

INTERNATIONAL STANDARD



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



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IEC 61000-2-4

Edition 3.0 2024-07
REDLINE VERSION

INTERNATIONAL STANDARD



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

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.100.10; 33.100.20

ISBN 978-2-8322-9462-8

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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.

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 (PWHB).

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.

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;

- 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: Electro-magnetic 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*⁴

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.

⁴~~To be published.~~

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.]

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.

[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 IEC 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".

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~~

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

~~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.~~

~~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

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

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

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

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):~~

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

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

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.

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;~~

~~—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:

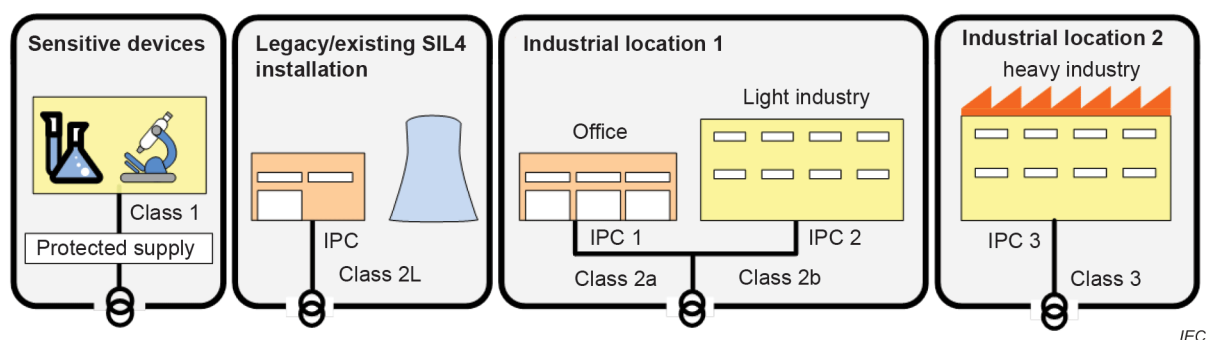


Figure 1 – Examples of the application of different electromagnetic environment classes in different industrial locations

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

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:

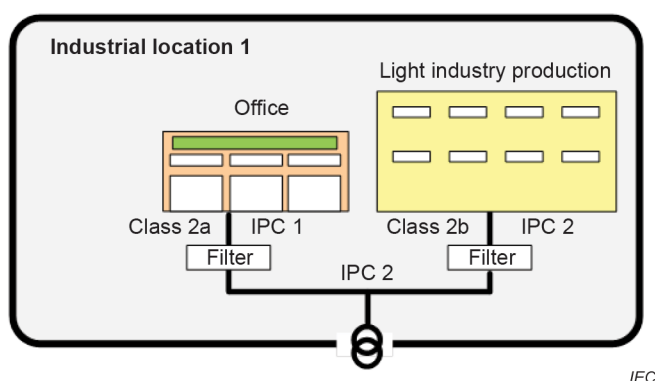


Figure 2 – Example of different parts of an installation separated by filters, where different electromagnetic environment classes are applied

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.

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.

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.~~

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

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.

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 $0,04 < m \leq 0,2$, and 0,4 for $m \leq 0,04$.

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.

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
$17 < h \leq 49$	$2,27 \times (17/h) - 0,27$	$2,27 \times (17/h) - 0,27$	$4,5 \times (17/h) - 0,5$

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.

**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
$21 < h \leq 45$	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
$10 < h \leq 50$	$0,25 \times (10/h) + 0,25$	$0,25 \times (10/h) + 0,25$	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	

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.

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 dB μ V	Class 2b U_h dB μ V	Class 3 U_h dB μ V
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.

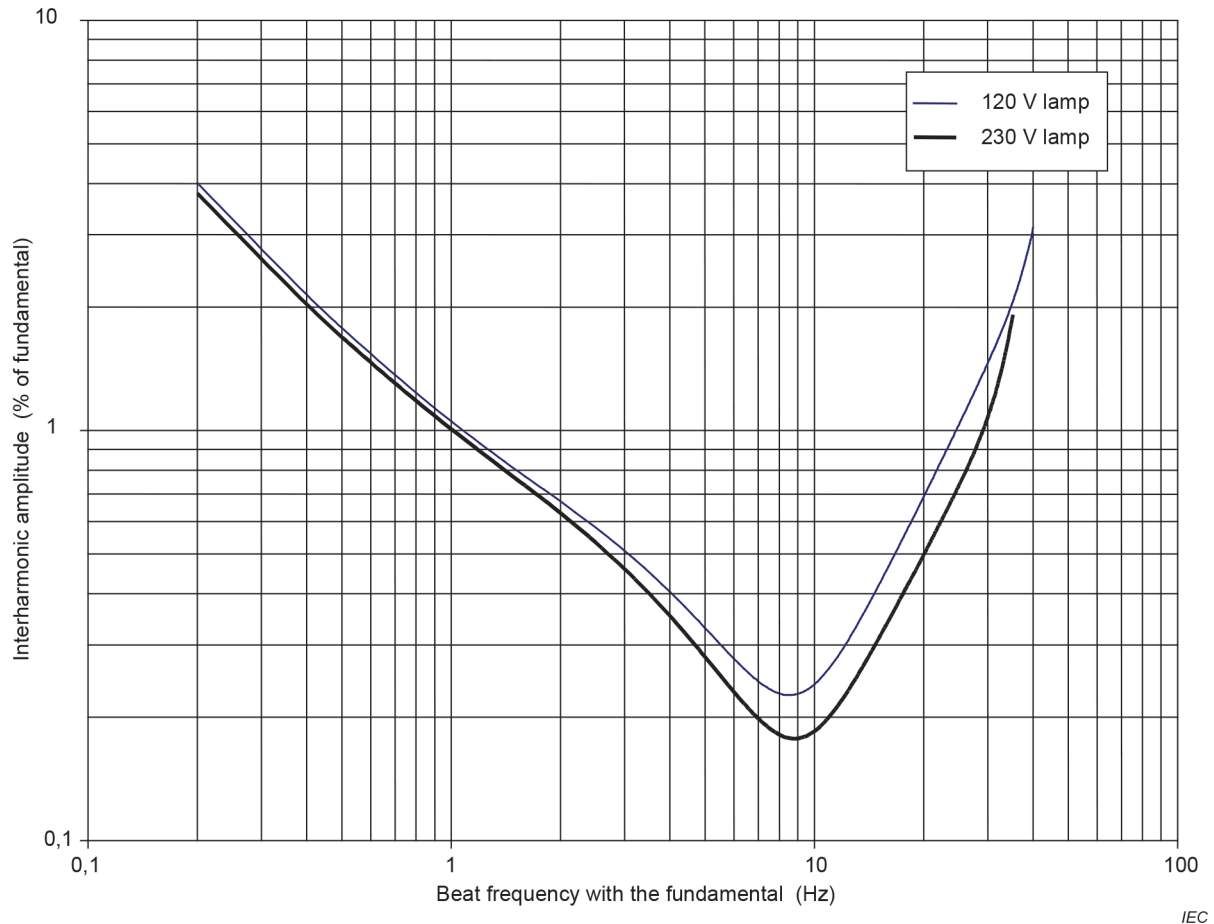
These compatibility levels for voltage distortion are reference levels for EMC coordination of immunity requirements and in the setting of emission limits in differential mode for emissions. However, if the emission limits are related to voltage distortion levels measured between any mains conductor (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

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)

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.

Accordingly, the measurement techniques defined in IEC 61000-4-7² 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:~~

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

~~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 IEC 61000-4-7 (IEC 60050-101) and IEC 60050-551-20.~~

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

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]

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

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.

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.

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

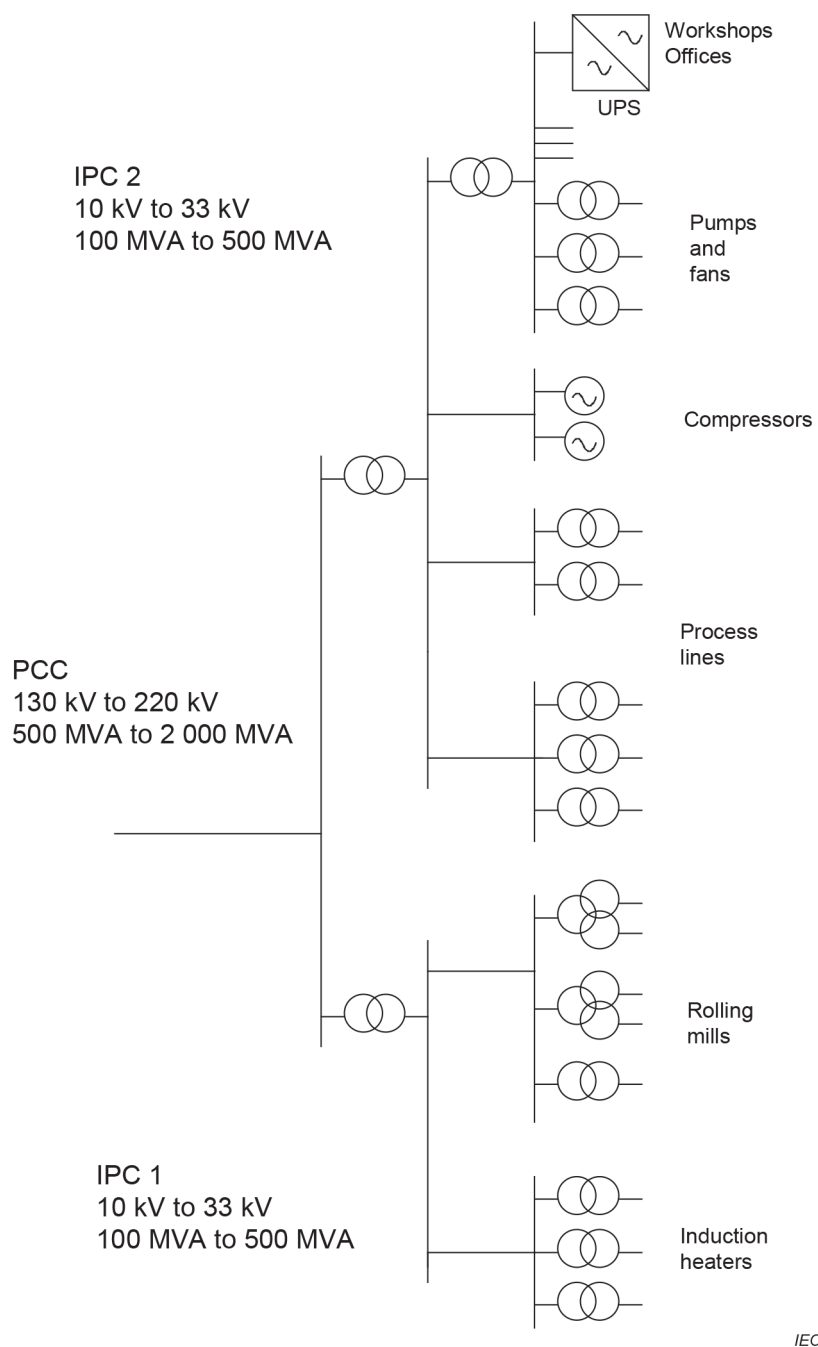


Figure B.1 – Example of power distribution in industry with rolling mills

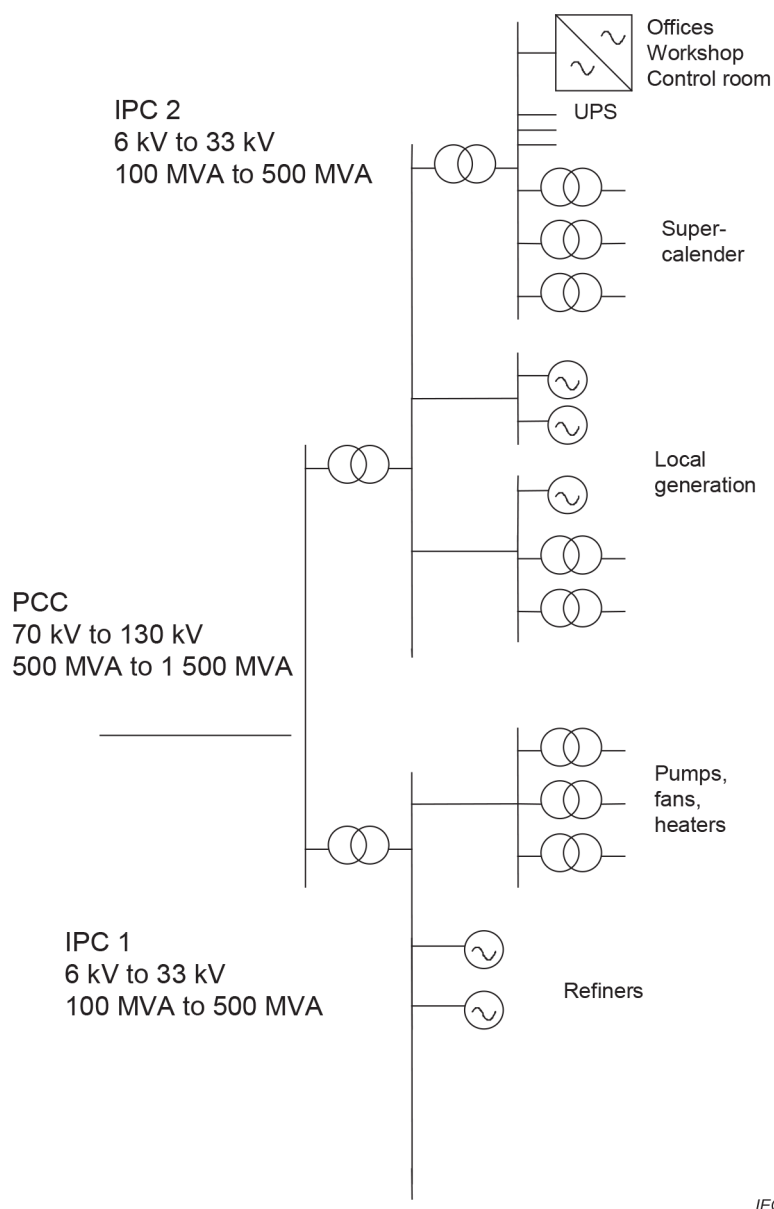


Figure B.2 – Example of power distribution in the paper industry

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 μ H 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.						

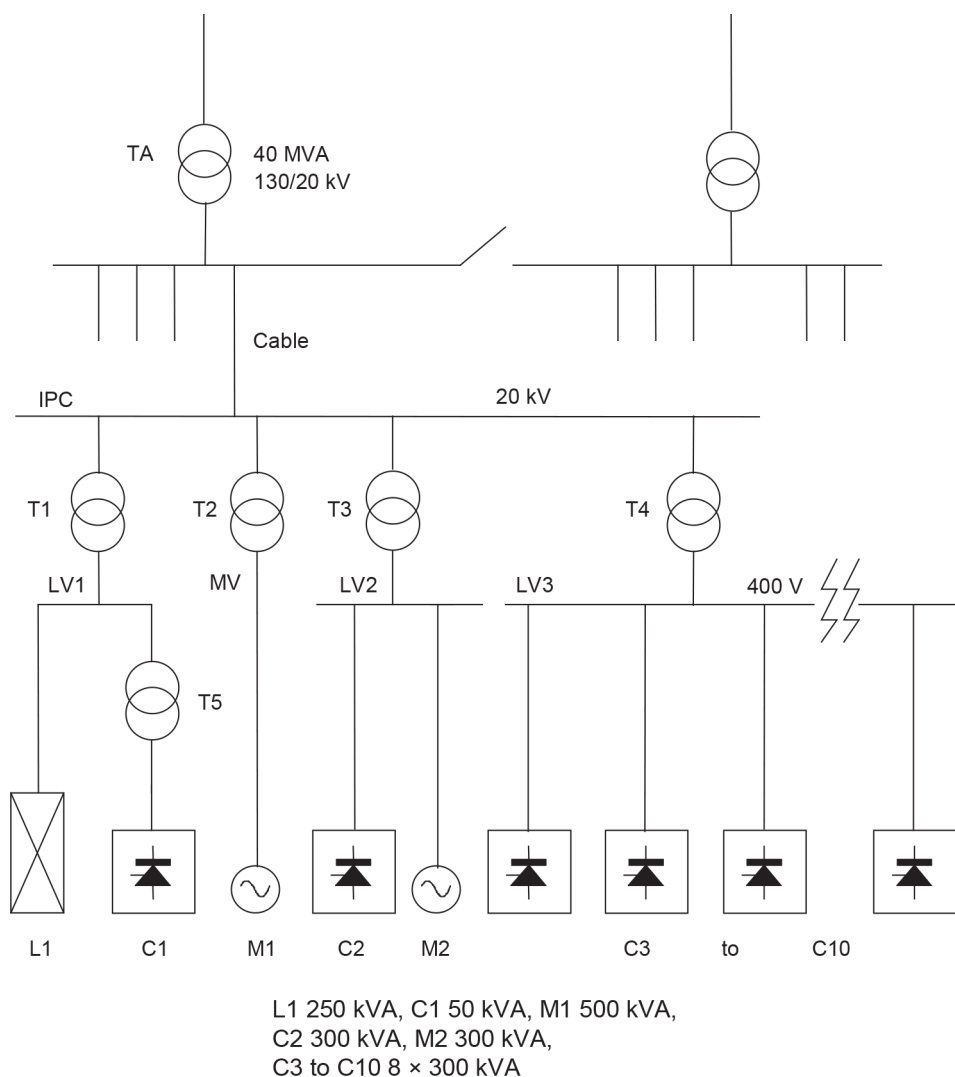


Figure B.3 – Example of power distribution in a generic manufacturing industry

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.

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 μ s 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.

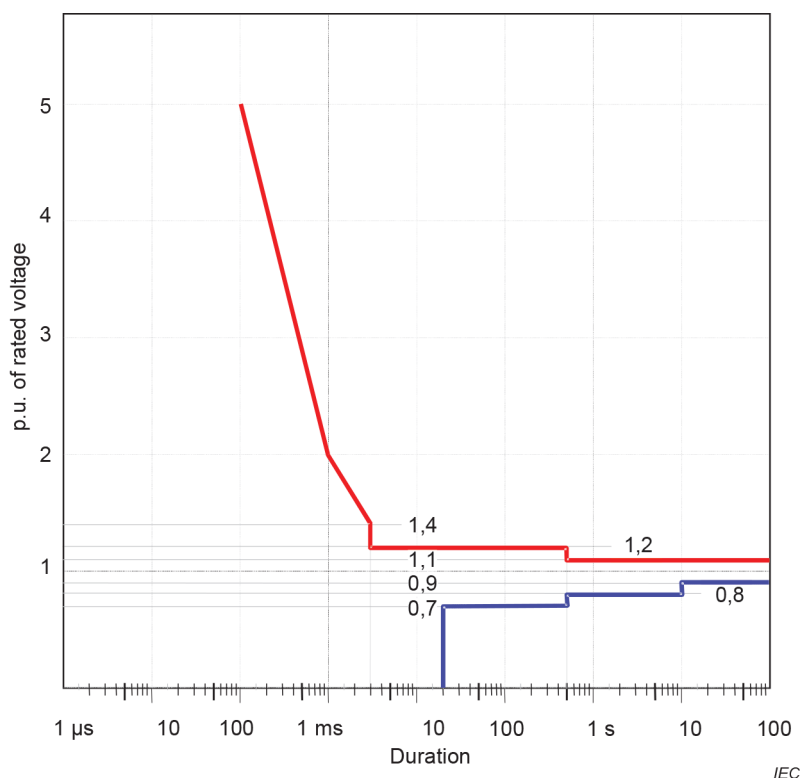


Figure B.4 – ITI (~~CEBEMA~~CBEMA) – Curve of tolerance envelope of ITE³

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.

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.

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.

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:

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

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

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.

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			60 Hz system		
	Interharmonic frequency f_m Hz	U_m %		Interharmonic frequency f_m Hz	U_m %	
		120 V system	230 V system		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
$0,60 < m \leq 0,64$	$30 < f_m \leq 32$	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
$0,76 < m \leq 0,84$	$38 < f_m \leq 42$	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	$57,6 < f_m \leq 62,4$	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
$1,08 < m \leq 1,12$	$54 < f_m \leq 56$	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
$1,28 < m \leq 1,32$	$64 < f_m \leq 66$	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

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.

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.

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.

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:

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

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.

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.