3.2.13
voltage dip
voltage sag
~~sudden reduction of the voltage at a particular point on an electricity supply system below a dip threshold voltage, followed by its recovery after a brief interval~~

~~NOTE 1 Typically a dip is associated with the occurrence and termination of a short circuit or other extreme current increase on the system or installations connected to it.~~

~~NOTE 2 Generally the threshold corresponds to the minimum value of the tolerance band.~~

temporary reduction of the voltage magnitude at a point in the electrical system below a threshold

Note 1 to entry: Typically a dip is associated with the occurrence and termination of a short circuit or other extreme current increase on the system or installations connected to it.

Note 2 to entry: Generally the dip threshold voltage corresponds to the minimum value of the nominal voltage tolerance.

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3.2.14
transient overvoltage
~~oscillatory or non-oscillatory overvoltage, highly damped and up to a few ms in duration. Compatibility level is related to the peak value line to earth~~

~~NOTE The origin of transient overvoltages is generally atmospheric or in operations in the network (switching, fuses). Its rise time may be from less than 1 µs to a few ms.~~

overvoltage with a duration of a few milliseconds or less, oscillatory or non-oscillatory, usually highly damped

Note 1 to entry: Transient overvoltages can be immediately followed by temporary overvoltages. In such cases the two overvoltages are considered as separate events.

[SOURCE: IEC 60050-614:2016, 614-03-14, modified – Note 2 has been deleted.]

3.2.15
industrial power electronic equipment
equipment not intended to be connected in a residential location and having emission and immunity either equal to or higher than those applicable to equipment intended to be used in a residential location

3.3 Abbreviated terms

AIC	Active infeed converter
DFT	Discrete Fourier transform
IPC	In-plant point of coupling
PCC	Point of common coupling
PLC	Power line communication
PWHD	Partial weighted harmonic distortion
PWM	Pulse width modulation
THD	Total harmonic distortion
UPS	Uninterruptible power system

4 Electromagnetic environment classes

Several electromagnetic environment classes can be defined for power distribution systems in the scope of this document. However, for simplicity ~~only three~~ the following environment classes are specified:

~~Class 1 This class applies to protected supplies and has compatibility levels lower than those on public networks. It relates to the use of equipment very sensitive to disturbances in the power supply, for instance electrical instrumentation in laboratories, some automation and protection equipment, some computers, etc.~~

~~Class 2 This class applies generally to PCCs and to IPCs in the environments of industrial and other non-public power supplies. The compatibility levels of this class are generally identical to those of public networks. Therefore, components designed for supply from public networks may be used in this class of industrial environment.~~

~~Class 3 This class applies only to IPCs in industrial environments. It has higher compatibility levels than those of class 2 for some disturbance phenomena. For instance, this class should be considered when any of the following conditions are met:~~

- ~~a major part of the load is fed through converters;~~
- ~~welding machines are present;~~
- ~~large motors are frequently started;~~

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~~– loads vary rapidly.~~

Class 1 This class applies to protected power supply systems, for which harmonic compatibility levels lower than those for public networks are necessary. It relates to the use of equipment which is very sensitive to disturbances in the power supply voltage (e.g. electrical instrumentation in laboratories, special automation and protection equipment, special computers).

Class 2L This class is a legacy from IEC 61000-2-4:2002 (second edition) for compatibility levels up to the 40th harmonic. The IPCs for class 2L, class 2a and class 2b correspond to the IPCs from the original class 2, hence the typical disturbance level in the frequency range up to the 40th harmonic in class 2L is expected to be similar to class 2a and class 2b. For the frequency range from the 40th harmonic to 150 kHz, class 2L is considered identical to class 2a. Class 2L is intended for some existing installations but it is not recommended for new types of installations.

NOTE 1 For some existing safety-related installations, for example in nuclear power plants, a new safety certification would be required if Class 2L were not included in this document.

Class 2a This class applies to IPCs (IPC1) in industrial locations at which no industrial power electronic equipment is intended to be connected (e.g. offices).

Class 2b This class applies to IPCs (IPC2) in industrial locations, at which industrial power electronic equipment is intended to be connected without a separation transformer to class 2a systems, but in which standard non-industrial equipment is also intended to be connected (e.g. light industry, commercial).

Class 3 IPCs (IPC3) in industrial locations which are separated by a separation transformer from areas in which non-industrial equipment is intended to be connected. This class should be considered when any of the following conditions are met:

- a major part of the load(s) is fed through converters (or systems of converters);
- welding machines are present;
- large motors are frequently started;
- other loads whose power consumption can vary rapidly.

The class applicable for new plants and extensions of existing plants cannot be determined a *priori* and should relate to the type of equipment and process under consideration.

Illustration of the above classes can be as shown in Figure 1:

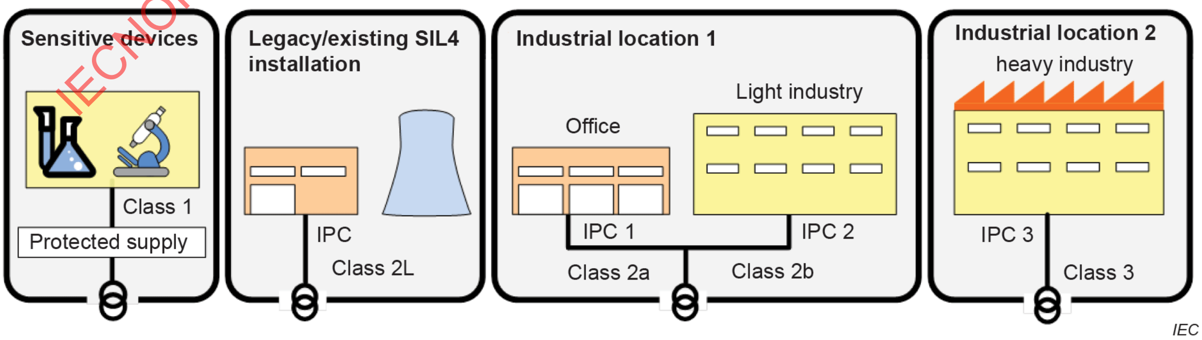

Figure 1 – Examples of the application of different electromagnetic environment classes in different industrial locations

NOTE 2 Class 1 environments normally contain equipment which requires protection from such apparatus as uninterruptible power systems (UPSs), filters or surge suppressors.

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NOTE 3 In some cases, highly sensitive equipment ~~may~~ can require compatibility levels lower than the ones relevant to class 1 environments. The compatibility levels will then be agreed upon case by case (controlled environment).

NOTE 4 The supply to highly disturbing loads, such as arc-furnaces and large converters which are generally supplied from a segregated busbar, frequently has disturbance levels in excess of class 3 (harsh environment). In such special ~~situations~~ installations with an overall power range typically > 200 kW, higher compatibility levels ~~should~~ will be agreed upon, considering the other loads' characteristics.

NOTE 5 Taking account of the diversity of industrial environments, different classes can be relevant for different phenomena in any given network.

NOTE 6 In the third picture of Figure 1, class 2a networks (office locations) and class 2b networks (light production locations) are directly connected. This is engineering practice in numerous installations. In these installations, the standard office equipment is in general sufficiently robust to withstand the disturbance level produced by the power electronic equipment in the light industrial location. In IEC 61000-2-4:2002 (second edition), this type of installation has not raised any questions because the compatibility levels were considered up to the 40th harmonic only, and different distortion levels above the 40th harmonic were not taken into account.

Should some mitigation be necessary, Figure 2 is an example:

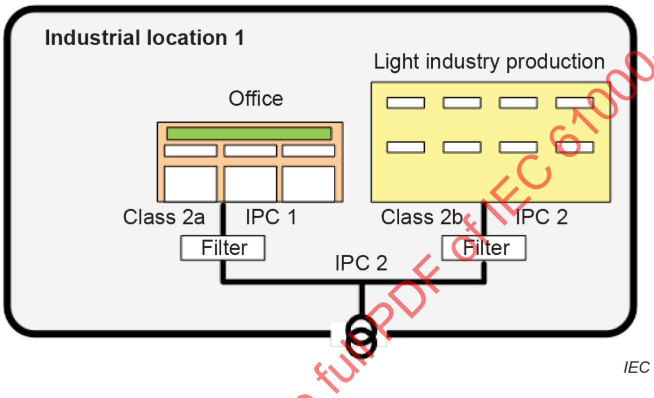

Figure 2 – Example of different parts of an installation separated by filters, where different electromagnetic environment classes are applied

In Figure 2, an office area is separated from a light industry production area using filters. At IPC1, class 2L or class 2a could apply according to the actual situation.

At the PCC, located in the public power distribution systems the compatibility levels defined in IEC 61000-2-2 apply for LV, and those defined in IEC 61000-2-12 apply for MV.

5 Introduction to the setting of compatibility levels for different types of electromagnetic disturbances

5.1 General comment

The compatibility levels are set down for the various disturbances on an individual basis only. However, the electromagnetic environment usually contains several disturbances simultaneously, and the performance of some equipment can be degraded by particular combinations of disturbances. See IEC 61000-2-2:2002, Clause A.2. The primary purpose of the compatibility levels is the coordination of emission limits and immunity test levels for equipment. The secondary purpose is to give an indication of the expected electromagnetic disturbance level in a local network.

Levels are provided in Table 1 to Table 5. See also guidance for interharmonics in Annex C.

IPCs should be categorized according to their compatibility levels. To enable the selection of specific equipment or devices such as rotating machines, power-capacitor banks, filters, it ~~may~~ can be necessary to obtain a specific description of the voltage deviations that ~~may~~ can be present at the equipment terminals. The technical committees responsible for the relevant product standards will specify the information to facilitate the proper selection of components.

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They should also take into account the compatibility levels in this document when specifying the supply operating conditions of the equipment.

Compatibility levels are given at the IPCs, but this does not imply that disturbances at these levels will satisfy the emission requirements at the PCC. This fact is to be carefully considered when selecting the equipment.

NOTE 1 Equipment operating within class 1 is generally low-voltage equipment.

NOTE 2 To illustrate disturbance levels caused by power converters in various industrial environments, a few examples of calculated results are given in Annex B.

NOTE 3 The compatibility levels of class 3 cover the possible disturbances in industrial environments. For a specific installation it is expected that only some types of disturbances occur with the level pertaining to class 3. Since equipment or devices have different sensitivities to the various types of disturbances, a specific equipment or device ~~may~~ can be used conditionally with a class 3 supply depending on the actual disturbance levels.

NOTE 4 Disturbance levels, which have both time and location variations, cannot be controlled at all locations and at all times. Therefore, evaluation ~~should~~ will be made for the entire industrial system being considered, rather than at a specific location within that system.

5.2 Voltage deviations

~~See Table 1.~~ The compatibility levels for voltage deviation are identical to the values for voltage tolerance in Table 1. For class 3, voltage deviations resulting in supply voltages in the range 0,85 ~~U_C~~ U_N to 0,9 ~~U_C~~ U_N are expected for a duration not longer than 60 s. For longer durations the range 0,9 ~~U_C~~ U_N to 1,1 ~~U_C~~ U_N applies.

NOTE 1 ~~Voltage fluctuation leading to flicker is generally of concern only to lighting equipment. This should be connected to a class 2 supply. The compatibility levels of IEC 61000-2-2 apply.~~ Voltage deviations leading to flicker are a concern for lighting equipment, which is typically connected to a class 2a, class 2b or class 2L power supply.

NOTE 2 In certain circumstances, some equipment might be sensitive to rapid voltage changes.

5.3 Voltage dips and short interruptions

For class 1 IPCs, a protection provided by UPSs is considered and dips are not expected.

For a discussion of the other aspects of these phenomena see Clause B.4.

5.4 Voltage ~~unbalance (~~imbalance~~)~~

In this document, voltage ~~unbalance~~ imbalance is considered only in relation to the negative phase sequence component, this being the component relevant to possible interference with equipment connected to the power supply systems covered by this document. In this document, voltage ~~unbalance~~ imbalance is considered in relation to long-term effect, i.e. for durations equal to or higher than 10 min.

NOTE 1 Some protection equipment ~~may~~ can be sensitive to the zero sequence voltage component. ~~Care should be taken of~~ This aspect at the installation level will be considered.

NOTE 2 Zero sequence voltages are of concern mainly for harmonics multiples of 3.

NOTE 3 Electronic converters produce characteristic harmonic orders due to their topology when used under their rated operating conditions. Different operating conditions such as ~~unbalance~~ imbalance, non-ideal commutation instants, ~~etc. may~~ can cause other harmonic orders to be produced.

The voltage ~~unbalance~~ imbalance caused by a single-phase load connected line-to-line is in practice equal to the ratio of the load power to the network three-phase short circuit power. If no substantial single-phase load is present, the compatibility levels of class ~~2~~ 2a and class 2b may be applied.

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5.5 Temporary power-frequency variation

The compatibility levels of power-frequency deviations of the public network apply to industrial plants fed from the public power supply.

For the most part, the range is within 1 Hz of the nominal frequency as stated in IEC 61000-2-2:2002, 4.8. Where synchronous interconnection is implemented on a continental scale, the variation is usually very much less.

The compatibility level for the temporary variation of frequency from the nominal frequency is ±1 Hz. The steady-state deviation of frequency from the nominal frequency is much less.

NOTE 1 For some equipment the rate of change of frequency is significant.

NOTE 2 ~~In the case of supply systems isolated from the public network, frequency variations up to ±4 % are expected. The actual compatibility levels in this instance are to be agreed upon.~~ In the case of islanded networks, frequency variations can be expected.

5.6 Harmonics

The compatibility levels for individual harmonic components of the voltage shall be understood to relate to ~~quasi-stationary or~~ steady-state harmonics and are given as reference values for both long-term effects and very short-term effects.

The long-term effects relate mainly to thermal effects on cables, transformers, motors, capacitors, etc. They arise from harmonic levels that are sustained for periods equal to or higher than 10 min.

With reference to long-term effects, compatibility levels for individual harmonic components of the voltage are given in Table 2 ~~to 4~~. The corresponding compatibility levels for the total harmonic distortion are given in ~~Table 5~~ Table 3.

Very short-term effects relate mainly to disturbing effects on electronic devices that ~~may~~ can be susceptible to harmonic levels sustained for 3 s or less. Transients are not included.

With reference to very short-term effects in class 1 and class 3, compatibility levels for individual harmonic components of the voltage, and for total harmonic distortion, are 1,5 times the values given in Table 2 ~~to 5~~ and Table 3.

In class ~~2~~ 2a and class 2b, they are the values given in Table 2 ~~to 4~~ multiplied by a factor k, where k is as follows:

~~The corresponding compatibility level for the total harmonic distortion in class 2 is 8 % (THD = 8 %) with reference to very short term.~~

$$k = 1{,}3 + \frac{0{,}7}{45} \times (h - 5) \tag{4}$$

NOTE 1 Commutation notches are included here as regards their contribution to the harmonic content of the voltage. Other aspects (for example, the influence on the commutation of other converters, or any influence on other equipment which involves the higher harmonic components of the spectrum) require a time-domain description (see the relevant product standard).

NOTE 2 Everywhere they are used in industrial networks, power factor correction capacitors ~~should be~~ are connected through series reactors, particularly those which are intended to be connected to IPCs of class 3. Where interharmonics ~~may~~ can be present, there is a risk of resonance effects, and this ~~should~~ will be carefully investigated. Where the absence of resonance effects is clearly proved and the higher harmonics values are far less than those given for class 3, series reactors ~~may~~ might not be necessary, but this will be checked carefully.

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NOTE 3 The values specified for total harmonic distortion are not related to specific equipment or devices but are concerned with the possible simultaneous presence of several harmonic components at significant amplitude.

5.7 Interharmonics

Annex C provides information on sources, effects and mitigation methods related to interharmonics. It also provides levels for guidance, until more experience makes publication of compatibility levels possible.

In this document, compatibility levels are given only for the case of an interharmonic voltage occurring at a frequency close to the fundamental frequency (50 Hz or 60 Hz), resulting in amplitude modulation of the supply voltage.

In these conditions certain loads that are sensitive to the square of the voltage, especially lighting devices, exhibit a beat effect, resulting in flicker (see Note 1 in 5.2.) The beat frequency is the difference between the frequencies of the two coincident voltages, i.e. between the interharmonic and fundamental frequencies.

NOTE 1 Below interharmonic order 0,2 compatibility levels are determined by flicker requirements, with P_{st} = 1. For this purpose the flicker severity ~~should~~ can be calculated in accordance with IEC TR 61000-3-7:2008, Annex A, using the shape factor given for periodic and sinusoidal voltage fluctuations. The conservative value of the shape factor is 0,8 for 0,04 < m ≤ 0,2, and 0,4 for m ≤ 0,04.

NOTE 2 A similar situation is possible when there is an appreciable level of voltage at a harmonic frequency (particularly of order 3 or 5) coincident with an interharmonic voltage at a nearby frequency. The effect ~~should~~ can be assessed by means of Figure 1, with amplitude given by the product of the relative amplitudes of the harmonic and interharmonic at the origin of the beat frequency. The result is unlikely to be significant.

The compatibility level for the interharmonic voltage in the above case, expressed as the ratio of its amplitude to that of the fundamental, is shown in Figure 1 as a function of the beat frequency. It is based on a flicker level of P_{st} = 1 for lamps operated at 120 V and 230 V and is applicable only to circuits which include lighting devices.

5.8 Voltage components at higher frequencies (above ~~50~~ 40th harmonic)

Distortion of the voltage waveform can be such as to be equivalent to the superposition of voltages at frequencies, some of which are greatly in excess of that of the ~~50~~ 40th harmonic. In the case of such higher frequency voltages it is generally not significant whether they are harmonics or interharmonics. They can occur both at discrete frequencies and in relatively broad bands of frequencies.

~~Until more experience makes publication of compatibility levels possible, Annex C.3 provides levels for guidance.~~

5.9 Transient overvoltages

The relative amplitude of transients is generally a function of their duration, of their frequency and of the voltage level of the network. For a discussion of these phenomena, see Clause B.5.

5.10 DC component

The voltage of industrial power supply systems covered by this document does not normally have a DC component at a significant level. That can arise, however, due to slight defects of symmetry of controlled loads which are directly connected without a dedicated separation transformer.

The critical point is the level of DC current. The value of the DC voltage depends not only upon DC current but also upon other factors, especially the resistance of the network at the point to be considered. Therefore, a compatibility level for the DC voltage is not specified.

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A DC component can cause unsymmetrical magnetization in transformers, leading to overheating and emission of harmonic voltages. Moreover, if flowing through the earth, such a DC current leads to increased corrosion of metal fixtures underground.

6 Compatibility levels

Compatibility levels in differential mode (L-L and L-N) for imbalance, harmonics, interharmonics and flicker are 95 % probability values.

Compatibility levels for voltage tolerance, voltage ~~unbalance~~ imbalance and power-frequency variations are given in Table 1.

Compatibility levels for harmonics are indicated in Table 2 ~~to 4~~.

Compatibility levels for total harmonic distortion are presented in ~~Table 5~~ Table 3.

The compatibility levels for voltage distortion above the 40th harmonic up to 9 kHz and from 9 kHz to 150 kHz are given in Table 4 and Table 5, respectively.

Interharmonic compatibility levels are represented in ~~Figure 1~~ Figure 3.

Table 1 – Compatibility levels for voltage tolerance, voltage ~~unbalance~~ imbalance and power-frequency variations

Disturbance		Class 1	Class ~~2~~ 2L, Class 2a, Class 2b	Class 3
Voltage tolerance, relative to nominal voltage U_N:	$\Delta U/U_N$	±8 %	±10 % [a]	+10 % to −15 % [b]
Voltage ~~unbalance~~ imbalance	U_{neg}/U_{pos}	2 %	2 %	3 %
Power-frequency deviations [c]	Δf	±1 Hz	±1 Hz	±1 Hz

[a] Value not defined in IEC 61000-2-2.

[b] See 5.2.

[c] ±2 Hz in case of ~~isolated~~ islanded networks.

~~**Table 2 – Compatibility levels for harmonics – Harmonic voltage components Odd harmonics non-multiple of three**~~

~~Order h~~	~~Class 1 U_h %~~	~~Class 2 U_h %~~	~~Class 3 U_h %~~
~~5~~	~~3~~	~~6~~	~~8~~
~~7~~	~~3~~	~~5~~	~~7~~
~~11~~	~~3~~	~~3,5~~	~~5~~
~~13~~	~~3~~	~~3~~	~~4,5~~
~~17~~	~~2~~	~~2~~	~~4~~
~~17 < h ≤ 49~~	~~2,27 × (17/h) – 0,27~~	~~2,27 × (17/h) – 0,27~~	~~4,5 × (17/h) – 0,5~~

~~NOTE In some cases where part of an industrial network is dedicated to large non-linear loads, the class 3 compatibility levels for that part of the network may be 1,2 times the above values. In such cases precautions should be taken regarding immunity of equipment connected. However, at the PCC (public network) the compatibility levels from IEC 61000-2-2 and IEC 61000-2-12 take precedence.~~

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~~Table 3 – Compatibility levels for harmonics – Harmonic voltage components Odd harmonics multiple of three~~

~~Order~~ ~~*h*~~	~~Class 1~~ ~~U_h~~ ~~%~~	~~Class 2~~ ~~U_h~~ ~~%~~	~~Class 3~~ ~~U_h~~ ~~%~~
~~3~~	~~3~~	~~5~~	~~6~~
~~9~~	~~1,5~~	~~1,5~~	~~2,5~~
~~15~~	~~0,3~~	~~0,4~~	~~2~~
~~21~~	~~0,2~~	~~0,3~~	~~1,75~~
~~21 < *h* ≤ 45~~	~~0,2~~	~~0,2~~	~~1~~

~~NOTE 1 These levels apply to zero sequence harmonics.~~

~~NOTE 2 In some cases where part of an industrial network is dedicated to large non-linear loads, the class 3 compatibility levels for that part of the network may be 1,2 times the above values. In such cases precautions should be taken regarding immunity of equipment connected. However, at the PCC (public network) the compatibility levels from IEC 61000-2-2 and IEC 61000-2-12 take precedence.~~

~~Table 4 – Compatibility levels – Harmonic voltage components even order~~

~~Order~~ ~~*h*~~	~~Class 1~~ ~~U_h~~ ~~%~~	~~Class 2~~ ~~U_h~~ ~~%~~	~~Class 3~~ ~~U_h~~ ~~%~~
~~2~~	~~2~~	~~2~~	~~3~~
~~4~~	~~1~~	~~1~~	~~1,5~~
~~6~~	~~0,5~~	~~0,5~~	~~1~~
~~8~~	~~0,5~~	~~0,5~~	~~1~~
~~10~~	~~0,5~~	~~0,5~~	~~1~~
~~10 < *h* ≤ 50~~	~~0,25 × (10/*h*) + 0,25~~	~~0,25 × (10/*h*) + 0,25~~	~~1~~

~~NOTE In some cases where part of an industrial network is dedicated to large non-linear loads, the class 3 compatibility levels for that part of the network may be 1,2 times the above values. In such cases precautions should be taken regarding immunity of equipment connected. However, at the PCC (public network) the compatibility levels from IEC 61000-2-2 and IEC 61000-2-12 take precedence.~~

Table 2 – Compatibility levels for harmonics – Harmonic voltage components

Order *h*	Class 1 U_h %	Class 2L U_h %	Class 2a, class 2b U_h %	Class 3 U_h %
2	2	2	2	3
3	3	5	5	6
4	1	1	1	3
5	3	6	6	8
6	0,50	0,50	1	3
7	3	5	5	7
8	0,50	0,50	1	3
9	1,5	1,5	1,5	3
10	0,50	0,50	1	3

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11	3	3,5	3,5	5
12	0,46	0,46	1	3
13	3	3	3	4,5
14	0,43	0,43	1	4,4
15	0,30	0,40	1	4,2
16	0,41	0,41	1,4	4,1
17	2	2	2	4
18	0,39	0,39	1,4	3,8
19	1,8	1,8	1,8	3,5
20	0,38	0,38	1,4	3,3
21	0,20	0,30	1,4	3,1
22	0,36	0,36	1,4	3
23	1,4	1,4	1,4	2,8
24	0,35	0,35	1,3	2,5
25	1,3	1,3	1,3	2,6
26	0,35	0,35	1,2	2,4
27	0,20	0,20	1,2	2,3
28	0,34	0,34	1,1	2,2
29	1,1	1,1	1,1	2,1
30	0,33	0,33	1	2,1
31	0,97	0,97	0,97	2
32	0,33	0,33	0,94	1,9
33	0,20	0,20	0,90	1,8
34	0,32	0,32	0,87	1,8
35	0,83	0,83	0,83	1,7
36	0,32	0,32	0,80	1,6
37	0,77	0,77	0,77	1,6
38	0,32	0,32	0,75	1,5
39	0,20	0,20	0,72	1,5
40	0,31	0,31	0,69	1,4
In some cases where part of an industrial network is dedicated to large non-linear loads, the class 3 compatibility levels for that part of the network may be 1,2 times the above values. In such cases precautions should be taken regarding immunity of equipment connected. However, at the PCC (public network) the compatibility levels from IEC 61000-2-2 and IEC 61000-2-12 take precedence.				

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Table ~~5~~ 3 – Compatibility levels for total voltage harmonic distortion

	Class 1	Class ~~2~~ 2L, class 2a, class 2b	Class 3
Total harmonic distortion (THD)	5 %	8 %	10 %
Partial weighted harmonic distortion (PWHD)	19,4 %	19,4 %	43,6 %
NOTE ~~In some cases where part of an industrial network is dedicated to large non-linear loads, the class 3 compatibility levels for that part of the network may be 1,2 times the above values. In such cases precautions should be taken regarding immunity of equipment connected. However, at the PCC (public network) the compatibility levels from IEC 61000-2-2 and IEC 61000-2-12 take precedence.~~ The PWHD compatibility levels were calculated from the individual harmonic voltage components from H14 to H40 defined for all classes defined in IEC 61000-2-4.			

Table 4 – Compatibility levels for low voltage networks in the frequency range from 2 kHz to 9 kHz

Frequency range kHz	Class 1, class 2L, class 2a U_N %	Class 2b U_N %	Class 3 U_N %
2 (2,4)[a] to 3	1,4	3	6
3 to 9	1,4 to 0,65[b]	3	6

NOTE The levels specified in Table 4 apply at the IPC. At the PCC (public network), the compatibility levels from IEC 61000-2-2 apply.

[a] The frequency range is 2 kHz to 3 kHz for 50 Hz systems and 2,4 kHz to 3 kHz for 60 Hz systems.

[b] The logarithm of the level decreases linearly with the logarithm of the frequency in the range 3 kHz to 9 kHz.

For the frequency range between 2 kHz and 9 kHz, compatibility levels are defined as a grouped value within a band of 200 Hz according to IEC 61000-4-7.

For MV networks, compatibility levels above 2 kHz are under consideration.

Table 5 – Compatibility levels for low voltage networks in the frequency range from 9 kHz to 150 kHz

Frequency range kHz	Class 1, class 2L, class 2a U_h dBµV	Class 2b U_h dBµV	Class 3 U_h dBµV
9 to 50	129,5 to 119[a]	137 to 126,5[a]	143 to 141[a]
50 to 150	113 to 89[a]	126,5 to 109[a]	141 to 139[a]

NOTE The levels specified in Table 5 apply at the IPC. At the PCC (public network), the compatibility levels from IEC 61000-2-2 apply.

[a] The logarithm of the level decreases linearly with the logarithm of the frequency in the range 9 kHz to 50 kHz and from 50 kHz to 150 kHz.

The compatibility levels U_h for voltage distortion in differential mode from 9 kHz to 150 kHz are related to disturbance levels between any phase conductors and between any phase conductor and the neutral conductor measured with a quasi-peak detector and with a bandwidth of 200 Hz in accordance with CISPR 16-1-1.

These compatibility levels for voltage distortion are reference levels for EMC coordination of immunity requirements and in the setting of emission limits in differential mode for emissions. However, if the emission limits are related to voltage distortion levels measured between any mains conductor (phase or neutral) and the earth (unsymmetrical voltages) in accordance with CISPR 16-2-1, the reference levels for EMC coordination in the setting of emission limits for unsymmetrical voltage distortion are 6 dB lower than the compatibility levels given in Table 5 for voltage distortion in differential mode.

NOTE 1 Measurements according to CISPR 16-2-1 are not applicable in IT networks. In IT networks, measurements can be done for example with a voltage probe.

NOTE 2 Based on the following assumptions, an emission margin equal to or higher than 3 dB between the equipment emission limits in differential mode for emissions and the corresponding compatibility levels, or a difference equal to or higher than 9 dB (3 dB for the emission margin + 6 dB for the conversion factor between the

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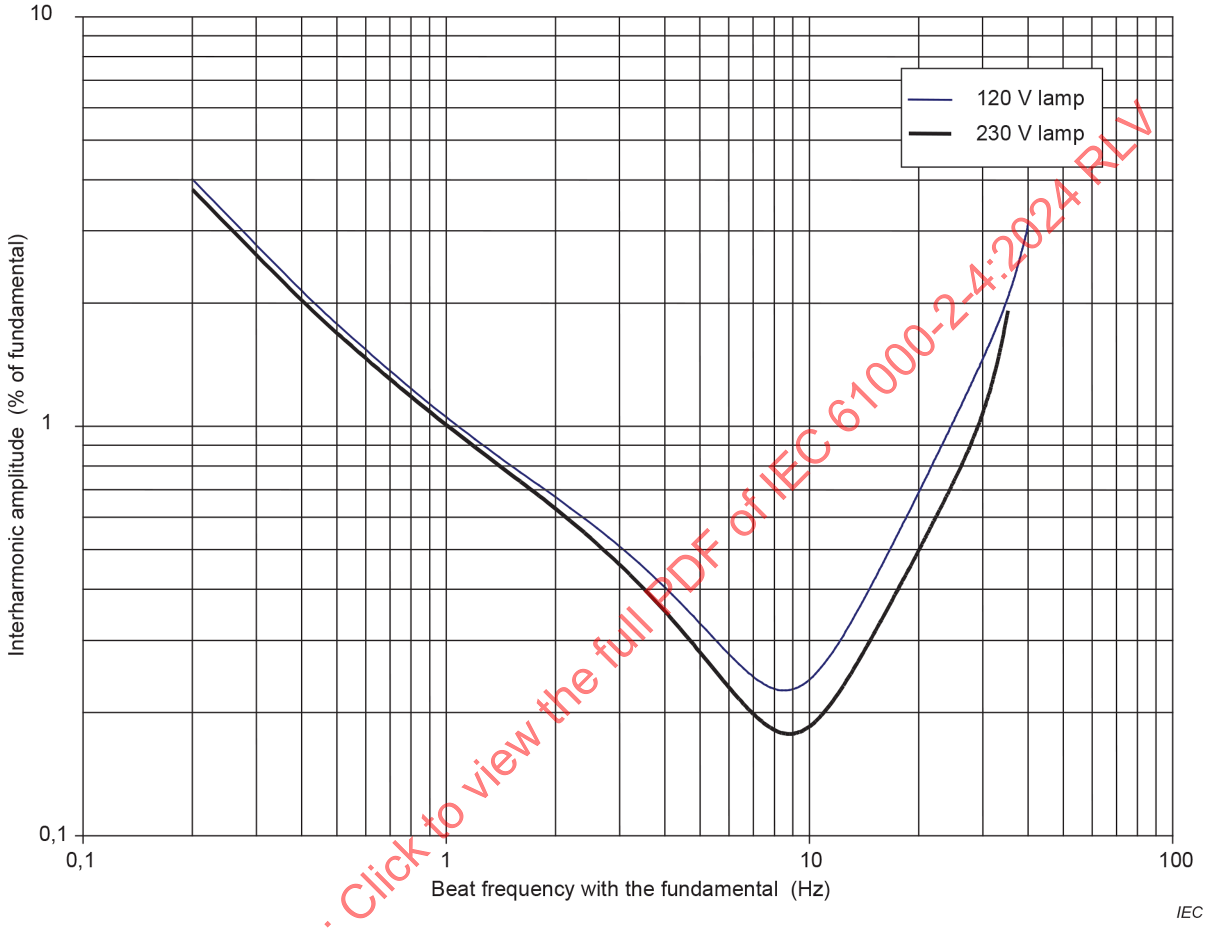
unsymmetrical voltages and the voltage in differential mode) between the equipment emission limits for unsymmetrical voltage distortion and the compatibility levels in differential mode given in Table 5 is sufficient:

– for each bandwidth of 200 Hz, the probability that the compatibility level is exceeded is lower than 5 %;

– at a given location, the disturbance level in a same bandwidth of 200 Hz does not result from more than two pieces of equipment generating non-intentional emissions close to the emission limit at the same time;

– non-intentional emissions from different equipment are generated independently from each other.



NOTE Compatibility levels for interharmonics near the fundamental frequency, 230 V and 120 V systems, corresponding to perception of flicker are given by Figure 1 as a function of the beat frequency, which makes the result independent from the system frequency.

Figure ~~1~~ 3 – Interharmonic compatibility levels (flickermeter response for P_{st} = 1 related to 60 W incandescent lamps)

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Annex A
(informative)

Explanations and examples for interharmonics

A.1 Resolution of non-sinusoidal voltages and currents

The distortion of the supply voltage from its intended sinusoidal waveshape is equivalent to the superposition on the intended voltage of one or more sinusoidal voltages at unwanted frequencies. (The discussion below is valid for both voltage and current – therefore the word “quantity” is used.)

Fourier series analysis (IEV 101-13-08) enables any non-sinusoidal but periodic quantity to be resolved into truly sinusoidal components at a series of frequencies, and in addition, at a DC component. The lowest frequency of the series is called the fundamental frequency f_f (IEV 101-14-50). The other frequencies in the series are integer multiples of the fundamental frequency and are called harmonic frequencies. The corresponding components of the periodic quantity are referred to as the fundamental and harmonic components, respectively.

The Fourier transform (IEV 101-13-09) ~~may~~ can be applied to any function, periodic or non-periodic. The result of the transform is a spectrum in the frequency domain, which in the case of a non-periodic time function is continuous and has no fundamental component. The particular case of application to a periodic function shows a lines spectrum in the frequency domain, where the lines of the spectrum are the fundamental and harmonics of the corresponding Fourier series.

The discrete Fourier transform (DFT) is the practical application of the Fourier transform. In practice the signal is analysed over a limited period of time (a window with duration T_w) using a limited number (M) of samples of the actual signal. The result of the DFT depends on the choice of these parameters, T_w and M. The inverse of T_w is the basic frequency f_b of the DFT.

The DFT is applied to the actual signal inside the window. The signal is not processed outside the window but is assumed to be an identical repetition of the signal inside the window. This results in an approximation of the actual signal by a virtual signal which is truly periodic and whose period is the time window.

The FFT (Fast Fourier Transform) is a special algorithm allowing short computation time. It requires the number of samples (M) to be an integer multiple of 2 ($M = 2^i$). (In other words, it does require the sampling frequency to be a locked integer power of 2 of the fundamental). However, modern digital signal processors have such capability that the extra complexity in a DFT (tables of sine and cosine functions) can be more economic and flexible than the frequency locked FFTs.

In order that the result of the DFT, applied to a function considered as periodic (see Clause A.2), is the same as the result of a Fourier series analysis, the fundamental frequency f_f is made an integer multiple of the basic frequency (this requires the sampling frequency to be an exact integer multiple of the basic frequency [$f_s = M \times f_b$]). The synchronous sampling is essential. Loss of synchronism can change the spectrum result, making extra lines appear and changing amplitudes of true lines.

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Accordingly, the measurement techniques defined in IEC 61000-4-7[2] and the definition of the fundamental frequency in 3.2.1 are consistent for application to all electrotechnical and power electronics items. Other cases ~~need~~ require further consideration.

As an illustration, the superposition of a sinusoidal ripple control signal at 175 Hz on a sinusoidal 50 Hz supply voltage ~~may~~ can be considered. This results in a periodic voltage having a period of 40 ms and a frequency of 25 Hz. A classical Fourier series analysis of this voltage yields a fundamental component of 25 Hz with zero amplitude and two components with non-zero amplitude, a 2nd harmonic (50 Hz) with amplitude equal to that of the supply voltage and a 7th harmonic (175 Hz) with an amplitude equal to that of the ripple control signal. The definitions in 3.2 avoid the confusion implicit in this approach and produce a result in line with the common practice of the DFT (as described in IEC 61000-4-7), showing a fundamental at 50 Hz and an interharmonic of order 3,5.

NOTE 1 When analysing the voltage of a power supply system, the component at the fundamental frequency is the component of the highest amplitude. This is not necessarily the first line in the spectrum obtained when applying a DFT to the time function.

NOTE 2 When analysing a current, the component at the fundamental frequency is not necessarily the component of the highest amplitude.

A.2 Time varying phenomena

The voltages and currents of a typical electricity supply system are affected by incessant switching and variation of both linear and non-linear loads. However, for analysis purposes, they are considered as stationary within the measurement window (approximately 200 ms), which is an integer multiple of the period of the power supply voltage. Harmonic analysers are designed to give the best compromise that technology can provide (see IEC 61000-4-7).

~~A.3 Definition of additional terms~~

~~The following definitions are complementary to those given in 3.2 and may be of practical use.~~

~~**A.3.1**~~
~~**total distortion content**~~
~~quantity remaining when the fundamental component is subtracted from an alternating quantity, all being treated as functions of time~~

~~NOTE The r.m.s. value of the total distortion content is:~~

$$\cancel{TDC = \sqrt{Q^2 - Q_1^2}}$$

~~Q_1 is the r.m.s. value of the fundamental component;~~

~~Q is the total r.m.s. value;~~

~~Q can represent either current or voltage.~~

~~It includes both harmonic and interharmonic components.~~

~~See also the definitions IEV 101-14-54 (IEC 60050-101) and IEV 551-20-11 (IEC 60050-551-20).~~

~~[2] Second edition, to be published.~~

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~~**A.3.2**~~
~~**total distortion ratio**~~
~~**TDR**~~
~~ratio of the r.m.s. value of the total distortion content of an alternating quantity to the r.m.s. value of the fundamental component of the quantity~~

~~[IEV 551-20-14, modified]~~

$$\cancel{TDR = \frac{TDC}{Q_1} = \frac{\sqrt{Q^2 - Q_1^2}}{Q_1}}$$

~~where~~

~~Q_1 is the r.m.s. value of the fundamental component;~~

~~Q is the total r.m.s. value;~~

~~Q can represent either current or voltage.~~

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Annex B
(informative)

Examples of expected disturbance levels in typical industrial networks

B.1 General

Annex B gives the results of the calculation of the disturbance levels at the IPCs in some typical industrial networks. The cases studied are as follows:

– rolling mills (Table B.1; Figure B.1);
– paper industry (Table B.1; Figure B.2);
– manufacturing industry (Table B.2; Figure B.3).

B.2 Voltage disturbance levels in industrial networks due to large converters

It can be seen that some IPCs, namely those feeding large converters, can have disturbance levels considerably higher than those specified for public networks.

It is especially the levels of higher order harmonics (the 11th order is given as example), the total harmonic distortion coefficient (THD) or the voltage changes that exceed the corresponding levels for public networks.

The reported results are not total disturbance levels since the contribution caused by disturbances present in the public supply is not considered.

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Table B.1 – Type of network

	Rolling mills			Paper industry		
	IPC 1	IPC 2	PCC	IPC 1	IPC 2	PCC
Harmonic voltages						
Average values						
U_5 (%)	3 to 6,5	2 to 3,9	1 to 2,2	1 to 1,7	1 to 2,3	0,5 to 1,1
U_{11} (%)	3 to 6,8	1,5 to 2,9	1 to 2	0,5 to 1,1	0,7 to 1,4	0,4 to 0,7
THD (%)	7 to 14,3	3,5 to 7,3	2 to 4,7	1,5 to 2,9	2 to 4	1 to 1,9
Harmonic voltages						
Peak values						
U_5 (%)	6 to 11,4	2,5 to 5,1	2 to 3,5	1 to 1,9	1,5 to 2,7	0,6 to 1,3
U_{11} (%)	6 to 11,5	2 to 4,2	2 to 3,3	0,5 to 1,2	0,8 to 1,6	0,4 to 0,8
THD (%)	12 to 24,7	5 to 9,9	4 to 7,3	1,5 to 3,3	2 to 4,6	1 to 2,3
Voltage changes ΔU (%)	2 to 4,7	0,5 to 1,2	0,5 to 1,2	< 0,1	< 0,3	< 0,1
Time interval between two voltage changes ΔT (s)	5 to 100	5 to 100	5 to 100	> 600	> 600	> 600

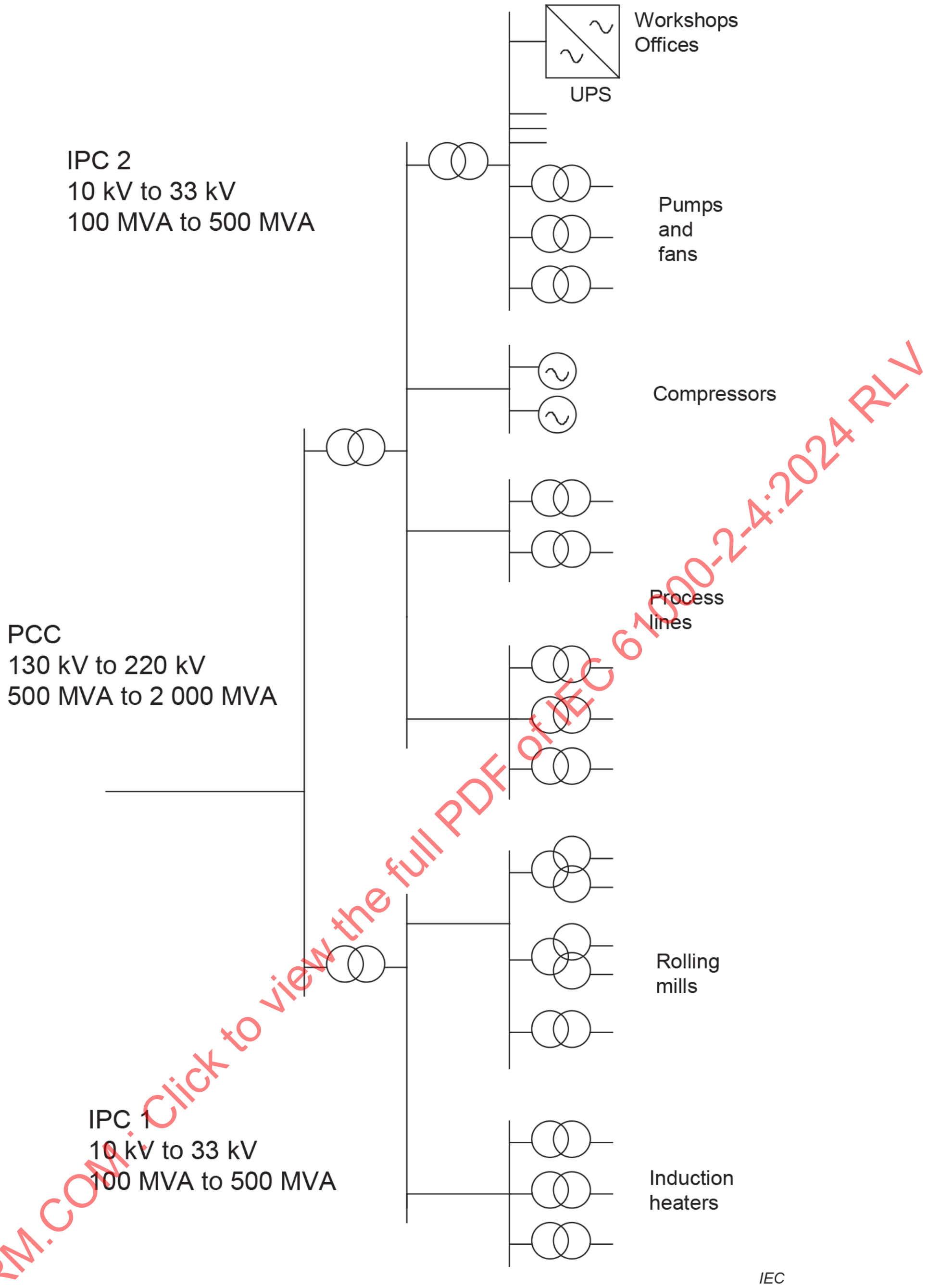

Figure B.1 – Example of power distribution in industry with rolling mills

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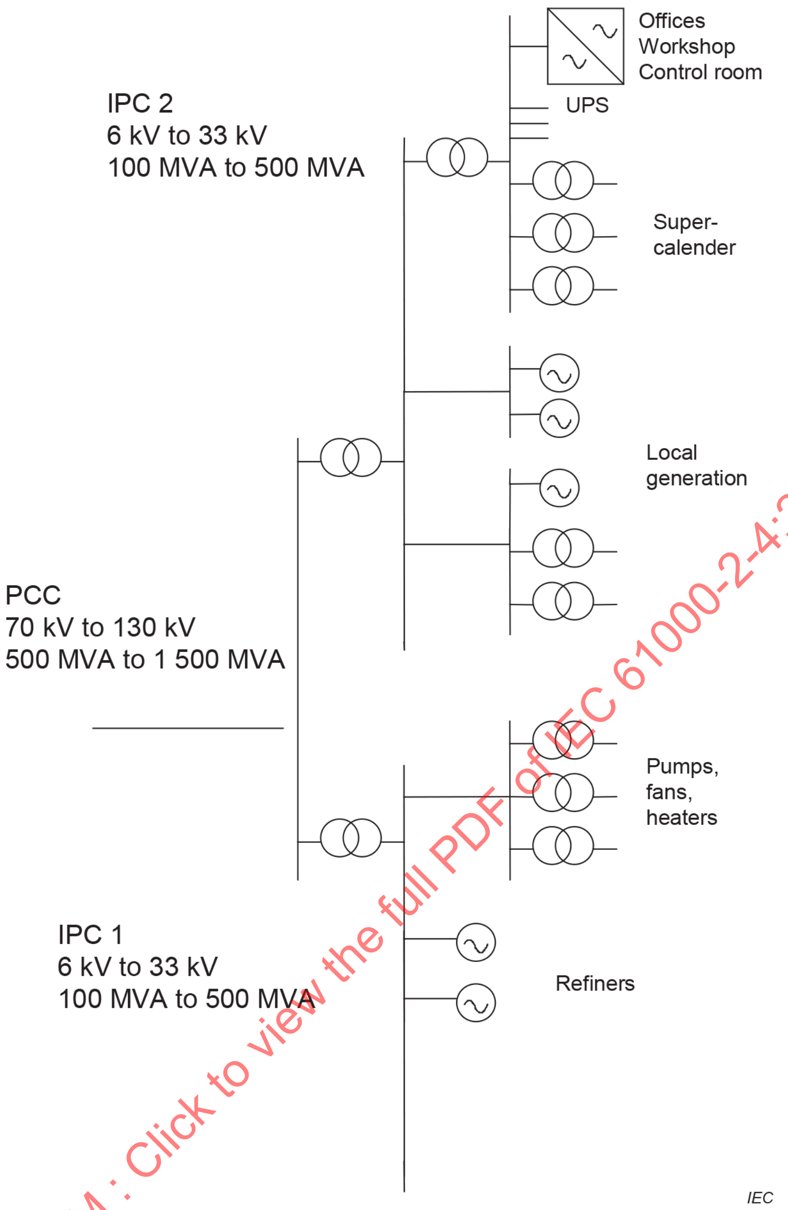

Figure B.2 – Example of power distribution in the paper industry

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B.3 Voltage disturbance levels in industrial networks at high load

The range of the given values depends on the assumed range of variation of the system parameters and of the coincidence factors.

No power capacitor is present and therefore the possible magnification of the harmonic voltages is neglected.

Table B.2 – Voltage disturbance levels in a typical manufacturing industry

	Impedance 1/MVA [a]	Short-circuit fault level (S_{SC}) MVA	Total load MVA	Converter load MVA	THD %	Voltage changes %
130 kV line	1/2 000	2 000				
Transformer TA	1/320	275,8				
MT cable	1/6 000					
IPC		266,6	2,3	1,25	1,08	0,6
Transformer T1	1/8,9					
LV1 line		8,6	0,3	0,05	1,34	2,4
Transformer T5	1/1,25					
Converter C1		1,09		0,05	10,6	
Transformer T3	1/12					
LV2 line		11,5	0,6	0,3	5,0	3,0
350 kVA motors		2,275	0,3			
60 µH reactor	1/8,5					
Converter C2		5,25		0,3	13,2	
Transformer T4	1/22,2					
LV3 line		20,5	0,9	0,9	10,1	3,1
400 V cable	1/582					
Converters C3 ..... C10		20		0,9	10,4	

[a] The impedances are in p.u. on a 1 MVA basis.

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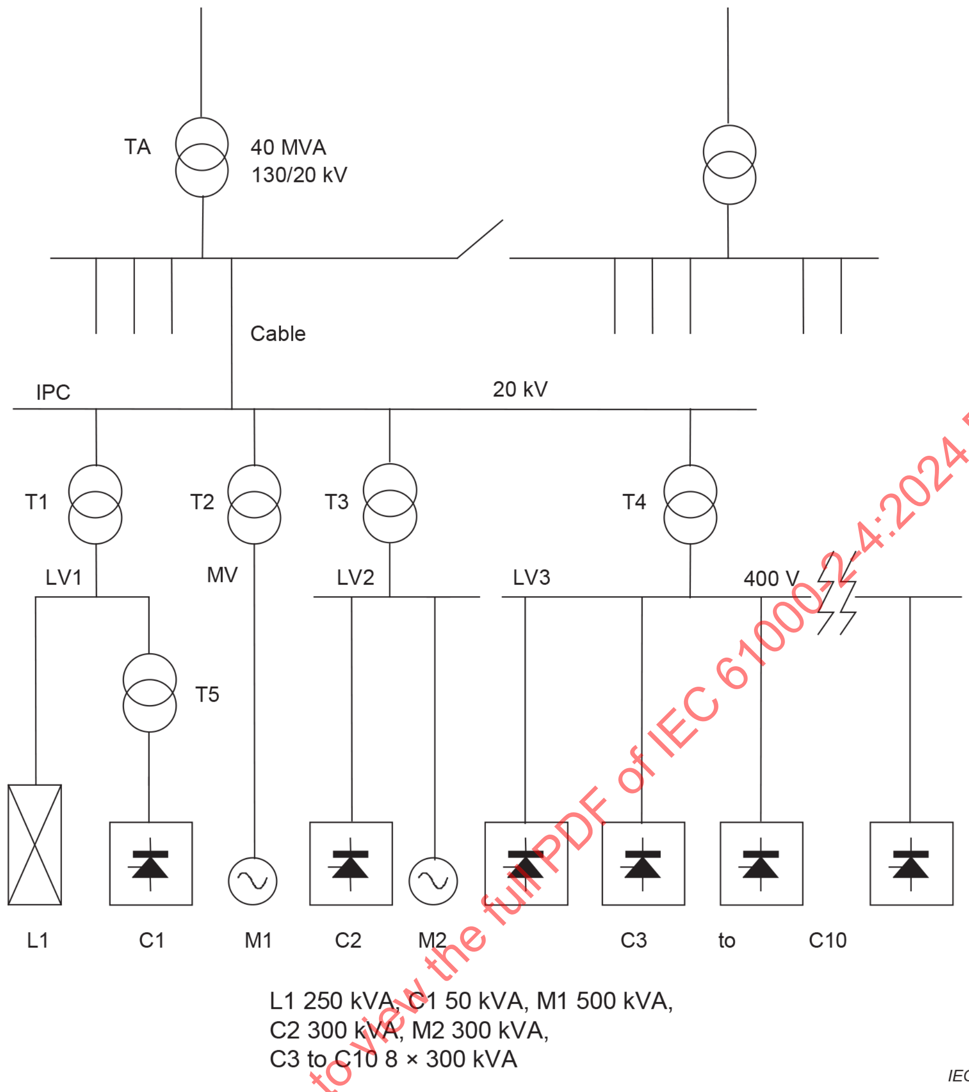

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Figure B.3 – Example of power distribution in a generic manufacturing industry

B.4 Voltage dips and short interruptions

B.4.1 Description

~~Voltage dips and short interruptions at the PCC have the main influence on these phenomena inside the installation.~~ Voltage dips and short interruptions are unpredictable, largely random events arising mainly from electrical faults on the power supply system or large installations. They are best described in statistical terms. See IEC TR 61000-2-8.

A voltage dip is a two-dimensional disturbance phenomenon, since the level of the disturbance increases with both the depth and duration of the dip.

The depth of the voltage dip depends on the proximity of the observation point to the point on the network at which the short circuit occurs. At that point the voltage collapses to near zero, so that the depth of the dip approaches 100 %. In the case of other causative events, such as a large load fluctuation, the depth is likely to be less.

A voltage dip ~~may~~ can last less than 0,1 s if the incident occurs in the transmission system and is eliminated by very fast systems of protection or if a self-clearing fault is involved. If the fault affects a lower level of the network and is cleared by certain protection systems used on those networks, it ~~may~~ can last up to a few seconds. Most voltage dips last between half a period and 1 000 ms.

The number of voltage dips is significant only when the immunity of a given device is insufficient for the depth-duration occurring. This number becomes an important data for choosing the appropriate level of immunity of a given process. The number for a particular line includes voltage dips produced by faults on other lines in the same network and voltage dips coming from upstream networks. (See also IEC TR 61000-2-8.)

In rural areas supplied by overhead lines, the number of voltage dips can reach several hundred per year, depending in particular on the number of lightning strokes and other meteorological conditions in the area.

On cable networks, the latest information indicates that an individual user of electricity connected at low voltage ~~may~~ can be subjected to voltage dips occurring at a rate which extends from around ten per year to about a hundred per year, depending on local conditions. The duration of these voltage dips is usually between half a cycle and 3 s.

Short supply interruptions last up to 180 s according to the type of reclosing or transfer system used in overhead networks. It ~~may~~ can be possible to reduce time in special cases. Frequently short supply interruptions are preceded by voltage dips. Distinction between a dip and a short interruption ~~may~~ can be difficult. By convention, a retained voltage below a certain level (10 % for example) ~~may~~ can be the criterion to make this distinction. However, in a three-phase system this condition is to be applied to each phase, simultaneously, to be considered as a short supply interruption.

B.4.2 Adaptation

~~The main requirement for compatibility levels is to enable immunity levels to be coordinated. However, the compatibility level would have to be expressed in a two-dimensional manner, to reflect the level of the disturbance. Sufficient data are not yet available to enable this to be done.~~

~~Especially~~ In the case of short interruptions, but also for the more severe voltage dips, immunity of electrical equipment is not, in the strict sense, an appropriate concept, since no electrical device can continue to operate as intended in the absence of its energy supply. Immunity from these disturbances is therefore a matter of either the fast restoration of energy from an alternative source or arranging for the equipment and its associated process to adapt in an intended manner to the brief interruption or diminution of power. This is a complex matter, having both technical and economic aspects, and is beyond the scope of this document (see Bibliography).

Values describing voltage dips and short interruptions for class 3 IPCs ~~may~~ can be established with due consideration of the following:

– the disturbance level values at the PCCs of the plant ~~may~~ can be adopted, but it should be remembered that these values can vary considerably with the type of supply system, high voltage or medium voltage via overhead lines or cables, single circuit or double circuits for example, and with the location of the site, exposed and prone to lightning for example;
– the presence of in-plant generation can reduce the severity of voltage dips and short-time interruptions;
– the contribution of the industrial plant to the voltage dips or short-time interruptions should be considered; for instance, as a consequence of severe faults, large voltage depressions can be caused by the simultaneous restarting of several induction motors in the plant;
– the short interruption values for class 3 IPCs refer to plants fed by one supply line only.

As a basis, the results of IEC TR 61000-2-8 ~~may~~ can be adopted.

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B.5 Transient overvoltages

Several phenomena, including the operation of switches and fuses and the occurrence of lightning strokes in proximity to the supply networks, give rise to transient overvoltages in low-voltage power supply systems and in the installations connected to them. The overvoltages ~~may~~ can be either oscillatory or non-oscillatory, are usually highly damped, and have rise times ranging from less than 1 µs to a few milliseconds.

The magnitude, duration, and energy-content of transient overvoltages vary with their origin. Generally, those of atmospheric origin have the higher amplitude, and those due to switching are longer in duration and contain the greater energy. Critical equipment ~~needs~~ have to be protected by surge protective devices, and these should generally be selected to cater for the greater energy content of the switching overvoltages.

Switching of capacitor banks is a common cause of transient overvoltages. Typically, their value at the point of incidence is less than twice the nominal voltage. However, wave reflections and voltage magnification can occur as the transient is propagated along a line, amplifying the overvoltage incident on connected equipment.

Figure B.4 shows an example of tolerance envelope for IT equipment which is applicable for single phase 120 V. Other types of equipment ~~may~~ can present different tolerance characteristics.

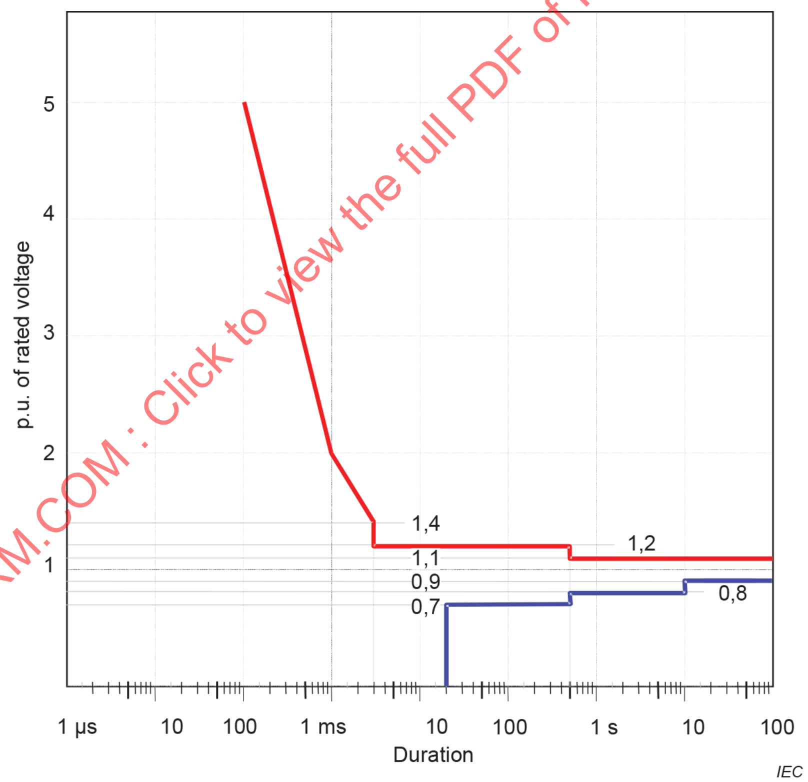

Figure B.4 – ITI (~~CEBEMA~~CBEMA) – Curve of tolerance envelope of ITE[3]

Transients of atmospheric origin have been recorded at magnitudes up to 6 kV on LV networks. This value should be considered for coordination of isolation.

[3] ITI = Information Technology Industry; CBEMA = Computer Business Equipment Manufacturers Association; ITE = information technology equipment.

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Taking into account that attenuation between the PCC and the practical input of the installation is not sufficiently known and that a 100 % immunity is a very costly fiction (if not impossible), the compatibility level for EMC purposes should be set much lower.

The transient overvoltages of external origin (coming from the public power supply system) ~~may~~ can be attenuated according to the location of the IPC within the installation.

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Annex C
(informative)

Interharmonics and voltages at higher frequencies and mitigation methods

C.1 Sources of interharmonics

C.1.1 Identification

Sources of interharmonics can be found in low-voltage networks as well as in medium-voltage and high-voltage networks. The interharmonics produced by low-voltage sources (welding machines, power converters, induction motors) mainly influence devices in their vicinity; the interharmonics produced in the medium-voltage ~~and/~~or the high-voltage networks (arc furnaces, power converters, induction motors), or both, flow in the low-voltage networks they supply. Interharmonics and voltages at higher frequency can also result from resonances present in the distribution system at frequencies matching with unstable poles of converter current controllers.

There is also low-level background Gaussian noise, with a continuous regular frequency spectrum, superimposed on the low-voltage curve even in the absence of a local source of interharmonics. Typical voltage levels, on a low-voltage network of 230 V, seem to be in the range of 40 mV to 50 mV, when measured with a filter bandwidth of 10 Hz, and 20 mV to 25 mV when measured with a filter bandwidth of 3 Hz.

Four main origins of interharmonics can be distinguished:

– electrical arc-furnaces, arc welding machines or plasma heaters, which have been known for many years as the major power source of interharmonics or sub-harmonics, the origin of which is in the process itself, ~~and/~~or in the position control of the electrodes for which the phenomenon is without any synchronism with the power frequency;

– power converters with active front end ~~may~~ can be operated at switching frequencies which generally are interharmonic frequencies; the effect of switching produces interharmonic voltages or currents;

– spurious coupling between circuits where the fundamental frequencies are different; this is the case of electronic frequency converters;

– intentional production of voltages at such interharmonic frequencies for the purpose of signal transmission.

C.1.2 Different types of sources of interharmonics

C.1.2.1 Random sources

Arc welding machines generate a continuous wide band frequency spectrum, associated with an intermittent process with the duration of the individual welding actions varying between 1 s and several seconds. They are mostly connected to the low-voltage network, preferably of low impedance in order to avoid disturbing flicker effects.

Arc furnaces produce continuous but randomly varying interharmonic frequency spectra due to the irregular input current. Their high rating (50 MW to 120 MW) make them always connected to the medium-voltage or high-voltage network. The highest emission level occurs during the starting-phase of a melting process.

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C.1.2.2 Sub-harmonics or interharmonics produced by the load of a line commutated converter

Electronic frequency converters have a different behaviour according to their structure. Direct converters, such as cycloconverters, consist of an assembly of semiconductor devices and their auxiliary circuits which, by means of their cyclic commutations, convert the input voltage at the fundamental frequency of the power supply network into an output voltage at a fundamental frequency, defined by the control of the converter to be suitable for feeding the load. (The load ~~may~~ can be a variable speed motor or a particular network at a fixed frequency, for example, 25 Hz or 16 Hz 2/3.) These cycloconverters have no decoupling function between the two different fundamental frequencies. Therefore, currents at multiples of the load frequency are circulating directly in the line side of the converter assembly of each phase. The line current has the form of a current at the power supply network frequency (plus its regular harmonics), modulated in amplitude depending on the load frequency.

NOTE For example, in a cycloconverter for a three-phase balanced load fed at the frequency f_L, the line currents combine in each phase at the point of coupling of the three individual multiphase converters (pulsation index p), each feeding a phase of the three-phase load. The combination of the line currents can be approached when considering the total active power and the total reactive power. In the case of a purely active load and of an ideal converter, the total active power is a constant (without fluctuating power) while the total reactive power is a constant with addition of a fluctuating component of low amplitude at a frequency of $2pf_L$. In the case of a purely reactive load and of an ideal converter, the total active power is zero, while the total reactive power is a constant. The line current resulting from these combinations contains a modulation at frequencies of $2pf_L$ and its multiples. Additional other interharmonic currents result from a non-linear command having a rating optimization purpose, and from the unavoidable imperfections of the system.

Indirect frequency converters have an intermediate DC link, with an input converter on the line side and an output converter (more often operating as an inverter) on the load side. For both structures, current stiff and voltage stiff, the DC link includes a filter decoupling the current or the voltage of the power supply system and of the load. Therefore, the two fundamental frequencies (supply and load) are decoupled. But infinite filtering does not exist, and the remaining coupling path produces currents on the supply network at frequencies present on the DC link and due to the load side. These frequencies are sub-harmonic and interharmonic relative to the power supply frequency. However, it should be underlined that this phenomenon is most often negligible for voltage source inverters.

Electronic frequency converters inject currents into the network at sub-harmonic and interharmonic frequencies that are mainly in the range from 0 Hz to 150 Hz or 300 Hz. These correspond to the fundamental frequency of the load, which is frequently a variable speed motor. The highest range of frequencies, up to 2 500 Hz, is much smaller in amplitude. The main difficulty is that those sub-harmonics or interharmonics are not at a fixed frequency.

Some semiconductor converters, used to feed particular networks at a fixed frequency, also produce sub-harmonics ~~and/~~or interharmonics, or both, at a fixed frequency.

Harmonic and interharmonic frequencies of such converters with an input fundamental frequency f and an output fundamental frequency F are defined by the following formula:

$$f_{h,m} = \left[\left(p_1 \times k_1\right) \pm 1\right] \times f \pm \left[\left(p_2 \times k_2\right)\right] \times F \qquad \text{(C.1)}$$

where

p_1 is the pulse number of the input converter;

p_2 is the pulse number of the output converter;

k_1, k_2 are the series of whole integers (0, 1, 2, 3...); and

if $k_2 = 0$, $f_{h,m} = f_h$ (harmonic frequencies).

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C.1.2.3 Sub-harmonics or interharmonics produced by ~~internal operation of a converter~~ active infeed converters

~~Some self-commutated converters have an active front end (using transistors or gate turn-off thyristors) operated at a switching frequency which is not an integer multiple of the network frequency. This switching frequency may be constant or variable according to criteria related to the operation of the converter itself. Each switching changes the current path, thereby showing a non-linearity to the network. This produces interharmonic voltages superimposed to the network voltage when the internal impedance of the switching circuits of the converter is low compared to the internal impedance of the network. This may also produce interharmonic currents injected into the network when the internal impedance of the switching circuits of the converter is high as compared to the internal impedance of the network. The interharmonic frequencies are related to the switching frequency, generally in the range of a few hundred hertz to a few tenths of kilohertz.~~

The behaviour of active infeed converters is described in detail in IEC TS 62578.

C.1.2.4 Other miscellaneous sources

Induction motors ~~may~~ can give rise to an irregular magnetizing current due to the slots in the stator and rotor – possibly in association with saturation of the iron – which generates interharmonics in the low-voltage network. At the normal speed of the motor, the disturbing frequencies are practically in the range of orders 10 to 40, but during the starting period they run through the whole frequency range up to their final value.

Voltages at interharmonic pre-defined frequencies are also produced intentionally by ripple control transmitters. The purpose and practice of ripple control transmitters is described in IEC 61000-2-2. Their frequency range is 110 Hz to 3 000 Hz with a maximum relative voltage level U_s/U_N of 9 % up to 500 Hz and decreasing (20 dB per decade) between 500 Hz and 3 000 Hz (1,5 %). ~~Other systems for mains signalling operate in higher frequency ranges (3 kHz to 20 kHz and 20 kHz to 148,5 kHz).~~ Other systems for mains signalling operate in higher frequency ranges, for example 3 kHz to 500 kHz (in some LV/MV installations 1,6 MHz to 30 MHz for broadband powerline communication (PLC), and 30 kHz to 500 kHz (in some countries 16 kHz to 1 MHz) for powerline carrier systems in MV/HV networks).

C.1.3 Effects of interharmonics and compatibility

Interharmonics introduce non-periodical or quasi-non-periodical phenomena superimposed on the periodical waveform of the voltage network. Therefore, the crest voltage is changed at a lower frequency where the difference of the involved frequencies appears as the disturbance. Each use of electricity where the crest voltage is of importance is then disturbed. Examples are lighting equipment, which ~~may~~ can flicker, and television receivers, which ~~may~~ can be disturbed.

Ripple control receivers are likely to be disturbed by interharmonics. For reception their minimum operating level is as low as 0,3 %, to take into account the different attenuations between the emitter and the receivers in the power supply network. Therefore, users of electricity should know whether such ripple control is in operation in their area and what the allocated frequency is. This minimum information is required to ensure compatibility.

The frequency of an interharmonic current ~~may~~ can occur and sweep in a wide range of frequencies without discontinuity. The resulting interharmonic voltage is defined by the current and the impedance at the particular frequency. The most spurious effect is the ability to excite anti-resonance frequencies arising from passive filters or power factor compensation capacitor banks connected to the network.

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C.1.4 Guidance levels

C.1.4.1 Levels related to flicker effect

The case of a voltage having a frequency which combines with the fundamental frequency and results in a beat frequency has been dealt with in 5.7. Table C.1 indicates the interharmonic voltage levels corresponding to the compatibility level given in Figure 1.

Table C.1 – Indicative values for interharmonic voltages in low-voltage networks with respect to the flicker effect

Order m	50 Hz system: Interharmonic frequency f_m Hz	50 Hz system: U_m % 120 V system	50 Hz system: U_m % 230 V system	60 Hz system: Interharmonic frequency f_m Hz	60 Hz system: U_m % 120 V system	60 Hz system: U_m % 230 V system
0,20 < m ≤ 0,60	10 < f_m ≤ 30	**0,68**	**0,51**	12,0 < f_m ≤ 36,0	**0,95**	**0,69**
0,60 < m ≤ 0,64	30 < ff_m ≤ 32	**0,57**	**0,43**	36,0 < f_m ≤ 38,4	**0,79**	**0,58**
0,64 < m ≤ 0,68	32 < f_m ≤ 34	**0,46**	**0,35**	38,4 < f_m ≤ 40,8	**0,64**	**0,48**
0,68 < m ≤ 0,72	34 < f_m ≤ 36	**0,37**	**0,28**	40,8 < f_m ≤ 43,2	**0,50**	**0,38**
0,72 < m ≤ 0,76	36 < f_m ≤ 38	**0,29**	**0,23**	43,2 < f_m ≤ 45,6	**0,39**	**0,30**
0,76 < m ≤ 0,84	38 < f_{mm} ≤ 42	**0,23**	**0,18**	45,6 < f_m ≤ 50,4	**0,23**	**0,18**
0,84 < m ≤ 0,88	42 < f_m ≤ 44	**0,23**	**0,18**	50,4 < f_m ≤ 52,8	**0,22**	**0,18**
0,88 < m ≤ 0,92	44 < f_m ≤ 46	**0,28**	**0,24**	52,8 < f_m ≤ 55,2	**0,22**	**0,20**
0,92 < m ≤ 0,96	46 < f_m ≤ 48	**0,40**	**0,36**	55,2 < f_m ≤ 57,6	**0,34**	**0,30**
0,96 < m < 1,04	48 < f_m ≤ 52	**0,67**	**0,64**	57,6 < f_{mm} ≤ 62,4	**0,59**	**0,56**
1,04 < m ≤ 1,08	52 < f_m ≤ 54	**0,40**	**0,36**	62,4 < f_m ≤ 64,8	**0,34**	**0,30**
1,08 < m ≤ 1,12	54 < f_{mm} ≤ 56	**0,28**	**0,24**	64,8 < f_m ≤ 67,2	**0,22**	**0,20**
1,12 < m ≤ 1,16	56 < f_m ≤ 58	**0,23**	**0,18**	67,2 < f_m ≤ 69,6	**0,22**	**0,18**
1,16 < m ≤ 1,24	58 < f_m ≤ 62	**0,23**	**0,18**	69,6 < f_m ≤ 74,4	**0,23**	**0,18**
1,24 < m ≤ 1,28	62 < f_m ≤ 64	**0,29**	**0,23**	74,4 < f_m ≤ 76,8	**0,39**	**0,30**
1,28 < m ≤ 1,32	64 < f_m ≤ 66	**0,37**	**0,28**	76,8 < f_m ≤ 79.2	**0,50**	**0,38**
1,32 < m ≤ 1,36	66 < f_m ≤ 68	**0,46**	**0,35**	79,2 < f_m ≤ 81,6	**0,64**	**0,48**
1,36 < m ≤ 1,40	68 < f_m ≤ 70	**0,57**	**0,43**	81,6 < f_m ≤ 84,0	**0,79**	**0,58**
1,40 < m ≤ 1,80	70 < f_m ≤ 90	**0,68**	**0,51**	84,0 < f_m ≤ 108,0	**0,95**	**0,69**

C.1.4.2 General levels

Levels given in ~~Table 4~~ Table 2 for the next higher even harmonic ~~may~~ can be taken as guidance for each interharmonic frequency.

The levels relevant to class 2 are set in consideration of the presence of ripple control devices. Since ripple control receivers, lighting equipment and television receivers are not generally present in industrial areas, the compatibility levels for class 3 are expected at higher values.

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NOTE 1 If such devices are present in the industrial area, they are not directly coupled to the circuit of class 3. For mitigation methods, see Clause C.2.

Where there is a risk of interference with mains signalling, ripple control, or other susceptible equipment, special care should be taken with regard to interharmonics. A class 2 environment should be preferred. For this class, the operational frequency of ripple control receivers is locally specified. The response level of these receivers can be as low as 0,3 % of the nominal supply voltage. A receiver can therefore be disturbed by an unintended interharmonic voltage, at its defined operational frequency, in excess of this value.

The interharmonic compatibility level at the operating frequency of the mains signalling or ripple control system is not defined. At the operating frequency, the emission level should be limited to 0,2 % of the nominal supply voltage, and the immunity of equipment should be defined according to the particular specifications of the corresponding transmitters and network conditions. See IEC 61000-2-2:2002, 4.4.

The use of a class 3 environment requires more investigation such as identification of the coupling path between the class 3 environment and the public supply network, or design of a decoupling system.

High values of interharmonics can be present at class 3 IPCs due especially to some kinds of converters. They can be as high as 2,5 % for frequencies below the 11th order, and up to 1 % for orders above 25. Due to their origin, these values are generally fluctuating and rapidly changing in both amplitude and frequency. For that reason, they ~~may~~ can cause resonances on capacitor banks and passive filters.

NOTE 2 Everywhere they are used in industrial networks, power factor correction capacitors ~~should~~ will be connected through series reactors, particularly those which are intended to be connected to IPCs of class 3.

C.2 Mitigation methods

C.2.1 General

It is generally a complex matter to decrease emissions of power converters. Where susceptible equipment is expected and cannot be avoided, a possible solution is to introduce an efficient decoupling between the circuits supplying the susceptible equipment and the circuits supplying the power converters by means of filters or even UPSs.

When the purpose of the conversion of power is to produce an adjustable fundamental frequency, a wide spectrum of interharmonic frequencies can be expected. The most complex aspect is due to the interharmonics which sweep the whole spectrum when the output of the converter is operated at a variable frequency.

Interharmonics of this kind are the result of the impossibility of obtaining a perfect decoupling between the input and the output of a converter. The components of the largest amplitude are generally at low or very low frequencies.

Another kind arises from the internal operation mode of the converter. The well-known example of pulse width modulation (PWM) operated converters shows an emission of interharmonics related to the switching frequency controlling the semiconductor devices. This switching frequency ~~may~~ can be fixed or adjustable depending on the control technique. Interharmonics of this last kind are at higher frequencies than the previous one. They are generally easier to filter.

C.2.2 Decrease emission levels

The selection of indirect converters facilitates the simple filtering of interharmonics emitted by the power conversion process when dedicated to variable frequency production. Indeed, the simple filtering ~~may~~ can be provided by increasing the internal filtering effectiveness of the natural structure of the converter. Such an increase of decoupling between output and input provides reduction of interharmonic current amplitude.

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In case of large converters this ~~may~~ will probably not be an economic solution, but it should be investigated as an alternative to external filtering. External filtering ~~may~~ can use passive filtering or active filtering.

Passive filtering requires particular attention to the width of the emission spectrum, particularly when the interharmonics sweep through the frequency spectrum. The risk of excitation of anti-resonance is so high that passive filters, if used, should be damped. Generally large power installations require careful and complete investigation to define the filtering system. Moreover, passive filters cannot be operated independently of each other or independently of reactive power compensation. Therefore, when passive filtering is used, the whole installation should be considered.

Active filtering can provide efficient solutions, particularly in the low or very low frequency range. Filtering is also effective for sub-harmonics or interharmonics. The main advantage of active filtering is that it is auto-adaptative to the frequency to be filtered. This property is intrinsic to their control, which is designed to first extract the harmonic content from a current which is to be compensated or from a voltage which is to be cleaned up. The second function of the control of the semiconductor devices is to operate the compensation or cleaning by means of an adapted PWM technique at the power stage. Therefore, unlike passive filters, which are tuned on particular orders, active filters can be considered as broad band filters. They provide attenuation of the harmonic (or interharmonic) emission from DC up to a few kiloHertz, leaving the fundamental frequency voltage or current unaffected.

However, converters operating with PWM introduce an interharmonic emission at frequencies associated with the switching frequency, which can be filtered if necessary.

C.2.3 Increase immunity

Product standards set immunity limits with reference to compatibility levels. However, when compatibility levels are still under consideration or when the relevant product standard is not available, a solution in case of susceptibility causing malfunction of an equipment, can often be found in appropriate filtering of the supply of the control part of the disturbed equipment. For equipment ~~needing~~ that has to be synchronized with the power supply system, the appropriate filtering ~~may~~ can be limited to the synchronizing circuit by means of a band pass filter tuned at the fundamental frequency. This generally affects circuits of low level of power.

The most efficient solution remains appropriate segregation of the circuits according to their use. In an industrial network, this segregation should always be established between the industrial applications and the offices, and within the industrial applications between the different loads which should be classified appropriately. This kind of segregation facilitates the design of correct decoupling and filtering of the whole installation, with the objective of the best technical and economical compromise.

C.2.4 Protection of ~~ripple control system~~ mains signaling

Identification of the frequency used by the ripple control system or mains signalling should be made available by the power supply authority.

Two aspects should be considered at the PCC of the installation:

– the maximum emission allowed for the whole installation in order not to disturb the signalling system;
– the minimum impedance, at the particular frequency of the signalling system, that is acceptable for operation of the transmission of the signalling system.

If a particular passive filtering or decoupling system is installed, ~~care should be taken to avoid~~ anti-resonance should be avoided in case of sweeping interharmonics.

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~~C.3 Voltages at higher frequencies~~

~~Distortion of the voltage wave form in the frequency band above the 50th harmonic and less than 9 kHz is also represented by sinusoidal components, which can occur both at discrete frequencies and in relatively broad bands of frequencies. In the case of such higher frequency voltages, it is generally not significant whether they are harmonics or interharmonics.~~

~~For a discrete frequency in the range above the 50th harmonic and up to 9 kHz, levels are expressed as the ratio *u* of the r.m.s. voltage at that frequency to the r.m.s. value of the fundamental component of the voltage.~~

~~For a band of frequencies above the 50th harmonic and up to 9 kHz, the levels are related to any 200 Hz bandwidth centred at frequency *F*, and are expressed as follows:~~

$$\cancel{u_b = \frac{1}{V_{1N}} \times \sqrt{\frac{1}{200\ \text{Hz}} \times \int_{F-100\ \text{Hz}}^{F+100\ \text{Hz}} V^2(f) \times df}}$$

~~where~~

~~V_{1N} is the rated r.m.s. value of the fundamental component;~~

~~$V(f)$ is the r.m.s. voltage at frequency f;~~

~~F is the centre frequency of the band (the band is above the 50th harmonic).~~

~~From experience, levels up to 80 % or 90 % of the following reference levels have been reported as already met in industrial networks:~~

~~u = 0,2 % for class 2 IPCs;~~

~~u = 1 % for class 3 IPCs.~~

~~u_b = 0,3 % for class 2 IPCs;~~

~~u_b = 1,5 % for class 3 IPCs;~~

~~and few troubles were reported on networks having values in excess of the above.~~

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Annex D
(informative)

Proving compatibility in the frequency range above 2 kHz in industrial MV networks

In order to ensure a long-term trouble-free operation of an industrial installation, the operator of a plant typically wants to make sure that compatibility requirements are met. In principle there are two possibilities to reach this goal, both of them having special challenges especially in the frequency range above 2 kHz:

1) Measurements: Measurements are the best means to prove compatibility in existing installations. However, typical measuring devices operate with an input voltage below 1 kV so that voltage transformers will be required for MV networks. Most voltage transformers (capacitive and inductive) used presently as standard equipment in MV networks are designed primarily for the transformation of fundamental frequency. Although many of them still provide reasonable results in the "classical" harmonic range up to 2 kHz, the measuring accuracy decreases with increasing frequency. Somewhere in the range between 5 kHz and 20 kHz most voltage transformers have a resonance point exaggerating measured voltage components at the secondary side of the VT. For higher frequencies, the transformation ratio between the primary and secondary side is undefined and varying, i.e. the measuring signal can over- or underestimate the primary voltage. In order to prove compatibility for voltage components above 2 kHz, voltage transformers with a known and tested frequency behaviour in the frequency under consideration should be used. Some manufacturers already promote new types of built-in voltage transformers for MV switchgear suitable to measure with a reasonable error also in the double-digit kHz range. Alternatively, a special measuring divider can be connected temporarily at MV level in order to take accurate measurements above 2 kHz.
2) Calculations: During the planning phase of an installation, calculations and simulations are the only possible means to prove compatibility for a future industrial plant. Well established and proven methods exist for this purpose for the "classical" harmonic range up to 2 kHz. For significantly higher frequencies, experiences with simulations are rather rare and this field is presently just developing. Several phenomena have to be taken into account which play a minor role in the lower harmonic range only:
   - Transformers typically have significant resonance points in the frequency range of around 10 kHz and above.
   - Frequency dependence of line impedances (inductance and resistance) becomes more and more important with increasing frequencies. (Line capacitances remain unchanged over the entire frequency range considered.)
   - Terminal stray capacitances of equipment connected (e.g. of motors and transformers) can have an impact on calculation results especially for higher frequencies.
   - Supply networks (often modeled as Thevenin impedances for harmonic calculations) typically have significant resonance points in the frequency range above 2 kHz (and in many cases already below this frequency). These resonances will have a significant impact on calculation results especially concerning the PCC with the public supply network.

   All these effects have to be considered for simulations in MV networks in order to obtain results which to a certain extent reflect the reality in the future plant. This means not only a significantly increased effort for these simulations but requires adequate input from equipment manufacturers as well as network operators.

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Annex E
(informative)

Examples of locations and installations covered by IEC 61000-2-4

E.1 General

The purpose of Annex E is to illustrate typical locations and installations relevant to the compatibility levels given in this document, and to provide guidance to the user of this document when selecting the appropriate environment class (see Clause 4).

Annex E provides only examples, and it is not intended to be exhaustive.

This document does not deal with installations for residential locations, directly supplied by the public mains and which are usually covered by IEC 61000-2-2.

A part of an installation supplied by the output of a power converter (e.g. loads supplied by an UPS) is not within the scope of this document.

The basic principle for this document is that installations covered by this document are for professional use and are separated from the public power distribution system by at least one transformer.

E.2 Mixed locations

Installations for residential locations and professional use can coexist in mixed locations. For example, a building can host separate and well identified areas for either residential locations or professional use, each one having its own dedicated power supply line, in which the industrial installation is supplied through a separation transformer.

NOTE In this document, shops, light industry, heavy industry (and similar) supplied through a separation transformer are covered by the term industrial.

E.3 Examples for industrial locations

Installation intended for professional use only.

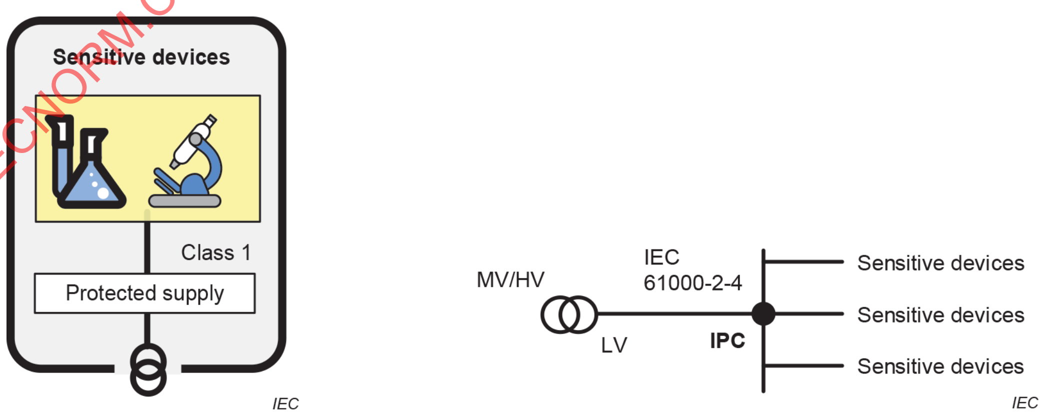

Figure E.1 – Example of class 1 environment

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This is a typical class 1 environment (Figure E.1).

One reference person (e.g. owner of the private building) is in charge of problems and maintenance.

Installation intended for professional use only.

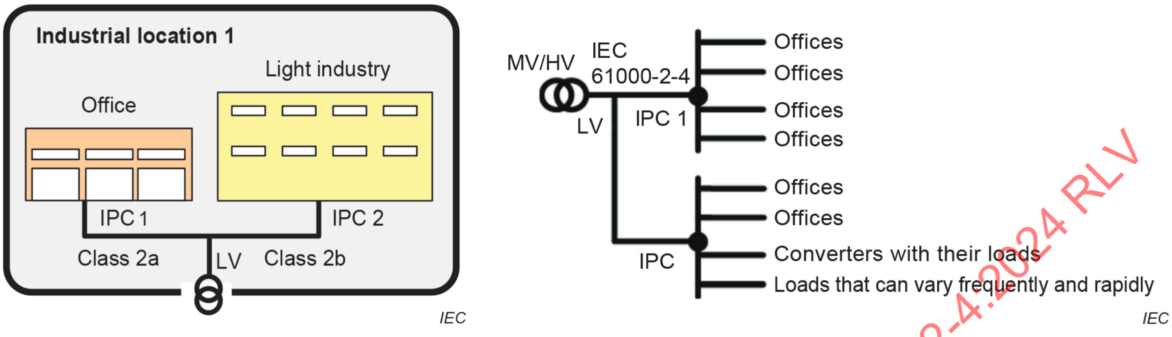

Figure E.2 – Example of class 2a and class 2b environments

These are typical class 2a and class 2b environments (Figure E.2).

One reference person (e.g. owner of the private building) is in charge of problems and maintenance.

In this example, IPC 1 characterises the compatibility level at the entrance of the office building and IPC characterises the compatibility level at the entrance of the light industry building.

NOTE 1 Concerning options for the supply of areas with different electromagnetic environment classes in the lower part of the figure; see Figure 2.

Installation intended for professional use only.

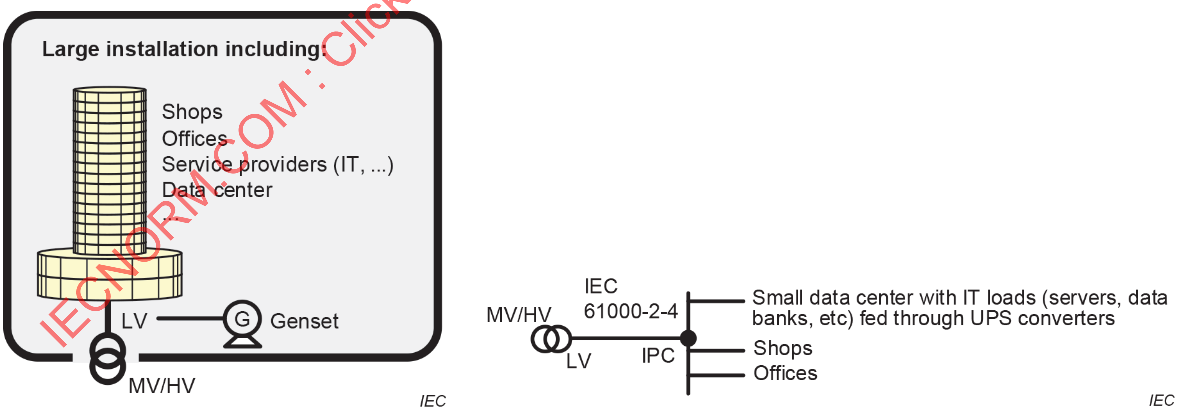

Figure E.3 – Example of an LV grid in a building supplied by a dedicated transformer

This type of area is supplied by a dedicated transformer (Figure E.3).

One reference person (e.g. owner of the private building) is in charge of problems and maintenance.

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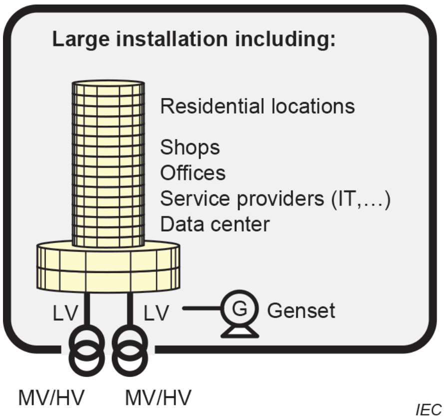
This environment might be classified either as class 2a or class 2b, with the IPC characterizing the compatibility level at the entrance of the building.

Mixed location



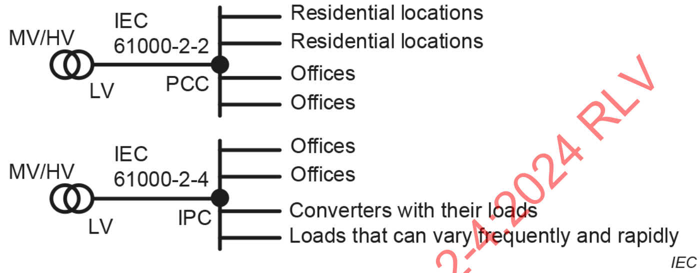


Figure E.4 – Example of an LV grid in a building including residential and industrial locations

In Figure E.4, the upper part of the building includes residential locations and thus is supplied by a public transformer. IEC 61000-2-2 applies at the PCC.

The other transformer supplies the part of the installation where only professional users are connected.

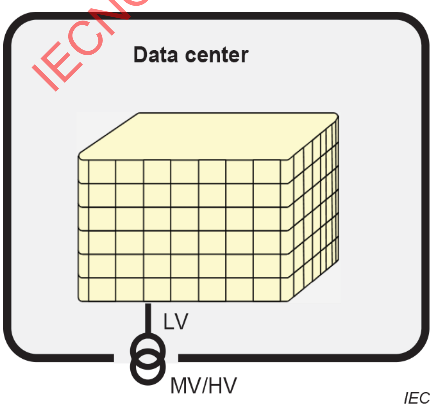
Compatibility levels at the primary side of the transformers are not specified in this document.

One reference person (e.g. owner of the private building) is in charge of problems and maintenance.

The lower part is an environment which might be classified as either class 2a or class 2b, with IPC 2 characterizing the compatibility level for the converters and loads that can vary frequently and rapidly.

NOTE 2 Concerning options for the supply of areas in the lower part of the figure see Figure 2.

Installation intended for professional use only.



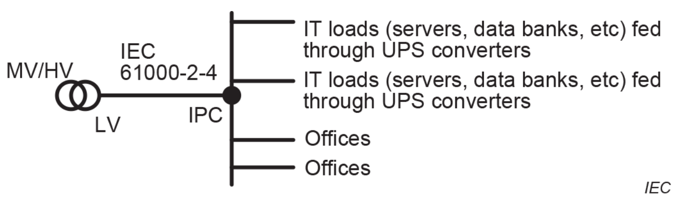


Figure E.5 – Example of an LV grid for a data center

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Compatibility levels for the primary side of the transformer (Figure E.5) are not specified in this document.

One reference person (e.g. owner of the private building) is in charge of problems and maintenance.

This environment is classified by the reference person either as class 2a or class 2b, with the IPC characterizing the compatibility level placed at the entrance of the building.

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Annex F
(informative)

Rationale for increased individual even and triplen compatibility levels and for splitting class 2 into class 2a, class 2b and class 2L

F.1 Rationale for increased individual even and triplen compatibility levels

F.1.1 Target

It was the target of this document to take into account the needs of modern power electronic equipment while maintaining the overall disturbance level of the networks within the scope. This has been achieved by increasing the individual even and triplen compatibility levels in Table 2 and by introducing a new quantity PWHD in Table 3.

F.1.2 The needs of modern power electronic equipment

Modern power electronic equipment, such as active infeed converters (AICs) according to IEC TS 62578, is an essential element of energy saving equipment and renewable energy generation. It operates as pulse width modulated (PWM) converter. The switching frequency of this equipment is typically in the range of a few kHz. The electromagnetic emissions of this technology consequently consist of spectral lines with frequencies of the switching frequency and its integer multiples.

In the frequency range below the switching frequency, this type of equipment produces only very low emissions. However, in order to prevent the emissions at switching frequency and above from flowing to the supply network, a low pass filter has to be inserted between the power converter and the supply network. This filter has to have a resonance frequency below the switching frequency of the converter. This resonance frequency will typically be in the range of 1 kHz to 2 kHz with a width of about ±400 Hz. In this frequency range, existing pre-distortion in the network and very low converter emissions will be amplified. The amplification factor can only be limited by filter damping. More excessive damping will cause increased losses of the filter.

The resulting emission spectra of these AICs will consequently consist of emissions at a low level in the range of the resonance frequency and of spectral lines at the switching frequency and its integer multiples. A typical spectrum is shown in Figure F.1 with an AIC operating at a switching frequency of 4 kHz and a filter resonance frequency of about 1,2 kHz.

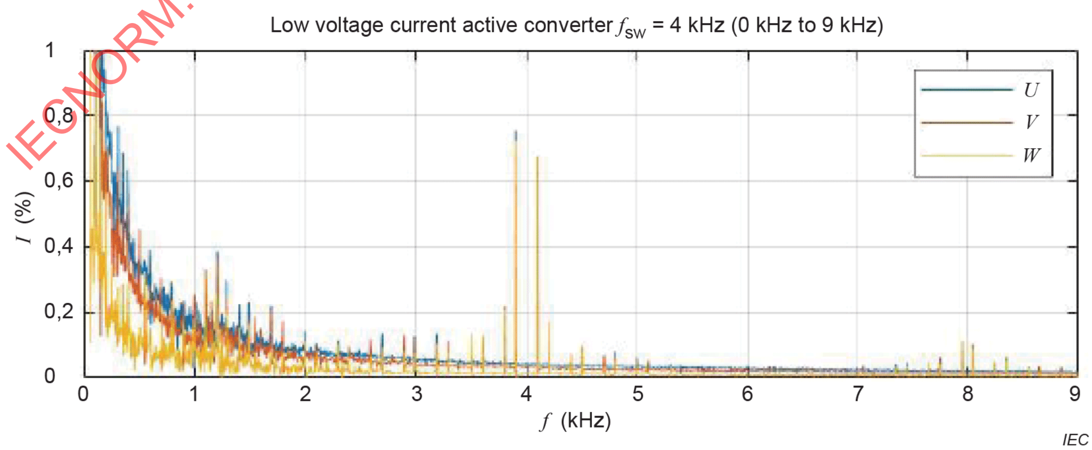

Figure F.1 – Emission spectrum of an active infeed converter

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All emissions of the AIC are independent of the supply frequency (50/60 Hz).

The compatibility levels defined in IEC 61000-2-4:2002 (second edition) made a systematic difference between characteristic (odd non triplen) frequencies on the one hand and even and triplen frequencies on the other hand. The compatibility levels for even and triplen harmonics are significantly lower. Calculating permissible emission limits for even and triplen harmonic frequencies results in extremely low values, which cannot be met by AIC equipment in the range of the resonance frequency of its line filter and which are at or below the accuracy specification of measurement equipment. Such overly stringent limits could reduce the acceptance level for energy saving equipment and jeopardize global targets for energy saving. This problem is particularly severe in the frequency range between H13 and H40, which is the range of the filter resonance described in the second paragraph of this rationale.

On the other hand, there are no reports on disturbance cases of equipment due to voltage distortions at even or triplen harmonic frequencies, particularly in the frequency range between H13 and H40. Consequently, the compatibility levels for even and triplen harmonics have been increased in this document to the values in Table 2.

F.1.3 Maintaining the overall disturbance level

As described above, the increase of emissions only occurs in a limited band around the resonance of the line filter of an AIC. It is consequently expected that the overall disturbance level in industrial networks remains unchanged. In order to ensure this, Table 3 does not only keep the THD value unchanged, but it additionally introduces a new quantity, PWHD. The values for PWHD are calculated by inserting the compatibility levels of IEC 61000-2-4:2002 (second edition) into Formula (1), meaning that also the PWHD remains unchanged. With THD and PWHD unchanged compared to IEC 61000-2-4:2002 (second edition), the overall disturbance level is maintained.

F.2 Rationale for splitting class 2 into class 2a, class 2b and class 2L

F.2.1 Target

It was the aim for class 2 of this document to:

a) provide compatibility levels identical to the public network described in IEC 61000-2-2;
b) allow power electronic converters which operate in class 2 networks according to IEC 61000-2-4:2002 (second edition) to still do so in class 2 networks according to this document;
c) prevent special safety-related networks (e.g. in nuclear power plants) from a safety re-certification.

As it was not possible to achieve all these targets with one set of compatibility levels, the class 2 from IEC 61000-2-4:2002 (second edition) was split into class 2a, class 2b and class 2L.

F.2.2 Class 2a

The compatibility levels of class 2a are identical to the compatibility levels in IEC 61000-2-2 when considering the increase of even and triplen compatibility levels according to Clause F.1.

F.2.3 Class 2b

In class 2 networks of IEC 61000-2-4:2002 (second edition), certain power electronic converters can be operated. They can face the issues described in F.1.2, but without considering how resonance effects of the compatibility levels, which are defined only up to the 40^{th} harmonic in IEC 61000-2-4:2002 (second edition), are met.

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However, in the frequency range above the 40th harmonic, these power electronic converters emit at a higher level (see Figure F.1), and the voltage distortion of the network will exceed the levels defined in IEC 61000-2-2. Consequently, higher compatibility levels than in class 2a are required for such networks in the frequency range above the 40th harmonic. As these networks are still intended to be classified as networks of class 2, this requires a split of the class 2 in IEC 61000-2-4:2002 (second edition). This has been achieved by introducing the new class 2b, which has the same compatibility levels as class 2a up to the 40th harmonic and higher compatibility levels above the 40th harmonic.

F.2.4 Class 2L

Even though it was agreed that the increased compatibility levels for even and triplen individual compatibility levels described in Clause F.1 do not lead to an increased disturbance level (see F.1.3), it is important for some sensitive networks, for example in safety related applications like nuclear power plants, not to increase any compatibility level in order to prevent a re-certification of the installation. However, the introduction of additional compatibility levels above the 40th harmonic is welcome for such networks. In order to accommodate these needs, the class 2L was introduced, which contains the compatibility levels from IEC 61000-2-4:2002 (second edition) class 2 up to the 40th harmonic and the compatibility levels from IEC 61000-2-2 above the 40th harmonic.

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[4] ~~To be published~~

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5 GUM: Guides to the expression of uncertainty in measurement.

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Compatibilité électromagnétique (CEM) –
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 2-4: Environment – Compatibility levels in power distribution systems in industrial locations for low-frequency conducted disturbances

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IEC 61000-2-4 has been prepared by subcommittee 77A: EMC – Low frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility. It is an International Standard.

This third edition cancels and replaces the second edition published in 2002. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) introduction of new classes 2a, 2b and 2L (former class 2);
b) modification of existing compatibility levels for class 3;
c) addition of compatibility levels in the frequency range 2 kHz to 150 kHz;

d) addition of compatibility levels using a new quantity: partial weighted harmonic distortion (PWHD).

The text of this International Standard is based on the following documents:

Draft	Report on voting
77A/1215/FDIS	77A/1221/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 61000 series, published under the general title *Electromagnetic compatibility (EMC)*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

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INTRODUCTION

IEC 61000 is published in separate parts according to the following structure:

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

Immunity limits (in so far as they do not fall under the responsibility of the product committees)

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

Each part is further subdivided into several parts, published either as International Standards, technical specifications or technical reports, some of which have already been published as sections. Others will be published with the part number followed by a dash and a second number identifying the subdivision (example: IEC 61000-3-11).

Detailed information on the various types of disturbances that can be expected on public power supply systems can be found in IEC 61000-2-1 and IEC 61000-2-12.

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ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 2-4: Environment – Compatibility levels in power distribution systems in industrial locations for low-frequency conducted disturbances

1 Scope

This part of IEC 61000 is related to conducted disturbances in the frequency range from 0 kHz to 150 kHz. It gives compatibility levels in differential mode (L-L and L-N) for industrial locations, with a nominal voltage up to 35 kV and a nominal frequency of 50 Hz or 60 Hz.

NOTE 1 Industrial locations are defined in 3.1.8.

Power distribution systems on ships, aircraft, offshore platforms and railways are not included.

NOTE 2 See also Annex E. The compatibility levels specified in this document apply at the in-plant point of coupling (IPC). The level of the low-frequency disturbances at the terminals of equipment receiving its supply from the IPC is generally assumed to be similar to the disturbance level at the IPC itself. However, in some situations this is not the case, particularly when a long feeder is dedicated to the supply of a particular load, or when a disturbance is generated or amplified within the installation of which the equipment forms a part.

Compatibility levels are specified for the types of low-frequency electromagnetic disturbances expected at any in-plant point of coupling (IPC) within industrial locations, for guidance in the definition of:

a) limits for disturbance emissions in industrial power distribution systems (including the planning levels defined in 3.1.5);

NOTE 3 A very wide range of conditions is possible in the electromagnetic environments of industrial networks. These are approximated in this document by the three classes described in Clause 4. However, it is the responsibility of the operator of such a network to take account of the particular electromagnetic and economic conditions, including equipment characteristics, in setting the above-mentioned limits.

b) immunity levels for the equipment within these systems.

The disturbance phenomena considered are:

– voltage deviations;
– voltage dips and short interruptions;
– voltage imbalance;
– power-frequency variations;
– harmonics up to order 40;
– interharmonics up to the 40th harmonic;
– voltage components above the 40th harmonic up to 150 kHz;
– DC component;
– transient overvoltages.

The compatibility levels are given for different classes of environment determined by the characteristics of the supply network and loads.

NOTE 4 Compatibility levels at the point of common coupling (PCC) on public networks are specified in IEC 61000-2-2 for low-voltage networks and IEC 61000-2-12 for medium-voltage networks. IEC TR 61000-3-6 and IEC TR 61000-3-7 describe the approach of power distribution system operators to the limitation of emissions from installations and large loads.

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2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 61000-2-2:2002, *Electromagnetic compatibility (EMC) – Part 2-2: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems*
IEC 61000-2-2:2002/AMD1:2017
IEC 61000-2-2:2002/AMD2:2018

IEC 61000-2-12, *Electromagnetic compatibility (EMC) – Part 2-12: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public medium-voltage power supply systems*

IEC 61000-4-7, *Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto*

CISPR 16-1-1, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus*

CISPR 16-2-1, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-1: Methods of measurement of disturbances and immunity – Conducted disturbance measurements*

3 Terms, definitions and abbreviated terms

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1 General definitions

3.1.1
electromagnetic disturbance
electromagnetic phenomenon that can degrade the performance of a device, equipment or system

[SOURCE: IEC 60050-161:2018, 161-01-05, modified – in the definition the words "or adversely affect living or inert matter" have been deleted and Note 1, Note 2, and Note 3 have been deleted.]

3.1.2
disturbance level
amount or magnitude of an electromagnetic disturbance, measured and evaluated in a specified way

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3.1.3
electromagnetic compatibility
EMC
ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

Note 1 to entry: Electromagnetic compatibility is a condition of the electromagnetic environment such that, for every phenomenon, the disturbance emission level is sufficiently low and immunity levels are sufficiently high so that all devices, equipment and systems operate as intended.

Note 2 to entry: Electromagnetic compatibility is achieved only if emission and immunity levels are controlled such that the immunity level of devices, equipment and systems, at any location, are not exceeded by the disturbance level at that location, resulting from the cumulative emission of all sources and other factors such as circuit impedances. Conventionally, compatibility is said to exist if the probability of the departure from intended performance or of the adverse effect is sufficiently low. See IEC 61000-2-1:1990, Clause 4.

Note 3 to entry: Where the context requires it, compatibility is intended to refer to a single disturbance or class of disturbances.

Note 4 to entry: Electromagnetic compatibility is a term used also to describe the field of study of the adverse electromagnetic effect which devices, equipment and systems undergo from each other or from electromagnetic phenomena.

[SOURCE: IEC 60050-161:2018, 161-01-07, modified – Note 1 to Note 4 have been added.]

3.1.4
(electromagnetic) compatibility level
specified electromagnetic disturbance level used as a reference level in a specified environment for coordination in the setting of emission and immunity limits

Note 1 to entry: By convention, the compatibility level is chosen so that there is only a small probability that it will be exceeded by the actual disturbance level.

[SOURCE: IEC 60050-161:1990, 161-03-10, modified – the last sentence of Note 1 is deleted because it is less relevant in industrial locations compared to public locations.]

3.1.5
planning level
level of a particular disturbance in a particular environment, adopted as a reference value for the limits to be set for the emission of large loads and installations, in order to coordinate those limits with all the limits adopted for equipment intended to be connected to the power supply system

Note 1 to entry: The planning level is locally specific and is adopted by those responsible for planning and operating the power supply network in the relevant area. (For further explanation, see IEC 61000-2-2:2002, Annex A and IEC 61000-1-2.)

3.1.6
industrial and private power distribution system
distribution network that is separated by at least one separation transformer from the public power supply system to which other customer installations are connected

3.1.7
point of common coupling
PCC
point on a public power supply network, electrically nearest to a particular load, at which other loads are, or could be, connected

Note 1 to entry: The PCC is usually the point for which electromagnetic compatibility in public networks is to be considered.

[SOURCE: IEC 60050-161:1990, 161-07-15, modified – the two notes have been deleted, the content of Note 2 is integrated in the definition and a new note has been added.]

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3.1.8
industrial location
location characterized by an installation consisting of a separate power distribution network, supplied by a high- or medium-voltage transformer, dedicated for the supply of this installation

Note 1 to entry: Industrial locations can generally be described by the existence of an installation with one or more of the following characteristics:

- significant amount of electrical power generated, transmitted and/or consumed;
- frequent switching of heavy inductive or capacitive loads;
- high currents and associated magnetic fields;
- presence of industrial, high power scientific and medical (ISM) equipment (for example, welding machines).

The electromagnetic environment at an industrial location is predominantly produced by the equipment and installation present at the location. There are types of industrial locations where some of the electromagnetic phenomena appear in a more severe degree than in other installations.

Example locations include metalworking, pulp and paper, chemical plants, car production, farm building, high voltage areas of airports.

Note 2 to entry: The connection between location and electromagnetic environment is given in 3.1.8.

[SOURCE: IEC 61000-6-4:2018, 3.1.12, modified – in the definition, “an installation consisting of” has been added, and the term reference in Note 2 has been updated.]

3.1.9
electromagnetic environment
totality of electromagnetic phenomena existing at a given location

Note 1 to entry: In general, the electromagnetic environment is time-dependent and its description can be better described with a statistical approach.

Note 2 to entry: It is very important not to confuse the concept of electromagnetic environment with the surrounding location.

[SOURCE: IEC 61000-6-4:2018, 3.1.13.]

3.1.10
in-plant point of coupling
IPC
point inside a non-public power distribution system, electrically nearest to a given load, at which loads from other branches are, or could be, connected

Note 1 to entry: The IPC is usually the point for which electromagnetic compatibility in industrial networks is to be considered.

3.2 Phenomena-related definitions

NOTE 1 The definitions below that relate to harmonics are based on the analysis of system voltages or currents by the discrete Fourier transform method (DFT). This is the practical application of the Fourier transform as defined in IEV 101-13-09. See Annex A.

NOTE 2 The Fourier transform of a function of time, whether periodic or non-periodic, is a function in the frequency domain and is referred to as the frequency spectrum of the time function, or simply spectrum. If the time function is periodic the spectrum is constituted of discrete lines (or components). If the time function is not periodic, the spectrum is a continuous function indicating components at all frequencies.

NOTE 3 Other definitions related to harmonics or interharmonics are given in IEC 60050 (all parts) and other standards. Some of those other definitions, although not used in this document, are discussed in Annex A.

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3.2.1
fundamental frequency
frequency, in the spectrum obtained from a Fourier transform of a time function, to which all the components of this spectrum are referred

Note 1 to entry: In the case of a periodic function, the fundamental frequency is generally equal to the frequency of the function itself (see Clause A.1.). For the purposes of this document, the fundamental frequency is also the same as the power supply frequency.

3.2.2
fundamental component
fundamental
spectral component of a periodic time function whose frequency is equal to the fundamental frequency

3.2.3
harmonic frequency
frequency which is an integer multiple of the fundamental frequency

3.2.4
harmonic order
ratio of the harmonic frequency to the fundamental frequency

Note 1 to entry: The recommended notation for harmonic order is "h".

3.2.5
harmonic component
spectral component of a periodic time function whose frequency is a harmonic frequency

Note 1 to entry: Harmonic components are often referred to as harmonics.

Note 2 to entry: See IEC 61000-4-7 for measuring conditions.

3.2.6
interharmonic frequency
any frequency between two consecutive harmonic frequencies

3.2.7
interharmonic order
ratio of an interharmonic frequency to the fundamental frequency

Note 1 to entry: This ratio is not an integer and can be indicated with "m".

3.2.8
interharmonic component
spectral component having an interharmonic frequency

Note 1 to entry: For brevity, such a component can be referred to simply as an interharmonic.

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3.2.9
total harmonic distortion
THD
ratio of the RMS value of the sum of all the harmonic components to the RMS value of the fundamental component

$$\mathrm{THD} = \sqrt{\sum_{h=2}^{40} \left(\frac{Q_h}{Q_1} \right)^2} \tag{1}$$

where:

Q represents either current or voltage

Q_1 is the RMS value of the fundamental component

h is the harmonic order

Q_h is the RMS value of the harmonic component of order h

3.2.10
partial weighted harmonic distortion
PWHD
ratio of the weighted sum of the squared harmonic components from order 14 to order 40, to the RMS value of the nominal component n

$$\mathrm{PWHD} = \sqrt{\sum_{h=14}^{40} h \cdot \left(\frac{Q_h}{Q_n} \right)^2} \tag{2}$$

where:

Q_n is the nominal value of the quantity (e.g. voltage)

h is the harmonic order

Q_h is the RMS value of the quantity harmonic component of order h

3.2.11
voltage unbalance
voltage imbalance
condition in a polyphase system in which the r.m.s. values of the fundamental component of the line-to-line voltages, or the phase angle between consecutive line-to-line voltages, are not all equal

Note 1 to entry: Generally, in relation to three-phase systems, the amount of voltage imbalance is quantified by the ratio between the negative sequence components and the positive sequence components. However, in some circumstances, it is more appropriate to use the ratio between zero sequence and positive sequence components.

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Note 2 to entry: Several approximations give reasonably accurate results for the levels of imbalance normally encountered (ratio of negative to positive sequence components), for example:

$$\text{voltage unbalance (imbalance)} = \sqrt{6 \times \frac{U_{12}^2 + U_{23}^2 + U_{31}^2}{(U_{12} + U_{23} + U_{31})^2} - 2} \qquad (3)$$

where

U_{12}, U_{23}, U_{31} are the three fundamental line-to-line voltages

[SOURCE: IEC 60050-161:1990, 161-08-09, modified – the definition was simplified and the reference to the "zero sequence component" was moved from the core of the definition to Note 1.]

3.2.12
voltage deviation
increase or decrease of the power supply RMS voltage, excluding transients with no remaining effects

Note 1 to entry: Voltage variations and voltage fluctuations are the major types of voltage deviations. Some voltage variations are fast due to the supply voltage adapting to different load conditions (for example, voltage taps changes of transformers, permanent effect of capacitor bank switching). Voltage fluctuations, which can cause flicker, are a different phenomenon (series of voltage deviations or cyclical voltage deviations, see IEC 61000-2-2:2002 and IEC 61000-2-2:2002/AMD2:2019, 4.2).

3.2.13
voltage dip
voltage sag
temporary reduction of the voltage magnitude at a point in the electrical system below a threshold

Note 1 to entry: Typically a dip is associated with the occurrence and termination of a short circuit or other extreme current increase on the system or installations connected to it.

Note 2 to entry: Generally the dip threshold voltage corresponds to the minimum value of the nominal voltage tolerance.

3.2.14
transient overvoltage
overvoltage with a duration of a few milliseconds or less, oscillatory or non-oscillatory, usually highly damped

Note 1 to entry: Transient overvoltages can be immediately followed by temporary overvoltages. In such cases the two overvoltages are considered as separate events.

[SOURCE: IEC 60050-614:2016, 614-03-14, modified – Note 2 has been deleted.]

3.2.15
industrial power electronic equipment
equipment not intended to be connected in a residential location and having emission and immunity either equal to or higher than those applicable to equipment intended to be used in a residential location

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3.3 Abbreviated terms

AIC	Active infeed converter
DFT	Discrete Fourier transform
IPC	In-plant point of coupling
PCC	Point of common coupling
PLC	Power line communication
PWHD	Partial weighted harmonic distortion
PWM	Pulse width modulation
THD	Total harmonic distortion
UPS	Uninterruptible power system

4 Electromagnetic environment classes

Several electromagnetic environment classes can be defined for power distribution systems in the scope of this document. However, for simplicity the following environment classes are specified:

Class 1 This class applies to protected power supply systems, for which harmonic compatibility levels lower than those for public networks are necessary. It relates to the use of equipment which is very sensitive to disturbances in the power supply voltage (e.g. electrical instrumentation in laboratories, special automation and protection equipment, special computers).

Class 2L This class is a legacy from IEC 61000-2-4:2002 (second edition) for compatibility levels up to the 40th harmonic. The IPCs for class 2L, class 2a and class 2b correspond to the IPCs from the original class 2, hence the typical disturbance level in the frequency range up to the 40th harmonic in class 2L is expected to be similar to class 2a and class 2b. For the frequency range from the 40th harmonic to 150 kHz, class 2L is considered identical to class 2a. Class 2L is intended for some existing installations but it is not recommended for new types of installations.

NOTE 1 For some existing safety-related installations, for example in nuclear power plants, a new safety certification would be required if Class 2L were not included in this document.

Class 2a This class applies to IPCs (IPC1) in industrial locations at which no industrial power electronic equipment is intended to be connected (e.g. offices).

Class 2b This class applies to IPCs (IPC2) in industrial locations, at which industrial power electronic equipment is intended to be connected without a separation transformer to class 2a systems, but in which standard non-industrial equipment is also intended to be connected (e.g. light industry, commercial).

Class 3 IPCs (IPC3) in industrial locations which are separated by a separation transformer from areas in which non-industrial equipment is intended to be connected. This class should be considered when any of the following conditions are met:

- a major part of the load(s) is fed through converters (or systems of converters);
- welding machines are present;
- large motors are frequently started;
- other loads whose power consumption can vary rapidly.

The class applicable for new plants and extensions of existing plants cannot be determined a *priori* and should relate to the type of equipment and process under consideration.

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Illustration of the above classes can be as shown in Figure 1:

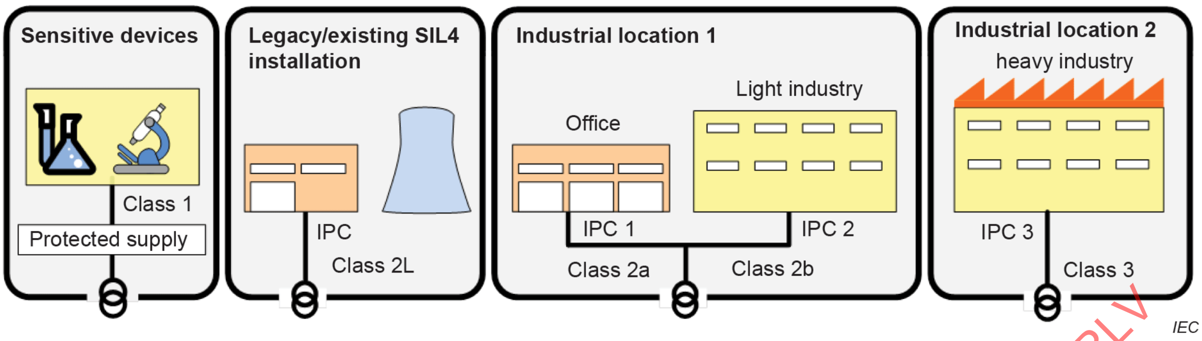

Figure 1 – Examples of the application of different electromagnetic environment classes in different industrial locations

NOTE 2 Class 1 environments normally contain equipment which requires protection from such apparatus as uninterruptible power systems (UPSs), filters or surge suppressors.

NOTE 3 In some cases, highly sensitive equipment can require compatibility levels lower than the ones relevant to class 1 environments. The compatibility levels will then be agreed upon case by case (controlled environment).

NOTE 4 The supply to highly disturbing loads, such as arc-furnaces and large converters which are generally supplied from a segregated busbar, frequently has disturbance levels in excess of class 3 (harsh environment). In such special installations with an overall power range typically > 200 kW, higher compatibility levels will be agreed upon, considering the other loads' characteristics.

NOTE 5 Taking account of the diversity of industrial environments, different classes can be relevant for different phenomena in any given network.

NOTE 6 In the third picture of Figure 1, class 2a networks (office locations) and class 2b networks (light production locations) are directly connected. This is engineering practice in numerous installations. In these installations, the standard office equipment is in general sufficiently robust to withstand the disturbance level produced by the power electronic equipment in the light industrial location. In IEC 61000-2-4:2002 (second edition), this type of installation has not raised any questions because the compatibility levels were considered up to the 40th harmonic only, and different distortion levels above the 40th harmonic were not taken into account.

Should some mitigation be necessary, Figure 2 is an example:

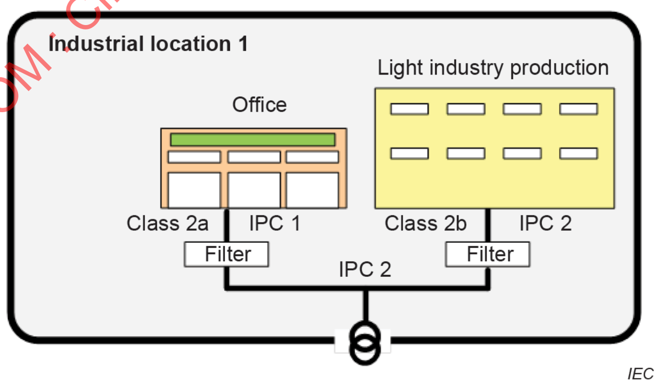

Figure 2 – Example of different parts of an installation separated by filters, where different electromagnetic environment classes are applied

In Figure 2, an office area is separated from a light industry production area using filters. At IPC1, class 2L or class 2a could apply according to the actual situation.

At the PCC, located in the public power distribution systems the compatibility levels defined in IEC 61000-2-2 apply for LV, and those defined in IEC 61000-2-12 apply for MV.

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5 Introduction to the setting of compatibility levels for different types of electromagnetic disturbances

5.1 General comment

The compatibility levels are set down for the various disturbances on an individual basis only. However, the electromagnetic environment usually contains several disturbances simultaneously, and the performance of some equipment can be degraded by particular combinations of disturbances. See IEC 61000-2-2:2002, Clause A.2. The primary purpose of the compatibility levels is the coordination of emission limits and immunity test levels for equipment. The secondary purpose is to give an indication of the expected electromagnetic disturbance level in a local network.

Levels are provided in Table 1 to Table 5. See also guidance for interharmonics in Annex C.

IPCs should be categorized according to their compatibility levels. To enable the selection of specific equipment or devices such as rotating machines, power-capacitor banks, filters, it can be necessary to obtain a specific description of the voltage deviations that can be present at the equipment terminals. The technical committees responsible for the relevant product standards will specify the information to facilitate the proper selection of components. They should also take into account the compatibility levels in this document when specifying the supply operating conditions of the equipment.

Compatibility levels are given at the IPCs, but this does not imply that disturbances at these levels will satisfy the emission requirements at the PCC. This fact is to be carefully considered when selecting the equipment.

NOTE 1 Equipment operating within class 1 is generally low-voltage equipment.

NOTE 2 To illustrate disturbance levels caused by power converters in various industrial environments, a few examples of calculated results are given in Annex B.

NOTE 3 The compatibility levels of class 3 cover the possible disturbances in industrial environments. For a specific installation it is expected that only some types of disturbances occur with the level pertaining to class 3. Since equipment or devices have different sensitivities to the various types of disturbances, a specific equipment or device can be used conditionally with a class 3 supply depending on the actual disturbance levels.

NOTE 4 Disturbance levels, which have both time and location variations, cannot be controlled at all locations and at all times. Therefore, evaluation will be made for the entire industrial system being considered, rather than at a specific location within that system.

5.2 Voltage deviations

The compatibility levels for voltage deviation are identical to the values for voltage tolerance in Table 1. For class 3, voltage deviations resulting in supply voltages in the range 0,85 U_N to 0,9 U_N are expected for a duration not longer than 60 s. For longer durations the range 0,9 U_N to 1,1 U_N applies.

NOTE 1 Voltage deviations leading to flicker are a concern for lighting equipment, which is typically connected to a class 2a, class 2b or class 2L power supply.

NOTE 2 In certain circumstances, some equipment might be sensitive to rapid voltage changes.

5.3 Voltage dips and short interruptions

For class 1 IPCs, a protection provided by UPSs is considered and dips are not expected.

For a discussion of the other aspects of these phenomena see Clause B.4.

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5.4 Voltage imbalance

In this document, voltage imbalance is considered only in relation to the negative phase sequence component, this being the component relevant to possible interference with equipment connected to the power supply systems covered by this document. In this document, voltage imbalance is considered in relation to long-term effect, i.e. for durations equal to or higher than 10 min.

NOTE 1 Some protection equipment can be sensitive to the zero sequence voltage component. This aspect at the installation level will be considered.

NOTE 2 Zero sequence voltages are of concern mainly for harmonics multiples of 3.

NOTE 3 Electronic converters produce characteristic harmonic orders due to their topology when used under their rated operating conditions. Different operating conditions such as imbalance, non-ideal commutation instants, can cause other harmonic orders to be produced.

The voltage imbalance caused by a single-phase load connected line-to-line is in practice equal to the ratio of the load power to the network three-phase short circuit power. If no substantial single-phase load is present, the compatibility levels of class 2a and class 2b may be applied.

5.5 Temporary power-frequency variation

The compatibility levels of power-frequency deviations of the public network apply to industrial plants fed from the public power supply.

For the most part, the range is within 1 Hz of the nominal frequency as stated in IEC 61000-2-2:2002, 4.8. Where synchronous interconnection is implemented on a continental scale, the variation is usually very much less.

The compatibility level for the temporary variation of frequency from the nominal frequency is ±1 Hz. The steady-state deviation of frequency from the nominal frequency is much less.

NOTE 1 For some equipment the rate of change of frequency is significant.

NOTE 2 In the case of islanded networks, frequency variations can be expected.

5.6 Harmonics

The compatibility levels for individual harmonic components of the voltage shall be understood to relate to steady-state harmonics and are given as reference values for both long-term effects and very short-term effects.

The long-term effects relate mainly to thermal effects on cables, transformers, motors, capacitors, etc. They arise from harmonic levels that are sustained for periods equal to or higher than 10 min.

With reference to long-term effects, compatibility levels for individual harmonic components of the voltage are given in Table 2. The corresponding compatibility levels for the total harmonic distortion are given in Table 3.

Very short-term effects relate mainly to disturbing effects on electronic devices that can be susceptible to harmonic levels sustained for 3 s or less. Transients are not included.

With reference to very short-term effects in class 1 and class 3, compatibility levels for individual harmonic components of the voltage, and for total harmonic distortion, are 1,5 times the values given in Table 2 and Table 3.

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In class 2a and class 2b, they are the values given in Table 2 multiplied by a factor k, where k is as follows:

$$k = 1{,}3 + \frac{0{,}7}{45} \times (h - 5) \tag{4}$$

NOTE 1 Commutation notches are included here as regards their contribution to the harmonic content of the voltage. Other aspects (for example, the influence on the commutation of other converters, or any influence on other equipment which involves the higher harmonic components of the spectrum) require a time-domain description (see the relevant product standard).

NOTE 2 Everywhere they are used in industrial networks, power factor correction capacitors are connected through series reactors, particularly those which are intended to be connected to IPCs of class 3. Where interharmonics can be present, there is a risk of resonance effects, and this will be carefully investigated. Where the absence of resonance effects is clearly proved and the higher harmonics values are far less than those given for class 3, series reactors might not be necessary, but this will be checked carefully.

NOTE 3 The values specified for total harmonic distortion are not related to specific equipment or devices but are concerned with the possible simultaneous presence of several harmonic components at significant amplitude.

5.7 Interharmonics

Annex C provides information on sources, effects and mitigation methods related to interharmonics. It also provides levels for guidance, until more experience makes publication of compatibility levels possible.

In this document, compatibility levels are given only for the case of an interharmonic voltage occurring at a frequency close to the fundamental frequency (50 Hz or 60 Hz), resulting in amplitude modulation of the supply voltage.

In these conditions certain loads that are sensitive to the square of the voltage, especially lighting devices, exhibit a beat effect, resulting in flicker (see Note 1 in 5.2.) The beat frequency is the difference between the frequencies of the two coincident voltages, i.e. between the interharmonic and fundamental frequencies.

NOTE 1 Below interharmonic order 0,2 compatibility levels are determined by flicker requirements, with P_{st} = 1. For this purpose the flicker severity can be calculated in accordance with IEC TR 61000-3-7:2008, Annex A, using the shape factor given for periodic and sinusoidal voltage fluctuations. The conservative value of the shape factor is 0,8 for 0,04 < m ≤ 0,2, and 0,4 for m ≤ 0,04.

NOTE 2 A similar situation is possible when there is an appreciable level of voltage at a harmonic frequency (particularly of order 3 or 5) coincident with an interharmonic voltage at a nearby frequency. The effect can be assessed by means of Figure 1, with amplitude given by the product of the relative amplitudes of the harmonic and interharmonic at the origin of the beat frequency. The result is unlikely to be significant.

The compatibility level for the interharmonic voltage in the above case, expressed as the ratio of its amplitude to that of the fundamental, is shown in Figure 1 as a function of the beat frequency. It is based on a flicker level of P_{st} = 1 for lamps operated at 120 V and 230 V and is applicable only to circuits which include lighting devices.

5.8 Voltage components at higher frequencies (above 40th harmonic)

Distortion of the voltage waveform can be such as to be equivalent to the superposition of voltages at frequencies, some of which are greatly in excess of that of the 40th harmonic. In the case of such higher frequency voltages it is generally not significant whether they are harmonics or interharmonics. They can occur both at discrete frequencies and in relatively broad bands of frequencies.

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5.9 Transient overvoltages

The relative amplitude of transients is generally a function of their duration, of their frequency and of the voltage level of the network. For a discussion of these phenomena, see Clause B.5.

5.10 DC component

The voltage of industrial power supply systems covered by this document does not normally have a DC component at a significant level. That can arise, however, due to slight defects of symmetry of controlled loads which are directly connected without a dedicated separation transformer.

The critical point is the level of DC current. The value of the DC voltage depends not only upon DC current but also upon other factors, especially the resistance of the network at the point to be considered. Therefore, a compatibility level for the DC voltage is not specified.

A DC component can cause unsymmetrical magnetization in transformers, leading to overheating and emission of harmonic voltages. Moreover, if flowing through the earth, such a DC current leads to increased corrosion of metal fixtures underground.

6 Compatibility levels

Compatibility levels in differential mode (L-L and L-N) for imbalance, harmonics, interharmonics and flicker are 95 % probability values.

Compatibility levels for voltage tolerance, voltage imbalance and power-frequency variations are given in Table 1.

Compatibility levels for harmonics are indicated in Table 2.

Compatibility levels for total harmonic distortion are presented in Table 3.

The compatibility levels for voltage distortion above the 40th harmonic up to 9 kHz and from 9 kHz to 150 kHz are given in Table 4 and Table 5, respectively.

Interharmonic compatibility levels are represented in Figure 3.

Table 1 – Compatibility levels for voltage tolerance, voltage imbalance and power-frequency variations

Disturbance		Class 1	Class 2L, Class 2a, Class 2b	Class 3
Voltage tolerance, relative to nominal voltage U_N:	$\Delta U/U_N$	±8 %	±10 % [a]	+10 % to −15 % [b]
Voltage imbalance	U_{neg}/U_{pos}	2 %	2 %	3 %
Power-frequency deviations [c]	Δf	±1 Hz	±1 Hz	±1 Hz

[a] Value not defined in IEC 61000-2-2.

[b] See 5.2.

[c] ±2 Hz in case of islanded networks.

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Table 2 – Compatibility levels for harmonics – Harmonic voltage components

Order h	Class 1 U_h %	Class 2L U_h %	Class 2a, class 2b U_h %	Class 3 U_h %
2	2	2	2	3
3	3	5	5	6
4	1	1	1	3
5	3	6	6	8
6	0,50	0,50	1	3
7	3	5	5	7
8	0,50	0,50	1	3
9	1,5	1,5	1,5	3
10	0,50	0,50	1	3
11	3	3,5	3,5	5
12	0,46	0,46	1	3
13	3	3	3	4,5
14	0,43	0,43	1	4,4
15	0,30	0,40	1	4,2
16	0,41	0,41	1,4	4,1
17	2	2	2	4
18	0,39	0,39	1,4	3,8
19	1,8	1,8	1,8	3,5
20	0,38	0,38	1,4	3,3
21	0,20	0,30	1,4	3,1
22	0,36	0,36	1,4	3
23	1,4	1,4	1,4	2,8
24	0,35	0,35	1,3	2,5
25	1,3	1,3	1,3	2,6
26	0,35	0,35	1,2	2,4
27	0,20	0,20	1,2	2,3
28	0,34	0,34	1,1	2,2
29	1,1	1,1	1,1	2,1
30	0,33	0,33	1	2,1
31	0,97	0,97	0,97	2
32	0,33	0,33	0,94	1,9
33	0,20	0,20	0,90	1,8
34	0,32	0,32	0,87	1,8
35	0,83	0,83	0,83	1,7
36	0,32	0,32	0,80	1,6
37	0,77	0,77	0,77	1,6
38	0,32	0,32	0,75	1,5
39	0,20	0,20	0,72	1,5
40	0,31	0,31	0,69	1,4

In some cases where part of an industrial network is dedicated to large non-linear loads, the class 3 compatibility levels for that part of the network may be 1,2 times the above values. In such cases precautions should be taken regarding immunity of equipment connected. However, at the PCC (public network) the compatibility levels from IEC 61000-2-2 and IEC 61000-2-12 take precedence.

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Table 3 – Compatibility levels for total voltage harmonic distortion

	Class 1	Class 2L, class 2a, class 2b	Class 3
Total harmonic distortion (THD)	5 %	8 %	10 %
Partial weighted harmonic distortion (PWHD)	19,4 %	19,4 %	43,6 %
NOTE The PWHD compatibility levels were calculated from the individual harmonic voltage components from H14 to H40 defined for all classes defined in IEC 61000-2-4.			

Table 4 – Compatibility levels for low voltage networks in the frequency range from 2 kHz to 9 kHz

Frequency range kHz	Class 1, class 2L, class 2a U_N %	Class 2b U_N %	Class 3 U_N %
2 (2,4)[a] to 3	1,4	3	6
3 to 9	1,4 to 0,65[b]	3	6

NOTE The levels specified in Table 4 apply at the IPC. At the PCC (public network), the compatibility levels from IEC 61000-2-2 apply.

[a] The frequency range is 2 kHz to 3 kHz for 50 Hz systems and 2,4 kHz to 3 kHz for 60 Hz systems.

[b] The logarithm of the level decreases linearly with the logarithm of the frequency in the range 3 kHz to 9 kHz.

For the frequency range between 2 kHz and 9 kHz, compatibility levels are defined as a grouped value within a band of 200 Hz according to IEC 61000-4-7.

For MV networks, compatibility levels above 2 kHz are under consideration.

Table 5 – Compatibility levels for low voltage networks in the frequency range from 9 kHz to 150 kHz

Frequency range kHz	Class 1, class 2L, class 2a U_h dBµV	Class 2b U_h dBµV	Class 3 U_h dBµV
9 to 50	129,5 to 119[a]	137 to 126,5[a]	143 to 141[a]
50 to 150	113 to 89[a]	126,5 to 109[a]	141 to 139[a]

NOTE The levels specified in Table 5 apply at the IPC. At the PCC (public network), the compatibility levels from IEC 61000-2-2 apply.

[a] The logarithm of the level decreases linearly with the logarithm of the frequency in the range 9 kHz to 50 kHz and from 50 kHz to 150 kHz.

The compatibility levels U_h for voltage distortion in differential mode from 9 kHz to 150 kHz are related to disturbance levels between any phase conductors and between any phase conductor and the neutral conductor measured with a quasi-peak detector and with a bandwidth of 200 Hz in accordance with CISPR 16-1-1.

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These compatibility levels for voltage distortion are reference levels for EMC coordination of immunity requirements and in the setting of emission limits in differential mode for emissions. However, if the emission limits are related to voltage distortion levels measured between any mains conductor (phase or neutral) and the earth (unsymmetrical voltages) in accordance with CISPR 16-2-1, the reference levels for EMC coordination in the setting of emission limits for unsymmetrical voltage distortion are 6 dB lower than the compatibility levels given in Table 5 for voltage distortion in differential mode.

NOTE 1 Measurements according to CISPR 16-2-1 are not applicable in IT networks. In IT networks, measurements can be done for example with a voltage probe.

NOTE 2 Based on the following assumptions, an emission margin equal to or higher than 3 dB between the equipment emission limits in differential mode for emissions and the corresponding compatibility levels, or a difference equal to or higher than 9 dB (3 dB for the emission margin + 6 dB for the conversion factor between the unsymmetrical voltages and the voltage in differential mode) between the equipment emission limits for unsymmetrical voltage distortion and the compatibility levels in differential mode given in Table 5 is sufficient:

– for each bandwidth of 200 Hz, the probability that the compatibility level is exceeded is lower than 5 %;
– at a given location, the disturbance level in a same bandwidth of 200 Hz does not result from more than two pieces of equipment generating non-intentional emissions close to the emission limit at the same time;
– non-intentional emissions from different equipment are generated independently from each other.

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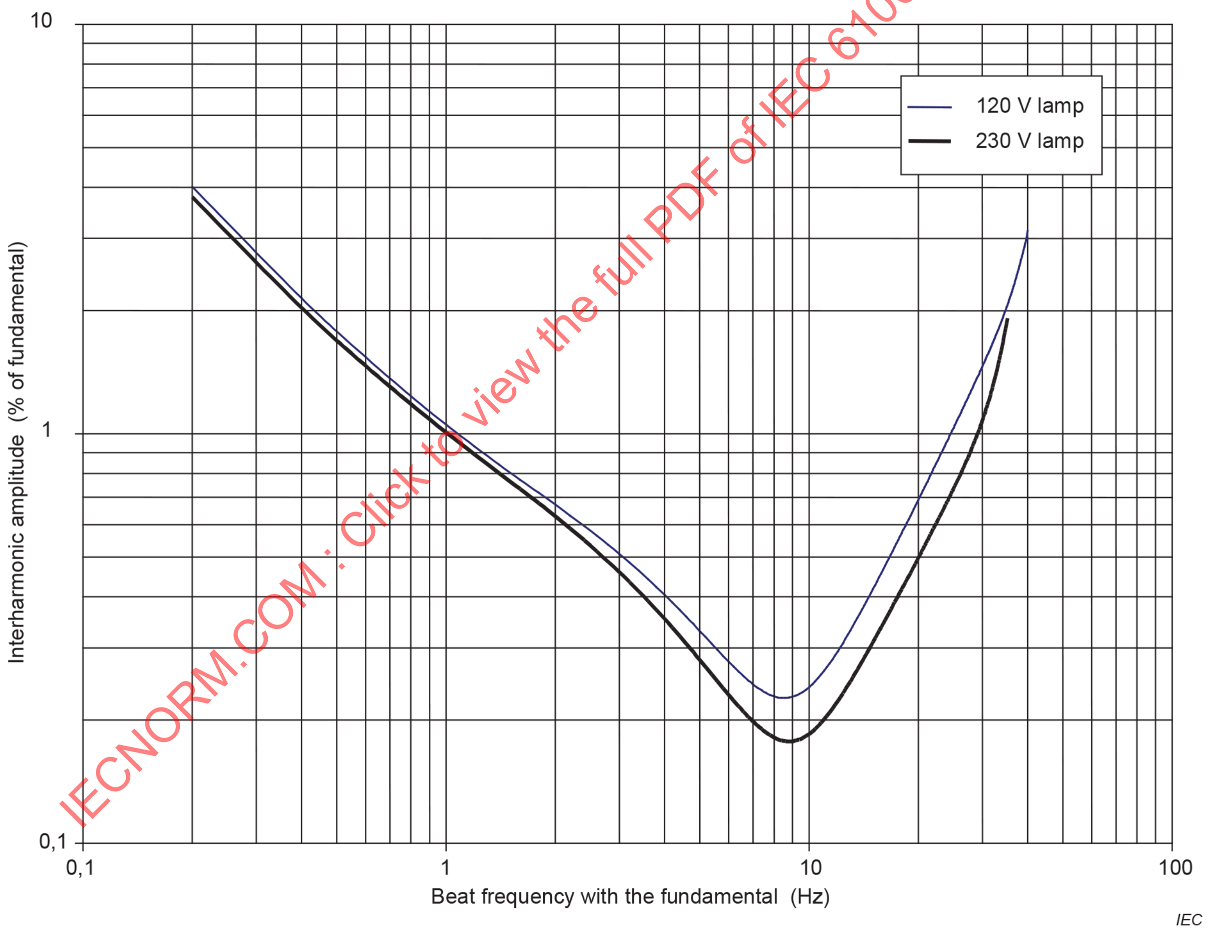

NOTE Compatibility levels for interharmonics near the fundamental frequency, 230 V and 120 V systems, corresponding to perception of flicker are given by Figure 1 as a function of the beat frequency, which makes the result independent from the system frequency.

Figure 3 – Interharmonic compatibility levels (flickermeter response for P_{st} = 1 related to 60 W incandescent lamps)

Annex A
(informative)

Explanations and examples for interharmonics

A.1 Resolution of non-sinusoidal voltages and currents

The distortion of the supply voltage from its intended sinusoidal waveshape is equivalent to the superposition on the intended voltage of one or more sinusoidal voltages at unwanted frequencies. (The discussion below is valid for both voltage and current – therefore the word “quantity” is used.)

Fourier series analysis (IEV 101-13-08) enables any non-sinusoidal but periodic quantity to be resolved into truly sinusoidal components at a series of frequencies, and in addition, at a DC component. The lowest frequency of the series is called the fundamental frequency f_f (IEV 101-14-50). The other frequencies in the series are integer multiples of the fundamental frequency and are called harmonic frequencies. The corresponding components of the periodic quantity are referred to as the fundamental and harmonic components, respectively.

The Fourier transform (IEV 101-13-09) can be applied to any function, periodic or non-periodic. The result of the transform is a spectrum in the frequency domain, which in the case of a non-periodic time function is continuous and has no fundamental component. The particular case of application to a periodic function shows a lines spectrum in the frequency domain, where the lines of the spectrum are the fundamental and harmonics of the corresponding Fourier series.

The discrete Fourier transform (DFT) is the practical application of the Fourier transform. In practice the signal is analysed over a limited period of time (a window with duration T_w) using a limited number (M) of samples of the actual signal. The result of the DFT depends on the choice of these parameters, T_w and M. The inverse of T_w is the basic frequency f_b of the DFT.

The DFT is applied to the actual signal inside the window. The signal is not processed outside the window but is assumed to be an identical repetition of the signal inside the window. This results in an approximation of the actual signal by a virtual signal which is truly periodic and whose period is the time window.

The FFT (Fast Fourier Transform) is a special algorithm allowing short computation time. It requires the number of samples (M) to be an integer multiple of 2 ($M = 2^i$). (In other words, it does require the sampling frequency to be a locked integer power of 2 of the fundamental). However, modern digital signal processors have such capability that the extra complexity in a DFT (tables of sine and cosine functions) can be more economic and flexible than the frequency-locked FFTs.

In order that the result of the DFT, applied to a function considered as periodic (see Clause A.2), is the same as the result of a Fourier series analysis, the fundamental frequency f_f is made an integer multiple of the basic frequency (this requires the sampling frequency to be an exact integer multiple of the basic frequency [$f_\mathrm{s} = M \times f_\mathrm{b}$]). The synchronous sampling is essential. Loss of synchronism can change the spectrum result, making extra lines appear and changing amplitudes of true lines.

Accordingly, the measurement techniques defined in IEC 61000-4-7 and the definition of the fundamental frequency in 3.2.1 are consistent for application to all electrotechnical and power electronics items. Other cases require further consideration.

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As an illustration, the superposition of a sinusoidal ripple control signal at 175 Hz on a sinusoidal 50 Hz supply voltage can be considered. This results in a periodic voltage having a period of 40 ms and a frequency of 25 Hz. A classical Fourier series analysis of this voltage yields a fundamental component of 25 Hz with zero amplitude and two components with non-zero amplitude, a 2nd harmonic (50 Hz) with amplitude equal to that of the supply voltage and a 7th harmonic (175 Hz) with an amplitude equal to that of the ripple control signal. The definitions in 3.2 avoid the confusion implicit in this approach and produce a result in line with the common practice of the DFT (as described in IEC 61000-4-7), showing a fundamental at 50 Hz and an interharmonic of order 3,5.

NOTE 1 When analysing the voltage of a power supply system, the component at the fundamental frequency is the component of the highest amplitude. This is not necessarily the first line in the spectrum obtained when applying a DFT to the time function.

NOTE 2 When analysing a current, the component at the fundamental frequency is not necessarily the component of the highest amplitude.

A.2 Time varying phenomena

The voltages and currents of a typical electricity supply system are affected by incessant switching and variation of both linear and non-linear loads. However, for analysis purposes, they are considered as stationary within the measurement window (approximately 200 ms), which is an integer multiple of the period of the power supply voltage. Harmonic analysers are designed to give the best compromise that technology can provide (see IEC 61000-4-7).

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Annex B
(informative)

Examples of expected disturbance levels in typical industrial networks

B.1 General

Annex B gives the results of the calculation of the disturbance levels at the IPCs in some typical industrial networks. The cases studied are as follows:

– rolling mills (Table B.1; Figure B.1);
– paper industry (Table B.1; Figure B.2);
– manufacturing industry (Table B.2; Figure B.3).

B.2 Voltage disturbance levels in industrial networks due to large converters

It can be seen that some IPCs, namely those feeding large converters, can have disturbance levels considerably higher than those specified for public networks.

It is especially the levels of higher order harmonics (the 11th order is given as example), the total harmonic distortion coefficient (THD) or the voltage changes that exceed the corresponding levels for public networks.

The reported results are not total disturbance levels since the contribution caused by disturbances present in the public supply is not considered.

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Table B.1 – Type of network

	Rolling mills			Paper industry		
	IPC 1	**IPC 2**	**PCC**	**IPC 1**	**IPC 2**	**PCC**
Harmonic voltages						
Average values						
U_5 (%)	3 to 6,5	2 to 3,9	1 to 2,2	1 to 1,7	1 to 2,3	0,5 to 1,1
U_{11} (%)	3 to 6,8	1,5 to 2,9	1 to 2	0,5 to 1,1	0,7 to 1,4	0,4 to 0,7
THD (%)	7 to 14,3	3,5 to 7,3	2 to 4,7	1,5 to 2,9	2 to 4	1 to 1,9
Harmonic voltages						
Peak values						
U_5 (%)	6 to 11,4	2,5 to 5,1	2 to 3,5	1 to 1,9	1,5 to 2,7	0,6 to 1,3
U_{11} (%)	6 to 11,5	2 to 4,2	2 to 3,3	0,5 to 1,2	0,8 to 1,6	0,4 to 0,8
THD (%)	12 to 24,7	5 to 9,9	4 to 7,3	1,5 to 3,3	2 to 4,6	1 to 2,3
Voltage changes ΔU (%)	2 to 4,7	0,5 to 1,2	0,5 to 1,2	< 0,1	< 0,3	< 0,1
Time interval between two voltage changes ΔT (s)	5 to 100	5 to 100	5 to 100	> 600	> 600	> 600

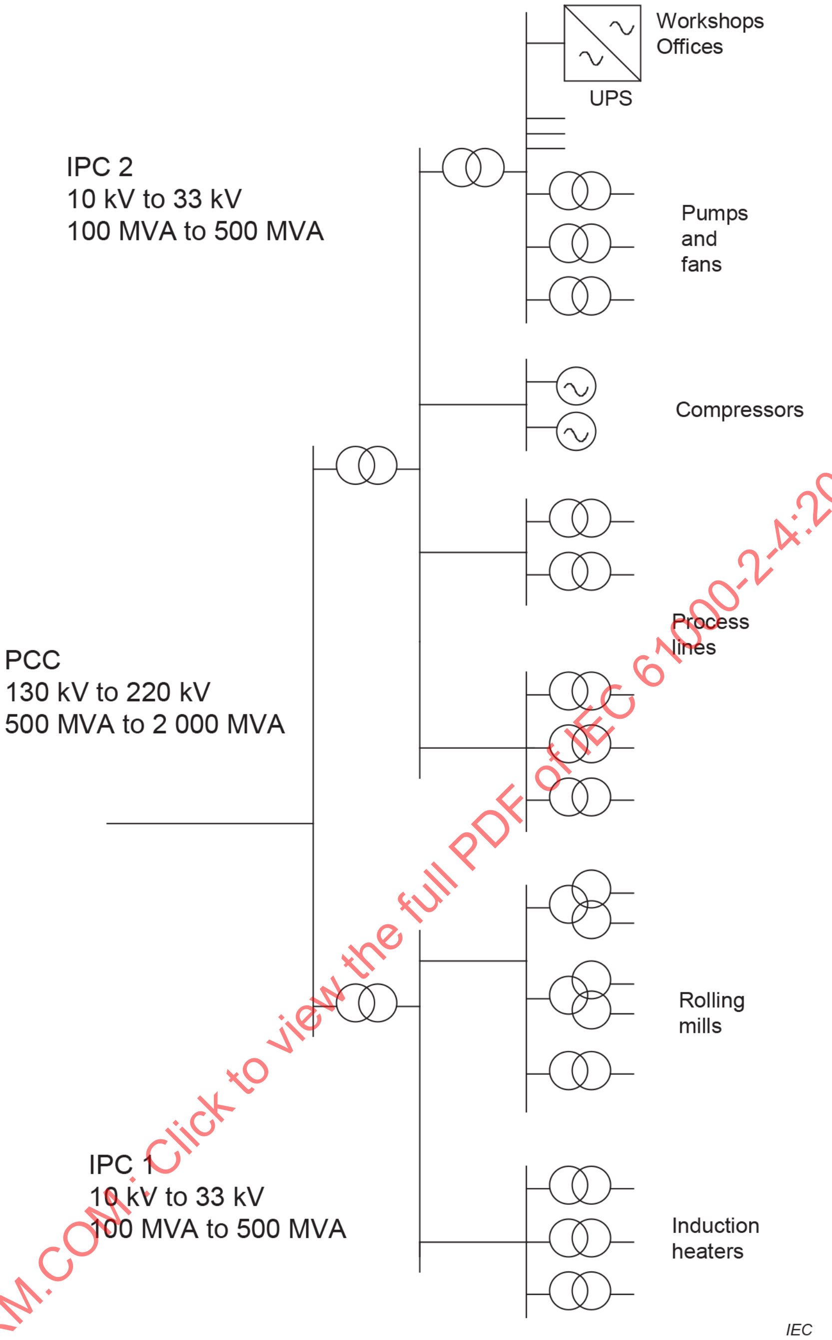

Figure B.1 – Example of power distribution in industry with rolling mills

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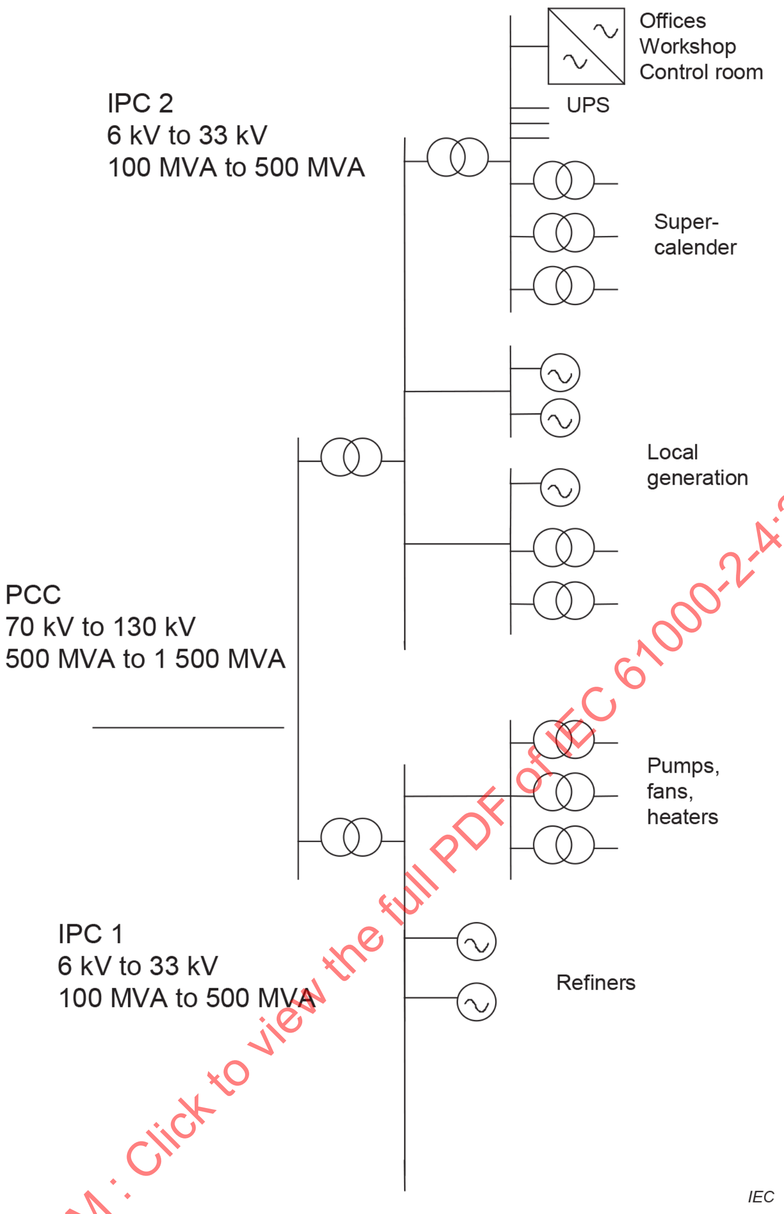

Figure B.2 – Example of power distribution in the paper industry

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B.3 Voltage disturbance levels in industrial networks at high load

The range of the given values depends on the assumed range of variation of the system parameters and of the coincidence factors.

No power capacitor is present and therefore the possible magnification of the harmonic voltages is neglected.

Table B.2 – Voltage disturbance levels in a typical manufacturing industry

	Impedance 1/MVA [a]	**Short-circuit fault level (S_{sc})** MVA	**Total load** MVA	**Converter load** MVA	**THD** %	**Voltage changes** %
130 kV line	1/2 000	2 000				
Transformer TA	1/320	275,8				
MT cable	1/6 000					
IPC		266,6	2,3	1,25	1,08	0,6
Transformer T1	1/8,9					
LV1 line		8,6	0,3	0,05	1,34	2,4
Transformer T5	1/1,25					
Converter C1		1,09		0,05	10,6	
Transformer T3	1/12					
LV2 line		11,5	0,6	0,3	5,0	3,0
350 kVA motors		2,275	0,3			
60 µH reactor	1/8,5					
Converter C2		5,25		0,3	13,2	
Transformer T4	1/22,2					
LV3 line		20,5	0,9	0,9	10,1	3,1
400 V cable	1/582					
Converters C3 ..... C10		20		0,9	10,4	

[a] The impedances are in p.u. on a 1 MVA basis.

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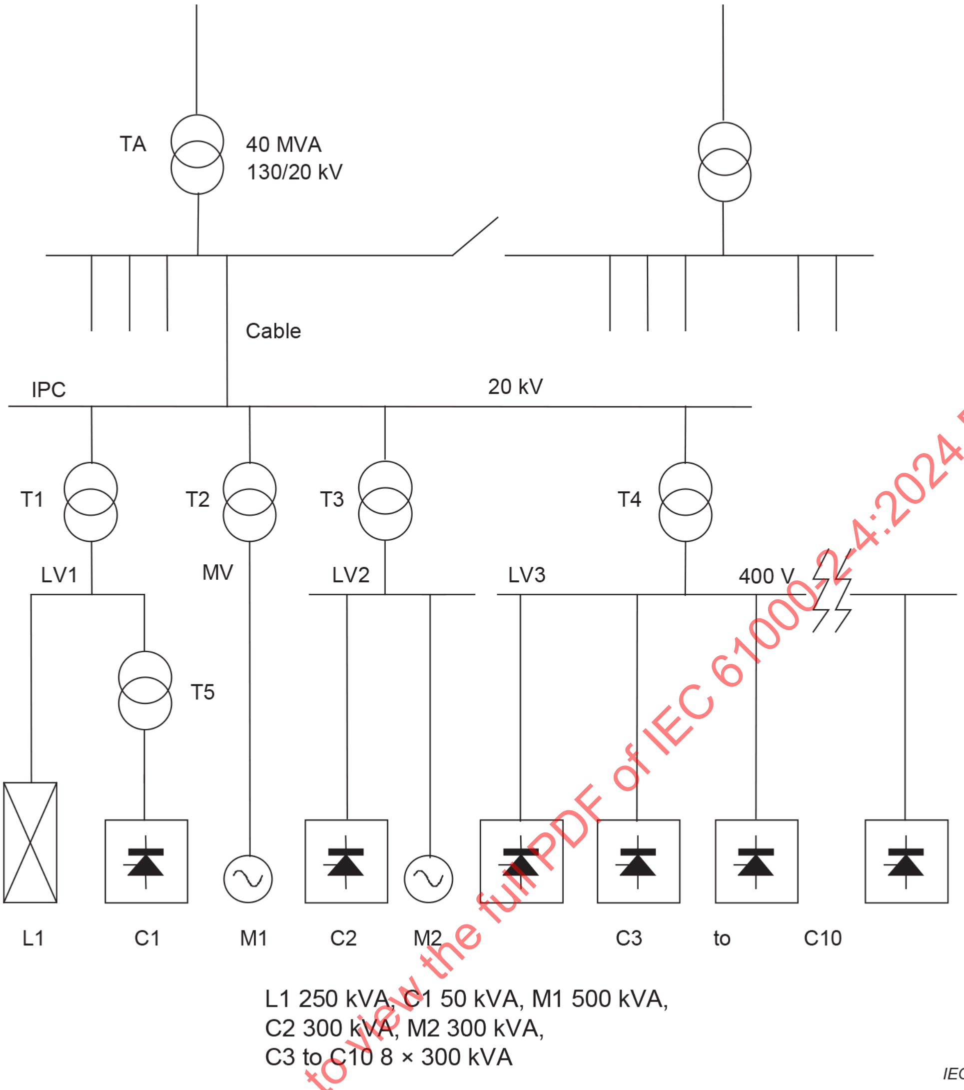

Figure B.3 – Example of power distribution in a generic manufacturing industry

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B.4 Voltage dips and short interruptions

B.4.1 Description

Voltage dips and short interruptions are unpredictable, largely random events arising mainly from electrical faults on the power supply system or large installations. They are best described in statistical terms. See IEC TR 61000-2-8.

A voltage dip is a two-dimensional disturbance phenomenon, since the level of the disturbance increases with both the depth and duration of the dip.

The depth of the voltage dip depends on the proximity of the observation point to the point on the network at which the short circuit occurs. At that point the voltage collapses to near zero, so that the depth of the dip approaches 100 %. In the case of other causative events, such as a large load fluctuation, the depth is likely to be less.

A voltage dip can last less than 0,1 s if the incident occurs in the transmission system and is eliminated by very fast systems of protection or if a self-clearing fault is involved. If the fault affects a lower level of the network and is cleared by certain protection systems used on those networks, it can last up to a few seconds. Most voltage dips last between half a period and 1 000 ms.

The number of voltage dips is significant only when the immunity of a given device is insufficient for the depth-duration occurring. This number becomes an important data for choosing the appropriate level of immunity of a given process. The number for a particular line includes voltage dips produced by faults on other lines in the same network and voltage dips coming from upstream networks. (See also IEC TR 61000-2-8.)

In rural areas supplied by overhead lines, the number of voltage dips can reach several hundred per year, depending in particular on the number of lightning strokes and other meteorological conditions in the area.

On cable networks, the latest information indicates that an individual user of electricity connected at low voltage can be subjected to voltage dips occurring at a rate which extends from around ten per year to about a hundred per year, depending on local conditions. The duration of these voltage dips is usually between half a cycle and 3 s.

Short supply interruptions last up to 180 s according to the type of reclosing or transfer system used in overhead networks. It can be possible to reduce time in special cases. Frequently short supply interruptions are preceded by voltage dips. Distinction between a dip and a short interruption can be difficult. By convention, a retained voltage below a certain level (10 % for example) can be the criterion to make this distinction. However, in a three-phase system this condition is to be applied to each phase, simultaneously, to be considered as a short supply interruption.

B.4.2 Adaptation

In the case of short interruptions, but also for the more severe voltage dips, immunity of electrical equipment is not, in the strict sense, an appropriate concept, since no electrical device can continue to operate as intended in the absence of its energy supply. Immunity from these disturbances is therefore a matter of either the fast restoration of energy from an alternative source or arranging for the equipment and its associated process to adapt in an intended manner to the brief interruption or diminution of power. This is a complex matter, having both technical and economic aspects, and is beyond the scope of this document (see Bibliography).

Values describing voltage dips and short interruptions for class 3 IPCs can be established with due consideration of the following:

– the disturbance level values at the PCCs of the plant can be adopted, but it should be remembered that these values can vary considerably with the type of supply system, high voltage or medium voltage via overhead lines or cables, single circuit or double circuits for example, and with the location of the site, exposed and prone to lightning for example;
– the presence of in-plant generation can reduce the severity of voltage dips and short-time interruptions;
– the contribution of the industrial plant to the voltage dips or short-time interruptions should be considered; for instance, as a consequence of severe faults, large voltage depressions can be caused by the simultaneous restarting of several induction motors in the plant;
– the short interruption values for class 3 IPCs refer to plants fed by one supply line only.

As a basis, the results of IEC TR 61000-2-8 can be adopted.

B.5 Transient overvoltages

Several phenomena, including the operation of switches and fuses and the occurrence of lightning strokes in proximity to the supply networks, give rise to transient overvoltages in low-voltage power supply systems and in the installations connected to them. The overvoltages can be either oscillatory or non-oscillatory, are usually highly damped, and have rise times ranging from less than 1 µs to a few milliseconds.

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The magnitude, duration, and energy-content of transient overvoltages vary with their origin. Generally, those of atmospheric origin have the higher amplitude, and those due to switching are longer in duration and contain the greater energy. Critical equipment have to be protected by surge protective devices, and these should generally be selected to cater for the greater energy content of the switching overvoltages.

Switching of capacitor banks is a common cause of transient overvoltages. Typically, their value at the point of incidence is less than twice the nominal voltage. However, wave reflections and voltage magnification can occur as the transient is propagated along a line, amplifying the overvoltage incident on connected equipment.

Figure B.4 shows an example of tolerance envelope for IT equipment which is applicable for single phase 120 V. Other types of equipment can present different tolerance characteristics.

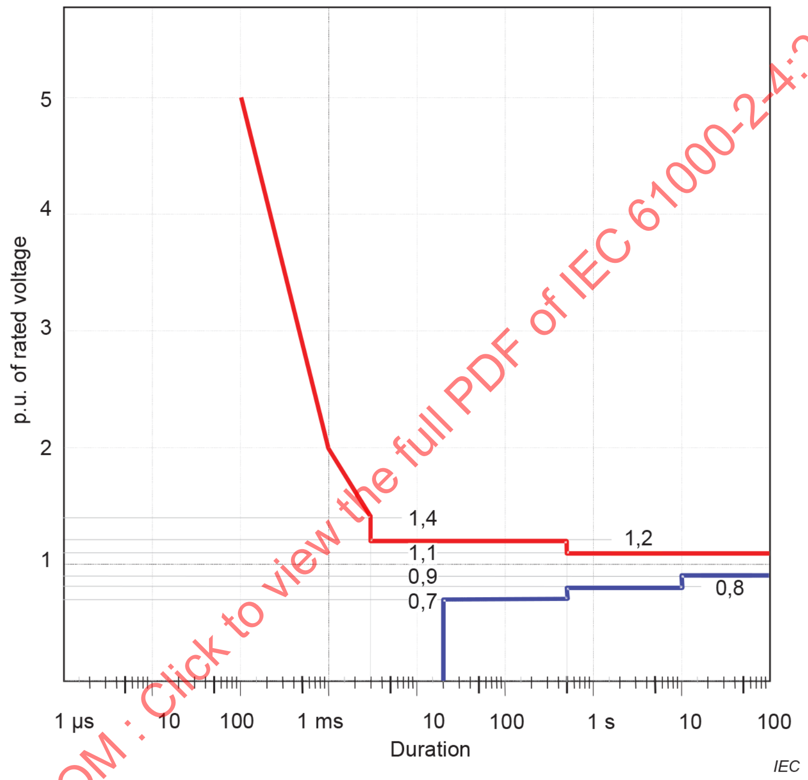

Figure B.4 – ITI (CBEMA) – Curve of tolerance envelope of ITE[1]

Transients of atmospheric origin have been recorded at magnitudes up to 6 kV on LV networks. This value should be considered for coordination of isolation.

Taking into account that attenuation between the PCC and the practical input of the installation is not sufficiently known and that a 100 % immunity is a very costly fiction (if not impossible), the compatibility level for EMC purposes should be set much lower.

The transient overvoltages of external origin (coming from the public power supply system) can be attenuated according to the location of the IPC within the installation.

[1] ITI = Information Technology Industry; CBEMA = Computer Business Equipment Manufacturers Association; ITE = information technology equipment.

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Annex C
(informative)

Interharmonics and voltages at higher frequencies and mitigation methods

C.1 Sources of interharmonics

C.1.1 Identification

Sources of interharmonics can be found in low-voltage networks as well as in medium-voltage and high-voltage networks. The interharmonics produced by low-voltage sources (welding machines, power converters, induction motors) mainly influence devices in their vicinity; the interharmonics produced in the medium-voltage or the high-voltage networks (arc furnaces, power converters, induction motors), or both, flow in the low-voltage networks they supply. Interharmonics and voltages at higher frequency can also result from resonances present in the distribution system at frequencies matching with unstable poles of converter current controllers.

There is also low-level background Gaussian noise, with a continuous regular frequency spectrum, superimposed on the low-voltage curve even in the absence of a local source of interharmonics. Typical voltage levels, on a low-voltage network of 230 V, seem to be in the range of 40 mV to 50 mV, when measured with a filter bandwidth of 10 Hz, and 20 mV to 25 mV when measured with a filter bandwidth of 3 Hz.

Four main origins of interharmonics can be distinguished:

– electrical arc-furnaces, arc welding machines or plasma heaters, which have been known for many years as the major power source of interharmonics or sub-harmonics, the origin of which is in the process itself, or in the position control of the electrodes for which the phenomenon is without any synchronism with the power frequency;
– power converters with active front end can be operated at switching frequencies which generally are interharmonic frequencies; the effect of switching produces interharmonic voltages or currents;
– spurious coupling between circuits where the fundamental frequencies are different; this is the case of electronic frequency converters;
– intentional production of voltages at such interharmonic frequencies for the purpose of signal transmission.

C.1.2 Different types of sources of interharmonics

C.1.2.1 Random sources

Arc welding machines generate a continuous wide band frequency spectrum, associated with an intermittent process with the duration of the individual welding actions varying between 1 s and several seconds. They are mostly connected to the low-voltage network, preferably of low impedance in order to avoid disturbing flicker effects.

Arc furnaces produce continuous but randomly varying interharmonic frequency spectra due to the irregular input current. Their high rating (50 MW to 120 MW) make them always connected to the medium-voltage or high-voltage network. The highest emission level occurs during the starting-phase of a melting process.

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C.1.2.2 Sub-harmonics or interharmonics produced by the load of a line commutated converter

Electronic frequency converters have a different behaviour according to their structure. Direct converters, such as cycloconverters, consist of an assembly of semiconductor devices and their auxiliary circuits which, by means of their cyclic commutations, convert the input voltage at the fundamental frequency of the power supply network into an output voltage at a fundamental frequency, defined by the control of the converter to be suitable for feeding the load. (The load can be a variable speed motor or a particular network at a fixed frequency, for example, 25 Hz or 16 Hz 2/3.) These cycloconverters have no decoupling function between the two different fundamental frequencies. Therefore, currents at multiples of the load frequency are circulating directly in the line side of the converter assembly of each phase. The line current has the form of a current at the power supply network frequency (plus its regular harmonics), modulated in amplitude depending on the load frequency.

NOTE For example, in a cycloconverter for a three-phase balanced load fed at the frequency f_L, the line currents combine in each phase at the point of coupling of the three individual multiphase converters (pulsation index p), each feeding a phase of the three-phase load. The combination of the line currents can be approached when considering the total active power and the total reactive power. In the case of a purely active load and of an ideal converter, the total active power is a constant (without fluctuating power) while the total reactive power is a constant with addition of a fluctuating component of low amplitude at a frequency of $2pf_L$. In the case of a purely reactive load and of an ideal converter, the total active power is zero, while the total reactive power is a constant. The line current resulting from these combinations contains a modulation at frequencies of $2pf_L$ and its multiples. Additional other interharmonic currents result from a non-linear command having a rating optimization purpose, and from the unavoidable imperfections of the system.

Indirect frequency converters have an intermediate DC link, with an input converter on the line side and an output converter (more often operating as an inverter) on the load side. For both structures, current stiff and voltage stiff, the DC link includes a filter decoupling the current or the voltage of the power supply system and of the load. Therefore, the two fundamental frequencies (supply and load) are decoupled. But infinite filtering does not exist, and the remaining coupling path produces currents on the supply network at frequencies present on the DC link and due to the load side. These frequencies are sub-harmonic and interharmonic relative to the power supply frequency. However, it should be underlined that this phenomenon is most often negligible for voltage source inverters.

Electronic frequency converters inject currents into the network at sub-harmonic and interharmonic frequencies that are mainly in the range from 0 Hz to 150 Hz or 300 Hz. These correspond to the fundamental frequency of the load, which is frequently a variable speed motor. The highest range of frequencies, up to 2 500 Hz, is much smaller in amplitude. The main difficulty is that those sub-harmonics or interharmonics are not at a fixed frequency.

Some semiconductor converters, used to feed particular networks at a fixed frequency, also produce sub-harmonics or interharmonics, or both, at a fixed frequency.

Harmonic and interharmonic frequencies of such converters with an input fundamental frequency f and an output fundamental frequency F are defined by the following formula:

$$f_{\mathrm{h,m}} = \left[\left(p_1 \times k_1\right) \pm 1\right] \times f \pm \left[\left(p_2 \times k_2\right)\right] \times F \quad \text{(C.1)}$$

where

p_1 is the pulse number of the input converter;

p_2 is the pulse number of the output converter;

k_1, k_2 are the series of whole integers (0, 1, 2, 3…); and

if $k_2 = 0$, $f_{\mathrm{h,m}} = f_{\mathrm{h}}$ (harmonic frequencies).

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C.1.2.3 Sub-harmonics or interharmonics produced by active infeed converters

The behaviour of active infeed converters is described in detail in IEC TS 62578.

C.1.2.4 Other miscellaneous sources

Induction motors can give rise to an irregular magnetizing current due to the slots in the stator and rotor – possibly in association with saturation of the iron – which generates interharmonics in the low-voltage network. At the normal speed of the motor, the disturbing frequencies are practically in the range of orders 10 to 40, but during the starting period they run through the whole frequency range up to their final value.

Voltages at interharmonic pre-defined frequencies are also produced intentionally by ripple control transmitters. The purpose and practice of ripple control transmitters is described in IEC 61000-2-2. Their frequency range is 110 Hz to 3 000 Hz with a maximum relative voltage level U_s/U_N of 9 % up to 500 Hz and decreasing (20 dB per decade) between 500 Hz and 3 000 Hz (1,5 %). Other systems for mains signalling operate in higher frequency ranges, for example 3 kHz to 500 kHz (in some LV/MV installations 1,6 MHz to 30 MHz for broadband powerline communication (PLC), and 30 kHz to 500 kHz (in some countries 16 kHz to 1 MHz) for powerline carrier systems in MV/HV networks).

C.1.3 Effects of interharmonics and compatibility

Interharmonics introduce non-periodical or quasi-non-periodical phenomena superimposed on the periodical waveform of the voltage network. Therefore, the crest voltage is changed at a lower frequency where the difference of the involved frequencies appears as the disturbance. Each use of electricity where the crest voltage is of importance is then disturbed. Examples are lighting equipment, which can flicker, and television receivers, which can be disturbed.

Ripple control receivers are likely to be disturbed by interharmonics. For reception their minimum operating level is as low as 0,3 %, to take into account the different attenuations between the emitter and the receivers in the power supply network. Therefore, users of electricity should know whether such ripple control is in operation in their area and what the allocated frequency is. This minimum information is required to ensure compatibility.

The frequency of an interharmonic current can occur and sweep in a wide range of frequencies without discontinuity. The resulting interharmonic voltage is defined by the current and the impedance at the particular frequency. The most spurious effect is the ability to excite anti-resonance frequencies arising from passive filters or power factor compensation capacitor banks connected to the network.

C.1.4 Guidance levels

C.1.4.1 Levels related to flicker effect

The case of a voltage having a frequency which combines with the fundamental frequency and results in a beat frequency has been dealt with in 5.7. Table C.1 indicates the interharmonic voltage levels corresponding to the compatibility level given in Figure 1.

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Table C.1 – Indicative values for interharmonic voltages in low-voltage networks with respect to the flicker effect

	50 Hz system			60 Hz system		
Order m	**Interharmonic frequency** f_m Hz	U_m % **120 V system**	 **230 V system**	**Interharmonic frequency** f_m Hz	U_m % **120 V system**	 **230 V system**
$0,20 < m \leq 0,60$	$10 < f_m \leq 30$	**0,68**	**0,51**	$12,0 < f_m \leq 36,0$	**0,95**	**0,69**
$0,60 < m \leq 0,64$	$30 < ff_m \leq 32$	**0,57**	**0,43**	$36,0 < f_m \leq 38,4$	**0,79**	**0,58**
$0,64 < m \leq 0,68$	$32 < f_m \leq 34$	**0,46**	**0,35**	$38,4 < f_m \leq 40,8$	**0,64**	**0,48**
$0,68 < m \leq 0,72$	$34 < f_m \leq 36$	**0,37**	**0,28**	$40,8 < f_m \leq 43,2$	**0,50**	**0,38**
$0,72 < m \leq 0,76$	$36 < f_m \leq 38$	**0,29**	**0,23**	$43,2 < f_m \leq 45,6$	**0,39**	**0,30**
$0,76 < m \leq 0,84$	$38 < f_{mm} \leq 42$	**0,23**	**0,18**	$45,6 < f_m \leq 50,4$	**0,23**	**0,18**
$0,84 < m \leq 0,88$	$42 < f_m \leq 44$	**0,23**	**0,18**	$50,4 < f_m \leq 52,8$	**0,22**	**0,18**
$0,88 < m \leq 0,92$	$44 < f_m \leq 46$	**0,28**	**0,24**	$52,8 < f_m \leq 55,2$	**0,22**	**0,20**
$0,92 < m \leq 0,96$	$46 < f_m \leq 48$	**0,40**	**0,36**	$55,2 < f_m \leq 57,6$	**0,34**	**0,30**
$0,96 < m < 1,04$	$48 < f_m \leq 52$	**0,67**	**0,64**	$57,6 < f_{mm} \leq 62,4$	**0,59**	**0,56**
$1,04 < m \leq 1,08$	$52 < f_m \leq 54$	**0,40**	**0,36**	$62,4 < f_m \leq 64,8$	**0,34**	**0,30**
$1,08 < m \leq 1,12$	$54 < f_{mm} \leq 56$	**0,28**	**0,24**	$64,8 < f_m \leq 67,2$	**0,22**	**0,20**
$1,12 < m \leq 1,16$	$56 < f_m \leq 58$	**0,23**	**0,18**	$67,2 < f_m \leq 69,6$	**0,22**	**0,18**
$1,16 < m \leq 1,24$	$58 < f_m \leq 62$	**0,23**	**0,18**	$69,6 < f_m \leq 74,4$	**0,23**	**0,18**
$1,24 < m \leq 1,28$	$62 < f_m \leq 64$	**0,29**	**0,23**	$74,4 < f_m \leq 76,8$	**0,39**	**0,30**
$1,28 < m \leq 1,32$	$64 < ff_m \leq 66$	**0,37**	**0,28**	$76,8 < f_m \leq 79.2$	**0,50**	**0,38**
$1,32 < m \leq 1,36$	$66 < f_m \leq 68$	**0,46**	**0,35**	$79,2 < f_m \leq 81,6$	**0,64**	**0,48**
$1,36 < m \leq 1,40$	$68 < f_m \leq 70$	**0,57**	**0,43**	$81,6 < f_m \leq 84,0$	**0,79**	**0,58**
$1,40 < m \leq 1,80$	$70 < f_m \leq 90$	**0,68**	**0,51**	$84,0 < f_m \leq 108,0$	**0,95**	**0,69**

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C.1.4.2 General levels

Levels given in Table 2 for the next higher even harmonic can be taken as guidance for each interharmonic frequency.

The levels relevant to class 2 are set in consideration of the presence of ripple control devices. Since ripple control receivers, lighting equipment and television receivers are not generally present in industrial areas, the compatibility levels for class 3 are expected at higher values.

NOTE 1 If such devices are present in the industrial area, they are not directly coupled to the circuit of class 3. For mitigation methods, see Clause C.2.

Where there is a risk of interference with mains signalling, ripple control, or other susceptible equipment, special care should be taken with regard to interharmonics. A class 2 environment should be preferred. For this class, the operational frequency of ripple control receivers is locally specified. The response level of these receivers can be as low as 0,3 % of the nominal supply voltage. A receiver can therefore be disturbed by an unintended interharmonic voltage, at its defined operational frequency, in excess of this value.

The interharmonic compatibility level at the operating frequency of the mains signalling or ripple control system is not defined. At the operating frequency, the emission level should be limited to 0,2 % of the nominal supply voltage, and the immunity of equipment should be defined according to the particular specifications of the corresponding transmitters and network conditions. See IEC 61000-2-2:2002, 4.4.

The use of a class 3 environment requires more investigation such as identification of the coupling path between the class 3 environment and the public supply network, or design of a decoupling system.

High values of interharmonics can be present at class 3 IPCs due especially to some kinds of converters. They can be as high as 2,5 % for frequencies below the 11th order, and up to 1 % for orders above 25. Due to their origin, these values are generally fluctuating and rapidly changing in both amplitude and frequency. For that reason, they can cause resonances on capacitor banks and passive filters.

NOTE 2 Everywhere they are used in industrial networks, power factor correction capacitors will be connected through series reactors, particularly those which are intended to be connected to IPCs of class 3.

C.2 Mitigation methods

C.2.1 General

It is generally a complex matter to decrease emissions of power converters. Where susceptible equipment is expected and cannot be avoided, a possible solution is to introduce an efficient decoupling between the circuits supplying the susceptible equipment and the circuits supplying the power converters by means of filters or even UPSs.

When the purpose of the conversion of power is to produce an adjustable fundamental frequency, a wide spectrum of interharmonic frequencies can be expected. The most complex aspect is due to the interharmonics which sweep the whole spectrum when the output of the converter is operated at a variable frequency.

Interharmonics of this kind are the result of the impossibility of obtaining a perfect decoupling between the input and the output of a converter. The components of the largest amplitude are generally at low or very low frequencies.

Another kind arises from the internal operation mode of the converter. The well-known example of pulse width modulation (PWM) operated converters shows an emission of interharmonics related to the switching frequency controlling the semiconductor devices. This switching frequency can be fixed or adjustable depending on the control technique. Interharmonics of this last kind are at higher frequencies than the previous one. They are generally easier to filter.

C.2.2 Decrease emission levels

The selection of indirect converters facilitates the simple filtering of interharmonics emitted by the power conversion process when dedicated to variable frequency production. Indeed, the simple filtering can be provided by increasing the internal filtering effectiveness of the natural structure of the converter. Such an increase of decoupling between output and input provides reduction of interharmonic current amplitude.

In case of large converters this will probably not be an economic solution, but it should be investigated as an alternative to external filtering. External filtering can use passive filtering or active filtering.

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Passive filtering requires particular attention to the width of the emission spectrum, particularly when the interharmonics sweep through the frequency spectrum. The risk of excitation of anti-resonance is so high that passive filters, if used, should be damped. Generally large power installations require careful and complete investigation to define the filtering system. Moreover, passive filters cannot be operated independently of each other or independently of reactive power compensation. Therefore, when passive filtering is used, the whole installation should be considered.

Active filtering can provide efficient solutions, particularly in the low or very low frequency range. Filtering is also effective for sub-harmonics or interharmonics. The main advantage of active filtering is that it is auto-adaptative to the frequency to be filtered. This property is intrinsic to their control, which is designed to first extract the harmonic content from a current which is to be compensated or from a voltage which is to be cleaned up. The second function of the control of the semiconductor devices is to operate the compensation or cleaning by means of an adapted PWM technique at the power stage. Therefore, unlike passive filters, which are tuned on particular orders, active filters can be considered as broad band filters. They provide attenuation of the harmonic (or interharmonic) emission from DC up to a few kiloHertz, leaving the fundamental frequency voltage or current unaffected.

However, converters operating with PWM introduce an interharmonic emission at frequencies associated with the switching frequency, which can be filtered if necessary.

C.2.3 Increase immunity

Product standards set immunity limits with reference to compatibility levels. However, when compatibility levels are still under consideration or when the relevant product standard is not available, a solution in case of susceptibility causing malfunction of an equipment, can often be found in appropriate filtering of the supply of the control part of the disturbed equipment. For equipment that has to be synchronized with the power supply system, the appropriate filtering can be limited to the synchronizing circuit by means of a band pass filter tuned at the fundamental frequency. This generally affects circuits of low level of power.

The most efficient solution remains appropriate segregation of the circuits according to their use. In an industrial network, this segregation should always be established between the industrial applications and the offices, and within the industrial applications between the different loads which should be classified appropriately. This kind of segregation facilitates the design of correct decoupling and filtering of the whole installation, with the objective of the best technical and economical compromise.

C.2.4 Protection of mains signaling

Identification of the frequency used by the ripple control system or mains signalling should be made available by the power supply authority.

Two aspects should be considered at the PCC of the installation:

– the maximum emission allowed for the whole installation in order not to disturb the signalling system;
– the minimum impedance, at the particular frequency of the signalling system, that is acceptable for operation of the transmission of the signalling system.

If a particular passive filtering or decoupling system is installed, anti-resonance should be avoided in case of sweeping interharmonics.

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Annex D
(informative)

Proving compatibility in the frequency range above 2 kHz in industrial MV networks

In order to ensure a long-term trouble-free operation of an industrial installation, the operator of a plant typically wants to make sure that compatibility requirements are met. In principle there are two possibilities to reach this goal, both of them having special challenges especially in the frequency range above 2 kHz:

1) Measurements: Measurements are the best means to prove compatibility in existing installations. However, typical measuring devices operate with an input voltage below 1 kV so that voltage transformers will be required for MV networks. Most voltage transformers (capacitive and inductive) used presently as standard equipment in MV networks are designed primarily for the transformation of fundamental frequency. Although many of them still provide reasonable results in the "classical" harmonic range up to 2 kHz, the measuring accuracy decreases with increasing frequency. Somewhere in the range between 5 kHz and 20 kHz most voltage transformers have a resonance point exaggerating measured voltage components at the secondary side of the VT. For higher frequencies, the transformation ratio between the primary and secondary side is undefined and varying, i.e. the measuring signal can over- or underestimate the primary voltage. In order to prove compatibility for voltage components above 2 kHz, voltage transformers with a known and tested frequency behaviour in the frequency under consideration should be used. Some manufacturers already promote new types of built-in voltage transformers for MV switchgear suitable to measure with a reasonable error also in the double-digit kHz range. Alternatively, a special measuring divider can be connected temporarily at MV level in order to take accurate measurements above 2 kHz.
2) Calculations: During the planning phase of an installation, calculations and simulations are the only possible means to prove compatibility for a future industrial plant. Well established and proven methods exist for this purpose for the "classical" harmonic range up to 2 kHz. For significantly higher frequencies, experiences with simulations are rather rare and this field is presently just developing. Several phenomena have to be taken into account which play a minor role in the lower harmonic range only:
   - Transformers typically have significant resonance points in the frequency range of around 10 kHz and above.
   - Frequency dependence of line impedances (inductance and resistance) becomes more and more important with increasing frequencies. (Line capacitances remain unchanged over the entire frequency range considered.)
   - Terminal stray capacitances of equipment connected (e.g. of motors and transformers) can have an impact on calculation results especially for higher frequencies.
   - Supply networks (often modeled as Thevenin impedances for harmonic calculations) typically have significant resonance points in the frequency range above 2 kHz (and in many cases already below this frequency). These resonances will have a significant impact on calculation results especially concerning the PCC with the public supply network.

   All these effects have to be considered for simulations in MV networks in order to obtain results which to a certain extent reflect the reality in the future plant. This means not only a significantly increased effort for these simulations but requires adequate input from equipment manufacturers as well as network operators.

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Annex E
(informative)

Examples of locations and installations covered by IEC 61000-2-4

E.1 General

The purpose of Annex E is to illustrate typical locations and installations relevant to the compatibility levels given in this document, and to provide guidance to the user of this document when selecting the appropriate environment class (see Clause 4).

Annex E provides only examples, and it is not intended to be exhaustive.

This document does not deal with installations for residential locations, directly supplied by the public mains and which are usually covered by IEC 61000-2-2.

A part of an installation supplied by the output of a power converter (e.g. loads supplied by an UPS) is not within the scope of this document.

The basic principle for this document is that installations covered by this document are for professional use and are separated from the public power distribution system by at least one transformer.

E.2 Mixed locations

Installations for residential locations and professional use can coexist in mixed locations. For example, a building can host separate and well identified areas for either residential locations or professional use, each one having its own dedicated power supply line, in which the industrial installation is supplied through a separation transformer.

NOTE In this document, shops, light industry, heavy industry (and similar) supplied through a separation transformer are covered by the term industrial.

E.3 Examples for industrial locations

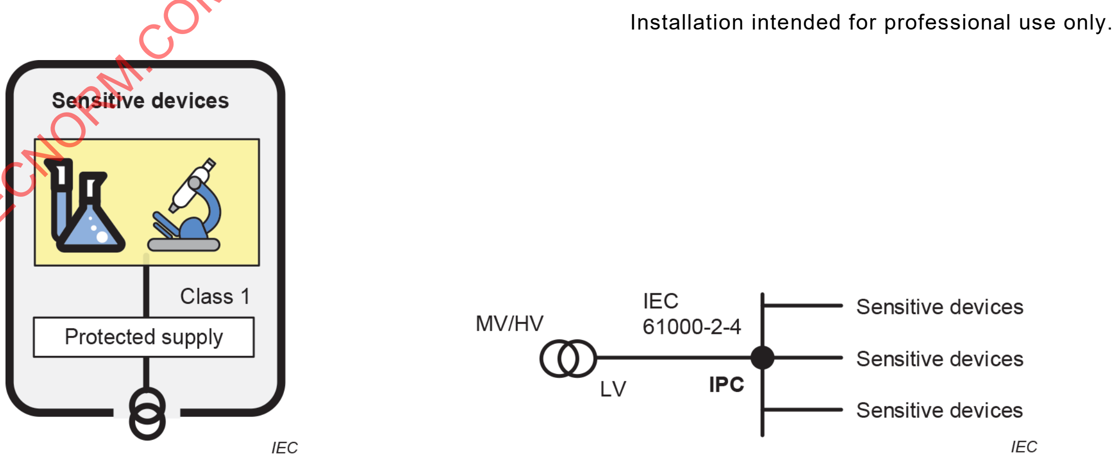

Figure E.1 – Example of class 1 environment

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This is a typical class 1 environment (Figure E.1).

One reference person (e.g. owner of the private building) is in charge of problems and maintenance.

Installation intended for professional use only.

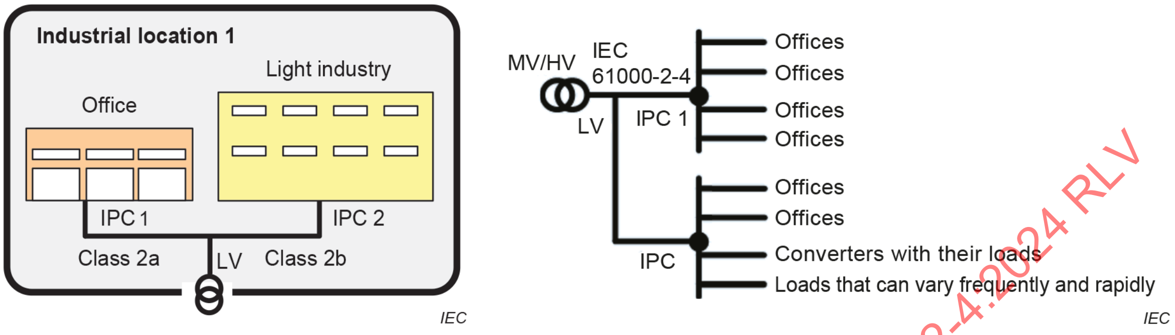

Figure E.2 – Example of class 2a and class 2b environments

These are typical class 2a and class 2b environments (Figure E.2).

One reference person (e.g. owner of the private building) is in charge of problems and maintenance.

In this example, IPC 1 characterises the compatibility level at the entrance of the office building and IPC characterises the compatibility level at the entrance of the light industry building.

NOTE 1 Concerning options for the supply of areas with different electromagnetic environment classes in the lower part of the figure; see Figure 2.

Installation intended for professional use only.

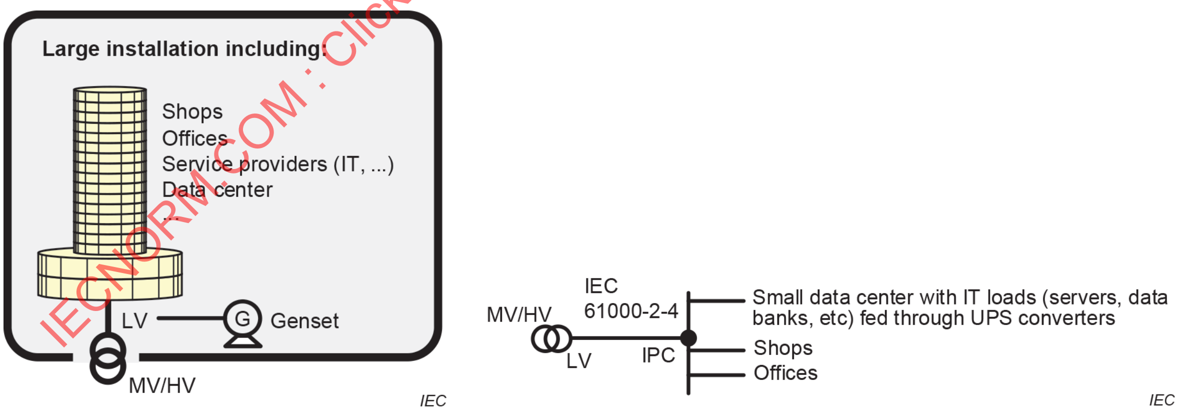

Figure E.3 – Example of an LV grid in a building supplied by a dedicated transformer

This type of area is supplied by a dedicated transformer (Figure E.3).

One reference person (e.g. owner of the private building) is in charge of problems and maintenance.

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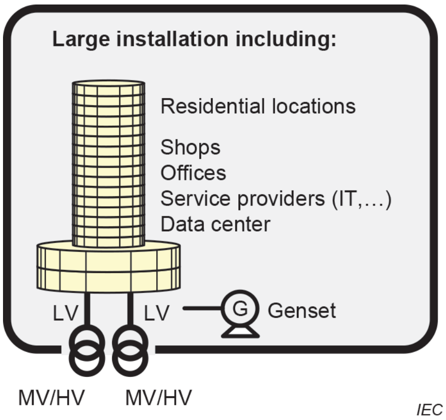
This environment might be classified either as class 2a or class 2b, with the IPC characterizing the compatibility level at the entrance of the building.

Mixed location



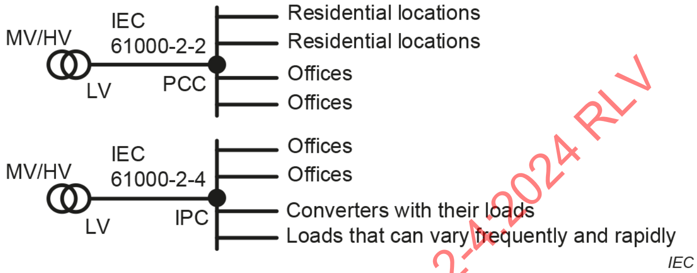


Figure E.4 – Example of an LV grid in a building including residential and industrial locations

In Figure E.4, the upper part of the building includes residential locations and thus is supplied by a public transformer. IEC 61000-2-2 applies at the PCC.

The other transformer supplies the part of the installation where only professional users are connected.

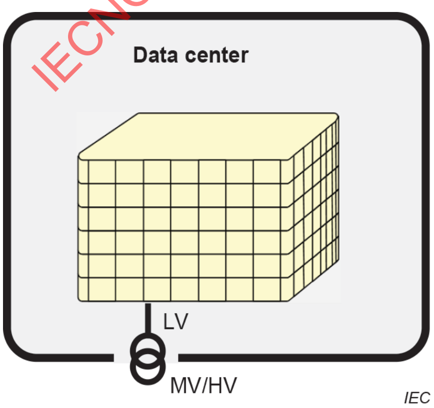
Compatibility levels at the primary side of the transformers are not specified in this document.

One reference person (e.g. owner of the private building) is in charge of problems and maintenance.

The lower part is an environment which might be classified as either class 2a or class 2b, with IPC 2 characterizing the compatibility level for the converters and loads that can vary frequently and rapidly.

NOTE 2 Concerning options for the supply of areas in the lower part of the figure see Figure 2.

Installation intended for professional use only.



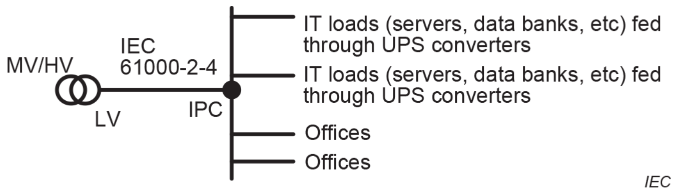


Figure E.5 – Example of an LV grid for a data center

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Compatibility levels for the primary side of the transformer (Figure E.5) are not specified in this document.

One reference person (e.g. owner of the private building) is in charge of problems and maintenance.

This environment is classified by the reference person either as class 2a or class 2b, with the IPC characterizing the compatibility level placed at the entrance of the building.

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Annex F
(informative)

Rationale for increased individual even and triplen compatibility levels and for splitting class 2 into class 2a, class 2b and class 2L

F.1 Rationale for increased individual even and triplen compatibility levels

F.1.1 Target

It was the target of this document to take into account the needs of modern power electronic equipment while maintaining the overall disturbance level of the networks within the scope. This has been achieved by increasing the individual even and triplen compatibility levels in Table 2 and by introducing a new quantity PWHD in Table 3.

F.1.2 The needs of modern power electronic equipment

Modern power electronic equipment, such as active infeed converters (AICs) according to IEC TS 62578, is an essential element of energy saving equipment and renewable energy generation. It operates as pulse width modulated (PWM) converter. The switching frequency of this equipment is typically in the range of a few kHz. The electromagnetic emissions of this technology consequently consist of spectral lines with frequencies of the switching frequency and its integer multiples.

In the frequency range below the switching frequency, this type of equipment produces only very low emissions. However, in order to prevent the emissions at switching frequency and above from flowing to the supply network, a low pass filter has to be inserted between the power converter and the supply network. This filter has to have a resonance frequency below the switching frequency of the converter. This resonance frequency will typically be in the range of 1 kHz to 2 kHz with a width of about ±400 Hz. In this frequency range, existing pre-distortion in the network and very low converter emissions will be amplified. The amplification factor can only be limited by filter damping. More excessive damping will cause increased losses of the filter.

The resulting emission spectra of these AICs will consequently consist of emissions at a low level in the range of the resonance frequency and of spectral lines at the switching frequency and its integer multiples. A typical spectrum is shown in Figure F.1 with an AIC operating at a switching frequency of 4 kHz and a filter resonance frequency of about 1,2 kHz.

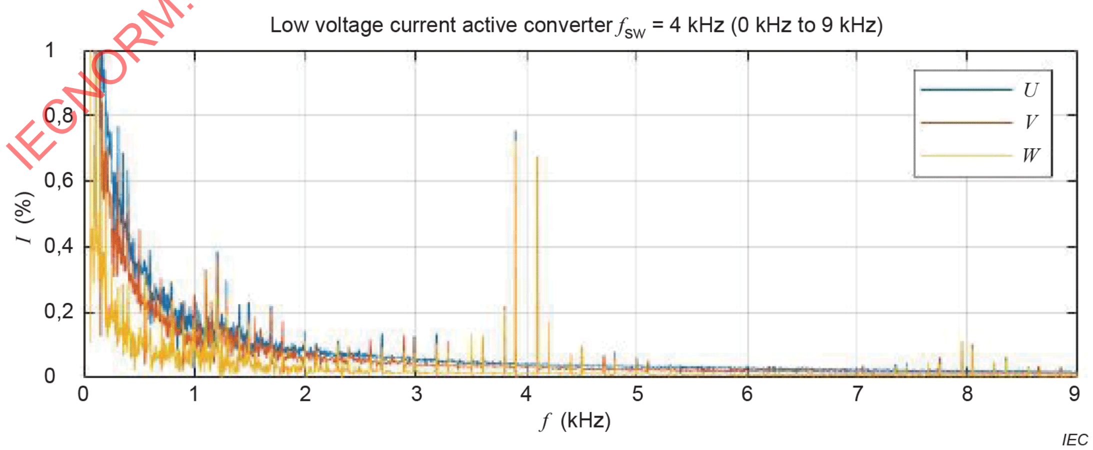

Figure F.1 – Emission spectrum of an active infeed converter

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All emissions of the AIC are independent of the supply frequency (50/60 Hz).

The compatibility levels defined in IEC 61000-2-4:2002 (second edition) made a systematic difference between characteristic (odd non triplen) frequencies on the one hand and even and triplen frequencies on the other hand. The compatibility levels for even and triplen harmonics are significantly lower. Calculating permissible emission limits for even and triplen harmonic frequencies results in extremely low values, which cannot be met by AIC equipment in the range of the resonance frequency of its line filter and which are at or below the accuracy specification of measurement equipment. Such overly stringent limits could reduce the acceptance level for energy saving equipment and jeopardize global targets for energy saving. This problem is particularly severe in the frequency range between H13 and H40, which is the range of the filter resonance described in the second paragraph of this rationale.

On the other hand, there are no reports on disturbance cases of equipment due to voltage distortions at even or triplen harmonic frequencies, particularly in the frequency range between H13 and H40. Consequently, the compatibility levels for even and triplen harmonics have been increased in this document to the values in Table 2.

F.1.3 Maintaining the overall disturbance level

As described above, the increase of emissions only occurs in a limited band around the resonance of the line filter of an AIC. It is consequently expected that the overall disturbance level in industrial networks remains unchanged. In order to ensure this, Table 3 does not only keep the THD value unchanged, but it additionally introduces a new quantity, PWHD. The values for PWHD are calculated by inserting the compatibility levels of IEC 61000-2-4:2002 (second edition) into Formula (1), meaning that also the PWHD remains unchanged. With THD and PWHD unchanged compared to IEC 61000-2-4:2002 (second edition), the overall disturbance level is maintained.

F.2 Rationale for splitting class 2 into class 2a, class 2b and class 2L

F.2.1 Target

It was the aim for class 2 of this document to:

a) provide compatibility levels identical to the public network described in IEC 61000-2-2;
b) allow power electronic converters which operate in class 2 networks according to IEC 61000-2-4:2002 (second edition) to still do so in class 2 networks according to this document;
c) prevent special safety-related networks (e.g. in nuclear power plants) from a safety re-certification.

As it was not possible to achieve all these targets with one set of compatibility levels, the class 2 from IEC 61000-2-4:2002 (second edition) was split into class 2a, class 2b and class 2L.

F.2.2 Class 2a

The compatibility levels of class 2a are identical to the compatibility levels in IEC 61000-2-2 when considering the increase of even and triplen compatibility levels according to Clause F.1.

F.2.3 Class 2b

In class 2 networks of IEC 61000-2-4:2002 (second edition), certain power electronic converters can be operated. They can face the issues described in F.1.2, but without considering how resonance effects of the compatibility levels, which are defined only up to the 40th harmonic in IEC 61000-2-4:2002 (second edition), are met.

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However, in the frequency range above the 40th harmonic, these power electronic converters emit at a higher level (see Figure F.1), and the voltage distortion of the network will exceed the levels defined in IEC 61000-2-2. Consequently, higher compatibility levels than in class 2a are required for such networks in the frequency range above the 40th harmonic. As these networks are still intended to be classified as networks of class 2, this requires a split of the class 2 in IEC 61000-2-4:2002 (second edition). This has been achieved by introducing the new class 2b, which has the same compatibility levels as class 2a up to the 40th harmonic and higher compatibility levels above the 40th harmonic.

F.2.4 Class 2L

Even though it was agreed that the increased compatibility levels for even and triplen individual compatibility levels described in Clause F.1 do not lead to an increased disturbance level (see F.1.3), it is important for some sensitive networks, for example in safety related applications like nuclear power plants, not to increase any compatibility level in order to prevent a re-certification of the installation. However, the introduction of additional compatibility levels above the 40th harmonic is welcome for such networks. In order to accommodate these needs, the class 2L was introduced, which contains the compatibility levels from IEC 61000-2-4:2002 (second edition) class 2 up to the 40th harmonic and the compatibility levels from IEC 61000-2-2 above the 40th harmonic.

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IEC TR 61000-3-6:2008, *Electromagnetic compatibility (EMC) – Part 3-6: Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems*

IEC TR 61000-3-7:2008, *Electromagnetic compatibility (EMC) – Part 3-7: Limits – Assessment of emission limits for fluctuating loads in MV and HV power systems*

IEC 61000-4-15:2010, *Electromagnetic compatibility (EMC) – Part 4-15: Testing and measurement techniques – Flickermeter – Functional and design specifications*

IEC 61511-1:2016, *Functional safety – Safety instrumented systems for the process industry sector – Part 1: framework, definitions, system, hardware and application programming requirements*

IEC TS 62578, *Power electronics systems and equipment – Operation conditions and characteristics of active infeed converter (AIC) applications including design recommendations for their emission values below 150 kHz*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM [2]:1995)*

IEEE Std 1346-1998, *IEEE Recommended Practice for Evaluating Electric Power System Compatibility with Electronic Process Equipment*

2 GUM: Guides to the expression of uncertainty in measurement.

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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COMPATIBILITÉ ÉLECTROMAGNÉTIQUE (CEM) –

Partie 2-4: Environnement – Niveaux de compatibilité dans les réseaux de distribution d'électricité sur des sites industriels pour les perturbations conduites à basse fréquence

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L'IEC 61000-2-4 a été établie par le sous-comité 77A: CEM – Phénomènes basse fréquence, du comité d'études 77 de l'IEC: Compatibilité électromagnétique. Il s'agit d'une Norme internationale.

Cette troisième édition annule et remplace la deuxième édition parue en 2002. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) ajout de nouvelles classes 2a, 2b et 2L (anciennement la classe 2);
b) modification des niveaux de compatibilité pour la classe 3;
c) ajout de niveaux de compatibilité dans la plage de fréquences de 2 kHz à 150 kHz;
d) ajout de niveaux de compatibilité qui utilisent une nouvelle grandeur: la distorsion harmonique partielle pondérée (PWHD).

Le texte de cette Norme internationale est issu des documents suivants:

Projet	Rapport de vote
77A/1215/FDIS	77A/1221/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à son approbation.

La version française de la norme n'a pas été soumise au vote.

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INTRODUCTION

L'IEC 61000 est publiée en plusieurs parties selon la structure suivante:

Partie 1: Généralités

Considérations générales (introduction, principes fondamentaux)

Définitions, terminologie

Partie 2: Environnement

Description de l'environnement

Classification de l'environnement

Niveaux de compatibilité

Partie 3: Limites

Limites d'émission

Limites d'immunité (dans la mesure où elles ne relèvent pas de la responsabilité des comités de produits)

Partie 4: Techniques d'essai et de mesure

Techniques de mesure

Techniques d'essai

Partie 5: Guides d'installation et d'atténuation

Lignes directrices d'installation

Méthodes et dispositifs d'atténuation

Partie 6: Normes génériques

Partie 9: Divers

Chaque partie est à son tour subdivisée en plusieurs parties, publiées soit comme des Normes internationales soit comme des Spécifications techniques ou des Rapports techniques, dont certaines ont déjà été publiées sous forme de sections. D'autres seront publiées avec le numéro de partie, suivi d'un tiret et complété d'un second numéro qui identifie la subdivision (l'IEC 61000-3-11, par exemple).

L'IEC 61000-2-1 et l'IEC 61000-2-12 fournissent des informations détaillées sur les différents types de perturbations que l'on peut s'attendre à rencontrer sur les réseaux publics d'alimentation électrique.

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COMPATIBILITÉ ÉLECTROMAGNÉTIQUE (CEM) –

Partie 2-4: Environnement – Niveaux de compatibilité dans les réseaux de distribution d'électricité sur des sites industriels pour les perturbations conduites à basse fréquence

1 Domaine d'application

La présente partie de l'IEC 61000 traite des perturbations conduites dans la plage de fréquences de 0 kHz à 150 kHz. Elle fournit les niveaux de compatibilité en mode différentiel (L-L et L-N) pour les sites industriels, avec une tension nominale jusqu'à 35 kV et une fréquence nominale de 50 Hz ou 60 Hz.

NOTE 1 Les sites industriels sont définis au 3.1.8.

Les réseaux de distribution d'électricité sur les navires, les aéronefs, les plateformes en mer et les réseaux ferroviaires sont exclus.

NOTE 2 Voir aussi l'Annexe E. Les niveaux de compatibilité spécifiés dans le présent document s'appliquent au point de couplage interne à l'installation (IPC). Le niveau des perturbations à basse fréquence aux bornes des équipements alimentés par l'IPC est par hypothèse généralement similaire au niveau de perturbation à l'emplacement de l'IPC. Toutefois, cela n'est pas le cas dans certaines situations, particulièrement avec un départ destiné à l'alimentation d'une charge spécifique par une ligne longue ou lorsqu'une perturbation est générée ou amplifiée dans l'installation dont les équipements font partie.

Les niveaux de compatibilité sont spécifiés pour les différents types de perturbations électromagnétiques à basse fréquence qui sont attendues en tout point de couplage interne à l'installation (IPC) dans des sites industriels, afin de fournir des recommandations pour définir:

a) les limites relatives aux émissions perturbatrices sur les réseaux de distribution d'électricité industriels (y compris les niveaux de planification définis au 3.1.5);

NOTE 3 Les conditions présentes dans les environnements électromagnétiques des réseaux industriels peuvent être très variées. Ces conditions sont représentées dans le présent document par les trois classes décrites à l'Article 4. Néanmoins, il est de la responsabilité de l'exploitant d'un tel réseau de prendre en compte les conditions électromagnétiques et économiques particulières, notamment les caractéristiques des équipements, pour établir les limites susmentionnées.

b) les niveaux d'immunité des équipements présents dans ces systèmes.

Les phénomènes perturbateurs suivants sont pris en compte:

– les écarts de tension;
– les creux de tension et les coupures brèves;
– les déséquilibres de tension;
– les variations de la fréquence du réseau d'alimentation;
– les harmoniques jusqu'au rang 40 inclus;
– les interharmoniques jusqu'au rang harmonique 40;
– les composantes de tension au-dessus du rang harmonique 40 jusqu'à 150 kHz;
– la composante continue;
– les surtensions transitoires.

Les niveaux de compatibilité sont donnés pour différentes classes d'environnement, qui sont déterminées par les caractéristiques du réseau d'alimentation et des charges associées.

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NOTE 4 Les niveaux de compatibilité au point de couplage commun (PCC) sur les réseaux publics sont spécifiés dans l'IEC 61000-2-2 pour les réseaux basse tension et dans l'IEC 61000-2-12 pour les réseaux moyenne tension. L'IEC TR 61000-3-6 et l'IEC TR 61000-3-7 décrivent l'approche des exploitants de réseaux de distribution d'électricité en ce qui concerne la limitation des émissions des installations et des charges importantes.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 61000-2-2:2002, *Compatibilité électromagnétique (CEM) – Partie 2-2: Environnement – Niveaux de compatibilité pour les perturbations conduites à basse fréquence et la transmission des signaux sur les réseaux publics d'alimentation basse tension*
IEC 61000-2-2:2002/AMD1:2017
IEC 61000-2-2:2002/AMD2:2018

IEC 61000-2-12, *Compatibilité électromagnétique (CEM) – Partie 2-12: Environnement – Niveaux de compatibilité pour les perturbations conduites à basse fréquence et la transmission des signaux sur les réseaux publics d'alimentation moyenne tension*

IEC 61000-4-7, *Compatibilité électromagnétique (CEM) – Partie 4-7: Techniques d'essai et de mesure – Guide général relatif aux mesures d'harmoniques et d'interharmoniques, ainsi qu'à l'appareillage de mesure, applicable aux réseaux d'alimentation et aux appareils qui y sont raccordés*

CISPR 16-1-1, *Spécification des méthodes et des appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques – Partie 1-1: Appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques – Appareils de mesure*

CISPR 16-2-1, *Spécifications des méthodes et des appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques – Partie 2-1: Méthodes de mesure des perturbations et de l'immunité – Mesures des perturbations conduites*

3 Termes, définitions et abréviations

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse https://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse https://www.iso.org/obp

3.1 Définitions générales

3.1.1
perturbation électromagnétique
phénomène électromagnétique susceptible de dégrader le fonctionnement d'un dispositif, d'un équipement ou d'un système

[SOURCE: IEC 60050-161:2018, 161-01-05, modifié – Dans la définition, les mots ", ou d'affecter défavorablement la matière vivante ou inerte" ont été supprimés. La Note 1, la Note 2 et la Note 3 ont été supprimées.]

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3.1.2
niveau de perturbation
valeur ou amplitude d'une perturbation électromagnétique, mesurée et évaluée dans des conditions spécifiées

3.1.3
compatibilité électromagnétique
CEM
aptitude d'un équipement ou d'un système à fonctionner dans son environnement électromagnétique de façon satisfaisante et sans produire lui-même des perturbations électromagnétiques intolérables pour tout ce qui se trouve dans cet environnement

Note 1 à l'article: La compatibilité électromagnétique est une condition de l'environnement électromagnétique telle que, pour chaque phénomène, le niveau d'émissions perturbatrices est suffisamment bas et les niveaux d'immunité sont suffisamment élevés pour que tous les dispositifs, appareils et systèmes fonctionnent de la manière prévue.

Note 2 à l'article: La compatibilité électromagnétique n'est assurée que si les niveaux d'émission et d'immunité sont maîtrisés de telle sorte que les niveaux d'immunité des dispositifs, appareils et systèmes en tout point du réseau ne sont pas dépassés par le niveau de perturbation observé à cet emplacement, qui résulte des émissions cumulées de l'ensemble des sources et d'autres facteurs, comme l'impédance des circuits. Par convention, la compatibilité électromagnétique est considérée comme établie si la probabilité d'écart par rapport aux performances attendues ou à l'effet indésirable est suffisamment basse. Voir l'IEC 61000-2-1:1990, Article 4.

Note 3 à l'article: Lorsque le contexte l'exige, la compatibilité électromagnétique est présumée couvrir une seule perturbation ou une classe de perturbations donnée.

Note 4 à l'article: La compatibilité électromagnétique est un terme également utilisé pour décrire le champ d'études relatif aux effets électromagnétiques indésirables subis par les dispositifs, appareils ou systèmes sous l'effet d'autres dispositifs, appareils ou systèmes, ou du fait de phénomènes électromagnétiques.

[SOURCE: IEC 60050-161:2018, 161-01-07, modifié – La Note 1 et la Note 4 ont été ajoutées.]

3.1.4
niveau de compatibilité (électromagnétique)
niveau de perturbation électromagnétique spécifié utilisé comme niveau de référence dans un environnement spécifié pour la coordination de l'établissement des limites d'émission et d'immunité

Note 1 à l'article: Par convention, le niveau de compatibilité est choisi de telle sorte qu'il n'ait qu'une faible probabilité d'être dépassé par le niveau réel de perturbation.

[SOURCE: IEC 60050-161:1990, 161-03-10, modifié – La dernière phrase de la Note 1 a été supprimée, car elle est moins pertinente pour les sites industriels que pour les sites publics.]

3.1.5
niveau de planification
niveau affecté à une perturbation donnée dans un environnement donné, adopté comme valeur de référence pour définir les limites d'émission applicables aux charges importantes et aux installations, dans le but de coordonner ces limites avec toutes les autres limites adoptées pour les appareils destinés à être raccordés au réseau d'alimentation électrique

Note 1 à l'article: Le niveau de planification est spécifique au site. Il est adopté par les responsables de la planification et de l'exploitation du réseau d'alimentation électrique à l'endroit considéré. (D'autres explications sont fournies dans l'IEC 61000-2-2:2002, Annexe A et l'IEC 61000-1-2.)

3.1.6
réseau de distribution d'électricité industriel et privé
réseau de distribution qui est séparé, par au moins un transformateur de séparation, du réseau public d'alimentation électrique auquel sont raccordées d'autres installations clients

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3.1.7
point de couplage commun
PCC
point d'un réseau d'alimentation électrique public, le plus proche électriquement d'une charge particulière, auquel d'autres charges sont ou peuvent être connectées

Note 1 à l'article: Le PCC est généralement le point pour lequel doit être étudiée la compatibilité électromagnétique sur les réseaux publics.

[SOURCE: IEC 60050-161:1990, 161-07-15, modifié – Les deux notes ont été supprimées. Le contenu de la Note 2 a été intégré à la définition et une nouvelle note a été ajoutée.]

3.1.8
site industriel
lieu caractérisé par une installation composée d'un réseau d'alimentation séparé, alimenté par un transformateur haute ou moyenne tension et dédié à l'alimentation de cette installation

Note 1 à l'article: Les sites industriels peuvent habituellement être décrits par l'existence d'une installation pour laquelle une ou plusieurs des caractéristiques suivantes s'appliquent:

- quantité importante de puissance électrique produite, transmise et/ou consommée;
- commutation fréquente de charges importantes inductives ou capacitives;
- courants élevés et champs magnétiques associés;
- présence d'appareils industriels, scientifiques et médicaux (ISM) de tensions et courants élevés (par exemple, machine à souder).

L'environnement électromagnétique sur un site industriel est principalement produit par un matériel et l'installation présente sur le site. Il y a des catégories d'emplacements industriels dans lesquels apparaissent certains phénomènes électromagnétiques à un degré plus sévère que dans d'autres installations.

Les exemples de sites comprennent les usines de la métallurgie, de l'industrie papetière, de produits chimiques, de construction automobile, les bâtiments agricoles, les zones d'aéroports à tension élevée.

Note 2 à l'article: La connexion entre le site et l'environnement électromagnétique est indiquée en 3.1.8.

[SOURCE: IEC 61000-6-4:2018, 3.1.12, modifié – Dans la définition, les mots "une installation composée d'un" ont été ajoutés. La référence du terme indiquée dans la Note 2 a été mise à jour.]

3.1.9
environnement électromagnétique
ensemble des phénomènes électromagnétiques existant à un endroit donné

Note 1 à l'article: L'environnement électromagnétique dépend en général du temps, et sa description peut être mieux définie en adoptant une approche statistique.

Note 2 à l'article: Il est très important de ne pas confondre le concept d'environnement électromagnétique avec le site environnant.

[SOURCE: IEC 61000-6-4:2018, 3.1.13]

3.1.10
point de couplage interne à l'installation
IPC
point à l'intérieur d'un réseau public de distribution d'électricité, le plus proche électriquement d'une charge particulière, auquel les charges d'autres branches sont ou peuvent être raccordées

Note 1 à l'article: L'abréviation "IPC" est dérivée du terme anglais développé correspondant "in-plant point of coupling".

Note 2 à l'article: L'IPC est généralement le point pour lequel la compatibilité électromagnétique sur les réseaux industriels doit être étudiée.

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3.2 Définitions relatives aux phénomènes

NOTE 1 Les définitions ci-dessous concernent les harmoniques; elles sont fondées sur l'analyse des tensions ou courants du réseau par la méthode de la transformée de Fourier discrète (TFD). La TFD est l'application pratique de la transformée de Fourier définie dans l'IEV 101-13-09. Voir l'Annexe A.

NOTE 2 La transformée de Fourier appliquée à une fonction du temps, qu'elle soit périodique ou non, est une fonction du domaine de fréquence et est appelée spectre de fréquences de la fonction du temps, ou plus simplement spectre. Si la fonction du temps est périodique, le spectre est constitué de raies (ou composantes) distinctes. Si la fonction du temps n'est pas périodique, le spectre est une fonction continue, qui présente des composantes à toutes les fréquences.

NOTE 3 D'autres définitions relatives aux harmoniques ou interharmoniques sont fournies dans l'IEC 60050 (toutes les parties) et dans d'autres normes. Certaines de ces définitions, même si elles ne sont pas utilisées dans le présent document, sont citées à l'Annexe A.

3.2.1
fréquence fondamentale
fréquence du spectre, obtenue à partir d'une transformée de Fourier sur une fonction du temps, par rapport à laquelle sont référencées toutes les composantes de ce spectre

Note 1 à l'article: Dans le cas d'une fonction périodique, la fréquence fondamentale est généralement égale à la fréquence de la fonction elle-même (voir l'Article A.1). Pour les besoins du présent document, la fréquence fondamentale est la même que la fréquence du réseau d'alimentation.

3.2.2
composante fondamentale
fondamental
composante spectrale d'une fonction du temps périodique dont la fréquence est égale à la fréquence fondamentale

3.2.3
fréquence harmonique
fréquence qui est un multiple entier de la fréquence fondamentale

3.2.4
rang harmonique
rapport de la fréquence harmonique à la fréquence fondamentale

Note 1 à l'article: La notation recommandée pour le rang harmonique est "h".

3.2.5
composante harmonique
composante spectrale d'une fonction du temps périodique dont la fréquence est une fréquence harmonique

Note 1 à l'article: Les composantes harmoniques sont souvent appelées harmoniques.

Note 2 à l'article: Pour les conditions de mesure, voir l'IEC 61000-4-7.

3.2.6
fréquence interharmonique
toute fréquence comprise entre deux fréquences harmoniques consécutives

3.2.7
rang interharmonique
rapport d'une fréquence interharmonique à la fréquence fondamentale

Note 1 à l'article: Ce rapport n'est pas un entier et peut être noté "m".

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3.2.8
composante interharmonique
composante spectrale ayant une fréquence interharmonique

Note 1 à l'article: Par souci de concision, cette composante peut être simplement désignée comme un interharmonique.

3.2.9
distorsion harmonique totale
THD
rapport de la valeur efficace de la somme de toutes les composantes harmoniques à la valeur efficace de la composante fondamentale

$$\mathrm{THD} = \sqrt{\sum_{h=2}^{40} \left(\frac{Q_\mathrm{h}}{Q_1} \right)^2} \tag{1}$$

où:

Q représente soit le courant soit la tension

Q_1 est la valeur efficace de la composante fondamentale

h est le rang harmonique

Q_h est la valeur efficace de la composante harmonique de rang h

Note 1 à l'article: L'abréviation "THD" est dérivée du terme anglais développé correspondant "total harmonic distortion".

3.2.10
distorsion harmonique partielle pondérée
PWHD
rapport de la somme pondérée des carrés des composantes harmoniques des rangs 14 à 40, à la valeur efficace de la composante nominale n

$$\mathrm{PWHD} = \sqrt{\sum_{h=14}^{40} h \cdot \left(\frac{Q_\mathrm{h}}{Q_\mathrm{n}} \right)^2} \tag{2}$$

où:

Q_n est la valeur nominale de la grandeur (tension, par exemple)

h est le rang harmonique

Q_h est la valeur efficace de la composante harmonique de rang h de la grandeur

Note 1 à l'article: L'abréviation "PWHD" est dérivée du terme anglais développé correspondant "partial weighted harmonic distortion".

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3.2.11
déséquilibre de tension
dans un réseau d'énergie électrique polyphasé, état dans lequel les valeurs efficaces de la composante fondamentale des tensions entre phases ou dans lequel la différence de phase entre les tensions entre phases consécutives ne sont pas toutes égales

Note 1 à l'article: En général, pour les réseaux triphasés, le degré de déséquilibre de tension est quantifié par le rapport entre les composantes inverses et les composantes directes. Toutefois, dans certaines circonstances, il est plus approprié d'utiliser le rapport entre les composantes homopolaires et les composantes directes.

Note 2 à l'article: Plusieurs formules d'approximation fournissent des résultats avec une exactitude raisonnable concernant les niveaux de déséquilibre normalement rencontrés (rapport entre les composantes inverses et les composantes directes), par exemple:

$$\text{déséquilibre de tension} = \sqrt{6 \times \frac{U_{12}^2 + U_{23}^2 + U_{31}^2}{(U_{12} + U_{23} + U_{31})^2} - 2} \qquad (3)$$

où

U_{12}, U_{23} et U_{31} représentent les trois tensions entre phases à la fréquence fondamentale

[SOURCE: IEC 60050-161:1990, 161-08-09, modifié – La définition a été simplifiée, et la référence à la "composante homopolaire" a été déplacée du corps de la définition dans la Note 1.]

3.2.12
écart de tension
augmentation ou diminution de la tension d'alimentation efficace, à l'exclusion des transitoires sans effets résiduels

Note 1 à l'article: Les variations de tension et les fluctuations de tension sont les principaux types d'écarts de tension. Certains écarts de tension sont rapides en raison de l'adaptation de la tension d'alimentation aux différentes conditions de charge (changements des prises de tension des transformateurs, effet permanent de la commutation des batteries de condensateurs, par exemple). Les fluctuations de tension, qui peuvent engendrer du papillotement (flicker), sont un phénomène différent (série d'écarts de tension ou écarts de tension cycliques, voir l'IEC 61000-2-2:2002 et l'IEC 61000-2-2:2002/AMD2:2019, 4.2).

3.2.13
creux de tension
réduction temporaire de l'amplitude de la tension en un point du système électrique au-dessous d'un seuil

Note 1 à l'article: Le creux de tension est généralement associé à l'apparition et à l'élimination d'un court-circuit ou de toute augmentation significative du courant sur le réseau ou dans les installations qui sont raccordées à ce dernier.

Note 2 à l'article: Généralement, la tension de seuil d'un creux correspond à la valeur minimale de la tolérance sur la tension nominale.

3.2.14
surtension transitoire
surtension d'une durée ne dépassant pas quelques millisecondes, oscillatoire ou non, généralement fortement amortie

Note 1 à l'article: Les surtensions transitoires peuvent être immédiatement suivies par des surtensions temporaires. Dans un tel cas, les deux surtensions sont considérées comme des évènements distincts.

[SOURCE: IEC 60050-614:2016, 614-03-14, modifié – La Note 2 a été supprimée.]

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3.2.15
équipement industriel d'électronique de puissance
équipement qui n'est pas destiné à être raccordé à un site résidentiel et dont les émissions et l'immunité sont supérieures ou égales à celles applicables aux équipements destinés à être utilisés dans un site résidentiel

3.3 Abréviations

AIC (Active Infeed Converter)	convertisseur à alimentation active
TFD	transformée de Fourier discrète
IPC (In-plant Point of Coupling)	point de couplage interne à l'installation
PCC	point de couplage commun
CPL	communication par courants porteurs en ligne
PWHD (Partial Weighted Harmonic Distortion)	distorsion harmonique partielle pondérée
MLI	modulation de largeur d'impulsion
THD (Total Harmonic Distortion)	distorsion harmonique totale
ASI	alimentation sans interruption

4 Classes d'environnement électromagnétique

Plusieurs classes d'environnement électromagnétique peuvent être définies pour les réseaux de distribution d'électricité relevant du domaine d'application du présent document. Toutefois, pour des raisons de simplicité, les classes d'environnement suivantes sont spécifiées:

Classe 1 Cette classe concerne les réseaux d'alimentation électrique protégés, où des niveaux de compatibilité harmonique inférieurs à ceux applicables aux réseaux publics sont nécessaires. Elle couvre l'utilisation d'appareils qui sont très sensibles aux perturbations de la tension d'alimentation (appareils de mesure électriques de laboratoires, dispositifs d'automatisation et de protection spéciaux, ordinateurs spéciaux, par exemple).

Classe 2L Cette classe est un reliquat de l'IEC 61000-2-4:2002 (deuxième édition) qui couvre les niveaux de compatibilité harmonique jusqu'au rang harmonique 40. Les IPC de classes 2L, 2a et 2b correspondent aux IPC de la classe 2 d'origine. Par conséquent, le niveau de perturbation caractéristique dans la plage de fréquences jusqu'au rang harmonique 40 dans la classe 2L est présumé être similaire à celui des classes 2a et 2b. Pour la plage de fréquences au-dessus du rang harmonique 40 jusqu'à 150 kHz, la classe 2L est considérée comme étant identique à la classe 2a. La classe 2L est destinée à certaines installations existantes, mais n'est pas recommandée pour les nouveaux types d'installations.

NOTE 1 Pour certaines installations de sécurité existantes, par exemple dans les centrales nucléaires, une nouvelle certification de sécurité serait exigée si la classe 2L n'était pas couverte dans le présent document.

Classe 2a Cette classe concerne les IPC (IPC 1) situés dans des sites industriels, où aucun équipement industriel d'électronique de puissance n'est destiné à être raccordé (bureaux, par exemple).

Classe 2b Cette classe concerne les IPC (IPC 2) situés dans des sites industriels, où des équipements industriels d'électronique de puissance sont destinés à être raccordés sans transformateur de séparation à des systèmes de classe 2a, mais dans lesquels des équipements non industriels normalisés sont également destinés à être raccordés (industrie légère, commerce, par exemple).

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Classe 3 Cette classe concerne les IPC (IPC 3) situés dans des sites industriels qui sont séparés par un transformateur de séparation des zones dans lesquelles des équipements non industriels sont destinés à être raccordés. Il convient d'envisager cette classe lorsque l'une des conditions suivantes est remplie:

- la majeure partie de la ou des charges est alimentée par des convertisseurs (ou systèmes de convertisseurs);
- des machines à souder sont présentes;
- des moteurs de forte puissance sont fréquemment démarrés;
- il existe d'autres charges dont la consommation d'énergie peut varier rapidement.

Il n'est *a priori* pas possible de déterminer la classe appropriée pour les nouvelles installations et les extensions d'installations existantes; il convient de choisir cette classe en fonction du type d'équipement et du procédé à l'étude.

La Figure 1 fournit des exemples d'application des classes d'environnement électromagnétique susmentionnées:

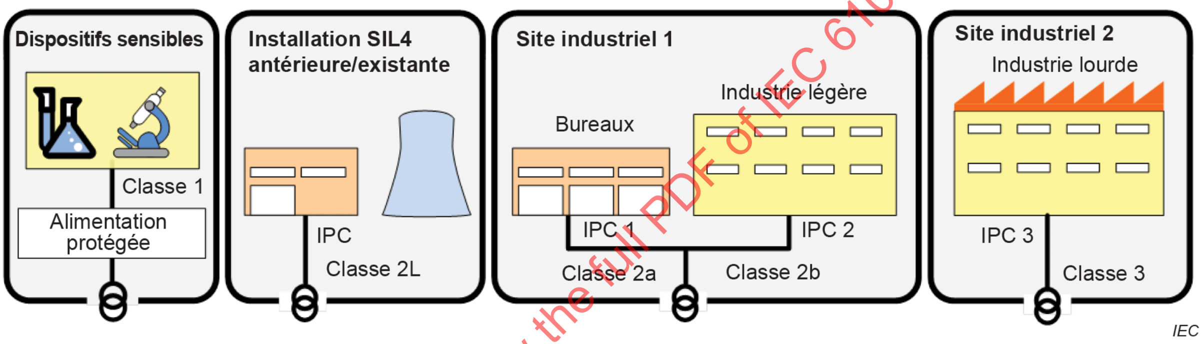

Figure 1 – Exemples d'application des différentes classes d'environnement électromagnétique dans différents sites industriels

NOTE 2 Les environnements de classe 1 comportent normalement des matériels qui exigent une protection par des appareils tels que des alimentations sans interruption (ASI), des filtres ou des parasurtenseurs.

NOTE 3 Dans certains cas, des équipements extrêmement sensibles peuvent exiger des niveaux de compatibilité inférieurs à ceux applicables aux environnements de classe 1. Les niveaux de compatibilité doivent alors faire l'objet d'un accord au cas par cas (environnement maîtrisé).

NOTE 4 L'alimentation de charges fortement perturbatrices, comme les fours à arc ou les convertisseurs de forte puissance, qui sont généralement alimentés par un jeu de barres séparé, présente fréquemment des niveaux de perturbation supérieurs à ceux de la classe 3 (environnement sévère). Dans ces installations spéciales où la plage de puissances totale est généralement > 200 kW, des niveaux de compatibilité plus élevés sont fixés par accord en fonction des caractéristiques des autres charges.

NOTE 5 Étant donné la diversité des environnements industriels, les différents phénomènes au sein d'un réseau donné peuvent être représentés par différentes classes.

NOTE 6 Dans la troisième image de la Figure 1, des réseaux de classe 2a (bureaux) et de classe 2b (sites de fabrication légère) sont raccordés en direct. Cette pratique d'ingénierie est couramment appliquée dans de nombreuses installations. Dans ces installations, les équipements de bureau normaux sont en général suffisamment résistants pour supporter le niveau de perturbation généré par les équipements d'électronique de puissance présents sur le site industriel léger. Dans l'IEC 61000-2-4:2002 (deuxième édition), ce type d'installation n'a pas soulevé de questions, car les niveaux de compatibilité ont été analysés jusqu'au rang harmonique 40 seulement et les différents niveaux de distorsion au-dessus du rang harmonique 40 n'ont pas été pris en compte.

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La Figure 2 donne un exemple de mesure d'atténuation possible:

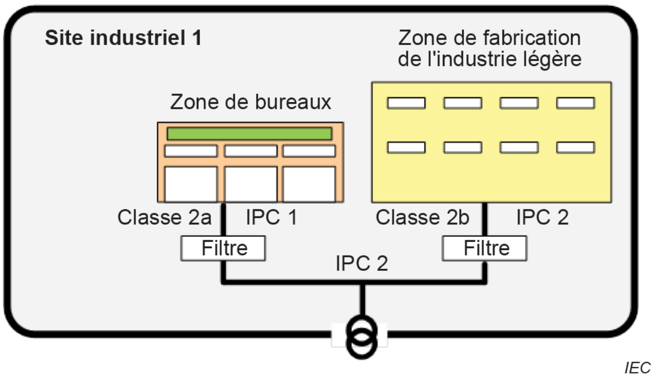

Figure 2 – Exemple d'installation où les différentes parties sont séparées par des filtres et où différentes classes d'environnement électromagnétique sont appliquées

Sur la Figure 2, une zone de bureaux est séparée d'une zone de fabrication de l'industrie légère par des filtres. Au niveau de l'IPC 1, la classe 2L ou 2a peut être appliquée selon la situation réelle.

Au niveau du PCC situé dans les réseaux publics de distribution d'électricité, les niveaux de compatibilité définis dans l'IEC 61000-2-2 et dans l'IEC 61000-2-12 s'appliquent aux réseaux BT et aux réseaux MT, respectivement.

5 Introduction à la définition des niveaux de compatibilité pour les différents types de perturbations électromagnétiques

5.1 Présentation générale

Les niveaux de compatibilité sont définis, au cas par cas, pour les différents types de perturbations. Cependant, l'environnement électromagnétique met généralement en jeu plusieurs perturbations de manière simultanée et la performance de certains équipements peut être dégradée par une combinaison spécifique de perturbations. Voir l'IEC 61000-2-2:2002, Article A.2. Le premier objectif des niveaux de compatibilité est de coordonner les limites d'émission et les niveaux d'essai d'immunité pour les équipements. Le second objectif est de fournir une indication du niveau de perturbation électromagnétique attendu dans un réseau local donné.

Ces niveaux sont indiqués dans les Tableaux 1 à 5. Pour obtenir des recommandations sur les interharmoniques, voir également l'Annexe C.

Il convient de classer les IPC en catégories en fonction de leurs niveaux de compatibilité. Pour choisir certains équipements ou dispositifs spécifiques (comme des machines tournantes, des batteries de condensateurs ou des filtres), il peut être nécessaire d'établir une description spécifique des écarts de tension susceptibles d'être observés aux bornes de ces équipements. Dans ce cadre, les comités d'études responsables des normes de produits concernées spécifient les informations qui permettent de choisir les composants appropriés. Il convient que ces comités tiennent également compte des niveaux de compatibilité spécifiés dans le présent document au moment de spécifier les conditions de fonctionnement de l'alimentation de l'équipement.

Les niveaux de compatibilité sont donnés au niveau de l'IPC, mais cela n'implique pas nécessairement que les perturbations à de tels niveaux respectent les exigences d'émission au niveau du PCC. Ce fait doit être examiné avec soin lors du choix des équipements.

NOTE 1 Les équipements relevant de la classe 1 sont généralement des équipements basse tension.

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NOTE 2 Pour comprendre les niveaux de perturbation causés par les convertisseurs de puissance dans différents environnements industriels, quelques exemples de résultats de calculs sont fournis à l'Annexe B.

NOTE 3 Les niveaux de compatibilité de la classe 3 couvrent les perturbations possibles dans les environnements industriels. Dans certaines installations spécifiques, il est attendu que seuls certains types de perturbations engendrent les niveaux applicables à la classe 3. Dans la mesure où les équipements ou dispositifs présentent des susceptibilités différentes aux différents types de perturbations, un appareil ou équipement spécifique peut être utilisé avec une alimentation de classe 3 sous certaines conditions, en fonction des niveaux de perturbation réels.

NOTE 4 Les niveaux de perturbation, qui varient dans le temps et d'un site à l'autre, ne peuvent pas être maîtrisés sur tous les sites et à tous les instants. C'est pourquoi une évaluation est effectuée sur l'ensemble du système industriel étudié, plutôt qu'en un endroit spécifique au sein de ce système.

5.2 Écarts de tension

Les niveaux de compatibilité pour les écarts de tension sont identiques aux valeurs de tolérance sur la tension indiquées dans le Tableau 1. Pour la classe 3, des écarts de tension engendrant des tensions d'alimentation dans la plage de 0,85 U_C à 0,9 U_C avec une durée inférieure ou égale à 60 s sont attendus. Pour les durées plus longues, la plage de 0,9 U_N à 1,1 U_N s'applique.

NOTE 1 Les écarts de tension engendrant du papillotement sont un problème pour les appareils d'éclairage, qui sont généralement connectés à une alimentation électrique de classe 2a, 2b ou 2L.

NOTE 2 Dans des circonstances particulières, certains équipements peuvent être sensibles aux variations rapides de la tension.

5.3 Creux de tension et coupures brèves

Pour les IPC de classe 1, une protection assurée par des ASI est envisagée et aucun creux de tension n'est présumé se produire.

L'Article B.4 traite des autres aspects liés à ces deux phénomènes.

5.4 Déséquilibres de tension

Dans le présent document, les déséquilibres de tension sont pris en compte uniquement par rapport à la composante inverse, c'est-à-dire la composante impliquée dans les brouillages susceptibles d'être causés par les matériels raccordés aux réseaux d'alimentation électrique couverts par le présent document. Dans le présent document, les déséquilibres de tension sont étudiés en ce qui concerne leurs effets à long terme, c'est-à-dire pour des durées supérieures ou égales à 10 min.

NOTE 1 Certains équipements de protection peuvent être sensibles aux composantes homopolaires de la tension. Cet aspect est pris en compte sur l'ensemble de l'installation.

NOTE 2 Les composantes homopolaires de la tension concernent principalement les harmoniques multiples de 3.

NOTE 3 Les convertisseurs électroniques génèrent des rangs harmoniques caractéristiques en raison de leur topologie lorsqu'ils sont utilisés dans leurs conditions de fonctionnement assignées. Différentes conditions de fonctionnement, comme des déséquilibres de tension, des instants de commutation non idéaux, peuvent causer la génération d'autres rangs harmoniques.

Le déséquilibre de tension causé par une charge monophasée raccordée entre deux phases est pratiquement égal au rapport de la puissance de cette charge à la puissance de court-circuit du réseau triphasé. En l'absence de charge monophasée importante, les niveaux de compatibilité des classes 2a et 2b peuvent être appliqués.

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5.5 Variations temporaires de la fréquence du réseau d'alimentation

Les niveaux de compatibilité pour les écarts de la fréquence du réseau d'alimentation public s'appliquent aux installations industrielles alimentées par le réseau public d'alimentation.

Dans la majorité des cas, l'intervalle de variation de la fréquence nominale est inférieur à 1 Hz, comme cela est indiqué dans l'IEC 61000-2-2:2002, 4.8. Lorsqu'une interconnexion synchrone est mise en place à l'échelle d'un continent, les variations sont généralement beaucoup plus faibles.

Le niveau de compatibilité pour les variations temporaires de la fréquence par rapport à la fréquence nominale est de ±1 Hz En régime établi, l'écart entre la fréquence et la fréquence nominale est beaucoup plus faible.

NOTE 1 Pour certains équipements, la variation de fréquence est rapide.

NOTE 2 Dans le cas des réseaux îlotés, des variations de fréquence peuvent être attendues.

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5.6 Harmoniques

Les niveaux de compatibilité pour les composantes harmoniques de la tension doivent être étudiés par rapport aux harmoniques en régime établi. Ils sont donnés en tant que valeurs de référence pour les effets à long terme et pour les effets à très court terme.

Les effets à long terme concernent principalement les effets thermiques sur les câbles, transformateurs, moteurs, condensateurs, etc. Ils résultent de niveaux d'harmoniques maintenus pendant 10 min ou plus.

Le Tableau 2 donne les niveaux de compatibilité relatifs aux composantes harmoniques de la tension pour les effets à long terme. Les niveaux de compatibilité correspondants pour la distorsion harmonique totale sont indiqués dans le Tableau 3.

Les effets à très court terme concernent principalement les perturbations agissant sur des dispositifs électroniques qui peuvent être sensibles à des niveaux d'harmoniques maintenus pendant 3 s ou moins. Les transitoires ne sont pas compris dans ces effets.

En ce qui concerne les effets à très court terme pour les classes 1 et 3, les niveaux de compatibilité pour les composantes harmoniques de la tension et pour la distorsion harmonique totale sont égaux à 1,5 fois les valeurs indiquées dans le Tableau 2 et le Tableau 3, respectivement.

Pour les classes 2a et 2b, les valeurs du Tableau 2 sont multipliées par le facteur k, où k est déterminé comme suit:

$$k = 1{,}3 + \frac{0{,}7}{45} \times (h - 5) \qquad (4)$$

NOTE 1 Les niveaux de compatibilité ci-dessus s'appliquent également aux encoches de commutation, dans la mesure où elles contribuent au résidu harmonique de la tension. D'autres aspects (influence sur la commutation d'autres convertisseurs, ou toute influence sur d'autres équipements qui concernent les composantes harmoniques de rang plus élevé du spectre, par exemple) exigent une description dans le domaine temporel (voir la norme de produit applicable).

NOTE 2 Lorsque des condensateurs d'amélioration du facteur de puissance sont utilisés dans des réseaux industriels, ils sont raccordés au réseau par des inductances série, en particulier ceux qui sont destinés à être raccordés à des IPC de classe 3. Lorsque des interharmoniques peuvent être présents, il existe un risque d'effets de résonance et ce risque est examiné avec soin. Lorsque l'absence d'effets de résonance est clairement démontrée et que les valeurs d'harmoniques maximales sont significativement inférieures aux niveaux applicables à la classe 3, l'emploi d'inductances série peut ne pas être nécessaire, mais cet aspect est examiné avec soin.

NOTE 3 Les valeurs spécifiées pour la distorsion harmonique totale ne concernent pas des équipements ou dispositifs spécifiques, mais ont pour objectif d'empêcher la présence simultanée de plusieurs composantes harmoniques d'amplitude significative.

5.7 Interharmoniques

L'Annexe C fournit des informations sur les sources, les effets et les méthodes d'atténuation des interharmoniques. À titre de recommandations, elle fournit également des niveaux indicatifs en attendant la disponibilité de données plus abondantes pour publier les niveaux de compatibilité applicables.

Le présent document ne donne des niveaux de compatibilité que dans le cas de tensions interharmoniques à une fréquence proche de la fréquence fondamentale (50 Hz ou 60 Hz), ce qui donne lieu à une modulation en amplitude de la tension d'alimentation.

Dans ces conditions, certaines charges sensibles au carré de la tension, en particulier les dispositifs d'éclairage, mettent en évidence un effet de battement provoquant du papillotement (voir la Note 1 en 5.2.) La fréquence de battement est la différence entre les fréquences des deux tensions coexistantes, c'est-à-dire entre la fréquence interharmonique et la fréquence fondamentale.

NOTE 1 Pour les rangs interharmoniques inférieurs à 0,2, les niveaux de compatibilité sont déterminés par les exigences relatives au papillotement, avec $P_{st} = 1$. À cet effet, la sévérité du papillotement peut être calculée conformément à l'IEC TR 61000-3-7:2008, Annexe A en utilisant le facteur de forme donné pour les fluctuations de tension périodiques et sinusoïdales. La valeur conservative du facteur de forme est 0,8 pour $0,04 < m \leq 0,2$ et 0,4 pour $m \leq 0,04$.

NOTE 2 Une situation analogue est possible lorsqu'un niveau de tension significatif à une fréquence harmonique donnée (en particulier de rang 3 ou 5) coexiste avec une tension interharmonique à une fréquence voisine. L'effet peut être observé sur la Figure 1, où l'amplitude est donnée par le produit des amplitudes relatives de la fréquence harmonique et de la fréquence interharmonique à l'origine de la fréquence de battement. Il est peu probable que le résultat soit pertinent.

Le niveau de compatibilité pour la tension interharmonique dans le cas ci-dessus, exprimé comme le rapport de son amplitude à celle de la fréquence fondamentale, est représenté sur la Figure 1 en fonction de la fréquence de battement. Il repose sur un niveau de papillotement $P_{st} = 1$ pour les lampes fonctionnant sous 120 V ou 230 V, et s'applique uniquement aux circuits qui comportent des dispositifs d'éclairage.

5.8 Composantes de tension aux fréquences plus élevées (au-dessus du rang harmonique 40)

La distorsion de l'onde de tension peut être considérée comme étant équivalente à la superposition des tensions à des fréquences dont certaines dépassent largement le rang harmonique 40. Dans le cas des fréquences les plus élevées, il n'est généralement pas pertinent de distinguer les tensions harmoniques et interharmoniques. Ces tensions peuvent apparaître à des fréquences spécifiques, mais également dans des bandes de fréquences relativement larges.

5.9 Surtensions transitoires

L'amplitude relative des transitoires est généralement fonction de leur durée, de leur fréquence et du niveau de tension du réseau. L'Article B.5 traite de ce phénomène.

5.10 Composante continue

Normalement, la tension des réseaux d'alimentation électrique industriels couverts par le présent document ne comporte pas de composante continue à un niveau significatif. De telles composantes continues peuvent néanmoins apparaître en raison de légers défauts de symétrie au niveau des charges maîtrisées, qui sont raccordées directement au réseau sans transformateur de séparation spécifique.

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Le niveau de courant continu est alors l'élément d'intérêt. La valeur de la tension continue de tension dépend non seulement du courant continu, mais également d'autres facteurs, notamment la résistance du réseau au point à étudier. Par conséquent, aucun niveau de compatibilité n'est spécifié pour la tension continue.

Une composante continue peut engendrer une magnétisation dissymétrique des transformateurs, et ainsi occasionner des échauffements supplémentaires et la génération de tensions harmoniques. En outre, si de tels courants continus passent par les circuits de terre, ils favorisent la corrosion des pièces métalliques enfouies.

6 Niveaux de compatibilité

Les niveaux de compatibilité en mode différentiel (L-L et L-N) pour les déséquilibres, les harmoniques, les interharmoniques et le papillotement sont donnés avec une probabilité de 95 %.

Les niveaux de compatibilité pour les tolérances sur la tension, les déséquilibres de tension et les variations de la fréquence du réseau d'alimentation sont indiqués dans le Tableau 1.

Les niveaux de compatibilité pour les harmoniques sont indiqués dans le Tableau 2.

Les niveaux de compatibilité pour la distorsion harmonique totale sont indiqués dans le Tableau 3.

Les niveaux de compatibilité pour la distorsion de tension en mode différentiel au-dessus du rang harmonique 40 jusqu'à 9 kHz et de 9 kHz à 150 kHz sont indiqués dans le Tableau 4 et le Tableau 5, respectivement.

Les niveaux de compatibilité pour les interharmoniques sont représentés sur la Figure 3.

Tableau 1 – Niveaux de compatibilité pour les tolérances sur la tension, les déséquilibres de tension et les variations de la fréquence du réseau d'alimentation

Perturbation		Classe 1	Classe 2L, classe 2a, classe 2b	Classe 3
Tolérance sur la tension nominale U_N	$\Delta U/U_N$	±8 %	±10 % [a]	+10 % à −15 % [b]
Déséquilibre de tension	U_{neg}/U_{pos}	2 %	2 %	3 %
Écart de la fréquence du réseau d'alimentation [c]	Δf	±1 Hz	±1 Hz	±1 Hz

[a] Valeur non définie dans l'IEC 61000-2-2.

[b] Voir le 5.2.

[c] 2 Hz dans le cas des réseaux îlotés.

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