

INTERNATIONAL STANDARD

NORME INTERNATIONALE



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

**Compatibilité électromagnétique (CEM) –
Partie 2-4: Environnement – Niveaux de compatibilité dans les réseaux de
distribution d'électricité sur des sites industriels pour les perturbations
conduites à basse fréquence**



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

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

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

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

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

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

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

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

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

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

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

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

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

- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

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

Part 1: General

General considerations (introduction, fundamental principles)
Definitions, terminology

Part 2: Environment

Description of the environment
Classification of the environment
Compatibility levels

Part 3: Limits

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

Part 4: Testing and measurement techniques

Measurement techniques
Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines
Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

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

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

ELECTROMAGNETIC COMPATIBILITY (EMC) –

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

1 Scope

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

NOTE 1 Industrial locations are defined in 3.1.8.

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

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

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

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

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

- b) immunity levels for the equipment within these systems.

The disturbance phenomena considered are:

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

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

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

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

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

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

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

3 Terms, definitions and abbreviated terms

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

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

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

3.1 General definitions

3.1.1

electromagnetic disturbance

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

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

3.1.2

disturbance level

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

3.1.3

electromagnetic compatibility

EMC

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

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

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

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

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

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

3.1.4

(electromagnetic) compatibility level

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

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

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

3.1.5

planning level

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

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

3.1.6

industrial and private power distribution system

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

3.1.7

point of common coupling

PCC

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

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

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

3.1.8

industrial location

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

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

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

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

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

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

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

3.1.9

electromagnetic environment

totality of electromagnetic phenomena existing at a given location

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

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

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

3.1.10

in-plant point of coupling

IPC

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

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

3.2 Phenomena-related definitions

NOTE 1 The definitions below that relate to harmonics are based on the analysis of system voltages or currents by the discrete Fourier transform method (DFT). This is the practical application of the Fourier transform as defined in 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 components of this spectrum are referred

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

3.2.2**fundamental component****fundamental**

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

3.2.3**harmonic frequency**

frequency which is an integer multiple of the fundamental frequency

3.2.4**harmonic order**

ratio of the harmonic frequency to the fundamental frequency

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

3.2.5**harmonic component**

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

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

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

3.2.6**interharmonic frequency**

any frequency between two consecutive harmonic frequencies

3.2.7**interharmonic order**

ratio of an interharmonic frequency to the fundamental frequency

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

3.2.8**interharmonic component**

spectral component having an interharmonic frequency

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

3.2.9**total harmonic distortion****THD**

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

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

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 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 power supply RMS voltage, excluding transients with no remaining effects

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

3.2.13 voltage dip voltage sag

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

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

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

3.2.14 transient overvoltage

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

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

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

3.2.15 industrial power electronic equipment

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

3.3 Abbreviated terms

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

4 Electromagnetic environment classes

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

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

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

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

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

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

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

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

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

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

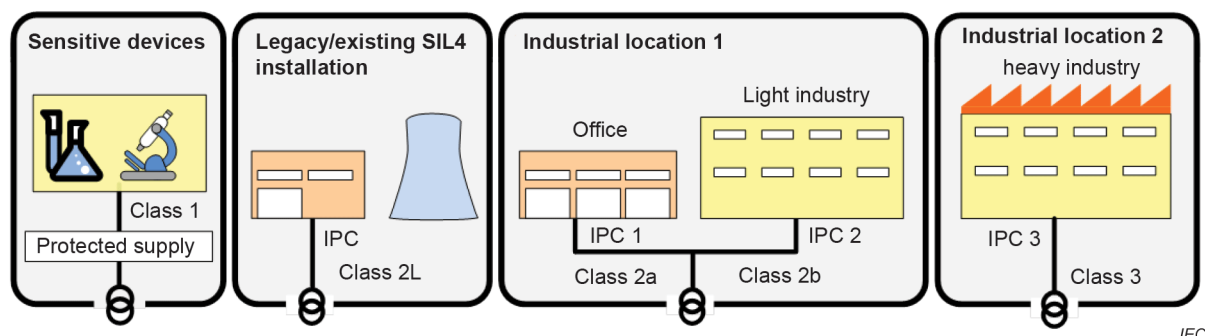


Figure 1 – Examples of the application of different electromagnetic environment classes in different industrial locations

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

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

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

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

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

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

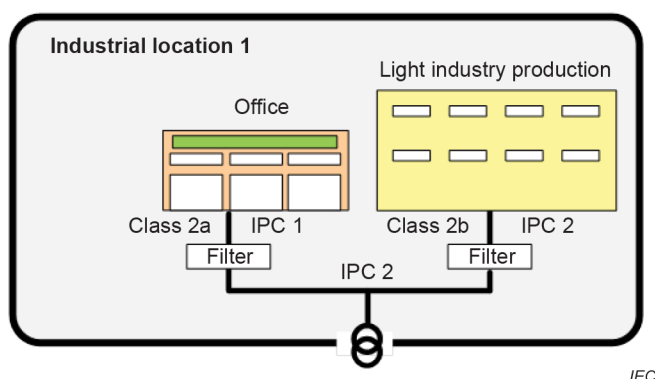


Figure 2 – Example of different parts of an installation separated by filters, where different electromagnetic environment classes are applied

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

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

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

5.1 General comment

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

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

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

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

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

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

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

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

5.2 Voltage deviations

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

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

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

5.3 Voltage dips and short interruptions

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

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

5.4 Voltage imbalance

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

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

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

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

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

5.5 Temporary power-frequency variation

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

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

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

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

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

5.6 Harmonics

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

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

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

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

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

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

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

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

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

5.7 Interharmonics

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

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

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

NOTE 1 Below interharmonic order 0,2 compatibility levels are determined by flicker requirements, with $P_{st} = 1$. For this purpose the flicker severity can be calculated in accordance with IEC TR 61000-3-7:2008, Annex A, using the shape factor given for periodic and sinusoidal voltage fluctuations. The conservative value of the shape factor is 0,8 for $0,04 < m \leq 0,2$, 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 can be assessed by means of Figure 1, with amplitude given by the product of the relative amplitudes of the harmonic and interharmonic at the origin of the beat frequency. The result is unlikely to be significant.

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

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

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

5.9 Transient overvoltages

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

5.10 DC component

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

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

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

6 Compatibility levels

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

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

Compatibility levels for harmonics are indicated in Table 2.

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

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

Interharmonic compatibility levels are represented in Figure 3.

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

Disturbance	Class 1	Class 2L, Class 2a, Class 2b	Class 3
Voltage tolerance, relative to nominal voltage U_N : $\Delta U/U_N$	±8 %	±10 % ^a	+10 % to –15 % ^b
Voltage imbalance U_{neg}/U_{pos}	2 %	2 %	3 %
Power-frequency deviations ^c Δf	±1 Hz	±1 Hz	±1 Hz
^a Value not defined in IEC 61000-2-2. ^b See 5.2. ^c ±2 Hz in case of islanded networks.			

Table 2 – Compatibility levels for harmonics – Harmonic voltage components

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

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

Table 3 – Compatibility levels for total voltage harmonic distortion

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

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

Frequency range kHz	Class 1, class 2L, class 2a U_N %	Class 2b U_N %	Class 3 U_N %
2 (2,4) ^a to 3	1,4	3	6
3 to 9	1,4 to 0,65 ^b	3	6
NOTE The levels specified in Table 4 apply at the IPC. At the PCC (public network), the compatibility levels from IEC 61000-2-2 apply.			
^a The frequency range is 2 kHz to 3 kHz for 50 Hz systems and 2,4 kHz to 3 kHz for 60 Hz systems.			
^b The logarithm of the level decreases linearly with the logarithm of the frequency in the range 3 kHz to 9 kHz.			

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

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

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

Frequency range kHz	Class 1, class 2L, class 2a U_h dBμV	Class 2b U_h dBμV	Class 3 U_h dBμV
9 to 50	129,5 to 119 ^a	137 to 126,5 ^a	143 to 141 ^a
50 to 150	113 to 89 ^a	126,5 to 109 ^a	141 to 139 ^a
NOTE The levels specified in Table 5 apply at the IPC. At the PCC (public network), the compatibility levels from IEC 61000-2-2 apply.			
^a The logarithm of the level decreases linearly with the logarithm of the frequency in the range 9 kHz to 50 kHz and from 50 kHz to 150 kHz.			

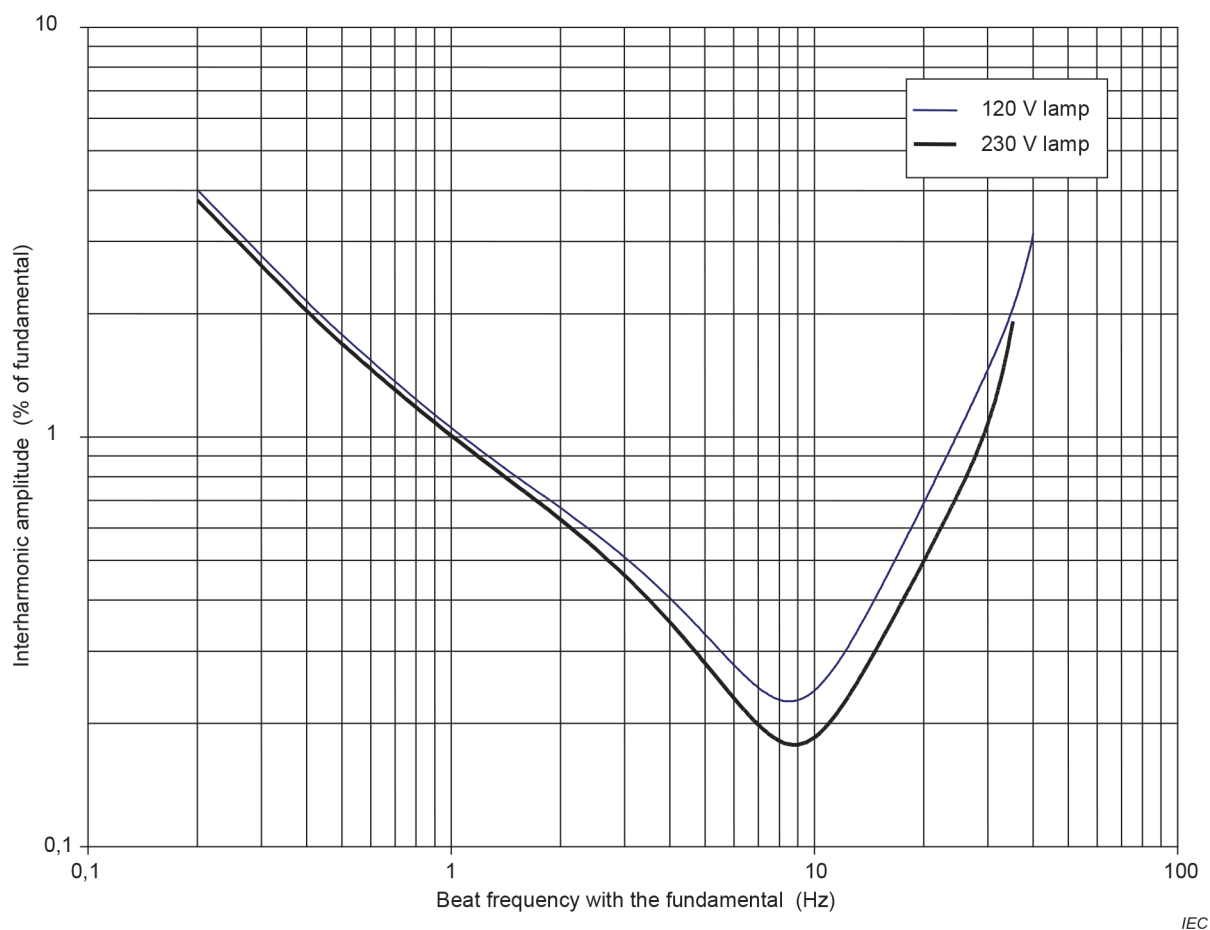
The compatibility levels U_h for voltage distortion in differential mode from 9 kHz to 150 kHz are related to disturbance levels between any phase conductors and between any phase conductor and the neutral conductor measured with a quasi-peak detector and with a bandwidth of 200 Hz in accordance with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

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

Annex A (informative)

Explanations and examples for interharmonics

A.1 Resolution of non-sinusoidal voltages and currents

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

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

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

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

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

The FFT (Fast Fourier Transform) is a special algorithm allowing short computation time. It requires the number of samples (M) to be an integer multiple of 2 ($M = 2^n$). (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 61000-4-7 and the definition of the fundamental frequency in 3.2.1 are consistent for application to all electrotechnical and power electronics items. Other cases require further consideration.

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

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

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

A.2 Time varying phenomena

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

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

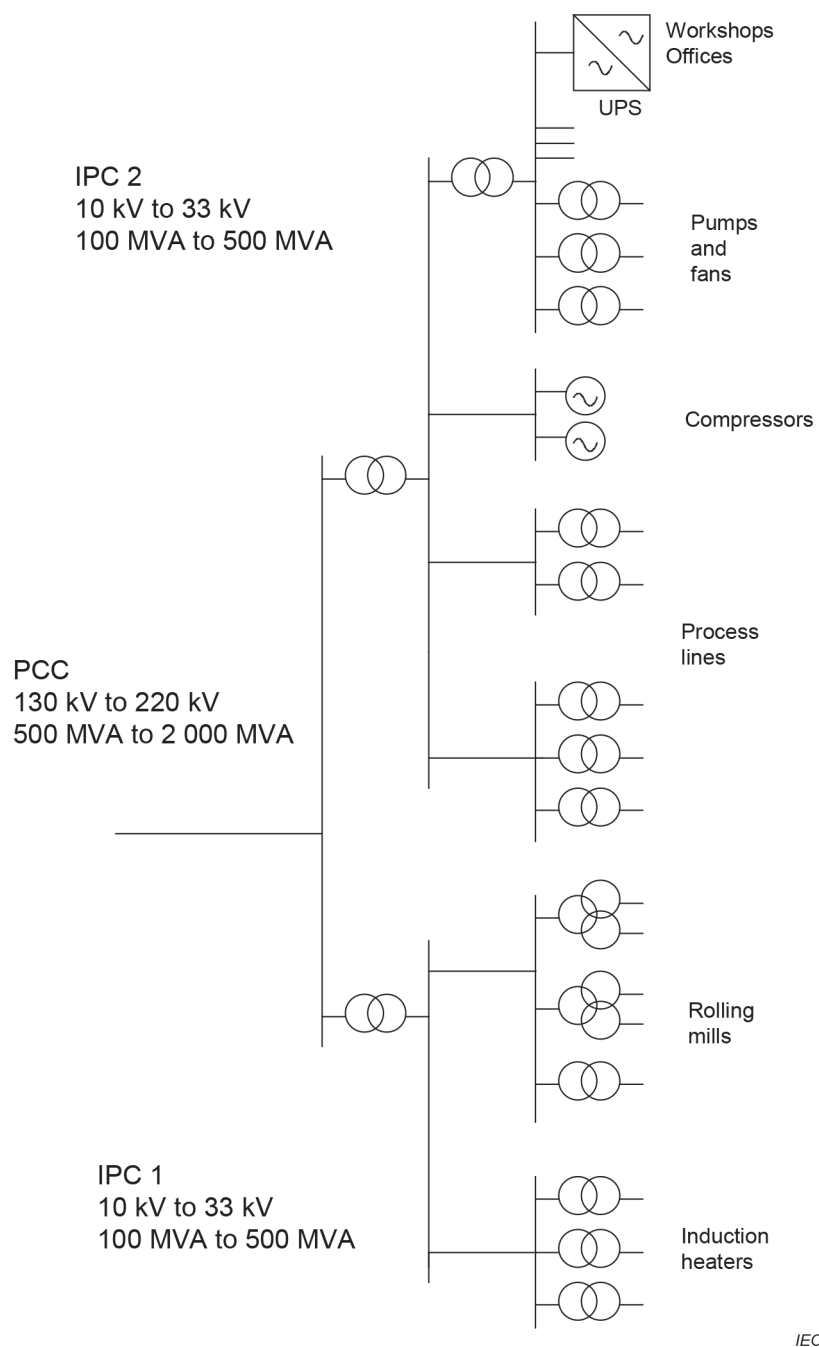


Figure B.1 – Example of power distribution in industry with rolling mills

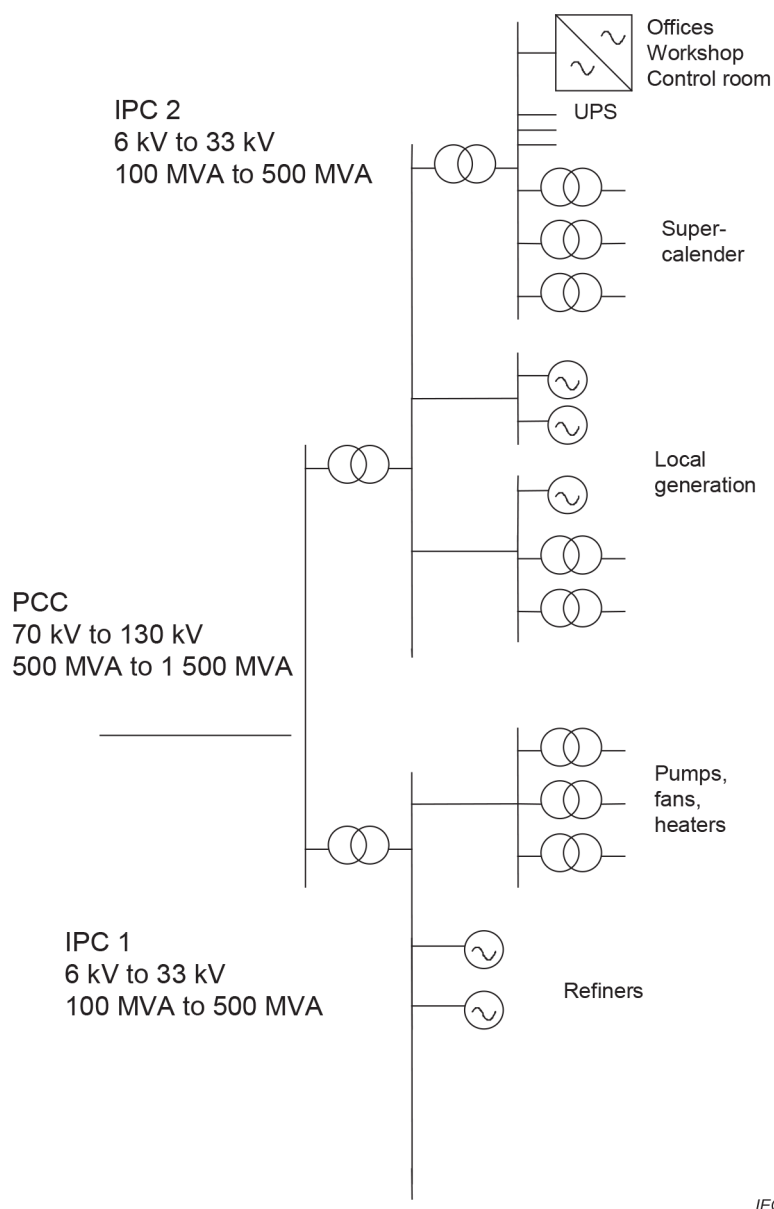


Figure B.2 – Example of power distribution in the paper industry

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.