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Adjustable speed electrical power drive systems –
Part 3: EMC requirements and specific test methods

IEC 61800-3:2017-02 RLV(en)

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ADJUSTABLE SPEED ELECTRICAL POWER DRIVE SYSTEMS –

Part 3: EMC requirements and specific test methods

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. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

International Standard IEC 61800-3 has been prepared by subcommittee 22G: Adjustable speed electric drive systems incorporating semiconductor power converters, of IEC technical committee 22: Power electronic systems and equipment.

This third edition cancels and replaces the second edition published in 2004 and Amendment 1:2011. This edition constitutes a technical revision.

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

a) clarification of requirements for the test report, particularly when a number of alternative test methods exist;
b) introduction of a more detailed test setup for radiated emission measurements, along with the introduction of a 3 m measurement distance for small size equipment;
c) general updates in the informative annexes.

The text of this standard is based on the following documents:

FDIS	Report on voting
22G/347/FDIS	22G/350/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2, and with IEC Guide 107.

A list of all parts in the IEC 61800 series, published under the general title *Adjustable speed electrical power drive systems*, 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 "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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ADJUSTABLE SPEED ELECTRICAL POWER DRIVE SYSTEMS –

Part 3: EMC requirements and specific test methods

1 Scope ~~and object~~

This part of IEC 61800 specifies electromagnetic compatibility (EMC) requirements for power drive systems (PDSs, defined in 3.1). These are adjustable speed AC or DC motor drives. Requirements are stated for PDSs with converter input and/or output voltages (line-to-line voltage), up to 35 kV AC RMS.

PDSs covered by this document are those installed in residential, commercial and industrial locations with the exception of traction applications, and electric vehicles. PDSs ~~may~~ can be connected to either industrial or public power distribution networks. Industrial networks are supplied by a dedicated distribution transformer, which is usually adjacent to or inside the industrial location, and supplies only industrial customers. Industrial networks can also be supplied by their own electric generating equipment. On the other hand, PDSs can be directly connected to low-voltage public mains networks which also supply ~~domestic~~ residential premises, and in which the neutral is generally earthed (grounded).

The scope of this part of IEC 61800, related to EMC, includes a broad range of PDSs from a few hundred watts to hundreds of megawatts. PDSs are often included in a larger system. The system aspect is not covered by this document but guidance is provided in the informative annexes.

The requirements have been selected so as to ensure EMC for PDSs at residential, commercial and industrial locations. The requirements cannot, however, cover extreme cases which ~~may~~ can occur with an extremely low probability. Changes in the EMC behaviour of a PDS, as a result of fault conditions, are not taken into account.

The object of this document is to define the limits and test methods for a PDS according to its intended use. This document includes immunity requirements and requirements for electromagnetic emissions.

NOTE 1 Emission can cause interference in other electronic equipment (for example radio receivers, measuring and computing devices). Immunity is ~~required~~ meant to protect the equipment from continuous and transient conducted and radiated disturbances including electrostatic discharges. The emission and immunity requirements are balanced against each other and against the actual environment of the PDS.

This document defines the minimum EMC requirements for a PDS.

Immunity requirements are given according to the environment classification. Low-frequency emission requirements are given according to the nature of the supply network. High-frequency emission requirements are given according to four categories of intended use, which cover both environment and bringing into operation.

As a product standard, this document ~~may~~ can be used for the assessment of PDS. It ~~may~~ can also be used for the assessment of complete drive modules (CDM) or basic drive modules (BDM) (see 3.1), which can be marketed separately.

This document contains

- conformity assessment requirements for products to be placed on the market, and

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- recommended engineering practice (see 6.5) for cases where high frequency emissions cannot be measured before the equipment is placed on the market (such PDSs are defined in 3.2.7 as category C4).

NOTE 2 The first edition of IEC 61800-3 identified that the intended use could require engineering for putting into service. This was done by the “restricted distribution mode”. Equipment ~~that used to be covered by the~~ formerly identified under “restricted distribution mode” is now covered ~~in the second edition~~ by categories C2 and C4 (see 3.2).

This document is intended as a complete EMC product standard for the EMC conformity assessment of products of categories C1, C2 and C3, when placing them on the market (see definitions 3.2.4 to 3.2.6).

Radio frequency emission of equipment of category C4 is only assessed when it is installed in its intended location. It is therefore treated as a fixed installation, for which this document gives rules of engineering practice in 6.5 and Annex E, although it gives no defined emission limits (except in case of complaint).

This document does not specify any safety requirements for the equipment such as protection against electric shocks, insulation co-ordination and related dielectric tests, unsafe operation, or unsafe consequences of a failure. It also does not cover safety and functional safety implications of electromagnetic phenomena.

In special cases, when highly susceptible apparatus is being used in proximity, additional mitigation measures ~~may~~ can have to be employed to reduce the electromagnetic emission further below the specified levels or additional countermeasures ~~may~~ can have to be employed to increase the immunity of the highly susceptible apparatus.

As an EMC product standard for PDSs, this document takes precedence over all aspects of the generic standards, and no additional EMC tests are ~~required or necessary~~ performed. If a PDS is included as part of equipment covered by a separate EMC product standard, the EMC standard of the complete equipment applies.

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 (131):2002, *International Electrotechnical Vocabulary (IEV) – Chapter 131: Circuit theory*~~

~~IEC 60050 (151):2001, *International Electrotechnical Vocabulary (IEV) – Chapter 151: Electrical and magnetic devices*~~

~~IEC 60050 (161):1990, *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*~~

IEC 60146-1-1: ~~1991~~ 2009, *Semiconductor convertors – General requirements and line commutated convertors – Part 1-1: Specifications of basic requirements*

~~IEC 60364-1:2001, *Electrical installations of buildings – Part 1: Fundamental principles, assessment of general characteristics, definitions*~~

~~IEC 60664-1:1992, *Insulation co-ordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*~~

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~~IEC 61000-1-1, *Electromagnetic compatibility (EMC) – Part 1: General – Section 1: Application and interpretation of fundamental definitions and terms*~~

~~IEC 61000-2-1:1990, *Electromagnetic compatibility (EMC) – Part 2: Environment – Section 1: Description of the environment – Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems*~~

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 61000-2-4:~~2003~~ 2002, *Electromagnetic compatibility (EMC) – Part 2-4: Environment – Compatibility levels in industrial plants for low-frequency conducted disturbances*

~~IEC 61000-2-6:1995, *Electromagnetic compatibility (EMC) – Part 2: Environment – Section 6: Assessment of the emission levels in the power supply of industrial plants as regards low-frequency conducted disturbances*~~

IEC 61000-3-2:~~2000~~ 2014, *Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)*

IEC 61000-3-3:~~1994~~ 2013, *Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection*

~~IEC 61000-3-4:1998, *Electromagnetic compatibility (EMC) – Part 3: Limits – Section 4: Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A*~~

~~IEC 61000-3-7:1996, *Electromagnetic compatibility (EMC) – Part 3: Limits – Section 7: Limits for fluctuating loads in MV and HV power systems – Basic EMC publication*~~

IEC 61000-3-11:2000, *Electromagnetic compatibility (EMC) – Part 3-11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤ 75 A and subject to conditional connection*

IEC 61000-3-12: 2011, *Electromagnetic compatibility (EMC) – Part 3-12: Limits – Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current > 16 A and ≤ 75 A per phase*

IEC 61000-4-2:2008, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test* ~~– Basic EMC publication~~

IEC 61000-4-3:~~2002~~ 2006, *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test* ~~Basic EMC publication~~

IEC 61000-4-4:~~1995~~ 2012, *Electromagnetic compatibility (EMC) – Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test* ~~Basic EMC publication~~
~~Amendment 1 (2000)~~
~~Amendment 2 (2001)~~

IEC 61000-4-5:~~1995~~ 2014, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

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IEC 61000-4-6:2003 2013, *Electromagnetic compatibility (EMC) – Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields*

IEC 61000-4-8:2001 2009, *Electromagnetic compatibility (EMC) – Part 4-8: Testing and measurement techniques – Power frequency magnetic field immunity test* Basic EMC publication

IEC 61000-4-11:2004, *Electromagnetic compatibility (EMC) – Part 4-11: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests*

IEC 61000-4-13:2002, *Electromagnetic compatibility (EMC) – Part 4-13: Testing and measurement techniques – Harmonics and interharmonics including mains signalling at a.c. power port, low frequency immunity tests*

IEC 61000-4-34:2005, *Electromagnetic compatibility (EMC) – Part 4-34: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests for equipment with input current more than 16 A per phase*

IEC 61800-1:1997, *Adjustable speed electrical power drive systems – Part 1: Rating specifications for low voltage d.c. power drive systems*

IEC 61800-2:1998, *Adjustable speed electrical power drive systems – Part 2: General requirements – Rating specifications for low voltage adjustable frequency a.c. power drive systems*

IEC 61800-4:2002, *Adjustable speed electrical power drive systems – Part 4: General requirements – Rating specifications for a.c. power drive systems above 1000 V and not exceeding 35 kV*

CISPR 11:2003 2015, *Industrial, scientific and medical (ISM) radio-frequency equipment – Electromagnetic Radio-frequency disturbance characteristics – Limits and methods of measurement*
CISPR 11:2015/AMD1:2016

CISPR 14, *Electromagnetic compatibility – Requirements for household appliances, electric tools and similar apparatus*

CISPR 16-1:2002, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1: Radio disturbance and immunity measuring apparatus*

CISPR 16-1-2:2014, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-2: Radio disturbance and immunity measuring apparatus – Coupling devices for conducted disturbance measurements*

CISPR 16-1-4:2010, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-4: Radio disturbance and immunity measuring apparatus – Antennas and test sites for radiated disturbance measurements*

CISPR 22:2003, *Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement*

CISPR 32:2015, *Electromagnetic compatibility of multimedia equipment – Emission requirements*

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3 Terms and definitions

3.1 Overview

For the purposes of this document, definitions related to EMC and to relevant phenomena to be found in IEC 60050(161), in CISPR, and also, the following additional terms and definitions apply.

A power drive system (PDS) consists of a motor and a complete drive module (CDM). It does not include the equipment driven by the motor. The CDM consists of a basic drive module (BDM) and its possible extensions such as the feeding section or some auxiliaries (e.g. ventilation). The BDM contains converter, control and self-protection functions. Figure 1 shows the boundary between the PDS and the rest of the installation and/or manufacturing process. IEC 61800-1, IEC 61800-2 and IEC 61800-4 give details for these definitions.

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

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

3.1 Installation and its content

Figure 1 shows the major parts of the PDS as defined below and the rest of the installation.

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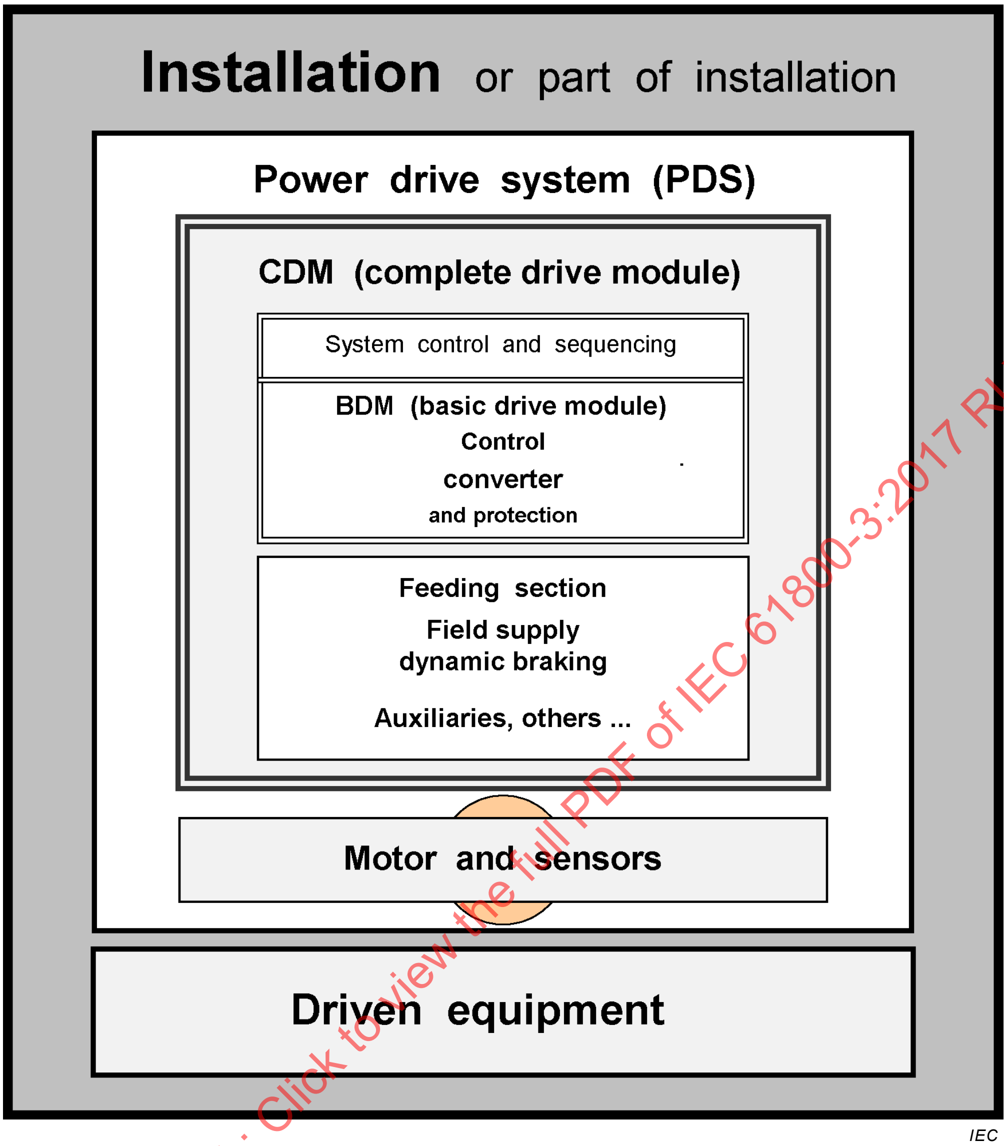

Figure 1 – ~~Definition of the~~ Installation and its content

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~~If the PDS has its own dedicated transformer, this transformer is included as a part of the CDM.~~

3.1.1
basic drive module
BDM
electronic power converter and related control, connected between an electric supply and a motor

Note 1 to entry: The BDM is capable of transmitting power from the electric supply to the motor and can be capable of transmitting power from the motor to the electric supply. The BDM controls some or all of the following aspects of power transmitted to the motor and motor output:

- current;
- frequency;
- voltage;
- speed;
- torque;
- force;

- position.

3.1.2
complete drive module
CDM
drive module consisting of, but not limited to, the BDM and extensions such as protection devices, transformers and auxiliaries

Note 1 to entry: The motor and the sensors which are mechanically coupled to the motor shaft are not included.

3.1.3
power drive system
PDS
system consisting of one or more complete drive module(s) (CDM) and a motor or motors

Note 1 to entry: Any sensors which are mechanically coupled to the motor shaft are also part of the PDS; however, the driven equipment is not included.

3.1.4
installation
equipment or equipments which include at least both the PDS and the driven equipment

3.1.5
small size equipment
equipment, either positioned on a table top, wall-mounted or standing on the floor which, including its cables and possible auxiliary equipment, fits in an imaginary cylindrical test volume of maximum 1,2 m in diameter and 1,5 m height (to ground plane)

Note 1 to entry: This definition has been modified to apply to measurement of radiated emissions from the enclosure port.

[SOURCE: CISPR 11:2015, 3.17, modified — The expression "wall-mounted" and "and possible auxiliary equipment" have been added, as well as the note to entry.]

3.1.6
wall-mounted equipment
CDM/BDM intended to be mounted on a vertical surface

3.2 Intended use

3.2.1
EMC plan
procedure for the EMC assessment when installing category C4 (see 3.2.7) equipment

3.2.2
first environment
environment that includes ~~domestic~~ residential premises and establishments directly connected without intermediate transformers to a low-voltage power supply network which supplies buildings used for ~~domestic~~ residential purposes

Note 1 to entry: Houses, apartments, commercial premises or offices in a residential building are examples of first environment locations.

3.2.3
second environment
environment that includes all establishments other than those directly connected to a low-voltage power supply network which supplies buildings used for ~~domestic~~ residential purposes

Note 1 to entry: Industrial areas or technical areas of any building fed from a dedicated transformer are examples of second environment locations.

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3.2.4
PDS of category C1
PDS of rated voltage less than 1 000 V, intended for use in the first environment

3.2.5
PDS of category C2
PDS of rated voltage less than 1 000 V, which is neither a plug in device nor a movable device and, when used in the first environment, is intended to be installed and commissioned only by a professional

Note 1 to entry: A professional is a person or an organisation having necessary skills in installing and/or commissioning power drive systems, including their EMC aspects.

3.2.6
PDS of category C3
PDS of rated voltage less than 1 000 V, intended for use in the second environment and not intended for use in the first environment

3.2.7
PDS of category C4
PDS of rated voltage equal to or above 1 000 V, or rated current equal to or above 400 A, or intended for use in complex systems in the second environment

3.3 Location, ports and interfaces

3.3.1
in situ
<test> location where the equipment is installed for its normal use by the end user

3.3.2
test site
<radiation> site meeting requirements necessary for correctly measuring, under defined conditions, electromagnetic fields emitted by a device under test

[SOURCE: IEC 60050-161:1990, 161-04-28]

3.3.3
port
access to a device or network where electromagnetic energy or signals may be supplied or received or where the device or network variables may be observed or measured

Note 1 to entry: Figure 2 illustrates the diversity of the ports of a PDS.

[SOURCE: IEC 60050-131:2002, 131-12-60, modified – The note to entry has been replaced by a new one.]

3.3.4
enclosure port
physical boundary of the PDS through which electromagnetic fields may radiate or impinge

Note 1 to entry: See Figure 2.

3.3.5
port for process measurement and control
input/output (I/O) port for a conductor or cable which connects the process to the PDS ~~as defined in Clause 3 (see Figure 2)~~

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3.3.6
power port
port which connects the PDS to the power supply, which also feeds other equipment

3.3.7
main power port
power port which feeds the PDS for only the power which, after electrical power conversion, is converted by the motor into mechanical power

3.3.8
auxiliary power port
power port which feeds only the auxiliaries of the PDS, including the field circuit, if any

~~**3.3.9**~~
~~**mechanical link**~~
~~mechanical connection between the shaft of the motor of the PDS and the driven equipment of the process as defined in Clause 3~~

3.3.9
signal interface
input/output (I/O) connection for a line connecting the basic drive module or complete drive module (BDM/CDM) to another part of the PDS

Note 1 to entry: See Figure 2.

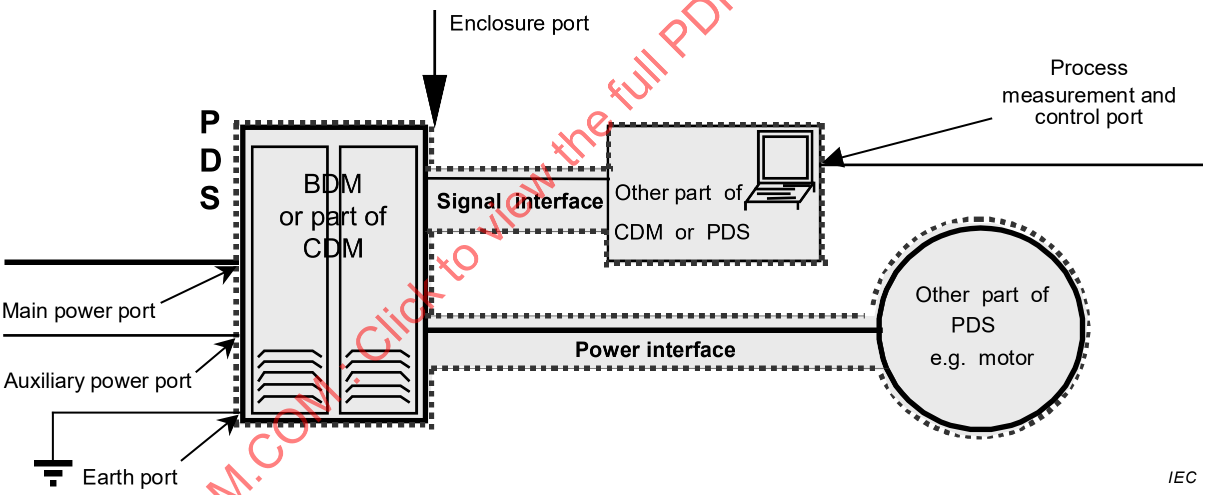

Figure 2 – Internal interfaces of the PDS and examples of ports

3.3.10
power interface
connections needed for the distribution of electrical power ~~within the PDS~~

Note 1 to entry: See Figure 3 for an example of power interface and Clause E.1 for an explanation.

Note 2 to entry: The power interfaces of the PDS may have different forms and extensions:

– Within the CDM/BDM

A power interface ~~may~~ can be the connection for distribution of electrical power from one part of the BDM/CDM to another part of the BDM/CDM. One power interface ~~may~~ can be common to different components of the PDS. For examples, see Figure 3 and Figure 4.

Figure 3 shows a power interface which distributes power from an input converter (where power is converted from the mains to another type, here DC power) to output inverters (where power is converted from an intermediate form (here DC) to another type (here AC) which can be directly applied to AC motors).

Figure 4 shows a power interface which distributes power from the secondary of a transformer (which is part of the CDM) to individual BDMs.

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– Within the PDS

Note that the connection between the inverter and the motor or the motors is also a power interface. It is the last power interface before the conversion to mechanical power.

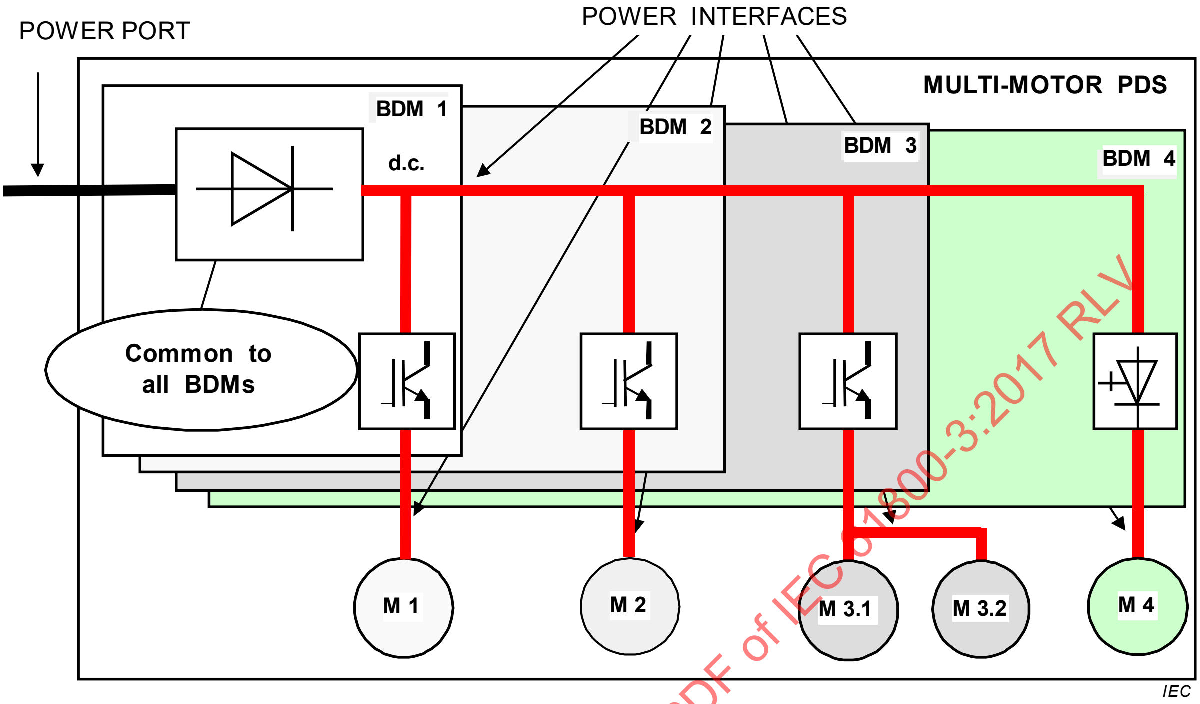

Figure 3 – Power interfaces of a PDS with common DC BUS

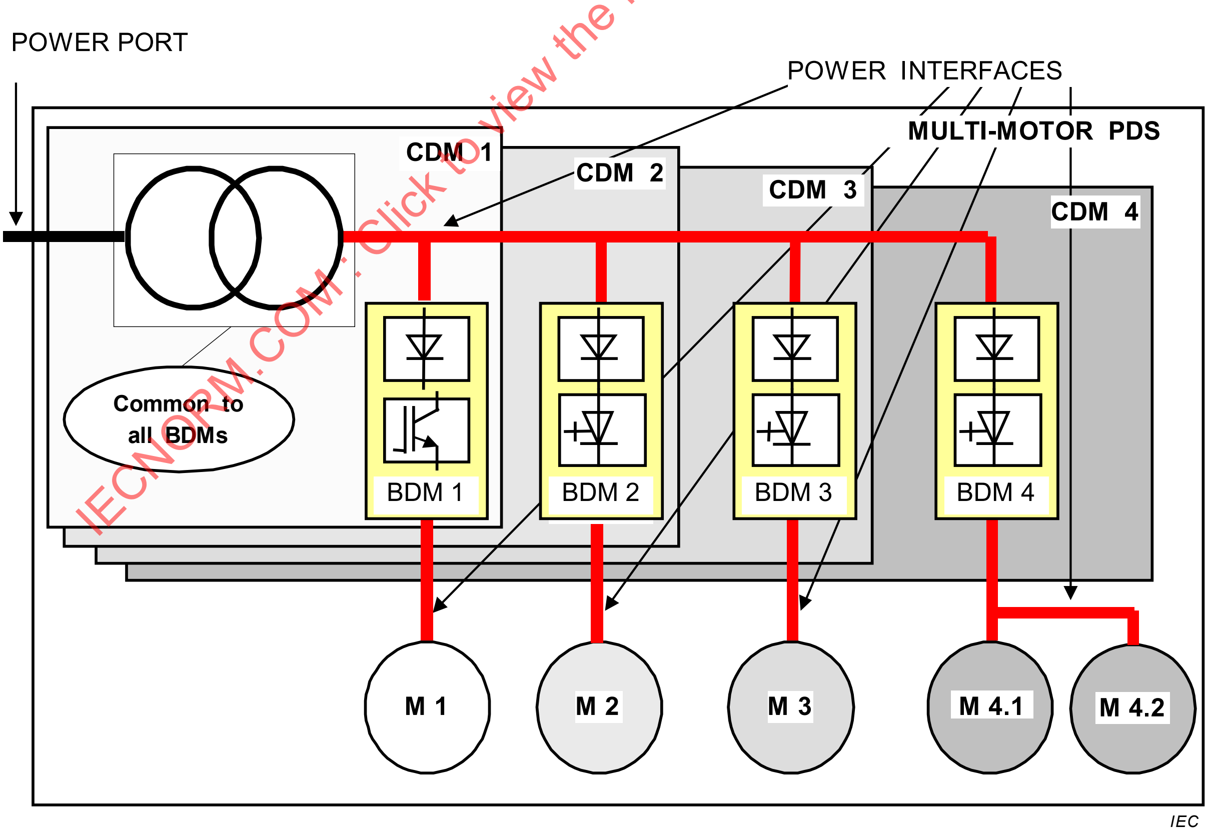

Figure 4 – Power interfaces with common input transformer

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~~3.3.12~~
~~PCC, IPC, PC~~
~~these definitions are given in IEC 61000-2-4~~

~~NOTE Briefly:~~

- ~~PCC is the point of common coupling on a public network;~~
- ~~IPC is the in-plant point of coupling;~~
- ~~PC is the point of coupling (for either of these cases).~~

3.3.11
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

[SOURCE: IEC 61000-2-4:2002, 3.1.6]

3.3.12
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 are, or could be, connected

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

[SOURCE: IEC 61000-2-4:2002, 3.1.7]

3.3.13
point of coupling
PC
point on a network which can be a public power supply network or a network inside a system or an installation

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3.4 Components of the PDS

3.4.1
converter
<of the BDM> unit which changes the form of electrical power supplied by the mains to the form fed to the motor(s) by changing one or more of the voltage, current and/or frequency

Note 1 to entry: The converter comprises electronic commutating devices and their associated commutation circuits. It is controlled by transistors or thyristors or any other power switching semiconductor devices.

Note 2 to entry: The converter can be line-commutated, load-commutated or self-commutated and can consist, for example, of one or more rectifiers or inverters.

3.4.2
motor
electric motor
electric machine intended to transform electric energy into mechanical energy

Note 1 to entry: For the purposes of this document, the motor includes all sensors which are mounted on it and which are relevant for supporting the operating mode and interacting with a CDM.

[SOURCE: IEC 60050:2001, 151-13-41, modified — The note has been added.]

~~3.4.3~~
~~**motor (of the PDS)**~~
~~for the purposes of this standard, the motor includes all sensors which are mounted on it and which are relevant for supporting the operating mode and interacting with a CDM~~

3.4.3
sub-component ~~**(of the PDS)**~~
~~for the purposes of this standard, a component of the PDS may be divided in sub-components, each of them being a~~ physical piece of equipment which can be operated separately with an intrinsic function defined by the manufacturer

Note 1 to entry: For the purpose of this document, a component of the PDS can be divided into sub-components.

Note 2 to entry: As an example, the control unit of a CDM may be a sub-component.

3.5 Phenomena-related definitions

3.5.1
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

[SOURCE: IEC 60050-161:1990, 161-01-07]

3.5.2
total harmonic current
THC
total RMS value of the harmonic current components of orders 2 to 40

$$THC = \sqrt{\sum_{h=2}^{40} I_h^2}$$

[SOURCE: IEC 61000-3-12:2011, 3.1]

3.5.3
total harmonic distortion
THD
ratio of the RMS value of the harmonic content to the RMS value of the fundamental component or the reference fundamental component of an alternating quantity

Note 1 to entry: The harmonic content depends on the choice of the fundamental component. If it is not clear from the context which one is used, an indication should be given.

Note 2 to entry: The total harmonic distortion can be restricted to a certain harmonic order (recommended notation "H"), which is 40 for the purpose of this document.

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

where, in addition to the notes to entry of B.2.2.7,

Q_1 is the RMS value of the fundamental component.

[SOURCE: IEC 60050-551:2001, 551-20-13, modified — The term "total harmonic ratio" has been deleted, the formula has been added and Note 1 to entry has been rephrased. In Note 2 to entry, the sentence "This is to be stated" has been deleted and the part "(recommended notation "H"), which is 40 for the purpose of this document" has been added.]

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3.5.4
voltage deviation
difference between the voltage at a given instant and the declared supply voltage

[SOURCE: IEC 60050-614:2016, 614-01-04]

3.5.5
voltage change
variation of the RMS or peak value of a voltage between two consecutive levels sustained for definite but unspecified durations

Note 1 to entry: Whether the RMS or peak value is chosen depends upon the application, and which is used should be specified.

[SOURCE: IEC 60050-161:1990, 161-08-01]

3.5.6
voltage fluctuation
series of voltage changes or a continuous variation of the RMS or peak value of the voltage

Note 1 to entry: Whether the RMS or peak value is chosen depends upon the application, and which is used should be specified.

[SOURCE: IEC 60050-161:1990, 161-08-05]

3.5.7
voltage dip
sudden reduction of the voltage at a point in an electrical system, followed by voltage recovery after a short period of time, from a few cycles to a few seconds

[SOURCE: IEC 60050-614:2016, 614-01-08, modified — The second preferred term "voltage sag" has been deleted. In the definition, the words "electric power system" has been replaced by "electrical system", and the words "from a few periods of the sinusoidal wave of the voltage to a few seconds" by "from a few cycles to a few seconds".]

4 Common requirements

4.1 General conditions

All phenomena, from the emission or immunity point of view, shall be considered individually. The limits are given for conditions which do not consider the cumulative effects of different phenomena.

For a realistic assessment of the EMC situation, a typical configuration shall be chosen.

The application of tests for evaluation of immunity depends on the particular PDS, its configuration, its ports, its technology and its operating conditions (see annexes).

4.2 Tests

4.2.1 Conditions

IEC 60146-1-1 and IEC 61800-2 distinguish between type test, routine test and special test. Unless otherwise stated, all the tests specified in this document are type tests only. The equipment shall meet the EMC requirements under all normal operating conditions as stated in the operating manual of the equipment when measured by the test methods specified in this document.

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NOTE 1 Due to local radio transmission legislation, some immunity tests can be subject to conditions which restrict the choice of location where they can be performed.

If necessary, safeguards shall be taken against any unintended effects on the total process that may result from an equipment failure while an EMC test is being conducted.

For the tests, ~~unless otherwise specified by the manufacturer,~~ the CDM shall be connected to a ~~standard~~ motor ~~of adequate ratings~~ recommended by the manufacturer with a cable and earthing rules defined by the manufacturer. ~~In some cases~~ Alternatively, a passive test load ~~conditions~~ (resistive, or resistive and inductive) may ~~additionally~~ be applied (for example, for evaluation of the low-frequency emissions), if permitted by the manufacturer.

NOTE 2 For high frequency emissions, passive test load can be unsuitable to simulate differential and common mode capacitances and couplings typically present.

The description of the tests, the test methods, the characteristics of the tests and the test set-ups are given in the referred standards and are not repeated here. If, however, modifications or additional requirements and information or specific test methods are needed for practical implementation and application of the tests, then they are given in this document.

A sufficient number of terminals shall be selected to simulate actual operating conditions and to ensure that all relevant types of termination are covered. The tests shall be carried out at the rated supply voltage and in a reproducible manner.

4.2.2 Test report

The test results shall be documented in a test report. The report shall clearly and unambiguously present all relevant information ~~of the tests (for example: load conditions, cable laying, etc.)~~ for reproducible testing. A functional description and detailed acceptance criteria provided by the manufacturer shall be noted in the test report.

Within the test report, the chosen test arrangements shall be justified. ~~A sufficient number of terminals shall be selected to simulate actual operating conditions and to ensure that all relevant types of termination are covered. The tests shall be carried out at the rated supply voltage and in a reproducible manner.~~ Whenever a subclause of this document offers alternative test methods, the chosen test method shall be stated in the test report. The information on test methods showed in Table 1 shall be given:

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Table 1 – Subclauses containing alternative test methods

Subclause	Test methods
5.1.2	Type of test: – general system performance test; or – special system performance test; or – sub-component performance test.
5.2 and sub-clauses	Immunity verification by: – calculation; or – simulation; or – test.
5.3.2	Fast transient burst for equipment ≥ 100 A: – direct coupling; or – capacitive clamp.
5.3.3	Fast transient burst for equipment ≥ 100 A: – direct coupling; or – capacitive clamp.
5.3.4	Immunity against electromagnetic fields: – PDS test; or – sub-components test.
6.2.1	Emission verification by: – calculation; or – simulation; or – test.
6.3.1.1	Test on a test site or in situ
6.3.1.2	Conducted emission tests: – with CISPR artificial mains network; or – with high impedance voltage probe.
6.3.1.3.3	Radiated emissions: measurement distance

4.3 Documentation for the user

The setting of limits and the structure of this document are based on the understanding that the installer and user are responsible for following the EMC recommendations of the manufacturer.

The manufacturer shall supply the documentation necessary for the ~~installer~~ correct installation of a BDM, CDM or ~~for the user of a~~ PDS ~~for the correct installation~~ into a typical system or process in the intended environment. This information includes any emission warnings required by 6.1 and Table 15. It also includes the warnings required by 5.3.2 in the case where the immunity of a BDM, CDM or PDS is not suitable for the second environment.

NOTE 1 From the emission point of view, a PDS (or BDM or CDM) with a lower emission category, such as C1, can always be used instead of one with a higher emission category, such as C3.

NOTE 2 Emission categories are independent of immunity. For example, a statement that a PDS has emission category C1 does not imply that the immunity is only suitable for the first environment.

If special EMC measures are necessary to fulfil the required limits, these shall be clearly stated in the user documentation. Where relevant, these can include the following:

- maximum and minimum acceptable supply network impedance;
- the use of shielded or special cables (power and/or control);
- cable shield connection requirements;

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- maximum permissible cable length;
- cable segregation;
- the use of external devices such as filters;
- the correct bonding to functional earth.

If different devices or connection requirements apply in different environments, this shall also be stated.

A list of auxiliary equipment (for example, options or enhancements) that can be added to the PDS, and which complies with the immunity and/or emission requirements shall be made available.

This information may also be covered in some part of the test report to clarify the final recommended arrangement.

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5 Immunity requirements

5.1 General conditions

5.1.1 Acceptance criteria (performance criteria)

The system performance relates to the functions of the BDM, or of the CDM, or of the PDS as a whole that are declared by the manufacturer.

The sub-component performance relates to the functions of the sub-components of the BDM, or of the CDM, or of the PDS that are declared by the manufacturer.

The sub-component performance may be tested as an alternative instead of the system performance to show immunity (see 5.1.2). In the test report, it shall be stated which test has been applied.

Although this document allows tests on sub-components (components of CDM/BDM), it is not intended to be used for the separate conformity assessment of sub-components.

The acceptance criteria shall be used to check the performance of a PDS against external disturbances. From the EMC point of view, any installation according to Figure 1 shall be running properly. Since a PDS is part of the functional sequence of a larger process than the PDS itself, the effect on this process caused by changes in the performance of the PDS is hard to forecast. However, this important aspect for large systems should be covered by an EMC plan (see Annex E).

The main functions of a PDS are energy conversion between the electrical form and the mechanical form, and the information processing necessary to perform this.

Table 2 classifies the effects of a given disturbance into three acceptance (performance) criteria: A, B and C, both for the PDS and for its sub-components.

Subclauses 5.2 and 5.3 state the acceptance criterion required for each phenomenon.

5.1.2 Selection of performance type

5.1.2.1 General or special system performance

The “general system performance” item from Table 2 shall be defined in accordance with the special application and typical configuration of the PDS. It is the responsibility of the manufacturer to select these items.

The special system performance, torque-generating behaviour, shall be tested only in cases where it is explicitly defined in the product specification. In this case, the torque generating performance can be directly or indirectly tested. The direct test uses an EMC immune torquemeter to measure torque disturbances.

Torque performance can be defined through the ability to keep current or speed constant, within specified tolerances, when a disturbance is applied (see also 5.1.3). Therefore, a test of current performance can be used as an indirect test of torque-generating performance. For EMC assessment, and unless otherwise agreed, the output current of the power converter is deemed to represent torque with sufficient accuracy. As an alternative, the indirect test can use speed performance provided the total inertia is specified.

5.1.2.2 Sub-component performance

Testing of sub-components with sub-component performance should be used in cases when a PDS cannot be put into service on a test site because of limitation on the physical size of the PDS, on the current or rated supply capability or load conditions. In any case, the test set-up shall be immune to the highest level of disturbance applied to the PDS or to the sub-component under test.

Testing of information processing and sensing functions, including optional accessories if any, shall be performed only in cases where the relevant ports or interfaces are available at the PDS. Testing of the sub-component performance, according to Table 2, where the functions exist, is sufficient to determine the compliance with this document.

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Table 2 – Criteria to prove the acceptance of a PDS against electromagnetic disturbances

Item	Acceptance (performance) criterion [a]		
	A	B	C
General system performance	No noticeable changes of the operating characteristic Operating as intended, within specified tolerance	Noticeable changes (visible or audible) of the operating characteristic Self-recoverable	Shutdown, changes in operating characteristics Triggering of protective devices [b] Not self-recoverable
Special system performance Torque generating behaviour	Torque deviation within specified tolerances	Temporary torque deviation outside specified tolerances Self-recoverable	Loss of torque Not self-recoverable
Sub-component performance Operation of power electronics and driving circuits	No malfunction of a power semiconductor	Temporary malfunction which cannot cause unintended shut-down of the PDS	Shut-down, triggering of protective devices [b] No loss of stored program No loss of user program No loss of settings Not self-recoverable
Sub-component performance Information processing and sensing functions	Undisturbed communication and data exchange to external devices	Temporarily disturbed communication, but no error reports of the internal or external devices which could cause shut-down	Errors in communication, loss of data and information No loss of stored program, no loss of user program No loss of settings. Not self-recoverable
Sub-component performance Operation of displays and control panels	No changes of visible display information, only slight light intensity fluctuation of LEDs, or slight movement of characters	Visible temporary changes of information, undesired LED illumination	Shut down, permanent loss of information, or unpermitted operating mode, obviously wrong display information No loss of stored program, no loss of user program No loss of settings

[a] Acceptance criteria A, B, C – False starts are not acceptable. A false start is an unintended change from the logical state "STOPPED" which can make the motor run.

[b] Acceptance criterion C – The function can be restored by operator intervention (manual reset). Opening of fuses is allowed for line-commutated converters operating in inverting mode.

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5.1.3 Conditions during the test

The load shall be within the manufacturer's specification and the actual load shall be noted in the test report.

Testing the torque generating behaviour as well as the information processing and sensing functions requires special test equipment with adapted immunity against the parasitic coupling of the test disturbance. It can only be used if the immunity of the test set-up can be proven by reference measurements. The evaluation of the torque disturbance can be performed by a torque transducer or by measurement or calculation of the torque generating current or other indirect techniques; an adapted and immune load shall be available at the test-site.

For testing the performance of the information processing or sensing function, suitable equipment shall be available to simulate the data communication or data evaluation. This equipment shall have sufficient immunity to operate correctly during the test.

Since the motor has been tested by its manufacturer according to the relevant standards, the motor component of the PDS, with exception of the sensors, does not need any additional EMC immunity test. Therefore, while the motor is connected to the BDM/CDM for the duration of the test, EMC immunity tests on the motor itself are not required.

The tests shall be applied to the relevant ports where they exist, including those of optional accessories if any. They shall be conducted in a well-defined and reproducible manner on a port-by-port basis. However, if several process measurement and control ports or signal interfaces have the same physical configuration (layout) it is sufficient to test one port or interface of that type.

In 5.2 and 5.3 the minimum requirements, tests and acceptance criteria are stated. The acceptance criteria refer to 5.1.1.

5.2 Basic immunity requirements – low-frequency disturbances

5.2.1 Common principle

The requirements in this subclause shall be used for designing the immunity of a PDS against low-frequency disturbances.

For the immunity requirements, the manufacturer may demonstrate compliance using either testing, calculation or simulation, and shall state the chosen verification method in the test report. Unless otherwise stated, it is sufficient to demonstrate that the power circuit will comply with the required acceptance criterion and that the ratings of input circuits (filters, etc.) will not be exceeded.

NOTE 1 A number of these phenomena are not required by the generic standards, but are important for the dimensioning of the power circuit of the PDS. It is difficult to test immunity against many of these phenomena, particularly when the input current exceeds 16 A or the supply voltage exceeds 400 V. However, experience of many years shows that, provided the power circuit operates correctly, the control part and the auxiliaries are generally immune. This is due to natural decoupling that exists in the PDS. Examples of such decoupling are that provided by power supplies and the time constants of auxiliary processes such as fans.

The compliance with the requirements of this document shall be stated in the user documentation. Where compliance is demonstrated by tests, the relevant basic standards in the IEC 61000-4 series may be considered (see Clause B.7).

NOTE 2 The electrical service conditions for the main and the auxiliary supply if any, are already defined in the PDS service conditions in the relevant standard IEC 61800-1 or IEC 61800-2 or IEC 61800-4. These service conditions include frequency variations, frequency rate of change, voltage variations, voltage fluctuations, voltage unbalance, harmonics and commutation notches.

~~NOTE 3 Possible consequences of exceeding the indicated levels (in accordance with IEC 60146-2) are:~~

~~F Functional with degradation of performance;~~

~~T Tripping or interruption of operation due to protective devices;~~

~~D Permanent damage (fuses acceptable).~~

~~Such consequences should not be regarded as an EMC concern, but as part of a safety analysis when relevant.~~

5.2.2 Harmonics and commutation notches/voltage distortion

5.2.2.1 Low voltage PDSs (voltage distortion)

The BDM, CDM or PDS shall sustain the immunity levels while meeting the performance criteria given in Table 3, Table 4 and Table 5. It shall be verified that these levels will not cause the ratings for the input circuits (filters, etc.) to be exceeded. Analysis of commutation notches shall be in the time domain. The manufacturer may verify immunity by calculation, simulation, or test, according to 5.2.1, and shall state the chosen verification method in the test report. If the chosen verification method is by test, it shall be performed using the PDS with the motor connected. For equipment rated below 16 A per phase, the test method of IEC 61000-4-13 can be applied.

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NOTE Frequency domain analysis of the contribution from notches to the total harmonic distortion will not ~~obviously reveal certain types of~~ fully account for harmful effects (see Clause B.1).

~~Table 2 – Minimum immunity requirements for harmonics and commutation notches/voltage distortion on power ports of low voltage PDSs~~

~~Phenomenon~~	~~First environment~~		~~Second environment~~		~~Performance (acceptance) criterion~~
	~~Reference document~~	~~Level~~	~~Reference document~~	~~Level~~	
~~Harmonics (*THD* and individual harmonic orders)~~	~~IEC 61000-2-2~~	~~Value of the compatibility level~~	~~IEC 61000-2-4 Class 3~~	~~Value of the compatibility level~~	~~A~~
~~Harmonics short term (< 15 s)~~	~~IEC 61000-2-2~~	~~1,5 times the value of the permanent compatibility levels~~	~~IEC 61000-2-4 Class 3~~	~~1,5 times the value of the permanent compatibility levels~~	~~B~~
~~Commutation notches~~	~~IEC 61000-1-1~~	~~No requirement~~	~~IEC 60146-1-1 Class B~~	~~Depth = 40 %, Total area = 250 in per cent degrees~~	~~A~~

Table 3 – Minimum immunity requirements for total harmonic distortion on power ports of low voltage PDSs

Phenomenon	First environment		Second environment		Performance (acceptance) criterion
	Reference document	Level	Reference document	Level	
Harmonics – THD	IEC 61000-2-2	8 %	IEC 61000-2-4 class 3	12 %	A

Table 4 – Minimum immunity requirements for individual harmonic orders on power ports of low voltage PDSs

Phenomenon Harmonic order	First environment		Second environment		Performance (acceptance) criterion
	Reference document	Level	Reference document	Level	
2	IEC 61000-4-13 class 2	3 %	IEC 61000-4-13 class 3	5 %	A
3		8 %		9 %	
4		1,5 %		2 %	
5		9 %		12 %	
Even orders $6 \leq h \leq 50$		No requirement		1,5 %	
7		7,5 %		10 %	
9		2,5 %		4 %	
11		5 %		7 %	
13		4,5 %		7 %	
15		No requirement		3 %	
17		3 %		6 %	
19		2 %		6 %	
21		No requirement		2 %	
23		2 %		6 %	

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Phenomenon Harmonic order	First environment		Second environment		Performance (acceptance) criterion
	Reference document	Level	Reference document	Level	
25		2 %		6 %	
27		No requirement		2 %	
29		1,5 %		5 %	
31		1,5 %		3 %	
33		No requirement		2 %	
35		1,5 %		3 %	
37		1,5 %		3 %	
39		No requirement		2 %	

NOTE 1 For individual harmonic orders in the first environment, levels are from Class 2 in IEC 61000-4-13 (these are approximately 1,5 times the compatibility levels of IEC 61000-2-4).

NOTE 2 For individual harmonic orders in the second environment, levels are from Class 3 in IEC 61000-4-13 (these are approximately 1,5 times the compatibility levels of IEC 61000-2-4).

Table 5 – Minimum immunity requirements for commutation notches on power ports of low voltage PDSs

Phenomenon	First environment		Second environment		Performance (acceptance) criterion
	Reference document	Level	Reference document	Level	
Commutation notches	(None)	No requirement	IEC 60146-1-1 Class B	Depth = 40 %, total area = 250 in % degrees	A

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5.2.2.2 PDSs of rated voltage above 1 000 V (voltage distortion)

5.2.2.2.1 Main power port

The PDS or BDM/CDM shall sustain the immunity levels given in Table 6. It shall be verified that these levels will not cause the ratings for the input circuits (filters, etc.) to be exceeded. Analysis of commutation notches shall be in the time domain. The manufacturer may verify immunity by calculation, simulation, or test, according to 5.2.1, and shall state the chosen verification method in the test report.

NOTE Frequency domain analysis of notches' contribution to total harmonic distortion will not obviously reveal certain types of harmful effects (see Clause B.1).

Table 6 – Minimum immunity requirements for harmonics and commutation notches/ voltage distortion on main power ports of PDSs of rated voltage above 1 000 V

Phenomenon	Reference document	Level	Performance (acceptance) criterion
Harmonics (*THD* and individual harmonic orders)	IEC 61000-2-4 Class 3	Value of the compatibility level	A ~~[a]~~
Harmonics short term (< 15 s)	IEC 61000-2-4 Class 2	1,5 times the value of the permanent compatibility levels	A ~~[a]~~
~~Interharmonics steady state~~	~~IEC 61000-2-4 Class 2~~	~~Value of the compatibility level~~	~~A [b]~~
~~Interharmonics short term (< 15 s)~~	~~IEC 61000-2-4 Class 2~~	~~1,5 times the value of the permanent compatibility levels~~	~~B [a]~~
Commutation notches	IEC 60146-1-1	Depth = 40% U_{LWM} (class B) Area [a] = 125 in per cent degrees (class C)	A ~~[a]~~

~~[a] The possible consequence of exceeding the level is T (see note 3 in 5.2.1).~~

~~[b] The possible consequence of exceeding the level is F (see note 3 in 5.2.1).~~

[a] Class C of IEC 60146-1-1 is appropriate for the primary side of the transformer.

5.2.2.2.2 Auxiliary power port

The auxiliary power ports of PDSs shall sustain the immunity levels for the second environment given in Table 3, Table 4 and Table 5 while meeting the performance criteria in those tables. It shall be verified that these levels will not cause the ratings for the input circuits (filters, etc.) to be exceeded. Analysis of commutation notches shall be in the time domain. The manufacturer may verify immunity by calculation, simulation, or test, according to 5.2.1, and shall state the chosen verification method in the test report.

NOTE Frequency domain analysis of notches' contribution to total harmonic distortion will not obviously reveal certain types of harmful effects (see Clause B.1).

~~**Table 4 – Minimum immunity requirements for harmonics and commutation notches/voltage distortion on auxiliary low voltage power ports of PDSs**~~

~~Phenomenon~~	~~Reference document~~	~~Level~~	~~Performance (acceptance) criterion~~
~~Harmonics (*THD* and individual harmonic orders)~~	~~IEC 61000-2-4 Class 2~~	~~Value of the compatibility level~~	~~A [a]~~
~~Harmonics short term (<15 s)~~	~~IEC 61000-2-4 Class 2~~	~~1,5 times the permanent compatibility levels~~	~~A [a]~~
~~Commutation notches~~	~~IEC 60146-1-1~~	~~Depth = 40%~~ U_{LWM} ~~Area [b] = 250 in per cent degrees~~	~~A [a]~~

~~[a] The possible consequence of exceeding the level is T (see note 3 in 5.2.1).~~

~~[b] According to IEC 60146-1-1 class B.~~

5.2.3 Voltage deviations ~~(variations, changes, fluctuations)~~, dips and short interruptions

5.2.3.1 Low voltage PDSs (voltage deviations)

The PDS or BDM/CDM shall sustain the immunity levels given in Table 7. The manufacturer may verify immunity by calculation, simulation, or test, according to 5.2.1, and shall state the chosen verification method in the test report.

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Table 7 – Minimum immunity requirements for voltage deviations, dips and short interruptions on power ports of low voltage PDSs

Phenomenon	First environment			Second environment			Performance (acceptance) criterion
	Reference document	Level		Reference document	Level		
Voltage deviations (> 60 s)	IEC 61000-2-2	±10 % [a]		IEC 61000-2-4 Class 2	±10 % [a]		A [b]
~~Voltage dips and short interruptions~~	~~IEC 61000-2-1 [c]~~	~~depth 10 % to 100 %~~		~~IEC 61000-2-1 [c]~~	~~Depth 10 % to 100 %~~		~~C [d]~~
Voltage dips [e]	IEC 61000-4-11 Class 2 or IEC 61000-4-34 Class 2 [f]	Volts remaining 0 % 70 %	Cycles 1 25/30 [c]	IEC 61000-4-11 Class 3 or IEC 61000-4-34 Class 3 [f]	Volts remaining 0 % 40 % 70 % 80 %	Cycles 1 10/12 [c] 25/30 [c] 250/300 [c]	C [d]
Short interruptions	IEC 61000-4-11 Class 2 or IEC 61000-4-34 Class 2 [f]	Volts remaining 0 %	Cycles 250/ 300 [c]	IEC 61000-4-11 Class 3 or IEC 61000-4-34 Class 3 [f]	Volts remaining 0 %	Cycles 250/300[c]	C [d]

~~[a] If class 3 of IEC 61000-2-4 is required, this should be agreed between the manufacturer and user.~~

[a] "Voltage deviation" is a supply voltage variation from the nominal supply voltage. Testing of voltage deviations for three phase PDS requires increasing or reducing the voltage of all three phases simultaneously.

[b] When the voltage is below nominal, the maximum output power ratings – speed and/or torque – may be reduced, because they are voltage dependent.

~~[c] Typical depths and durations of voltage dips are given in 8.1.2 of IEC 61000-2-1.~~

[c] "x/y cycles" means "x cycles for 50 Hz test" and "y cycles for 60 Hz test".

[d] Opening of fuses is allowed for line-commutated converters operating in inverting mode.

[e] Power ports with current rating ≥75 A: the method of the voltage drop test according to 7.5 of IEC 61400-21:2008 may be used.

[f] IEC 61000-4-11 applies to equipment rated less than or equal to 16 A and IEC 61000-4-34 to equipment rated above 16 A.

~~NOTE 1~~ A PDS is used for energy conversion, and a voltage dip represents a loss of available energy. It ~~may~~ can be necessary to trip for safety reasons, even during a voltage dip of 30 % to 50 % amplitude and 0,3 s duration.

NOTE 1 A decreasing input voltage, even with few milliseconds duration, ~~may~~ can result in blowing of fuses when applied to a line commutated thyristor converter operating under regeneration mode.

NOTE 2 The effect of a voltage dip (energy reduction) on the process cannot be defined without detailed knowledge of the process itself. This effect is a system and rating aspect, and will generally be greatest when the power demand (including losses) on the PDS is higher than the available power.

Where it is possible and not dangerous, the behaviour of the PDS during short interruptions may be verified by switching off and on the mains supply during the standard operating conditions of the PDS (see B.6.1).

The manufacturer shall state in the user documentation the degradation of performance resulting from voltage dips or short interruptions.

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NOTE 3 Improvements to the immunity (use of UPS, stand-by generator, derating, etc.) ~~may~~ can result in a considerable increase in the size and cost of the PDS and ~~may~~ can reduce the efficiency or power factor. Operation such as automatic restart ~~may~~ can have safety consequences, and are not covered by this document.

5.2.3.2 PDSs of rated voltage above 1 000 V (voltage deviations)

5.2.3.2.1 Main power port

Main power ports of PDSs shall sustain the immunity levels given in Table 8. The manufacturer may verify immunity by calculation, simulation, or test, according to 5.2.1, and shall state the chosen verification method in the test report.

Table 8 – Minimum immunity requirements for voltage deviations, dips and short interruptions on main power ports of rated voltage above 1 000 V of PDSs

Phenomenon	Reference document	Level		Performance (acceptance) criterion
Voltage deviations exceeding 1 min	IEC 61000-2-4 Class 3	±10 %		A [a]
Voltage deviations not exceeding 1 min	IEC 61000-2-4 Class 3	~~Maximum step amplitude: 12 % of nominal voltage within the tolerance band~~ +10 % to –15 %		A [a]
~~Voltage changes~~	~~IEC 61000-2-4~~ ~~Class 3~~	~~Minimum interval between steps: 2 s~~		~~A [a]~~
~~Voltage dips and short interruptions~~	~~IEC 61000-2-1 [b]~~	~~Depth and duration~~ ~~15 % to 50 % and $t \leq 100$ ms~~ ~~15 % to 100 %~~		~~B, C [c]~~ ~~C~~
Voltage dips	IEC 61000-4-34 [b]	Volts remaining 0 % 40 % 70 % 80 %	Cycles 1 10/12 [c] 25/30 [c] 250/300 [c]	C [d]
Short interruptions	IEC 61000-4-34 [b]	Volts remaining 0 %	Cycles 250/300 [c]	C [d]

[a] "Voltage deviation" is a supply voltage variation from the nominal supply voltage. Testing of voltage deviations for three phase PDSs requires increasing or reducing the voltage of all three phases simultaneously.

When considering voltage deviations, any voltage steps shall not exceed ±12 % of nominal voltage and the time between steps shall not be less than 2 s.

When the voltage is below nominal, the maximum output power ratings – speed and/or torque – may be reduced, because they are voltage dependent.

~~The possible consequence of exceeding the level is T or D (see note 3 in 5.2.1), in the last case the system supplier should provide information on the actual behaviour of the PDS.~~

[b] Typical depths and durations of voltage dips are given in ~~8.1.2 of IEC 61000-2-1~~ IEC TR 61000-2-8.

~~[c] Criterion C applies only to line or load-commutated thyristor controlled converters.~~

[c] "x/y cycles" means "x cycles for 50 Hz test" and "y cycles for 60 Hz test".

[d] Opening of fuses is allowed for line-commutated converters operating in inverting mode.

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The manufacturer shall state in the user documentation the degradation of performance resulting from voltage dips or short interruptions.

5.2.3.2.2 Auxiliary power port

The auxiliary power ports of PDSs shall sustain the immunity levels given in Table 9. The manufacturer may verify immunity by calculation, simulation, or test, and shall state the chosen verification method in the test report.

Table 9 – Minimum immunity requirements for voltage deviations, dips and short interruptions on auxiliary low voltage power ports of PDSs

Phenomenon	Reference document	Level		Performance (acceptance) criterion
Voltage deviations exceeding 1 min	IEC 61000-2-4 Class 3	±10 %		A [a]
Voltage deviations not exceeding 1 min	IEC 61000-2-4 Class 3	+10 % to –15 %		A [a]
~~Voltage dips and short interruptions~~	~~IEC 61000-2-1 [b]~~	~~Depth and duration~~ ~~15 % to 50 % and $t \leq 100$ ms~~ ~~15 % to 100 % and $t \leq 5$ s~~		~~B~~ ~~B~~
Voltage dips	IEC 61000-4-11 or IEC 61000-4-34 [b]	Volts remaining	Cycles	C
		0 %	1	
		40 %	10/12 [a]	
		70 %	25/30 [a]	
		80 %	250/300 [a]	
Short interruptions	IEC 61000-4-11 Class 3 or IEC 61000-4-34 Class 3 [b]	Volts remaining	Cycles	C
		0 %	250/300 [a]	

~~[a] The possible consequence of exceeding the level is T (see note 3 in 5.2.1).~~

[a] "x/y cycles" means "x cycles for 50 Hz test" and "y cycles for 60 Hz test".

~~[b] Typical depths and durations of voltage dips are given in 8.1.2 of IEC 61000-2-1.~~

[b] IEC 61000-4-11 applies to equipment less or equal to 16 A and IEC 61000-4-34 applies to equipment above 16 A.

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5.2.4 Voltage unbalance and frequency variations

5.2.4.1 Low voltage PDSs

Definition and assessment of voltage unbalance are explained in B.5.2.

The PDS or BDM/CDM shall comply with the immunity levels given in Table 10. The manufacturer may verify immunity by calculation, simulation, or test, and shall state the chosen verification method in the test report. During verification, the rated load condition shall be used.

Table 10 – Minimum immunity requirements for voltage unbalance and frequency variations on power ports of low voltage PDSs

Phenomenon	First environment		Second environment		Performance (acceptance) criterion
	Reference document	Level	Reference document	Level	
Voltage unbalance [a]	IEC 61000-2-2	2 % negative sequence component	IEC 61000-2-4 Class 3	3 % negative sequence component	A [b]
Frequency variations	IEC 61000-2-2	±2 %	IEC 61000-2-4	±2 % ±4 % where the supply is separated from public supply networks	A
Frequency rate of change		1 %/second		±1 %/s 2 %/s where the supply is separated from public supply network	A

[a] Not relevant for single phase PDSs.
[b] In case of test, use test time of 30 s ± 5 s.

5.2.4.2 PDSs of rated voltage above 1 000 V

5.2.4.2.1 Main power port

Definition and assessment of voltage unbalance are explained in B.5.2.

The PDS or BDM/CDM shall sustain the immunity levels given in Table 11. The manufacturer may verify immunity by calculation, simulation, or test, and shall state the chosen verification method in the test report. During verification, the rated load condition shall be used.

Table 11 – Minimum immunity requirements for voltage unbalance and frequency variations on main power ports of rated voltage above 1 000 V of PDSs

Phenomenon	Reference document	Level	Performance (acceptance) criterion
Voltage unbalance	IEC 61000-2-4 Class 2	2 % negative sequence component	A
Frequency variations	IEC 61000-2-4	±2 % ±4 % where the supply is separated from public supply networks	A ~~[b]~~ A ~~[c]~~
Frequency rate of change		±1 %/s 2 %/s where the supply is separated from public supply networks	A ~~[b]~~ A ~~[c]~~

~~[a] The possible consequence of exceeding the level is F or T. In the latter case, the system supplier should provide information on the actual behaviour of the PDS (see note 3 in 5.2.1).~~
~~[b] The possible consequence of exceeding the level is F (see note 3 in 5.2.1).~~
~~[c] The possible consequence of exceeding the level is T (see note 3 in 5.2.1).~~

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5.2.4.2.2 Auxiliary power port

Definition and assessment of voltage unbalance are explained in B.5.2.

The auxiliary power ports of PDSs shall sustain the immunity levels given in Table 12. The manufacturer may verify immunity by calculation, simulation, or test, and shall state the chosen verification method in the test report.

Table 12 – Minimum immunity requirements for voltage unbalance and frequency variations on auxiliary low voltage power ports of PDSs

Phenomenon	Reference document	Level	Performance (acceptance) criterion
Voltage unbalance	IEC 61000-2-4 Class 3	3 % negative sequence component	A
Frequency variations	IEC 61000-2-4	±2 % ±4 % where the supply is separated from public supply networks	 A [b] A [c]

~~[a] The possible consequence of exceeding the level is F or T. In the latter case, the system supplier should provide information on the actual behaviour of the PDS (see note 3 in 5.2.1).~~

~~[b] The possible consequence of exceeding the level is F (see note 3 in 5.2.1).~~

~~[c] The possible consequence of exceeding the level is T (see note 3 in 5.2.1).~~

5.2.5 Supply influences – Magnetic fields

Immunity tests according to IEC 61000-4-8 are not required (see Clause A.3 for explanation).

5.3 Basic immunity requirements – High-frequency disturbances

5.3.1 Conditions

In the following Table 13 and Table 14, the minimum immunity requirements for high-frequency disturbance tests and acceptance criteria are stated. The acceptance criteria refer to 5.1.1. Explanations are given in Clause A.3.

5.3.2 First environment

The levels in Table 13 shall be applied to PDSs which are intended to be used in the first environment.

If a CDM/BDM is designed to have immunity according to Table 13, it shall include a written warning in the instructions for use which indicates that it is not intended to be used in an industrial installation.

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Table 13 – Minimum immunity requirements for PDSs intended for use in the first environment

Port	Phenomenon	Basic standard for test method	Level	Performance (acceptance) criterion
Enclosure port	ESD (electrostatic discharge)	IEC 61000-4-2	4 kV CD or 8 kV AD if CD impossible	B
	Radio-frequency electromagnetic field, amplitude modulated	IEC 61000-4-3 see also 5.3.4	80 MHz to 1 000 MHz 3 V/m 80 % AM (1 kHz)	A
	Radio-frequency electromagnetic field, amplitude modulated	IEC 61000-4-3 See also 5.3.4	1,4 GHz to 2,0 GHz 3 V/m 80 % AM (1 kHz)	A
	Radio-frequency electromagnetic field, amplitude modulated	IEC 61000-4-3 See also 5.3.4	2,0 GHz to 2,7 GHz 1 V/m 80 % AM (1 kHz)	A
Power ports (except auxiliary DC power ports below 60 V)	Fast transient-burst	IEC 61000-4-4	1 kV/5 kHz [a]	B
	Surge [b] 1,2/50 μs, 8/20 μs	IEC 61000-4-5	1 kV [c] 2 kV [d]	B
	Conducted radio-frequency common mode	IEC 61000-4-6 see also 5.3.4	0,15 MHz to 80 MHz 3 V 80 % AM (1 kHz)	A
Power interfaces	Fast transient-burst [e]	IEC 61000-4-4	1 kV/5 kHz Capacitive clamp	B
Ports for process measurement control lines and signal interfaces Auxiliary DC power ports below 60 V	Fast transient-burst [e]	IEC 61000-4-4	~~1~~ 0,5 kV/5 kHz Capacitive clamp	B
	Conducted radio-frequency common mode [e]	IEC 61000-4-6 see also 5.3.4	0,15 MHz to 80 MHz 3 V 80 % AM (1 kHz)	A

CD: contact discharge AD: air discharge AM: amplitude modulation

[a] Power ports with current rating < 100 A: direct coupling using the coupling and decoupling network. Power ports with current rating ≥ 100 A: direct coupling or capacitive clamp without decoupling network. If the capacitive clamp is used, test level shall be 2 kV/5 kHz. The chosen test method shall be stated in the test report.

[b] Applicable only to power ports with current consumption < 63 A during light load test conditions as specified in 5.1.3. ~~The rated impulse voltage of the basic insulation shall not be exceeded (see IEC 60664-1).~~

[c] Coupling line-to-line.

[d] Coupling line-to-earth.

[e] Applicable only to ports or interfaces with cables whose total length according to the manufacturer's functional specification may exceed 3 m.

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5.3.3 Second environment

The levels in Table 14 shall be applied to PDSs which are intended to be used in the second environment. This also applies to the low voltage ports, or the low voltage interfaces (power, signal) of PDSs of rated voltage above 1 000 V.

NOTE Examples of low voltage ports and interfaces of a PDS of rated voltage above 1 000 V are as follows:

LV enclosure port	enclosure of auxiliaries, control and protection;
LV power ports	LV power supply of PDS;
LV power interfaces	auxiliary supply distribution within main components of PDS;
LV signal interfaces	LV signal interfaces within main components of PDS;
LV process port	signal port of the PDS.

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Table 14 – Minimum immunity requirements for PDSs intended for use in the second environment

Port	Phenomenon	Basic standard for test method	Level	Performance (acceptance) criterion
Enclosure port	ESD (electrostatic discharge)	IEC 61000-4-2	4 kV CD or 8 kV AD if CD impossible	B
	Radio-frequency electromagnetic field, amplitude modulated	IEC 61000-4-3 see also 5.3.4	80 MHz to 1 000 MHz 10 V/m 80 % AM (1 kHz)	A
	Radio-frequency electromagnetic field, amplitude modulated	IEC 61000-4-3 see also 5.3.4	1,4 GHz to 2,0 GHz 3 V/m 80 % AM (1 kHz)	A
	Radio-frequency electromagnetic field, amplitude modulated	IEC 61000-4-3 see also 5.3.4	2,0 GHz to 2,7 GHz 1 V/m 80 % AM (1 kHz)	A
Power ports (except auxiliary DC power ports below 60 V)	Fast transient-burst	IEC 61000-4-4	2 kV/5 kHz [a]	B
	Surge [b] 1,2/50 μs, 8/20 μs	IEC 61000-4-5	1 kV [c] 2 kV [d]	B
	Conducted radio-frequency common mode [e]	IEC 61000-4-6 see also 5.3.4	0,15 MHz to 80 MHz 10 V 80 % AM (1 kHz)	A
Power Interfaces	Fast transient-burst [e]	IEC 61000-4-4	2 kV/5 kHz Capacitive clamp	B
Signal interfaces	Fast transient-burst [e]	IEC 61000-4-4	1 kV/5 kHz Capacitive clamp	B
	Conducted radio-frequency common mode [e]	IEC 61000-4-6 see also 5.3.4	0,15 MHz to 80 MHz 10 V 80 % AM (1 kHz)	A
Ports for process measurement control lines Auxiliary DC power ports below 60 V	Fast transient-burst [e]	IEC 61000-4-4	2 kV/5 kHz Capacitive clamp	B
	Surge [f] 1,2/50 μs, 8/20 μs	IEC 61000-4-5	1 kV [d,f]	B
	Conducted radio-frequency common mode [e]	IEC 61000-4-6 see also 5.3.4	0,15 MHz to 80 MHz 10 V 80 % AM (1 kHz)	A
CD: contact discharge AD: air discharge AM: amplitude modulation				

[a] Power ports with current rating < 100 A: direct coupling using the coupling and decoupling network. Power ports with current rating ≥ 100 A: direct coupling or capacitive clamp without decoupling network. If the capacitive clamp is used, the test level shall be 4 kV/~~2,5~~ 5 kHz. The chosen test method shall be stated in the test report.

[b] Applicable only to power ports with current consumption < 63 A during light load test conditions as specified in 5.1.3. ~~The rated impulse voltage of the basic insulation shall not be exceeded (see IEC 60664-1).~~

[c] Coupling line-to-line.

[d] Coupling line-to-earth.

[e] Applicable only to ports or interfaces with cables whose total length according to the manufacturer's functional specification may exceed 3 m.

[f] Applicable only to ports with cables whose total length according to the manufacturer's functional specification may exceed 30 m. In the case of a shielded cable, a direct coupling to the shield is applied. This immunity requirement does not apply to fieldbus or other signal interfaces where the use of surge protection devices is not practical for technical reasons. The test is not required where normal functioning cannot be achieved because of the impact of the coupling/decoupling network on the equipment under test (EUT).

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These phenomena are not relevant for application to the ports of rated insulation voltage above 1 000 V. For simplicity, such ports are named HV ports of PDSs of rated voltage above 1 000 V.

NOTE Examples of HV ports and interfaces of a PDS of rated voltage above 1 000 V are as follows:

HV enclosure port	enclosure of transformer, converter section and motor;
HV power port	primary side of transformer;
HV power interfaces	HV distribution within main components of PDS;
HV signal interfaces	HV signal interfaces within main components of PDS.

5.3.4 Immunity against electromagnetic fields

If the PDS is

- of rated voltage not more than 500 V,
- of rated current not more than 200 A,
- of total mass not more than 250 kg, and
- of height, width, and depth not more than 1,9 m,

the tests of IEC 61000-4-3 and IEC 61000-4-6 shall be performed (see 5.3.2 and 5.3.3).

If the PDS is larger or of higher rating than in the above paragraph, then the manufacturer shall choose either

- to perform the tests of IEC 61000-4-3 and IEC 61000-4-6 on the PDS, or
- to perform the tests of IEC 61000-4-3 and IEC 61000-4-6 on sensitive sub-components and state the chosen test method in the test report.

If the motor is too large to be put into service on a test site, the motor may be replaced by one of smaller size, provided this does not adversely affect the operation of the CDM/BDM.

~~In the case where only sub-components have been tested, a test against radio-communication devices of common industrial use should be performed on the complete PDS, as described in A.3.2.2. This test is only valid for the specific location, installed equipment and frequencies tested.~~

5.4 Application of immunity requirements – Statistical aspect

When choosing the acceptance level for a specific test of a PDS, it shall be understood that the test result implies only a probability of performance. Depending on the acceptance criterion and the application of a PDS, this probability shall be considered in specifying the number of test pulses or duration of the test.

Immunity requirements in 5.3 shall be verified by performing a type-test on a representative unit. The manufacturer or supplier shall ensure the EMC performance of the product is maintained in production by using some form of quality control.

Measurement results obtained for a PDS while installed in its place of use (not on a test site) shall relate to that installation only.

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6 Emission

6.1 General emission requirements

The measurements shall be made in the operating mode producing the largest emission in the frequency band, while being consistent with the normal application.

Table 15 summarises the requirements, according to the classification of the PDS (see 3.2).

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Table 15 – Summary of emission requirements

Category	Low-frequency Disturbance voltage (power port)	High-frequency Disturbance voltage (power port)	Radiated emissions (enclosure port and others)
Category C1	Product assessment Requirements: - 6.2.2, - 6.2.3.1 or 6.2.3.2 or 6.2.3.3, - 6.2.4, - 6.2.5 Recommendations on load conditions: - B.2.3.3 and B.3.2 ~~1st environment~~	Product assessment Conducted emission limits: - 6.4.1.1, Table 16	Product assessment Radiated emission limits: - 6.4.1.3, Table 17 Other emission requirements: - 6.4.1.2; - 6.4.1.4
Category C2	Product assessment Requirements: - 6.2.2, - 6.2.3.1 or 6.2.3.2 or 6.2.3.3, - 6.2.4, - 6.2.5 Recommendations on load conditions: - B.2.3.3 and B.3.2 ~~1st environment or public network.~~	Product assessment Conducted emission limits: - 6.4.1.1, Table 16 Warning in the instruction for use: - 6.4.1.1	Product assessment Radiated emission limits: - 6.4.1.3, Table 17 Other emission requirements: - 6.4.1.2; - 6.4.1.4 Warning in the instruction for use: - 6.4.1.3
Category C3	Product assessment Requirements: - 6.2.2, - 6.2.3.4, - 6.2.4, - 6.2.5 Recommendations on load conditions: - B.2.3.3 and general rules B.3.3 and B.4 ~~2nd environment~~	Product assessment Conducted emission limits: - 6.4.2.2, Table 19 Warning in the instruction for use: - 6.4.2.1	Product assessment Radiated emission limits: - 6.4.2.4, Table 20 Other emission requirements: - 6.4.2.3 Warning in the instruction for use: - 6.4.2.1
Category C4	Engineering practice Requirements: - 6.2.2, - 6.2.3.4, - 6.2.4, - 6.2.5 Recommendations on load conditions: - B.2.3.3 and general rules B.3.3 and B.4 ~~2nd environment~~	Engineering practice Either - apply the requirements of Category C3 above, or - 6.5~~ – EMC plan~~	Engineering practice Either - apply requirements of Category C3 above, or - 6.5~~ – EMC plan~~

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6.2 Basic low-frequency emission limits

6.2.1 Compliance method

Compliance can be verified by calculation, simulation or test. The chosen verification method shall be stated in the test report.

6.2.2 Commutation notches

Commutation notches are measured on the power ports using an oscilloscope (see B.1.1). They are produced by controlled line-commutated converters (see 2.5.4.1 of IEC 60146-1-1).

Where it is known that the input circuit of the PDS does not produce notches or only produces notches of negligible amplitude (for example diode rectifiers), emission of notches need not be considered.

NOTE 1 The main practical case where emission of notches should be considered is the case of thyristor converters (line commutated). RFI filters are practical cases of equipment which can be affected by notches. They can be overloaded or subjected to repetitive overvoltages.

NOTE A diode rectifier is an uncontrolled line-commutated converter, which produces commutation notches of negligible amplitude. Some self-commutated converters (for example an indirect converter of the voltage source inverter type with an active front end) can produce commutation notches depending on the PWM pattern.

Where notches are to be considered, the manufacturer shall provide the following information to the user:

- value of any decoupling reactances which are included in the PDS;
- available decoupling reactances which can be externally added for mitigation (see B.1.2).

The recommendations of B.1.3 should be followed.

6.2.3 Harmonics and interharmonics

6.2.3.1 Low-voltage public supply network – Equipment covered by IEC 61000-3-2

Equipment may contain one or several PDSs and also other loads.

When a PDS is an equipment within the scope of IEC 61000-3-2, the requirements of that standard apply. However, when one or more PDSs are included in equipment within the scope of IEC 61000-3-2, the requirements of that standard apply to the complete equipment and not to the individual PDS. It is the responsibility of the equipment manufacturer to define the boundary of the system or sub-system to which IEC 61000-3-2 applies, and the method which demonstrates compliance of the equipment.

6.2.3.2 Low-voltage public supply network – Equipment covered by IEC 61000-3-12

When a PDS is within the scope of IEC 61000-3-12, the requirements of that standard apply. However, when one or more PDSs are included in equipment within the scope of IEC 61000-3-12, the requirements of that standard apply to the complete equipment and not to the individual PDS. It is the responsibility of the equipment manufacturer to define the boundary of the system or sub-system to which IEC 61000-3-12 applies, and the method which demonstrates compliance of the equipment.

6.2.3.3 Low-voltage public supply network – Equipment not covered by IEC 61000-3-2 or IEC 61000-3-12

For equipment not covered by IEC 61000-3-2 or IEC 61000-3-12 (rated current above 16 75 A) recommendations may be found in the technical report IEC 61000-3-4 and in Clause B.4. Where, for technical or economic reasons as explained in Annexes B and C of this standard,

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stage 1 or stage 2 of IEC 61000-3-4 cannot be applied, the approach of stage 3 is facilitated by Annex B.

The manufacturer shall provide in the documentation of the PDS, or on request, the ratio of the current harmonic level *THC*, under rated load conditions, as a percentage of the rated fundamental to the RMS current on the power port, as well as the harmonic currents up to the 40th harmonic. This may be produced by calculation, simulation or test.

For the purpose of calculation or simulation, the applied voltage shall be assumed to have a *THD* less than 1 %. The internal impedance of the network shall be assumed to be purely inductive. If the specific location of the PDS is not known, the harmonic currents shall be calculated assuming that the PDS is connected to a PC with the highest value of R_{SI} permitted by the PDS manufacturer.

$$R_{SI} = \frac{I_{SC}}{I_{LN}}$$

where

I_{SC} is the short circuit current at the considered PC;

I_{LN} is the rated input current of the PDS.

If the manufacturer does not state a maximum value of R_{SI}, a value of 250 shall be assumed. If the specific location of the PDS is known, the supply impedance at that location should shall be used.

The PDS manufacturer shall calculate the harmonic currents for each order up to the 40th. The current *THD* (orders up to and including 40) shall also be calculated.

A guide for calculation of harmonics is given in Clause A.1 and Clause A.2 of IEC TR 61000-2-6:1995. Guidelines for the summation of harmonics of different sources are also given in 7.4 of IEC TR 61000-2-6:1995.

Effects of interharmonics are considered in B.4.3. Methods for calculation are given in Annex C of IEC TR 61000-2-6:1995.

6.2.3.4 Industrial networks

If a PDS is to be used in an installation which is not directly supplied from a public low voltage network, IEC 61000-3-2 and IEC 61000-3-4 61000-3-12 are not applicable. Therefore, a reasonable approach which considers the total installation should be used (see Clause B.4).

NOTE For network voltages above 1 000 V, the total installation may can be subject to rules from the utility, usually based on IEC TR 61000-3-6. These rules apply to the installation as a whole, not to individual equipment. These rules usually take the existing harmonic currents and voltage distortion within the system into account. An efficient and simplified approach is provided by Table B.2.

In the case of a PDS of rated voltage above 1 000 V, harmonic emissions from the main power port and the auxiliary power ports shall be considered separately.

6.2.4 Voltage fluctuations

6.2.4.1 Conditions

Equipment may contain one or several PDSs and also other loads which are capable of causing voltage fluctuations.

NOTE 1 Voltage fluctuations may can be caused, for instance, by frequently changing the load of a PDS, or by sub-harmonics of slip energy recovery of asynchronous motors. Voltage fluctuations may can also be caused by interharmonics at frequencies slightly different from the fundamental or from predominant harmonics. The emission

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is typically generated by cyclo-converters or current source inverters. See B.4.3 and B.6.2. Interharmonics are covered by compatibility levels given in IEC 61000-2-4 or in IEC 61000-2-12.

NOTE 2 Voltage fluctuations are dependent on the impedance of the installation and the duty cycle of the load. In some applications, the user ~~may~~ can reduce voltage fluctuations by adjusting the load duty cycle by changing speed ramp rate or using other techniques.

~~NOTE 3~~ Most voltage fluctuations depend upon the installation. Therefore, this system aspect should be the responsibility of the user or of the installer. The compatibility levels given in IEC 61000-2-4 for voltage changes should not be exceeded considering cumulative effects from all equipment.

~~6.2.4.2 Low voltage PDSs~~

~~When a PDS is equipment within the scope of IEC 61000-3-3, the requirements of that standard apply. However, when one or more PDSs are included in equipment within the scope of IEC 61000-3-3, the requirements of that standard apply to the complete equipment and not to the individual PDS.~~

~~When a PDS is an equipment within the scope of IEC 61000-3-11, the requirements of that standard apply. However, when one or more PDSs are included in equipment within the scope of IEC 61000-3-11, the requirements of that standard apply to the complete equipment and not to the individual PDS.~~

~~6.2.4.3 PDSs of rated voltage above 1 000 V~~

~~The technical report IEC 61000-3-7 applies to the total installation considering all circuits on the load side of the PCC. Application of this report generally results in local rules from the utility. Compliance with the rules requires the assessment of total fluctuation emission of the total installation to which the considered PDS contributes.~~

~~NOTE Most voltage fluctuations are relevant to the installation. Therefore, this system aspect should be the responsibility of the user or of the installer. The compatibility levels given in IEC 61000-2-12 for voltage changes should not be exceeded considering cumulative effects from all equipment.~~

6.2.4.2 PDS in the scope of IEC 61000-3-3 and IEC 61000-3-11

When a PDS is within the scope of IEC 61000-3-3, the requirements of that standard apply. However, when one or more PDSs are included in equipment within the scope of IEC 61000-3-3, the requirements of that standard apply to the complete equipment and not to the individual PDS.

When a PDS is within the scope of IEC 61000-3-11, the requirements of that standard apply. However, when one or more PDSs are included in equipment within the scope of IEC 61000-3-11, the requirements of that standard apply to the complete equipment and not to the individual PDS.

NOTE Application of the voltage fluctuation limits of IEC 61000-3-3 and 61000-3-11 is only possible when the characteristics of the load provided by the driven equipment are known. For that reason, only the machine builder and/or end user are capable of characterizing compliance with regard to the voltage fluctuation limits.

6.2.4.3 PDS not in the scope of IEC 61000-3-3 and IEC 61000-3-11

For equipment not in the scope of IEC 61000-3-3 and IEC 61000-3-11, emissions of voltage fluctuations are generally dependent on the loading conditions and this document cannot give requirements.

NOTE Local rules given by local authorities can apply to the complete installation.

6.2.5 Emissions in the frequency range from 2 kHz to 9 kHz

In the frequency range from 2 kHz to 9 kHz, limits are not specified.

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NOTE 1 IEC SC 77A is working on compatibility levels in this frequency range.

NOTE 2 Until limits are specified in this frequency range, design recommendations for emission values for PDS and CDM can be found in IEC TS 62578:2015, Annex B.

6.2.6 Common mode harmonic emission (low-frequency common mode voltage)

The switching frequency of the converter of the PDS is often in the audible frequency range and, in particular, the frequency range commonly used by telephone and data systems. To avoid the risk of crosstalk to signal cables, the installation instructions shall either recommend that the power interface cable be segregated from signal cables or state alternative mitigation methods.

6.3 Conditions related to high-frequency emission measurement

6.3.1 General requirements

6.3.1.1 Common conditions

The rate of change of voltage or current is expected to be the main source of high-frequency emission. For this type of ~~emission~~ disturbance, the highest values of the dv/dt ~~values of the PDS~~ are mostly relevant ~~and these can be achieved~~ which usually occurs with output currents lower than the rated current of the PDS. Therefore, these tests are light load tests. The tests shall be applied to the relevant ports where they exist and shall be performed in a well-defined and reproducible manner on a port-by-port basis.

The test method shall comply with 7.3 to 7.4 and Clause 8 of CISPR 11:2015/AMD1:2016~~, paying particular attention to earth connections~~. The requirements for configuration of test setup for the PDS considering cables arrangement are derived from 7.5 of CISPR 11:2015/AMD1:2016, paying particular attention to earth connections. An example for a typical PDS test set up and cable arrangement for measurements of radiated disturbances in 3 m separation distance is described in 6.3.1.3 below. The load and cable lengths shall be within the manufacturer's specification and the actual load and power interface cable length shall be noted in the test report.

It shall be stated in the test report whether the tests have been performed on a test site or as *in situ* tests.

6.3.1.2 Conducted emissions

The measurement equipment for evaluation of high-frequency mains terminal (power port) disturbance voltage emission is either the artificial mains network (50 Ω/50 µH, see CISPR 16-1-2 and CISPR 11) where it can be applied, or the high impedance voltage probe according to 5.2.1 of CISPR 16-1-2:2014, where the artificial mains network is not applicable. The chosen test method shall be stated in the test report. Common-mode absorption devices (CMAD) shall not be used as part of the test setup for conducted emission measurement.

NOTE A CMAD is a piece of test equipment placed on certain cables during radiated emission measurements to improve reproducibility (see 6.3.1.3.4).

For *in situ* measurement of the mains disturbance voltage, a high impedance voltage probe without an artificial mains network shall be used (see 7.3.3 of CISPR 11:2015). The same can be applied if the PDS has an input current greater than 100 A, or if the input voltage is greater than or equal to 500 V, or if the PDS contains a line commutated converter (see A.4.1.2).

6.3.1.3 Radiated emissions

6.3.1.3.1 Type of test site

Equipment of category C1 and category C2 shall be measured on a test site compliant with requirements of CISPR 16-1-4. The measurement distance shall be stated in the test report.

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Equipment of category C3 should preferably be tested on a test site compliant with requirements of CISPR 16-1-4. However, when this proves to be impossible for practical reasons of weight, size or power, tests may be done in a location not fully compliant with the test site requirements. The use of this location shall be justified in the test report.

In the case of radiated emission tests on a test site, CISPR 11 allows test sites that are either an open-area test site (OATS) or a semi-anechoic chamber (SAC).

NOTE For radiated emissions measurement in a fully-anechoic room (FAR) test conditions and requirement are under consideration in CISPR/B. It is intended that they will be made available in CISPR 11.

6.3.1.3.2 Test volume

The measurement distance is considered between the reference point (RP) of the antenna calibration and the boundary of the EUT's test volume (see Figure 5 to Figure 7).

The selection of measurement distances shall comply with the requirements of 6.2.2.3 and 8.3.4 of CISPR 11:2015.

The boundary of the EUT's test volume is the imaginary cylinder around the complete configuration of the EUT. This boundary is shown as item H in Figure 5 and Figure 6. The motor and all the cables shall be inside the imaginary cylinder unless the cables leave the cylinder through CMAD(s). The height of the imaginary cylinder is measured from the floor, regardless of whether the EUT is table-top, wall-mounted equipment or standing on the floor.

The EUT is considered as small size equipment if the boundary of the EUT's test volume complies with the definition of 3.1.5. The maximum boundary for small size equipment is shown as item K in Figure 5 to Figure 7. The dimensions of the test volume should be measured with a tolerance of ±0,1 m.

The use of CMADs is recommended, as they contribute to reproducible test results. However, the use of CMADs is not mandatory. They serve to define the common mode impedance and resonances in the frequency range above 30 MHz, thus improving reproducibility.

6.3.1.3.3 Selection of measurement distance

Subclauses 6.4.1.3 and 6.4.2.4 give emission limits for tests at 10 m and 3 m distance.

Small size equipment meeting the size criterion defined in 3.1.5 may be tested at either 10 m or 3 m. Equipment not meeting this size criterion shall be tested at 10 m.

Special requirements relating to the test setup are specified in 6.3.1.3.4 to 6.3.1.3.6 for better reproducibility of measurement at 3 m. In cases where these requirements are practical for measurement at 10 m distance, they will also improve reproducibility at that distance.

6.3.1.3.4 Auxiliaries and peripherals

When auxiliaries or peripheral equipment are not part of the EUT (see EUT 2 in Figure 5 and Figure 6) they may be placed outside the test volume. However, if they cannot be excluded from the maximum test volume because the interconnecting cables are too short or for other reasons, these auxiliaries or peripheral equipment are put on the positioning table or on the insulated plane.

Restriction of radiation assessment to the cable fractions inside the test volume can be achieved for example by application at the cables of common-mode absorption devices (CMAD) at the position where they leave the test volume. CISPR 16-2-3 gives further guidance on the application of CMAD(s).

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6.3.1.3.5 Motor

For radiated emission, light load condition is usually acceptable for the PDS operation (see A.2.1 for information on load conditions).

The power rating of the motor used during the radiated emission test may be lower than the power rating of the CDM, but shall be large enough to allow correct operation of the inverter part of the CDM.

The motor can be put inside or outside the test volume. The power interface cable between the CDM/BDM and the motor shall be exposed to the antenna with at least 0,8 m length inside the test volume, unless the maximum cable length stated in the information for the user is shorter.

The position of the motor and the cable arrangement shall be stated in the test report.

6.3.1.3.6 Layout of setup for radiated emission tests

Examples of typical layouts for radiated emission tests are given in Figure 5 to Figure 7 below.

If a special earthing conductor is used (see "C" in Figure 7), its length shall be at least 1 m, and it shall be connected as shown in the user documentation.

NOTE 1 An example of a special earthing conductor is a second protective earthing conductor, which could be used for compliance with 4.3.5.5.2 of IEC 61800-5-1:2007.

If the motor is placed far from the turntable, the motor cable can be passed through the floor of the turntable (see dotted line path "A" in Figure 7). If the motor is placed beside the turntable (see "F" in Figure 7) and prevents the turntable from moving, special care should be considered for performing radiated emission measurement as for *in situ* condition (see A.4.2).

The use of an AMN in radiated emission tests is recommended but not mandatory.

Auxiliaries and peripheral equipment that are not part of the EUT should be located outside the test volume. However, if the connecting cables between them and the EUT cannot be extended to run outside the test volume, these auxiliaries and peripherals can be placed inside the test volume (see Figure 5 and Figure 6) or on the turntable (see Figure 7).

The spacing between all enclosures (EUT, peripheral etc.) should be ≥ 0,1 m. This is shown by item "D" in Figure 5 to Figure 7.

Where an interconnecting cable has an excess length, item "B" in Figure 5 and Figure 7 shows a cable bundle, as required by 7.5.2 of CISPR 11:2015. The excess cable is bundled between 0,3 m and 0,4 m in the middle of the cable length.

NOTE 2 The reference point of the antenna calibration is considered for the measuring distance as shown by item "RP" in Figure 5 to Figure 7.

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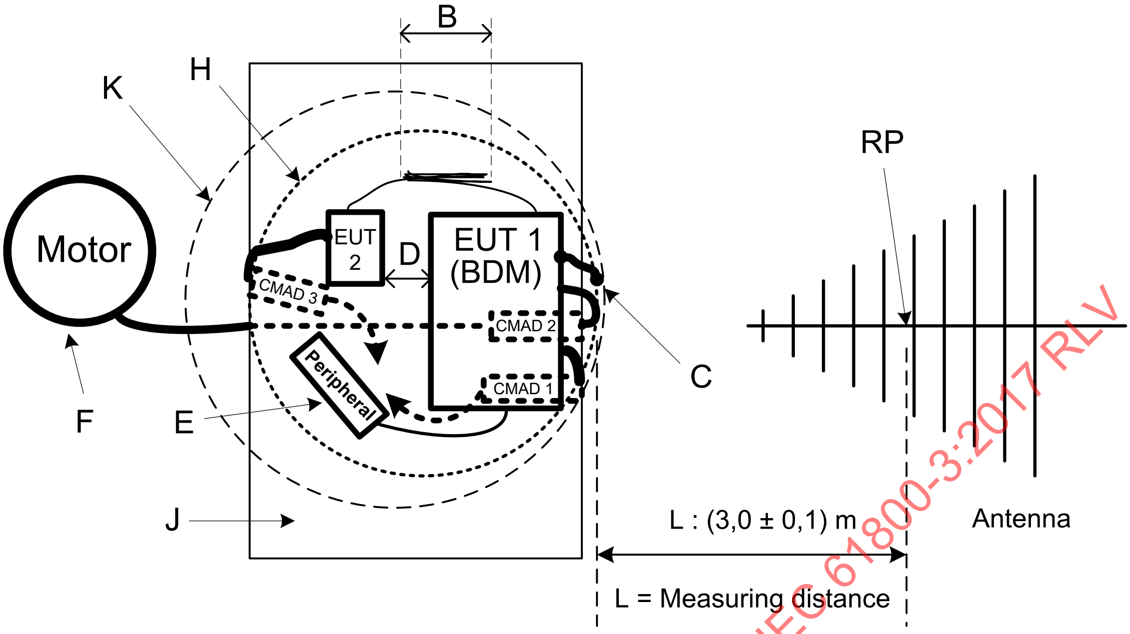

Key

B Excess cable is in a bundle of between 0,3 m and 0,4 m in the middle of the cable length.

C Special earthing connection, only if specified in the user documentation.

D Spacing between enclosures should be ≥ 0,1 m.

E The peripheral or auxiliary device is in the test volume only if the cables cannot be extended to allow the peripheral to be outside the test volume.

F Motor

H Test volume. This is the boundary of the imaginary cylinder around the complete configuration of the EUT (BDM/CDM parts of the PDS).

J Positioning table of insulating material, with height 0,8 m ± 0,01 m above the ground plane.

K Boundary of maximum test volume for small size equipment as defined in 3.1.5.

L Measuring distance. This distance is measured between the test volume, H, and the reference point of the antenna calibration, RP.

RP Reference point of the antenna calibration

Figure 5 – Example for a typical cable arrangement for measurements in 3 m separation distance, for a table-top or wall-mounted equipment, top view

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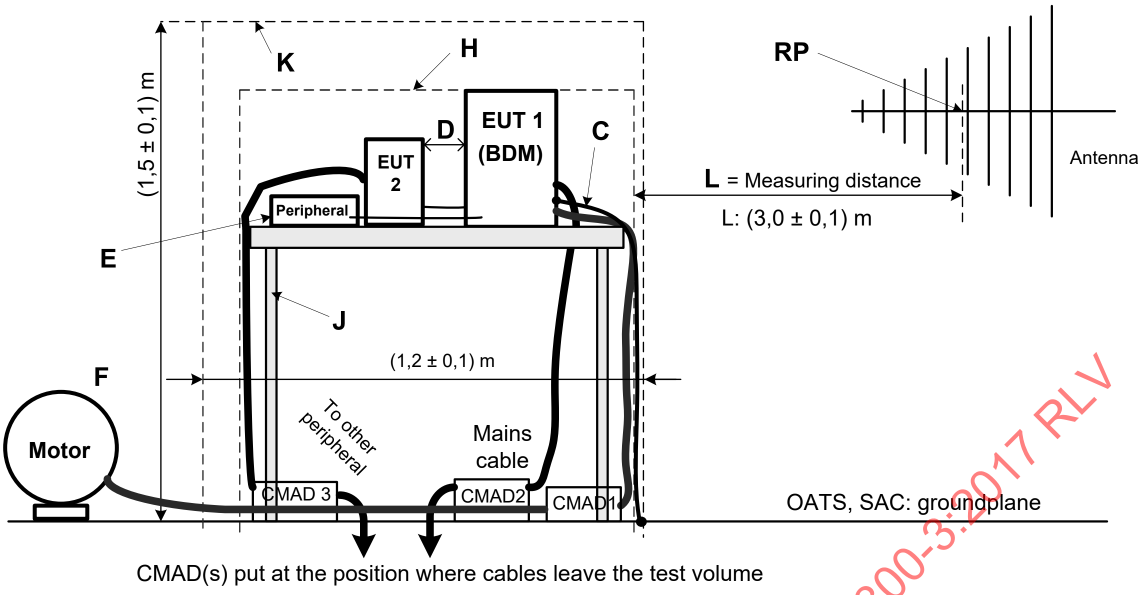

Key

C Special earthing connection, only if specified in the user documentation.

D Spacing between enclosures should be ≥ 0,1 m.

E The peripheral or auxiliary device is in the test volume only if the cables cannot be extended to allow the peripheral to be outside the test volume.

F Motor

H Test volume. This is the boundary of the imaginary cylinder around the complete configuration of the EUT (BDM/CDM parts of the PDS).

J Positioning table of insulating material, with height 0,8 m ± 0,01 m above the ground plane.

K Boundary of maximum test volume for small size equipment as defined in 3.1.5.

L Measuring distance. This distance is measured between the test volume, H, and the reference point of the antenna calibration, RP.

RP Reference point of the antenna calibration

Figure 6 – Example for a typical cable arrangement for measurements in 3 m separation distance for a table-top or wall-mounted equipment, side view

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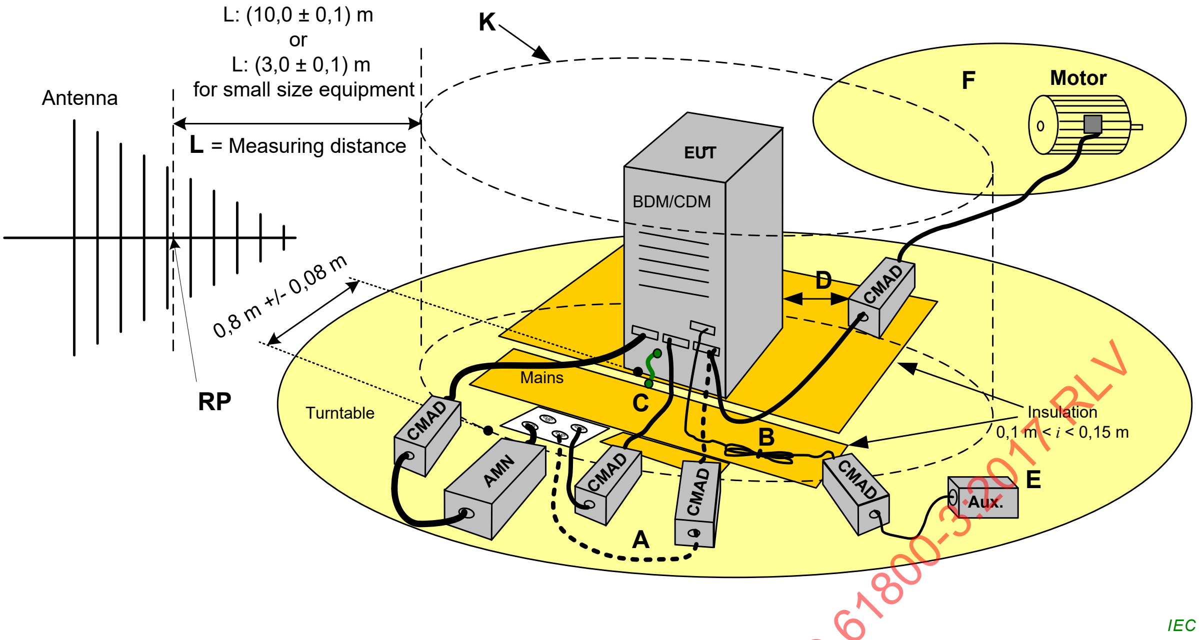

Key

A The dotted line shows the route of the motor cable when the motor is placed far from the turntable.

B Excess cable is in a bundle of between 0,3 m and 0,4 m in the middle of the cable length.

C Special earthing connection, only if specified in the user documentation.

D Spacing between enclosures should be ≥ 0,1 m.

E The peripheral or auxiliary device is in the test volume only if the cables cannot be extended to allow the peripheral to be outside the test volume.

F Motor

K Boundary of maximum test volume for small size equipment as defined in 3.1.5.

L Measuring distance. This distance is measured between the test volume and the reference point of the antenna calibration, RP.

RP Reference point of the antenna calibration

Figure 7 – Example for a typical test set up for measurement of conducted and/or radiated disturbances from a floor-standing PDS, 3D view

6.3.2 Connection requirements

If the PDS is measured on a test site, the test set up, including length and position of power and control cables, shall be representative of intended application(s), as defined by the manufacturer and described in the user documentation (see 4.3). The test set-up shall be stated in the test report.

If the PDS is measured *in situ*, the cable and the earthing arrangements are those of that application.

6.4 Basic high-frequency emission limits

6.4.1 Equipment of categories C1 and C2

6.4.1.1 Power port disturbance voltage

Limits for mains terminal disturbance voltage (power ports) are given in Table 16.

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Table 16 – Limits for mains terminal disturbance voltage in the frequency band 150 kHz to 30 MHz

	Category C1		Category C2	
Frequency band MHz	**Quasi peak** dB(μV)	**Average** dB(μV)	**Quasi peak** dB(μV)	**Average** dB(μV)
$0{,}15 \leq f < 0{,}50$	66 Decreases with log of frequency down to 56	56 Decreases with log of frequency down to 46	79	66
$0{,}5 \leq f \leq 5{,}0$	56	46	73	60
$5{,}0 < f < 30{,}0$	60	50	73	60

Where a PDS does not comply with the limits of category C1, the following warning shall be included in the instruction for use:

> **Warning**
>
> In a ~~domestic~~ residential environment, this product may cause radio interference in which case supplementary mitigation measures may be required.

NOTE High-frequency common mode filtering introduces capacitive coupling paths to earth. In the case of a supply system in which the neutral is isolated from earth or connected to earth through a high impedance ("IT ~~supply network~~ system" as defined in 312.2.3 of IEC 60364-1:2005), these capacitive coupling paths can be harmful (see D.2.2).

In the frequency range from 9 kHz to 150 kHz, limits are not specified.

NOTE 1 IEC SC 77A is working on compatibility levels in this frequency range.

NOTE 2 Until limits are specified in this frequency range, design recommendations for emission values for PDS and CDM can be found in IEC TS 62578:2015, Annex B.

6.4.1.2 Process measurement and control ports

If a process measurement and control port is intended for connection to a fieldbus, then the port shall comply with the conducted emission requirements of the relevant standard for that fieldbus.

If a process measurement and control port is intended for connection to a public telecommunication network, then this port shall be regarded as a telecommunication port. The conducted emission requirements of CISPR ~~22~~ 32, class B apply to that port.

6.4.1.3 Radiation – Enclosure port

Limits for electromagnetic radiation disturbance (enclosure port, see definition in 3.3.4 and Figure 2) are given in Table 17.

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Table 17 – Limits for electromagnetic radiation disturbance in the frequency band 30 MHz to 1 000 MHz

	Electric field strength component Quasi-peak dB(μV/m)			
	Measurement distance 10 m [a]		**Measurement distance 3 m** [a]	
Frequency band MHz	**Category C1**	**Category C2**	**Category C1**	**Category C2**
$30 \le f \le 230$	30	40	40	50
$230 < f \le 1\,000$	37	47	47	57

[a] For selection of measurement distance, see 6.3.1.3.3.

~~For category C1, if the field strength measurement at 10 m cannot be made because of high ambient noise levels or for other reasons, measurement may be made at 3 m. If the 3 m distance is used, the measurement result obtained shall be normalised to 10 m by subtracting 10 dB from the result. In this case, care should be taken to avoid near field effects, particularly when the PDS is not of an appropriately small size, and at frequencies near 30 MHz.~~

The measurement distance shall be stated in the test report.

Where a PDS does not comply with the limits of category C1, the following warning shall be included in the instructions for use:

> **Warning**
>
> In a ~~domestic~~ residential environment, this product may cause radio interference, in which case supplementary mitigation measures may be required.

6.4.1.4 Power interface emission

For a PDS to be operated in the first environment, the limitation of emission shall be provided by means of one of the following options.

a) Measurements on the power interface need not be performed if the length of the corresponding cable is less than 2 m, or if a shielded cable is used. The shielding shall then be of high frequency quality, continuous throughout its length and at least connected to the CDM and motor via 360° terminations.

b) The emission shall be checked by measuring the disturbance voltage at the power interface in the BDM, ~~according to CISPR 14 and applying the limits given in Table 16~~ using the high impedance voltage probe described in 5.2.1 of CISPR 16-1-2:2014. The limits given in Table 18 below shall be applied.

c) Where mitigation methods applied are not suitable for checking according to item b) (for example common mode mitigation methods), the effectiveness of the mitigation method shall be checked by establishing a coupling between the mains input cable and the motor cable during the measurement of the mains terminal disturbance voltage according to 6.4.1.1. This coupling shall be established over the 1 m distance separating the EUT and the AMN by running the motor cable parallel to the mains cable with a separation not exceeding 10 cm over a length of at least 0,60 m.

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Table 18 – Limits of disturbance voltage on the power interface

Frequency band MHz	Measurement at rated output current	
	Quasi peak dB(μV)	Average dB(μV)
0,15 ≤ f < 0,5	80	70
0,50 ≤ f < 30	74	64
NOTE The above limits are derived from CISPR 14-1.		

6.4.2 Equipment of category C3

6.4.2.1 Information requirement

If a PDS does not meet the limits of category C1 or C2, a warning shall be included in the instructions for use stating that

- this type of PDS is not intended to be used on a low-voltage public network which supplies ~~domestic~~ residential premises, and
- radio frequency interference is expected if used on such a network.

The manufacturer shall provide a guide for installation and use, including recommended mitigation devices.

6.4.2.2 Power port disturbance voltage

Limits for mains terminal disturbance voltage (power ports) of PDSs are given in Table 19. The same limits apply to low voltage power ports of PDSs of rated voltage above 1 000 V.

Table 19 – Limits for mains terminal disturbance voltage in the frequency band 150 kHz to 30 MHz for a PDS in the second environment – PDS of category C3

Size of PDS [a]	Frequency band MHz	Quasi peak dB(μV)	Average dB(μV)
I ≤ 100 A	0,15 ≤ f < 0,50	100	90
	0,5 ≤ f ≤ 5,0	86	76
	5,0 < f < 30,0	90 Decreases with log of frequency down to ~~70~~ 73	80 Decreases with log of frequency down to 60
100 A < I	0,15 ≤ f < 0,50	130	120
	0,5 ≤ f < 5,0	125	115
	5,0 ≤ f < 30,0	115	105
These limits do not apply to power ports operating above 1 000 V.			
[a] Size of the PDS refers to rated current (I) of the port.			

See also Clause D.2.

For PDS above 100 A without dedicated transformer, to avoid the risk of crosstalk to signal cables, the installation instructions shall either recommend that the power cables be segregated from signal cables or state alternative mitigation methods.

In the frequency range from 9 kHz to 150 kHz, limits are not specified.

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NOTE 1 IEC SC 77A is working on compatibility levels in this frequency range.

NOTE 2 Until limits are specified in this frequency range, design recommendations for emission values for PDS and CDM can be found in IEC TS 62578:2015, Annex B.

6.4.2.3 Process measurement and control ports

If a process measurement and control port is intended for connection to a fieldbus, then the port shall comply with the conducted emission requirements of the relevant standard for that fieldbus.

If a process measurement and control port is intended for connection to a public telecommunication network, then this port shall be regarded as a telecommunication port. The conducted emission requirements of CISPR 22, class A, apply to that port.

6.4.2.4 Radiation – Enclosure port

Limits for electromagnetic radiation disturbance (enclosure port, see definition in 3.3.4 and Figure 2) of PDSs are given in Table 20.

Table 20 – Limits for electromagnetic radiation disturbance in the frequency band 30 MHz to 1 000 MHz for a PDS in the second environment – PDS of category C3

	Electric field strength component Quasi-peak dB(μV/m)	
Frequency band MHz	**Measurement distance 10 m** [a]	**Measurement distance 3 m** [a]
$30 \leq f \leq 230$	50	60
$230 < f \leq 1\,000$	60	70
NOTE In the next edition of IEC 61800-3, it will be the target to align the values in this table with CISPR 11.		
[a] For selection of measurement distance, see 6.3.1.3.3.		

~~NOTE This table will be reconsidered in the future according to the work which is ongoing in CISPR/B.~~

The measurement distance shall be stated in the test report.

6.4.2.5 Power interface

For a PDS to be operated in the second environment, the instructions for installation and use shall contain all the necessary information on the installation of the power interface as required in 4.3.

6.5 Engineering practice

6.5.1 PDS of category C4

For PDSs of category C4, the following procedure shall be used.

General conditions

Due to technical reasons, there are some applications where it is not possible for the PDS to comply with the limits of Table 19 and Table 20. These applications are for large ratings or to meet specific technical requirements:

- voltage above 1 000 V;

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- current above 400 A;
- networks isolated from earth, or connected to earth through a high impedance ("IT power supply system" according to 312.2.3 of IEC 60364-1:2005);
- where required dynamic performances will be limited as a result of filtering.

In these applications of category C4 equipment, the user and the manufacturer shall agree on an EMC plan to meet the EMC requirements of the intended application (see Annex E). In this situation, the user defines the EMC characteristics of the environment including the whole installation and the neighbourhood (see Figure 8). The manufacturer shall provide information on typical emission levels of the PDS which is to be installed. In the case of interference, the requirements and the procedure in 6.5.2 shall be applied.

NOTE Examples of common mitigation methods resulting from the EMC plan are: global filtering, dedicated special transformer, separation of cables.

Filtering in IT ~~-network~~ power supply systems

The use of filtered PDSs in an isolated, or high-impedance earthed, industrial distribution network ~~may~~ can cause a safety risk, if not properly designed for these applications. In the case of IT networks for complex industrial systems, limits cannot be set. The diversity of solutions resulting from the knowledge of the system cannot be standardised. The main considerations are related to fault conditions and filter leakage current.

a) Short circuit ~~to earth~~ on the motor side of the PDS. If the PDS is allowed to continue to run in this condition, high levels of high frequency current will flow in the filtering capacitors. This can ~~cause a trip of the IT monitoring system which will lead to an undesired process shut down~~ damage the filter capacitors. Short circuit to earth on the motor side can cause the application of common mode voltage to other neighbouring equipment.
b) Undesired fail detection by the ~~IT monitoring system~~ insulation monitoring device (IMD) according to IEC 61557-8 because of increased capacitance to earth, which ~~will~~ can lead to an undesired process shut down.

The solutions are based on a case by case analysis.

6.5.2 Limits outside the boundary of an installation, for a PDS of category C4 – Example of propagation of disturbances

6.5.2.1 General

For PDSs in the second environment, the user shall ensure that excessive disturbances are not induced into neighbouring low-voltage networks, even if propagation is through a medium-voltage network.

In the case of complaints about interference occurring at a neighbouring low-voltage network, or in the case of a dispute between the user of a PDS (for example within installation 2 – see Figure 8), and a victim on another network (for example within installation 1), it shall first be clearly established that the disturbance of victim equipment (in installation 1) occurs when the supposed emitting PDS (installation 2) is operated.

6.5.2.2 Interference due to conduction

In this case, the measurements shall be carried out at the low-voltage secondary of the medium-voltage transformer of the installation (installation 1) where the victim is situated (see Figure 8 for point of measurement). The requirements given by Table 21 or Table 22 and Table 23 including the reservations concerning ambient noise, shall be fulfilled.

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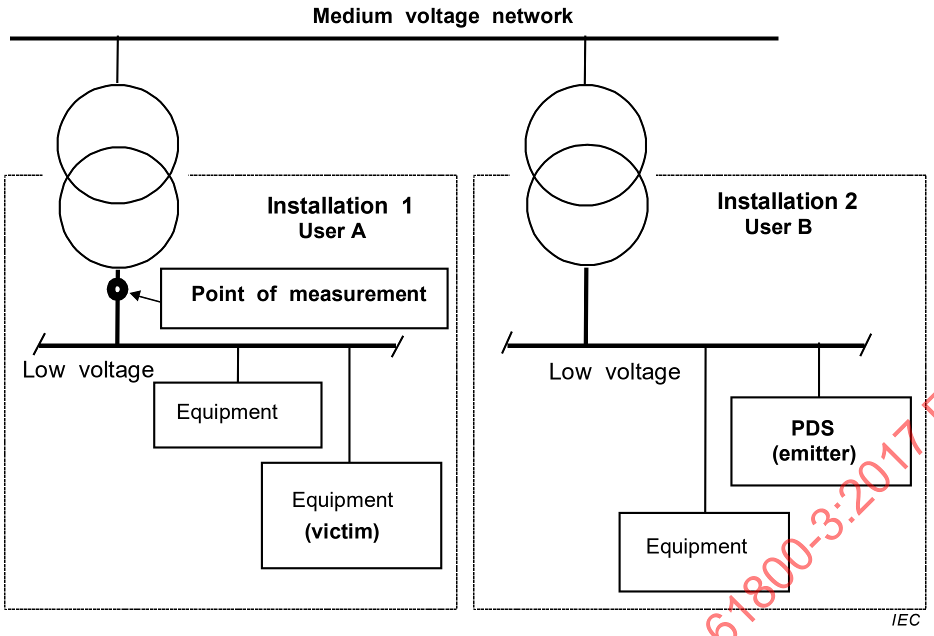

Figure 8 – Propagation of disturbances

~~NOTE~~ This method can be applied to different parts of the same installation in the case of PDS of rated voltage above 1 000 V with limits reported in the EMC plan. In this case, in-situ measurement of propagated disturbance voltage should be carried out at the low-voltage secondary of the high-voltage transformer (part 1 of the installation) which is electrically the closest to the PDS considered as emitter (see Figure 9 for point of measurement).

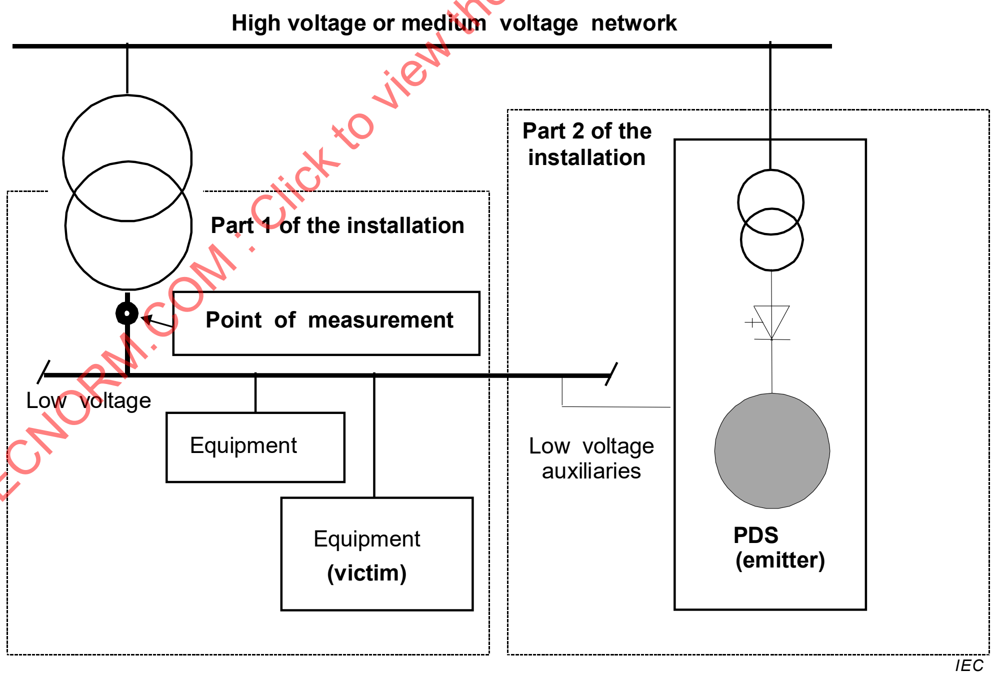

Figure 9 – Propagation of disturbances in installation with a PDS rated > 1 000 V

If installation 1 in Figure 8 belongs to the first environment, the disturbance voltage shall comply with the limits of Table 21.

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Table 21 – Limits for propagated disturbance voltage ("outside" in the first environment)

Frequency band MHz	**Quasi peak** dB(μV)	**Average** dB(μV)
0,15 ≤ f < 0,50	66 Decreases with log. of frequency down to 56	56 Decreases with log. of frequency down to 46
0,5 ≤ f ≤ 5,0	56	46
5,0 < f < 30,0	60	50

If installation 1 in Figure 8 or part 1 of the installation in Figure 9 belongs to the second environment, the disturbance voltage shall comply with the limits of Table 22.

Table 22 – Limits for propagated disturbance voltage ("outside" in the second environment)

Frequency band MHz	**Quasi peak** dB(μV)	**Average** dB(μV)
0,15 ≤ f < 0,50	79	66
0,5 ≤ f ≤ 5,0	73	60
5,0 < f < 30,0	73	60

If the ambient noise (without operation of the PDS which is the supposed emitter) exceeds the limits (Table 21 and Table 22), the supposed emitting PDS is only considered to fail if a characteristic set of emitted frequencies can be recognised and exceeds the measured ambient noise.

6.5.2.3 Interference due to radiation

6.5.2.3.1 Radiation above 30 MHz

In case of interference, the radiation shall be measured at a distance of 10 m from the boundary of the installation, if interference occurs outside in the first environment or at a distance of 30 m from the boundary of the installation, if interference occurs outside in the second environment. The measured field strength shall comply with Table 23.

Table 23 – Limits for propagated electromagnetic disturbance above 30 MHz

Frequency band MHz	**Electric field strength component** **Quasi peak** dB(μV/m)
30 ≤ f ≤ 230	30
230 < f ≤ 1 000	37

If the ambient noise (without operation of the PDS which is the supposed emitter) exceeds the limits (Table 23), the supposed emitting PDS is only considered to fail if a characteristic set of emitted frequencies can be recognised and exceeds the measured ambient noise.

The emissions from the PDS shall be suppressed until they are below the limits, or below the ambient noise, whichever is the higher.

See also A.4.3.

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6.5.2.3.2 Radiation between 0,150 MHz and 30 MHz

In case of interference, the radiation shall be measured at a distance of 10 m from the boundary of the installation if interference occurs in the first environment, or at a distance of 30 m from the boundary of the installation if interference occurs in the second environment.

A magnetic loop antenna according to CISPR 16-1-4 shall be used. The values shall not exceed those given in Table 24 at the frequencies for which interference occurs.

Table 24 – Limits for electromagnetic disturbance below 30 MHz

Frequency band MHz	**Magnetic field strength component** ~~**expressed in electric field units**~~ **Quasi peak** dB(~~µV/m~~ µA/m)
0,15 ≤ f < 0,49	~~75~~ 13,5
0,49 ≤ f < 3,95	~~65~~ 3,5
3,95 ≤ f < 20	~~50~~ -11,5
20 ≤ f ≤ 30	~~40~~ -21,5

6.6 Application of emission requirements – Statistical aspects

6.6 applies only to PDSs of categories C1, C2 and C3.

Conformance of the PDSs of categories C1, C2 and C3 shall be verified by performing a type test on a representative model. For simplicity, this type test may be made on one appliance only. The manufacturer or supplier shall ensure by means of his quality system that the EMC performance of the product is maintained.

~~In the case of a dispute, a PDS of categories C1, C2 and C3 shall only be considered to fail the requirements of this standard if the production fails the statistical assessment requirements according to Clause 11 of CISPR 11. Therefore, the evaluation shall be made on a well-defined test site.~~

As far as statistical aspects are concerned, Annex H of CISPR 11:2015 applies.

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Annex A
(informative)

EMC techniques

A.1 General overview of EMC phenomena

A.1.1 Phenomena

Many phenomena are described in IEC 61000-2-5. Definitions of low-frequency phenomena are given in IEC 61000-2-1.

Operation of a PDS includes a fundamental state to which are superimposed harmonic states due to non-linearity of the converter and/or inverter, and high-frequency phenomena due to fast switching of the power electronic devices of the converter and/or inverter. Therefore, the PDS can emit both low-frequency and high-frequency disturbances.

Reciprocally, other apparatus or systems in the neighbourhood of the PDS can produce low-frequency and high-frequency disturbances which can affect the operation of the PDS.

The electromagnetic disturbances to be considered for the implementation and use of a PDS using power electronics can be classified. Each of these phenomena can be considered as low-frequency disturbances or high-frequency disturbances. In this standard, the boundary between low and high frequency is 9 kHz according to International Telecommunication Union (ITU).

For a PDS both are of concern:

– fundamental frequencies, which are less than 9 kHz, are intentionally produced to provide power for the motor;
– and as a secondary phenomenon, frequencies higher than 9 kHz can be used by the control, for example PWM of the inverter control, microprocessor clock.

In each case, conducted and radiated disturbances are identified.

For conduction, the following are of interest.

– differential mode voltage: concerns a disturbance which appears between the input terminals (or output terminals), of an equipment;
– common mode voltage: concerns a disturbance which appears between the average of an input or an output and earth or a reference earthing connection.

The above text is an explanation – precise definition is in IEC 60050(161).

For radiation the following are of interest:

– the near field: distance to the (parasitic) transmitter less than $\lambda/2\pi$;
– the far field: distance to the (parasitic) transmitter greater than $\lambda/2\pi$;

λ is the wavelength of the considered signal.

The study of the electromagnetic compatibility of a system considers each of these cases, both from the emission and immunity points of view.

Table A.1 summarises the classification.

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Table A.1 – EMC overview

Frequency	Propagation	Coupling		Emission	Immunity
Low frequency $0 \leq f < 9$ kHz	Conducted	Common mode		Harmonics of order multiple of 3 (zero sequence) Residual currents	Power frequency voltage
		Differential mode		Harmonics, interharmonics and commutation notches Consequence on mains signalling	Commutation notches Voltage fluctuations Dips and short interruptions Transient overvoltages Phase fluctuations Unbalanced voltages Frequency fluctuations DC components
	Radiated	Near field	Magnetic coupling	Magnetic field	Magnetic field
			Capacitive coupling	Electric field	Electric field
		Far field			
High frequency 9 kHz $\leq f$	Conducted	Common mode		Induced Rf[a] voltages and currents	Induced RF[a] voltages and currents Unidirectional transients
		Differential mode			Induced RF[a] voltages and currents Unidirectional transients
	Radiated	Near field		Electric (high impedance) Magnetic (low impedance)	Pulse magnetic fields (portable transmitters) Portable transmitters
		Far field		Electromagnetic fields	RF[a] electromagnetic fields
Large spectrum		Air discharge Contact discharge			

[a] RF : radio frequency

NOTE In this standard, the limit between low-frequency and high-frequency is 9 kHz according to common practice in IEC. This terminology does not refer to broadcasting bands.

Industrial experience has shown that the main causes of non-compatibility are due to conducted disturbances, with perhaps an exception due to portable transmitters such as walkie-talkies. This standard deals with the disturbances which are particularly relevant to PDSs.

A.1.2 Compatibility levels

If EMC is to be ensured, the emissions from equipment and the disturbances received by this equipment should be measured and characterised. Figure A.1 summarises the different levels which should be known.

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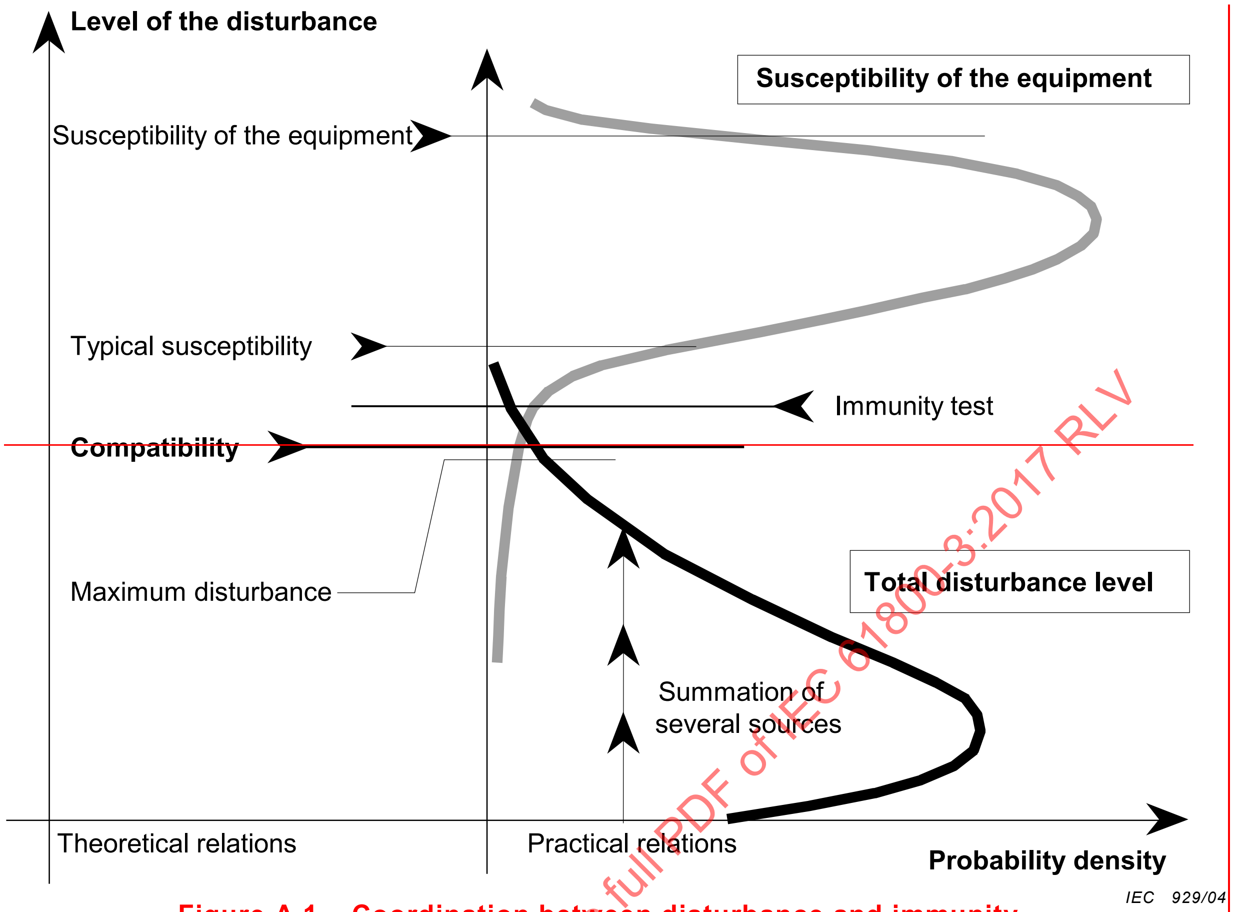

~~Figure A.1 – Coordination between disturbance and immunity~~

A.1 Application of PDSs and EMC

The range of application of PDSs is so large that any attempt to establish an exhaustive list will fail. However, the examples given here show PDSs used in a range of very different environments. Because the definition of EMC is more dependent on the environment than on the product itself, any code of practice should consider this fact. For example, the limitation of emission in buildings used for ~~domestic~~ residential purpose should be quite different from that used for rolling mills in an industrial plant.

Examples of application of PDSs are listed here:

- machine tools, robots, test equipment in production, test benches;
- paper machines, textile production machine, calenders in rubber industry;
- process lines in plastic industries or in metal industries, rolling mills;
- cement crushing machines, cement kilns, mixers, centrifuges, extrusion machines;
- drilling machines;
- conveyors, material handling machines, hoisting equipment (cranes, gantries, etc.);
- propulsion of ships, etc.;
- pumps, fans, and so on.

These examples use PDSs covered by this document. However, electric vehicles and particularly traction drives are excluded from the scope of this document (see Clause 1).

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A.2 Load conditions regarding high-frequency phenomena

A.2.1 Load conditions during emission tests

The load on the motor normally has little effect on the EMC characteristics of the PDS. Therefore, the PDS need not be tested for EMC characteristics at all load conditions, but only at a load that is representative of all operating emissions. The manufacturer should certify that the load conditions he has selected for the test meet this criterion.

The radiated and conducted emissions of a PDS are mainly caused by sharp transitions of its output voltage that are used to produce low-frequency, or DC output power. The voltage spectrum of the waveform can have sufficient energy at high frequencies for the PDS to radiate electrical energy from its input power wires, cabinet, motor leads, and motor case. Since the radiated energy is caused by the voltage transitions, tests should be performed at conditions where the voltage transitions have the largest amount of high-frequency content. Tests need not be performed at other conditions.

The sharpness of output transitions can be affected by the switching speed of the power device that is used in the PDS. IGBTs (transistors) are extremely fast devices that in combination with the recovery characteristics of the diodes used in some types of inverters can cause dv/dt that can be greater than 1 000 V/µs. It is important to note that the abruptness of the diode recovery is an important component of this high dv/dt. Even though the level of the recovery current is load dependent, the abruptness of the diode recovery is not as dependent on the load level. Note that attenuation measures should be rated to cover saturation effects of filter elements (for example saturation of interference suppression inductors).

On the other hand, it is important to consider the effect of passive capacitive, resistive, or inductive power circuit components, such as snubber components that are used to control the rate of rise of this voltage. The output waveform with these devices present can have dv/dt characteristics that are load dependent. In this case, it is important that the PDS be tested at the worst case dv/dt point of operation.

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A.2.2 Load conditions during immunity tests

The load on the motor normally has little effect on the EMC characteristics of the PDS. Therefore, the PDS need not be tested for EMC characteristics at all load conditions, but only at a load that is representative of all susceptibilities. The manufacturer should certify that the load conditions he has selected for the test meet this criterion.

Generally, load conditions do not affect the immunity of a PDS to low or high-frequency disturbances. The failures of the power and control circuitry are generally associated with voltage not current levels. Testing at light load does not detect slight changes in the settings of protective circuitry, i.e. over current, over voltage. If these levels are critical to the proper operation of a PDS, the test should verify the immunity at these points of operation.

If the torque-generating behaviour criterion is used, the load should be at such a level that it is possible to measure the torque disturbance associated with the low or high-frequency tests. This will require a motor and a torque-measuring device. The motor should have a load that can be used in the electromagnetic environment of the test. If indirect torque-measuring methods are used, the PDS should be operated at a load level which is sufficient for any torque disturbances to be measured.

A.2.3 Load test

A light load test, i.e. a test with the motor running at no load, can be used to verify the EMC characteristics of a PDS if the above conditions are met. Tests can even be performed using passive power resistors and inductors that simulate the load condition of a motor. It is also important to note that the motor case can act as an antenna element. If a passive load is used, this antenna effect should also be simulated.

The manufacturer of the PDS should provide certification that the load on the PDS during any test will produce the worst case or most sensitive conditions for his particular product. This certification can be by test of a representative product, or by calculation or simulation.

A.3 Some immunity aspects

A.3 Immunity to power frequency magnetic fields

Testing according to IEC 61000-4-8 is usual where components sensitive to magnetic field are used. PDSs frequently use Hall-effect current sensors. However, these sensors are designed to operate in locations where high levels of magnetic fields exist (close vicinity of power conductors). Those amplitudes are much higher than the levels of the test according to IEC 61000-4-8. For example, it can be calculated that a 10 A current (assumed to be alone on an infinite straight line) produces a magnetic field of 320 A/m at 5 mm. It can therefore be considered that the disturbance applied by the test is negligible compared to the operating environment of this sensitive component.

A.3.2 Electromagnetic field immunity test

A.3.2.1 Low level electromagnetic fields (EM-fields)

Industrial, scientific and medical (ISM) radio-frequency equipment, some welders, dryers, etc. can be sources of low-level electromagnetic fields. These devices are all present in the domestic and industrial environment. The resulting field strengths are expected to be less than 3 V/m at the enclosure port of the PDS.

The established experience with PDSs shows that provided an intrinsic operational availability is realised, the radiated EM-fields from other PDSs and other low level EM-fields from commercial broadcasting stations are not matters of complaint.

A.3.2.2 Complementary test

The field strength decreases in inverse proportion to the distance between the transmitting antenna and the possible victim, and increases only with the square root of antenna input power. Therefore, attention should be drawn to the transmitters which can be operated in close proximity about 1 m from the PDS. These communication devices are the dominant radiating interference sources affecting electronic equipment. Examples of usual local sources of continuous high-frequency disturbances are mobile telecommunication equipment such as walkie-talkies or cordless telephones.

A large PDS cannot be installed and operated correctly in a test site (shielded room) for the test of IEC 61000-4-3. Therefore, to verify the complete assembly of the PDS in the case where only sub-components have been tested, an alternative complementary test can be performed with radio-communication devices of common industrial use as emitters.

During the test, the PDS is operated and monitored according to 5.1.3, and under normal operating conditions (for example doors closed).

Because this test is not performed in a shielded room, only transmitters which are legally approved for use at the test location can be used. The following transmitters are recommended:

– devices such as walkie-talkies which are commonly used in close proximity at the user's premises;

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~~– digital mobile telephone, unless they are prohibited at the operating location at the user's premises, and if they are able to transmit at their rated power.~~

~~Care should be taken that the battery pack or the power supply of the transmitter is at full capability. If the transmitter is able to adjust the power of the emission (as battery saving feature), care should be taken that this possibility is disabled. The list and characteristics of transmitter (type, power and frequencies) used during the test should be stated by the manufacturer in the user information.~~

~~The transmitter is hand-held close to a vertical surface of the CDM/BDM. The closest point of the antenna to the PDS is between 0,5 m and 1,0 m from the PDS. The transmitter is switched from "receive" to "transmit" and back to "receive". Care should be taken that the dwell time of the transmission is not less than the time necessary for the PDS to be able to respond. In the case of a telephone type of device, where the user cannot switch between "transmit" and "receive", a telephone number is transmitted instead.~~

~~There should be at least three transmissions for each antenna orientation: vertical, horizontal in a plane parallel to the surface of the PDS, and perpendicular to the PDS (pointing towards the PDS).~~

~~This procedure should be carried out:~~

~~– on at least five positions on each vertical surface of the CDM/BDM;~~

~~– at all openings of these vertical surfaces, a ventilation grille is considered to be one opening;~~

~~– at the surface of the motor, if it includes sensors.~~

~~The whole procedure should then be repeated for at least two different transmission frequencies.~~

A.4 High-frequency emission measurement techniques

A.4.1 Impedance/artificial mains network (AMN)

A.4.1.1 Circuit of AMN

Since the high-frequency disturbance source within a drive has a source impedance, the disturbance voltage measurement is affected by the network impedance. Particularly at lower frequencies, the impedance of the mains can be regarded as inductive. However, there can be resonances due to various capacitances of the system. For further information, see 6.6 of IEC TR 61000-2-3:1992.

Where possible, an AMN should be used to standardise the supply impedance used during type tests. This improves the repeatability between different test sites.

The characteristics of various networks are defined in Clause 4 of ~~CISPR 16-1 (2002)~~ CISPR 16-1-2:2014. For the frequency range of disturbance voltage measurements defined in this document, the 50 Ω // 50 µH network or the 50 Ω // 50 µH + 5 Ω network can be used. Between 150 kHz and 30 MHz, the equipment under test (power drive system) sees an impedance to earth of 50 Ω in parallel with 50 µH, regardless of the impedance of the incoming mains supply.

~~The AMN contains the circuit reproduced for each phase. The neutral, if used, is connected through a circuit identical to that used for each phase.~~

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A.4.1.2 PDS with which the AMN cannot be used

A.4.1.2.1 Reasons of impossibility

At lower frequencies, the inductors inside the 50 Ω // 50 μH AMN add 50 μH to the impedance of the mains supply. The inductors inside the 50 Ω // 50 μH + 5 Ω AMN add 300 μH. This additional impedance can prevent correct operation of some PDSs (for example, commutation notches become excessively wide at high current and low firing angle, if the supply inductance is too high). In these cases, the AMN cannot be used.

~~The AMNs described above are only rated for use up to 100 A, so they cannot be used for PDSs rated greater than this. For a very large PDS (example rated current above 400 A), the supply impedance will be lower than the impedance of the AMN. In this case, use of an AMN would give excessively high readings.~~

~~For supply voltages higher than 400 V nominal, it can be difficult to obtain an AMN on the market.~~

~~For these cases, the PDS should be connected directly to the mains supply and the disturbance voltage can be measured with a high impedance probe.~~

If an AMN is not commercially available, the methods in A.4.1.2.2 or A.4.1.2.3 can be applied. The method in A.4.1.2.3 is preferred. In cases where high current prevents the use of the standard AMN method, the following steps should be used to improve correlation:

1) measure with the standard AMN method at the maximum possible power level of the AMN;
2) measure with the alternative method according to A.4.1.2.2 or A.4.1.2.3 at the same power level;
3) note the difference in results between the two measurements;
4) measure with the alternative method according to A.4.1.2.2 or A.4.1.2.3 at the desired power level;
5) Correct the result from step 4) according to the difference noted in step 3).

A.4.1.2.2 High impedance voltage probe

When an AMN is not used, the disturbance voltage can be measured using a high impedance voltage probe, as described in 5.2.1 of ~~CISPR 16-1 (2002)~~ CISPR 16-1-2:2014. Since the power frequency current does not pass through the probe, it can be used with PDSs of even the highest current ratings.

By adjusting the value and voltage rating of the capacitor, this probe can be used with supplies at least up to 1 000 V. If the capacitor value is reduced, its effect on the scaling of the measurement should be allowed for in calibration, as stated in CISPR 16-1-2.

The probe is connected between the line and the reference earth. If the CDM/BDM has an earthed metal frame, this can be taken as the reference earth. This connection should be to the supply leads as they enter the CDM/BDM. The connections to the probe should be as short as possible, preferably less than 0,5 m.

CISPR 16-1-2 provides a warning about the need to minimise the loop area formed between the lead connected to the probe, the conductor tested and the reference earth. This is to reduce susceptibility to magnetic fields.

A.4.1.2.3 Alternative method for high current PDS

In some cases, it can be difficult to use the high impedance probe because of safety reasons during changing of phases, and the readings can be several tens of decibels higher (because of mismatched impedance) than those which are obtained with an AMN measurement.

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An alternative method, which has been experienced in some countries for a number of years, uses a low current AMN (for example 25 A) as a voltage probe, even with a high current PDS (above several hundreds of amperes). This method is described in Clause A.5 of ~~CISPR 16-2 (2003)~~ CISPR 16-2-1:2014. The PDS is not disconnected from its supply network.

The load side of the AMN should be connected to the supply lines of the PDS at the power port terminals by a 1 m cable. There should be some inductance (for example connection cabling) between the PC and the AMN connection. The mains side of the AMN should be left open (for example no connection to peripherals). The receiver should be connected to the AMN as usual. The measurement results, with this method, are quite similar to that of a virtual AMN of several hundreds of amperes.

A.4.2 Performing high-frequency in situ emission tests

~~A.4.2.1 Measuring apparatus~~

~~A.4.2.1.1 Purpose of the information~~

~~For definitive information, reference should be made to the normative parts of this standard and of CISPR 11 and CISPR 16-1. Some additional clarifications are given here for those users of this standard who are not familiar with radio-frequency disturbance measurement methods.~~

~~A.4.2.1.2 Spectrum analysers~~

~~Spectrum analysers are frequently used for evaluation of high-frequency disturbances. However, many spectrum analysers are not fully compliant with CISPR 16-1 and problems can occur.~~

~~If there is a lack of front-end selectivity, intermodulation can occur, leading to incorrect readings. Some spectrum analysers do not have the correct bandwidths, again resulting in error.~~

~~Spectrum analysers use peak detectors for normal scanning. However, CISPR standards require the use of receivers with special detectors known as quasi peak and average. Sometimes, the quasi-peak detector is known as a "CISPR detector". Some spectrum analysers have these available as an option. CISPR 16-1 requires high overload capabilities for quasi-peak and average detectors, which can be a problem for many spectrum analysers.~~

~~If a spectrum analyser is fully compliant with CISPR 16-1, this should be stated by the manufacturer of the analyser.~~

~~A.4.2.1.3 Suitability of test receivers~~

~~To determine whether an instrument (spectrum analyser or test receiver) is suitable, the supplier of the instrument should be asked whether the instrument is fully compliant with CISPR 16-1. But to aid understanding of the requirements, a summary of some of the main features is given here.~~

~~For mains terminal disturbance measurements, a receiver should cover the frequency range 150 kHz to 30 MHz. Both quasi-peak and average detectors should be present. The bandwidth should be 9 kHz.~~

~~The frequency range 9 kHz to 150 kHz is also available on some receivers. In this frequency range, a quasi-peak detector should be available and the bandwidth should be 200 Hz.~~

~~The receiver for electromagnetic radiation disturbance (radiated emissions) measurements should cover the band 30 MHz to 1 000 MHz. Here, the bandwidth is 120 kHz and a quasi-peak detector should be used.~~

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~~A.4.2.2 Measuring techniques~~

~~A.4.2.2.1 Aliasing~~

~~The receiver should be allowed to remain tuned to a given frequency for a period of time which is long enough to allow the detector output to settle. If a test receiver (or spectrum analyser) is scanned too quickly, the detector will not settle properly and a phenomenon called aliasing will occur, resulting in incorrect readings. This point is particularly significant with power electronics, including PDSs, due to low pulse repetition frequencies (50/60 Hz to several kilohertz). If peaks or troughs in the waveform appear to move across the screen, there is aliasing and the sweep time should be increased.~~

~~In the type of spectrum analyser frequently used for evaluation of high-frequency disturbances, a local oscillator is swept across the frequency range. This should not be confused with analysers which use Fast Fourier Transform of time domain samples.~~

~~At those frequencies where the readings are close to the limit, a measurement should be made without the receiver scanning. This avoids the problem of inaccuracy caused by aliasing at these frequencies.~~

~~A.4.2.2.2 Peak, quasi-peak and average~~

~~Peak, quasi-peak and average detectors will give the same reading in the presence of continuous sine-wave signal, provided that the bandwidth is the same. In the presence of an impulsive signal, such as PWM, the highest reading will be given by the peak detector and the lowest by the average detector. The difference between the readings produced by the different detectors is greatest when the pulse repetition frequency is much lower than the receiver bandwidth.~~

~~A.4.2.2.3 Ambient noise~~

~~The requirements for limitation of ambient noise are given in 6.1 of CISPR 11 (2003).~~

~~Care should be taken to ensure that the ambient noise does not cause erroneous readings. When monitoring the ambient noise level from the incoming mains supply, it should be noted that an open-circuit contactor or switch will provide attenuation that will not be present when the PDS is running.~~

~~A.4.2.2.4 Disposition of PDS during the test~~

~~The test is intended to simulate actual operating conditions. Therefore, the equipment should be operated in a manner which can be expected in normal use. For example, covers and doors which are closed during normal operation should be closed during the test. Some other requirements are given in the normative part of this standard.~~

~~A.4.2.2.5 Measuring radiated emissions~~

~~Antennas and test sites for radiated emissions are described in detail in 5.5 and 5.6 of CISPR 16-1 (2002).~~

~~To standardise the measurements of radiated emissions, a special open-area test site (OATS) is used. This contains a metallic ground plane with sufficient conductivity to give consistent reflectivity.~~

~~The equipment under test is mounted on a turntable to enable the radiated emissions in the various directions to be measured.~~

~~To ensure that measurements are in the far field at the lowest frequency (30 MHz), the antenna is mounted 10 m or 30 m from the equipment under test.~~

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The antenna is raised and lowered in both vertical and horizontal polarizations to find the maximum emission at any given frequency.

A.4.2.2.6 In situ tests

When equipment cannot be tested on a test site, tests are performed in situ. In this case, extra care should be taken to avoid problems caused by ambient noise, as described above.

Testing in situ is not as repeatable as testing on a test site. Therefore, some care should be taken when using the results of in-situ testing on one site to predict compliance for a product produced in quantity.

One approach, used in the United States when tests have not been carried out on a test site, is to perform the in-situ test in the first three locations where the equipment is installed. If the equipment is found to comply with the limits in all three locations, it is considered that the equipment will comply with the limits in the general case.

For large equipment, the antenna may be moved around the equipment to determine the highest emission spot.

A.4.3 Established experience with high power PDSs

For several decades, the experience in different countries has shown that the established procedures of legislation and protection of radio-communication services against high-frequency disturbances have been proved in practice with excellent results. As an example, the procedure which has been used in Germany for many years is described below.

Under this procedure, because high power equipment intended for use in the second environment is part of an installation, it is not tested on a test site. See [4][1]. The same rules apply to equipment which is built by the user himself, under his own responsibility; see [5]. The emission limits of such a high power installation are referenced to the actual boundary of the installation terrain, even in the case of measurement and control equipment which is intended to be installed there. The emission limits have been applied with respect to the boundary of the installation (the measurement point for conducted mains terminal disturbance voltage is the low-voltage secondary of the next available medium-voltage transformer, and for the radiated emissions a 30 m distance to the boundary); see [4] and [5].

As a result, the procedure stated in 6.5 follows this experience. Such a use of a PDS (category C4) requires EMC competence. Such competence should be applied to the design of the apparatus, or the manufacturer and the user should define the best economical appropriate compatibility levels in a specific environment.

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1 — The figures in square brackets refer to the bibliography.

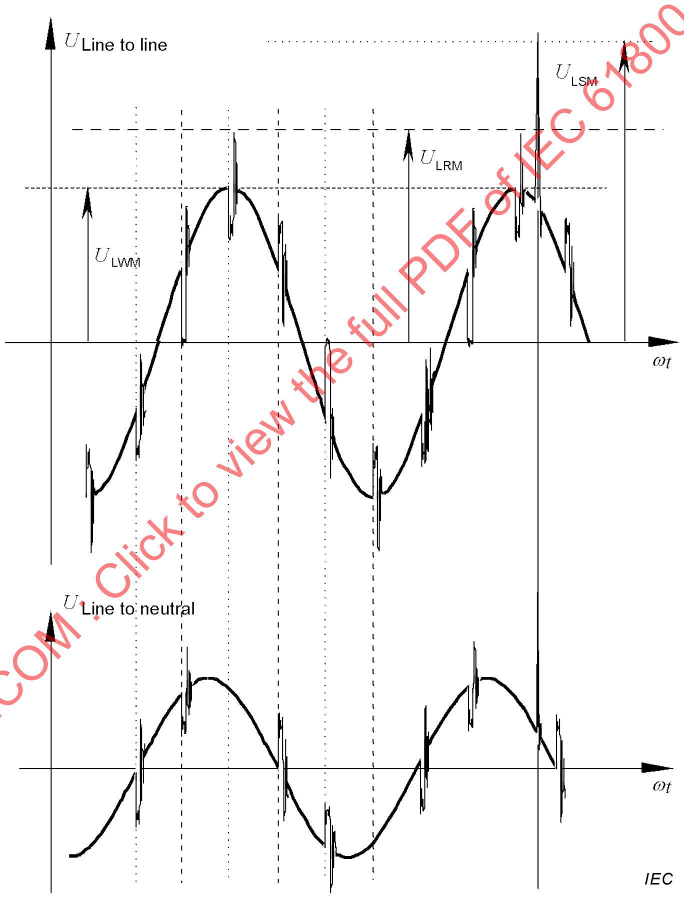
Annex B
(informative)

Low-frequency phenomena

B.1 Commutation notches

B.1.1 Occurrence – description

Commutation notches (see IEC 60050-551:1998, 551-16-06) are caused by line-to-line short circuits which occur at the terminals of a thyristor converter. This occurs when current is commutated from one phase of the supply to the next. Voltage notches are deviations of the AC mains voltage from the instantaneous value of the fundamental. The magnitude of the commutation notch, seen elsewhere in the supply system, depends on the ratio of supply impedance and decoupling reactance in the thyristor converter.



NOTE Typical range of per unit values are provided for reference only.

The figure assumes there is no impedance between PDS terminals and the converter.

Repetitive transients	(U_{LRM}/U_{LWM}) = 1,25 to 1,50; depending on the snubber design with respect to di/dt and I_{RR} (dynamic reverse current of the semiconductor).
Non-repetitive transients	(U_{LSM}/U_{LWM}) = 1,80 to 2,50 depending on additional protective devices.

Figure B.1 – Typical waveform of commutation notches – Distinction from non-repetitive transient

Analysis of notches considers a wider range of frequencies than normal harmonic analysis. Their time-domain characteristics cause effects which cannot be understood by a simple harmonic analysis. Therefore, they are analysed in the time domain using an oscilloscope.

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The following should first be remembered:

- in simple cases where the rule applies, it is assumed that the network impedance can be modelled with a pure reactance: $Z = L\omega$ (this assumption is not valid in cases where capacitors or long cables are present; resonances can occur in such cases);
- the immunity against commutation notches is classified in 5.4.1 and Table 9 of IEC 60146-1-1:~~1991~~ 2009 where their measurement is defined in depth (in % of U_{LWM}) and in area (depth multiplied by width, in % degrees); IEC 60146-1-1 defines U_{LWM} as the maximum instantaneous value of U_L excluding transients (therefore this is the amplitude), where U_L is the line-to-line voltage on the line side of the converter or transformer, if any.

If the converter does not include any inductance, the depth d of the principal notch in the line-to-line voltage at the terminals of the converter itself (not the terminals of the BDM/CDM) is given by

$$d = 100 \sin \alpha \quad (\%)$$

where α represents the firing angle of a phase controlled converter (referred to the natural commutation point of a diode);

- the principal notch is characterised by a value of 0 V (line-to-line voltage at the converter's terminals);
- the approximation gives an under-evaluation of d for $\alpha < 90°$, and an over-evaluation of d for $\alpha > 90°$.

The notch area a can be approximated by a simple relationship (example of a three-phase bridge, see the conditions of the approximation in the note below):

$$a = 8\,000\,(Z_t \times I_{1L}/U_L) \text{ (\% degrees)}$$

where

Z_t is the total line impedance per phase (here assumed to be a pure reactance), including any impedance in the CDM;

I_{1L} is the fundamental component of the line-side current;

U_L is the line-to-line voltage.

It can be seen that the worst case occurs when the PDS is at current limit conditions.

NOTE During commutation angle u, from α to $(\alpha + u)$, the commutating voltage is:

$$\sqrt{2}\,U_L \sin \omega t$$

and

$$\sqrt{2}\,U_L \sin \omega t = 2\,L_t\,\mathrm{d}I/\mathrm{d}t$$

the area of the commutation notch is

$$A = \int_{\alpha}^{\alpha+u} U(\theta)\,d\theta = 2\,L_t \int_{\alpha}^{\alpha+u} \frac{di}{dt}\frac{dt}{d\theta}\,d\theta \quad \text{(in volt x radian)}$$

$A = 2\,L_t\,\omega\,I_\alpha$ which means $A = 2\,Z_t\,I_\alpha$

where I_α is the commutated current.

To take into account the ripple in a three-phase bridge, assume $I_\alpha \approx 0{,}75\,I_d$, where I_d is the DC current:

$$A = 1{,}5\,Z_t\,I_d$$

and with a in % degrees

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$a = 100\ A\ (360/2\ \pi)\ (1/\sqrt{2}\ U_L) = 6\ 077\ (Z_t\ I_d/U_L)$

$a = 7\ 794\ (Z_t\ I_{1L}/U_L)$

$a \approx 8\ 000\ (Z_t\ I_{1L}/U_L)$ or in per units values $a \approx 4\ 500\ (z_t\ i_L)$

B.1.2 Calculation

B.1.2.1 General assessment

When the assumptions listed above are valid, the notch depth at the PC is:

$$d_{PC}\ \% = 100 \sin \alpha\ \mathbf{(}\ Z_c/(Z_c + Z_d)\ \mathbf{)} = 100 \sin \alpha\ (Z_c/Z_t)$$

where Z_t is the total line impedance.

$$Z_t = Z_c + Z_d$$

where

Z_d is the decoupling reactance between the PC and the converter terminals (whether included or not in the CDM);

Z_c is the supply network impedance at the PC.

The amplitude of the ability of control of the converter (for example the case of a three-phase controlled bridge), is often represented by sin α. The notch depth varies from 100 % at the converter terminals to 0 % at a zero impedance source.

Adding a decoupling reactance Z_d between the PC and the BDM reduces the notch depth and increases the notch width at the PC, but the notch area remains constant.

$$a_{PC} = 8\ 000\ (Z_c \times I_{1L}/U_L)\ (\%\ \text{degrees})$$

In simple cases where the above assumptions apply, these equations can be used to define the required decoupling reactance. Knowing the notch depth limit (see Table B.1) and the control amplitude ability of the converter, the notch depth at the PC gives the ratio:

$$Z_c/(Z_c + Z_d)$$

Then Z_c, defined by the user, allows calculation of Z_d by the installer, from which the internal decoupling reactance if any (given by the manufacturer) can be subtracted. The remaining value is the reactance to be added for correct decoupling.

NOTE The calculations above do not take account of transients at the beginning and at the end of the notch.

B.1.2.2 Practical rules

The calculation above defines the practical rule for decoupling the emission by means of a reactance Z_d. This is summarised below. The fundamental relations, assuming the network impedance is a pure reactance, are:

$$Z_c = L_c \times \omega$$

$$Z_t = Z_c + Z_d$$

$$d_{PC}\ \% = 100 \sin \alpha\ (Z_c/Z_t)$$

$$a_{PC}\ \%\ \text{degrees} = 8\ 000\ (Z_c \times I_{1L}/U_L)$$

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If multiple converters are connected to the same line, 5.4.2 of IEC TR 60146-1-2:2011 should be considered.

However, it should be remembered that compliance with the notch emission criterion does not automatically ensure compliance with harmonic emission criteria. Similarly, compliance with harmonic emission criteria does not automatically ensure compliance with the notch emission criteria. The immunity aspect is not entirely covered by the harmonic distortion criteria. Indeed, since the harmonic criterion does not imply any phase relationship between the different harmonic components, it does not prevent a particular voltage waveform from being applied to the PDS. Because the particular waveform of commutation notches (dv/dt, possible zero crossing) affects operation of snubbers or can affect electronic control operation as well, a particular immunity criterion is stated in IEC 61800-1 ~~(1997)~~ and in IEC 61800-2 ~~(1998)~~, it is even defined as electrical service conditions in 4.1.1 of IEC 61800-1:1997 and 4.9 of IEC 61800-2:2015.

B.1.3 Recommendations regarding commutation notches

B.1.3.1 Emission

The recommendation does not apply to power converters with such a structure that commutation notches are known not to exist or to have only negligible amplitude.

~~NOTE~~ For example, an indirect converter of the voltage source inverter type with an active front end equipped with a decoupling filter designed for attenuation of the effects of the switching frequency does not produce notches. A simple diode rectifier produces notches of negligible amplitude. The main practical case where emission of notches should be considered is the case of thyristor converters (line commutated).

Compliance with the recommendations related to commutation notches does not avoid the need to verify compliance with the requirements for harmonics. The depth of the principal notch at the PC (PCC or IPC) should be limited according to Table B.1, with a line impedance assumed to be a pure reactance:

$$Z = L\ \omega$$

and having a value of 1,5 % (related to the rated power of the PDS).

NOTE 1 When installing the PDS, the line impedance is practically defined from the short-circuit power S_{sc} at the PC:

$$Z_{sc} = U_{LN}^2/S_{sc}$$

Table B.1 – Maximum allowable depth of commutation notches at the PC

	First environment	Second environment
Maximum notch depth	20 % Class C of IEC 60146-1-1 or comply with the requirements of the local supply authority	40 % Class B of IEC 60146-1-1 or agreement with the user

NOTE 2 This rule cannot be used in cases where resonances can be expected due to capacitors or long length of cables.

~~NOTE~~ In the case of certain distribution networks, special consideration ~~may~~ can be required (for example internal distribution networks in hospitals). In such cases, the conditions should be specified by the user.

Compliance may be determined by calculation, simulation or measurement.

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If the PDS deviates from this recommendation, and in order to make the user able to comply with this recommendation, the manufacturer should provide the following information in the user documentation:

- the maximum and the minimum line impedance for correct operation of the CDM/BDM;
- details of the decoupling reactance Z_d if any, that is included in the CDM/BDM.
- details of the available decoupling reactances Z_d which can be delivered as optional items.

NOTE 3 The maximum line impedance is directly related to the maximum notch area at the PC (see B.1.1).

However, in the case of multiple PDSs connected to the same PC, notch limitation is a system consideration and a simple rule cannot be defined.

~~NOTE~~ The main practical case where immunity against notches should be considered for other equipment is the case of RFI filters.

B.1.3.2 Immunity

The harmful effect of notches on a PDS can be much greater than that which would be indicated by a frequency domain analysis of their contribution to the total harmonic distortion. Therefore, a time domain analysis of commutation notches is necessary. Note that the stress due to harmonics and commutation notches affects the electronic control and some power devices as well (snubbers for instance). Because electronic control malfunctions will occur immediately, and snubbers have a short thermal time constant, the duration of a test, if any, for permanent conditions need not exceed 1 h.

Some practical cases where immunity against notches should be considered are:

- where operation is affected instantaneously, for example the effect on electronic synchronisation circuits where the zero crossing of voltage is taken as reference;
- thermal overload, for example overload of snubber circuits in the power converter;
- overvoltage on L-C circuits, for example RFI filters.

B.2 Definitions related to harmonics and interharmonics

B.2.1 General discussion

B.2.1.1 Resolution of non-sinusoidal voltages and currents

Classical Fourier series analysis (~~IEV 101-13-08~~ IEC 60050-103:2009, 103-07-18) enables any non-sinusoidal but periodic quantity to be resolved into truly sinusoidal components at a series of frequencies, and in addition, a DC component. The lowest frequency of the series is called the fundamental frequency (~~IEV 101-14-49~~ IEC 60050-161:1990, 161-02-17). The other frequencies in the series are integer multiples of the fundamental frequency, and are called harmonic frequencies. The corresponding components are referred to as the fundamental and harmonic components, respectively.

The Fourier transform (~~IEV 101-13-09~~ IEC 60050-103, 103-04-01) may 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 line spectrum in the frequency domain, where the lines of the spectrum are the fundamental and harmonics of the corresponding Fourier series.

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.

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

B.2.1.2 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 61000-4-7:2002).

B.2.2 Phenomena related definitions

B.2.2.1
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

Note 1 to entry: For the purposes of IEC 61800, it is the same as the power frequency supplying the converter, or supplied by the converter according to the case which is considered.

Note 2 to entry: IEC 60050:2001, 551-20-01 and IEC 60050:2001, 551-20-02 defines the components as a result of the Fourier analysis; frequencies are therefore a consequence. In B.2.2, the definitions follow the approach of SC 77A defining first the frequencies, the components being a consequence. There is no contradiction between the two different approaches.

Note 3 to entry: In the case of a periodic function, the fundamental frequency is generally equal to the frequency of the function itself (see IEC 60050:2001, 551-20-03 and IEC 60050:2001, 551-20-01). The above definition corresponds to the genuine definition of "reference fundamental frequency" according to IEC 60050:2001, 551-20-04 and IEC 60050:2001, 551-20-02, for which the term "reference" may be omitted where there is no risk of ambiguity.

Note 4 to entry: 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 5 to entry: 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 load), and even if the generator feeding the network is a static converter.

[SOURCE: ~~IEV 101-14-50, modified~~ IEC 61000-2-2:2002, 3.2.1, modified — In the definition, the sentence starting with "For the purposes of this standard" has been moved to a note. The notes have been rephrased, and new notes have been added.]

B.2.2.2
fundamental component
fundamental
the component whose frequency is the fundamental frequency

B.2.2.3
harmonic frequency
frequency which is an integer multiple greater than one of the fundamental frequency or of the reference fundamental frequency. ~~The ratio of this frequency to the fundamental frequency is named harmonic order (recommended notation " *h* "), see IEV 551-20-07, IEV 551-20-05 and IEV 551-20-09~~

[SOURCE: IEC 60050-551:2001, 551-20-05]

B.2.2.4
harmonic component
~~any of the~~ sinusoidal component of a periodic quantity having a harmonic frequency. ~~Its value is normally expressed as an r.m.s. value~~

Note 1 to entry: For brevity, such a component may be referred to simply as a harmonic.

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Note 2 to entry: The value of a harmonic component is normally expressed as an RMS value.

[SOURCE: IEC 60050-551:2001, 551-20-07, modified – The note has been deleted and replaced by Notes 1 and 2 to entry.]

B.2.2.5
harmonic order
ratio of the frequency of any sinusoidal component to the fundamental frequency or the reference fundamental frequency

Note 1 to entry: The harmonic order of the fundamental component or the reference fundamental component is one.

Note 2 to entry: The recommended notation is "h".

[SOURCE: IEC 60050-551:2001, 551-20-09, modified — Note 2 to entry has been added.]

B.2.2.6
interharmonic frequency
~~any~~ frequency which is a non-integer multiple of the reference fundamental frequency

Note 1 to entry: By extension of the 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 to entry: In the case where $m < 1$, the term of sub-harmonic frequency may also be used (see IEC 60050-551:2001, 551-20-10).

[SOURCE: ~~IEV 551-20-07, IEV 551-20-05 and IEV 551-20-09~~ IEC 60050-551:2001, 551-20-06, modified — The notes have been added.]

B.2.2.7
interharmonic component
sinusoidal component of a periodic quantity having an interharmonic frequency. ~~Its value is normally expressed as an r.m.s. value.~~

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

Note 2 to entry: For the purposes of IEC 61800, and as stated in IEC 61000-4-7, the time window has a width of 10 fundamental periods (50 Hz systems) or 12 fundamental periods (60 Hz systems), i.e. approximately 200 ms. The difference in frequency between two consecutive interharmonic components is, therefore, approximately 5 Hz. In case of other fundamental frequencies, the time window should be selected between 6 fundamental periods (approximately 1 000 ms at 6 Hz) and 18 fundamental periods (approximately 100 ms at 180 Hz).

[SOURCE: IEC 60050-551:2001, 551-20-08, modified — The note has been deleted and replaced by Notes 1 and 2 to entry]

B.2.2.8
harmonic content
sum of the harmonic components of a periodic quantity

Note 1 to entry: The harmonic content is a time function.

Note 2 to entry: For practical analysis, an approximation of the periodicity may be necessary.

Note 3 to entry: The harmonic content depends on the choice of the fundamental component. If it is not clear from the context which one is used, an indication should be given.

Note 4 to entry: The RMS value of the harmonic content is

$$HC = \sqrt{\sum_{h=2}^{h=H} (Q_h)^2}$$

where

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Q represents either the current or the voltage;

h is the harmonic order (according to B.2.2.5);

H is 40 for the purposes of this document.

[SOURCE: IEC 60050-551:2001, 551-20-12, modified — Note 4 to entry has been added.]

B.2.2.8
total harmonic distortion (*THD*)
ratio of the r.m.s. value of the harmonic content to the r.m.s. value of the fundamental component or the reference fundamental component of an alternating quantity

[IEV 551-20-13]

NOTE 1 The harmonic content depends on the choice of the fundamental component. If it is not clear from the context which one is used, an indication should be given.

NOTE 2 The total harmonic ratio may be restricted to a certain harmonic order (recommended notation " H "), 40 for the purpose of this standard.

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

where in addition to notations in B.2.2.7

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

B.2.2.9
total distortion content
quantity obtained by subtracting from an alternating quantity its fundamental component or its reference fundamental component

Note 1 to entry: The total distortion content includes harmonic components and interharmonic components if any.

Note 2 to entry: The total distortion content depends on the choice of the fundamental component. If it is not clear from the context which one is subtracted, an indication should be given.

Note 3 to entry: The total distortion content is a time function.

Note 4 to entry: An alternating quantity (abbreviated as Q) is a periodic quantity with zero DC component.

Note 5 to entry: The RMS value of the total distortion content is:

$$DC = \sqrt{Q^2 - Q_1^2}$$

where notations come from B.2.2.8. See also IEV 101-14-54 and IEC 60050-161:1990, 161-02-21 and IEC 60050-551:2001, 551-20-06.

[SOURCE: IEC 60050-551:2001, 551-20-11, modified — The brackets in Note 4 to entry have been added, as well as Note 5 to entry.]

B.2.2.10
total distortion ratio
TDR
ratio of the RMS value of the total distortion content to the RMS value of the fundamental component or the reference fundamental component of an alternating quantity

Note 1 to entry: The total distortion ratio depends on the choice of the fundamental component. If it is not clear from the context which one is used an indication should be given.

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

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[SOURCE: IEC 60050-551:2001, 551-20-14, modified — The abbreviated term *TDR* has been added.]

~~**B.2.2.11**~~
~~**total distortion factor (*TDF*)**~~
~~ratio of the r.m.s. value of the total distortion content to the r.m.s. value of an alternating quantity~~

~~[IEV 101-14-55 and IEV 551-20-16]~~

~~NOTE 1 The total distortion factor depends on the choice of the fundamental component. If it is not clear from the context which one is used an indication should be given.~~

$$TDF = \frac{DC}{Q} = \frac{\sqrt{Q^2 - Q_1^2}}{Q}$$

~~NOTE 2 The ratio between *TDF* and *TDR* equals the ratio between the r.m.s. value of the fundamental component and the total r.m.s. value. It is the fundamental factor (IEV 161-02-22):~~

$$FF = \frac{TDF}{TDR} = \frac{Q_1}{Q} \leq 1$$

B.2.2.11
individual distortion ratio
IDR
ratio of any harmonic component to the fundamental:

$$IDR = \frac{Q_h}{Q_1}$$

Note 1 to entry: In IEC 60050-161:1990, 161-02-20, this term is named "*n*th harmonic ratio".

B.2.3 Conditions of application

B.2.3.1 Reference values

For the purposes of this document and for clarity, limits are referred to the corresponding rated value.

Limits for *THD* and *TDR* are applied to:

$$THD_N = \sqrt{\sum_{h=2}^{h=H} \left(\frac{Q_h}{Q_{N1}}\right)^2} \text{, and}$$

$$TDR = \frac{\sqrt{Q^2 - Q_1^2}}{Q_1} \text{, or}$$

$$IDR = \frac{Q_h}{Q_{N1}}$$

where Q_{N1} is the rated RMS value of the fundamental.

NOTE 1 It is important to note that *THD* does not include interharmonics, and that the upper limit *H* is generally 40. *TDR* does include interharmonics and frequencies above the order 40 up to 9 kHz. If interharmonics and emissions at frequencies above order 40, are negligible, *THD* and *TDR* are equal. ~~The total distortion factor *TDF*,~~

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~~referring the distortion to the total r.m.s. value of the voltage or of the current is rarely used and should be disregarded to avoid confusion.~~

Assessment of emission should be made under the operating conditions which provide the maximum value of the harmonic content in current according to IEC 61000-3-12, and in reference to the rated value. Nevertheless, interharmonics should be considered separately.

NOTE 2 The harmonic content in current (HCI) is designated as the total harmonic current (THC) in IEC 61000-3-12. Where interharmonics can be disregarded, it represents a good approximation of the total distortion content in current (DCI):

$$THC = HCI = \sqrt{\sum_{h=2}^{h=40} (I_h)^2} \approx DCI = (\sqrt{I^2 - I_1^2})$$

B.2.3.2 Systems and installations

A PDS is generally a component of a larger system which can be as large as a complete processing line in the paper or metal industry. To avoid any confusion in this document, the word "installation" is used exclusively to designate the complete installation which is connected to a PCC (point of common coupling) on a public power supply network.

B.2.3.3 Load conditions

For the system, the steady state conditions represent the worst case conditions provided that the overload conditions (acceleration or other) do not exceed a total duration of 5 % in a 24 h period, and 1 % in a 7 day period. If the load of the system is defined by a cycle, assessment of harmonic emission during a period of highest load should be performed according to the measurement method defined in IEC 61000-4-7.

Overload conditions are not considered for assessment of low voltage PDS with rated input current below 75 A (see B.3.2.2).

B.2.3.4 Agreed power

The agreed power S_{ST} defines the equivalent reference current I_{TN} (total RMS value):

$$S_{ST} = U_N \times I_{TN} \times \sqrt{3}$$

where

U_N is the nominal (or declared) line-to-line voltage at the PCC;

I_{TN} is the reference current.

Note that I_{TN} is close to the tripping current value of the main circuit breaker of the installation. S_{ST} represents the power which can be delivered at any time, by the public supply network, to the installation. It can be assumed that for each agreed internal power there exists a reasonable short-circuit power (fault level) S_{SC} defined at the PCC. This is the responsibility of the power distribution authority.

NOTE The "agreed power" results from an agreement between the user (owner of the installation) and the utility authority.

Where the agreed power is used to define the reference current to which harmonic currents are compared in order to express them in p.u. (per unit), the reference current I_{TN1} is by convention equal to I_{TN}

B.2.3.5 Agreed internal power (extension of the definition of agreed power)

The agreed internal power S_{ITA} , for an installation at a defined IPC "α", defines the equivalent reference current I_{TNA} (total RMS value) for the part A of the installation fed from α:

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$$S_{ITA} = U_N \times I_{TNA} \times \sqrt{3}$$

where U_N is the rated line-to-line voltage at the IPC "α".

Note that I_{TNA} is the rated current of the feeding section of the part A of the installation. I_{TNA} is close to the rating of the circuit-breaker protecting this part A. It can be assumed that for each agreed internal power there exists a reasonable short-circuit power (fault level) $S_{SC\alpha}$ defined at the IPC "α". This is the responsibility of those in charge of internal power distribution.

B.2.3.6 Short-circuit current ratio of the source in the installation

R_{SI} is the ratio of the short-circuit power of the source at a defined PC to the rated apparent power of the installation, or of a part of the installation, supplied from this PC (see Figure B.2):

$$R_{SIA} = S_{SC\alpha}/S_{ITA} = I_{SC\alpha}/I_{TNA}$$

The subscript "A" indicates the considered part of the installation and the subscript "α" indicates which PC is at the origin of this part.

NOTE 1 ~~1.5.35 of IEC 60146-1-1 (1991) and 3.69 of IEC 62103 (2003)~~ Subclause 3.9.9 of IEC 60146-1-1:2009 defines the relative short-circuit power (R_{SC}) as the "ratio of the short-circuit power of the source to the ~~fundamental~~ rated apparent power on the line side of the ~~convertor(s)~~ converters. It refers to a given point of the network, for specified operating conditions and specified network configuration.". This is the same concept. However, R_{SI} is referring to the rated apparent power of the total load downstream of the point of coupling instead of the fundamental apparent power of a defined load (the converter) downstream of the point of coupling.

NOTE 2 This definition can be applied to the totality of the installation. In this case, the point of coupling (PC) is the point of common coupling (PCC), and I_{TNA} corresponds to the agreed power.

NOTE 3 This definition can also be applied to a part of an installation of rated current I_{TNA}. The short-circuit current ratio of the source in the installation R_{SIA} is expressed as the ratio of the short-circuit current at the internal point of coupling (IPCα) of the part of the installation to its rated current.

NOTE 4 By extension, this definition can also be applied to a part of an equipment of rated current I_{TNi}. R_{SIi} is expressed as the ratio of the short-circuit current available at the internal considered point (delivered by the source) to the rated current of part of the equipment supplied. This extension is strictly dedicated for consideration of internal constraints of equipment.

NOTE 5 In Figure B.2, the installation shows a part A with a short-circuit current ratio of the source R_{SIA}. The part A contains part B, part B has a short-circuit current ratio of the source R_{SIB}, part A also contains a part C, etc. The part B contains in turn a part B1, a part B2, etc. This partition allows an analysis and the assessment of the different short-circuit current ratios of the source at the different possible points of coupling.

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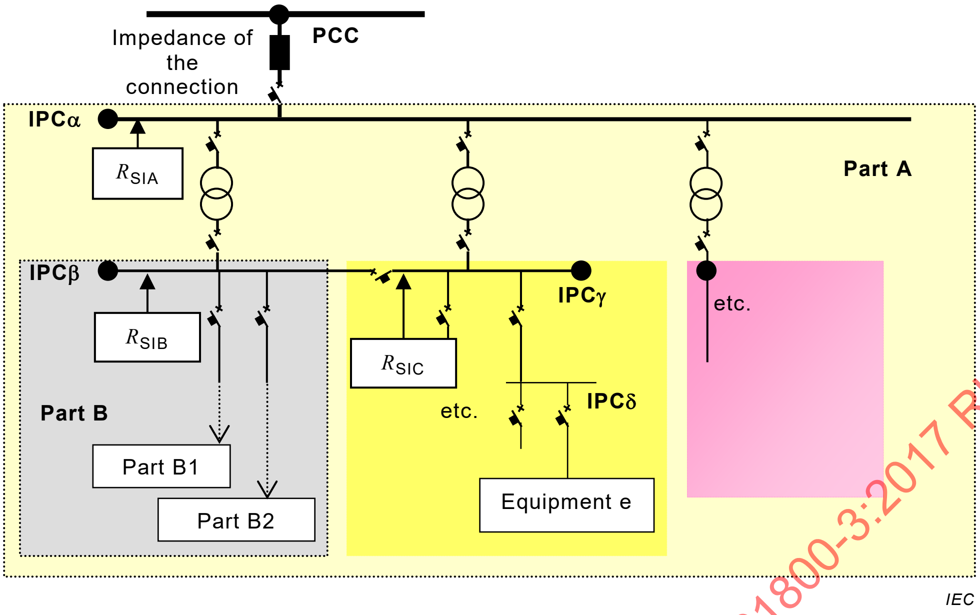

Figure B.2 – PCC, IPC, installation current ratio and R_{SI}

B.2.3.7 Short-circuit ratio

R_{SC} is the ratio of the short-circuit power of the source at the PCC to the rated apparent power of the equipment (see ~~IEC 61000-3-4 or future~~ IEC 61000-3-12):

$$R_{SC} = S_{SC}/S_{Ne} = I_{SC}/I_{LNe}$$

NOTE 1 With the example of Figure B.3, it can be expressed as a function of the relevant R_{SI}. The piece of equipment (e) is fed from a bus bar (IPC$_\delta$), with a point of common coupling (PCC) at which the short-circuit current is I_{SC}, and draws a rated current I_{LNe}. Applying the above definitions gives:

$$R_{SIe} = S_{SC\delta}/S_{ITe} = I_{SC\delta}/I_{LNe} = (I_{SC\delta}/I_{SC}) \times (I_{SC}/I_{LNe}) = (S_{SC\delta}/S_{SC}) \times (R_{SCE})$$

or $$R_{SCE} = (S_{SC}/S_{SC\delta}) \times R_{SIe}$$

This definition is suitable, in the application of ~~IEC 61000-3-4 or future~~ IEC 61000-3-12, for defining the condition of connection of a piece of equipment to the low voltage public supply network.

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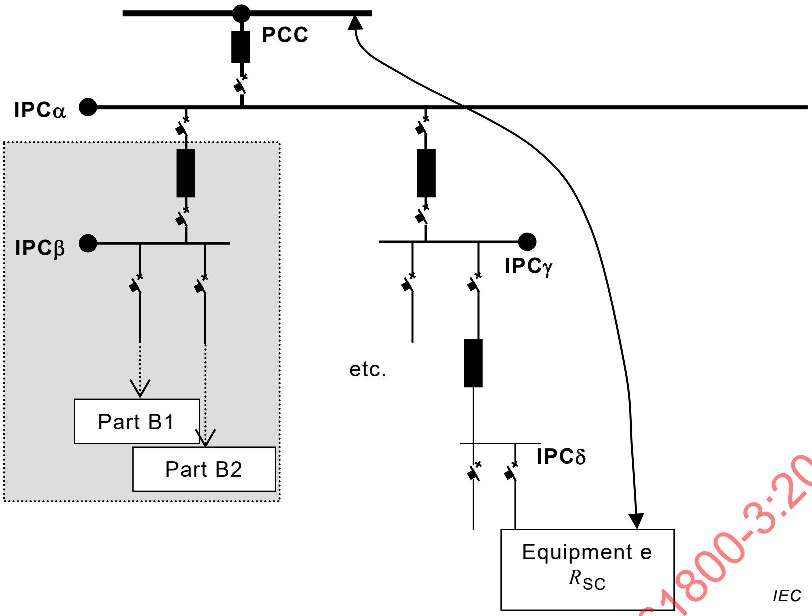

Figure B.3 – PCC, IPC, installation current ratio and R_{SC}

NOTE 2 Clause A.2 of IEC TR 61000-2-6:1995 gives another definition of R_{SC} for rectifiers referring to the DC current.

B.2.3.8 Non-distorting PDS

A PDS complying with the limits of IEC 61000-3-2, or with the limits for R_{SCE} = 33 in Table 2 of ~~stage 1 of the technical report IEC 61000-3-4~~ IEC 61000-3-12:2011 can be labelled: "Non-distorting PDS". The use of such a PDS is allowed without any restriction.

B.3 Application of harmonic emission standards

B.3.1 General

In the theoretical study of power converters and their use, converters have been modelled as sources of harmonic currents. Some new converters of voltage source type (using forced commutation and PWM control) are better described as harmonic voltage sources, therefore they are connected to the PC (which is also a voltage source) through an impedance (reactor) which converts them into harmonic current sources.

However, this common model is not suitable when the internal harmonic impedance of the converter is low compared to that of the network. As a simple example, consider the case of a diode rectifier and capacitive filtering, in which both the AC and DC sides are without any decoupling reactor. The circuit component with the lowest harmonic impedance determines the harmonic voltage.

A minimum knowledge of the system is necessary for establishing a model of the harmonic sources. The harmonic current source model is often suitable for most converters and harmonic orders up to 25. However, this model should be revised for frequencies above the harmonic order 40, where harmonic voltage source models are generally more convenient. Special care should be taken to define the appropriate model in the medium range between harmonic order 25 and 40.

Different models have already been given to define the order and the amplitude of the different harmonic components for different types of converters. A summary of these publications is given in IEC TR 61000-2-6:1995, Clause A.1, and in IEC 61800-1:1997, Annex B~~, or IEC 61800-2, Annex B~~, which include information from IEC TR 60146-1-2.

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Such an analysis is not repeated here.

A PDS is often a harmonic current source which contributes to harmonic voltages. The harmonic voltages ~~have to~~ should be compared to compatibility levels from IEC 61000-2-2 or IEC 61000-2-4. The influence of operating and installation conditions should also be considered. This is pointed out in IEC TR 61000-2-6, which also gives methods for summation of harmonics. Naturally, this has consequences on the appropriate mitigation methods (see Annex C) and on practical rules for connection of a PDS (see Clause B.4).

Industrial practice, with PDSs of category C4, establishes optimal solutions from both the technical and economical points of view. These include adapted mitigation methods, for example, the use of defined phase shifting transformers applied to different PDSs.

Filtering each PDS individually can cause a severe risk of multiple resonance frequencies. Additionally, because the harmonic impedance and the existing voltage distortion are generally unknown and unstable, the rating of the filter is particularly difficult to define. Therefore, a global approach to filtering of the whole installation should be used. Such an approach is developed in IEEE Std 519™.

B.3.2 Public networks

B.3.2.1 General conditions

For low voltage PDSs of rated input current exceeding 16 A and up to and including 75 A per phase, ~~the future~~ IEC 61000-3-12 specifies the limitation of harmonic currents injected into the public supply system. The limits given in ~~the future~~ IEC 61000-3-12 are primarily applicable to electrical and electronic equipment intended to be connected to public low-voltage AC distribution systems.

When a PDS is equipment within the scope of ~~the future~~ IEC 61000-3-12, the requirements of that standard apply. However, when one or more PDSs are included in equipment within the scope of ~~the future~~ IEC 61000-3-12, the requirements of that standard apply to the complete equipment and not to the individual PDS.

The test set-up for direct measurement or for validation of a computer simulation for PDSs within the scope of ~~IEC 61000-3-4 or of the future~~ IEC 61000-3-12 consists of a voltage source and measuring equipment as described in ~~the future IEC 61000-3-12~~ IEC 61000-4-7. If a synchronous machine is used as an independent source for the test, it should be noted that its harmonic impedance is determined by the negative sequence impedance, not by the short circuit current.

NOTE 1 If the PDS includes a phase shift transformer, the point of measurement is on the primary side.

Measurements are performed under steady state conditions. Power overload conditions (affecting torque at full speed) are quite exceptional applications, and if any, are sufficiently limited in time not to be considered.

~~There is no fundamental difference in the process of harmonic emission of power electronic converters regarding their operating mode, either consumption of energy or regeneration of energy. Therefore, four quadrant PDSs only need to be tested in the motoring mode.~~

The emission level may be assessed either by direct measurement or by a validated simulation under the conditions defined in ~~the future~~ IEC 61000-3-12. ~~An overview of the method can be found in flow charts in Figure B.4 and Figure B.5.~~

The following two operating conditions are defined to cover the different types of PDSs:

- rated input current at base speed in motoring mode (voltage source inverter);

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- rated torque at 66 % of base speed in motoring mode (thyristor DC drive or current source inverter).

NOTE 2 IEC 61800-1 and IEC 61800-2 define base speed as the lowest speed at which the motor is capable of delivering maximum output power. In the case of a voltage source inverter, this is often the same speed as if the motor was fed directly from the mains supply.

For equipment neither covered by IEC 61000-3-2 nor by ~~the future~~ IEC 61000-3-12 (for example rated current above 75 A), recommendations are given ~~in the technical report IEC 61000-3-4 and~~ in Clause B.4.

NOTE 3 Harmonics of the different electrical components of the equipment can be summed using the more exact analytical physical law suitable to the nature of the PDS and to the nature of the other components (see B.3.3).

B.3.2.2 Assessment by simulation

The simulation assessment of individual harmonic emission of a PDS should follow the basic rules summarised in Figure B.4. Characterisation of the PDS and of the voltage source is the starting stage.

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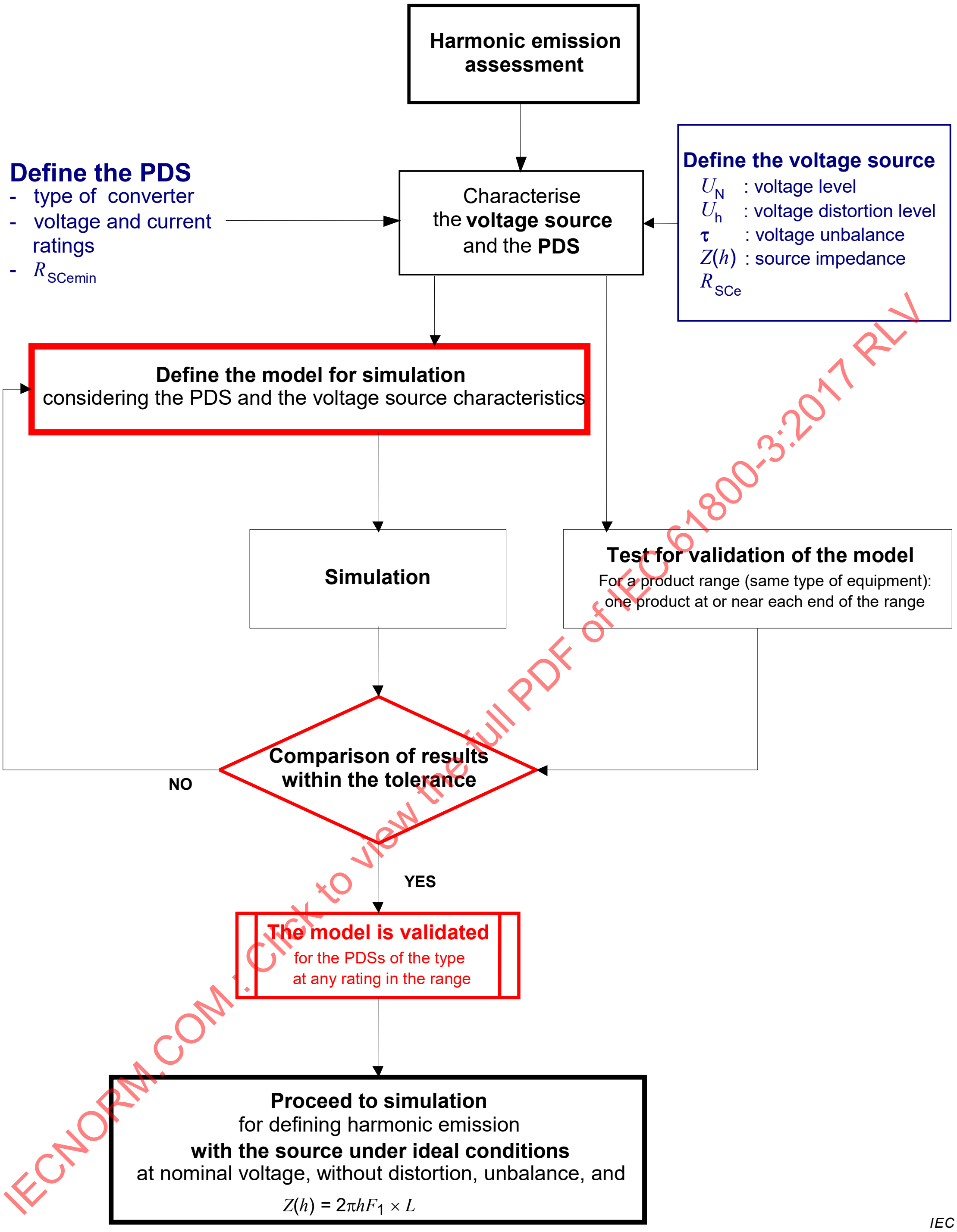

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Figure B.4 – Assessment of the harmonic emission of a PDS

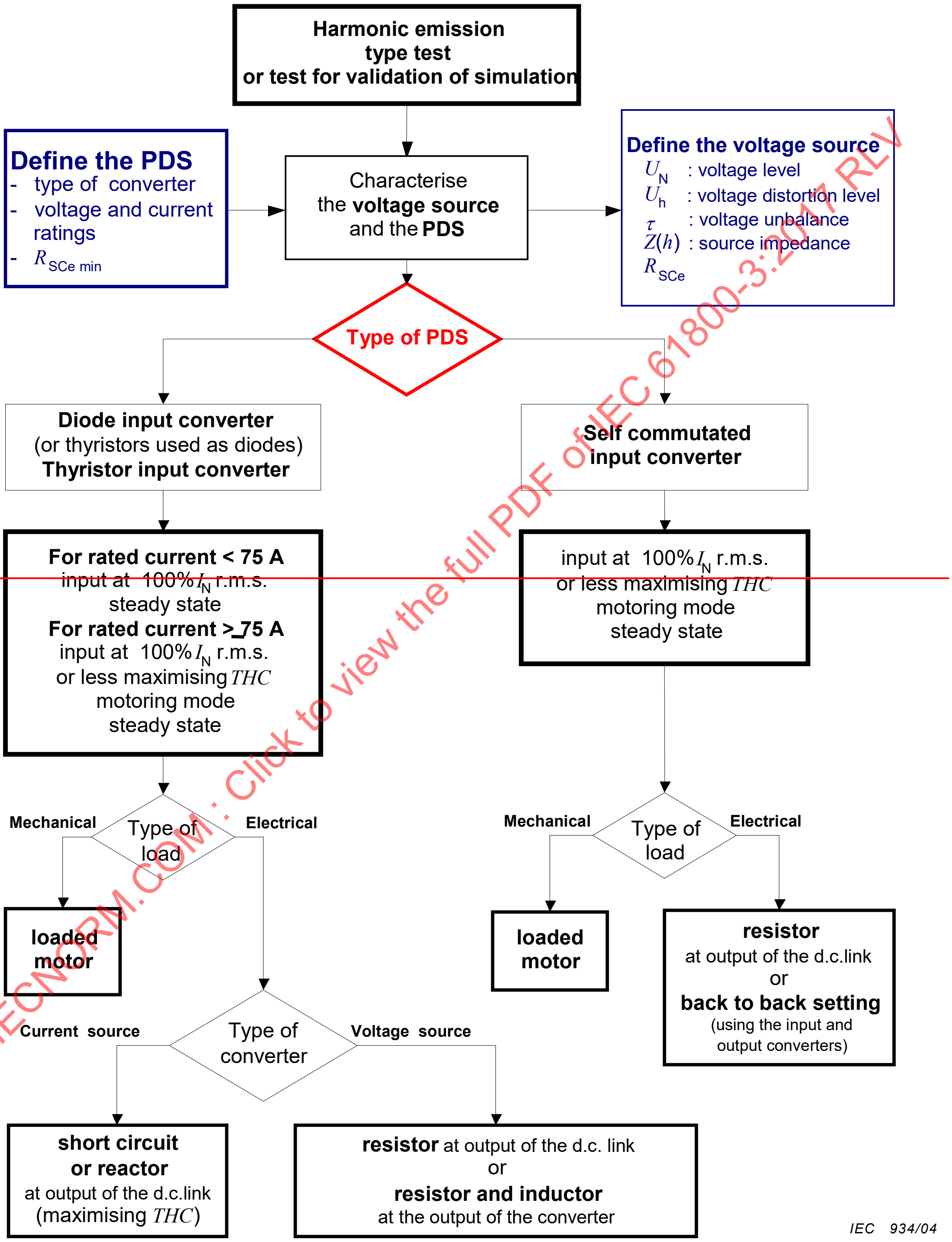
In the case of high power or medium voltage equipment, the validation of the simulation may be a more complex process than the process described here.

B.3.2.3 Load conditions for assessment by test

B.3.2.3.1 General

When the harmonic emission of a PDS is measured individually, ~~the load conditions according to the type of converter of the PDS are summarised in Figure B.5 and details are given in B.3.2.3.1 to B.3.2.4~~ the characterisation of the voltage source and the PDS is performed as in B.3.2.2. For equipment with rated input current above 16 A and up to 75 A, IEC 61000-3-12 requires the R_{SCEmin} during the test to be at least 1,6 times the R_{SCE} which is referenced for compliance declaration. The load conditions are set as follows:

- 100% rated input current or less, maximising THC;
- motoring operation;
- steady state.



~~Figure B.5 – Load conditions for the measurement of harmonic emission of a PDS~~

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Figure B.5 illustrates the test set-up with a mechanical load. Figure B.6 and Figure B.7 illustrate the electrical possibilities when a mechanical load is not available.

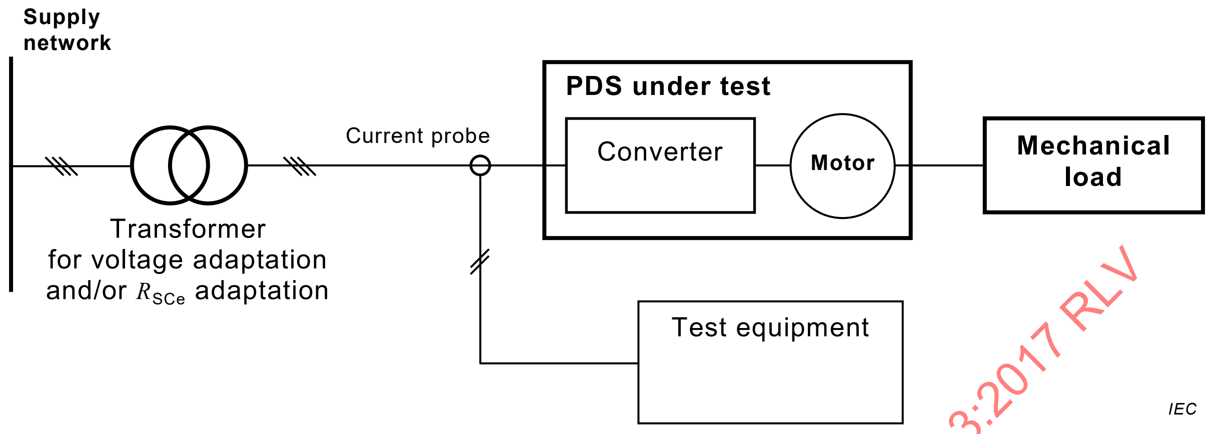

Figure B.5 – Test set-up with mechanical load

B.3.2.3.2 Diode input rectifier

PDS with diode input rectifier (or thyristor rectifier, the thyristors being used as diodes with a function of contactor) may be tested at 100 % rated input RMS current as defined by the manufacturer's specification. The necessary load to obtain the input current may be provided by a motor defined by the manufacturer and a mechanical load for steady state operation.

The loaded motor may be replaced by an electrical load which is connected either at the output of the converter, or at the output of the DC link:

- at the output of the converter, the electrical load should consist of a reactor and a resistor (see Figure B.6);
- at the output of the DC link, the electrical load should consist of a resistor (see Figure B.7).

For rated input currents equal to or greater than 75 A, the rated input current condition may be replaced by the condition maximising the *THC*.

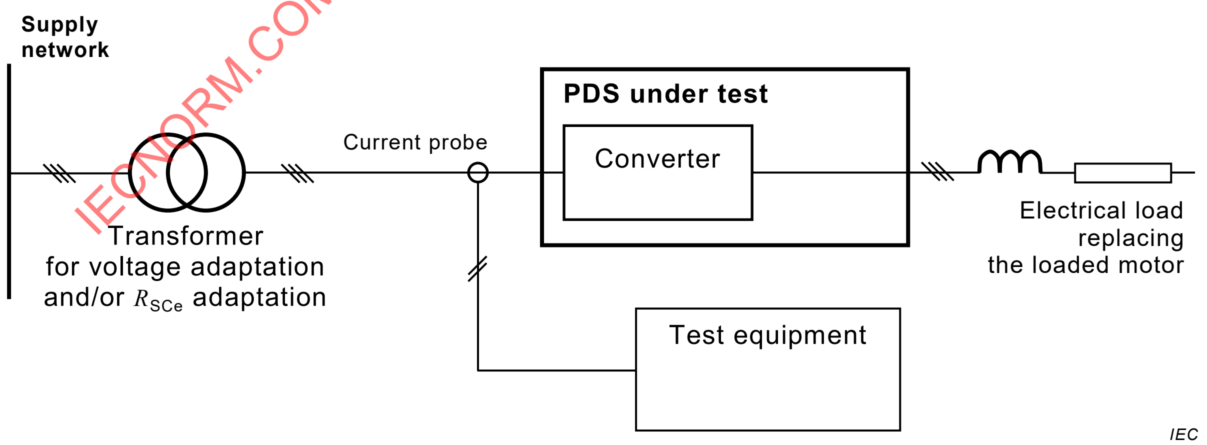

Figure B.6 – Test set-up with electrical load replacing the loaded motor

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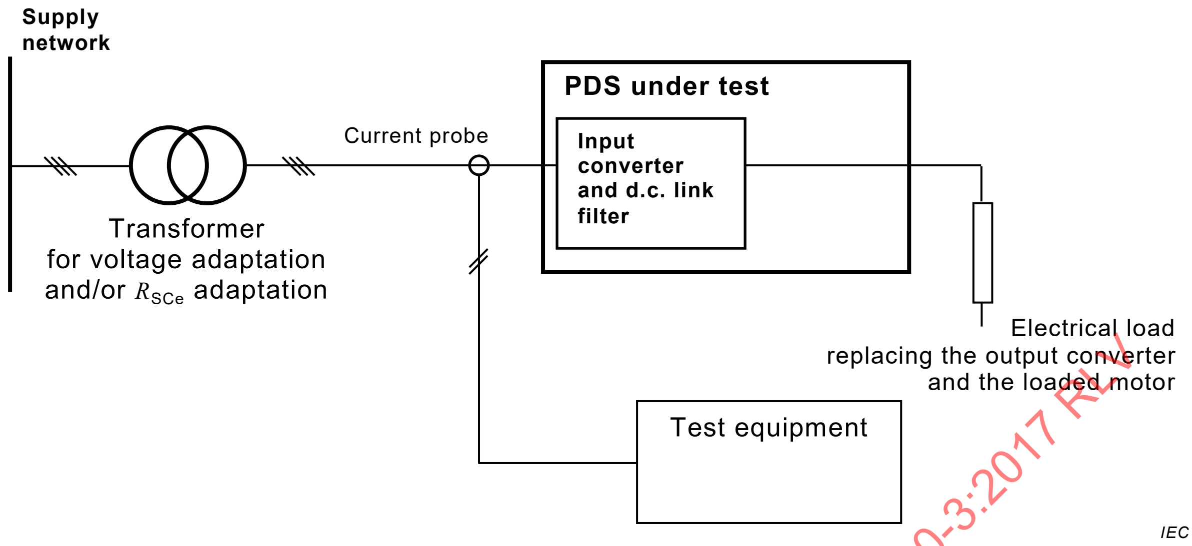

Figure B.7 – Test set-up with resistive load

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B.3.2.3.3 Line commutated input converter

PDS with a line commutated input converter (thyristor converter) is tested at rated RMS input current as defined by the manufacturer's specification, or less for maximising *THC*. No test for regenerating conditions is required. The necessary load to obtain the corresponding input current may be provided by a motor defined by the manufacturer and a mechanical load for steady state operation.

In the case of a current source converter, the loaded motor may be replaced by an inductor at the output of the DC link (instead of the motor). In the case of a voltage source converter, the loaded motor may be replaced by a resistor at the output of the DC link (see Figure B.7).

NOTE Conditions producing maximum *THC* are close to the conditions producing the maximum value of peak-to-peak ripple current, in the DC link at the output of the input converter.

B.3.2.3.4 Self-commutated input converter

PDS with self-commutated input converter is tested at rated RMS input current as defined by the manufacturer's specification, or less for maximising *THC*. No test for regenerating conditions is required. The necessary load to obtain the corresponding input current may be provided by a motor defined by the manufacturer and a mechanical load for steady state operation.

The loaded motor may be replaced by a resistor at the output of the DC link. A back to back setting for loading is also possible; in such a case, it is obvious that only the current of the input converter is measured.

B.3.2.4 Representative maximum of *THC*

It is not always necessary to operate at the rated input current to comply with the requirement of maximising the current *THC* (total harmonic content in current).

NOTE In this document, *THC* is the total harmonic content (see B.2.2.8) which is consistent with IEC 60050-551:2001, 551-20-12. In IEC 61000-3-12, *THC* represents the total harmonic current which can be considered as an abbreviation of total harmonic content in current.

For certain types of converters (for example current source), the ripple current in the DC link depends on the speed of the motor. Worst conditions are obtained at zero speed, which is equivalent to the loaded motor replaced by an inductor at the output of the DC link. This case is generally not representative of normal operation of the PDS.

For a PDS of rated input current equal to or above 75 A, two operating conditions are required in order to assess the harmonic emissions of the different types of PDS:

- rated input current at base speed in motoring mode (voltage source inverter);
- rated motor current at 66 % of base speed in motoring mode (thyristor DC drive or current source inverter).

For other types of PDS, where it is not obvious which of the above conditions is the worst case, both of these conditions should be assessed. In both cases harmonic currents should be assessed as a percentage of the rated fundamental input current. The case with the higher value of *THC* should be considered as the worst case.

When these two conditions cannot be assessed (by test or by validated simulation), or for low voltage PDS of rated input current less than 75 A, as an alternative, it is admitted to verify the maximum *THC* condition by means of the following simplified method. The current may be set below the rated input current, provided it produces the maximum absolute ripple current in the DC link. The condition can be checked by verifying the waveform of the current at the appropriate location on the DC link.

Conditions providing a representative maximum of *THC* are also met with electrical loads by adjustment of the mean value of the current in the DC link. They may be taken to specify the load conditions of the test for validation of a simulation.

The *IDR* (individual distortion ratio, see B.2.2.11) measured under those conditions provides an overestimation of the most significant harmonic components of the current. They also may be taken as result of the test when the rated current cannot be achieved, and when simulation is not used.

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B.3.3 Summation methods for harmonics in an installation – Practical rules

B.3.3.1 Principle

Harmonic emissions from the different components are summed in the most appropriate way. The chosen method of summation can be a fast but conservative approximation. When more precision is required, the appropriate summation law may be chosen, according to the nature and structure of the converters of the PDSs. The result is referenced to the rated fundamental current of the apparatus or of the system (agreed internal power).

B.3.3.2 Simple arithmetic summation of harmonic currents

In this approach, harmonic currents are summed arithmetically (this approach is simple but often highly conservative). Calculation of the individual distortion ratio *IDR* (for each order), or of the total harmonic distortion *THD*, is performed for three-phase components, using the following equation applied to all distorting components (pieces of equipment) belonging to an installation or to a part of an installation.

HD is the generic symbol for *IDR* or *THD*. The subscript "eq" indicates that this value is attached to a particular piece of equipment in the system. The subscript "IT" indicates that the example is related to a part of an installation, however the same applies to the whole installation (using subscript "ST").

$$HD = \sum_{\mathrm{eq}} HD_{\mathrm{eq}} \times \frac{S_{\mathrm{eq}}}{S_{\mathrm{IT}}}$$

In the equation HD_{eq} is referenced to the rated fundamental current of the component (piece of equipment), and *HD* is referenced to the rated fundamental current of the part of the installation (agreed internal power).

Single-phase components are taken into account by means of an unbalance penalty coefficient:

- for single-phase loads, phase-to-phase, the coefficient is √3:

$$\sqrt{3}\left(HD_{\text{eq}} \times \frac{S_{\text{eq}}}{S_{\text{IT}}} \right)$$

- for single-phase loads, phase-to-neutral, the coefficient is 3:

$$3\left(HD_{\text{eq}} \times \frac{S_{\text{eq}}}{S_{\text{IT}}} \right)$$

The penalty coefficient is applied to those terms related to the loads in excess which create the unbalance condition.

Example: S_{IT} = 150 kVA

Piece of distorting equipment N°1: S_{eq} = 25 kVA with HD = 65 % , related to its rated current;

HD_{eq1} = 65 x (25/150)% = 10,8 % , related to I_{TN1} (or S_{IT}).

Piece of distorting equipment N°2: S_{eq} = 10 kVA with HD = 10 % , related to its rated current;

HD_{eq2} = 10 x (10/150) % = 0,7 % , related to I_{TN1} (or S_{IT}).

Piece of distorting equipment N°3: S_{eq} = 1 kVA with HD = 85 % , related to its rated current,

but single-phase (phase-to-phase), equivalent to 1,73 times its rating as balanced load, with harmonics multiple of three (to be considered):

HD_{eq3} = 85 x (1,0/150) x 1,73 = 1,0 % related to I_{TN1} (or S_{IT}).

For the system HD = (10,8 + 0,7 + 1,0) % = 12,5 % with $\Sigma\, S_{\text{eq}}/S_{\text{IT}}$ = (25 + 10 + 1)/150 = 0,240

The calculation should be performed for each harmonic order and for THD.

B.3.3.3 Pseudo-quadratic (variable exponent) summation law

The summation of harmonic currents can be made with a more representative law:

- current known to be in phase (for example diode rectifier), arithmetic summation of each order

$$I_{\text{h}} = \Sigma_{\text{i}}\, I_{\text{hi}}$$

- random phase relationship between currents, exponent and summation of each order

$$I_{\text{h}} = \left[\sum_{\text{i}} I_{\text{hi}}{}^{\alpha} \right]^{\frac{1}{\alpha}}$$

where

α = 1 for h < 5;

α = 1,4 for 5 ≤ h < 10;

α = 2 for 10 ≤ h.

The above formulae can be applied to individual harmonic orders and also to THD.

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This method gives an assessment of harmonic current emissions from the system. The result is referenced to the rated fundamental current of the system (agreed internal power) and may be used to show compliance with IEC 61000-3-2 or ~~future~~ IEC 61000-3-12 ~~(stage 1 or 2)~~ according to the rating of the machine or of the system. It may even be used for assessment of larger industrial systems or installations.

Typical environments where this approach applies are equipment for light industry with "agreed power" between 30 kVA and 100 kVA, or installation for light industry with "agreed power" between 100 kVA and 300 kVA.

B.3.3.4 Approach for industrial networks based on calculation and/or measurements

If compliance with harmonic emission limits cannot be proved by the above approximations, a more accurate assessment of harmonic emissions should be used. This concerns the total current demand of the installation.

The total harmonic current produced by the installation, including the load to be installed, should be established by calculation or measurement. The actual phase relationships between harmonic producing loads should be taken into account so that cancellation effects are not ignored.

Typical environments where this approach applies are light industry with "agreed power" higher than 100 kVA or industry.

B.4 Installation rules – Assessment of harmonic compatibility

B.4.1 Low power industrial three-phase system

B.4.1 is intended to provide guidance for the use of PDSs for their incorporation in products, apparatus or more generally in systems. Applying harmonic limits to each PDS can result in an uneconomic solution and/or in a technical nonsense. It is often better to apply a global approach to filtering of the whole installation. This requires a summation of the harmonic currents produced within an installation.

The procedure for the assessment of harmonic emissions is summarised in Figure B.8.

As stated in 6.2.3.1 and 6.2.3.2, IEC 61000-3-2 and ~~the future~~ IEC 61000-3-12 apply to apparatus comprising PDSs that are directly connected to a PCC in a public low-voltage network. Checking of compliance is performed by comparing, with tables in the appropriate referenced standard, the levels of individual ~~distortion ratio *IDR* (for each order), and total harmonic distortion (*THD*)~~ harmonic currents and total harmonic current (THC) produced by the system or apparatus.

For PDSs which are not covered by these publications, the following procedure can be used as a guide. The usual approach is to apply limits of harmonic current to the complete installation. The assessment of the total harmonic emission is performed with appropriate summation laws, according to the required approximation (see B.3.3). Simplified methods and criteria are possible when the agreed power is within a medium range (for example between 100 kVA and 300 kVA), as suggested in Figure B.8, or according to local rules. It is in the responsibility of the user to meet the adequate limits at the PCC.

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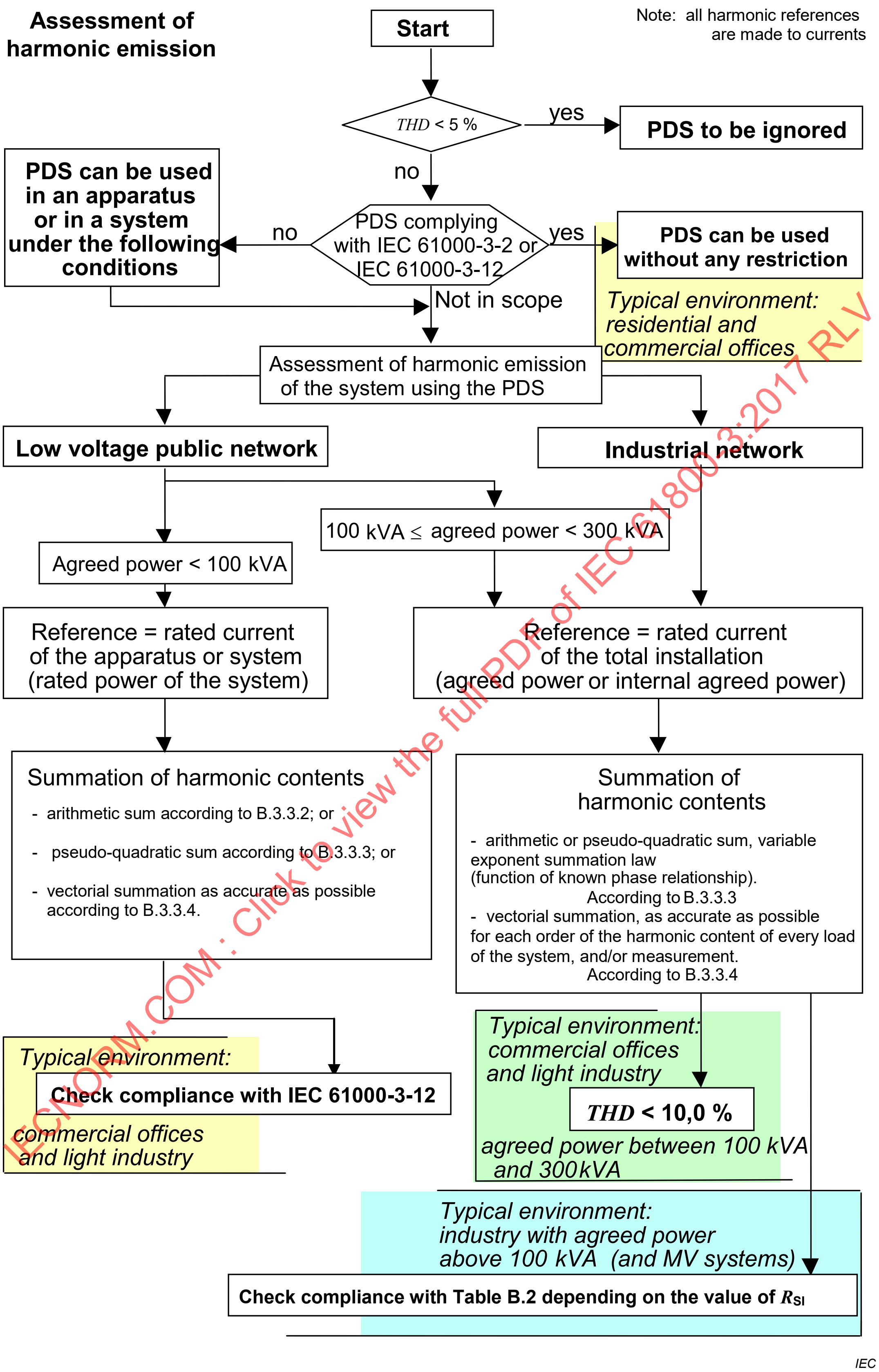

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Figure B.8 – Assessment of harmonic emission where PDS is used (apparatus, systems or installations)

B.4.2 Large industrial system

B.4.2.1 Principles

B.4.2 is intended to provide guidance for the use of PDSs for their incorporation in systems. Applying harmonic limits to each PDS can result in an uneconomic solution and/or in a technical nonsense. It is often better to apply a global approach to filtering of the whole installation. This requires a summation of the harmonic currents produced within an installation.

The procedure for the assessment of harmonic emissions is summarised in Figure B.8.

IEC TR 61000-3-6 should be applied directly for installations supplied by a medium voltage power supply network, which is the case for large PDSs and particularly those of rated voltage above 1 000 V AC.

It is usual to separate the installation into different parts according to natural decoupling devices (e.g. transformers). The separation should result from the analysis of the complete network, taking possible resonances into account (see Figure B.2).

The location of required filters should be carefully established, but it is evident that filtering each PDS is not practicable.

The usual approach is to apply limits of harmonic current to the complete installation, or to parts of the installation as seen above. In critical cases, a more detailed analysis involving the existing level of voltage harmonic distortion is used.

B.4.2.2 Current distortion determination method for complete installation

In this approach, harmonic current limits are applied to the whole installation. Limits are applied both to individual distortion ratios (*IDR*) for individual orders and to *THD*.

The harmonic currents of the total installation should be in accordance with the following Table B.2 at the defined point of coupling. See definition of R_{SI} in B.2.3.6. The PDS supplier and customer should agree on the point of coupling (PCC or IPC) and on the applications of other emission limits coming from local regulations. The point of coupling should be an identified bus bar.

NOTE From the definition of R_{SI}, dedicated to a defined bus bar, it is clear that all loads fed from this bus bar contribute to the definition of the corresponding current (I_{TN}) to be taken into account for calculation of harmonic emission.

In the USA, IEEE Std 519 applies this approach at all voltage levels for electricity distribution networks. Table B.2 gives an example of practical limits already experienced in North America.

Harmonic currents are expressed as percentages of the total current corresponding to the internal agreed power of the AC supply of the total installation (*IDR*). In the case of a PCC, the load current is defined by the "agreed power", as agreed between the user and the utility. In the case of an IPC, the rated fundamental load current is equal to the rated load current of the feeder to the IPC. See subclauses B.2.3.5 and B.2.3.6.

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Table B.2 – Harmonic current emission requirements relative to the total current of the agreed power at the PCC or IPC

	Individual distortion ratio *IDR*					
RSI	$h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 40$	***TDR***
$R_{SI} < 20$	4 %	2 %	1,5 %	0,6 %	0,3 %	5 %
$20 \leq R_{SI} < 50$	7 %	3,5 %	2,5 %	1 %	0,5 %	8 %
$50 \leq R_{SI} < 100$	10 %	4,5 %	4 %	1,5 %	0,7 %	12 %
$100 \leq R_{SI} < 1000$	12 %	5,5 %	5 %	2 %	1 %	15 %
$1000 \leq R_{SI}$	15 %	7 %	6 %	2,5 %	1,4 %	20 %

Even harmonics are limited to 25 % of the odd harmonics.

For systems with a pulse number (= q) higher than 6, the limits for each individual harmonic are increased by the factor $\sqrt{q/6}$. This corresponds for a 12 pulse system to $\sqrt{2}$. The *THD* limit remains unchanged.

B.4.2.3 Case by case analysis

As an alternative, a complete analysis of the system can be conducted, and should be conducted in critical cases. The results of the analysis can then be used to correctly define the total filtering, or other mitigation methods.

The following procedure should be adopted:

- assess the existing level of harmonic voltage distortion at the PCC (at the responsibility of the operator of the distribution network – public or private);
- calculate or measure the harmonic impedance of the supply at the PC (at the responsibility of the operator of the distribution network – public or private if PCC – and the responsibility of the user if IPC – internal point of coupling); IEC TR 61000-2-6:1995, Clause A.2, gives information on the harmonic impedance encountered in networks;
- calculate or measure harmonic currents that the PDS to be connected is going to inject into the system (at the responsibility of the manufacturer);
- calculate harmonic voltages that can result from this (at the responsibility of the user).

NOTE All the rules and methods listed in IEC TR 61000-3-6, although defined for medium voltage (from 1 kV up to and including 35 kV) or high voltage (> 35 kV) public networks, are applicable to industrial networks, including their low voltage parts.

In the case of a PCC, the resulting harmonic voltages should not exceed the planning levels defined by the utility. In the case of an IPC, the resulting harmonic voltages should not exceed the compatibility levels.

Compatibility levels for harmonic voltages are defined by IEC 61000-2-2 on low voltage public systems, by IEC 61000-2-12 on medium voltage public systems and by IEC 61000-2-4 on private industrial systems.

At the PC an available nominal power (called agreed internal power) can be defined. In the case of a PCC this is the “agreed power” (see B.2.3.4 and B.2.3.5). A disturbance allowance can be allocated to the PDS to be connected. The reasonable solution consists of defining this disturbance allowance proportional to the ratio of the PDS's rated power to the agreed internal power at the PC, and proportional to compatibility levels defined by standards quoted in B.4.2.3.

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B.4.2.4 Telephone interference

In North America and Finland, the parallel construction of energy distribution and telephone lines has led to the introduction of *TIF* (telephone interference factor). IEEE 519~~ (1992)~~-2014, Annex B, presents the result of a weighting of the various harmonics.

The equivalent psophometric current is defined as $I_p = I \times TIF$,

and the local recommended practices require that $I_p < I_{pA}$

Within the installation, the common mode harmonic emission on the motor cable can cause interference with telephone lines if they are running in parallel. This should be avoided (see 6.2.5).

B.4.3 Interharmonics and voltages or currents at higher frequencies

In this frequency range, above harmonic order 40 and up to 9 kHz, the PDS should be considered as a voltage source emitter. There are no emission requirements for PDSs until compatibility levels will be standardised.

However, application of certain types of PDSs can require the consideration of the emission of interharmonics or of currents or voltages at higher frequencies (up to 9 kHz). This is mainly the case for high power PDSs such as cyclo-converters or current source inverters. This can also be the case for active front-end converters where the PWM switching is directly coupled to the network.

Interharmonics at frequencies slightly different from the fundamental or from predominant harmonics can also cause voltage fluctuations (see B.6.2). They result from beat frequencies which can be seen on non-linear systems such as lighting (function of the square of the voltage). The non-linear response of the disturbed equipment causes the sum and difference of the different harmonic or interharmonic frequencies to appear. The difference frequency can be in the range that causes flicker. The main origin is cyclo-converters or current source inverters. This case is covered by compatibility levels given in IEC 61000-2-4.

~~Interharmonics can directly affect power factor correction capacitor banks and harmonic filters, particularly due to resonances.~~

~~The emission should be limited to 80 % of the indicative voltage levels below (from Annex C of IEC 61000-2-4 (2002)).~~

~~– 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;~~

~~where "u" is the ratio of the r.m.s. voltage at that frequency to the r.m.s. value of the fundamental component of the voltage, and "u_b" is the level related to any 200 Hz bandwidth centred at frequency F, and 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;~~

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~~F is the centre frequency of the band (the band is above the 40th harmonic).~~

~~At higher frequencies, the origin is mainly from active front-end converters where the PWM switching is strongly coupled to the network.~~

B.5 Voltage unbalance

B.5.1 Origin

Voltage unbalance on a three-phase system is generally caused by unequal loading on two of the three phases by single-phase loads. The voltage unbalance is directly related to the amount of the single-phase load as a percentage of the rating, and to the impedance of the mains supply. As an example, consider a three-phase transformer with a defined regulation, and only a single-phase load connected between two phases. If the load is a significant percentage of the kVA rating of the transformer, the output voltages (phase to neutral) of the two phases connected to the load will be reduced while the third winding without any load will remain the same.

Significant unbalance on transformers will cause excessive heating. The manufacturer should be consulted to determine if the transformer is capable of supplying single-phase loads that are a significant percentage of its rated kVA capacity.

Other three-phase loads connected to an unbalanced three-phase source of power are generally affected in a detrimental manner. As an example, the unbalance will cause a reverse sequence current to flow in a three-phase induction motor, which will reduce the torque output at rated current or cause excessive heating at rated output of the motor. In some motors, an unbalance of 3 % can result in a 10 % derating of their output. If an unbalance condition exists on the mains supplying a three-phase motor, it is important to consult the motor manufacturer to determine the proper derating for safe operation.

B.5.2 Definition and assessment

B.5.2.1 Definition

Voltage unbalance is defined in IEC 61000-2-2, IEC 61000-2-4 or IEC 61000-2-12. Some methods of calculation are given below.

In a polyphase system, voltage unbalance is a condition in which the RMS values of the fundamental component of the line-to-line voltages, or the phase angle between consecutive phases, are not all equal. For the purposes of this document, the degree of that inequality is expressed as the ratio of the negative sequence component to the positive sequence component.

In some circumstances, the zero-sequence component should be included in the assessment of voltage unbalance.

B.5.2.2 Complete analysis

The accurate definition relates to symmetrical component analysis of the three-phase system. This type of analysis is based on the concept that any phase voltage deviation from the ideal three-phase system can be described by the addition of three vectors. They are called the zero, positive and negative sequence vectors and are defined as follows.

$\underline{U}_{A} = \underline{U}_{A0} + \underline{U}_{A1} + \underline{U}_{A2}$ phase A voltage

$\underline{U}_{A0} = (\underline{U}_{A} + \underline{U}_{B} + \underline{U}_{C})/3$ zero sequence component

$\underline{U}_{A1} = (\underline{U}_{A} + a\,\underline{U}_{B} + a^2\,\underline{U}_{C})/3$ positive sequence component

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$\underline{U}_{A2}$ = $(\underline{U}_A + a^2\,\underline{U}_B + a\,\underline{U}_C)/3$ negative sequence component

where $\underline{U}_A$, $\underline{U}_B$, and $\underline{U}_C$ are the phase voltage vectors and "a" is the operator,

$a = -\,(1/2) + j\,(\sqrt{3}/2\,)$.

The ratio of the negative sequence to the positive sequence voltage is the voltage unbalance. This is as follows:

$$\tau\,\% = 100\;U_2/U_1$$

Example 1 Amplitudes and phase angles of line-to-neutral voltages are known allowing the line-to-line voltages and the corresponding phase angles to be calculated.

~~U_{AN} = 231,00 and 0,0°, U_{BN} = 220,00 and −125,1°, U_{CN} = 215,00 and 109,8°~~

~~U_{AB} = 400,32 and 26,7°, U_{BC} = 386,00 and −98,0°, U_{CA} = 364,98 and 146,3°~~

~~resulting in U_0 = 22,36 35,2°, U_2 = 20,40 and 90,7°, U_1 = 383,51 and −5,0°~~

~~and voltage unbalance: τ = 100 (20,36/383,51) = 5,320 %, with a zero sequence component of 5,831 %.~~

U_{AN} = 231,00 and 0,0°, U_{BN} = 220,00 and −125,1°, U_{CN} = 215,00 and 109,8°

U_{AB} = 400,26 and 26,7° , U_{BC} = 386,03 and − 98,0°, U_{CA} = 365,01 and 146,3°

resulting in zero sequence U_0 = 12,91 and 35,2°,

positive sequence U_1 = 221,41 and −5,0°,

negative sequence U_2 = 11,78 and 90,7°,

and voltage unbalance: τ = 100 (11,78/221,41) = 5,32 %, with a zero sequence component of 5,83 %.

Example 2 Amplitudes and phase angles of line-to-neutral voltages are known allowing the line-to-line voltages and the corresponding phase angles to be calculated:

~~U_{AN} = 230,00 and 0,0°, U_{BN} = 280,00 and −135,0°, U_{CN} = 170,00 and 130,0°~~

~~U_{AB} = 471,50 and 24,8°, U_{BC} = 339,94 and −105,1°, U_{CA} = 363,40 and 159,0°~~

~~resulting in U_0 = 59,34 and −138,8°, U_2 = 85,79 and 48,1°, U_1 = 386,40 and −3,7°~~

~~and voltage unbalance: τ = 100 (85,79/386,40) = 22,230 %, with a zero sequence component 15,356 %.~~

U_{AN} = 230,00 and 0,0°, U_{BN} = 280,00 and −135,0°, U_{CN} = 170,00 and 130,0°

U_{AB} = 471,57 and 24,8°, U_{BC} = 340,00 and −105,1°, U_{CA} = 363,41 and 159,0°

resulting in zero sequence U_0 = 34,26 and −138,7°,

positive sequence U_1 = 223,09 and −3,7°,

negative sequence U_2 = 49,59 and 48,1°,

and voltage unbalance: τ = 100 (49,59/223,09) = 22,23 %, with a zero sequence component 15,36 %.

B.5.2.3 Approximate method

Three approximations are given below. The first one usually provides the best results, with an error less than 5 % for any kind of unbalance for which the line-to-neutral voltages have phase angles within a tolerance of ±15°, and the amplitude within a tolerance of ±20 % compared to the corresponding ideal balanced system (positive sequence or negative sequence).

U_{12}, U_{23} and U_{31} are the three line-to-line voltages, with $\delta_{ij} = (U_{ij} - U_{average})/(3 \times U_{average})$ for each of the three line-to-line voltages, and τ the voltage unbalance as the ratio of the negative sequence voltage amplitude to the positive sequence voltage amplitude,

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$$\tau \approx \sqrt{6\sum_{1}^{3}\delta_{ij}^{2}}$$

The much more simple approximation:

$$\tau \approx \left(\frac{2}{3}\right)\times\left[\frac{U_{max}-U_{min}}{U_{average}}\right]$$

provides acceptable results (absolute error generally less than 1 %) for τ up to 7 %.

The formula proposed by NEMA also gives acceptable results (absolute error generally less than 1 %) for τ up to 10 % or where phase shifts are large:

$$\tau \approx \frac{MAX\left|U_{ij}-U_{average}\right|}{U_{average}}$$

Example 1 As above:

~~U_{AN} = 231,00 U_{BN} = 220,00 and U_{CN} = 215,00~~

~~U_{AB} = 400,32 U_{BC} = 386,00 and U_{CA} = 364,98~~

~~$U_{average}$ = (400,32+386,00+364,98)/3 = 383,77 and without decimals $U_{average}$ = (400+386+365)/3= 383,66~~

~~δ_{12} = 1,432 % δ_{23} = 0,197 % δ_{31} = –1,629 %~~

~~The voltage unbalance is [6(1,432^2+0,197^2+1,629^2)]$^{1/2}$ = 5,3 %~~

~~or (2/3) × (U_{max} – U_{min})/$U_{average}$ = (2/3) × (400 – 365)/383,7 = 6,1 %, or using the last approximation: 18,7/383,7 = 4,9 %.~~

U_{AN} = 231,00 U_{BN} = 220,00 and U_{CN} = 215,00

U_{AB} = 400,26 U_{BC} = 386,03 and U_{CA} = 365,01

$U_{average}$ = (400,26 + 386,03 + 365,01)/3 = 384,07 and without decimals $U_{average}$ = (400 + 386 + 365)/3 = 383,66

δ_{12} = 1,433 % δ_{23} = 0,197 % δ_{31} = –1,629 %

The voltage unbalance is [6 (1,433^2 + 0,197^2 + 1,629^2)]$^{1/2}$ = 5,3 %

or (2/3) x (U_{max} – U_{min}) / $U_{average}$ = (2/3) x (400 – 365)/383,7 = 6,1 %, or using the last approximation: 19,1/383,7 = 5,0 %.

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Example 2 As above:

U_{AN} = 230,00 U_{BN} = 280,00 and U_{CN} = 170,00

U_{AB} = 471 U_{BC} = 340 and U_{CA} = 363

$U_{average}$ = (472+340+363)/3 = 391,7

δ_{12} = 6,801 % δ_{23} = –4,397 % δ_{31} = –2,404 %

The voltage unbalance is $[6(6{,}801^2 + 4{,}397^2 + 4{,}397^2)]^{1/2}$ = 20,7 %

or (2/3) × (U_{max} – U_{min})/$U_{average}$ = (2/3) × (472 – 340)/391,7 = 22,4 %, or using the last approximation: 80,3/391,7 = 20,5 %.

U_{AN} = 230,00 U_{BN} = 280,00 and U_{CN} = 170,00

U_{AB} = 471,57 U_{BC} = 340 and U_{CA} = 363,41

$U_{average}$ = (471,57 + 340 + 363,41) / 3 = 391,66

δ_{12} = 6,801 % δ_{23} = –4,397 % δ_{31} = –2,404 %

The voltage unbalance is $[6\ (6{,}801^2 + 4{,}397^2 + 4{,}397^2)]^{1/2}$ = 20,7 %

or (2/3) x (U_{max} – U_{min}) / $U_{average}$ = (2/3) x (472 – 340) / 391,7 = 22,4 %, or using the last approximation: 80,6/391,7 = 20,6 %.

B.5.3 Effect on PDSs

The effect on the PDS will vary depending on the type of power circuit and control method used. Each type of control and circuit should be analysed in detail. Generally, the effect will be small on controlled or uncontrolled converters that supply resistive loads. Phase controlled converters of the type that use phase shifted line voltage for their reference will be affected less than converters that use a voltage ramp synchronised to the line using zero crossings for their reference. Controlled or uncontrolled converters that supply capacitor banks, used in the DC loop of indirect converters (voltage source inverters), will have current unbalances that are significantly larger than the voltage unbalance and larger than converters that supply an inductive load such as a DC motor.

Special care should be taken with the design of converters that supply capacitor banks since the peak current is greatly magnified by the voltage unbalance. For very large capacitor banks where the ripple voltage is small, the peak current from each phase is limited only by the source impedance and any additional impedance in the PDS and the difference between the capacitor bank voltage and the line voltage. The ratio of peak currents between phases can be as large as 20 % for 3 % voltage unbalance with a 1 % source impedance. Fortunately, this is an extreme condition since it is unlikely that single-phase loading could cause this magnitude of unbalance with a 1 % source impedance.

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B.6 Voltage dips – Voltage fluctuations

B.6.1 Voltage dips

B.6.1.1 Definition

Perhaps the most common form of low-frequency disturbance is the voltage dip or a reduction of voltage on one or all of the three phases. A voltage dip is a sudden reduction of the voltage at a point in the electrical system, followed by voltage recovery after a short period of time, from half a cycle to a few seconds. A voltage dip is generally caused by the clearing of faults by the utility supplying the mains or by the starting of large motors in or near the user's location. Surveys by different utilities in different countries have shown that voltage dips can range from a time of half a cycle to 15 cycles or more at voltages outside the 10 % voltage tolerance. The residual voltage (lowest value of the voltage during the dip) is now preferred to the depth of the dip to characterise the magnitude (the depth is the difference between the reference voltage and the residual voltage). The residual voltage largely depends on the relative location of the voltage source (generally a high voltage/medium voltage substation), the event equivalent to a short circuit and the observation point. Comprehensive information is available in IEC TR 61000-2-8.

B.6.1.2 Effect on PDSs

B.6.1.2.1 Fundamentals

Voltage dips can have detrimental effects upon the performance of PDSs. When the supply voltage is reduced, usually the power that can be transferred from the mains to the motor is also reduced. However, some PDS converters compensate for voltage dips over limited ranges by changing control angles for input rectifiers. Also of concern, regenerative converters that transfer mechanical power from the motor back to the mains may encounter issues with voltage dips.

The effect of voltage dips on PDS should be considered according to the physical nature of the driven equipment. Moreover, the electronic control of the PDS and the power converter components ~~have to~~ should be distinguished (see IEC TR 61000-2-8).

The control part could be immune, with performance criterion A, to certain types of dips, and this could be of no use unless it is consistent with the behaviour of the converter or of the driven equipment. The converter has no energy storage capability. The driven equipment generally has little energy storage capability, which can be used under certain conditions. To claim that a PDS is immune to voltage dips purely on the basis of the immunity of the control part would be misleading. The use of a specific sequence in the control should be documented to make it possible for the user to define the suitable adaptation to the driven equipment.

B.6.1.2.2 Controlled converters

Controlled converters, such as those that are made up of thyristors, GTOs (gate turn off thyristor), or transistors, are generally used to convert the AC mains to a variable DC voltage. The logic that is used to synchronise the control of the power semiconductors is often designed to inhibit rectification when the mains voltage drops below a specific value. In some cases, the control is shut off until the user resets the logic or, in others, operation will be resumed only if the voltage returns within a specified amount of time. Normally, the PDS will not be able to control the motor during the dip interval and control could be lost until the logic is reset. If the process that the PDS is controlling is critical, discussions with the PDS manufacturer should occur such that the reaction of the logic to the voltage dip is compatible with the process needs. In some critical cases, it is necessary to apply additional measures (for example alternative power sources) to carry the process through severe voltage dips.

During voltage dips, the power available from the BDM/CDM and to the motor is reduced. This can affect operation depending on the motor operating points. Consider the case of a controlled 6-thyristor bridge supplying power to a DC motor. If the motor is running at high speed, a voltage dip can cause the peak line voltage to drop below the armature voltage. The thyristors will be commutated off by the armature circuit and the current in the armature circuit will be reduced. If on the other hand, a voltage dip occurs when the motor is running at low speed, the control circuitry can advance the control point to compensate for the reduced voltage. In this case, the control of the motor will not be affected. For critical loads, the effect of a voltage dip should be discussed with the manufacturer of the PDS to determine how the control circuitry will react.

Regenerative converters of the type that use the line voltage to commutate the thyristors in the bridge are particularly sensitive to voltage dips. If the line voltage drops too low during this reverse power flow, control of the power flow from the motor to the mains is lost since the thyristors cannot be turned off. If the control circuitry does not react or if the dip is particularly abrupt or occurs after a thyristor is turned on, the previously conducting thyristor cannot be turned off and excessive uncontrolled currents can flow from the motor. These currents can

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result in potentially detrimental effects on the process or even damage to the motor. For critical loads, the effect of voltage dips on regenerative converters should be discussed with the manufacturer of the PDS to determine how the control and power circuits will react during this interval. For critical loads, additional circuitry can be added to force-commutate the thyristors or alternative power sources can be used to carry the PDS through the dips.

Regenerative converters of the type that are force commutated by some means can also be affected by voltage dips. This is because the reduction in voltage during the dip can reduce the amount of power that can be transferred from the load to the motor and to the mains. If this condition exists, control of the motor can be lost during this interval.

B.6.1.2.3 Uncontrolled converters

Uncontrolled converters such as diode bridges are not greatly affected by a voltage dip, with the exception of the high inrush currents which can flow into the capacitor banks of voltage source converters after the voltage reappears. However, their output power and voltage are reduced during the voltage dip. This can cause detrimental effects on other parts of the PDS. If, for example, the converter is supplying power to an inverter, the output voltage of the inverter will be limited and control of the AC motor will be lost.

Some manufacturers also inhibit operation when the voltage feeding the inverter drops below a specific value. Some designs also require that the logic be reset before operation can continue. Other designs will restart operation when the voltage returns, but control of the motor is lost during the interval that the logic is inhibited. This interval can be extended by the time needed to synchronise the inverter control logic with the actual speed of the motor after control is lost.

The synchronisation is needed to match the output frequency of the inverter to the actual speed of the motor. The synchronisation process determines the appropriate frequency and voltage that should be applied to the motor for smooth transition from coasting to control.

PDSs of the type that would have a very large capacitor bank could ride through short voltage dips because of the energy stored in the capacitor bank. Generally, it is not economical to make a capacitor bank large enough to operate through voltage dips. In the case of critical loads, a battery can be used to supply power during the voltage dip. PDSs with adapted control can be able to continue operation during voltage interruption, provided the output power is near zero. In all cases, the effects of voltage dips on the operation of the PDS should be discussed with the manufacturer to determine if the PDS is compatible with process needs.

B.6.1.2.4 General protection types

It has been shown that immunity to voltage dips is very dependent on the nature of the converter and on the load behaviour. Absolute protection can be very expensive, and the choice of the protection should be carefully compared with the process requirements.

Absolute protection requires a backup power supply. For example, this can be a UPS (uninterruptible power system), external to the PDS, or a DC source (battery) supplying the DC link of a voltage source inverter.

Ridethrough sequence is a technique which uses the possibilities of the command to avoid transient overcurrent, but without backup energy. Therefore, the speed of a passive load will necessarily decrease with a rate approximately given by the ratio of the load torque to the inertia. For safety reasons, this kind of protection cannot be used with active loads (example of hoisting during regeneration where mechanical braking is necessary).

Flying restart is the continuation of the ridethrough sequence which can be used in case of passive loads with long or very long coast down times. This can also be a protection against dips or short interruptions.

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Automatic restart always implies safety conditions, which are the responsibility of the user.

B.6.2 Voltage fluctuation

Interharmonics can cause flicker on lighting equipment, as explained in B.4.3, and compatibility levels are given in IEC 61000-2-2, in IEC 61000-2-4, in IEC 61000-2-12 according to the type of network. Interharmonic emission of a PDS should be limited in such a way that the calculated interharmonic voltage at the IPC, due to a given PDS, does not exceed 80 % of the voltage compatibility levels.

PDSs driving large loads such as punch presses, flying saws and machine tools will require large currents from the mains periodically. This will cause voltage fluctuations of the mains voltage. The source impedance of the mains supplying these PDSs should be sized so that the voltage fluctuation does not exceed the 10 % tolerance.

Peak loads that on average do not exceed the ratings of the supply system, but will produce deviations of the supply voltage that exceed the tolerance should also be considered when sizing this impedance. On the public network, the voltage fluctuation from a single piece of equipment is not supposed to exceed 3 %. If fluctuations are frequent, flicker limits ~~have to~~ should be applied to the public network and to any network which supplies a lighting load (see 6.2.4).

B.7 Verification of immunity to low frequency disturbances

According to 5.2.1, the immunity of the PDS to low frequency phenomena may be verified by calculation, simulation or test. The manufacturer can use the cells of Table B.3 to identify which verification method has been used for each phenomenon.

Table B.3 – Verification plan for immunity to low frequency disturbances

Phenomena	Calculation	Simulation	Test	Analysis	Not applicable
Harmonics					
Commutation notches					
Voltage variations					
Voltage changes					
Voltage fluctuations					
Voltage dips					
Voltage unbalance					
Frequency variations					
Supply influences – Magnetic fields					

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Annex C
(informative)

Reactive power compensation – Filtering

C.1 Installation

C.1.1 Usual operation

A user of electricity, supplied by a distribution network, generally has several or many apparatuses finally connected at the same PCC. The term "installation" is used to describe the combination of apparatus, equipment or systems and their feeding systems which are connected at the PCC.

In the same way, many industrial apparatuses include more than a single PDS.

A discussion of power factor, reactive power and harmonic emission of a single PDS is not sufficient and can cause unnecessary technical difficulties. In reality, the solution which is required is a solution for the installation. The installation contains many different loads.

Under steady state conditions at any point of a three-phase a.c. network, the line-to-neutral voltage and the line current are periodic quantities, of period T, and frequency $f = 1/T$. The voltage and current are rarely without phase shift and they include harmonics which distort their pure sinusoidal waveforms. However, electrical energy is distributed by means of voltage sources, so at any point of a supply (supply of a converter or supply of an industrial installation), the current waveform is more distorted than the voltage waveform. Therefore, for calculation of active and reactive power, it is reasonable to assume that at any point of the network, the voltage is a pure sinusoidal wave whose root mean square value (line-to-neutral) equals V. Calculation of the active power P, on a single-phase is defined by

$$P = \frac{1}{T}\int_0^T v(t)\, i(t)\, \mathrm{d}t$$

which can be simplified and gives:

$$P = V\, I_1 \cos(\varphi_1)$$

where

I_1 is the root mean square of the fundamental component of the line current;

φ_1 is the phase shift between the fundamental component of the current and the line-to-neutral voltage.

P is conventionally positive when the current I has a phase shift of less than $\pi/2$ relative to the voltage, (with voltage in volts and current in amps give the power in watts). With the same assumptions, the reactive power Q expressed in reactive volt amps [var] is defined by

$$Q = V\, I_1 \sin(\varphi_1)$$

This quantity shows evidence of reactive elements such as reactors or capacitors inside the industrial installation. It is said that those components are consumers of reactive power when the quantity Q is positive (reactors) or are producing reactive power when the quantity Q is negative (capacitors).

Similarly, the apparent power S (in volt amps [VA]) at a point of the network is defined as the product of the root mean square of voltage (line-to-neutral) and line current:

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$$S = V\,I_1$$

On a three-phase network, the active power, the reactive power and the apparent power are the sums of the corresponding power on each phase, which gives for a balanced system:

$$P = 3\,V\,I_1 \cos(\varphi_1) = \sqrt{3}\,U\,I_1 \cos(\varphi_1)$$

$$Q = 3\,V\,I_1 \sin(\varphi_1) = \sqrt{3}\,U\,I_1 \sin(\varphi 1)$$

$$S = 3\,V\,I = \sqrt{3}\,U\,I$$

with U, root mean square of the line-to-line voltage.

The power factor λ is defined as the ratio of the active power to the apparent power and is expressed in single-phase and three-phase as well with the following equation:

$$\lambda = \frac{P}{S} = \frac{I_1}{I}\cos(\varphi_1)$$

This fundamental equation shows that the power factor depends on both displacement factor and harmonic content of the current.

As a summary, the fundamental assumption which is stated is that the voltage is considered as a pure sinusoidal waveform and the current is distorted. This assumption is made for the calculation of power and all the consequences such as power factor. For other calculations, such as harmonic voltage distortion contribution of a load, the internal impedance of the network should be considered. The voltage distortion contribution of this load can be calculated from the distorted current flowing at this point and the internal impedance seen from this point.

C.1.2 Power definitions under distorted conditions

Under distorted conditions, there is an extension of the definition of power compared to sinusoidal or non-distorted conditions. The total apparent power S, to which an electrical component is subjected, is defined in balanced three phase systems as follows:

$$S = 3\,V\,I = 3\sqrt{\sum_{1}^{\infty} V_k^2 \sum_{1}^{\infty} I_k^2}$$

Due to the presence of high-order harmonics of voltage and current superposed to the fundamental, the expressions of the active power P and reactive power Q become:

$$P = 3\sum_{1}^{\infty} V_k\;\, I_k\;\, cos\varphi_k$$

$$Q = 3\sum_{1}^{\infty} V_k\;\, I_k\;\, sin\varphi_k$$

and the apparent power is defined as:

$$A = \sqrt{P^2 + Q^2}$$

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This power is different from the total apparent power. In particular, the following relation applies:

$$S^2 = P^2 + Q^2 + D^2$$

where D (defined as distortion power) takes into account the power resulting from voltage and current components with different ordinal numbers.

The sum of the squares of the reactive power Q and the distortion power D gives the square of the non active power N:

$$N^2 = Q^2 + D^2$$

This power is defined as non-active because it is the difference between the square of the total apparent power S and the square of the active power P:

$$N^2 = S^2 - P^2$$

The total power factor λ between the active power P and the total apparent power S seen from the network can be written as:

$$\lambda = \frac{P}{S}$$

The power factor correction refers to this parameter.

The total displacement factor under distorted conditions, cosϕ, is an extension of the usual displacement factor under sinusoidal conditions, and is defined as:

$$cos\phi = \frac{P}{A}$$

If there is no distortion in the waveforms of voltage and current, both displacement factors coincide.

In order to express the influence of the distortion power D, a distortion factor cosψ can be introduced and defined as:

$$cos\psi = \frac{\lambda}{cos\phi} = \frac{A}{S}$$

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C.1.3 Practical solutions

C.1.3.1 Common practice

It is well-known that to avoid overrating of the installation and an unnecessary increase of the current flowing in the distribution network, it is necessary to work with a good power factor. But practical use considered this power factor only from the reactive power point of view; in fact, it has been seen here that harmonic content is also concerned.

It has usually been the case that an industrial installation consumes reactive power. Therefore, it has also been usual to install a global compensation in order to reduce the displacement factor and so reduce the installation's consumption of reactive power. In order to do that, capacitors were installed whether close to the consumer of reactive power, or globally close to the PCC. In some countries, utilities introduce taxes for that displacement factor, particularly when the distribution network is heavily used.

C.1.3.2 Evolution of common practice

Because power factor is of concern and because of increasing use of distorting loads, harmonic compensation is also necessary. This harmonic compensation can be performed globally with filtering of the complete installation or locally with filters close to the distorting loads. It can also be better to use non-polluting loads.

From this introduction, it can be seen that two types of compensation are necessary: displacement factor and current harmonic content. Two methods can be used for each of these compensation types: a global approach for the total installation or a local approach for each distorting load. Four cases can be seen, but none is independent so this problem ~~has to~~ should be discussed in more detail.

C.1.4 Reactive power compensation

C.1.4.1 General compensation criteria

Power factor correction equipment is composed of capacitor banks connected to the power line by electromechanical or static contactors. The following covers phenomena related by use of capacitor banks connected by electromechanical contactors.

The size of the capacitor bank to be installed is a function of the active and reactive power compensation needed by the system, and also of their variation during the day (load-time characteristics). It is also a function of the pricing practice of the utility.

The correction is frequently defined with the mean value of energy consumption (active and reactive) during the heavy duty times of the day, within a one month period.

NOTE The concept of reactive energy used in Annex C is defined by the time integral of the reactive power.

For rating, it is necessary to know the utility criteria:

- heavy duty times in a day;
- limits of reactive power ratio free of charge (for example tan φ);
- user data such as load-time characteristic.

It can be seen that correction of reactive power consumption cannot be constant nor permanent. A permanent correction would actually lead to reactive power injection in the supply network at certain times. The result would be an increase of the voltage in the user's installation which is not necessarily an advantage. Such a study is of concern for a complete installation and almost impossible for each PDS.

Another point is that capacitors can be installed either on the low-voltage side or on the medium-voltage side. Common practice shows that the installation on the MV side has an economical advantage, as soon as reactive power correction reaches 600 kvar. For lower ratings the LV side should be preferred.

If power factor correction capacitors are to be installed in networks with harmonic current sources, it is recommended that reactors should be added in series with the capacitors. This is so that the resulting resonance frequencies are shifted below the lowest frequency of the characteristic harmonics, normally the 5th (see C.1.4.4).

C.1.4.2 Application to low-voltage correction

C.1.4.2.1 Different solutions

According to local conditions, three types of correction can be defined:

- individual apparatus correction;

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- section correction;
- global correction.

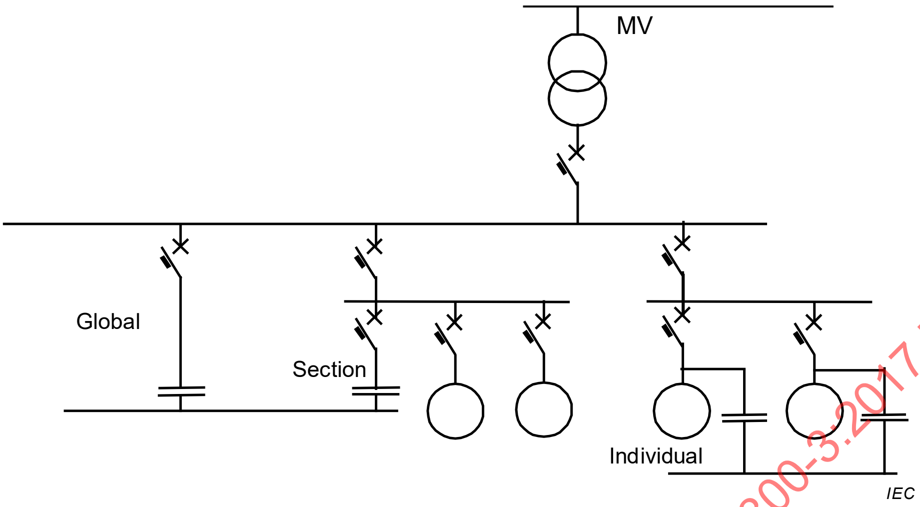

Figure C.1 – Reactive power compensation

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C.1.4.2.2 Individual compensation – for motor directly coupled to network

Individual compensation is particularly advisable when a fixed speed motor rated higher than 25 kW exists and if it is to be run for the majority of working hours. This applies in particular to motors driving high-inertia machines, such as fans. The operating switch of the motor automatically connects or disconnects the capacitor. It is advisable to verify that there is not a risk of resonance.

a) ***Advantages:*** The reactive energy is produced directly at the point at which it is consumed. A reduction in the reactive current load results along the whole length of the power supply cable. Individual compensation thus makes the most important contribution to the reduction of apparent power, and of voltage drops and losses in the conductors.

b) ***Disadvantages:*** The individual compensation is relatively costly, several small capacitors being more expensive than a single large capacitor bank. When the capacitors are connected, they raise the voltage of the plant network locally. It would thus seem necessary to be able to disconnect them during periods of low load (and therefore increased voltage) in the public network in order to reduce the voltage. Indeed, a high voltage would entail the risk of placing excessive stress on the equipment, thus causing its premature ageing. The capacitors should consequently be connected, if possible, to the network by means of their own switchgear. Another important disadvantage is that the proliferation of capacitors in an industrial network increases the risks of resonance. All these factors significantly reduce the potential advantages to be gained from individual compensation.

C.1.4.2.3 Compensation by section

In the case of compensation by section, a single bank of capacitors, operated by means of its own switchgear, compensates a group of consumers of reactive energy located in a workshop or in an area.

a) ***Advantages:*** The compensation by section requires less investment than individual compensation. However, the load curves should be well-known in advance to enable correct sizing of the batteries of capacitors and to avoid the risks of overcompensation (when the reactive power supplied is greater than that required), which produces permanent overvoltages, leading to premature ageing. The bank of capacitors have their own switchgear, thus making it easy to disconnect them during periods of low loads on the public network, even when the corresponding power consumers remain connected.

b) ***Disadvantages:*** The power supply cables of the various power consumers ~~have to~~ should be sized to carry both the reactive and active currents. In addition, provision should be made to protect the capacitors (for example fuses, circuit-breakers, etc.), and discharge them for safety purposes (discharging resistors) during maintenance operations. The fuses should also be regularly monitored.

C.1.4.2.4 Global compensation

In the case of global compensation, the production of reactive energy is concentrated at a single point, most frequently in the substation, or in an area which is sufficiently large and well-ventilated. In installations which have only small power consumers, it is generally advisable to adopt automatically controlled central compensation, again so as to avoid overcompensation. Where the load curve shows little fluctuation, it is necessary merely to engage the whole battery during the periods of operation of the installations.

a) ***Advantages:*** The capacitors have a good utilisation factor, and the installation is easier to monitor. In addition, with automatic control by the capacitor bank, the load curve of the plant can be followed effectively, while avoiding manual intervention (i.e. manual engaging and disengaging). This solution is potentially beneficial from an economic point of view if the load variations are not attributable to specific power consumers.

b) ***Disadvantages:*** The installations downstream of the global compensation connection carry all of the reactive power.

C.1.4.3 Application to medium-voltage correction

Compensation is generally carried out on a centralised basis. The capacitors are grouped in banks in the medium-voltage substation. The banks are connected to the medium-voltage bus via a circuit-breaker. Their power can reach several megavars (Mvar), and they can be divided into smaller sections which are brought into operation successively in order to obtain optimum compensation as a function of the daily load curve. Each section is operated by a switch provided for this purpose as a function of daily load curve or on-line control.

a) ***Advantages:*** When the banks of capacitors have power levels greater than 600 kvar, the cost of medium voltage compensation is typically less than that of low-voltage compensation.

b) ***Disadvantages:*** This method of compensation provides no relief to the part of the network which is located downstream of the capacitors. Engaging the capacitor bank causes voltage transients. Operation requires more attention than with capacitors in the low-voltage section.

C.1.4.4 Risks of resonance

Risks of resonance are due to the simultaneous presence in a network of capacitors for compensating reactive power and sources of harmonic currents comprising static converters. A simplified single-line diagram of a network, including a passive load R-L and a battery of capacitors compensating the load on a global basis, is shown in Figure C.2.

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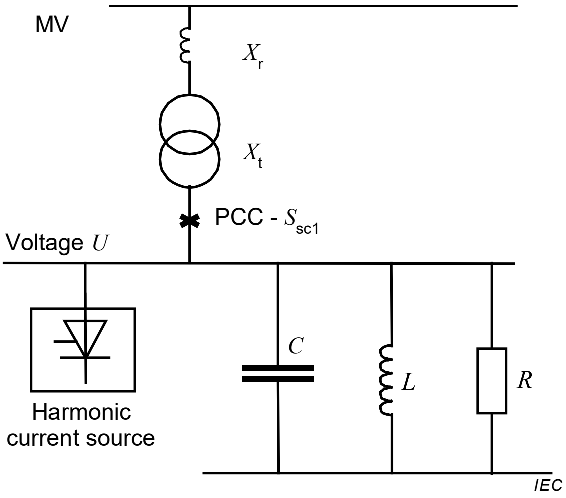

Key

P	active power of the passive load and losses
Q	reactive power of the passive load
X_r	impedance of power supply network of short-circuit power S_{sc0}
X_t	impedance of transformer of apparent power S_N (reactance x_{sc})
PCC	point of common coupling on the secondary bus with short-circuit power S_{sc1}
R,L	resistance and reactance corresponding to the active and reactive power P and Q of the load
C	capacitor for compensating reactive energy of power Q_{cond}

Figure C.2 – Simplified diagram of an industrial network

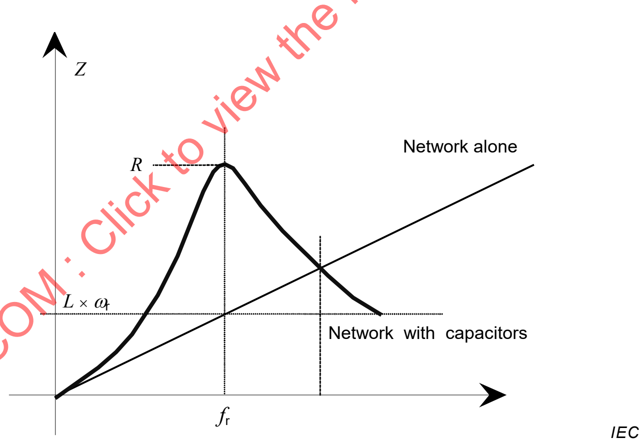

Figure C.3 – Impedance versus frequency of the simplified network

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Figure C.3 illustrates the changes of the harmonic impedance of the network at the PCC and the risks of resonance associated with the presence of a source of harmonic currents. The upstream impedances X_r and X_t contribute to a reduction in the short-circuit power available at PCC from the value S_{sc0} to the value S_{sc1}:

$$S_{sc1} = (1/S_{sc0} + X_{sc}/S_N)^{-1}$$

Therefore, (Z_h), the equivalent harmonic impedance of the network at the PCC, for harmonic order h, has the following value:

$$Z_h = (h\ U)^2\ [(h^2\ Q_{cond} - S_{sc1} - Q)^2 + h^2\ P^2\ ]^{-½}$$

and the resonant frequency is:

$$f_r = f_1 [(S_{sc1} + Q)/Q_{cond}]^{1/2}$$

where f_1 is the frequency of the fundamental.

Figure C.3 shows the variation in the impedance Z_h as a function of frequency, and the impedance of the network only due to X_r and X_t. Note that Z_h shows an amplification at the resonant frequency f_r compared to the impedance of the network alone. Examples of network impedance and damping considerations are given in IEC TR 61000-3-6.

When, at certain harmonic frequencies, the network impedance is high and injection of harmonic currents arises at the corresponding frequencies, considerable harmonic voltages result, as can be found by applying Ohm's law. There is resonance between the inductive reactors and the network capacitors. This has a variety of consequences.

a) There is a risk of overloading the capacitors due to the overcurrents flowing through them, particularly due to the high frequencies of harmonics.
b) There is a risk of breakdown at the terminals of these capacitors due to the considerable harmonic voltages.
c) A high harmonic voltage at the terminals of an industrial installation can give rise to abnormal operation of apparatus with sensitive electronics and to overheating in motor windings.
d) The occurrence of harmonic voltages will lead to a generation of harmonic currents in the distribution network and in other customers' installations.

Care should be taken either to reduce the emission of the harmonic current sources, or to install filters. The location of capacitors in an industrial network is thus an important factor in the occurrence of resonances.

Problems of resonance often necessitate a detailed analysis of the electrical network before they can be solved. These problems are not systematic in nature but, when they do occur, their consequences often mean damage to equipment, not to mention the effects of accelerated ageing.

The above analysis is limited to one reactive power compensation circuit. It is pointed out that multiplication of such circuits in a network multiplies the resonance risks.

C.1.5 Filtering methods

C.1.5.1 Criteria

Filtering of an installation is not relevant for this document. The application to PDSs has similar difficulties as that of filtering an installation. Moreover, the analysis developed in C.1.4.2, C.1.4.3 and C.1.4.4 about reactive power compensation could be followed with a similar approach and similar conclusions, only the initial criteria are specific.

When an excessively high-voltage distortion level can be expected, filtering should be applied. The voltage distortion level is assessed according to Clauses B.3 and B.4. A particular PDS to be filtered is known with its conventional harmonic emission characteristics, i.e. levels of harmonic current are known. But this characteristic is not sufficient to define a filter.

A filter generally consists of equipment which is connected to the network and which presents a very low impedance at the particular frequencies which ~~have to be~~ are filtered. Therefore, the filter absorbs harmonic currents of those particular frequencies. However, there is no discrimination between the harmonic current coming from the PDS, and whose preferred path of low impedance is through the filter (instead of the network of higher impedance), and the

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harmonic current coming from the existing harmonic voltage on the network. The latter current is only limited by the sum of harmonic impedance of the network and impedance of the filter (see Figure C.4). From this discussion, it can be seen that designing a filter is a rather complex affair which requires the knowledge of the three basic parameters:

- current to be filtered, the origin of which is the PDS (responsibility of the manufacturer of the PDS);
- existing harmonic voltage (compatibility levels could be chosen but would generally lead to overrating of the filter);
- harmonic impedance at the PC (responsibility of the operator of the distribution network, who is the user inside the factory in case of IPC, or the operator of the public distribution network in case of PCC).

The design of such filters requires exchange of information between the system supplier and the user.

It is important to note that knowing the harmonic voltage is of no use if the harmonic impedance is unknown. Often, preliminary measurements of voltages and impedance are needed for a correct rating of the filter.

Finally, the risk of multiple resonances is pointed out for similar reasons which have been developed in C.1.4.4.

C.1.5.2 Passive filter

The most traditional filters are resonant circuits (inductance and capacitors in series) or damped circuits by addition of resistors or more complex structures adding poles and zeros to the impedance of the filter.

A filter presents a very low impedance at a particular frequency which is a multiple of the power frequency. A bank of filters using different resonant circuits in parallel provides filtering of several harmonic orders 5, 7, 11, and 13 for example (see Figure C.4). They also may include high pass circuits. They are designed for a fixed power frequency and, in particular when they are only slightly damped, the effectiveness of the filter is dependent upon the stability of the power frequency.

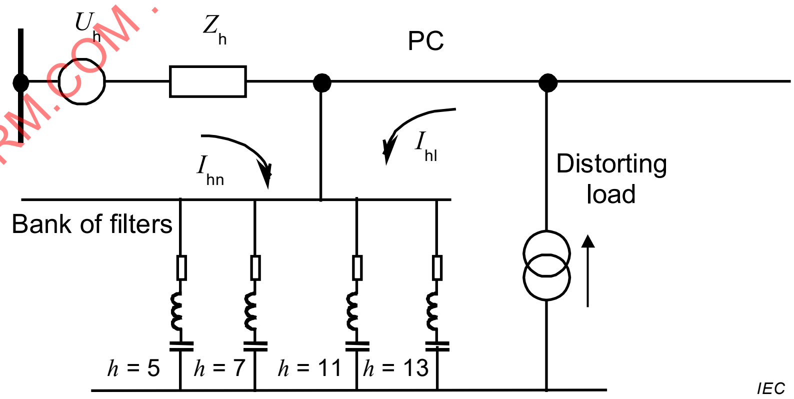

Figure C.4 – Example of passive filter battery

Note that filtering of interharmonics requires damped filters and is only efficient in a narrow band of frequencies.

Two main phenomena are pointed out regarding the risk of resonances.

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- A resonance generally exists at a frequency which is a little bit lower than the tuning frequency. It is necessary to verify that this will not affect the ripple control or mains signalling which can be used on the network. It is the responsibility of the user with help from the utility to inform the manufacturer of such possible mains signalling with the characteristics of the carrier frequency.
- Filtering of each PDS multiplies the risk of resonances, and the result can affect a large part of the installation. Generally, only a case by case analysis can get rid of these difficulties, which is the reason why a global compensation should be preferred.

C.1.5.3 Location of the filter

In the case of an individual filter, the filtering equipment ~~has to~~ should be as close as possible to the distorting PDS.

But with the preferred method of global compensation, the location and structure of the filter should be chosen in regard to the parameters of the installation:

- natural uncoupled sections in the network;
- other distorting PDSs or distorting loads with their distorting characteristics, i.e. conventional harmonic current emission;
- impedances of the distribution network particularly presence of long lengths of cable, or reactive power compensation circuits (see Clause C.2).

C.2 Reactive power and harmonics

C.2.1 Usual installation mitigation methods

As indicated in C.1.1, reactive power compensation and harmonic current filtering techniques are quite linked, so they cannot be correctly applied independently.

Referring to C.1.4.4, the risk of resonance exists as soon as a capacitor is connected to a network which is naturally inductive. Electric cables also introduce capacitances into a network. The following example shows that, with a capacitor compensating reactive power, the harmonic currents at the PCC are increased. Significant harmonic currents also flow to the capacitor.

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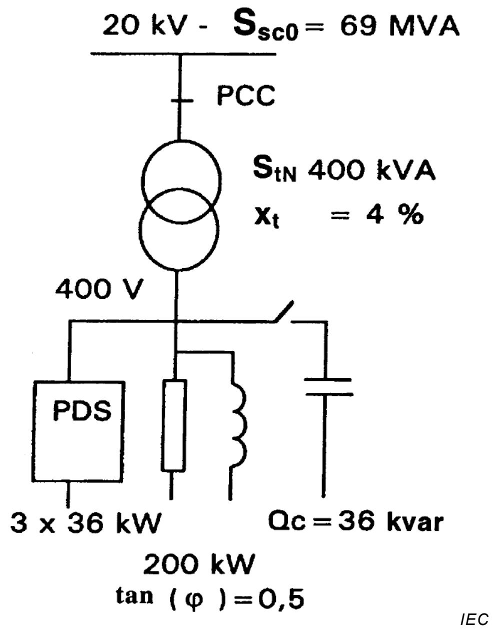
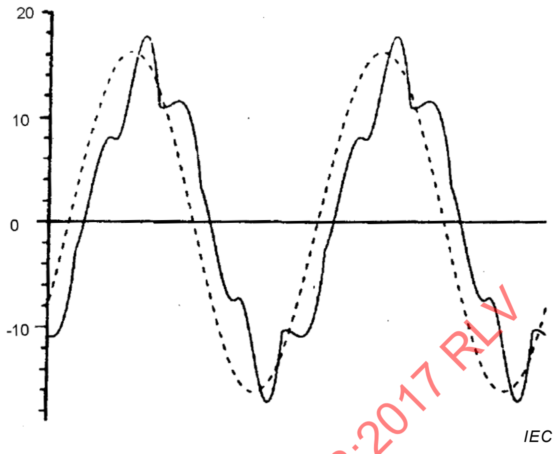


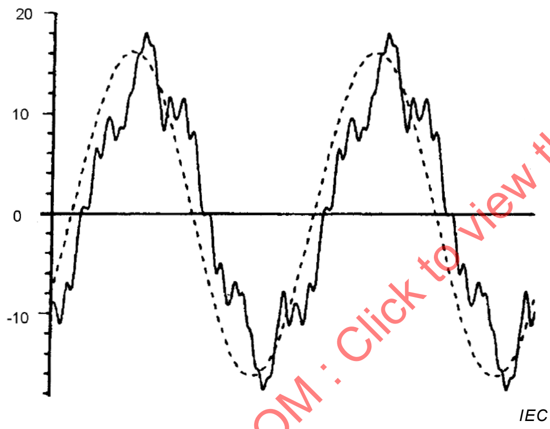
a) Circuit diagram



Solid line – current in amperes

Dashed line – line to neutral voltage in kV

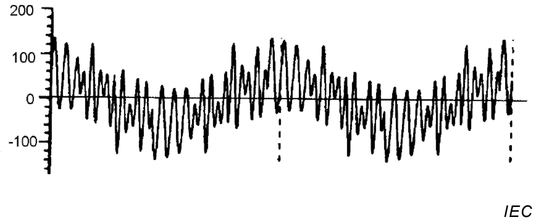
b) Waveforms at PCC when Q_C is not connected



Solid line – current in amperes

Dashed line – line to neutral voltage in kV

c) Waveforms at PCC when Q_C is connected



Solid line – current in amperes

d) Current in Q_C

Figure C.5 – Example of inadequate solution in reactive power compensation

It can be seen in Figure C.5 that the problem is complex with only one capacitor, and increases with the number of capacitors used for compensating reactive power. The multiplication in a network of capacitors for passive filtering and for compensation of reactive power as well, increases the number of possible resonance frequencies. Therefore, global compensation, taking the whole system into account, will show the best results.

Moreover, proceeding separately to reactive power compensation and to filtering increases the risk of over production of reactive power. Actually, efficient passive filtering also produces a significant amount of reactive power. Therefore, considering both phenomena together gives the opportunity to define a better solution by designing optimum equipment for the whole installation.

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C.2.2 Other solutions

C.2.2.1 General

The main drawback of passive filters is often their inability to adapt to network changes and filter component variations (ageing, temperature, etc.). A passive filter is efficient if its impedance at given frequency is very low compared to that of the source. However, in certain cases, compensation becomes difficult if the source (i.e. the network) impedance is low or if the filter frequency characteristics are not accurately tuned to the harmonics generated by the load. But, above all, the most serious problems are series or parallel resonances with the network which can occur.

Consequently, both for the electrical utility and/or the user, other compensation methods can be required to make optimum use of the energy drawn from the network. New solutions, offering better performance, are under consideration and some have already reached the production stage. These solutions are active power filters, and non-polluting PDSs including power factor correction network controls.

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C.2.2.2 Active filters

~~The principle of active filtering consists of connecting between the load and the network power source, a converter consisting of an inverter-type power converter, which can compensate for current or voltage harmonics. When an active filter is connected in parallel and injects a harmonic current to oppose that generated by the load, it is referred to as a parallel or shunt filter. If the active filter is in series with the network, it compensates for the harmonic voltage at the load connection point. The essential advantage of an active filter, compared with a passive filter, is its ability to adapt to network or load changes.~~

~~Various filter structures are possible using parallel or series connections. However, it would seem that using active filters in conjunction with passive components could improve performance and extend the potential applications of active filters by reducing ratings, and allowing connections to MV levels. Moreover, there is a slight tendency for the cost of active filters to drop.~~

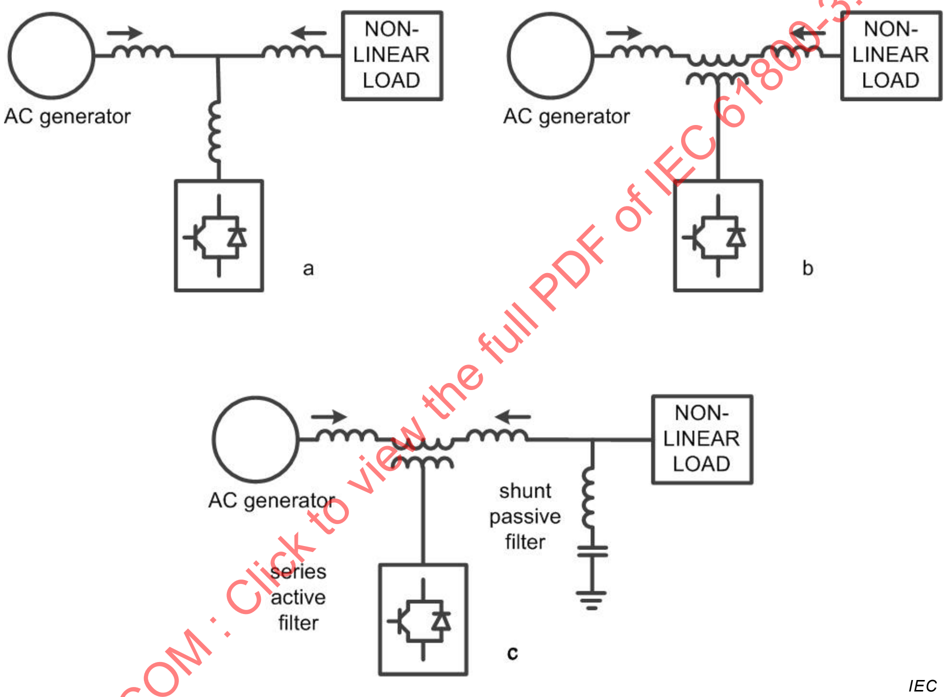
All active filters have been developed based on the active PWM converters. They can be divided into two types, regardless of the configuration topology:

- Power factor correction converters (PFC) normally used for low power applications. These do not have any influence on the active power, or the ability to operate as rectifiers. They work in DC and are in cascade with AC-DC converters;
- Active infeed converters (AIC), often known as active front end (AFE). These are AC-DC converters which can pass active power as well as influencing the reactive power. AICs operate in four quadrants. They can be classified as current source inverters (CSI) or voltage source inverters (VSI). The CSI PWM modulated bridge inverters behave as a source of non-sinusoidal current, and have current harmonics due to non-linear loads. They have an inductance on the DC bus which ensures the circulation of a continuous current in the d.c. link. CSI inverters have a good reliability, but have large losses and require high values of capacitive filters in parallel to the network terminals, to eliminate the unwanted harmonic currents. Furthermore, CSI inverters cannot be used in a multilevel configuration for high power compensation. The other type of AIC converter is the VSI PWM modulated inverter. This converter is more convenient for active power filter applications because it is lighter, cheaper, and extensible to multi-level and multi-phase versions, in order to improve its performance for power factor correction for higher powers and lower switching frequencies. The VSI PWM modulated shunt inverter can be connected to the DC bus through a coupling reactor and an electrolytic capacitor that maintains a constant voltage at its ends and free from ripple. Active filters can be classified taking into account the type of converter, the control scheme and the characteristics of compensation.

From the topological point of view, active filters can be shunt type or series hybrid, the latter intended as a combination of passive and active compensation. The active shunt filters are used to compensate the harmonic currents, reactive power and unbalanced loads.

The shunt active filters compensate current harmonics by injecting equal but opposite harmonic current. In this case, the active filter operates as a current source injecting harmonic components that are 180° out of phase with those generated by the load. As a result, the components of the harmonic currents are eliminated by the active filter; and the current flowing from the source (a.c. generator) remains sinusoidal and in phase with the relative phase to neutral voltage. This principle is applicable to any type of load considered as a source of harmonics. Furthermore, with a control system of this type, the power active filter can also compensate the power factor of the load. The energy distribution system sees the combination of non-linear load and active filter as an ideal resistor.

The series type active filters are connected in series between the load and the mains network. The series active filter is frequently connected through a transformer type coupling.



Key

a Shunt connection active filter

b Series connection active filters

c Hybrid active filters

Figure C.6 – VSI PWM active filter topologies

The hybrid configuration is a combination of a series active filter and a shunt passive filter. This topology is suitable for reactive power compensation of high power systems, because the power rating of the active filter as the PFC is a small percentage (about 10 %) of the power rating of the load. Most of the hybrid filter is formed by the shunt passive filter LC, used to compensate the lower order harmonics and reactive power.

The active filter for the compensation of the harmonics and the reduction of the phase shift is located, regardless of the connection, between the network and the non-linear load and is often made by placing a switching converter between the input rectifier and the storage capacitor. The control is carried out so that the input current follows the input voltage. The

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most widely used type of switching circuit is a boost converter. It does not mean that the converter operates in boost mode, i.e., step-up, but only that the circuit is boost type of circuit.

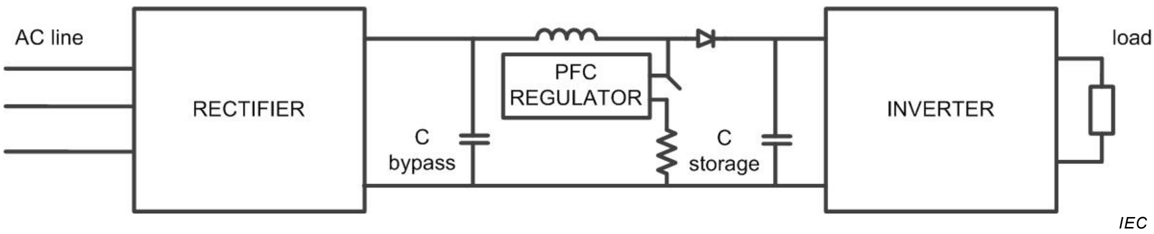

Figure C.7 – Boost mode converter

The PFC changes a distorted waveform to build a sinusoidal current that is in phase with the input voltage. There are various techniques to achieve a sinusoidal waveform of the input current with low distortion, i.e. with low harmonic content.

In the PFC boost circuit, the inductor is in series with the AC power line. Therefore, the current input to the rectifier block is not a pulse waveform. The use of PFC includes the active regulation of the waveform of the input current I_1, the filtering of the switching frequency, feedback sensing of the current source for the control of the waveform and the feedback control for output voltage regulation.

An active PFC has a higher efficiency and is significantly smaller and lighter than the passive filter. In fact, it can operate at a higher switching frequency than the line frequency, allowing a strong reduction of the size and cost of passive filter elements.

~~C.2.2.3 Non-distorting PDS~~

~~New network converter structures represent an alternative to active filters. These single or three-phase structures replace the diode or thyristor line commutated converters. They allow correction of the PDS's power factor both by placing the current drawn from the network in phase with the network voltage and by minimising harmonic currents. The components used in these converters are more expensive since both the turn-on and turn-off switching is controlled. A classical structure for these network converters is the voltage inverter-type power converter, using six transistors or six GTOs. Power drive systems including this type of power factor correction network bridge are named clean or non-distorting PDSs.~~

C.2.2.3 Active infeed converter

The term "active infeed converter" (AIC) refers to a power converter placed on the network side with switching components such as IGBTs. The system includes, in addition to the front end, a bank of DC link capacitors and a load side inverter. The front end works as a rectifier, but during a regenerative mode can operate as an inverter feeding the network with recovered energy.

During periods when the energy flows from the network to the load, the converter operates as a rectifier with voltage AC input and voltage DC output. It works as a step-up chopper as the voltage on the DC link might be higher than the peak voltage of AC grid. The requirement of a constant voltage on the DC link is present both in rectifier and inverter operations. The voltage ripple can be reduced by placing the capacitor bank on the DC link.

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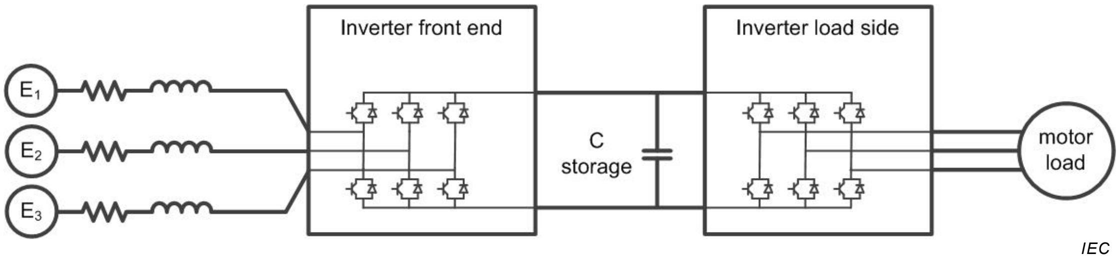

Figure C.8 – Front-End inverter system

Figure C.8 shows the system with the two converters, including the presence of the inductance necessary for boost operations in the line side. Additional filtering may be necessary on the mains side to comply with compatibility levels at the PWM frequency and its harmonics (see IEC 62578). An AIC can be considered as a synchronous voltage source connected in shunt mode and a compensator together with an element that can store energy such as the capacitor in the DC link. Because of its ability to regulate energy, the AIC has some advantages used to maintain compatibility levels required by the network.

These capabilities can be summarized as:

- the maximum achievable compensation is limited only by the value of the maximum permissible current of the switches and the ratio between the AC voltage and the DC link voltage. The AIC can keep the maximum value of volt-amperes reactive compensation and the desired voltage on the DC link even in the presence of severe dips in the mains voltage;
- the AIC can operate over the whole range of current, even with voltage reduced. Sometimes it can tolerate network voltages reduced even by 20 %;
- by doing so, both with the elimination of harmonics and production of reactive currents, it increases the margin of stability in presence of failure;
- the response time of an AIC, acting as a compensator, can be a fraction of a half cycle (10 ms). By comparison, in the case of controlled thyristors the dynamic response time is as long as 5 to 6 cycles;
- the control strategy allows the AIC to exchange active and reactive power to and from the system to the AC line;
- due to the ability to exchange active power, the AIC can be used to adjust the damping of oscillations in the secondary winding of a transformer.

C.2.2.4 Application

The costs of such systems are or can be an important part of the costs of the distorting loads that they correct (PDSs or others). This should be understood regarding investment, operation and maintenance as well. Note that operation generates costs with increasing losses and also gains with decreasing reactive power consumption. Costs are balanced with the technical objective which does not allow any alternative to "Ensure EMC" (i.e. compliance with compatibility levels).

Another point is that the compensation can be global, local or combined more easily than with passive solutions because of reduction of resonance risks.

Last but not least, these active solutions increase the number of commutating electronic power devices and are responsible for an increase in high-frequency emissions.

The ideal solution does not exist, and all these elements should be considered. However, the definition of the solution of a particular problem should take into account the particular environment of this problem. The particular environment belongs to a generic class, but is refined by the very knowledge of the industrial conditions in each case.

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Annex D
(informative)

Considerations on high-frequency emission

D.1 User guidelines

D.1.1 Expected emission of PDSs

D.1.1.1 PDS and its components

In industrial environments, or public networks which do not supply buildings used for ~~domestic~~ residential purposes, the customers who use PDSs on these networks have a general technical competence and are aware of EMC phenomena.

When selling the components of a PDS, the manufacturer cannot build-in mitigation methods against radio interference, because they are not aware of the EMC boundary conditions of the final installation. Moreover, the user of the components should have a free decision from the economical point of view, to use global or local filtering or screening methods, natural mitigation through distances, or the use of distributed parasitic elements of the existing installation, to achieve electromagnetic compatibility in a case by case manner.

D.1.1.2 ~~Conducted voltage~~ Mains terminal disturbance voltage

The methods and values of quantitative judgement to achieve EMC are well-described in the normative part of this document. ~~An important item of information for the user of an unfiltered PDS to evaluate possible mitigation methods, is the level of conducted voltage disturbances in the frequency range of 150 kHz up to 30 MHz, which could be expected on the power port of a PDS.~~ The level of mains terminal disturbance voltage in the frequency range of 150 kHz up to 30 MHz is important information for the user of an unfiltered PDS, in order to evaluate possible mitigation methods.

The following results are based on measurements made on ~~several types of~~ converters, mainly PDSs ~~(voltage source type and current source type)~~, located in various countries ~~between 1990 and 1994~~ in 2012. For an evaluation of the range of emission levels which can usually be expected, the frequency range was divided into the three usual parts (CISPR 11: 0,15 MHz to 0,50 MHz; 0,50 MHz to 5,0 MHz and 5,0 MHz to 30 MHz), and the maximum level from each PDS in every part was recorded as representative of that section. The measurements were made using quasi-peak detectors ~~in most of the cases~~. ~~A range width of ± 20 dB from the mean value V_{dist} was assumed, see Figure D.1, to allow for about 91 % of the variance arising from different load conditions (light load and maximum load), different rated input voltages (230 V, 400 V, 460 V, 690 V) and different rated powers (0,75 kVA to 740 kVA).~~ Different load conditions (light load and maximum load), different rated input voltages (400 V to 690 V) and different rated powers (75 kVA to 1 000 kVA) were measured.

~~According to the physical background of the emission, the average of the peak readings can be arbitrarily approximated by two straight lines with slopes of 20 dB/decade and 40 dB/decade. The two lines cross at the transition frequency f_{trans} ≈ 2 MHz and, according to reference [7], can be analytically described by~~

$$\overline{U}_{dist}/\text{dB}(\mu\text{V}) = 20\log\frac{80\ \text{V}\times 10\ \text{kHz}}{\pi\times f\times 1\ \mu\text{V}}$$

~~if 100 kHz ≤ F ≤ F_{trans}~~

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$$\overline{U}_{\text{dist}}/\text{dB}(\mu\text{V}) = 20\log\frac{80\ \text{V}\times 10\ \text{kHz}\times F_{\text{trans}}}{\pi\times f^2\times 1\ \mu\text{V}}$$

if $F_{\text{trans}} \le F \le 30$ MHz.

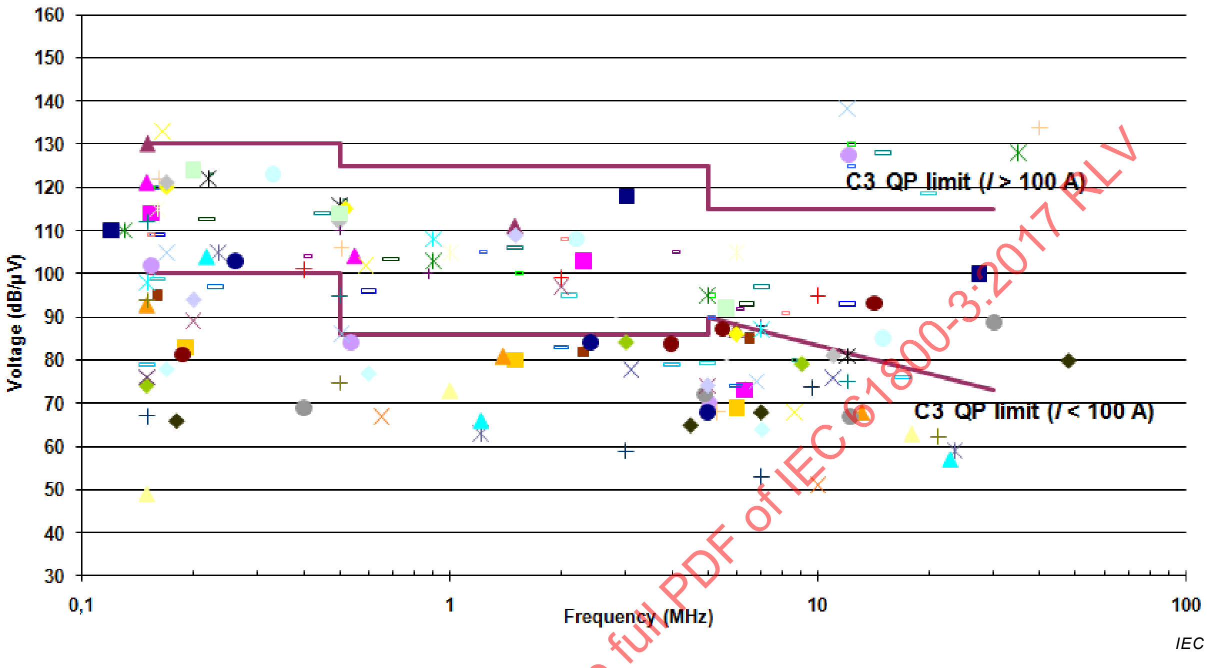

Figure D.1 – Conducted emission of various unfiltered PDSs

The results are given in peak values. According to reference [2], the quasi-peak value is lower than the peak value, becoming progressively lower as the switching frequency of the power devices is reduced. For a PDS with a switching frequency in the range 200 Hz to 10 kHz, the quasi-peak value is generally 5 dB to 2 dB lower than the peak value. In the cases of measurement results that were only available as quasi-peak recordings, this correction was used for the evaluation of Figure D.1.

In most cases, this equipment is used without interference, but mitigation methods (for example HF filtering) have to should be taken in the vicinity of a radio-receiver or of a sensitive apparatus, such as for very low-voltage measurements.

D.1.1.3 Radiated disturbances

Measurements related to the radiated emissions have not been deeply investigated due to the lack of complaints in this range. However, what can be expected from the equipment is shown in Figure D.2. The evaluated results represent measurements corrected to peak values at 10 m measuring distance for PDS with or without different applied mitigation methods.

The continuation of the expected disturbance voltage ranges from Figure D.1 in the area above 30 MHz is only a rough approximation with very few representative values, but could show enough data to explain why there is a lack of complaints. As can be seen from this figure, the mean values of radiated emissions above 100 MHz are frequently crossing below the limits of CISPR 11 without mitigation methods.

An analytical approach is not presented in this range. The reason for that is the main sources of radiated emissions in most of the cases are the microprocessors or some active driven

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power supplies within the equipment and not the main power electronics of the converters at all.

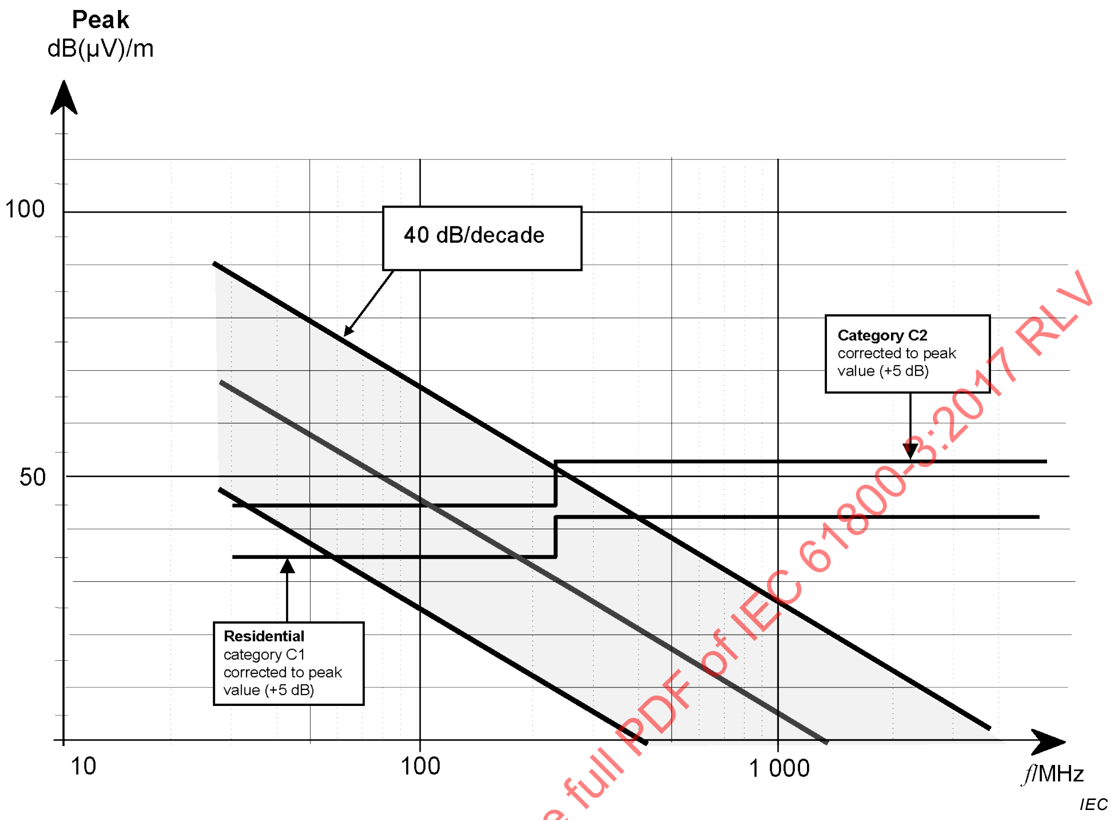

Figure D.2 – Expected radiated emission of PDS up to rated voltage 400 V
Peak values normalised at 10 m

D.1.1.4 Emission from the power interface

The emission from the power interface is mainly due to common mode voltage. The common mode voltage on the power interface can have a high d*v*/d*t*. This high d*v*/d*t* induces current in the stray capacitance of both the cable and the electrical load (generally, the electrical load consists of the windings of the armature of a motor). These stray currents come back to their source through earth and either the supply network or input filters of the corresponding converter. Therefore, the emission from the power interface is linked with the disturbance voltage which is measured on the power port.

D.1.2 Guidelines

D.1.2.1 Public low-voltage network

The potential effects of the disturbances produced by a PDS depend upon the environment in which the PDS is used.

In some countries, small commercial or light industrial premises can be supplied by a public low-voltage supply which also supplies ~~domestic~~ residential premises. In this system, there is no galvanic isolation between the three-phase input terminals of the PDS in the commercial or light industrial premises and the mains supply sockets in the ~~domestic~~ residential premises.

Where an unsuppressed PDS is directly connected to a public low-voltage supply which supplies ~~domestic~~ residential premises, there is a significant risk of disturbance to radio and television reception. In this environment, it is strongly recommended that the mains input of

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the PDS be filtered. Therefore, the user should select a PDS which complies with the appropriate limits given in 6.4.

D.1.2.2 Second environment

In an industrial environment, not on a public low-voltage supply, the common practice for many years has been to use unfiltered PDSs. In general, these have worked correctly and have not disturbed other equipment. This has been shown by a general lack of complaints about radio interference in industry. Therefore, they are compatible.

If problems do occur, they are likely to be due to the conducted disturbances from the BDM/CDM. These disturbances propagate along the supply and motor cables and can be coupled into other equipment by conduction, inductive or capacitive coupling, or radiation.

There can be problems if an unfiltered PDS is used in close proximity to particularly sensitive equipment. However, a PDS may not be the only source of disturbance and the sensitive equipment is usually of lower power rating than the PDS. Therefore, improving the immunity of the sensitive equipment can be a more economical solution than filtering the emissions from the PDS.

Problems are usually prevented by following normal installation guidelines, involving segregation of signal and power cables. If these are insufficient, either the immunity of the victim should be increased or the emissions from the PDS should be reduced, depending on which is the most economical solution.

The use of a commercially available EMC filter on the power interface between the BDM/CDM and the motor can lead to problems. It is likely that the capacitors in this filter would be damaged by the fast switching edges present on the BDM/CDM end of this interface.

If a shielded or armoured cable is used for the connection between the BDM/CDM and the motor without the BDM/CDM input being filtered, the coupling from the motor cable will decrease, but the conducted disturbances in the mains supply will increase, due to the capacitance of the armoured cable. Therefore, if a shielded or armoured cable between BDM/CDM and motor is being used to solve an EMC problem, a filter should be connected to the mains input of the BDM/CDM. However, minimising the length of the motor cable will generally assist in reduction of radiated emission of this cable.

Since filtering would cause safety problems in systems which are isolated from earth, the only solution in this case is to ensure that other equipment has sufficient immunity for this environment. In the case of systems in which one live line is connected to earth (known in some countries as "corner grounded" systems), the Y-class (line-to-earth) capacitors should be rated for the full line-to-line voltage.

D.1.2.3 Categories C1 and C3

The manufacturer should provide the information necessary for the user to select the correct emission category and to install the equipment correctly. This information should include clear instructions on the installation of any filters supplied as loose items. If special cables are required, this should also be stated.

Cabinet builders often use insulation withstand tests to check the quality of their wiring. However, an EMC filter is usually less able to withstand this test than the power converter. Therefore, the manufacturer should provide clear instructions on this subject to the user.

If the PDS is unsuppressed or is of a high emission category, the manufacturer should indicate this clearly in the user documentation. In this case, ~~according to~~ 6.4.1.1 and 6.4.1.3 require that the manufacturer shall provide a warning that the PDS is not to be used in a public low-voltage network which supplies ~~domestic~~ residential premises.

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If the PDS generates commutation notches on the input, this should be indicated in the user information.

In case of problems, the manufacturer should offer (at the cost of the user) the solution necessary to make the PDS comply with a lower emission category.

D.1.2.4 Categories C2 and C4

In this case, the user has the technical competence to apply a correct EMC concept for the installation. The manufacturer should provide information about the emission category of the PDS.

The user will be able to select the correct combination of emission category and mitigation measures to provide the most economical solution for the installation.

D.2 Safety and RFI-filtering in power supply systems

D.2.1 Safety and leakage currents

The RFI-filtering sufficient to meet the emission limits is well-known in the state of the art. It is important to consider that the capacitance values and therefore the energy content and finally the effectiveness of Y-type capacitors used for the filters are limited by the normative requirements of safety standards, such as IEC 60065 in the case of plug-in apparatus. If the leakage current through this RFI-filtering capacitance to earth is too high, the effectiveness of ~~differential protection (earth fault protection)~~ protective measures with RCDs or RCMs within these supply systems can be compromised.

Safety requirements related to leakage current, including requirements for warnings, are given in IEC 61800-5-1.

D.2.2 Safety and RFI-filtering in power supply systems isolated from earth

In complex processes like rolling mills, bar mills or paper mills as well as centrifugal and auxiliary equipment in the sugar industry, crane equipment and chemical industry, it is useful and state of the art to have a distributed ~~isolated~~ IT power supply system. Even if, for example, the motors are installed outside the building and are exposed to high humidity, it may be necessary to continue the process in spite of one ~~short circuit~~ insulation fault to earth. This ~~short circuit~~ insulation fault is detected via an ~~"earth fault monitoring system" and allows the whole process to be safely run until the next service interval~~ insulation monitoring device (IMD) which may be combined with an insulation fault location system (IFLS) according IEC 61557-9. This measure allows the whole process to be safely run until the next service interval.

This "process safety philosophy" in industrial installations could be disturbed by a lot of parasitic elements as shown in Figure D.3 for example by capacitances C_{pv} between supply network and earth. The resulting capacitance is the sum of all Y-type capacitances and parasitic capacitances. The sum of all C_{pv} can reach values of several microfarads. Any RFI-filtering system would increase this capacitance-to-earth to an extremely high value because of the large number of Y-type capacitances used (for example n-times the capacitors C_y). With increasing capacitance it would become more and more difficult and finally impossible to detect an ~~earth~~ insulation fault correctly.

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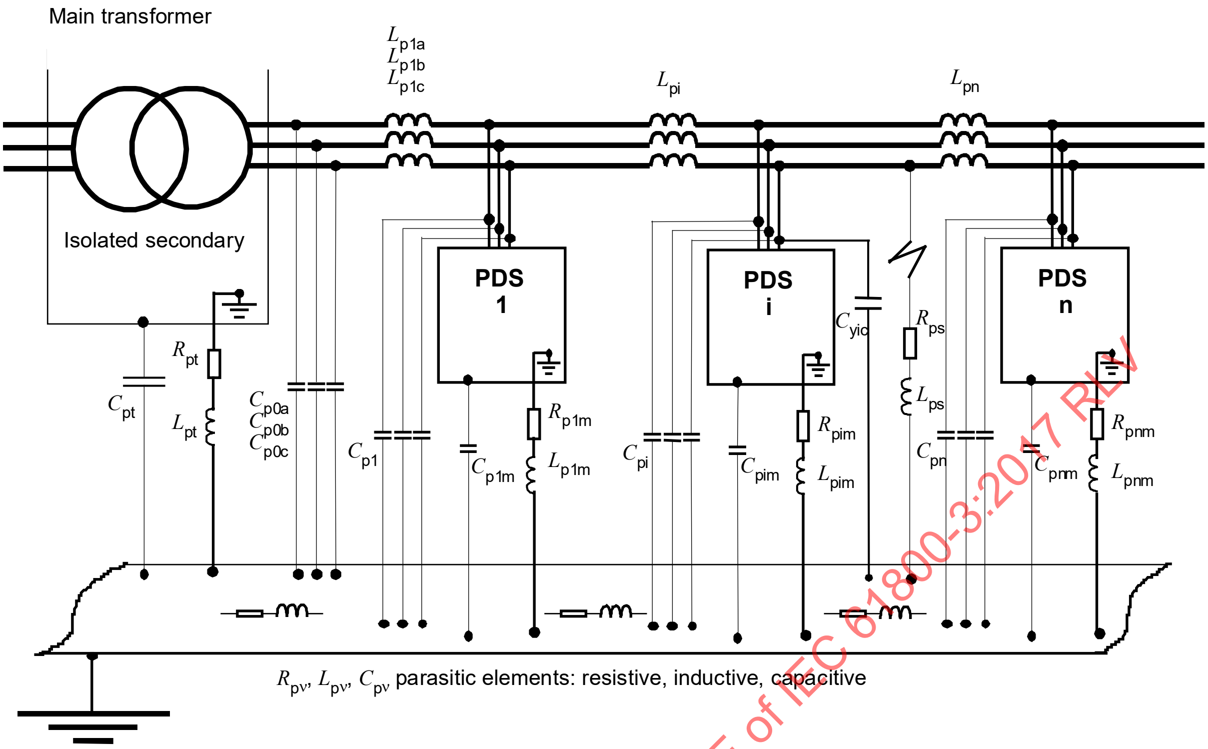

Several PDS are working together in a complex process with distributed isolated power supply. IEC

Figure D.3 – Safety and filtering

With RFI-filtering devices (C_y), any ~~short circuit~~ insulation fault to earth will cause very high current values to flow through the semiconductor switches within the power drive system. This is equivalent to short circuit conditions in the earthing network on any output failure. This would lead to a tripping of function and releasing of electronic emergency protective devices and finally to an undesired process shutdown with unforeseeable economic consequences.

These are the reasons why RFI-filtering is not compatible with isolated networks of distributed processes and therefore is not discussed in the above-mentioned examples. On the other hand, it can be expected that RFI-filtering would not be very effective in these networks. This is because the return path of disturbance current flow to the disturbing source in systems isolated from earth is only capacitive. It will be hard to define or calculate because of resonances with the parasitic line inductances L_{pv}. Finally, an increase of the disturbance currents flowing through some C_y's through this less defined path could lead to interference problems with other equipment working on the same supply system.

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Annex E
(informative)

EMC analysis and EMC plan for PDS of category C4

E.1 General – System EMC analysis applied to PDSs

E.1.1 Electromagnetic environment

E.1.1.1 General

Following the first standardised classification of intended use (see definitions in 3.2), a more detailed and adapted description may be conducted. Various approaches may be used to describe the electromagnetic environment (EM environment). The general characteristics of the environment on which compatibility levels may be based should be defined. If electromagnetic compatibility of systems is to be achieved, the immunity characteristics of equipment should be considered together with installation practices and design, physical separation, filtering, and shielding.

According to the types of PDSs, particular classes of environment can be determined.

E.1.1.2 General modelling

A system consists of some subsystems. The existing devices (subsystems) can have two functions: emission and/or susceptibility (Figure E.1).

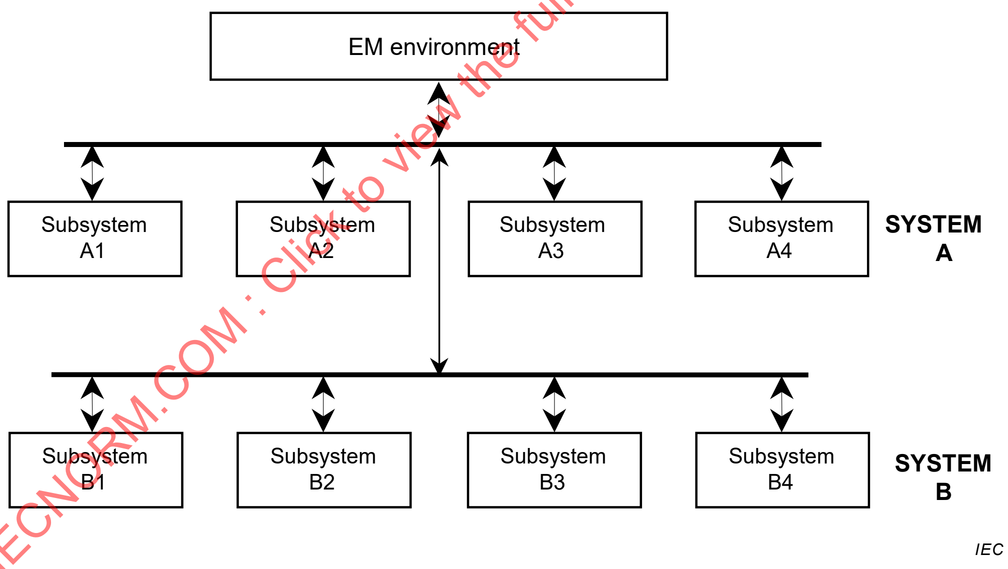

Figure E.1 – Interaction between systems and EM environment

Emitting devices determine the electromagnetic environment. Emission may reach the susceptible devices through various coupling types. General interactions are defined between subsystem i and subsystem j, and subsystem i and the environment. These interactions are defined with a coupling model using various coupling types (common impedance coupling, coupling by induction, and radiation – see Table E.1).

This model helps to define various EMC problems and to define specific limits. Some examples are given in Figure E.1 and Table E.1.

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E.1.2 System EMC analysis techniques

E.1.2.1 Zone concept

The system EMC analysis tasks should be performed utilising knowledge of signal characteristics in each subsystem, noise immunity levels of critical circuits, engineering evaluation tests, and consideration of the operational EM environment. Models for sources (transmitters), receivers, antennas, propagation media and coupling paths should be developed as necessary. The objective of the system EMC analysis is to assist in the development of design requirements and procedures to ensure that the drive system meets the EMC requirements.

A zone concept for the drive system should be defined based on the operational electromagnetic environment and the susceptibility of subsystems and equipment. Specific acceptance criteria should be established for each zone prior to each EMC test. These criteria should define the procedure used for the drive system performance during the immunity testing and to detect malfunctions or deviations from specification requirements. The acceptance criteria for a particular subsystem (or equipment) should be included in the applicable EMC test procedure. The zone concept is illustrated in Figure E.2.

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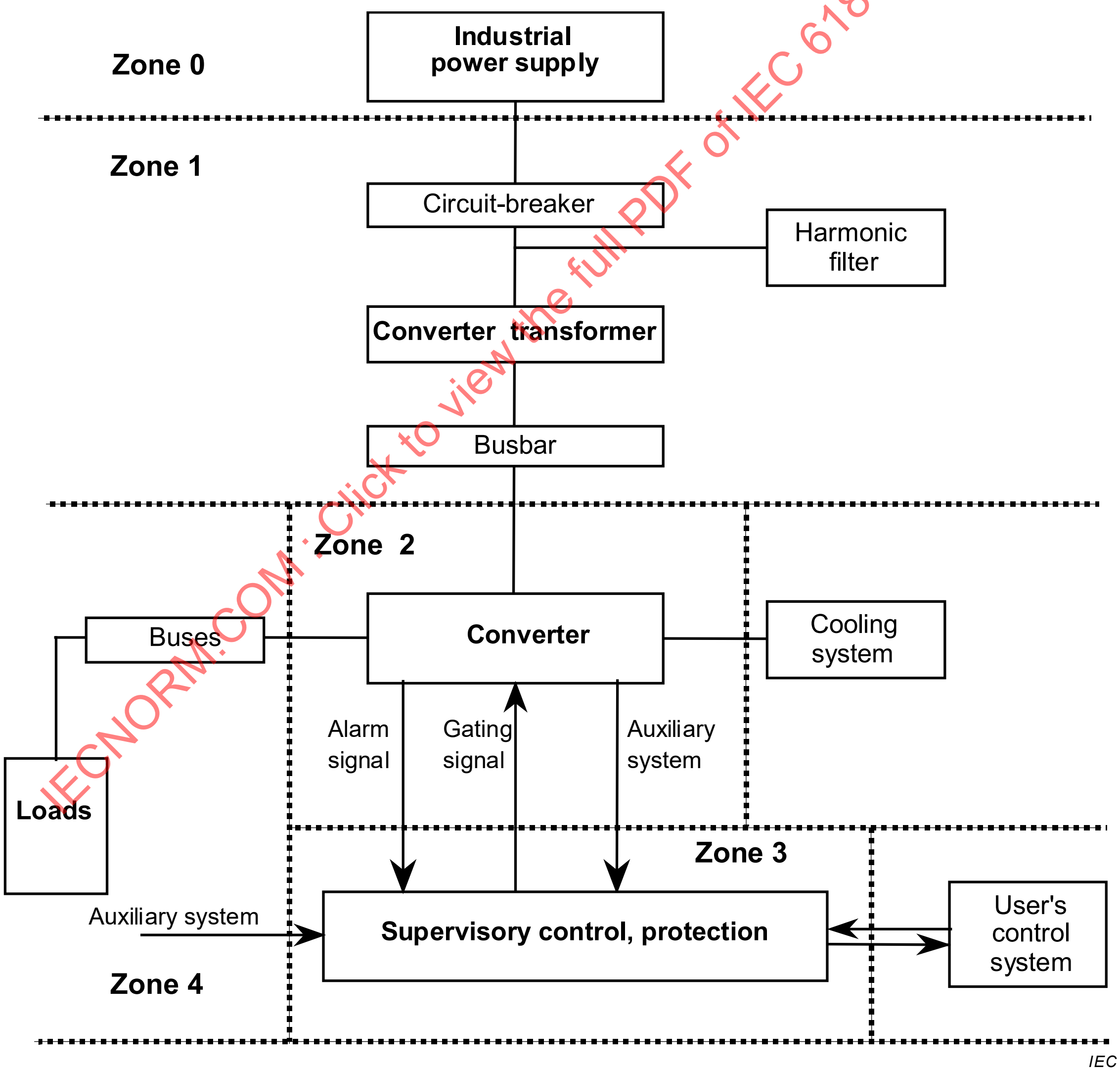

Figure E.2 – Zone concept

E.1.2.2 Interfaces

Table E.1 gives an example of the power interfaces between the subsystems of the PDS (as shown in Figure E.3), and the types of interference (conducted, radiated).

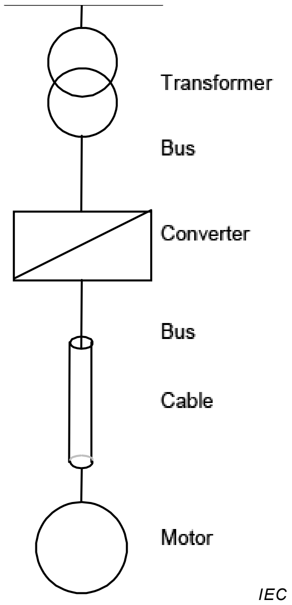

Figure E.3 – Example of drive

Table E.1 – EM interaction between subsystems and environment

	Subsystems as susceptible device				
Subsystems as EM-source	Environment	Trans-former	Converter	Cable	Motor
Environment	N/A	CI	CI Rad.	CI	CI
Transformer	CI E, H, Rad.	N/A	CI	N/A	N/A
Converter	CI Rad.	CI	N/A	CI	N/A
Cable	CI Rad.	Rad.	CI Rad.	N/A	CI
Motor	Rad.	N/A	CI	CI	N/A

NOTE Coupling model:

– common impedance coupling

CI: both resistive and reactive coupling

N/A: not applicable

– coupling by induction

E: electrical field coupling

H: magnetic field coupling

Rad: radiation coupling

E.1.2.3 Equipment

The electromagnetic characteristics of each equipment (emission, immunity) and the zone to which it belongs should be determined.

In cases where an EMC plan is required according to 6.5.1, the following form can be used.

NOTE This plan is based on IEC TR 61000-5-1.

This EMC plan covers the use of a PDS in a specific installation. The purpose of the plan is to make an EMC analysis at installation level. Based on the EMC analysis, the measures to achieve electromagnetic compatibility will be defined.

E.2 Example of EMC plan ~~for general applications~~

E.2.1 Project data and description

According to 6.5.1, the EMC plan reflects the agreement and the exchange of technical data between the user and the manufacturer. It should define the responsibilities of the manufacturer of the PDS, the installer and the user. The EMC plan is established jointly by all three parties. Any question which is not relevant to the particular application may be omitted.

The EMC plan is divided into two parts:

- E.2 defines the items which should normally be agreed;
- E.3 defines additional items that may be necessary in certain applications.

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NOTE ~~Use~~ The marking N/A is used if the requirement is not applicable. ~~Provide~~ An explanation is provided in such a case.

The example proposed below contains questions, the answers to which can constitute an EMC plan.

Name of manufacturer/supplier
Name of end user
Order No. .... Date

Type of facility (e.g. chemical factory, paper machine)
Application (e.g. pump. fan, conveyor) .....
EMC responsible person(s) ....

E.2.2 Electromagnetic environment analysis

E.2.2.1 Facility data

Installation location

Description of the neighbourhood (next to the second environment in which the PDS is installed)
First environment Second environment
The distance from the building/room of PDS to first environment: .... metres
The distance from the building/room of PDS to the other premises in the second environment: .... metres

Building and room construction

Type (wood, brick, concrete, steel, aluminium, etc.) ....
Reinforcement (steel, etc.) Yes .... No ....
Dedicated room for system Yes .... No.....................

Room layout

Sketch room layout as close to scale as possible. Shows all major equipment: windows, doors, etc.

E.2.2.2 Power and earthing data

Power distribution

Power distribution system for PDS:
Identification of the point of coupling (identification code for distribution panel, switchgear or transformer).......
Type of distribution system (example TN-C, TN-S; TT, IT)
The type of power supply for PDS:
Wye ...... Delta .... Number of phases ... Number of wires .....
Earth bus: how and where bonded? ....

Wiring diagram

Draw a single-line diagram of site power distribution system from the main supply transformer to the PDS. Show all transformers, distribution panels, etc. Also indicate nominal voltage, power rating, cable routing and method, number of conductors and approximate length of cables/busbars involved.

E.2.2.3 EMC data

PDS earthing

PDS earth reference? ...... Single point........ Meshed ....
Provide a schematic of equipotential bonding.

PDS shielding

Are shielded cabinets for CDM/BDM used? Yes....... No........

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Describe:

Are shielded cables used? Yes....... No........
Describe:

Other measures used (e.g. container)? Yes....... No........
Describe (consider also motors and cables):

RFI sensitive equipment in facility

Any equipment in the building or near installation location sensitive to RF disturbances?
Yes .... No
Describe: (e.g. process control and measurement, data buses, computers, etc.)

Approximate distance from PDS/cabling of PDS: .... metres
Most likely coupling path for disturbance: Conducted.......... Radiated ......

RFI sensitive equipment outside facility

Any broadcast or communications receiver antennas visible or near facility?
Yes .... No
Describe (e.g. radar, radio/TV broadcast, amateur, microwave or other):
Frequency.......... Distances from the antenna .... metres

Citizen band (CB), walkie-talkies, wireless communication, remote control or clock synchronisation system used on facility?
Yes .... No
Describe:

E.2.3 EMC analysis

E.2.3.1 Identify the most sensitive equipment or systems

Analyse electromagnetic environment constraints to installation.

E.2.3.2 Identify the most likely disturbing parts of PDS

Analyse electromagnetic environment constraints to installation.

E.2.3.3 Are there risks of malfunction of items listed in E.2.3.2, due to disturbances from the PDS?

Yes .... No
Describe:

E.2.4 Establishment of installation rules

E.2.4.1 Earthing

Note the recommendations given by the manufacturer of PDS, when determining the installation rules. To ensure the EMC effectiveness of the earthing, assess the items below:

- earthing system of PDS (single point/meshed);
- equipotential bonding:
  - interconnection of exposed conductive parts;
  - interconnection of metal structures of PDS to the earthing system.
- HF quality of connections:
  - metal-to-metal bonding by fasteners;
  - removal of paint or any other insulating material where necessary.
- describe (EMC solutions).

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E.2.4.2 Cables and wiring

E.2.4.2.1 Cable selection

Note the recommendations given by the manufacturer of PDS, when determining the installation rules. To ensure the EMC effectiveness of cables, assess the items below:

- the signal type (e.g. digital data, PWM to a motor);
- unused conductors;
- type of cable and type of shielding (if any);
- describe (EMC solutions).

E.2.4.2.2 Routing

Note the recommendations given by the manufacturer of PDS, when determining the installation rules. To ensure the EMC effectiveness of cabling, assess the items below:

- separation of high-power and low power, or signal cables;
- minimisation of parallel length;
- segregation distances;
- cable intersection at 90°;
- use of conduits and cable trays as parallel-earthed conductor;
- cable positioning in cable trays;
- earthing of cable trays;
- describe (EMC solutions).

E.2.4.3 Shielding of PDS cabinet

Note the recommendations given by the manufacturer of PDS, when determining the installation rules. To ensure the EMC effectiveness of enclosures, assess the items below:

- continuity of metallic enclosure;
- dimension of slots and openings;
- cable entry through the earth reference plane;
- connection of cable shields to earth reference plane (360° preferred);
- describe (EMC solutions).

E.2.4.4 Dedicated transformer

Note the recommendations given by the manufacturer of PDS, when determining the installation rules. To ensure EMC effectiveness, consider the use of the following:

- dedicated isolation transformer;
- transformer with electrostatic shield;
- describe (size, location).

E.2.4.5 Filtering

Note the recommendations given by the manufacturer of PDS, when determining the installation rules. To ensure EMC effectiveness, consider the use of the following:

- centralised or distributed RFI-filter-configurations;
- signal line filtering;
- filtering power interface if appropriate;

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- describe (EMC solutions)

E.2.4.6 Additional mitigation techniques

Note the recommendations given by the manufacturer of PDS, when determining the installation rules. Are other mitigation techniques necessary? Yes No

Consider the use of the following:

- electrical separation of circuits;
- optical fibres;
- galvanic isolation for data lines (example optocouplers, transformers);
- extra protection for sensitive devices;
- describe (EMC solutions)

E.2.5 Formal result and maintenance

Check that the installation is built according to the defined installation rules.

Do all details follow the defined installation rules? Yes No

Describe any action to correct failings.

Define instructions for maintaining EMC characteristics of the installation (e.g. measures against corrosion, dust which might weaken the contact between the door and the frame, loosening of connections).

Signature(s) by person(s) responsible for EMC:

Date

Signature(s)

E.3 Example of supplement to EMC plan for particular application

E.3.1 Electromagnetic environment complementary analysis

E.3.1.1 Power distribution from utility substation to facility main supply transformer

The questions in E.3 are related to factors external to the PDS which can be relevant to the EMC performance in a more complex application.

<u>Electrical utility service supplier</u>:

Approximate distance from the nearest utility substation (if known):

Utility service distribution from the substation:

overhead lines buried combination

describe

<u>Facility main supply transformer characteristic</u>: kVA

input (primary): volts number of phases

type of connection: Delta Wye

other, describe

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Output to internal distribution (secondary)

volts number of wires number of phases

Type of connection: Delta Wye

Is the transformer earthed? (describe how and where)

Building earthing electrode consisting of

Earth rod Multiple rods Earth grid Earth plate

Buried conduit Water pipe Building steel

If other, describe

Draw wiring diagram

Draw a single-line diagram of site power distribution system from the utility substation to main supply transformer. Show all transformers, distribution panels, etc.

Earth electrode impedance in ohms (if known)

E.3.1.2 Power distribution from facility main supply transformer to local distribution panel/switch gear/transformer for PDS

The questions in E.3 are related to factors external to the PDS which can be relevant to the EMC performance in a more complex application.

Wiring diagram

Draw a single-line diagram of facility power distribution system from the main supply transformer to the local distribution panel/switchgear/transformer.

Local power distribution panel/switchgear/transformer

Panel/switchgear/transformer identification

Panel construction: how and where bonded

Type of power supply for panel/switchgear/transformer

Wye Delta number of phases

number of wires wire size (phase/neutral/PE): Cu Al

Neutral bus: how and where bonded

Earth bus: how and where bonded

Individual insulated PE wire from PDS or part of PDS

Yes No

Describe

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E.3.2 EMC analysis

E.3.2.1 Frequency plan

RFI survey needed

Yes No

Explain

If yes, issuing a frequency plan/table might clarify the situation. An example is given below in Table E.2.

Table E.2 – Frequency analysis

Equipment	Unit	Frequency	Band-width	Description of frequency source	V	A	Waveform	Type Em	Type Im	Ref. Doc.
Inverter N°1	IGBT-module	5 kHz		Output switching frequency	510		PWM	X		
Inverter N°2	IGBT-module	5 kHz		Output switching frequency	510		PWM	X		
Inverter N°1	Motor control	40 MHz		TTL clock	15		TTL clock	X		
Inverter N°2	Motor control	40 MHz		TTL clock	15		TTL clock	X		
Inverters	Output current sensor	1 kHz		Sampling frequency	0,03				X	
Auxiliary equipment	Power supply	200 kHz		Switching frequency	230		Spike	X		
Cordless telephones									X	
Business radio	Transmitter/ receiver							X	X	
Amateur radio	Transmitter/ receiver	144 MHz							X	

Em: emission

Im: immunity

Ref. doc: reference number of the specification of the item

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Risks of malfunction of items listed in above, due to disturbances from the PDS, should be analysed and adequate measures should be defined.

E.3.2.2 EMC testing

List the references of EMC test reports.

Is further specific EMC-testing necessary?

Yes No

If yes, a procedure as follows may be necessary:

- prepare an EMC test plan (refer to EMC analysis);

- perform EMC tests and write test reports.

Are the test results acceptable?

Yes No

Describe any action to correct failings:

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[46] IEC 61557-8:2014, *Electrical safety in low voltage distribution systems up to 1 000 V a.c. and 1 500 V d.c. – Equipment for testing, measuring or monitoring of protective measures – Part 8: Insulation monitoring devices for IT systems*

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[3] ~~To be published.~~

[47] IEC 61557-9, *Electrical safety in low voltage distribution systems up to 1 000 V a.c. and 1 500 V d.c. – Equipment for testing, measuring or monitoring of protective measures – Part 9: Equipment for insulation fault location in IT systems*

[48] IEC 61800-1:1997, *Adjustable speed electrical power drive systems – Part 1: General requirements – Rating specifications for low voltage adjustable speed d.c. power drive systems*

[49] IEC 61800-2:2015, *Adjustable speed electrical power drive systems – Part 2: General requirements – Rating specifications for low voltage adjustable speed a.c. power drive systems*

[50] IEC 61800-4:2002, *Adjustable speed electrical power drive systems – Part 4: General requirements – Rating specifications for a.c. power drive systems above 1000 V a.c. and not exceeding 35 kV*

[51] IEC 61800-5-1:~~2003~~ 2007, *Adjustable speed electrical power drive systems – Part 5-1: Safety requirements – Electrical, thermal and energy*

~~IEC 62103:2003, *Electronic Equipment for use in power installations*~~

[52] IEC TS 62578:2015, *Power electronics systems and equipment – Operation conditions and characteristics of active infeed converter (AIC) applications including design recommendations for their emission values below 150 kHz*

[53] CISPR 14-1:2016, *Electromagnetic compatibility – Requirements for household appliances, electric tools and similar apparatus – Part 1: Emission*

[54] CISPR 16-2-1:2014, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-1: Methods of measurement of disturbances and immunity – Conducted disturbance measurements*

[55] CISPR 16-2-3:2016, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-3: Methods of measurement of disturbances and immunity – Radiated disturbance measurements*

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IEC 61800-3

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INTERNATIONAL STANDARD

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ADJUSTABLE SPEED ELECTRICAL POWER DRIVE SYSTEMS –

Part 3: EMC requirements and specific test methods

FOREWORD

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International Standard IEC 61800-3 has been prepared by subcommittee 22G: Adjustable speed electric drive systems incorporating semiconductor power converters, of IEC technical committee 22: Power electronic systems and equipment.

This third edition cancels and replaces the second edition published in 2004 and Amendment 1:2011. This edition constitutes a technical revision.

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

a) clarification of requirements for the test report, particularly when a number of alternative test methods exist;
b) introduction of a more detailed test setup for radiated emission measurements, along with the introduction of a 3 m measurement distance for small size equipment;
c) general updates in the informative annexes.

The text of this standard is based on the following documents:

FDIS	Report on voting
22G/347/FDIS	22G/350/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2, and with IEC Guide 107.

A list of all parts in the IEC 61800 series, published under the general title *Adjustable speed electrical power drive systems*, 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 "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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

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ADJUSTABLE SPEED ELECTRICAL POWER DRIVE SYSTEMS –

Part 3: EMC requirements and specific test methods

1 Scope

This part of IEC 61800 specifies electromagnetic compatibility (EMC) requirements for power drive systems (PDSs, defined in 3.1). These are adjustable speed AC or DC motor drives. Requirements are stated for PDSs with converter input and/or output voltages (line-to-line voltage), up to 35 kV AC RMS.

PDSs covered by this document are those installed in residential, commercial and industrial locations with the exception of traction applications, and electric vehicles. PDSs can be connected to either industrial or public power distribution networks. Industrial networks are supplied by a dedicated distribution transformer, which is usually adjacent to or inside the industrial location, and supplies only industrial customers. Industrial networks can also be supplied by their own electric generating equipment. On the other hand, PDSs can be directly connected to low-voltage public mains networks which also supply residential premises, and in which the neutral is generally earthed (grounded).

The scope of this part of IEC 61800, related to EMC, includes a broad range of PDSs from a few hundred watts to hundreds of megawatts. PDSs are often included in a larger system. The system aspect is not covered by this document but guidance is provided in the informative annexes.

The requirements have been selected so as to ensure EMC for PDSs at residential, commercial and industrial locations. The requirements cannot, however, cover extreme cases which can occur with an extremely low probability. Changes in the EMC behaviour of a PDS, as a result of fault conditions, are not taken into account.

The object of this document is to define the limits and test methods for a PDS according to its intended use. This document includes immunity requirements and requirements for electromagnetic emissions.

NOTE 1 Emission can cause interference in other electronic equipment (for example radio receivers, measuring and computing devices). Immunity is meant to protect the equipment from continuous and transient conducted and radiated disturbances including electrostatic discharges. The emission and immunity requirements are balanced against each other and against the actual environment of the PDS.

This document defines the minimum EMC requirements for a PDS.

Immunity requirements are given according to the environment classification. Low-frequency emission requirements are given according to the nature of the supply network. High-frequency emission requirements are given according to four categories of intended use, which cover both environment and bringing into operation.

As a product standard, this document can be used for the assessment of PDS. It can also be used for the assessment of complete drive modules (CDM) or basic drive modules (BDM) (see 3.1), which can be marketed separately.

This document contains

- conformity assessment requirements for products to be placed on the market, and

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- recommended engineering practice (see 6.5) for cases where high frequency emissions cannot be measured before the equipment is placed on the market (such PDSs are defined in 3.2.7 as category C4).

NOTE 2 The first edition of IEC 61800-3 identified that the intended use could require engineering for putting into service. This was done by the “restricted distribution mode”. Equipment formerly identified under “restricted distribution mode” is now covered by categories C2 and C4 (see 3.2).

This document is intended as a complete EMC product standard for the EMC conformity assessment of products of categories C1, C2 and C3, when placing them on the market (see definitions 3.2.4 to 3.2.6).

Radio frequency emission of equipment of category C4 is only assessed when it is installed in its intended location. It is therefore treated as a fixed installation, for which this document gives rules of engineering practice in 6.5 and Annex E, although it gives no defined emission limits (except in case of complaint).

This document does not specify any safety requirements for the equipment such as protection against electric shocks, insulation co-ordination and related dielectric tests, unsafe operation, or unsafe consequences of a failure. It also does not cover safety and functional safety implications of electromagnetic phenomena.

In special cases, when highly susceptible apparatus is being used in proximity, additional mitigation measures can have to be employed to reduce the electromagnetic emission further below the specified levels or additional countermeasures can have to be employed to increase the immunity of the highly susceptible apparatus.

As an EMC product standard for PDSs, this document takes precedence over all aspects of the generic standards, and no additional EMC tests are performed. If a PDS is included as part of equipment covered by a separate EMC product standard, the EMC standard of the complete equipment applies.

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2 Normative references

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

IEC 60146-1-1:2009, *Semiconductor convertors – General requirements and line commutated convertors – Part 1-1: Specifications of basic requirements*

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 61000-2-4:2002, *Electromagnetic compatibility (EMC) – Part 2-4: Environment – Compatibility levels in industrial plants for low-frequency conducted disturbances*

IEC 61000-3-2:2014, *Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)*

IEC 61000-3-3:2013, *Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection*

IEC 61000-3-11:2000, *Electromagnetic compatibility (EMC) – Part 3-11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤ 75 A and subject to conditional connection*

IEC 61000-3-12: 2011, *Electromagnetic compatibility (EMC) – Part 3-12: Limits – Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current > 16 A and ≤ 75 A per phase*

IEC 61000-4-2:2008, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test*

IEC 61000-4-3:2006, *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test*

IEC 61000-4-4:2012, *Electromagnetic compatibility (EMC) – Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test*

IEC 61000-4-5:2014, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

IEC 61000-4-6:2013, *Electromagnetic compatibility (EMC) – Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields*

IEC 61000-4-8:2009, *Electromagnetic compatibility (EMC) – Part 4-8: Testing and measurement techniques – Power frequency magnetic field immunity test*

IEC 61000-4-11:2004, *Electromagnetic compatibility (EMC) – Part 4-11: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests*

IEC 61000-4-13:2002, *Electromagnetic compatibility (EMC) – Part 4-13: Testing and measurement techniques – Harmonics and interharmonics including mains signalling at a.c. power port, low frequency immunity tests*

IEC 61000-4-34:2005, *Electromagnetic compatibility (EMC) – Part 4-34: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests for equipment with input current more than 16 A per phase*

CISPR 11:2015, *Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement*
CISPR 11:2015/AMD1:2016

CISPR 16-1-2:2014, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-2: Radio disturbance and immunity measuring apparatus – Coupling devices for conducted disturbance measurements*

CISPR 16-1-4:2010, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-4: Radio disturbance and immunity measuring apparatus – Antennas and test sites for radiated disturbance measurements*

CISPR 22, *Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement*

CISPR 32:2015, *Electromagnetic compatibility of multimedia equipment – Emission requirements*

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3 Terms and definitions

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

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

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

3.1 Installation and its content

Figure 1 shows the major parts of the PDS as defined below and the rest of the installation.

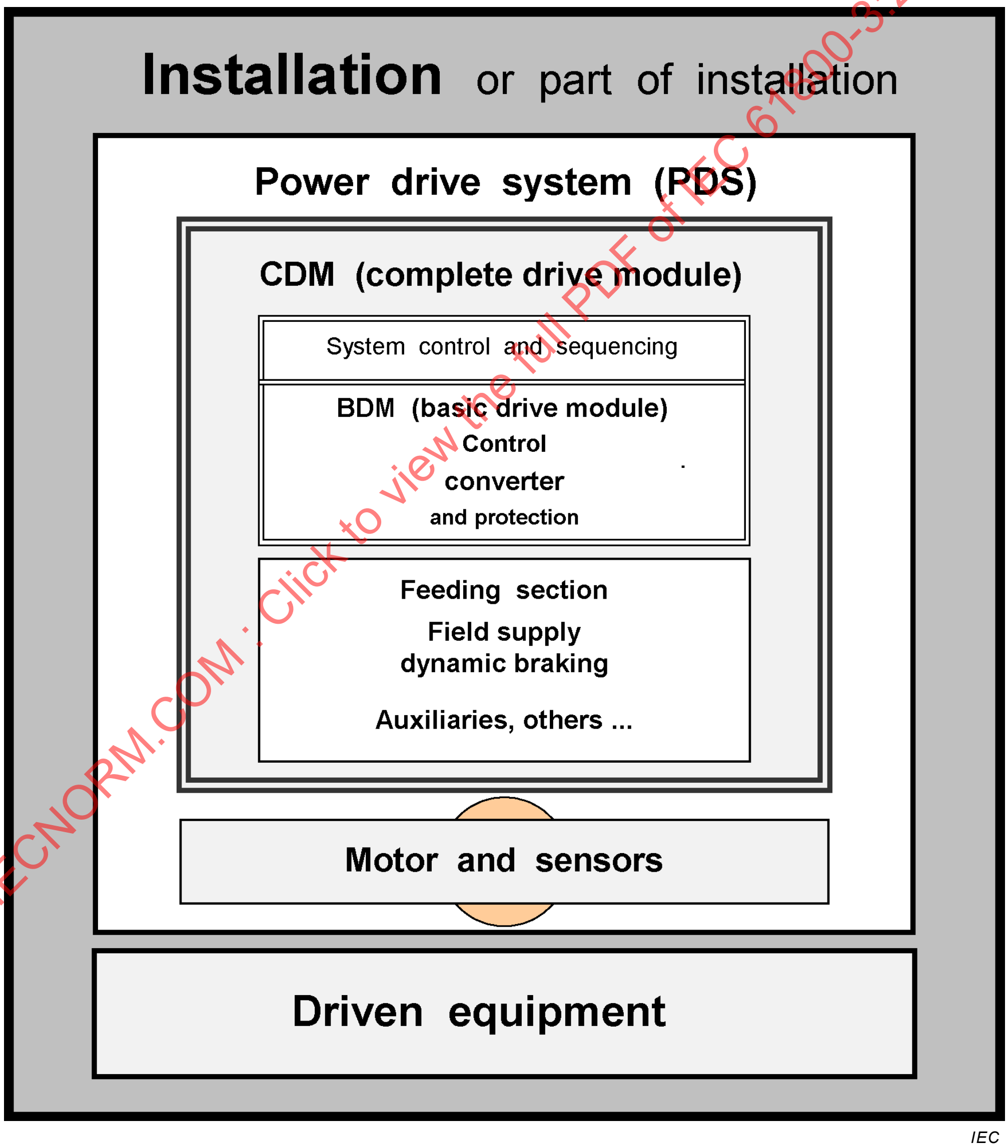

Figure 1 – Installation and its content

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3.1.1
basic drive module
BDM
electronic power converter and related control, connected between an electric supply and a motor

Note 1 to entry: The BDM is capable of transmitting power from the electric supply to the motor and can be capable of transmitting power from the motor to the electric supply. The BDM controls some or all of the following aspects of power transmitted to the motor and motor output:

- current;
- frequency;
- voltage;
- speed;
- torque;
- force;
- position.

3.1.2
complete drive module
CDM
drive module consisting of, but not limited to, the BDM and extensions such as protection devices, transformers and auxiliaries

Note 1 to entry: The motor and the sensors which are mechanically coupled to the motor shaft are not included.

3.1.3
power drive system
PDS
system consisting of one or more complete drive module(s) (CDM) and a motor or motors

Note 1 to entry: Any sensors which are mechanically coupled to the motor shaft are also part of the PDS; however, the driven equipment is not included.

3.1.4
installation
equipment or equipments which include at least both the PDS and the driven equipment

3.1.5
small size equipment
equipment, either positioned on a table top, wall-mounted or standing on the floor which, including its cables and possible auxiliary equipment, fits in an imaginary cylindrical test volume of maximum 1,2 m in diameter and 1,5 m height (to ground plane)

Note 1 to entry: This definition has been modified to apply to measurement of radiated emissions from the enclosure port.

[SOURCE: CISPR 11:2015, 3.17, modified — The expression "wall-mounted" and "and possible auxiliary equipment" have been added, as well as the note to entry.]

3.1.6
wall-mounted equipment
CDM/BDM intended to be mounted on a vertical surface

3.2 Intended use

3.2.1
EMC plan
procedure for the EMC assessment when installing category C4 (see 3.2.7) equipment

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3.2.2
first environment
environment that includes residential premises and establishments directly connected without intermediate transformers to a low-voltage power supply network which supplies buildings used for residential purposes

Note 1 to entry: Houses, apartments, commercial premises or offices in a residential building are examples of first environment locations.

3.2.3
second environment
environment that includes all establishments other than those directly connected to a low-voltage power supply network which supplies buildings used for residential purposes

Note 1 to entry: Industrial areas or technical areas of any building fed from a dedicated transformer are examples of second environment locations.

3.2.4
PDS of category C1
PDS of rated voltage less than 1 000 V, intended for use in the first environment

3.2.5
PDS of category C2
PDS of rated voltage less than 1 000 V, which is neither a plug in device nor a movable device and, when used in the first environment, is intended to be installed and commissioned only by a professional

Note 1 to entry: A professional is a person or an organisation having necessary skills in installing and/or commissioning power drive systems, including their EMC aspects.

3.2.6
PDS of category C3
PDS of rated voltage less than 1 000 V, intended for use in the second environment and not intended for use in the first environment

3.2.7
PDS of category C4
PDS of rated voltage equal to or above 1 000 V, or rated current equal to or above 400 A, or intended for use in complex systems in the second environment

3.3 Location, ports and interfaces

3.3.1
in situ
<test> location where the equipment is installed for its normal use by the end user

3.3.2
test site
<radiation> site meeting requirements necessary for correctly measuring, under defined conditions, electromagnetic fields emitted by a device under test

[SOURCE: IEC 60050-161:1990, 161-04-28]

3.3.3
port
access to a device or network where electromagnetic energy or signals may be supplied or received or where the device or network variables may be observed or measured

Note 1 to entry: Figure 2 illustrates the diversity of the ports of a PDS.

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[SOURCE: IEC 60050-131:2002, 131-12-60, modified – The note to entry has been replaced by a new one.]

3.3.4
enclosure port
physical boundary of the PDS through which electromagnetic fields may radiate or impinge

Note 1 to entry: See Figure 2.

3.3.5
port for process measurement and control
input/output (I/O) port for a conductor or cable which connects the process to the PDS

3.3.6
power port
port which connects the PDS to the power supply, which also feeds other equipment

3.3.7
main power port
power port which feeds the PDS for only the power which, after electrical power conversion, is converted by the motor into mechanical power

3.3.8
auxiliary power port
power port which feeds only the auxiliaries of the PDS, including the field circuit, if any

3.3.9
signal interface
input/output (I/O) connection for a line connecting the basic drive module or complete drive module (BDM/CDM) to another part of the PDS

Note 1 to entry: See Figure 2.

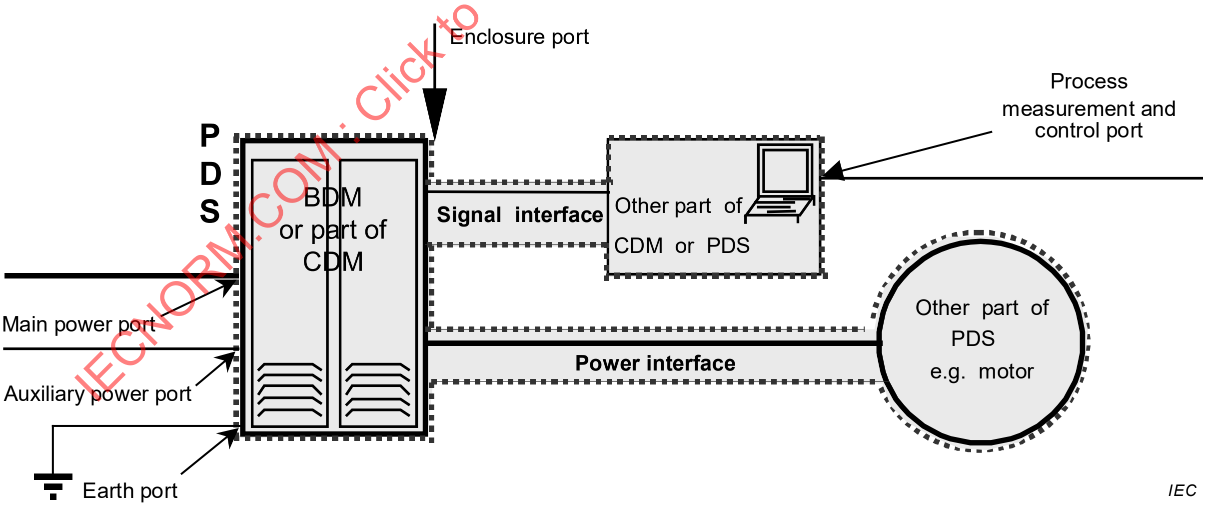

Figure 2 – Internal interfaces of the PDS and examples of ports

3.3.10
power interface
connections needed for the distribution of electrical power

Note 1 to entry: See Figure 3 for an example of power interface and Clause E.1 for an explanation.

Note 2 to entry: The power interfaces of the PDS may have different forms and extensions:

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– Within the CDM/BDM

A power interface can be the connection for distribution of electrical power from one part of the BDM/CDM to another part of the BDM/CDM. One power interface can be common to different components of the PDS. For examples, see Figure 3 and Figure 4.

Figure 3 shows a power interface which distributes power from an input converter (where power is converted from the mains to another type, here DC power) to output inverters (where power is converted from an intermediate form (here DC) to another type (here AC) which can be directly applied to AC motors).

Figure 4 shows a power interface which distributes power from the secondary of a transformer (which is part of the CDM) to individual BDMs.

– Within the PDS

Note that the connection between the inverter and the motor or the motors is also a power interface. It is the last power interface before the conversion to mechanical power.

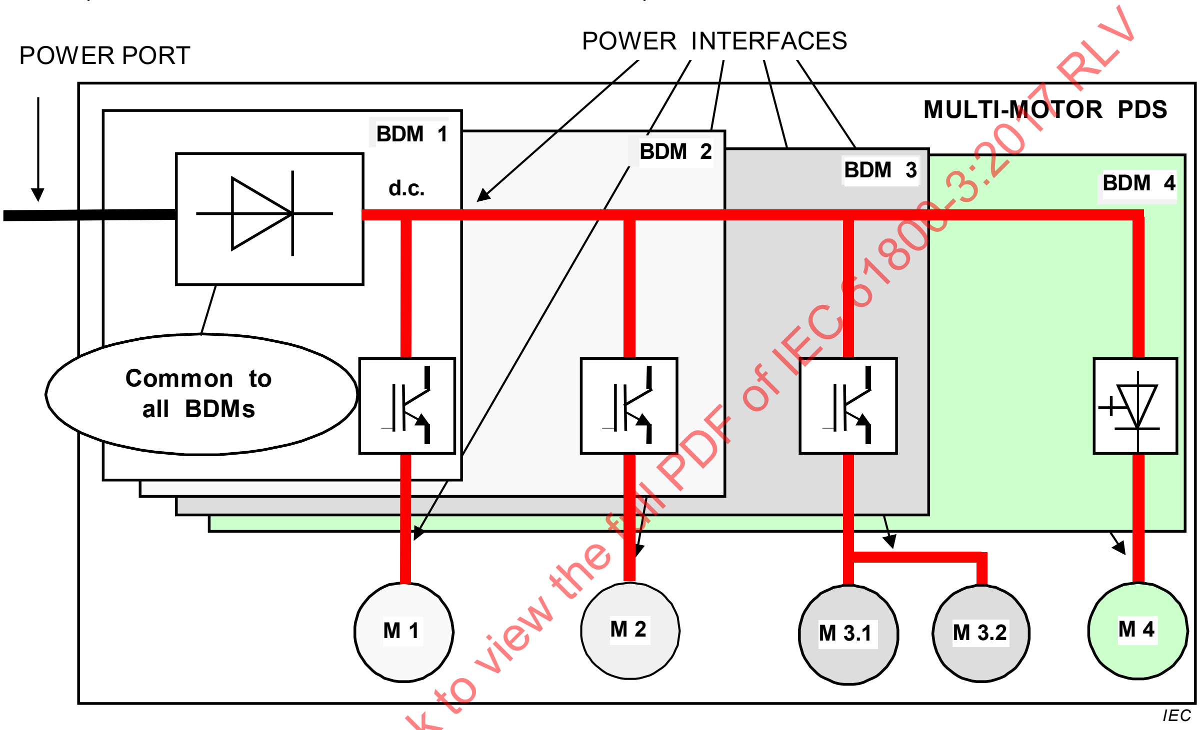

Figure 3 – Power interfaces of a PDS with common DC BUS

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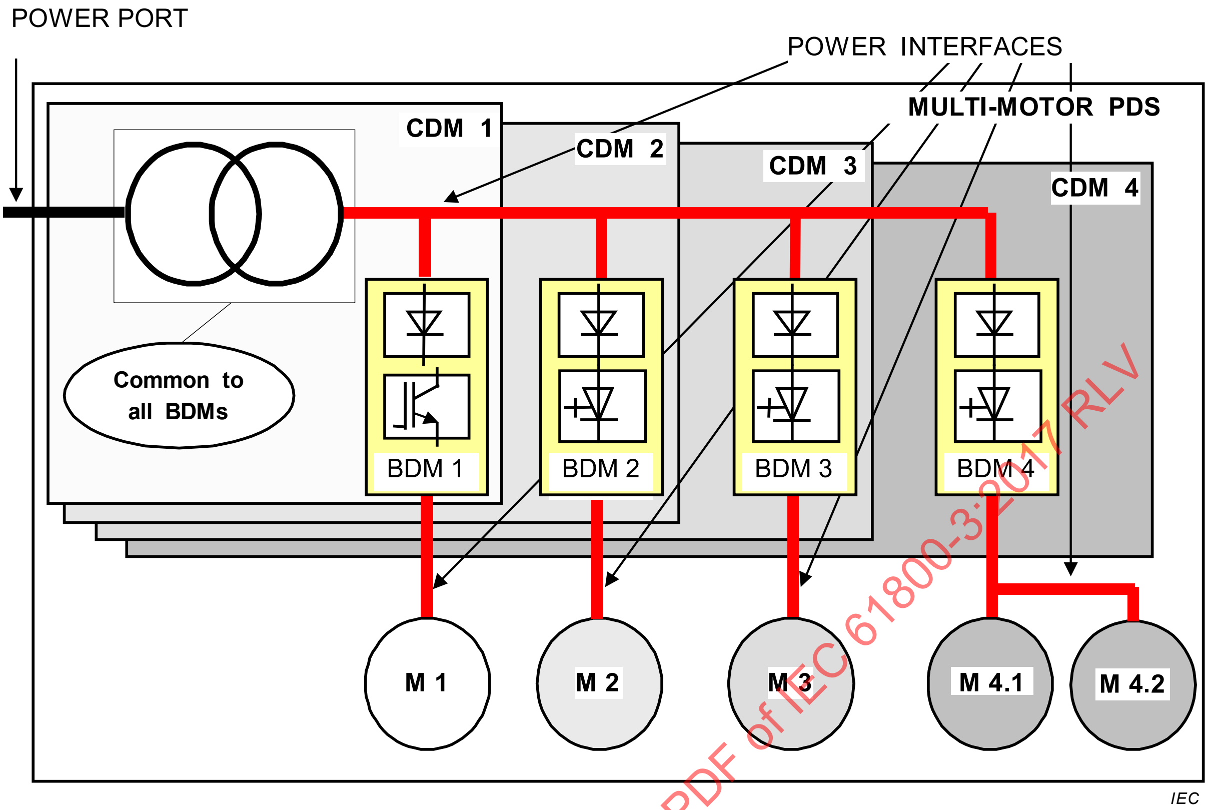

Figure 4 – Power interfaces with common input transformer

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3.3.11
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

[SOURCE: IEC 61000-2-4:2002, 3.1.6]

3.3.12
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 are, or could be, connected

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

[SOURCE: IEC 61000-2-4:2002, 3.1.7]

3.3.13
point of coupling
PC
point on a network which can be a public power supply network or a network inside a system or an installation

3.4 Components of the PDS

3.4.1
converter
<of the BDM> unit which changes the form of electrical power supplied by the mains to the form fed to the motor(s) by changing one or more of the voltage, current and/or frequency

Note 1 to entry: The converter comprises electronic commutating devices and their associated commutation circuits. It is controlled by transistors or thyristors or any other power switching semiconductor devices.

Note 2 to entry: The converter can be line-commutated, load-commutated or self-commutated and can consist, for example, of one or more rectifiers or inverters.

3.4.2
motor
electric motor
electric machine intended to transform electric energy into mechanical energy

Note 1 to entry: For the purposes of this document, the motor includes all sensors which are mounted on it and which are relevant for supporting the operating mode and interacting with a CDM.

[SOURCE: IEC 60050:2001, 151-13-41, modified — The note has been added.]

3.4.3
sub-component
physical piece of equipment which can be operated separately with an intrinsic function defined by the manufacturer

Note 1 to entry: For the purpose of this document, a component of the PDS can be divided into sub-components.

Note 2 to entry: As an example, the control unit of a CDM may be a sub-component.

3.5 Phenomena-related definitions

3.5.1
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

[SOURCE: IEC 60050-161:1990, 161-01-07]

3.5.2
total harmonic current
THC
total RMS value of the harmonic current components of orders 2 to 40

$$THC = \sqrt{\sum_{h=2}^{40} I_h^2}$$

[SOURCE: IEC 61000-3-12:2011, 3.1]

3.5.3
total harmonic distortion
THD
ratio of the RMS value of the harmonic content to the RMS value of the fundamental component or the reference fundamental component of an alternating quantity

Note 1 to entry: The harmonic content depends on the choice of the fundamental component. If it is not clear from the context which one is used, an indication should be given.

Note 2 to entry: The total harmonic distortion can be restricted to a certain harmonic order (recommended notation "H"), which is 40 for the purpose of this document.

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

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where, in addition to the notes to entry of B.2.2.7,

Q_1 is the RMS value of the fundamental component.

[SOURCE: IEC 60050-551:2001, 551-20-13, modified — The term "total harmonic ratio" has been deleted, the formula has been added and Note 1 to entry has been rephrased. In Note 2 to entry, the sentence "This is to be stated" has been deleted and the part "(recommended notation "H"), which is 40 for the purpose of this document" has been added.]

3.5.4
voltage deviation
difference between the voltage at a given instant and the declared supply voltage

[SOURCE: IEC 60050-614:2016, 614-01-04]

3.5.5
voltage change
variation of the RMS or peak value of a voltage between two consecutive levels sustained for definite but unspecified durations

Note 1 to entry: Whether the RMS or peak value is chosen depends upon the application, and which is used should be specified.

[SOURCE: IEC 60050-161:1990, 161-08-01]

3.5.6
voltage fluctuation
series of voltage changes or a continuous variation of the RMS or peak value of the voltage

Note 1 to entry: Whether the RMS or peak value is chosen depends upon the application, and which is used should be specified.

[SOURCE: IEC 60050-161:1990, 161-08-05]

3.5.7
voltage dip
sudden reduction of the voltage at a point in an electrical system, followed by voltage recovery after a short period of time, from a few cycles to a few seconds

[SOURCE: IEC 60050-614:2016, 614-01-08, modified — The second preferred term "voltage sag" has been deleted. In the definition, the words "electric power system" has been replaced by "electrical system", and the words "from a few periods of the sinusoidal wave of the voltage to a few seconds" by "from a few cycles to a few seconds".]

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4 Common requirements

4.1 General conditions

All phenomena, from the emission or immunity point of view, shall be considered individually. The limits are given for conditions which do not consider the cumulative effects of different phenomena.

For a realistic assessment of the EMC situation, a typical configuration shall be chosen.

The application of tests for evaluation of immunity depends on the particular PDS, its configuration, its ports, its technology and its operating conditions (see annexes).

4.2 Tests

4.2.1 Conditions

IEC 60146-1-1 and IEC 61800-2 distinguish between type test, routine test and special test. Unless otherwise stated, all the tests specified in this document are type tests only. The equipment shall meet the EMC requirements under all normal operating conditions as stated in the operating manual of the equipment when measured by the test methods specified in this document.

NOTE 1 Due to local radio transmission legislation, some immunity tests can be subject to conditions which restrict the choice of location where they can be performed.

If necessary, safeguards shall be taken against any unintended effects on the total process that may result from an equipment failure while an EMC test is being conducted.

For the tests, the CDM shall be connected to a motor recommended by the manufacturer with a cable and earthing rules defined by the manufacturer. Alternatively, a passive test load (resistive, or resistive and inductive) may be applied (for example, for evaluation of the low-frequency emissions), if permitted by the manufacturer.

NOTE 2 For high frequency emissions, passive test load can be unsuitable to simulate differential and common mode capacitances and couplings typically present.

The description of the tests, the test methods, the characteristics of the tests and the test set-ups are given in the referred standards and are not repeated here. If, however, modifications or additional requirements and information or specific test methods are needed for practical implementation and application of the tests, then they are given in this document.

A sufficient number of terminals shall be selected to simulate actual operating conditions and to ensure that all relevant types of termination are covered. The tests shall be carried out at the rated supply voltage and in a reproducible manner.

4.2.2 Test report

The test results shall be documented in a test report. The report shall clearly and unambiguously present all relevant information for reproducible testing. A functional description and detailed acceptance criteria provided by the manufacturer shall be noted in the test report.

Within the test report, the chosen test arrangements shall be justified. Whenever a subclause of this document offers alternative test methods, the chosen test method shall be stated in the test report. The information on test methods showed in Table 1 shall be given:

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Table 1 – Subclauses containing alternative test methods

Subclause	Test methods
5.1.2	Type of test: – general system performance test; or – special system performance test; or – sub-component performance test.
5.2 and sub-clauses	Immunity verification by: – calculation; or – simulation; or – test.
5.3.2	Fast transient burst for equipment ≥ 100 A: – direct coupling; or – capacitive clamp.
5.3.3	Fast transient burst for equipment ≥ 100 A: – direct coupling; or – capacitive clamp.
5.3.4	Immunity against electromagnetic fields: – PDS test; or – sub-components test.
6.2.1	Emission verification by: – calculation; or – simulation; or – test.
6.3.1.1	Test on a test site or in situ
6.3.1.2	Conducted emission tests: – with CISPR artificial mains network; or – with high impedance voltage probe.
6.3.1.3.3	Radiated emissions: measurement distance

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4.3 Documentation for the user

The setting of limits and the structure of this document are based on the understanding that the installer and user are responsible for following the EMC recommendations of the manufacturer.

The manufacturer shall supply the documentation necessary for the correct installation of a BDM, CDM or PDS into a typical system or process in the intended environment. This information includes any emission warnings required by 6.1 and Table 15. It also includes the warnings required by 5.3.2 in the case where the immunity of a BDM, CDM or PDS is not suitable for the second environment.

NOTE 1 From the emission point of view, a PDS (or BDM or CDM) with a lower emission category, such as C1, can always be used instead of one with a higher emission category, such as C3.

NOTE 2 Emission categories are independent of immunity. For example, a statement that a PDS has emission category C1 does not imply that the immunity is only suitable for the first environment.

If special EMC measures are necessary to fulfil the required limits, these shall be clearly stated in the user documentation. Where relevant, these can include the following:

- maximum and minimum acceptable supply network impedance;
- the use of shielded or special cables (power and/or control);
- cable shield connection requirements;

- maximum permissible cable length;
- cable segregation;
- the use of external devices such as filters;
- the correct bonding to functional earth.

If different devices or connection requirements apply in different environments, this shall also be stated.

A list of auxiliary equipment (for example, options or enhancements) that can be added to the PDS, and which complies with the immunity and/or emission requirements shall be made available.

This information may also be covered in some part of the test report to clarify the final recommended arrangement.

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5 Immunity requirements

5.1 General conditions

5.1.1 Acceptance criteria (performance criteria)

The system performance relates to the functions of the BDM, or of the CDM, or of the PDS as a whole that are declared by the manufacturer.

The sub-component performance relates to the functions of the sub-components of the BDM, or of the CDM, or of the PDS that are declared by the manufacturer.

The sub-component performance may be tested as an alternative instead of the system performance to show immunity (see 5.1.2). In the test report, it shall be stated which test has been applied.

Although this document allows tests on sub-components (components of CDM/BDM), it is not intended to be used for the separate conformity assessment of sub-components.

The acceptance criteria shall be used to check the performance of a PDS against external disturbances. From the EMC point of view, any installation according to Figure 1 shall be running properly. Since a PDS is part of the functional sequence of a larger process than the PDS itself, the effect on this process caused by changes in the performance of the PDS is hard to forecast. However, this important aspect for large systems should be covered by an EMC plan (see Annex E).

The main functions of a PDS are energy conversion between the electrical form and the mechanical form, and the information processing necessary to perform this.

Table 2 classifies the effects of a given disturbance into three acceptance (performance) criteria: A, B and C, both for the PDS and for its sub-components.

Subclauses 5.2 and 5.3 state the acceptance criterion required for each phenomenon.

5.1.2 Selection of performance type

5.1.2.1 General or special system performance

The “general system performance” item from Table 2 shall be defined in accordance with the special application and typical configuration of the PDS. It is the responsibility of the manufacturer to select these items.

The special system performance, torque-generating behaviour, shall be tested only in cases where it is explicitly defined in the product specification. In this case, the torque generating performance can be directly or indirectly tested. The direct test uses an EMC immune torquemeter to measure torque disturbances.

Torque performance can be defined through the ability to keep current or speed constant, within specified tolerances, when a disturbance is applied (see also 5.1.3). Therefore, a test of current performance can be used as an indirect test of torque-generating performance. For EMC assessment, and unless otherwise agreed, the output current of the power converter is deemed to represent torque with sufficient accuracy. As an alternative, the indirect test can use speed performance provided the total inertia is specified.

5.1.2.2 Sub-component performance

Testing of sub-components with sub-component performance should be used in cases when a PDS cannot be put into service on a test site because of limitation on the physical size of the PDS, on the current or rated supply capability or load conditions. In any case, the test set-up shall be immune to the highest level of disturbance applied to the PDS or to the sub-component under test.

Testing of information processing and sensing functions, including optional accessories if any, shall be performed only in cases where the relevant ports or interfaces are available at the PDS. Testing of the sub-component performance, according to Table 2, where the functions exist, is sufficient to determine the compliance with this document.

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Table 2 – Criteria to prove the acceptance of a PDS against electromagnetic disturbances

Item	Acceptance (performance) criterion [a]		
	A	B	C
General system performance	No noticeable changes of the operating characteristic Operating as intended, within specified tolerance	Noticeable changes (visible or audible) of the operating characteristic Self-recoverable	Shutdown, changes in operating characteristics Triggering of protective devices [b] Not self-recoverable
Special system performance Torque generating behaviour	Torque deviation within specified tolerances	Temporary torque deviation outside specified tolerances Self-recoverable	Loss of torque Not self-recoverable
Sub-component performance Operation of power electronics and driving circuits	No malfunction of a power semiconductor	Temporary malfunction which cannot cause unintended shut-down of the PDS	Shut-down, triggering of protective devices [b] No loss of stored program No loss of user program No loss of settings Not self-recoverable
Sub-component performance Information processing and sensing functions	Undisturbed communication and data exchange to external devices	Temporarily disturbed communication, but no error reports of the internal or external devices which could cause shut-down	Errors in communication, loss of data and information No loss of stored program, no loss of user program No loss of settings. Not self-recoverable
Sub-component performance Operation of displays and control panels	No changes of visible display information, only slight light intensity fluctuation of LEDs, or slight movement of characters	Visible temporary changes of information, undesired LED illumination	Shut down, permanent loss of information, or unpermitted operating mode, obviously wrong display information No loss of stored program, no loss of user program No loss of settings

[a] Acceptance criteria A, B, C – False starts are not acceptable. A false start is an unintended change from the logical state "STOPPED" which can make the motor run.

[b] Acceptance criterion C – The function can be restored by operator intervention (manual reset). Opening of fuses is allowed for line-commutated converters operating in inverting mode.

5.1.3 Conditions during the test

The load shall be within the manufacturer's specification and the actual load shall be noted in the test report.

Testing the torque generating behaviour as well as the information processing and sensing functions requires special test equipment with adapted immunity against the parasitic coupling of the test disturbance. It can only be used if the immunity of the test set-up can be proven by reference measurements. The evaluation of the torque disturbance can be performed by a torque transducer or by measurement or calculation of the torque generating current or other indirect techniques; an adapted and immune load shall be available at the test-site.

For testing the performance of the information processing or sensing function, suitable equipment shall be available to simulate the data communication or data evaluation. This equipment shall have sufficient immunity to operate correctly during the test.

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Since the motor has been tested by its manufacturer according to the relevant standards, the motor component of the PDS, with exception of the sensors, does not need any additional EMC immunity test. Therefore, while the motor is connected to the BDM/CDM for the duration of the test, EMC immunity tests on the motor itself are not required.

The tests shall be applied to the relevant ports where they exist, including those of optional accessories if any. They shall be conducted in a well-defined and reproducible manner on a port-by-port basis. However, if several process measurement and control ports or signal interfaces have the same physical configuration (layout) it is sufficient to test one port or interface of that type.

In 5.2 and 5.3 the minimum requirements, tests and acceptance criteria are stated. The acceptance criteria refer to 5.1.1.

5.2 Basic immunity requirements – low-frequency disturbances

5.2.1 Common principle

The requirements in this subclause shall be used for designing the immunity of a PDS against low-frequency disturbances.

For the immunity requirements, the manufacturer may demonstrate compliance using either testing, calculation or simulation, and shall state the chosen verification method in the test report. Unless otherwise stated, it is sufficient to demonstrate that the power circuit will comply with the required acceptance criterion and that the ratings of input circuits (filters, etc.) will not be exceeded.

NOTE 1 A number of these phenomena are not required by the generic standards, but are important for the dimensioning of the power circuit of the PDS. It is difficult to test immunity against many of these phenomena, particularly when the input current exceeds 16 A or the supply voltage exceeds 400 V. However, experience of many years shows that, provided the power circuit operates correctly, the control part and the auxiliaries are generally immune. This is due to natural decoupling that exists in the PDS. Examples of such decoupling are that provided by power supplies and the time constants of auxiliary processes such as fans.

The compliance with the requirements of this document shall be stated in the user documentation. Where compliance is demonstrated by tests, the relevant basic standards in the IEC 61000-4 series may be considered (see Clause B.7).

NOTE 2 The electrical service conditions for the main and the auxiliary supply if any, are already defined in the PDS service conditions in the relevant standard IEC 61800-1 or IEC 61800-2 or IEC 61800-4. These service conditions include frequency variations, frequency rate of change, voltage variations, voltage fluctuations, voltage unbalance, harmonics and commutation notches.

5.2.2 Harmonics and commutation notches/voltage distortion

5.2.2.1 Low voltage PDSs (voltage distortion)

The BDM, CDM or PDS shall sustain the immunity levels while meeting the performance criteria given in Table 3, Table 4 and Table 5. It shall be verified that these levels will not cause the ratings for the input circuits (filters, etc.) to be exceeded. Analysis of commutation notches shall be in the time domain. The manufacturer may verify immunity by calculation, simulation, or test, according to 5.2.1, and shall state the chosen verification method in the test report. If the chosen verification method is by test, it shall be performed using the PDS with the motor connected. For equipment rated below 16 A per phase, the test method of IEC 61000-4-13 can be applied.

NOTE Frequency domain analysis of the contribution from notches to the total harmonic distortion will not fully account for harmful effects (see Clause B.1).

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Table 3 – Minimum immunity requirements for total harmonic distortion on power ports of low voltage PDSs

Phenomenon	First environment		Second environment		Performance (acceptance) criterion
	Reference document	Level	Reference document	Level	
Harmonics – THD	IEC 61000-2-2	8 %	IEC 61000-2-4 class 3	12 %	A

Table 4 – Minimum immunity requirements for individual harmonic orders on power ports of low voltage PDSs

Phenomenon Harmonic order	First environment		Second environment		Performance (acceptance) criterion
	Reference document	Level	Reference document	Level	
2	IEC 61000-4-13 class 2	3 %	IEC 61000-4-13 class 3	5 %	A
3		8 %		9 %	
4		1,5 %		2 %	
5		9 %		12 %	
Even orders $6 \leq h \leq 50$		No requirement		1,5 %	
7		7,5 %		10 %	
9		2,5 %		4 %	
11		5 %		7 %	
13		4,5 %		7 %	
15		No requirement		3 %	
17		3 %		6 %	
19		2 %		6 %	
21		No requirement		2 %	
23		2 %		6 %	
25		2 %		6 %	
27		No requirement		2 %	
29		1,5 %		5 %	
31		1,5 %		3 %	
33		No requirement		2 %	
35		1,5 %		3 %	
37		1,5 %		3 %	
39		No requirement		2 %	

NOTE 1 For individual harmonic orders in the first environment, levels are from Class 2 in IEC 61000-4-13 (these are approximately 1,5 times the compatibility levels of IEC 61000-2-4).

NOTE 2 For individual harmonic orders in the second environment, levels are from Class 3 in IEC 61000-4-13 (these are approximately 1,5 times the compatibility levels of IEC 61000-2-4).

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Table 5 – Minimum immunity requirements for commutation notches on power ports of low voltage PDSs

Phenomenon	First environment		Second environment		Performance (acceptance) criterion
	Reference document	Level	Reference document	Level	
Commutation notches	(None)	No requirement	IEC 60146-1-1 Class B	Depth = 40 %, total area = 250 in % degrees	A

5.2.2.2 PDSs of rated voltage above 1 000 V (voltage distortion)

5.2.2.2.1 Main power port

The PDS or BDM/CDM shall sustain the immunity levels given in Table 6. It shall be verified that these levels will not cause the ratings for the input circuits (filters, etc.) to be exceeded. Analysis of commutation notches shall be in the time domain. The manufacturer may verify immunity by calculation, simulation, or test, according to 5.2.1, and shall state the chosen verification method in the test report.

NOTE Frequency domain analysis of notches' contribution to total harmonic distortion will not obviously reveal certain types of harmful effects (see Clause B.1).

Table 6 – Minimum immunity requirements for harmonics and commutation notches/ voltage distortion on main power ports of PDSs of rated voltage above 1 000 V

Phenomenon	Reference document	Level	Performance (acceptance) criterion
Harmonics (*THD* and individual harmonic orders)	IEC 61000-2-4 Class 3	Value of the compatibility level	A
Harmonics short term (< 15 s)	IEC 61000-2-4 Class 2	1,5 times the value of the permanent compatibility levels	A
Commutation notches	IEC 60146-1-1	Depth = 40% U_{LWM} (class B) Area [a] = 125 in per cent degrees (class C)	A
[a] Class C of IEC 60146-1-1 is appropriate for the primary side of the transformer.			

5.2.2.2.2 Auxiliary power port

The auxiliary power ports of PDSs shall sustain the immunity levels for the second environment given in Table 3, Table 4 and Table 5 while meeting the performance criteria in those tables. It shall be verified that these levels will not cause the ratings for the input circuits (filters, etc.) to be exceeded. Analysis of commutation notches shall be in the time domain. The manufacturer may verify immunity by calculation, simulation, or test, according to 5.2.1, and shall state the chosen verification method in the test report.

NOTE Frequency domain analysis of notches' contribution to total harmonic distortion will not obviously reveal certain types of harmful effects (see Clause B.1).

5.2.3 Voltage deviations, dips and short interruptions

5.2.3.1 Low voltage PDSs (voltage deviations)

The PDS or BDM/CDM shall sustain the immunity levels given in Table 7. The manufacturer may verify immunity by calculation, simulation, or test, according to 5.2.1, and shall state the chosen verification method in the test report.

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Table 7 – Minimum immunity requirements for voltage deviations, dips and short interruptions on power ports of low voltage PDSs

Phenomenon	First environment			Second environment			Performance (acceptance) criterion
	Reference document	Level		Reference document	Level		
Voltage deviations (> 60 s)	IEC 61000-2-2	±10 % [a]		IEC 61000-2-4 Class 2	±10 % [a]		A [b]
Voltage dips [e]	IEC 61000-4-11 Class 2 or IEC 61000-4-34 Class 2 [f]	Volts remaining 0 % 70 %	Cycles 1 25/30 [c]	IEC 61000-4-11 Class 3 or IEC 61000-4-34 Class 3 [f]	Volts remaining 0 % 40 % 70 % 80 %	Cycles 1 10/12 [c] 25/30 [c] 250/300 [c]	C [d]
Short interruptions	IEC 61000-4-11 Class 2 or IEC 61000-4-34 Class 2 [f]	Volts remaining 0 %	Cycles 250/300 [c]	IEC 61000-4-11 Class 3 or IEC 61000-4-34 Class 3 [f]	Volts remaining 0 %	Cycles 250/300 [c]	C [d]

[a] "Voltage deviation" is a supply voltage variation from the nominal supply voltage. Testing of voltage deviations for three phase PDS requires increasing or reducing the voltage of all three phases simultaneously.

[b] When the voltage is below nominal, the maximum output power ratings – speed and/or torque – may be reduced, because they are voltage dependent.

[c] "x/y cycles" means "x cycles for 50 Hz test" and "y cycles for 60 Hz test".

[d] Opening of fuses is allowed for line-commutated converters operating in inverting mode.

[e] Power ports with current rating ≥75 A: the method of the voltage drop test according to 7.5 of IEC 61400-21:2008 may be used.

[f] IEC 61000-4-11 applies to equipment rated less than or equal to 16 A and IEC 61000-4-34 to equipment rated above 16 A.

A PDS is used for energy conversion, and a voltage dip represents a loss of available energy. It can be necessary to trip for safety reasons, even during a voltage dip of 30 % to 50 % amplitude and 0,3 s duration.

NOTE 1 A decreasing input voltage, even with few milliseconds duration, can result in blowing of fuses when applied to a line commutated thyristor converter operating under regeneration mode.

NOTE 2 The effect of a voltage dip (energy reduction) on the process cannot be defined without detailed knowledge of the process itself. This effect is a system and rating aspect, and will generally be greatest when the power demand (including losses) on the PDS is higher than the available power.

Where it is possible and not dangerous, the behaviour of the PDS during short interruptions may be verified by switching off and on the mains supply during the standard operating conditions of the PDS (see B.6.1).

The manufacturer shall state in the user documentation the degradation of performance resulting from voltage dips or short interruptions.

NOTE 3 Improvements to the immunity (use of UPS, stand-by generator, derating, etc.) can result in a considerable increase in the size and cost of the PDS and can reduce the efficiency or power factor. Operation such as automatic restart can have safety consequences, and are not covered by this document.

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5.2.3.2 PDSs of rated voltage above 1 000 V (voltage deviations)

5.2.3.2.1 Main power port

Main power ports of PDSs shall sustain the immunity levels given in Table 8. The manufacturer may verify immunity by calculation, simulation, or test, according to 5.2.1, and shall state the chosen verification method in the test report.

Table 8 – Minimum immunity requirements for voltage deviations, dips and short interruptions on main power ports of rated voltage above 1 000 V of PDSs

Phenomenon	Reference document	Level		Performance (acceptance) criterion
Voltage deviations exceeding 1 min	IEC 61000-2-4 Class 3	±10 %		A [a]
Voltage deviations not exceeding 1 min	IEC 61000-2-4 Class 3	+10 % to –15 %		A [a]
Voltage dips	IEC 61000-4-34 [b]	Volts remaining 0 % 40 % 70 % 80 %	Cycles 1 10/12 [c] 25/30 [c] 250/300 [c]	C [d]
Short interruptions	IEC 61000-4-34 [b]	Volts remaining 0 %	Cycles 250/300 [c]	C [d]

[a] "Voltage deviation" is a supply voltage variation from the nominal supply voltage. Testing of voltage deviations for three phase PDSs requires increasing or reducing the voltage of all three phases simultaneously.

When considering voltage deviations, any voltage steps shall not exceed ±12 % of nominal voltage and the time between steps shall not be less than 2 s.

When the voltage is below nominal, the maximum output power ratings – speed and/or torque – may be reduced, because they are voltage dependent.

[b] Typical depths and durations of voltage dips are given in IEC TR 61000-2-8.

[c] "x/y cycles" means "x cycles for 50 Hz test" and "y cycles for 60 Hz test".

[d] Opening of fuses is allowed for line-commutated converters operating in inverting mode.

The manufacturer shall state in the user documentation the degradation of performance resulting from voltage dips or short interruptions.

5.2.3.2.2 Auxiliary power port

The auxiliary power ports of PDSs shall sustain the immunity levels given in Table 9. The manufacturer may verify immunity by calculation, simulation, or test, and shall state the chosen verification method in the test report.

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Table 9 – Minimum immunity requirements for voltage deviations, dips and short interruptions on auxiliary low voltage power ports of PDSs

Phenomenon	Reference document	Level		Performance (acceptance) criterion
Voltage deviations exceeding 1 min	IEC 61000-2-4 Class 3	±10 %		A
Voltage deviations not exceeding 1 min	IEC 61000-2-4 Class 3	+10 % to –15 %		A
Voltage dips	IEC 61000-4-11 or IEC 61000-4-34 [b]	Volts remaining	Cycles	C
		0 %	1	
		40 %	10/12 [a]	
		70 %	25/30 [a]	
		80 %	250/300 [a]	
Short interruptions	IEC 61000-4-11 Class 3 or IEC 61000-4-34 Class 3 [b]	Volts remaining	Cycles	C
		0 %	250/300 [a]	

[a] "*x*/*y* cycles" means "*x* cycles for 50 Hz test" and "*y* cycles for 60 Hz test".

[b] IEC 61000-4-11 applies to equipment less or equal to 16 A and IEC 61000-4-34 applies to equipment above 16 A.

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5.2.4 Voltage unbalance and frequency variations

5.2.4.1 Low voltage PDSs

Definition and assessment of voltage unbalance are explained in B.5.2.

The PDS or BDM/CDM shall comply with the immunity levels given in Table 10. The manufacturer may verify immunity by calculation, simulation, or test, and shall state the chosen verification method in the test report. During verification, the rated load condition shall be used.

Table 10 – Minimum immunity requirements for voltage unbalance and frequency variations on power ports of low voltage PDSs

Phenomenon	First environment		Second environment		Performance (acceptance) criterion
	Reference document	Level	Reference document	Level	
Voltage unbalance [a]	IEC 61000-2-2	2 % negative sequence component	IEC 61000-2-4 Class 3	3 % negative sequence component	A[b]
Frequency variations	IEC 61000-2-2	±2 %	IEC 61000-2-4	±2 % ±4 % where the supply is separated from public supply networks	A
Frequency rate of change		1 %/second		±1 %/s 2 %/s where the supply is separated from public supply network	A

[a] Not relevant for single phase PDSs.

[b] In case of test, use test time of 30 s ± 5 s.

5.2.4.2 PDSs of rated voltage above 1 000 V

5.2.4.2.1 Main power port

Definition and assessment of voltage unbalance are explained in B.5.2.

The PDS or BDM/CDM shall sustain the immunity levels given in Table 11. The manufacturer may verify immunity by calculation, simulation, or test, and shall state the chosen verification method in the test report. During verification, the rated load condition shall be used.

Table 11 – Minimum immunity requirements for voltage unbalance and frequency variations on main power ports of rated voltage above 1 000 V of PDSs

Phenomenon	Reference document	Level	Performance (acceptance) criterion
Voltage unbalance	IEC 61000-2-4 Class 2	2 % negative sequence component	A
Frequency variations	IEC 61000-2-4	±2 % ±4 % where the supply is separated from public supply networks	A A
Frequency rate of change		±1 %/s 2 %/s where the supply is separated from public supply networks	A A

5.2.4.2.2 Auxiliary power port

Definition and assessment of voltage unbalance are explained in B.5.2.

The auxiliary power ports of PDSs shall sustain the immunity levels given in Table 12. The manufacturer may verify immunity by calculation, simulation, or test, and shall state the chosen verification method in the test report.

Table 12 – Minimum immunity requirements for voltage unbalance and frequency variations on auxiliary low voltage power ports of PDSs

Phenomenon	Reference document	Level	Performance (acceptance) criterion
Voltage unbalance	IEC 61000-2-4 Class 3	3 % negative sequence component	A
Frequency variations	IEC 61000-2-4	±2 % ±4 % where the supply is separated from public supply networks	A A

5.2.5 Supply influences – Magnetic fields

Immunity tests according to IEC 61000-4-8 are not required (see Clause A.3 for explanation).

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5.3 Basic immunity requirements – High-frequency disturbances

5.3.1 Conditions

In the following Table 13 and Table 14, the minimum immunity requirements for high-frequency disturbance tests and acceptance criteria are stated. The acceptance criteria refer to 5.1.1. Explanations are given in Clause A.3.

5.3.2 First environment

The levels in Table 13 shall be applied to PDSs which are intended to be used in the first environment.

If a CDM/BDM is designed to have immunity according to Table 13, it shall include a written warning in the instructions for use which indicates that it is not intended to be used in an industrial installation.

Table 13 – Minimum immunity requirements for PDSs intended for use in the first environment

Port	Phenomenon	Basic standard for test method	Level	Performance (acceptance) criterion
Enclosure port	ESD (electrostatic discharge)	IEC 61000-4-2	4 kV CD or 8 kV AD if CD impossible	B
	Radio-frequency electromagnetic field, amplitude modulated	IEC 61000-4-3 see also 5.3.4	80 MHz to 1 000 MHz 3 V/m 80 % AM (1 kHz)	A
	Radio-frequency electromagnetic field, amplitude modulated	IEC 61000-4-3 See also 5.3.4	1,4 GHz to 2,0 GHz 3 V/m 80 % AM (1 kHz)	A
	Radio-frequency electromagnetic field, amplitude modulated	IEC 61000-4-3 See also 5.3.4	2,0 GHz to 2,7 GHz 1 V/m 80 % AM (1 kHz)	A
Power ports (except auxiliary DC power ports below 60 V)	Fast transient-burst	IEC 61000-4-4	1 kV/5 kHz [a]	B
	Surge [b] 1,2/50 μs, 8/20 μs	IEC 61000-4-5	1 kV [c] 2 kV [d]	B
	Conducted radio-frequency common mode	IEC 61000-4-6 see also 5.3.4	0,15 MHz to 80 MHz 3 V 80 % AM (1 kHz)	A
Power interfaces	Fast transient-burst [e]	IEC 61000-4-4	1 kV/5 kHz Capacitive clamp	B
Ports for process measurement control lines and signal interfaces Auxiliary DC power ports below 60 V	Fast transient-burst [e]	IEC 61000-4-4	0,5 kV/5 kHz Capacitive clamp	B
	Conducted radio-frequency common mode [e]	IEC 61000-4-6 see also 5.3.4	0,15 MHz to 80 MHz 3 V 80 % AM (1 kHz)	A
CD: contact discharge AD: air discharge AM: amplitude modulation				

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a	Power ports with current rating < 100 A: direct coupling using the coupling and decoupling network. Power ports with current rating ≥ 100 A: direct coupling or capacitive clamp without decoupling network. If the capacitive clamp is used, test level shall be 2 kV/5 kHz. The chosen test method shall be stated in the test report.
b	Applicable only to power ports with current consumption < 63 A during light load test conditions as specified in 5.1.3.
c	Coupling line-to-line.
d	Coupling line-to-earth.
e	Applicable only to ports or interfaces with cables whose total length according to the manufacturer's functional specification may exceed 3 m.

5.3.3 Second environment

The levels in Table 14 shall be applied to PDSs which are intended to be used in the second environment. This also applies to the low voltage ports, or the low voltage interfaces (power, signal) of PDSs of rated voltage above 1 000 V.

NOTE Examples of low voltage ports and interfaces of a PDS of rated voltage above 1 000 V are as follows:

LV enclosure port	enclosure of auxiliaries, control and protection;
LV power ports	LV power supply of PDS;
LV power interfaces	auxiliary supply distribution within main components of PDS;
LV signal interfaces	LV signal interfaces within main components of PDS;
LV process port	signal port of the PDS.

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Table 14 – Minimum immunity requirements for PDSs intended for use in the second environment

Port	Phenomenon	Basic standard for test method	Level	Performance (acceptance) criterion
Enclosure port	ESD (electrostatic discharge)	IEC 61000-4-2	4 kV CD or 8 kV AD if CD impossible	B
	Radio-frequency electromagnetic field, amplitude modulated	IEC 61000-4-3 see also 5.3.4	80 MHz to 1 000 MHz 10 V/m 80 % AM (1 kHz)	A
	Radio-frequency electromagnetic field, amplitude modulated	IEC 61000-4-3 see also 5.3.4	1,4 GHz to 2,0 GHz 3 V/m 80 % AM (1 kHz)	A
	Radio-frequency electromagnetic field, amplitude modulated	IEC 61000-4-3 see also 5.3.4	2,0 GHz to 2,7 GHz 1 V/m 80 % AM (1 kHz)	A
Power ports (except auxiliary DC power ports below 60 V)	Fast transient-burst	IEC 61000-4-4	2 kV/5 kHz [a]	B
	Surge [b] 1,2/50 µs, 8/20 µs	IEC 61000-4-5	1 kV [c] 2 kV [d]	B
	Conducted radio-frequency common mode [e]	IEC 61000-4-6 see also 5.3.4	0,15 MHz to 80 MHz 10 V 80 % AM (1 kHz)	A
Power Interfaces	Fast transient-burst [e]	IEC 61000-4-4	2 kV/5 kHz Capacitive clamp	B
Signal interfaces	Fast transient-burst [e]	IEC 61000-4-4	1 kV/5 kHz Capacitive clamp	B
	Conducted radio-frequency common mode [e]	IEC 61000-4-6 see also 5.3.4	0,15 MHz to 80 MHz 10 V 80 % AM (1 kHz)	A
Ports for process measurement control lines Auxiliary DC power ports below 60 V	Fast transient-burst [e]	IEC 61000-4-4	2 kV/5 kHz Capacitive clamp	B
	Surge [f] 1,2/50 µs, 8/20 µs	IEC 61000-4-5	1 kV [d,f]	B
	Conducted radio-frequency common mode [e]	IEC 61000-4-6 see also 5.3.4	0,15 MHz to 80 MHz 10 V 80 % AM (1 kHz)	A

CD: contact discharge AD: air discharge AM: amplitude modulation

[a] Power ports with current rating < 100 A: direct coupling using the coupling and decoupling network. Power ports with current rating ≥ 100 A: direct coupling or capacitive clamp without decoupling network. If the capacitive clamp is used, the test level shall be 4 kV/5 kHz. The chosen test method shall be stated in the test report.

[b] Applicable only to power ports with current consumption < 63 A during light load test conditions as specified in 5.1.3.

[c] Coupling line-to-line.

[d] Coupling line-to-earth.

[e] Applicable only to ports or interfaces with cables whose total length according to the manufacturer's functional specification may exceed 3 m.

[f] Applicable only to ports with cables whose total length according to the manufacturer's functional specification may exceed 30 m. In the case of a shielded cable, a direct coupling to the shield is applied. This immunity requirement does not apply to fieldbus or other signal interfaces where the use of surge protection devices is not practical for technical reasons. The test is not required where normal functioning cannot be achieved because of the impact of the coupling/decoupling network on the equipment under test (EUT).

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These phenomena are not relevant for application to the ports of rated insulation voltage above 1 000 V. For simplicity, such ports are named HV ports of PDSs of rated voltage above 1 000 V.

NOTE Examples of HV ports and interfaces of a PDS of rated voltage above 1 000 V are as follows:

HV enclosure port	enclosure of transformer, converter section and motor;
HV power port	primary side of transformer;
HV power interfaces	HV distribution within main components of PDS;
HV signal interfaces	HV signal interfaces within main components of PDS.

5.3.4 Immunity against electromagnetic fields

If the PDS is

– of rated voltage not more than 500 V,
– of rated current not more than 200 A,
– of total mass not more than 250 kg, and
– of height, width, and depth not more than 1,9 m,

the tests of IEC 61000-4-3 and IEC 61000-4-6 shall be performed (see 5.3.2 and 5.3.3).

If the PDS is larger or of higher rating than in the above paragraph, then the manufacturer shall choose either

– to perform the tests of IEC 61000-4-3 and IEC 61000-4-6 on the PDS, or
– to perform the tests of IEC 61000-4-3 and IEC 61000-4-6 on sensitive sub-components and state the chosen test method in the test report.

If the motor is too large to be put into service on a test site, the motor may be replaced by one of smaller size, provided this does not adversely affect the operation of the CDM/BDM.

5.4 Application of immunity requirements – Statistical aspect

When choosing the acceptance level for a specific test of a PDS, it shall be understood that the test result implies only a probability of performance. Depending on the acceptance criterion and the application of a PDS, this probability shall be considered in specifying the number of test pulses or duration of the test.

Immunity requirements in 5.3 shall be verified by performing a type-test on a representative unit. The manufacturer or supplier shall ensure the EMC performance of the product is maintained in production by using some form of quality control.

Measurement results obtained for a PDS while installed in its place of use (not on a test site) shall relate to that installation only.

6 Emission

6.1 General emission requirements

The measurements shall be made in the operating mode producing the largest emission in the frequency band, while being consistent with the normal application.

Table 15 summarises the requirements, according to the classification of the PDS (see 3.2).

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Table 15 – Summary of emission requirements

Category	Low-frequency Disturbance voltage (power port)	High-frequency Disturbance voltage (power port)	Radiated emissions (enclosure port and others)
Category C1	Product assessment Requirements: - 6.2.2, - 6.2.3.1 or 6.2.3.2 or 6.2.3.3, - 6.2.4, - 6.2.5 Recommendations on load conditions: - B.2.3.3 and B.3.2	Product assessment Conducted emission limits: - 6.4.1.1, Table 16	Product assessment Radiated emission limits: - 6.4.1.3, Table 17 Other emission requirements: - 6.4.1.2; - 6.4.1.4
Category C2	Product assessment Requirements: - 6.2.2, - 6.2.3.1 or 6.2.3.2 or 6.2.3.3, - 6.2.4, - 6.2.5 Recommendations on load conditions: - B.2.3.3 and B.3.2	Product assessment Conducted emission limits: - 6.4.1.1, Table 16 Warning in the instruction for use: - 6.4.1.1	Product assessment Radiated emission limits: - 6.4.1.3, Table 17 Other emission requirements: - 6.4.1.2; - 6.4.1.4 Warning in the instruction for use: - 6.4.1.3
Category C3	Product assessment Requirements: - 6.2.2, - 6.2.3.4, - 6.2.4, - 6.2.5 Recommendations on load conditions: - B.2.3.3 and general rules B.3.3 and B.4	Product assessment Conducted emission limits: - 6.4.2.2, Table 19 Warning in the instruction for use: - 6.4.2.1	Product assessment Radiated emission limits: - 6.4.2.4, Table 20 Other emission requirements: - 6.4.2.3 Warning in the instruction for use: - 6.4.2.1
Category C4	Engineering practice Requirements: - 6.2.2, - 6.2.3.4, - 6.2.4, - 6.2.5 Recommendations on load conditions: - B.2.3.3 and general rules B.3.3 and B.4	Engineering practice Either - apply the requirements of Category C3 above, or - 6.5	Engineering practice Either - apply requirements of Category C3 above, or - 6.5

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6.2 Basic low-frequency emission limits

6.2.1 Compliance method

Compliance can be verified by calculation, simulation or test. The chosen verification method shall be stated in the test report.

6.2.2 Commutation notches

Commutation notches are measured on the power ports using an oscilloscope (see B.1.1). They are produced by controlled line-commutated converters.

Where it is known that the input circuit of the PDS does not produce notches or only produces notches of negligible amplitude (for example diode rectifiers), emission of notches need not be considered.

The main practical case where emission of notches should be considered is the case of thyristor converters (line commutated). RFI filters are practical cases of equipment which can be affected by notches. They can be overloaded or subjected to repetitive overvoltages.

NOTE A diode rectifier is an uncontrolled line-commutated converter, which produces commutation notches of negligible amplitude. Some self-commutated converters (for example an indirect converter of the voltage source inverter type with an active front end) can produce commutation notches depending on the PWM pattern.

Where notches are to be considered, the manufacturer shall provide the following information to the user:

- value of any decoupling reactances which are included in the PDS;
- available decoupling reactances which can be externally added for mitigation (see B.1.2).

The recommendations of B.1.3 should be followed.

6.2.3 Harmonics and interharmonics

6.2.3.1 Low-voltage public supply network – Equipment covered by IEC 61000-3-2

Equipment may contain one or several PDSs and also other loads.

When a PDS is within the scope of IEC 61000-3-2, the requirements of that standard apply. However, when one or more PDSs are included in equipment within the scope of IEC 61000-3-2, the requirements of that standard apply to the complete equipment and not to the individual PDS. It is the responsibility of the equipment manufacturer to define the boundary of the system or sub-system to which IEC 61000-3-2 applies, and the method which demonstrates compliance of the equipment.

6.2.3.2 Low-voltage public supply network – Equipment covered by IEC 61000-3-12

When a PDS is within the scope of IEC 61000-3-12, the requirements of that standard apply. However, when one or more PDSs are included in equipment within the scope of IEC 61000-3-12, the requirements of that standard apply to the complete equipment and not to the individual PDS. It is the responsibility of the equipment manufacturer to define the boundary of the system or sub-system to which IEC 61000-3-12 applies, and the method which demonstrates compliance of the equipment.

6.2.3.3 Low-voltage public supply network – Equipment not covered by IEC 61000-3-2 or IEC 61000-3-12

For equipment not covered by IEC 61000-3-2 or IEC 61000-3-12 (rated current above 75 A), recommendations may be found in Clause B.4.

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The manufacturer shall provide in the documentation of the PDS, or on request, the ratio of the current harmonic level *THC*, under rated load conditions, to the RMS current on the power port, as well as the harmonic currents up to the 40th harmonic. This may be produced by calculation, simulation or test.

For the purpose of calculation or simulation, the applied voltage shall be assumed to have a *THD* less than 1 %. The internal impedance of the network shall be assumed to be purely inductive. If the specific location of the PDS is not known, the harmonic currents shall be calculated assuming that the PDS is connected to a PC with the highest value of R_{SI} permitted by the PDS manufacturer.

$$R_{SI} = \frac{I_{SC}}{I_{LN}}$$

where

I_{SC} is the short circuit current at the considered PC;

I_{LN} is the rated input current of the PDS.

If the manufacturer does not state a maximum value of R_{SI}, a value of 250 shall be assumed. If the specific location of the PDS is known, the supply impedance at that location shall be used.

A guide for calculation of harmonics is given in Clause A.1 and Clause A.2 of IEC TR 61000-2-6:1995. Guidelines for the summation of harmonics of different sources are also given in 7.4 of IEC TR 61000-2-6:1995.

Effects of interharmonics are considered in B.4.3. Methods for calculation are given in Annex C of IEC TR 61000-2-6:1995.

6.2.3.4 Industrial networks

If a PDS is to be used in an installation which is not directly supplied from a public low voltage network, IEC 61000-3-2 and IEC 61000-3-12 are not applicable. Therefore, a reasonable approach which considers the total installation should be used (see Clause B.4).

NOTE For network voltages above 1 000 V, the total installation can be subject to rules from the utility, usually based on IEC TR 61000-3-6. These rules apply to the installation as a whole, not to individual equipment. These rules usually take the existing harmonic currents and voltage distortion within the system into account. An efficient and simplified approach is provided by Table B.2.

In the case of a PDS of rated voltage above 1 000 V, harmonic emissions from the main power port and the auxiliary power ports shall be considered separately.

6.2.4 Voltage fluctuations

6.2.4.1 Conditions

Equipment may contain one or several PDSs and also other loads which are capable of causing voltage fluctuations.

NOTE 1 Voltage fluctuations can be caused, for instance, by frequently changing the load of a PDS, or by sub-harmonics of slip energy recovery of asynchronous motors. Voltage fluctuations can also be caused by interharmonics at frequencies slightly different from the fundamental or from predominant harmonics. The emission is typically generated by cyclo-converters or current source inverters. See B.4.3 and B.6.2. Interharmonics are covered by compatibility levels given in IEC 61000-2-4 or in IEC 61000-2-12.

NOTE 2 Voltage fluctuations are dependent on the impedance of the installation and the duty cycle of the load. In some applications, the user can reduce voltage fluctuations by adjusting the load duty cycle by changing speed ramp rate or using other techniques.

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Most voltage fluctuations depend upon the installation. Therefore, this system aspect should be the responsibility of the user or of the installer. The compatibility levels given in IEC 61000-2-4 for voltage changes should not be exceeded considering cumulative effects from all equipment.

6.2.4.2 PDS in the scope of IEC 61000-3-3 and IEC 61000-3-11

When a PDS is within the scope of IEC 61000-3-3, the requirements of that standard apply. However, when one or more PDSs are included in equipment within the scope of IEC 61000-3-3, the requirements of that standard apply to the complete equipment and not to the individual PDS.

When a PDS is within the scope of IEC 61000-3-11, the requirements of that standard apply. However, when one or more PDSs are included in equipment within the scope of IEC 61000-3-11, the requirements of that standard apply to the complete equipment and not to the individual PDS.

NOTE Application of the voltage fluctuation limits of IEC 61000-3-3 and 61000-3-11 is only possible when the characteristics of the load provided by the driven equipment are known. For that reason, only the machine builder and/or end user are capable of characterizing compliance with regard to the voltage fluctuation limits.

6.2.4.3 PDS not in the scope of IEC 61000-3-3 and IEC 61000-3-11

For equipment not in the scope of IEC 61000-3-3 and IEC 61000-3-11, emissions of voltage fluctuations are generally dependent on the loading conditions and this document cannot give requirements.

NOTE Local rules given by local authorities can apply to the complete installation.

6.2.5 Emissions in the frequency range from 2 kHz to 9 kHz

In the frequency range from 2 kHz to 9 kHz, limits are not specified.

NOTE 1 IEC SC 77A is working on compatibility levels in this frequency range.

NOTE 2 Until limits are specified in this frequency range, design recommendations for emission values for PDS and CDM can be found in IEC TS 62578:2015, Annex B.

6.2.6 Common mode harmonic emission (low-frequency common mode voltage)

The switching frequency of the converter of the PDS is often in the audible frequency range and, in particular, the frequency range commonly used by telephone and data systems. To avoid the risk of crosstalk to signal cables, the installation instructions shall either recommend that the power interface cable be segregated from signal cables or state alternative mitigation methods.

6.3 Conditions related to high-frequency emission measurement

6.3.1 General requirements

6.3.1.1 Common conditions

The rate of change of voltage or current is expected to be the main source of high-frequency emission. For this type of disturbance, the highest values of the dv/dt are mostly relevant, which usually occurs with output currents lower than the rated current of the PDS. Therefore, these tests are light load tests. The tests shall be applied to the relevant ports where they exist and shall be performed in a well-defined and reproducible manner on a port-by-port basis.

The test method shall comply with 7.3 to 7.4 and Clause 8 of CISPR 11:2015/AMD1:2016. The requirements for configuration of test setup for the PDS considering cables arrangement are derived from 7.5 of CISPR 11:2015/AMD1:2016, paying particular attention to earth

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connections. An example for a typical PDS test set up and cable arrangement for measurements of radiated disturbances in 3 m separation distance is described in 6.3.1.3 below. The load and cable lengths shall be within the manufacturer's specification and the actual load and power interface cable length shall be noted in the test report.

It shall be stated in the test report whether the tests have been performed on a test site or as *in situ* tests.

6.3.1.2 Conducted emissions

The measurement equipment for evaluation of high-frequency mains terminal (power port) disturbance voltage emission is either the artificial mains network (50 Ω/50 µH, see CISPR 16-1-2 and CISPR 11) where it can be applied, or the high impedance voltage probe according to 5.2.1 of CISPR 16-1-2:2014, where the artificial mains network is not applicable. The chosen test method shall be stated in the test report. Common-mode absorption devices (CMAD) shall not be used as part of the test setup for conducted emission measurement.

NOTE A CMAD is a piece of test equipment placed on certain cables during radiated emission measurements to improve reproducibility (see 6.3.1.3.4).

For *in situ* measurement of the mains disturbance voltage, a high impedance voltage probe without an artificial mains network shall be used (see 7.3.3 of CISPR 11:2015). The same can be applied if the PDS has an input current greater than 100 A, or if the input voltage is greater than or equal to 500 V, or if the PDS contains a line commutated converter (see A.4.1.2).

6.3.1.3 Radiated emissions

6.3.1.3.1 Type of test site

Equipment of category C1 and category C2 shall be measured on a test site compliant with requirements of CISPR 16-1-4. The measurement distance shall be stated in the test report.

Equipment of category C3 should preferably be tested on a test site compliant with requirements of CISPR 16-1-4. However, when this proves to be impossible for practical reasons of weight, size or power, tests may be done in a location not fully compliant with the test site requirements. The use of this location shall be justified in the test report.

In the case of radiated emission tests on a test site, CISPR 11 allows test sites that are either an open-area test site (OATS) or a semi-anechoic chamber (SAC).

NOTE For radiated emissions measurement in a fully-anechoic room (FAR) test conditions and requirement are under consideration in CISPR/B. It is intended that they will be made available in CISPR 11.

6.3.1.3.2 Test volume

The measurement distance is considered between the reference point (RP) of the antenna calibration and the boundary of the EUT's test volume (see Figure 5 to Figure 7).

The selection of measurement distances shall comply with the requirements of 6.2.2.3 and 8.3.4 of CISPR 11:2015.

The boundary of the EUT's test volume is the imaginary cylinder around the complete configuration of the EUT. This boundary is shown as item H in Figure 5 and Figure 6. The motor and all the cables shall be inside the imaginary cylinder unless the cables leave the cylinder through CMAD(s). The height of the imaginary cylinder is measured from the floor, regardless of whether the EUT is table-top, wall-mounted equipment or standing on the floor.

The EUT is considered as small size equipment if the boundary of the EUT's test volume complies with the definition of 3.1.5. The maximum boundary for small size equipment is

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shown as item K in Figure 5 to Figure 7. The dimensions of the test volume should be measured with a tolerance of ±0,1 m.

The use of CMADs is recommended, as they contribute to reproducible test results. However, the use of CMADs is not mandatory. They serve to define the common mode impedance and resonances in the frequency range above 30 MHz, thus improving reproducibility.

6.3.1.3.3 Selection of measurement distance

Subclauses 6.4.1.3 and 6.4.2.4 give emission limits for tests at 10 m and 3 m distance.

Small size equipment meeting the size criterion defined in 3.1.5 may be tested at either 10 m or 3 m. Equipment not meeting this size criterion shall be tested at 10 m.

Special requirements relating to the test setup are specified in 6.3.1.3.4 to 6.3.1.3.6 for better reproducibility of measurement at 3 m. In cases where these requirements are practical for measurement at 10 m distance, they will also improve reproducibility at that distance.

6.3.1.3.4 Auxiliaries and peripherals

When auxiliaries or peripheral equipment are not part of the EUT (see EUT 2 in Figure 5 and Figure 6) they may be placed outside the test volume. However, if they cannot be excluded from the maximum test volume because the interconnecting cables are too short or for other reasons, these auxiliaries or peripheral equipment are put on the positioning table or on the insulated plane.

Restriction of radiation assessment to the cable fractions inside the test volume can be achieved for example by application at the cables of common-mode absorption devices (CMAD) at the position where they leave the test volume. CISPR 16-2-3 gives further guidance on the application of CMAD(s).

6.3.1.3.5 Motor

For radiated emission, light load condition is usually acceptable for the PDS operation (see A.2.1 for information on load conditions).

The power rating of the motor used during the radiated emission test may be lower than the power rating of the CDM, but shall be large enough to allow correct operation of the inverter part of the CDM.

The motor can be put inside or outside the test volume. The power interface cable between the CDM/BDM and the motor shall be exposed to the antenna with at least 0,8 m length inside the test volume, unless the maximum cable length stated in the information for the user is shorter.

The position of the motor and the cable arrangement shall be stated in the test report.

6.3.1.3.6 Layout of setup for radiated emission tests

Examples of typical layouts for radiated emission tests are given in Figure 5 to Figure 7 below.

If a special earthing conductor is used (see "C" in Figure 7), its length shall be at least 1 m, and it shall be connected as shown in the user documentation.

NOTE 1 An example of a special earthing conductor is a second protective earthing conductor, which could be used for compliance with 4.3.5.5.2 of IEC 61800-5-1:2007.

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If the motor is placed far from the turntable, the motor cable can be passed through the floor of the turntable (see dotted line path "A" in Figure 7). If the motor is placed beside the turntable (see "F" in Figure 7) and prevents the turntable from moving, special care should be considered for performing radiated emission measurement as for *in situ* condition (see A.4.2).

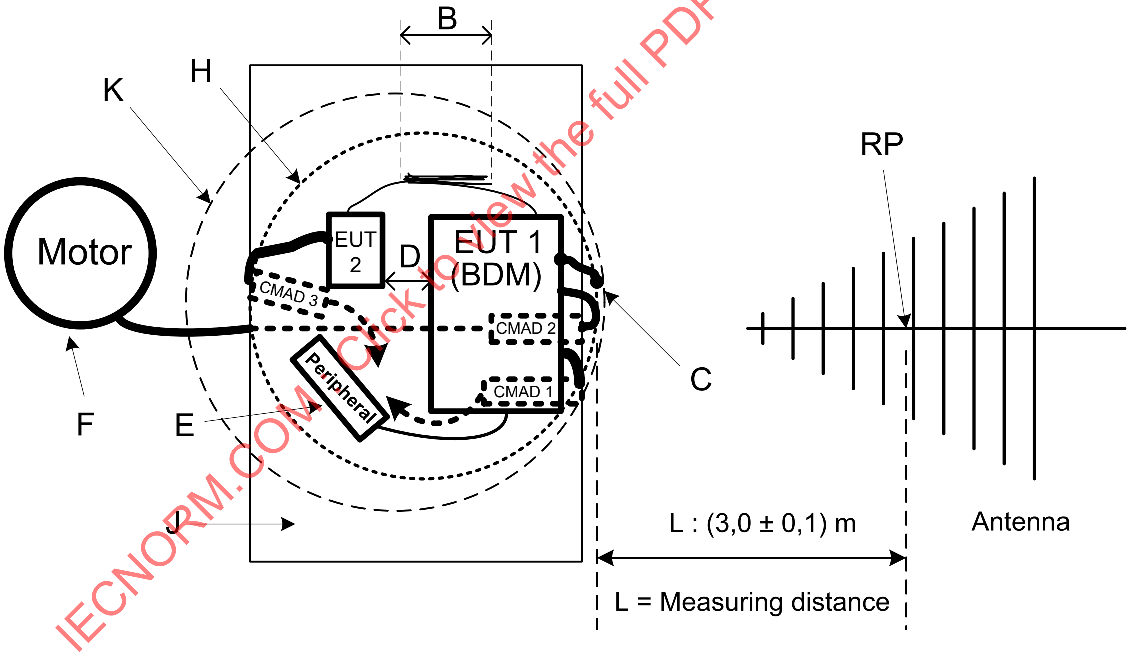
The use of an AMN in radiated emission tests is recommended but not mandatory.

Auxiliaries and peripheral equipment that are not part of the EUT should be located outside the test volume. However, if the connecting cables between them and the EUT cannot be extended to run outside the test volume, these auxiliaries and peripherals can be placed inside the test volume (see Figure 5 and Figure 6) or on the turntable (see Figure 7).

The spacing between all enclosures (EUT, peripheral etc.) should be ≥ 0,1 m. This is shown by item "D" in Figure 5 to Figure 7.

Where an interconnecting cable has an excess length, item "B" in Figure 5 and Figure 7 shows a cable bundle, as required by 7.5.2 of CISPR 11:2015. The excess cable is bundled between 0,3 m and 0,4 m in the middle of the cable length.

NOTE 2 The reference point of the antenna calibration is considered for the measuring distance as shown by item "RP" in Figure 5 to Figure 7.



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Key

B Excess cable is in a bundle of between 0,3 m and 0,4 m in the middle of the cable length.

C Special earthing connection, only if specified in the user documentation.

D Spacing between enclosures should be ≥ 0,1 m.

E The peripheral or auxiliary device is in the test volume only if the cables cannot be extended to allow the peripheral to be outside the test volume.

F Motor

H Test volume. This is the boundary of the imaginary cylinder around the complete configuration of the EUT (BDM/CDM parts of the PDS).

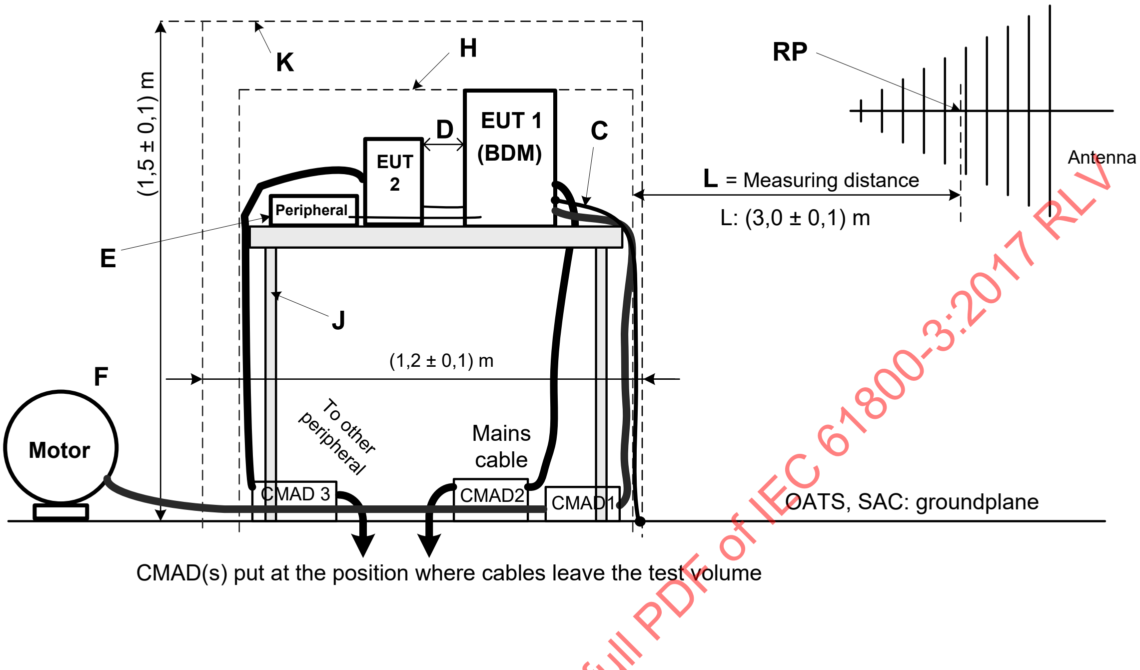
J Positioning table of insulating material, with height 0,8 m ± 0,01 m above the ground plane.

K Boundary of maximum test volume for small size equipment as defined in 3.1.5.

L Measuring distance. This distance is measured between the test volume, H, and the reference point of the antenna calibration, RP.

RP Reference point of the antenna calibration

Figure 5 – Example for a typical cable arrangement for measurements in 3 m separation distance, for a table-top or wall-mounted equipment, top view



Key

C Special earthing connection, only if specified in the user documentation.

D Spacing between enclosures should be ≥ 0,1 m.

E The peripheral or auxiliary device is in the test volume only if the cables cannot be extended to allow the peripheral to be outside the test volume.

F Motor

H Test volume. This is the boundary of the imaginary cylinder around the complete configuration of the EUT (BDM/CDM parts of the PDS).

J Positioning table of insulating material, with height 0,8 m ± 0,01 m above the ground plane.

K Boundary of maximum test volume for small size equipment as defined in 3.1.5.

L Measuring distance. This distance is measured between the test volume, H, and the reference point of the antenna calibration, RP.

RP Reference point of the antenna calibration

Figure 6 – Example for a typical cable arrangement for measurements in 3 m separation distance for a table-top or wall-mounted equipment, side view

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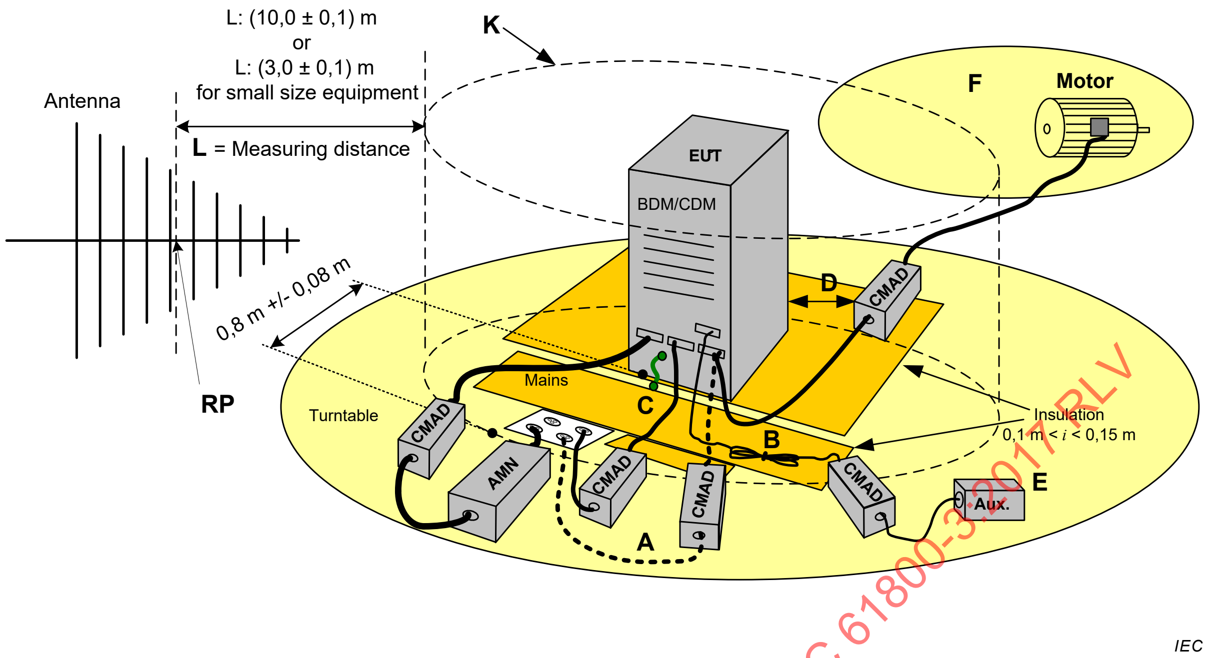

Key

A The dotted line shows the route of the motor cable when the motor is placed far from the turntable.

B Excess cable is in a bundle of between 0,3 m and 0,4 m in the middle of the cable length.

C Special earthing connection, only if specified in the user documentation.

D Spacing between enclosures should be ≥ 0,1 m.

E The peripheral or auxiliary device is in the test volume only if the cables cannot be extended to allow the peripheral to be outside the test volume.

F Motor

K Boundary of maximum test volume for small size equipment as defined in 3.1.5.

L Measuring distance. This distance is measured between the test volume and the reference point of the antenna calibration, RP.

RP Reference point of the antenna calibration

Figure 7 – Example for a typical test set up for measurement of conducted and/or radiated disturbances from a floor-standing PDS, 3D view

6.3.2 Connection requirements

If the PDS is measured on a test site, the test set up, including length and position of power and control cables, shall be representative of intended application(s), as defined by the manufacturer and described in the user documentation (see 4.3). The test set-up shall be stated in the test report.

If the PDS is measured *in situ*, the cable and the earthing arrangements are those of that application.

6.4 Basic high-frequency emission limits

6.4.1 Equipment of categories C1 and C2

6.4.1.1 Power port disturbance voltage

Limits for mains terminal disturbance voltage (power ports) are given in Table 16.

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Table 16 – Limits for mains terminal disturbance voltage in the frequency band 150 kHz to 30 MHz

	Category C1		Category C2	
Frequency band MHz	**Quasi peak** dB(μV)	**Average** dB(μV)	**Quasi peak** dB(μV)	**Average** dB(μV)
$0,15 \leq f < 0,50$	66 Decreases with log of frequency down to 56	56 Decreases with log of frequency down to 46	79	66
$0,5 \leq f \leq 5,0$	56	46	73	60
$5,0 < f < 30,0$	60	50	73	60

Where a PDS does not comply with the limits of category C1, the following warning shall be included in the instruction for use:

Warning

In a residential environment, this product may cause radio interference in which case supplementary mitigation measures may be required.

NOTE High-frequency common mode filtering introduces capacitive coupling paths to earth. In the case of a supply system in which the neutral is isolated from earth or connected to earth through a high impedance ("IT system" as defined in 312.2.3 of IEC 60364-1:2005), these capacitive coupling paths can be harmful (see D.2.2).

In the frequency range from 9 kHz to 150 kHz, limits are not specified.

NOTE 1 IEC SC 77A is working on compatibility levels in this frequency range.

NOTE 2 Until limits are specified in this frequency range, design recommendations for emission values for PDS and CDM can be found in IEC TS 62578:2015, Annex B.

6.4.1.2 Process measurement and control ports

If a process measurement and control port is intended for connection to a fieldbus, then the port shall comply with the conducted emission requirements of the relevant standard for that fieldbus.

If a process measurement and control port is intended for connection to a public telecommunication network, then this port shall be regarded as a telecommunication port. The conducted emission requirements of CISPR 32, class B apply to that port.

6.4.1.3 Radiation – Enclosure port

Limits for electromagnetic radiation disturbance (enclosure port, see definition in 3.3.4 and Figure 2) are given in Table 17.

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Table 17 – Limits for electromagnetic radiation disturbance in the frequency band 30 MHz to 1 000 MHz

	Electric field strength component Quasi-peak dB(μV/m)			
	Measurement distance 10 m [a]		Measurement distance 3 m [a]	
Frequency band MHz	**Category C1**	**Category C2**	**Category C1**	**Category C2**
30 ≤ f ≤ 230	30	40	40	50
230 < f ≤ 1 000	37	47	47	57

[a] For selection of measurement distance, see 6.3.1.3.3.

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The measurement distance shall be stated in the test report.

Where a PDS does not comply with the limits of category C1, the following warning shall be included in the instructions for use:

> **Warning**
>
> In a residential environment, this product may cause radio interference, in which case supplementary mitigation measures may be required.

6.4.1.4 Power interface emission

For a PDS to be operated in the first environment, the limitation of emission shall be provided by means of one of the following options.

a) Measurements on the power interface need not be performed if the length of the corresponding cable is less than 2 m, or if a shielded cable is used. The shielding shall then be of high frequency quality, continuous throughout its length and at least connected to the CDM and motor via 360° terminations.

b) The emission shall be checked by measuring the disturbance voltage at the power interface in the BDM, using the high impedance voltage probe described in 5.2.1 of CISPR 16-1-2:2014. The limits given in Table 18 below shall be applied.

c) Where mitigation methods applied are not suitable for checking according to item b) (for example common mode mitigation methods), the effectiveness of the mitigation method shall be checked by establishing a coupling between the mains input cable and the motor cable during the measurement of the mains terminal disturbance voltage according to 6.4.1.1. This coupling shall be established over the 1 m distance separating the EUT and the AMN by running the motor cable parallel to the mains cable with a separation not exceeding 10 cm over a length of at least 0,60 m.

Table 18 – Limits of disturbance voltage on the power interface

Frequency band MHz	Measurement at rated output current	
	Quasi peak dB(μV)	**Average** dB(μV)
0,15 ≤ f < 0,5	80	70
0,50 ≤ f < 30	74	64

NOTE The above limits are derived from CISPR 14-1.

6.4.2 Equipment of category C3

6.4.2.1 Information requirement

If a PDS does not meet the limits of category C1 or C2, a warning shall be included in the instructions for use stating that

- this type of PDS is not intended to be used on a low-voltage public network which supplies residential premises, and
- radio frequency interference is expected if used on such a network.

The manufacturer shall provide a guide for installation and use, including recommended mitigation devices.

6.4.2.2 Power port disturbance voltage

Limits for mains terminal disturbance voltage (power ports) of PDSs are given in Table 19. The same limits apply to low voltage power ports of PDSs of rated voltage above 1 000 V.

Table 19 – Limits for mains terminal disturbance voltage in the frequency band 150 kHz to 30 MHz for a PDS in the second environment – PDS of category C3

Size of PDS [a]	**Frequency band** MHz	**Quasi peak** dB(μV)	**Average** dB(μV)
$I \leq 100$ A	$0,15 \leq f < 0,50$	100	90
	$0,5 \leq f \leq 5,0$	86	76
	$5,0 < f < 30,0$	90 Decreases with log of frequency down to 73	80 Decreases with log of frequency down to 60
100 A $< I$	$0,15 \leq f < 0,50$	130	120
	$0,5 \leq f < 5,0$	125	115
	$5,0 \leq f < 30,0$	115	105
These limits do not apply to power ports operating above 1 000 V.			
[a] Size of the PDS refers to rated current (I) of the port.			

See also Clause D.2.

For PDS above 100 A without dedicated transformer, to avoid the risk of crosstalk to signal cables, the installation instructions shall either recommend that the power cables be segregated from signal cables or state alternative mitigation methods.

In the frequency range from 9 kHz to 150 kHz, limits are not specified.

NOTE 1 IEC SC 77A is working on compatibility levels in this frequency range.

NOTE 2 Until limits are specified in this frequency range, design recommendations for emission values for PDS and CDM can be found in IEC TS 62578:2015, Annex B.

6.4.2.3 Process measurement and control ports

If a process measurement and control port is intended for connection to a fieldbus, then the port shall comply with the conducted emission requirements of the relevant standard for that fieldbus.

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If a process measurement and control port is intended for connection to a public telecommunication network, then this port shall be regarded as a telecommunication port. The conducted emission requirements of CISPR 22, class A, apply to that port.

6.4.2.4 Radiation – Enclosure port

Limits for electromagnetic radiation disturbance (enclosure port, see definition in 3.3.4 and Figure 2) of PDSs are given in Table 20.

Table 20 – Limits for electromagnetic radiation disturbance in the frequency band 30 MHz to 1 000 MHz for a PDS in the second environment – PDS of category C3

	Electric field strength component Quasi-peak dB(µV/m)	
Frequency band MHz	**Measurement distance 10 m** [a]	**Measurement distance 3 m** [a]
$30 \leq f \leq 230$	50	60
$230 < f \leq 1\,000$	60	70

NOTE In the next edition of IEC 61800-3, it will be the target to align the values in this table with CISPR 11.

[a] For selection of measurement distance, see 6.3.1.3.3.

The measurement distance shall be stated in the test report.

6.4.2.5 Power interface

For a PDS to be operated in the second environment, the instructions for installation and use shall contain all the necessary information on the installation of the power interface as required in 4.3.

6.5 Engineering practice

6.5.1 PDS of category C4

For PDSs of category C4, the following procedure shall be used.

General conditions

Due to technical reasons, there are some applications where it is not possible for the PDS to comply with the limits of Table 19 and Table 20. These applications are for large ratings or to meet specific technical requirements:

- voltage above 1 000 V;
- current above 400 A;
- networks isolated from earth, or connected to earth through a high impedance ("IT power supply system" according to 312.2.3 of IEC 60364-1:2005);
- where required dynamic performances will be limited as a result of filtering.

In these applications of category C4 equipment, the user and the manufacturer shall agree on an EMC plan to meet the EMC requirements of the intended application (see Annex E). In this situation, the user defines the EMC characteristics of the environment including the whole installation and the neighbourhood (see Figure 8). The manufacturer shall provide information on typical emission levels of the PDS which is to be installed. In the case of interference, the requirements and the procedure in 6.5.2 shall be applied.

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NOTE Examples of common mitigation methods resulting from the EMC plan are: global filtering, dedicated special transformer, separation of cables.

Filtering in IT power supply systems

The use of filtered PDSs in an isolated, or high-impedance earthed, industrial distribution network can cause a safety risk, if not properly designed for these applications. In the case of IT networks for complex industrial systems, limits cannot be set. The diversity of solutions resulting from the knowledge of the system cannot be standardised. The main considerations are related to fault conditions and filter leakage current.

a) Short circuit on the motor side of the PDS. If the PDS is allowed to continue to run in this condition, high levels of high frequency current will flow in the filtering capacitors. This can damage the filter capacitors. Short circuit to earth on the motor side can cause the application of common mode voltage to other neighbouring equipment.
b) Undesired fail detection by the insulation monitoring device (IMD) according to IEC 61557-8 because of increased capacitance to earth, which can lead to an undesired process shut down.

The solutions are based on a case by case analysis.

6.5.2 Limits outside the boundary of an installation, for a PDS of category C4 – Example of propagation of disturbances

6.5.2.1 General

For PDSs in the second environment, the user shall ensure that excessive disturbances are not induced into neighbouring low-voltage networks, even if propagation is through a medium-voltage network.

In the case of complaints about interference occurring at a neighbouring low-voltage network, or in the case of a dispute between the user of a PDS (for example within installation 2 – see Figure 8), and a victim on another network (for example within installation 1), it shall first be clearly established that the disturbance of victim equipment (in installation 1) occurs when the supposed emitting PDS (installation 2) is operated.

6.5.2.2 Interference due to conduction

In this case, the measurements shall be carried out at the low-voltage secondary of the medium-voltage transformer of the installation (installation 1) where the victim is situated (see Figure 8 for point of measurement). The requirements given by Table 21 or Table 22 and Table 23 including the reservations concerning ambient noise, shall be fulfilled.

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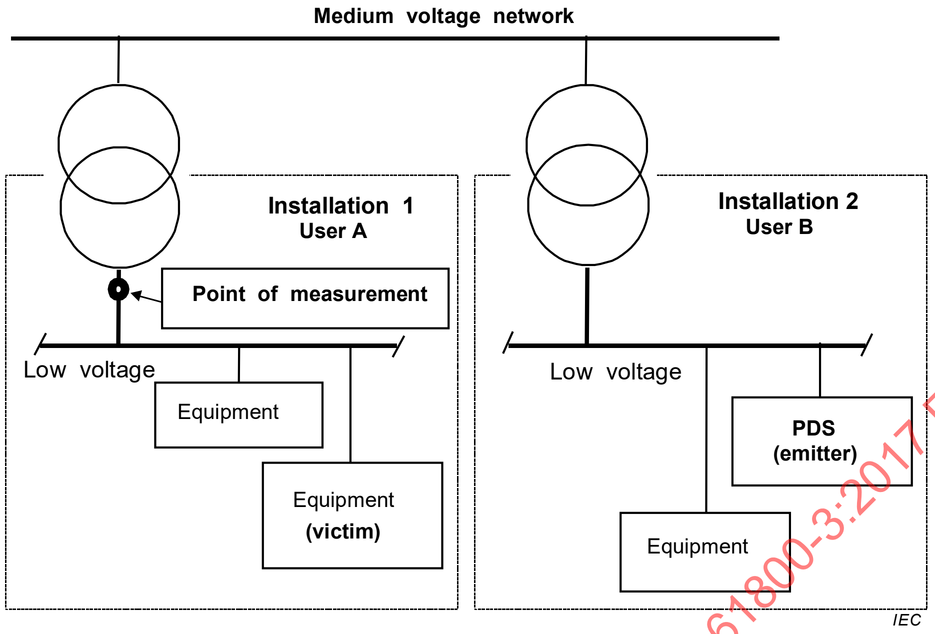

Figure 8 – Propagation of disturbances

This method can be applied to different parts of the same installation in the case of PDS of rated voltage above 1 000 V with limits reported in the EMC plan. In this case, in-situ measurement of propagated disturbance voltage should be carried out at the low-voltage secondary of the high-voltage transformer (part 1 of the installation) which is electrically the closest to the PDS considered as emitter (see Figure 9 for point of measurement).

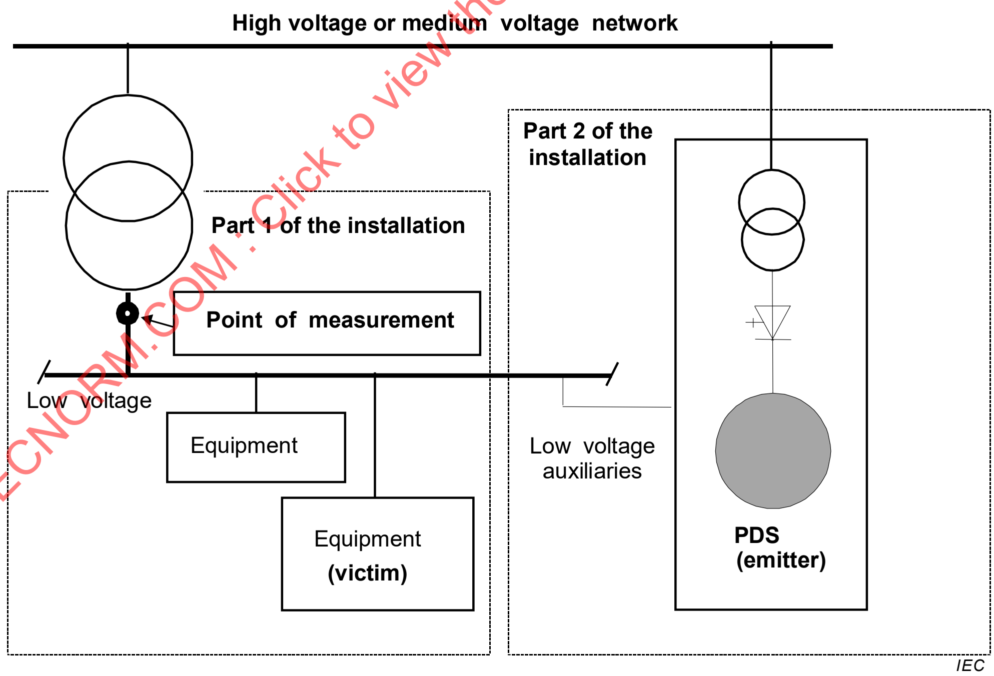

Figure 9 – Propagation of disturbances in installation with a PDS rated > 1 000 V

If installation 1 in Figure 8 belongs to the first environment, the disturbance voltage shall comply with the limits of Table 21.

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Table 21 – Limits for propagated disturbance voltage ("outside" in the first environment)

Frequency band MHz	**Quasi peak** dB(μV)	**Average** dB(μV)
0,15 ≤ f < 0,50	66 Decreases with log. of frequency down to 56	56 Decreases with log. of frequency down to 46
0,5 ≤ f ≤ 5,0	56	46
5,0 < f < 30,0	60	50

If installation 1 in Figure 8 or part 1 of the installation in Figure 9 belongs to the second environment, the disturbance voltage shall comply with the limits of Table 22.

Table 22 – Limits for propagated disturbance voltage ("outside" in the second environment)

Frequency band MHz	**Quasi peak** dB(μV)	**Average** dB(μV)
0,15 ≤ f < 0,50	79	66
0,5 ≤ f ≤ 5,0	73	60
5,0 < f < 30,0	73	60

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If the ambient noise (without operation of the PDS which is the supposed emitter) exceeds the limits (Table 21 and Table 22), the supposed emitting PDS is only considered to fail if a characteristic set of emitted frequencies can be recognised and exceeds the measured ambient noise.

6.5.2.3 Interference due to radiation

6.5.2.3.1 Radiation above 30 MHz

In case of interference, the radiation shall be measured at a distance of 10 m from the boundary of the installation, if interference occurs outside in the first environment or at a distance of 30 m from the boundary of the installation, if interference occurs outside in the second environment. The measured field strength shall comply with Table 23.

Table 23 – Limits for propagated electromagnetic disturbance above 30 MHz

Frequency band MHz	**Electric field strength component Quasi peak** dB(μV/m)
30 ≤ f ≤ 230	30
230 < f ≤ 1 000	37

If the ambient noise (without operation of the PDS which is the supposed emitter) exceeds the limits (Table 23), the supposed emitting PDS is only considered to fail if a characteristic set of emitted frequencies can be recognised and exceeds the measured ambient noise.

The emissions from the PDS shall be suppressed until they are below the limits, or below the ambient noise, whichever is the higher.

See also A.4.3.

6.5.2.3.2 Radiation between 0,150 MHz and 30 MHz

In case of interference, the radiation shall be measured at a distance of 10 m from the boundary of the installation if interference occurs in the first environment, or at a distance of 30 m from the boundary of the installation if interference occurs in the second environment.

A magnetic loop antenna according to CISPR 16-1-4 shall be used. The values shall not exceed those given in Table 24 at the frequencies for which interference occurs.

Table 24 – Limits for electromagnetic disturbance below 30 MHz

Frequency band MHz	**Magnetic field strength component** **Quasi peak** dB(μA/m)
$0,15 \le f < 0,49$	13,5
$0,49 \le f < 3,95$	3,5
$3,95 \le f < 20$	-11,5
$20 \le f \le 30$	-21,5

6.6 Application of emission requirements – Statistical aspects

6.6 applies only to PDSs of categories C1, C2 and C3.

Conformance of the PDSs of categories C1, C2 and C3 shall be verified by performing a type test on a representative model. For simplicity, this type test may be made on one appliance only. The manufacturer or supplier shall ensure by means of his quality system that the EMC performance of the product is maintained.

As far as statistical aspects are concerned, Annex H of CISPR 11:2015 applies.

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Annex A
(informative)

EMC techniques

A.1 Application of PDSs and EMC

The range of application of PDSs is so large that any attempt to establish an exhaustive list will fail. However, the examples given here show PDSs used in a range of very different environments. Because the definition of EMC is more dependent on the environment than on the product itself, any code of practice should consider this fact. For example, the limitation of emission in buildings used for residential purpose should be quite different from that used for rolling mills in an industrial plant.

Examples of application of PDSs are listed here:

- machine tools, robots, test equipment in production, test benches;
- paper machines, textile production machine, calenders in rubber industry;
- process lines in plastic industries or in metal industries, rolling mills;
- cement crushing machines, cement kilns, mixers, centrifuges, extrusion machines;
- drilling machines;
- conveyors, material handling machines, hoisting equipment (cranes, gantries, etc.);
- propulsion of ships, etc.;
- pumps, fans, and so on.

These examples use PDSs covered by this document. However, electric vehicles and particularly traction drives are excluded from the scope of this document (see Clause 1).

A.2 Load conditions regarding high-frequency phenomena

A.2.1 Load conditions during emission tests

The load on the motor normally has little effect on the EMC characteristics of the PDS. Therefore, the PDS need not be tested for EMC characteristics at all load conditions, but only at a load that is representative of all operating emissions. The manufacturer should certify that the load conditions he has selected for the test meet this criterion.

The radiated and conducted emissions of a PDS are mainly caused by sharp transitions of its output voltage that are used to produce low-frequency, or DC output power. The voltage spectrum of the waveform can have sufficient energy at high frequencies for the PDS to radiate electrical energy from its input power wires, cabinet, motor leads, and motor case. Since the radiated energy is caused by the voltage transitions, tests should be performed at conditions where the voltage transitions have the largest amount of high-frequency content. Tests need not be performed at other conditions.

The sharpness of output transitions can be affected by the switching speed of the power device that is used in the PDS. IGBTs (transistors) are extremely fast devices that in combination with the recovery characteristics of the diodes used in some types of inverters can cause dv/dt that can be greater than 1 000 V/µs. It is important to note that the abruptness of the diode recovery is an important component of this high dv/dt. Even though the level of the recovery current is load dependent, the abruptness of the diode recovery is not as dependent on the load level. Note that attenuation measures should be rated to cover saturation effects of filter elements (for example saturation of interference suppression inductors).

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On the other hand, it is important to consider the effect of passive capacitive, resistive, or inductive power circuit components, such as snubber components that are used to control the rate of rise of this voltage. The output waveform with these devices present can have d*v*/d*t* characteristics that are load dependent. In this case, it is important that the PDS be tested at the worst case d*v*/d*t* point of operation.

A.2.2 Load conditions during immunity tests

The load on the motor normally has little effect on the EMC characteristics of the PDS. Therefore, the PDS need not be tested for EMC characteristics at all load conditions, but only at a load that is representative of all susceptibilities. The manufacturer should certify that the load conditions he has selected for the test meet this criterion.

Generally, load conditions do not affect the immunity of a PDS to low or high-frequency disturbances. The failures of the power and control circuitry are generally associated with voltage not current levels. Testing at light load does not detect slight changes in the settings of protective circuitry, i.e. over current, over voltage. If these levels are critical to the proper operation of a PDS, the test should verify the immunity at these points of operation.

If the torque-generating behaviour criterion is used, the load should be at such a level that it is possible to measure the torque disturbance associated with the low or high-frequency tests. This will require a motor and a torque-measuring device. The motor should have a load that can be used in the electromagnetic environment of the test. If indirect torque-measuring methods are used, the PDS should be operated at a load level which is sufficient for any torque disturbances to be measured.

A.2.3 Load test

A light load test, i.e. a test with the motor running at no load, can be used to verify the EMC characteristics of a PDS if the above conditions are met. Tests can even be performed using passive power resistors and inductors that simulate the load condition of a motor. It is also important to note that the motor case can act as an antenna element. If a passive load is used, this antenna effect should also be simulated.

The manufacturer of the PDS should provide certification that the load on the PDS during any test will produce the worst case or most sensitive conditions for his particular product. This certification can be by test of a representative product, or by calculation or simulation.

A.3 Immunity to power frequency magnetic fields

Testing according to IEC 61000-4-8 is usual where components sensitive to magnetic field are used. PDSs frequently use Hall-effect current sensors. However, these sensors are designed to operate in locations where high levels of magnetic fields exist (close vicinity of power conductors). Those amplitudes are much higher than the levels of the test according to IEC 61000-4-8. For example, it can be calculated that a 10 A current (assumed to be alone on an infinite straight line) produces a magnetic field of 320 A/m at 5 mm. It can therefore be considered that the disturbance applied by the test is negligible compared to the operating environment of this sensitive component.

A.4 High-frequency emission measurement techniques

A.4.1 Impedance/artificial mains network (AMN)

A.4.1.1 Circuit of AMN

Since the high-frequency disturbance source within a drive has a source impedance, the disturbance voltage measurement is affected by the network impedance. Particularly at lower frequencies, the impedance of the mains can be regarded as inductive. However, there can

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be resonances due to various capacitances of the system. For further information, see 6.6 of IEC TR 61000-2-3:1992.

Where possible, an AMN should be used to standardise the supply impedance used during type tests. This improves the repeatability between different test sites.

The characteristics of various networks are defined in Clause 4 of CISPR 16-1-2:2014. For the frequency range of disturbance voltage measurements defined in this document, the 50 Ω // 50 µH network or the 50 Ω // 50 µH + 5 Ω network can be used. Between 150 kHz and 30 MHz, the equipment under test (power drive system) sees an impedance to earth of 50 Ω in parallel with 50 µH, regardless of the impedance of the incoming mains supply.

A.4.1.2 PDS with which the AMN cannot be used

A.4.1.2.1 Reasons of impossibility

At lower frequencies, the inductors inside the 50 Ω // 50 µH AMN add 50 µH to the impedance of the mains supply. The inductors inside the 50 Ω // 50 µH + 5 Ω AMN add 300 µH. This additional impedance can prevent correct operation of some PDSs (for example, commutation notches become excessively wide at high current and low firing angle, if the supply inductance is too high). In these cases, the AMN cannot be used.

If an AMN is not commercially available, the methods in A.4.1.2.2 or A.4.1.2.3 can be applied. The method in A.4.1.2.3 is preferred. In cases where high current prevents the use of the standard AMN method, the following steps should be used to improve correlation:

1) measure with the standard AMN method at the maximum possible power level of the AMN;
2) measure with the alternative method according to A.4.1.2.2 or A.4.1.2.3 at the same power level;
3) note the difference in results between the two measurements;
4) measure with the alternative method according to A.4.1.2.2 or A.4.1.2.3 at the desired power level;
5) Correct the result from step 4) according to the difference noted in step 3).

A.4.1.2.2 High impedance voltage probe

When an AMN is not used, the disturbance voltage can be measured using a high impedance voltage probe, as described in 5.2.1 of CISPR 16-1-2:2014. Since the power frequency current does not pass through the probe, it can be used with PDSs of even the highest current ratings.

By adjusting the value and voltage rating of the capacitor, this probe can be used with supplies at least up to 1 000 V. If the capacitor value is reduced, its effect on the scaling of the measurement should be allowed for in calibration, as stated in CISPR 16-1-2.

The probe is connected between the line and the reference earth. If the CDM/BDM has an earthed metal frame, this can be taken as the reference earth. This connection should be to the supply leads as they enter the CDM/BDM. The connections to the probe should be as short as possible, preferably less than 0,5 m.

CISPR 16-1-2 provides a warning about the need to minimise the loop area formed between the lead connected to the probe, the conductor tested and the reference earth. This is to reduce susceptibility to magnetic fields.

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A.4.1.2.3 Alternative method for high current PDS

In some cases, it can be difficult to use the high impedance probe because of safety reasons during changing of phases, and the readings can be several tens of decibels higher (because of mismatched impedance) than those which are obtained with an AMN measurement.

An alternative method, which has been experienced in some countries for a number of years, uses a low current AMN (for example 25 A) as a voltage probe, even with a high current PDS (above several hundreds of amperes). This method is described in Clause A.5 of CISPR 16-2-1:2014). The PDS is not disconnected from its supply network.

The load side of the AMN should be connected to the supply lines of the PDS at the power port terminals by a 1 m cable. There should be some inductance (for example connection cabling) between the PC and the AMN connection. The mains side of the AMN should be left open (for example no connection to peripherals). The receiver should be connected to the AMN as usual. The measurement results, with this method, are quite similar to that of a virtual AMN of several hundreds of amperes.

A.4.2 Performing high-frequency in situ emission tests

When equipment cannot be tested on a test site, tests are performed in situ. In this case, extra care should be taken to avoid problems caused by ambient noise.

Testing in situ is not as repeatable as testing on a test site. Therefore, some care should be taken when using the results of in-situ testing on one site to predict compliance for a product produced in quantity.

For large equipment, the antenna may be moved around the equipment to determine the highest emission spot.

A.4.3 Established experience with high power PDSs

For several decades, the experience in different countries has shown that the established procedures of legislation and protection of radio-communication services against high-frequency disturbances have been proved in practice with excellent results. As an example, the procedure which has been used for many years is described below.

Under this procedure, because high power equipment intended for use in the second environment is part of an installation, it is not tested on a test site. See [4][1]. The same rules apply to equipment which is built by the user himself, under his own responsibility; see [5]. The emission limits of such a high power installation are referenced to the actual boundary of the installation terrain, even in the case of measurement and control equipment which is intended to be installed there. The emission limits have been applied with respect to the boundary of the installation (the measurement point for mains terminal disturbance voltage is the low-voltage secondary of the next available medium-voltage transformer, and for the radiated emissions a 30 m distance to the boundary); see [4] and [5].

As a result, the procedure stated in 6.5 follows this experience. Such a use of a PDS (category C4) requires EMC competence. Such competence should be applied to the design of the apparatus, or the manufacturer and the user should define the appropriate compatibility levels in a specific environment.

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1 The figures in square brackets refer to the bibliography.

Annex B
(informative)

Low-frequency phenomena

B.1 Commutation notches

B.1.1 Occurrence – description

Commutation notches (see IEC 60050-551:1998, 551-16-06) are caused by line-to-line short circuits which occur at the terminals of a thyristor converter. This occurs when current is commutated from one phase of the supply to the next. Voltage notches are deviations of the AC mains voltage from the instantaneous value of the fundamental. The magnitude of the commutation notch, seen elsewhere in the supply system, depends on the ratio of supply impedance and decoupling reactance in the thyristor converter.

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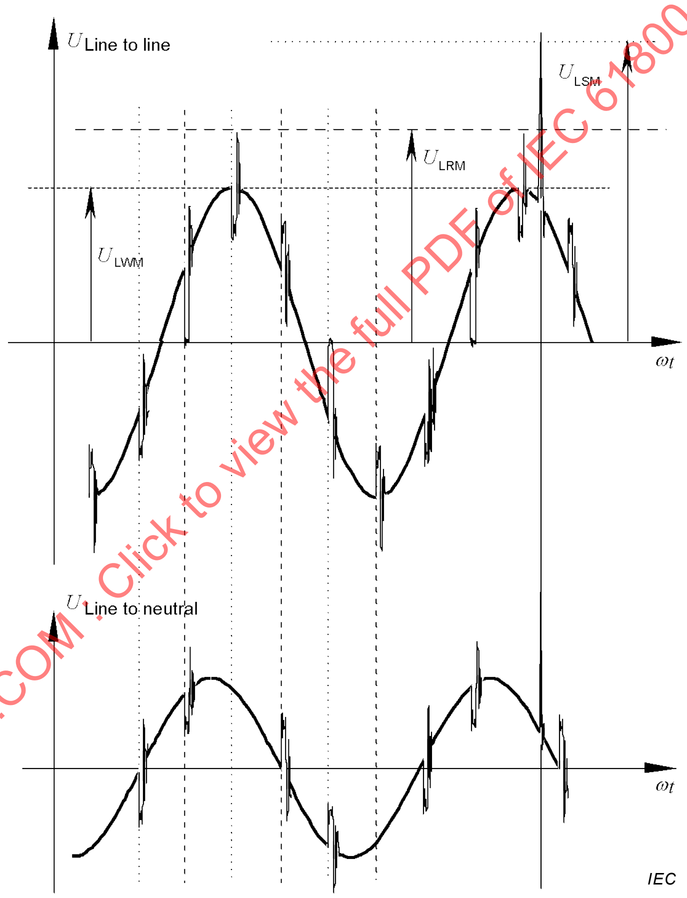

NOTE Typical range of per unit values are provided for reference only.

The figure assumes there is no impedance between PDS terminals and the converter.

Repetitive transients	(U_{LRM}/U_{LWM}) = 1,25 to 1,50; depending on the snubber design with respect to di/dt and I_{RR} (dynamic reverse current of the semiconductor).
Non-repetitive transients	(U_{LSM}/U_{LWM}) = 1,80 to 2,50 depending on additional protective devices.

Figure B.1 – Typical waveform of commutation notches – Distinction from non-repetitive transient

Analysis of notches considers a wider range of frequencies than normal harmonic analysis. Their time-domain characteristics cause effects which cannot be understood by a simple harmonic analysis. Therefore, they are analysed in the time domain using an oscilloscope.

The following should first be remembered:

- in simple cases where the rule applies, it is assumed that the network impedance can be modelled with a pure reactance: $Z = L\omega$ (this assumption is not valid in cases where capacitors or long cables are present; resonances can occur in such cases);
- the immunity against commutation notches is classified in 5.4.1 and Table 9 of IEC 60146-1-1:2009 where their measurement is defined in depth (in % of U_{LWM}) and in area (depth multiplied by width, in % degrees); IEC 60146-1-1 defines U_{LWM} as the maximum instantaneous value of U_L excluding transients (therefore this is the amplitude), where U_L is the line-to-line voltage on the line side of the converter or transformer, if any.

If the converter does not include any inductance, the depth d of the principal notch in the line-to-line voltage at the terminals of the converter itself (not the terminals of the BDM/CDM) is given by

$$d = 100 \sin \alpha \quad (\%)$$

where α represents the firing angle of a phase controlled converter (referred to the natural commutation point of a diode);

- the principal notch is characterised by a value of 0 V (line-to-line voltage at the converter's terminals);
- the approximation gives an under-evaluation of d for α < 90°, and an over-evaluation of d for α > 90°.

The notch area a can be approximated by a simple relationship (example of a three-phase bridge, see the conditions of the approximation in the note below):

$$a = 8\,000\ (Z_t \times I_{1L}/U_L)\ (\%\ \text{degrees})$$

where

Z_t is the total line impedance per phase (here assumed to be a pure reactance), including any impedance in the CDM;

I_{1L} is the fundamental component of the line-side current;

U_L is the line-to-line voltage.

It can be seen that the worst case occurs when the PDS is at current limit conditions.

NOTE During commutation angle u, from α to $(\alpha + u)$, the commutating voltage is:

$$\sqrt{2}\ U_L \sin \omega t$$

and

$$\sqrt{2}\ U_L \sin \omega t = 2\ L_t\ \mathrm{d}I/\mathrm{d}t$$

the area of the commutation notch is

$$A = \int_{\alpha}^{\alpha+u} U(\theta)\,d\theta = 2\,L_t \int_{\alpha}^{\alpha+u} \frac{di}{dt}\frac{dt}{d\theta}\,d\theta \quad \text{(in volt x radian)}$$

$$A = 2\ L_t\ \omega\ I_\alpha \quad \text{which means} \quad A = 2\ Z_t\ I_\alpha$$

where I_α is the commutated current.

To take into account the ripple in a three-phase bridge, assume $I_\alpha \approx 0{,}75\ I_d$, where I_d is the DC current:

$$A = 1{,}5\ Z_t\ I_d$$

and with a in % degrees

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$$a = 100\ A\ (360/2\ \pi)\ (1/\sqrt{2}\ U_L) = 6\ 077\ (Z_t\ I_d/U_L)$$

$$a = 7\ 794\ (Z_t\ I_{1L}/U_L)$$

$$a \approx 8\ 000\ (Z_t\ I_{1L}/U_L) \text{ or in per units values } \quad a \approx 4\ 500\ (z_t\ i_L)$$

B.1.2 Calculation

B.1.2.1 General assessment

When the assumptions listed above are valid, the notch depth at the PC is:

$$d_{PC}\ \% = 100 \sin \alpha\ \mathbf{(}\ Z_c/(Z_c + Z_d)\ \mathbf{)} = 100 \sin \alpha\ (Z_c/Z_t)$$

where Z_t is the total line impedance.

$$Z_t = Z_c + Z_d$$

where

Z_d is the decoupling reactance between the PC and the converter terminals (whether included or not in the CDM);

Z_c is the supply network impedance at the PC.

The amplitude of the ability of control of the converter (for example the case of a three-phase controlled bridge), is often represented by sin α. The notch depth varies from 100 % at the converter terminals to 0 % at a zero impedance source.

Adding a decoupling reactance Z_d between the PC and the BDM reduces the notch depth and increases the notch width at the PC, but the notch area remains constant.

$$a_{PC} = 8\ 000\ (Z_c \times I_{1L}/U_L)\ (\%\ \text{degrees})$$

In simple cases where the above assumptions apply, these equations can be used to define the required decoupling reactance. Knowing the notch depth limit (see Table B.1) and the control amplitude ability of the converter, the notch depth at the PC gives the ratio:

$$Z_c/(Z_c + Z_d)$$

Then Z_c, defined by the user, allows calculation of Z_d by the installer, from which the internal decoupling reactance if any (given by the manufacturer) can be subtracted. The remaining value is the reactance to be added for correct decoupling.

NOTE The calculations above do not take account of transients at the beginning and at the end of the notch.

B.1.2.2 Practical rules

The calculation above defines the practical rule for decoupling the emission by means of a reactance Z_d. This is summarised below. The fundamental relations, assuming the network impedance is a pure reactance, are:

$$Z_c = L_c \times \omega$$

$$Z_t = Z_c + Z_d$$

$$d_{PC}\ \% = 100 \sin \alpha\ (Z_c/Z_t)$$

$$a_{PC}\ \%\ \text{degrees} = 8\ 000\ (Z_c \times I_{1L}/U_L)$$

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If multiple converters are connected to the same line, 5.4.2 of IEC TR 60146-1-2:2011 should be considered.

However, it should be remembered that compliance with the notch emission criterion does not automatically ensure compliance with harmonic emission criteria. Similarly, compliance with harmonic emission criteria does not automatically ensure compliance with the notch emission criteria. The immunity aspect is not entirely covered by the harmonic distortion criteria. Indeed, since the harmonic criterion does not imply any phase relationship between the different harmonic components, it does not prevent a particular voltage waveform from being applied to the PDS. Because the particular waveform of commutation notches (dv/dt, possible zero crossing) affects operation of snubbers or can affect electronic control operation as well, a particular immunity criterion is stated in IEC 61800-1 and in IEC 61800-2, it is even defined as electrical service conditions in 4.1.1 of IEC 61800-1:1997 and 4.9 of IEC 61800-2:2015.

B.1.3 Recommendations regarding commutation notches

B.1.3.1 Emission

The recommendation does not apply to power converters with such a structure that commutation notches are known not to exist or to have only negligible amplitude.

For example, an indirect converter of the voltage source inverter type with an active front end equipped with a decoupling filter designed for attenuation of the effects of the switching frequency does not produce notches. A simple diode rectifier produces notches of negligible amplitude. The main practical case where emission of notches should be considered is the case of thyristor converters (line commutated).

Compliance with the recommendations related to commutation notches does not avoid the need to verify compliance with the requirements for harmonics. The depth of the principal notch at the PC (PCC or IPC) should be limited according to Table B.1, with a line impedance assumed to be a pure reactance:

$$Z = L\,\omega$$

and having a value of 1,5 % (related to the rated power of the PDS).

NOTE 1 When installing the PDS, the line impedance is practically defined from the short-circuit power S_{sc} at the PC:

$$Z_{sc} = U_{LN}^2 / S_{sc}$$

Table B.1 – Maximum allowable depth of commutation notches at the PC

	First environment	Second environment
Maximum notch depth	20 % Class C of IEC 60146-1-1 or comply with the requirements of the local supply authority	40 % Class B of IEC 60146-1-1 or agreement with the user

NOTE 2 This rule cannot be used in cases where resonances can be expected due to capacitors or long length of cables.

In the case of certain distribution networks, special consideration can be required (for example internal distribution networks in hospitals). In such cases, the conditions should be specified by the user.

Compliance may be determined by calculation, simulation or measurement.

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If the PDS deviates from this recommendation, and in order to make the user able to comply with this recommendation, the manufacturer should provide the following information in the user documentation:

- the maximum and the minimum line impedance for correct operation of the CDM/BDM;
- details of the decoupling reactance Z_d if any, that is included in the CDM/BDM.
- details of the available decoupling reactances Z_d which can be delivered as optional items.

NOTE 3 The maximum line impedance is directly related to the maximum notch area at the PC (see B.1.1).

However, in the case of multiple PDSs connected to the same PC, notch limitation is a system consideration and a simple rule cannot be defined.

The main practical case where immunity against notches should be considered for other equipment is the case of RFI filters.

B.1.3.2 Immunity

The harmful effect of notches on a PDS can be much greater than that which would be indicated by a frequency domain analysis of their contribution to the total harmonic distortion. Therefore, a time domain analysis of commutation notches is necessary. Note that the stress due to harmonics and commutation notches affects the electronic control and some power devices as well (snubbers for instance). Because electronic control malfunctions will occur immediately, and snubbers have a short thermal time constant, the duration of a test, if any, for permanent conditions need not exceed 1 h.

Some practical cases where immunity against notches should be considered are:

- where operation is affected instantaneously, for example the effect on electronic synchronisation circuits where the zero crossing of voltage is taken as reference;
- thermal overload, for example overload of snubber circuits in the power converter;
- overvoltage on L-C circuits, for example RFI filters.

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B.2 Definitions related to harmonics and interharmonics

B.2.1 General discussion

B.2.1.1 Resolution of non-sinusoidal voltages and currents

Classical Fourier series analysis (IEC 60050-103:2009, 103-07-18) enables any non-sinusoidal but periodic quantity to be resolved into truly sinusoidal components at a series of frequencies, and in addition, a DC component. The lowest frequency of the series is called the fundamental frequency (IEC 60050-161:1990, 161-02-17). The other frequencies in the series are integer multiples of the fundamental frequency, and are called harmonic frequencies. The corresponding components are referred to as the fundamental and harmonic components, respectively.

The Fourier transform (IEC 60050-103, 103-04-01) may 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 line spectrum in the frequency domain, where the lines of the spectrum are the fundamental and harmonics of the corresponding Fourier series.

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.

B.2.1.2 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 61000-4-7:2002).

B.2.2 Phenomena related definitions

B.2.2.1
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

Note 1 to entry: For the purposes of IEC 61800, it is the same as the power frequency supplying the converter, or supplied by the converter according to the case which is considered.

Note 2 to entry: IEC 60050:2001, 551-20-01 and IEC 60050:2001, 551-20-02 defines the components as a result of the Fourier analysis; frequencies are therefore a consequence. In B.2.2, the definitions follow the approach of SC 77A defining first the frequencies, the components being a consequence. There is no contradiction between the two different approaches.

Note 3 to entry: In the case of a periodic function, the fundamental frequency is generally equal to the frequency of the function itself (see IEC 60050:2001, 551-20-03 and IEC 60050:2001, 551-20-01). The above definition corresponds to the genuine definition of "reference fundamental frequency" according to IEC 60050:2001, 551-20-04 and IEC 60050:2001, 551-20-02, for which the term "reference" may be omitted where there is no risk of ambiguity.

Note 4 to entry: 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 5 to entry: 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 load), and even if the generator feeding the network is a static converter.

[SOURCE: IEC 61000-2-2:2002, 3.2.1, modified — In the definition, the sentence starting with "For the purposes of this standard" has been moved to a note. The notes have been rephrased, and new notes have been added.]

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B.2.2.2
fundamental component
fundamental
the component whose frequency is the fundamental frequency

B.2.2.3
harmonic frequency
frequency which is an integer multiple greater than one of the fundamental frequency or of the reference fundamental frequency

[SOURCE: IEC 60050-551:2001, 551-20-05]

B.2.2.4
harmonic component
sinusoidal component of a periodic quantity having a harmonic frequency

Note 1 to entry: For brevity, such a component may be referred to simply as a harmonic.

Note 2 to entry: The value of a harmonic component is normally expressed as an RMS value.

[SOURCE: IEC 60050-551:2001, 551-20-07, modified – The note has been deleted and replaced by Notes 1 and 2 to entry.]

B.2.2.5
harmonic order
ratio of the frequency of any sinusoidal component to the fundamental frequency or the reference fundamental frequency

Note 1 to entry: The harmonic order of the fundamental component or the reference fundamental component is one.

Note 2 to entry: The recommended notation is "h".

[SOURCE: IEC 60050-551:2001, 551-20-09, modified — Note 2 to entry has been added.]

B.2.2.6
interharmonic frequency
frequency which is a non-integer multiple of the reference fundamental frequency

Note 1 to entry: By extension of the 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 to entry: In the case where $m < 1$, the term of sub-harmonic frequency may also be used (see IEC 60050-551:2001, 551-20-10).

[SOURCE: IEC 60050-551:2001, 551-20-06, modified — The notes have been added.]

B.2.2.7
interharmonic component
sinusoidal component of a periodic quantity having an interharmonic frequency

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

Note 2 to entry: For the purposes of IEC 61800, and as stated in IEC 61000-4-7, the time window has a width of 10 fundamental periods (50 Hz systems) or 12 fundamental periods (60 Hz systems), i.e. approximately 200 ms. The difference in frequency between two consecutive interharmonic components is, therefore, approximately 5 Hz. In case of other fundamental frequencies, the time window should be selected between 6 fundamental periods (approximately 1 000 ms at 6 Hz) and 18 fundamental periods (approximately 100 ms at 180 Hz).

[SOURCE: IEC 60050-551:2001, 551-20-08, modified — The note has been deleted and replaced by Notes 1 and 2 to entry]

B.2.2.8
harmonic content
sum of the harmonic components of a periodic quantity

Note 1 to entry: The harmonic content is a time function.

Note 2 to entry: For practical analysis, an approximation of the periodicity may be necessary.

Note 3 to entry: The harmonic content depends on the choice of the fundamental component. If it is not clear from the context which one is used, an indication should be given.

Note 4 to entry: The RMS value of the harmonic content is

$$HC = \sqrt{\sum_{h=2}^{h=H} (Q_h)^2}$$

where

Q represents either the current or the voltage;

h is the harmonic order (according to B.2.2.5);

H is 40 for the purposes of this document.

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[SOURCE: IEC 60050-551:2001, 551-20-12, modified — Note 4 to entry has been added.]

B.2.2.9
total distortion content
quantity obtained by subtracting from an alternating quantity its fundamental component or its reference fundamental component

Note 1 to entry: The total distortion content includes harmonic components and interharmonic components if any.

Note 2 to entry: The total distortion content depends on the choice of the fundamental component. If it is not clear from the context which one is subtracted, an indication should be given.

Note 3 to entry: The total distortion content is a time function.

Note 4 to entry: An alternating quantity (abbreviated as Q) is a periodic quantity with zero DC component.

Note 5 to entry: The RMS value of the total distortion content is:

$$DC = \sqrt{Q^2 - Q_1^2}$$

where notations come from B.2.2.8. See also IEC 60050-161:1990, 161-02-21 and IEC 60050-551:2001, 551-20-06.

[SOURCE: IEC 60050-551:2001, 551-20-11, modified — The brackets in Note 4 to entry have been added, as well as Note 5 to entry.]

B.2.2.10
total distortion ratio
TDR
ratio of the RMS value of the total distortion content to the RMS value of the fundamental component or the reference fundamental component of an alternating quantity

Note 1 to entry: The total distortion ratio depends on the choice of the fundamental component. If it is not clear from the context which one is used an indication should be given.

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

[SOURCE: IEC 60050-551:2001, 551-20-14, modified — The abbreviated term *TDR* has been added.]

B.2.2.11
individual distortion ratio
IDR
ratio of any harmonic component to the fundamental:

$$IDR = \frac{Q_h}{Q_1}$$

Note 1 to entry: In IEC 60050-161:1990, 161-02-20, this term is named "nth harmonic ratio".

B.2.3 Conditions of application

B.2.3.1 Reference values

For the purposes of this document and for clarity, limits are referred to the corresponding rated value.

Limits for *THD* and *TDR* are applied to:

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$$THD_N = \sqrt{\sum_{h=2}^{h=H} \left(\frac{Q_h}{Q_{N1}} \right)^2} \text{, and}$$

$$TDR = \frac{\sqrt{Q^2 - Q_1^2}}{Q_1} \text{, or}$$

$$IDR = \frac{Q_h}{Q_{N1}}$$

where Q_{N1} is the rated RMS value of the fundamental.

NOTE 1 It is important to note that *THD* does not include interharmonics, and that the upper limit *H* is generally 40. *TDR* does include interharmonics and frequencies above the order 40 up to 9 kHz. If interharmonics and emissions at frequencies above order 40, are negligible, *THD* and *TDR* are equal.

Assessment of emission should be made under the operating conditions which provide the maximum value of the harmonic content in current according to IEC 61000-3-12, and in reference to the rated value. Nevertheless, interharmonics should be considered separately.

NOTE 2 The harmonic content in current (*HCI*) is designated as the total harmonic current (*THC*) in IEC 61000-3-12. Where interharmonics can be disregarded, it represents a good approximation of the total distortion content in current (*DCI*):

$$THC = HCI = \sqrt{\sum_{h=2}^{h=40} (I_h)^2} \approx DCI = (\sqrt{I^2 - I_1^2})$$

B.2.3.2 Systems and installations

A PDS is generally a component of a larger system which can be as large as a complete processing line in the paper or metal industry. To avoid any confusion in this document, the word "installation" is used exclusively to designate the complete installation which is connected to a PCC (point of common coupling) on a public power supply network.

B.2.3.3 Load conditions

For the system, the steady state conditions represent the worst case conditions provided that the overload conditions (acceleration or other) do not exceed a total duration of 5 % in a 24 h period, and 1 % in a 7 day period. If the load of the system is defined by a cycle, assessment of harmonic emission during a period of highest load should be performed according to the measurement method defined in IEC 61000-4-7.

Overload conditions are not considered for assessment of low voltage PDS with rated input current below 75 A (see B.3.2.2).

B.2.3.4 Agreed power

The agreed power S_{ST} defines the equivalent reference current I_{TN} (total RMS value):

$$S_{ST} = U_N \times I_{TN} \times \sqrt{3}$$

where

U_N is the nominal (or declared) line-to-line voltage at the PCC;

I_{TN} is the reference current.

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Note that I_{TN} is close to the tripping current value of the main circuit breaker of the installation. S_{ST} represents the power which can be delivered at any time, by the public supply network, to the installation. It can be assumed that for each agreed internal power there exists a reasonable short-circuit power (fault level) S_{SC} defined at the PCC. This is the responsibility of the power distribution authority.

NOTE The "agreed power" results from an agreement between the user (owner of the installation) and the utility authority.

Where the agreed power is used to define the reference current to which harmonic currents are compared in order to express them in p.u. (per unit), the reference current I_{TN1} is by convention equal to I_{TN}

B.2.3.5 Agreed internal power (extension of the definition of agreed power)

The agreed internal power S_{ITA} , for an installation at a defined IPC "α", defines the equivalent reference current I_{TNA} (total RMS value) for the part A of the installation fed from α:

$$S_{ITA} = U_N \times I_{TNA} \times \sqrt{3}$$

where U_N is the rated line-to-line voltage at the IPC "α".

Note that I_{TNA} is the rated current of the feeding section of the part A of the installation. I_{TNA} is close to the rating of the circuit-breaker protecting this part A. It can be assumed that for each agreed internal power there exists a reasonable short-circuit power (fault level) $S_{SC\alpha}$ defined at the IPC "α". This is the responsibility of those in charge of internal power distribution.

B.2.3.6 Short-circuit current ratio of the source in the installation

R_{SI} is the ratio of the short-circuit power of the source at a defined PC to the rated apparent power of the installation, or of a part of the installation, supplied from this PC (see Figure B.2):

$$R_{SIA} = S_{SC\alpha}/S_{ITA} = I_{SC\alpha}/I_{TNA}$$

The subscript "A" indicates the considered part of the installation and the subscript "α" indicates which PC is at the origin of this part.

NOTE 1 Subclause 3.9.9 of IEC 60146-1-1:2009 defines the relative short-circuit power (R_{SC}) as the "ratio of the short-circuit power of the source to the rated apparent power on the line side of the converters. It refers to a given point of the network, for specified operating conditions and specified network configuration.". This is the same concept. However, R_{SI} is referring to the rated apparent power of the total load downstream of the point of coupling instead of the fundamental apparent power of a defined load (the converter) downstream of the point of coupling.

NOTE 2 This definition can be applied to the totality of the installation. In this case, the point of coupling (PC) is the point of common coupling (PCC), and I_{TNA} corresponds to the agreed power.

NOTE 3 This definition can also be applied to a part of an installation of rated current I_{TNA}. The short-circuit current ratio of the source in the installation R_{SIA} is expressed as the ratio of the short-circuit current at the internal point of coupling (IPCα) of the part of the installation to its rated current.

NOTE 4 By extension, this definition can also be applied to a part of an equipment of rated current I_{TNi}. R_{SIi} is expressed as the ratio of the short-circuit current available at the internal considered point (delivered by the source) to the rated current of part of the equipment supplied. This extension is strictly dedicated for consideration of internal constraints of equipment.

NOTE 5 In Figure B.2, the installation shows a part A with a short-circuit current ratio of the source R_{SIA}. The part A contains part B, part B has a short-circuit current ratio of the source R_{SIB}, part A also contains a part C, etc. The part B contains in turn a part B1, a part B2, etc. This partition allows an analysis and the assessment of the different short-circuit current ratios of the source at the different possible points of coupling.

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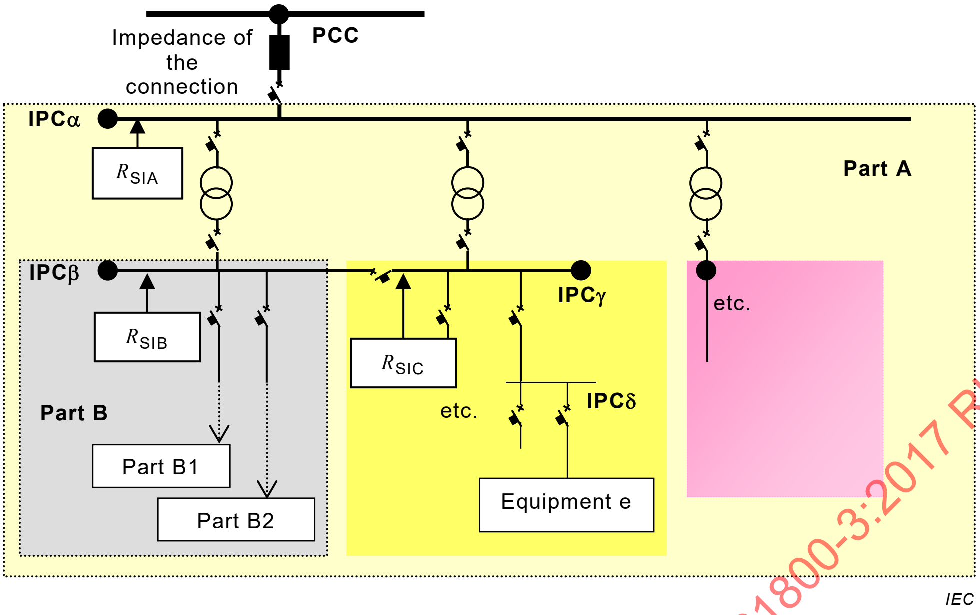

Figure B.2 – PCC, IPC, installation current ratio and R_{SI}

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B.2.3.7 Short-circuit ratio

R_{SC} is the ratio of the short-circuit power of the source at the PCC to the rated apparent power of the equipment (see IEC 61000-3-12):

$$R_{SC} = S_{SC}/S_{Ne} = I_{SC}/I_{LNe}$$

NOTE 1 With the example of Figure B.3, it can be expressed as a function of the relevant R_{SI}. The piece of equipment (e) is fed from a bus bar (IPC_{δ}), with a point of common coupling (PCC) at which the short-circuit current is I_{SC}, and draws a rated current I_{LNe}. Applying the above definitions gives:

$$R_{SIe} = S_{SC\delta}/S_{ITe} = I_{SC\delta}/I_{LNe} = (I_{SC\delta}/I_{SC}) \times (I_{SC}/I_{LNe}) = (S_{SC\delta}/S_{SC}) \times (R_{SCE})$$

or $$R_{SCE} = (S_{SC}/S_{SC\delta}) \times R_{SIe}$$

This definition is suitable, in the application of IEC 61000-3-12, for defining the condition of connection of a piece of equipment to the low voltage public supply network.

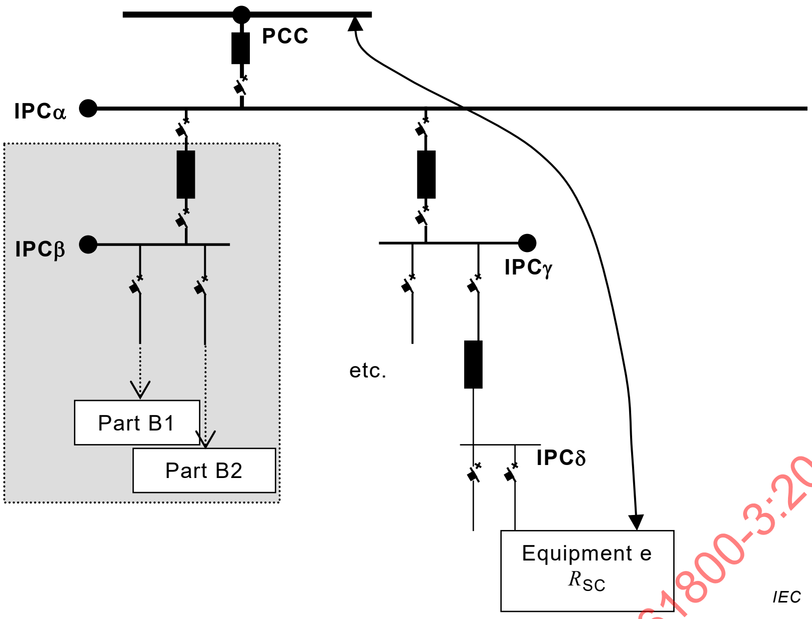

Figure B.3 – PCC, IPC, installation current ratio and R_{SC}

NOTE 2 Clause A.2 of IEC TR 61000-2-6:1995 gives another definition of R_{SC} for rectifiers referring to the DC current.

B.2.3.8 Non-distorting PDS

A PDS complying with the limits of IEC 61000-3-2, or with the limits for R_{SCE} = 33 in Table 2 of IEC 61000-3-12:2011, can be labelled: "Non-distorting PDS". The use of such a PDS is allowed without any restriction.

B.3 Application of harmonic emission standards

B.3.1 General

In the theoretical study of power converters and their use, converters have been modelled as sources of harmonic currents. Some new converters of voltage source type (using forced commutation and PWM control) are better described as harmonic voltage sources, therefore they are connected to the PC (which is also a voltage source) through an impedance (reactor) which converts them into harmonic current sources.

However, this common model is not suitable when the internal harmonic impedance of the converter is low compared to that of the network. As a simple example, consider the case of a diode rectifier and capacitive filtering, in which both the AC and DC sides are without any decoupling reactor. The circuit component with the lowest harmonic impedance determines the harmonic voltage.

A minimum knowledge of the system is necessary for establishing a model of the harmonic sources. The harmonic current source model is often suitable for most converters and harmonic orders up to 25. However, this model should be revised for frequencies above the harmonic order 40, where harmonic voltage source models are generally more convenient. Special care should be taken to define the appropriate model in the medium range between harmonic order 25 and 40.

Different models have already been given to define the order and the amplitude of the different harmonic components for different types of converters. A summary of these publications is given in IEC TR 61000-2-6:1995, Clause A.1, and in IEC 61800-1:1997, Annex B, , which include information from IEC TR 60146-1-2.

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Such an analysis is not repeated here.

A PDS is often a harmonic current source which contributes to harmonic voltages. The harmonic voltages should be compared to compatibility levels from IEC 61000-2-2 or IEC 61000-2-4. The influence of operating and installation conditions should also be considered. This is pointed out in IEC TR 61000-2-6, which also gives methods for summation of harmonics. Naturally, this has consequences on the appropriate mitigation methods (see Annex C) and on practical rules for connection of a PDS (see Clause B.4).

Industrial practice, with PDSs of category C4, establishes optimal solutions from both the technical and economical points of view. These include adapted mitigation methods, for example, the use of defined phase shifting transformers applied to different PDSs.

Filtering each PDS individually can cause a severe risk of multiple resonance frequencies. Additionally, because the harmonic impedance and the existing voltage distortion are generally unknown and unstable, the rating of the filter is particularly difficult to define. Therefore, a global approach to filtering of the whole installation should be used. Such an approach is developed in IEEE Std 519™.

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B.3.2 Public networks

B.3.2.1 General conditions

For low voltage PDSs of rated input current exceeding 16 A and up to and including 75 A per phase, IEC 61000-3-12 specifies the limitation of harmonic currents injected into the public supply system. The limits given in IEC 61000-3-12 are primarily applicable to electrical and electronic equipment intended to be connected to public low-voltage AC distribution systems.

When a PDS is equipment within the scope of IEC 61000-3-12, the requirements of that standard apply. However, when one or more PDSs are included in equipment within the scope of IEC 61000-3-12, the requirements of that standard apply to the complete equipment and not to the individual PDS.

The test set-up for direct measurement or for validation of a computer simulation for PDSs within the scope of IEC 61000-3-12 consists of a voltage source and measuring equipment as described in IEC 61000-4-7. If a synchronous machine is used as an independent source for the test, it should be noted that its harmonic impedance is determined by the negative sequence impedance, not by the short circuit current.

NOTE 1 If the PDS includes a phase shift transformer, the point of measurement is on the primary side.

Measurements are performed under steady state conditions. Power overload conditions (affecting torque at full speed) are quite exceptional applications, and if any, are sufficiently limited in time not to be considered.

The emission level may be assessed either by direct measurement or by a validated simulation under the conditions defined in IEC 61000-3-12. The following two operating conditions are defined to cover the different types of PDSs:

- rated input current at base speed in motoring mode (voltage source inverter);
- rated torque at 66 % of base speed in motoring mode (thyristor DC drive or current source inverter).

NOTE 2 IEC 61800-1 and IEC 61800-2 define base speed as the lowest speed at which the motor is capable of delivering maximum output power. In the case of a voltage source inverter, this is often the same speed as if the motor was fed directly from the mains supply.

For equipment neither covered by IEC 61000-3-2 nor by IEC 61000-3-12 (for example rated current above 75 A), recommendations are given in Clause B.4.

NOTE 3 Harmonics of the different electrical components of the equipment can be summed using the more exact analytical physical law suitable to the nature of the PDS and to the nature of the other components (see B.3.3).

B.3.2.2 Assessment by simulation

The simulation assessment of individual harmonic emission of a PDS should follow the basic rules summarised in Figure B.4. Characterisation of the PDS and of the voltage source is the starting stage.

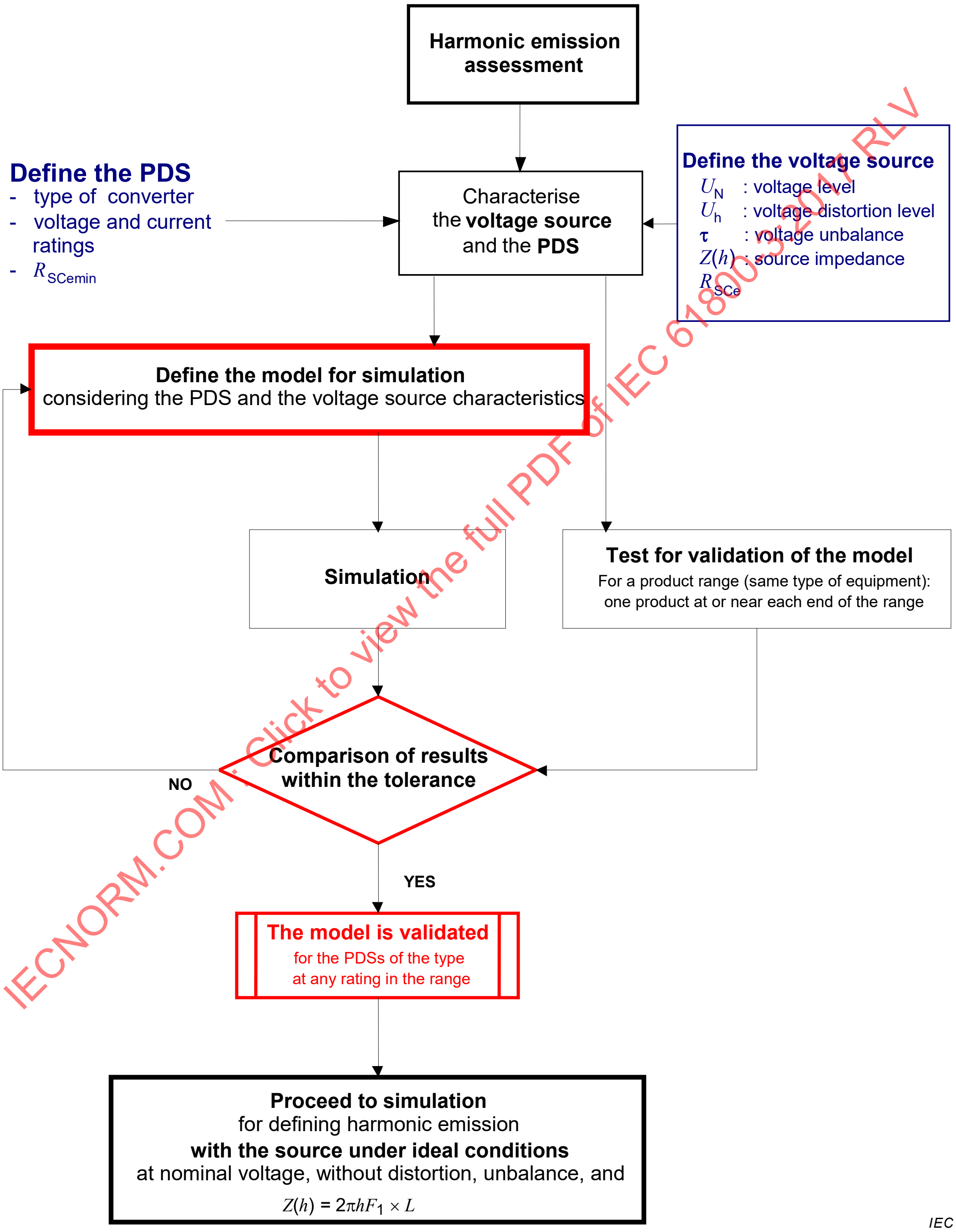

Figure B.4 – Assessment of the harmonic emission of a PDS

In the case of high power or medium voltage equipment, the validation of the simulation may be a more complex process than the process described here.

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B.3.2.3 Load conditions for assessment by test

B.3.2.3.1 General

When the harmonic emission of a PDS is measured individually, the characterisation of the voltage source and the PDS is performed as in B.3.2.2. For equipment with rated input current above 16 A and up to 75 A, IEC 61000-3-12 requires the R_{SCEmin} during the test to be at least 1,6 times the R_{SCE} which is referenced for compliance declaration. The load conditions are set as follows:

- 100% rated input current or less, maximising THC;
- motoring operation;
- steady state.

Figure B.5 illustrates the test set-up with a mechanical load. Figure B.6 and Figure B.7 illustrate the electrical possibilities when a mechanical load is not available.

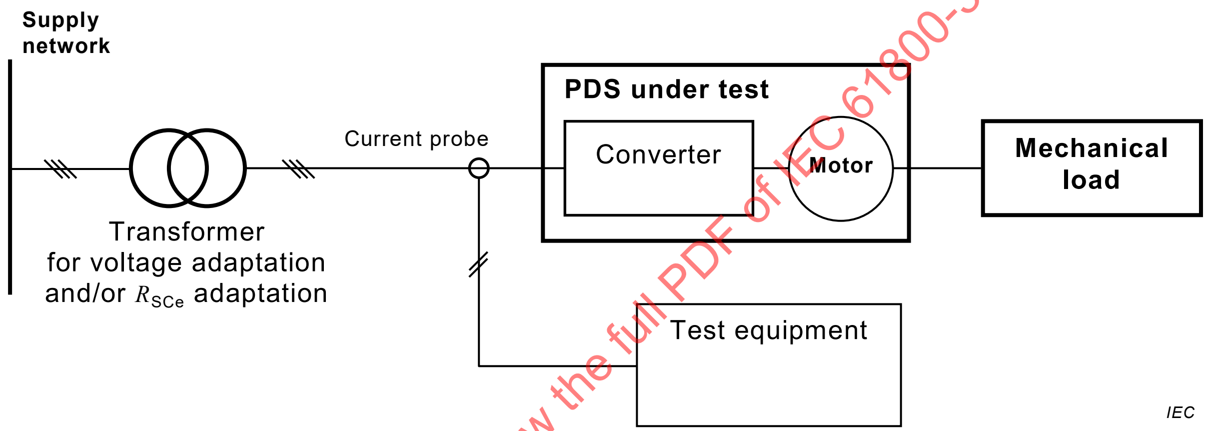

Figure B.5 – Test set-up with mechanical load

B.3.2.3.2 Diode input rectifier

PDS with diode input rectifier (or thyristor rectifier, the thyristors being used as diodes with a function of contactor) may be tested at 100 % rated input RMS current as defined by the manufacturer's specification. The necessary load to obtain the input current may be provided by a motor defined by the manufacturer and a mechanical load for steady state operation.

The loaded motor may be replaced by an electrical load which is connected either at the output of the converter, or at the output of the DC link:

- at the output of the converter, the electrical load should consist of a reactor and a resistor (see Figure B.6);
- at the output of the DC link, the electrical load should consist of a resistor (see Figure B.7).

For rated input currents equal to or greater than 75 A, the rated input current condition may be replaced by the condition maximising the *THC*.

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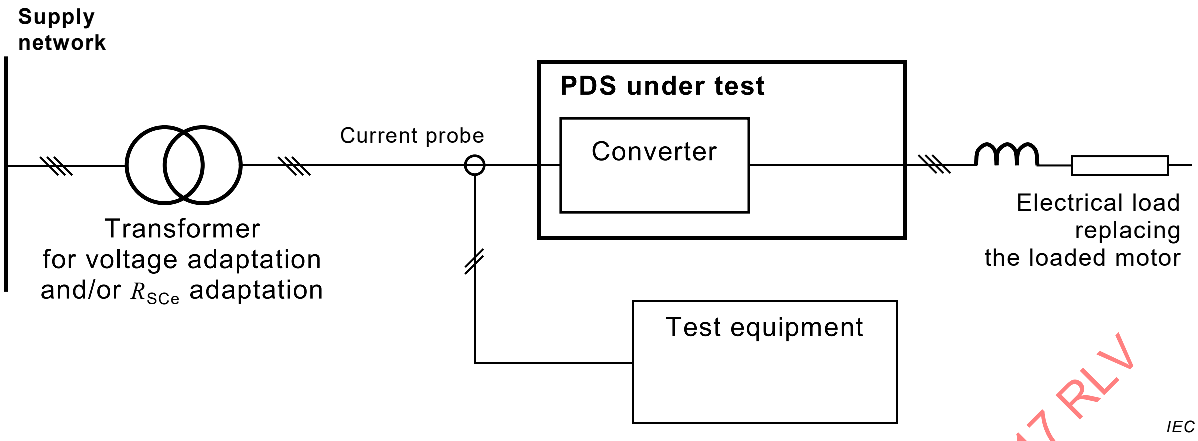

Figure B.6 – Test set-up with electrical load replacing the loaded motor

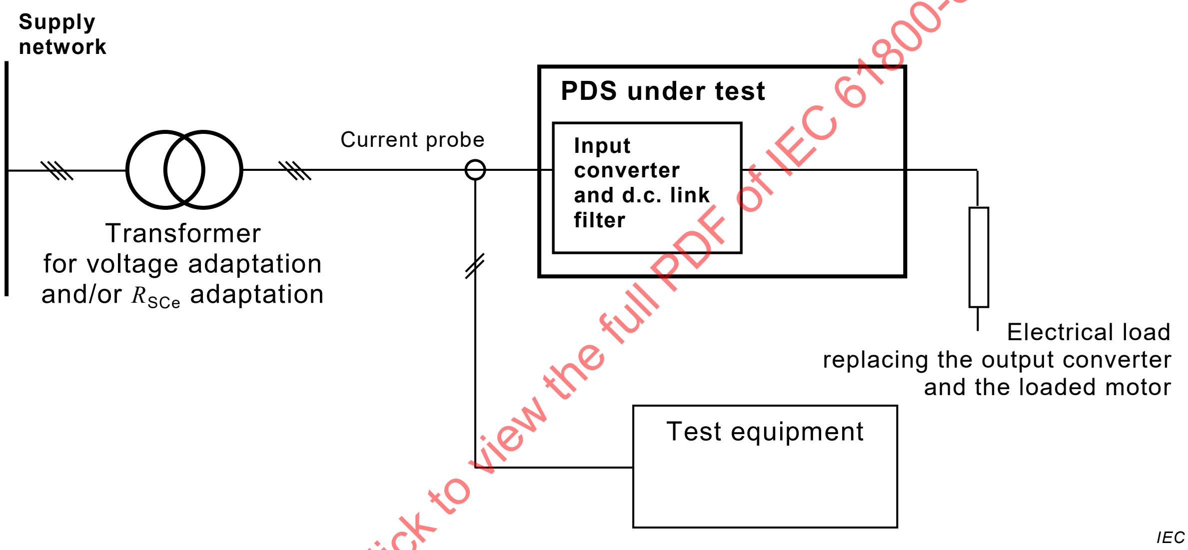

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Figure B.7 – Test set-up with resistive load

B.3.2.3.3 Line commutated input converter

PDS with a line commutated input converter (thyristor converter) is tested at rated RMS input current as defined by the manufacturer's specification, or less for maximising *THC*. No test for regenerating conditions is required. The necessary load to obtain the corresponding input current may be provided by a motor defined by the manufacturer and a mechanical load for steady state operation.

In the case of a current source converter, the loaded motor may be replaced by an inductor at the output of the DC link (instead of the motor). In the case of a voltage source converter, the loaded motor may be replaced by a resistor at the output of the DC link (see Figure B.7).

NOTE Conditions producing maximum *THC* are close to the conditions producing the maximum value of peak-to-peak ripple current, in the DC link at the output of the input converter.

B.3.2.3.4 Self-commutated input converter

PDS with self-commutated input converter is tested at rated RMS input current as defined by the manufacturer's specification, or less for maximising *THC*. No test for regenerating conditions is required. The necessary load to obtain the corresponding input current may be provided by a motor defined by the manufacturer and a mechanical load for steady state operation.

The loaded motor may be replaced by a resistor at the output of the DC link. A back to back setting for loading is also possible; in such a case, it is obvious that only the current of the input converter is measured.

B.3.2.4 Representative maximum of *THC*

It is not always necessary to operate at the rated input current to comply with the requirement of maximising the current *THC* (total harmonic content in current).

NOTE In this document, *THC* is the total harmonic content (see B.2.2.8) which is consistent with IEC 60050-551:2001, 551-20-12. In IEC 61000-3-12, *THC* represents the total harmonic current which can be considered as an abbreviation of total harmonic content in current.

For certain types of converters (for example current source), the ripple current in the DC link depends on the speed of the motor. Worst conditions are obtained at zero speed, which is equivalent to the loaded motor replaced by an inductor at the output of the DC link. This case is generally not representative of normal operation of the PDS.

For a PDS of rated input current equal to or above 75 A, two operating conditions are required in order to assess the harmonic emissions of the different types of PDS:

- rated input current at base speed in motoring mode (voltage source inverter);
- rated motor current at 66 % of base speed in motoring mode (thyristor DC drive or current source inverter).

For other types of PDS, where it is not obvious which of the above conditions is the worst case, both of these conditions should be assessed. In both cases harmonic currents should be assessed as a percentage of the rated fundamental input current. The case with the higher value of *THC* should be considered as the worst case.

When these two conditions cannot be assessed (by test or by validated simulation), or for low voltage PDS of rated input current less than 75 A, as an alternative, it is admitted to verify the maximum *THC* condition by means of the following simplified method. The current may be set below the rated input current, provided it produces the maximum absolute ripple current in the DC link. The condition can be checked by verifying the waveform of the current at the appropriate location on the DC link.

Conditions providing a representative maximum of *THC* are also met with electrical loads by adjustment of the mean value of the current in the DC link. They may be taken to specify the load conditions of the test for validation of a simulation.

The *IDR* (individual distortion ratio, see B.2.2.11) measured under those conditions provides an overestimation of the most significant harmonic components of the current. They also may be taken as result of the test when the rated current cannot be achieved, and when simulation is not used.

B.3.3 Summation methods for harmonics in an installation – Practical rules

B.3.3.1 Principle

Harmonic emissions from the different components are summed in the most appropriate way. The chosen method of summation can be a fast but conservative approximation. When more precision is required, the appropriate summation law may be chosen, according to the nature and structure of the converters of the PDSs. The result is referenced to the rated fundamental current of the apparatus or of the system (agreed internal power).

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B.3.3.2 Simple arithmetic summation of harmonic currents

In this approach, harmonic currents are summed arithmetically (this approach is simple but often highly conservative). Calculation of the individual distortion ratio *IDR* (for each order), or of the total harmonic distortion *THD*, is performed for three-phase components, using the following equation applied to all distorting components (pieces of equipment) belonging to an installation or to a part of an installation.

HD is the generic symbol for *IDR* or *THD*. The subscript "eq" indicates that this value is attached to a particular piece of equipment in the system. The subscript "IT" indicates that the example is related to a part of an installation, however the same applies to the whole installation (using subscript "ST").

$$HD = \sum_{eq} HD_{eq} \times \frac{S_{eq}}{S_{IT}}$$

In the equation HD_{eq} is referenced to the rated fundamental current of the component (piece of equipment), and *HD* is referenced to the rated fundamental current of the part of the installation (agreed internal power).

Single-phase components are taken into account by means of an unbalance penalty coefficient:

- for single-phase loads, phase-to-phase, the coefficient is √3:

$$\sqrt{3}\left(HD_{eq} \times \frac{S_{eq}}{S_{IT}}\right)$$

- for single-phase loads, phase-to-neutral, the coefficient is 3:

$$3\left(HD_{eq} \times \frac{S_{eq}}{S_{IT}}\right)$$

The penalty coefficient is applied to those terms related to the loads in excess which create the unbalance condition.

Example: S_{IT} = 150 kVA

Piece of distorting equipment N°1: S_{eq} = 25 kVA with *HD* = 65 % , related to its rated current;

HD_{eq1} = 65 x (25/150)% = 10,8 % , related to I_{TN1} (or S_{IT}).

Piece of distorting equipment N°2: S_{eq} = 10 kVA with *HD* = 10 % , related to its rated current;

HD_{eq2} = 10 x (10/150) % = 0,7 % , related to I_{TN1} (or S_{IT}).

Piece of distorting equipment N°3: S_{eq} = 1 kVA with *HD* = 85 % , related to its rated current,

but single-phase (phase-to-phase), equivalent to 1,73 times its rating as balanced load, with harmonics multiple of three (to be considered):

HD_{eq3} = 85 x (1,0/150) x 1,73 = 1,0 % related to I_{TN1} (or S_{IT}).

For the system *HD* = (10,8 + 0,7 + 1,0) % = 12,5 % with Σ S_{eq}/S_{IT} = (25 + 10 + 1)/150 = 0,240

The calculation should be performed for each harmonic order and for *THD*.

B.3.3.3 Pseudo-quadratic (variable exponent) summation law

The summation of harmonic currents can be made with a more representative law:

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- current known to be in phase (for example diode rectifier), arithmetic summation of each order

$$I_h = \Sigma_i I_{hi}$$

- random phase relationship between currents, exponent and summation of each order

$$I_h = \left[\sum_i I_{hi}{}^{\alpha} \right]^{\frac{1}{\alpha}}$$

where

α = 1 for $h < 5$;

α = 1,4 for $5 \leq h < 10$;

α = 2 for $10 \leq h$.

The above formulae can be applied to individual harmonic orders and also to THD.

This method gives an assessment of harmonic current emissions from the system. The result is referenced to the rated fundamental current of the system (agreed internal power) and may be used to show compliance with IEC 61000-3-2 or IEC 61000-3-12 according to the rating of the machine or of the system. It may even be used for assessment of larger industrial systems or installations.

Typical environments where this approach applies are equipment for light industry with "agreed power" between 30 kVA and 100 kVA, or installation for light industry with "agreed power" between 100 kVA and 300 kVA.

B.3.3.4 Approach for industrial networks based on calculation and/or measurements

If compliance with harmonic emission limits cannot be proved by the above approximations, a more accurate assessment of harmonic emissions should be used. This concerns the total current demand of the installation.

The total harmonic current produced by the installation, including the load to be installed, should be established by calculation or measurement. The actual phase relationships between harmonic producing loads should be taken into account so that cancellation effects are not ignored.

Typical environments where this approach applies are light industry with "agreed power" higher than 100 kVA or industry.

B.4 Installation rules – Assessment of harmonic compatibility

B.4.1 Low power industrial three-phase system

B.4.1 is intended to provide guidance for the use of PDSs for their incorporation in products, apparatus or more generally in systems. Applying harmonic limits to each PDS can result in an uneconomic solution and/or in a technical nonsense. It is often better to apply a global approach to filtering of the whole installation. This requires a summation of the harmonic currents produced within an installation.

The procedure for the assessment of harmonic emissions is summarised in Figure B.8.

As stated in 6.2.3.1 and 6.2.3.2, IEC 61000-3-2 and IEC 61000-3-12 apply to apparatus comprising PDSs that are directly connected to a PCC in a public low-voltage network.

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Checking of compliance is performed by comparing, with tables in the appropriate referenced standard, the levels of individual harmonic currents and total harmonic current (THC) produced by the system or apparatus.

For PDSs which are not covered by these publications, the following procedure can be used as a guide. The usual approach is to apply limits of harmonic current to the complete installation. The assessment of the total harmonic emission is performed with appropriate summation laws, according to the required approximation (see B.3.3). Simplified methods and criteria are possible when the agreed power is within a medium range (for example between 100 kVA and 300 kVA), as suggested in Figure B.8, or according to local rules. It is in the responsibility of the user to meet the adequate limits at the PCC.

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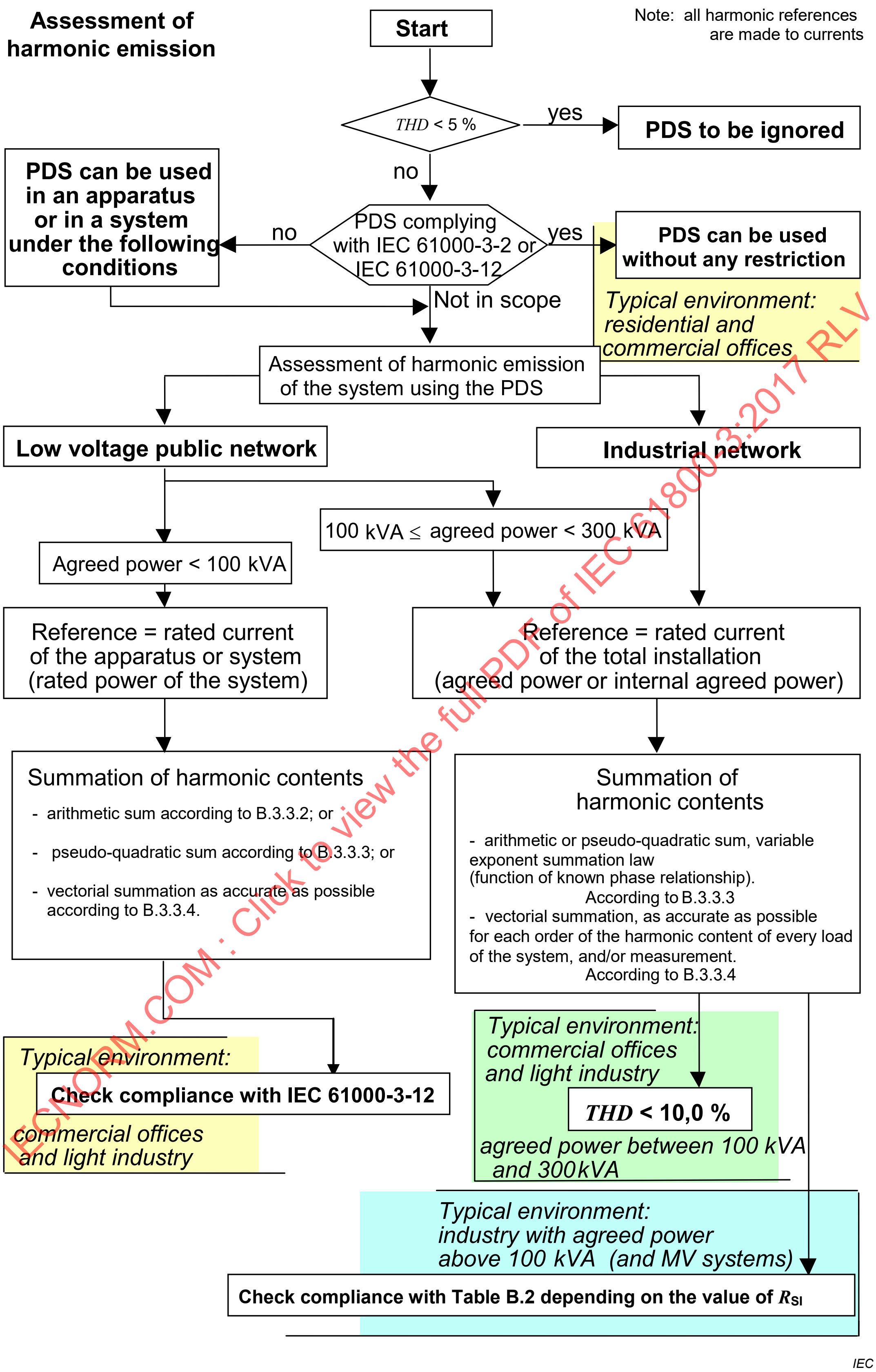

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Figure B.8 – Assessment of harmonic emission where PDS is used (apparatus, systems or installations)

B.4.2 Large industrial system

B.4.2.1 Principles

B.4.2 is intended to provide guidance for the use of PDSs for their incorporation in systems. Applying harmonic limits to each PDS can result in an uneconomic solution and/or in a technical nonsense. It is often better to apply a global approach to filtering of the whole installation. This requires a summation of the harmonic currents produced within an installation.

The procedure for the assessment of harmonic emissions is summarised in Figure B.8.

IEC TR 61000-3-6 should be applied directly for installations supplied by a medium voltage power supply network, which is the case for large PDSs and particularly those of rated voltage above 1 000 V AC.

It is usual to separate the installation into different parts according to natural decoupling devices (e.g. transformers). The separation should result from the analysis of the complete network, taking possible resonances into account (see Figure B.2).

The location of required filters should be carefully established, but it is evident that filtering each PDS is not practicable.

The usual approach is to apply limits of harmonic current to the complete installation, or to parts of the installation as seen above. In critical cases, a more detailed analysis involving the existing level of voltage harmonic distortion is used.

B.4.2.2 Current distortion determination method for complete installation

In this approach, harmonic current limits are applied to the whole installation. Limits are applied both to individual distortion ratios (*IDR*) for individual orders and to *THD*.

The harmonic currents of the total installation should be in accordance with the following Table B.2 at the defined point of coupling. See definition of R_{SI} in B.2.3.6. The PDS supplier and customer should agree on the point of coupling (PCC or IPC) and on the applications of other emission limits coming from local regulations. The point of coupling should be an identified bus bar.

NOTE From the definition of R_{SI}, dedicated to a defined bus bar, it is clear that all loads fed from this bus bar contribute to the definition of the corresponding current (I_{TN}) to be taken into account for calculation of harmonic emission.

In the USA, IEEE Std 519 applies this approach at all voltage levels for electricity distribution networks. Table B.2 gives an example of practical limits already experienced in North America.

Harmonic currents are expressed as percentages of the total current corresponding to the internal agreed power of the AC supply of the total installation (*IDR*). In the case of a PCC, the load current is defined by the "agreed power", as agreed between the user and the utility. In the case of an IPC, the rated fundamental load current is equal to the rated load current of the feeder to the IPC. See subclauses B.2.3.5 and B.2.3.6.

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Table B.2 – Harmonic current emission requirements relative to the total current of the agreed power at the PCC or IPC

	Individual distortion ratio *IDR*					
RSI	$h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 40$	***TDR***
$R_{SI} < 20$	4 %	2 %	1,5 %	0,6 %	0,3 %	5 %
$20 \leq R_{SI} < 50$	7 %	3,5 %	2,5 %	1 %	0,5 %	8 %
$50 \leq R_{SI} < 100$	10 %	4,5 %	4 %	1,5 %	0,7 %	12 %
$100 \leq R_{SI} < 1000$	12 %	5,5 %	5 %	2 %	1 %	15 %
$1000 \leq R_{SI}$	15 %	7 %	6 %	2,5 %	1,4 %	20 %
Even harmonics are limited to 25 % of the odd harmonics. For systems with a pulse number (= q) higher than 6, the limits for each individual harmonic are increased by the factor $\sqrt{q/6}$. This corresponds for a 12 pulse system to $\sqrt{2}$. The *THD* limit remains unchanged.						

B.4.2.3 Case by case analysis

As an alternative, a complete analysis of the system can be conducted, and should be conducted in critical cases. The results of the analysis can then be used to correctly define the total filtering, or other mitigation methods.

The following procedure should be adopted:

- assess the existing level of harmonic voltage distortion at the PCC (at the responsibility of the operator of the distribution network – public or private);
- calculate or measure the harmonic impedance of the supply at the PC (at the responsibility of the operator of the distribution network – public or private if PCC – and the responsibility of the user if IPC – internal point of coupling); IEC TR 61000-2-6:1995, Clause A.2, gives information on the harmonic impedance encountered in networks;
- calculate or measure harmonic currents that the PDS to be connected is going to inject into the system (at the responsibility of the manufacturer);
- calculate harmonic voltages that can result from this (at the responsibility of the user).

NOTE All the rules and methods listed in IEC TR 61000-3-6, although defined for medium voltage (from 1 kV up to and including 35 kV) or high voltage (> 35 kV) public networks, are applicable to industrial networks, including their low voltage parts.

In the case of a PCC, the resulting harmonic voltages should not exceed the planning levels defined by the utility. In the case of an IPC, the resulting harmonic voltages should not exceed the compatibility levels.

Compatibility levels for harmonic voltages are defined by IEC 61000-2-2 on low voltage public systems, by IEC 61000-2-12 on medium voltage public systems and by IEC 61000-2-4 on private industrial systems.

At the PC an available nominal power (called agreed internal power) can be defined. In the case of a PCC this is the "agreed power" (see B.2.3.4 and B.2.3.5). A disturbance allowance can be allocated to the PDS to be connected. The reasonable solution consists of defining this disturbance allowance proportional to the ratio of the PDS's rated power to the agreed internal power at the PC, and proportional to compatibility levels defined by standards quoted in B.4.2.3.

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B.4.2.4 Telephone interference

In North America and Finland, the parallel construction of energy distribution and telephone lines has led to the introduction of *TIF* (telephone interference factor). IEEE 519-2014, Annex B, presents the result of a weighting of the various harmonics.

The equivalent psophometric current is defined as $I_{\mathrm{p}} = I \times TIF$,

and the local recommended practices require that $I_{\mathrm{p}} < I_{\mathrm{pA}}$

Within the installation, the common mode harmonic emission on the motor cable can cause interference with telephone lines if they are running in parallel. This should be avoided (see 6.2.5).

B.4.3 Interharmonics and voltages or currents at higher frequencies

In this frequency range, above harmonic order 40 and up to 9 kHz, the PDS should be considered as a voltage source emitter. There are no emission requirements for PDSs until compatibility levels will be standardised.

However, application of certain types of PDSs can require the consideration of the emission of interharmonics or of currents or voltages at higher frequencies (up to 9 kHz). This is mainly the case for high power PDSs such as cyclo-converters or current source inverters. This can also be the case for active front-end converters where the PWM switching is directly coupled to the network.

Interharmonics at frequencies slightly different from the fundamental or from predominant harmonics can also cause voltage fluctuations (see B.6.2). They result from beat frequencies which can be seen on non-linear systems such as lighting (function of the square of the voltage). The non-linear response of the disturbed equipment causes the sum and difference of the different harmonic or interharmonic frequencies to appear. The difference frequency can be in the range that causes flicker. The main origin is cyclo-converters or current source inverters. This case is covered by compatibility levels given in IEC 61000-2-4.

B.5 Voltage unbalance

B.5.1 Origin

Voltage unbalance on a three-phase system is generally caused by unequal loading on two of the three phases by single-phase loads. The voltage unbalance is directly related to the amount of the single-phase load as a percentage of the rating, and to the impedance of the mains supply. As an example, consider a three-phase transformer with a defined regulation, and only a single-phase load connected between two phases. If the load is a significant percentage of the kVA rating of the transformer, the output voltages (phase to neutral) of the two phases connected to the load will be reduced while the third winding without any load will remain the same.

Significant unbalance on transformers will cause excessive heating. The manufacturer should be consulted to determine if the transformer is capable of supplying single-phase loads that are a significant percentage of its rated kVA capacity.

Other three-phase loads connected to an unbalanced three-phase source of power are generally affected in a detrimental manner. As an example, the unbalance will cause a reverse sequence current to flow in a three-phase induction motor, which will reduce the torque output at rated current or cause excessive heating at rated output of the motor. In some motors, an unbalance of 3 % can result in a 10 % derating of their output. If an unbalance condition exists on the mains supplying a three-phase motor, it is important to consult the motor manufacturer to determine the proper derating for safe operation.

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B.5.2 Definition and assessment

B.5.2.1 Definition

Voltage unbalance is defined in IEC 61000-2-2, IEC 61000-2-4 or IEC 61000-2-12. Some methods of calculation are given below.

In a polyphase system, voltage unbalance is a condition in which the RMS values of the fundamental component of the line-to-line voltages, or the phase angle between consecutive phases, are not all equal. For the purposes of this document, the degree of that inequality is expressed as the ratio of the negative sequence component to the positive sequence component.

In some circumstances, the zero-sequence component should be included in the assessment of voltage unbalance.

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B.5.2.2 Complete analysis

The accurate definition relates to symmetrical component analysis of the three-phase system. This type of analysis is based on the concept that any phase voltage deviation from the ideal three-phase system can be described by the addition of three vectors. They are called the zero, positive and negative sequence vectors and are defined as follows.

$\underline{U}_{A}$	=	$\underline{U}_{A0} + \underline{U}_{A1} + \underline{U}_{A2}$	phase A voltage
$\underline{U}_{A0}$	=	$(\underline{U}_{A} + \underline{U}_{B} + \underline{U}_{C})/3$	zero sequence component
$\underline{U}_{A1}$	=	$(\underline{U}_{A} + a\,\underline{U}_{B} + a^2\,\underline{U}_{C})/3$	positive sequence component
$\underline{U}_{A2}$	=	$(\underline{U}_{A} + a^2\,\underline{U}_{B} + a\,\underline{U}_{C})/3$	negative sequence component

where $\underline{U}_{A}$, $\underline{U}_{B}$, and $\underline{U}_{C}$ are the phase voltage vectors and "a" is the operator,

$a = -(1/2) + j\,(\sqrt{3}/2)$.

The ratio of the negative sequence to the positive sequence voltage is the voltage unbalance. This is as follows:

$$\tau\,\% = 100\ U_2/U_1$$

Example 1 Amplitudes and phase angles of line-to-neutral voltages are known allowing the line-to-line voltages and the corresponding phase angles to be calculated.

U_{AN} = 231,00 and 0,0°,	U_{BN} = 220,00 and –125,1°,	U_{CN} = 215,00 and 109,8°
U_{AB} = 400,26 and 26,7° ,	U_{BC} = 386,03 and – 98,0°,	U_{CA} = 365,01 and 146,3°

resulting in	zero sequence	U_0 = 12,91 and 35,2°,
	positive sequence	U_1 = 221,41 and –5,0°,
	negative sequence	U_2 = 11,78 and 90,7°,

and voltage unbalance: τ = 100 (11,78/221,41) = 5,32 %, with a zero sequence component of 5,83 %.

Example 2 Amplitudes and phase angles of line-to-neutral voltages are known allowing the line-to-line voltages and the corresponding phase angles to be calculated:

U_{AN} = 230,00 and 0,0°,	U_{BN} = 280,00 and –135,0°,	U_{CN} = 170,00 and 130,0°
U_{AB} = 471,57 and 24,8°,	U_{BC} = 340,00 and –105,1°,	U_{CA} = 363,41 and 159,0°

resulting in zero sequence U_0 = 34,26 and –138,7°,
positive sequence U_1 = 223,09 and –3,7°,
negative sequence U_2 = 49,59 and 48,1°,

and voltage unbalance: τ = 100 (49,59/223,09) = 22,23 %, with a zero sequence component 15,36 %.

B.5.2.3 Approximate method

Three approximations are given below. The first one usually provides the best results, with an error less than 5 % for any kind of unbalance for which the line-to-neutral voltages have phase angles within a tolerance of ±15°, and the amplitude within a tolerance of ±20 % compared to the corresponding ideal balanced system (positive sequence or negative sequence).

U_{12}, U_{23} and U_{31} are the three line-to-line voltages, with $\delta_{ij} = (U_{ij} - U_{average})/(3 \times U_{average})$ for each of the three line-to-line voltages, and τ the voltage unbalance as the ratio of the negative sequence voltage amplitude to the positive sequence voltage amplitude,

$$\tau \approx \sqrt{6\sum_{1}^{3}\delta_{ij}^{2}}$$

The much more simple approximation:

$$\tau \approx \left(\frac{2}{3}\right)\times\left[\frac{U_{max} - U_{min}}{U_{average}}\right]$$

provides acceptable results (absolute error generally less than 1 %) for τ up to 7 %.

The formula proposed by NEMA also gives acceptable results (absolute error generally less than 1 %) for τ up to 10 % or where phase shifts are large:

$$\tau \approx \frac{MAX\left|U_{ij} - U_{average}\right|}{U_{average}}$$

Example 1 As above:

U_{AN} = 231,00 U_{BN} = 220,00 and U_{CN} = 215,00

U_{AB} = 400,26 U_{BC} = 386,03 and U_{CA} = 365,01

$U_{average}$ = (400,26 + 386,03 + 365,01)/3 = 384,07 and without decimals $U_{average}$ = (400 + 386 + 365)/3 = 383,66

δ_{12} = 1,433 % δ_{23} = 0,197 % δ_{31} = –1,629 %

The voltage unbalance is $[6\ (1{,}433^2 + 0{,}197^2 + 1{,}629^2)]^{1/2}$ = 5,3 %

or (2/3) x (U_{max} – U_{min}) / $U_{average}$ = (2/3) x (400 – 365)/383,7 = 6,1 %, or using the last approximation: 19,1/383,7 = 5,0 %.

Example 2 As above:

U_{AN} = 230,00 U_{BN} = 280,00 and U_{CN} = 170,00

U_{AB} = 471,57 U_{BC} = 340 and U_{CA} = 363,41

$U_{average}$ = (471,57 + 340 + 363,41) / 3 = 391,66

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δ_{12} = 6,801 % δ_{23} = –4,397 % δ_{31} = –2,404 %

The voltage unbalance is $[6 (6,801^2 + 4,397^2 + 4,397^2)]^{1/2}$ = 20,7 %

or (2/3) x (U_{max} – U_{min}) / $U_{average}$ = (2/3) x (472 – 340) / 391,7 = 22,4 %, or using the last approximation: 80,6/391,7 = 20,6 %.

B.5.3 Effect on PDSs

The effect on the PDS will vary depending on the type of power circuit and control method used. Each type of control and circuit should be analysed in detail. Generally, the effect will be small on controlled or uncontrolled converters that supply resistive loads. Phase controlled converters of the type that use phase shifted line voltage for their reference will be affected less than converters that use a voltage ramp synchronised to the line using zero crossings for their reference. Controlled or uncontrolled converters that supply capacitor banks, used in the DC loop of indirect converters (voltage source inverters), will have current unbalances that are significantly larger than the voltage unbalance and larger than converters that supply an inductive load such as a DC motor.

Special care should be taken with the design of converters that supply capacitor banks since the peak current is greatly magnified by the voltage unbalance. For very large capacitor banks where the ripple voltage is small, the peak current from each phase is limited only by the source impedance and any additional impedance in the PDS and the difference between the capacitor bank voltage and the line voltage. The ratio of peak currents between phases can be as large as 20 % for 3 % voltage unbalance with a 1 % source impedance. Fortunately, this is an extreme condition since it is unlikely that single-phase loading could cause this magnitude of unbalance with a 1 % source impedance.

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B.6 Voltage dips – Voltage fluctuations

B.6.1 Voltage dips

B.6.1.1 Definition

Perhaps the most common form of low-frequency disturbance is the voltage dip or a reduction of voltage on one or all of the three phases. A voltage dip is a sudden reduction of the voltage at a point in the electrical system, followed by voltage recovery after a short period of time, from half a cycle to a few seconds. A voltage dip is generally caused by the clearing of faults by the utility supplying the mains or by the starting of large motors in or near the user's location. Surveys by different utilities in different countries have shown that voltage dips can range from a time of half a cycle to 15 cycles or more at voltages outside the 10 % voltage tolerance. The residual voltage (lowest value of the voltage during the dip) is now preferred to the depth of the dip to characterise the magnitude (the depth is the difference between the reference voltage and the residual voltage). The residual voltage largely depends on the relative location of the voltage source (generally a high voltage/medium voltage substation), the event equivalent to a short circuit and the observation point. Comprehensive information is available in IEC TR 61000-2-8.

B.6.1.2 Effect on PDSs

B.6.1.2.1 Fundamentals

Voltage dips can have detrimental effects upon the performance of PDSs. When the supply voltage is reduced, usually the power that can be transferred from the mains to the motor is also reduced. However, some PDS converters compensate for voltage dips over limited ranges by changing control angles for input rectifiers. Also of concern, regenerative converters that transfer mechanical power from the motor back to the mains may encounter issues with voltage dips.

The effect of voltage dips on PDS should be considered according to the physical nature of the driven equipment. Moreover, the electronic control of the PDS and the power converter components should be distinguished (see IEC TR 61000-2-8).

The control part could be immune, with performance criterion A, to certain types of dips, and this could be of no use unless it is consistent with the behaviour of the converter or of the driven equipment. The converter has no energy storage capability. The driven equipment generally has little energy storage capability, which can be used under certain conditions. To claim that a PDS is immune to voltage dips purely on the basis of the immunity of the control part would be misleading. The use of a specific sequence in the control should be documented to make it possible for the user to define the suitable adaptation to the driven equipment.

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B.6.1.2.2 Controlled converters

Controlled converters, such as those that are made up of thyristors, GTOs (gate turn off thyristor), or transistors, are generally used to convert the AC mains to a variable DC voltage. The logic that is used to synchronise the control of the power semiconductors is often designed to inhibit rectification when the mains voltage drops below a specific value. In some cases, the control is shut off until the user resets the logic or, in others, operation will be resumed only if the voltage returns within a specified amount of time. Normally, the PDS will not be able to control the motor during the dip interval and control could be lost until the logic is reset. If the process that the PDS is controlling is critical, discussions with the PDS manufacturer should occur such that the reaction of the logic to the voltage dip is compatible with the process needs. In some critical cases, it is necessary to apply additional measures (for example alternative power sources) to carry the process through severe voltage dips.

During voltage dips, the power available from the BDM/CDM and to the motor is reduced. This can affect operation depending on the motor operating points. Consider the case of a controlled 6-thyristor bridge supplying power to a DC motor. If the motor is running at high speed, a voltage dip can cause the peak line voltage to drop below the armature voltage. The thyristors will be commutated off by the armature circuit and the current in the armature circuit will be reduced. If on the other hand, a voltage dip occurs when the motor is running at low speed, the control circuitry can advance the control point to compensate for the reduced voltage. In this case, the control of the motor will not be affected. For critical loads, the effect of a voltage dip should be discussed with the manufacturer of the PDS to determine how the control circuitry will react.

Regenerative converters of the type that use the line voltage to commutate the thyristors in the bridge are particularly sensitive to voltage dips. If the line voltage drops too low during this reverse power flow, control of the power flow from the motor to the mains is lost since the thyristors cannot be turned off. If the control circuitry does not react or if the dip is particularly abrupt or occurs after a thyristor is turned on, the previously conducting thyristor cannot be turned off and excessive uncontrolled currents can flow from the motor. These currents can result in potentially detrimental effects on the process or even damage to the motor. For critical loads, the effect of voltage dips on regenerative converters should be discussed with the manufacturer of the PDS to determine how the control and power circuits will react during this interval. For critical loads, additional circuitry can be added to force-commutate the thyristors or alternative power sources can be used to carry the PDS through the dips.

Regenerative converters of the type that are force commutated by some means can also be affected by voltage dips. This is because the reduction in voltage during the dip can reduce the amount of power that can be transferred from the load to the motor and to the mains. If this condition exists, control of the motor can be lost during this interval.

B.6.1.2.3 Uncontrolled converters

Uncontrolled converters such as diode bridges are not greatly affected by a voltage dip, with the exception of the high inrush currents which can flow into the capacitor banks of voltage source converters after the voltage reappears. However, their output power and voltage are reduced during the voltage dip. This can cause detrimental effects on other parts of the PDS. If, for example, the converter is supplying power to an inverter, the output voltage of the inverter will be limited and control of the AC motor will be lost.

Some manufacturers also inhibit operation when the voltage feeding the inverter drops below a specific value. Some designs also require that the logic be reset before operation can continue. Other designs will restart operation when the voltage returns, but control of the motor is lost during the interval that the logic is inhibited. This interval can be extended by the time needed to synchronise the inverter control logic with the actual speed of the motor after control is lost.

The synchronisation is needed to match the output frequency of the inverter to the actual speed of the motor. The synchronisation process determines the appropriate frequency and voltage that should be applied to the motor for smooth transition from coasting to control.

PDSs of the type that would have a very large capacitor bank could ride through short voltage dips because of the energy stored in the capacitor bank. Generally, it is not economical to make a capacitor bank large enough to operate through voltage dips. In the case of critical loads, a battery can be used to supply power during the voltage dip. PDSs with adapted control can be able to continue operation during voltage interruption, provided the output power is near zero. In all cases, the effects of voltage dips on the operation of the PDS should be discussed with the manufacturer to determine if the PDS is compatible with process needs.

B.6.1.2.4 General protection types

It has been shown that immunity to voltage dips is very dependent on the nature of the converter and on the load behaviour. Absolute protection can be very expensive, and the choice of the protection should be carefully compared with the process requirements.

Absolute protection requires a backup power supply. For example, this can be a UPS (uninterruptible power system), external to the PDS, or a DC source (battery) supplying the DC link of a voltage source inverter.

Ridethrough sequence is a technique which uses the possibilities of the command to avoid transient overcurrent, but without backup energy. Therefore, the speed of a passive load will necessarily decrease with a rate approximately given by the ratio of the load torque to the inertia. For safety reasons, this kind of protection cannot be used with active loads (example of hoisting during regeneration where mechanical braking is necessary).

Flying restart is the continuation of the ridethrough sequence which can be used in case of passive loads with long or very long coast down times. This can also be a protection against dips or short interruptions.

Automatic restart always implies safety conditions, which are the responsibility of the user.

B.6.2 Voltage fluctuation

Interharmonics can cause flicker on lighting equipment, as explained in B.4.3, and compatibility levels are given in IEC 61000-2-2, in IEC 61000-2-4, in IEC 61000-2-12 according to the type of network. Interharmonic emission of a PDS should be limited in such a way that the calculated interharmonic voltage at the IPC, due to a given PDS, does not exceed 80 % of the voltage compatibility levels.

PDSs driving large loads such as punch presses, flying saws and machine tools will require large currents from the mains periodically. This will cause voltage fluctuations of the mains voltage. The source impedance of the mains supplying these PDSs should be sized so that the voltage fluctuation does not exceed the 10 % tolerance.

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Peak loads that on average do not exceed the ratings of the supply system, but will produce deviations of the supply voltage that exceed the tolerance should also be considered when sizing this impedance. On the public network, the voltage fluctuation from a single piece of equipment is not supposed to exceed 3 %. If fluctuations are frequent, flicker limits should be applied to the public network and to any network which supplies a lighting load (see 6.2.4).

B.7 Verification of immunity to low frequency disturbances

According to 5.2.1, the immunity of the PDS to low frequency phenomena may be verified by calculation, simulation or test. The manufacturer can use the cells of Table B.3 to identify which verification method has been used for each phenomenon.

Table B.3 – Verification plan for immunity to low frequency disturbances

Phenomena	Calculation	Simulation	Test	Analysis	Not applicable
Harmonics					
Commutation notches					
Voltage variations					
Voltage changes					
Voltage fluctuations					
Voltage dips					
Voltage unbalance					
Frequency variations					
Supply influences – Magnetic fields					

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Annex C
(informative)

Reactive power compensation – Filtering

C.1 Installation

C.1.1 Usual operation

A user of electricity, supplied by a distribution network, generally has several or many apparatuses finally connected at the same PCC. The term "installation" is used to describe the combination of apparatus, equipment or systems and their feeding systems which are connected at the PCC.

In the same way, many industrial apparatuses include more than a single PDS.

A discussion of power factor, reactive power and harmonic emission of a single PDS is not sufficient and can cause unnecessary technical difficulties. In reality, the solution which is required is a solution for the installation. The installation contains many different loads.

C.1.2 Power definitions under distorted conditions

Under distorted conditions, there is an extension of the definition of power compared to sinusoidal or non-distorted conditions. The total apparent power S, to which an electrical component is subjected, is defined in balanced three phase systems as follows:

$$S = 3\,V\,I = 3\sqrt{\sum_{1}^{\infty} V_k^2 \sum_{1}^{\infty} I_k^2}$$

Due to the presence of high-order harmonics of voltage and current superposed to the fundamental, the expressions of the active power P and reactive power Q become:

$$P = 3\sum_{1}^{\infty} V_k\ I_k\ cos\varphi_k$$

$$Q = 3\sum_{1}^{\infty} V_k\ I_k\ sin\varphi_k$$

and the apparent power is defined as:

$$A = \sqrt{P^2 + Q^2}$$

This power is different from the total apparent power. In particular, the following relation applies:

$$S^2 = P^2 + Q^2 + D^2$$

where D (defined as distortion power) takes into account the power resulting from voltage and current components with different ordinal numbers.

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The sum of the squares of the reactive power Q and the distortion power D gives the square of the non active power N:

$$N^2 = Q^2 + D^2$$

This power is defined as non-active because it is the difference between the square of the total apparent power S and the square of the active power P:

$$N^2 = S^2 - P^2$$

The total power factor λ between the active power P and the total apparent power S seen from the network can be written as:

$$\lambda = \frac{P}{S}$$

The power factor correction refers to this parameter.

The total displacement factor under distorted conditions, cosϕ, is an extension of the usual displacement factor under sinusoidal conditions, and is defined as:

$$cos\phi = \frac{P}{A}$$

If there is no distortion in the waveforms of voltage and current, both displacement factors coincide.

In order to express the influence of the distortion power D, a distortion factor cosψ can be introduced and defined as:

$$cos\psi = \frac{\lambda}{cos\phi} = \frac{A}{S}$$

C.1.3 Practical solutions

C.1.3.1 Common practice

It is well-known that to avoid overrating of the installation and an unnecessary increase of the current flowing in the distribution network, it is necessary to work with a good power factor. But practical use considered this power factor only from the reactive power point of view; in fact, it has been seen here that harmonic content is also concerned.

It has usually been the case that an industrial installation consumes reactive power. Therefore, it has also been usual to install a global compensation in order to reduce the displacement factor and so reduce the installation's consumption of reactive power. In order to do that, capacitors were installed whether close to the consumer of reactive power, or globally close to the PCC. In some countries, utilities introduce taxes for that displacement factor, particularly when the distribution network is heavily used.

C.1.3.2 Evolution of common practice

Because power factor is of concern and because of increasing use of distorting loads, harmonic compensation is also necessary. This harmonic compensation can be performed globally with filtering of the complete installation or locally with filters close to the distorting loads. It can also be better to use non-polluting loads.

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From this introduction, it can be seen that two types of compensation are necessary: displacement factor and current harmonic content. Two methods can be used for each of these compensation types: a global approach for the total installation or a local approach for each distorting load. Four cases can be seen, but none is independent so this problem should be discussed in more detail.

C.1.4 Reactive power compensation

C.1.4.1 General compensation criteria

Power factor correction equipment is composed of capacitor banks connected to the power line by electromechanical or static contactors. The following covers phenomena related by use of capacitor banks connected by electromechanical contactors.

The size of the capacitor bank to be installed is a function of the active and reactive power compensation needed by the system, and also of their variation during the day (load-time characteristics). It is also a function of the pricing practice of the utility.

The correction is frequently defined with the mean value of energy consumption (active and reactive) during the heavy duty times of the day, within a one month period.

NOTE The concept of reactive energy used in Annex C is defined by the time integral of the reactive power.

For rating, it is necessary to know the utility criteria:

- heavy duty times in a day;
- limits of reactive power ratio free of charge (for example tan φ);
- user data such as load-time characteristic.

It can be seen that correction of reactive power consumption cannot be constant nor permanent. A permanent correction would actually lead to reactive power injection in the supply network at certain times. The result would be an increase of the voltage in the user's installation which is not necessarily an advantage. Such a study is of concern for a complete installation and almost impossible for each PDS.

Another point is that capacitors can be installed either on the low-voltage side or on the medium-voltage side. Common practice shows that the installation on the MV side has an economical advantage, as soon as reactive power correction reaches 600 kvar. For lower ratings the LV side should be preferred.

If power factor correction capacitors are to be installed in networks with harmonic current sources, it is recommended that reactors should be added in series with the capacitors. This is so that the resulting resonance frequencies are shifted below the lowest frequency of the characteristic harmonics, normally the 5th (see C.1.4.4).

C.1.4.2 Application to low-voltage correction

C.1.4.2.1 Different solutions

According to local conditions, three types of correction can be defined:

- individual apparatus correction;
- section correction;
- global correction.

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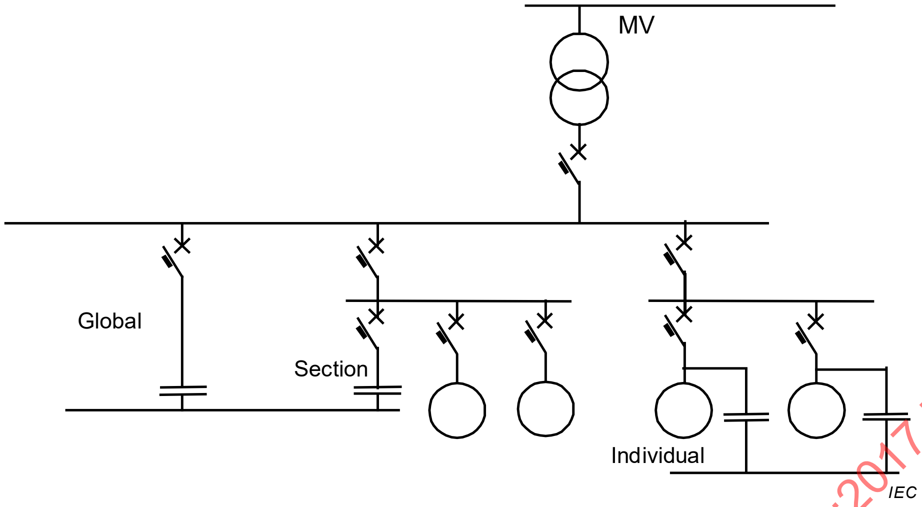

Figure C.1 – Reactive power compensation

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C.1.4.2.2 Individual compensation – for motor directly coupled to network

Individual compensation is particularly advisable when a fixed speed motor rated higher than 25 kW exists and if it is to be run for the majority of working hours. This applies in particular to motors driving high-inertia machines, such as fans. The operating switch of the motor automatically connects or disconnects the capacitor. It is advisable to verify that there is not a risk of resonance.

a) ***Advantages:*** The reactive energy is produced directly at the point at which it is consumed. A reduction in the reactive current load results along the whole length of the power supply cable. Individual compensation thus makes the most important contribution to the reduction of apparent power, and of voltage drops and losses in the conductors.

b) ***Disadvantages:*** The individual compensation is relatively costly, several small capacitors being more expensive than a single large capacitor bank. When the capacitors are connected, they raise the voltage of the plant network locally. It would thus seem necessary to be able to disconnect them during periods of low load (and therefore increased voltage) in the public network in order to reduce the voltage. Indeed, a high voltage would entail the risk of placing excessive stress on the equipment, thus causing its premature ageing. The capacitors should consequently be connected, if possible, to the network by means of their own switchgear. Another important disadvantage is that the proliferation of capacitors in an industrial network increases the risks of resonance. All these factors significantly reduce the potential advantages to be gained from individual compensation.

C.1.4.2.3 Compensation by section

In the case of compensation by section, a single bank of capacitors, operated by means of its own switchgear, compensates a group of consumers of reactive energy located in a workshop or in an area.

a) ***Advantages:*** The compensation by section requires less investment than individual compensation. However, the load curves should be well-known in advance to enable correct sizing of the batteries of capacitors and to avoid the risks of overcompensation (when the reactive power supplied is greater than that required), which produces permanent overvoltages, leading to premature ageing. The bank of capacitors have their own switchgear, thus making it easy to disconnect them during periods of low loads on the public network, even when the corresponding power consumers remain connected.

b) ***Disadvantages:*** The power supply cables of the various power consumers should be sized to carry both the reactive and active currents. In addition, provision should be made to protect the capacitors (for example fuses, circuit-breakers, etc.), and discharge them for safety purposes (discharging resistors) during maintenance operations. The fuses should also be regularly monitored.

C.1.4.2.4 Global compensation

In the case of global compensation, the production of reactive energy is concentrated at a single point, most frequently in the substation, or in an area which is sufficiently large and well-ventilated. In installations which have only small power consumers, it is generally advisable to adopt automatically controlled central compensation, again so as to avoid overcompensation. Where the load curve shows little fluctuation, it is necessary merely to engage the whole battery during the periods of operation of the installations.

a) ***Advantages:*** The capacitors have a good utilisation factor, and the installation is easier to monitor. In addition, with automatic control by the capacitor bank, the load curve of the plant can be followed effectively, while avoiding manual intervention (i.e. manual engaging and disengaging). This solution is potentially beneficial from an economic point of view if the load variations are not attributable to specific power consumers.
b) ***Disadvantages:*** The installations downstream of the global compensation connection carry all of the reactive power.

C.1.4.3 Application to medium-voltage correction

Compensation is generally carried out on a centralised basis. The capacitors are grouped in banks in the medium-voltage substation. The banks are connected to the medium-voltage bus via a circuit-breaker. Their power can reach several megavars (Mvar), and they can be divided into smaller sections which are brought into operation successively in order to obtain optimum compensation as a function of the daily load curve. Each section is operated by a switch provided for this purpose as a function of daily load curve or on-line control.

a) ***Advantages:*** When the banks of capacitors have power levels greater than 600 kvar, the cost of medium voltage compensation is typically less than that of low-voltage compensation.
b) ***Disadvantages:*** This method of compensation provides no relief to the part of the network which is located downstream of the capacitors. Engaging the capacitor bank causes voltage transients. Operation requires more attention than with capacitors in the low-voltage section.

C.1.4.4 Risks of resonance

Risks of resonance are due to the simultaneous presence in a network of capacitors for compensating reactive power and sources of harmonic currents comprising static converters. A simplified single-line diagram of a network, including a passive load R-L and a battery of capacitors compensating the load on a global basis, is shown in Figure C.2.

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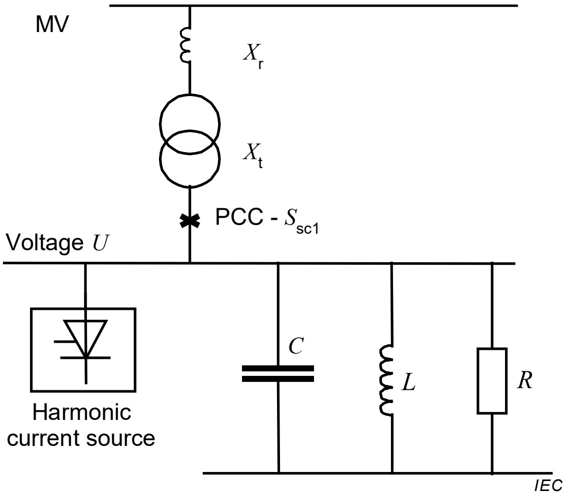

Key

P	active power of the passive load and losses
Q	reactive power of the passive load
X_r	impedance of power supply network of short-circuit power S_{sc0}
X_t	impedance of transformer of apparent power S_N (reactance x_{sc})
PCC	point of common coupling on the secondary bus with short-circuit power S_{sc1}
R,L	resistance and reactance corresponding to the active and reactive power P and Q of the load
C	capacitor for compensating reactive energy of power Q_{cond}

Figure C.2 – Simplified diagram of an industrial network

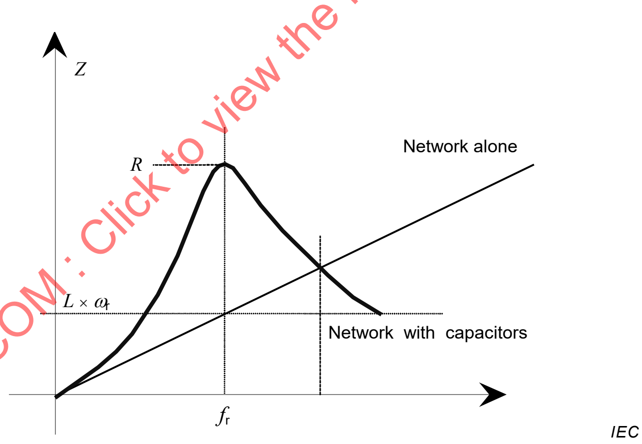

Figure C.3 – Impedance versus frequency of the simplified network

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Figure C.3 illustrates the changes of the harmonic impedance of the network at the PCC and the risks of resonance associated with the presence of a source of harmonic currents. The upstream impedances X_r and X_t contribute to a reduction in the short-circuit power available at PCC from the value S_{sc0} to the value S_{sc1}:

$$S_{sc1} = (1/S_{sc0} + X_{sc}/S_N)^{-1}$$

Therefore, (Z_h), the equivalent harmonic impedance of the network at the PCC, for harmonic order h, has the following value:

$$Z_h = (h\ U)^2\ [(h^2\ Q_{cond} - S_{sc1} - Q)^2 + h^2\ P^2\ ]^{-½}$$

and the resonant frequency is:

$$f_r = f_1 [(S_{sc1} + Q)/Q_{cond}]^{1/2}$$

where f_1 is the frequency of the fundamental.

Figure C.3 shows the variation in the impedance Z_h as a function of frequency, and the impedance of the network only due to X_r and X_t. Note that Z_h shows an amplification at the resonant frequency f_r compared to the impedance of the network alone. Examples of network impedance and damping considerations are given in IEC TR 61000-3-6.

When, at certain harmonic frequencies, the network impedance is high and injection of harmonic currents arises at the corresponding frequencies, considerable harmonic voltages result, as can be found by applying Ohm's law. There is resonance between the inductive reactors and the network capacitors. This has a variety of consequences.

a) There is a risk of overloading the capacitors due to the overcurrents flowing through them, particularly due to the high frequencies of harmonics.
b) There is a risk of breakdown at the terminals of these capacitors due to the considerable harmonic voltages.
c) A high harmonic voltage at the terminals of an industrial installation can give rise to abnormal operation of apparatus with sensitive electronics and to overheating in motor windings.
d) The occurrence of harmonic voltages will lead to a generation of harmonic currents in the distribution network and in other customers' installations.

Care should be taken either to reduce the emission of the harmonic current sources, or to install filters. The location of capacitors in an industrial network is thus an important factor in the occurrence of resonances.

Problems of resonance often necessitate a detailed analysis of the electrical network before they can be solved. These problems are not systematic in nature but, when they do occur, their consequences often mean damage to equipment, not to mention the effects of accelerated ageing.

The above analysis is limited to one reactive power compensation circuit. It is pointed out that multiplication of such circuits in a network multiplies the resonance risks.

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C.1.5 Filtering methods

C.1.5.1 Criteria

Filtering of an installation is not relevant for this document. The application to PDSs has similar difficulties as that of filtering an installation. Moreover, the analysis developed in C.1.4.2, C.1.4.3 and C.1.4.4 about reactive power compensation could be followed with a similar approach and similar conclusions, only the initial criteria are specific.

When an excessively high-voltage distortion level can be expected, filtering should be applied. The voltage distortion level is assessed according to Clauses B.3 and B.4. A particular PDS to be filtered is known with its conventional harmonic emission characteristics, i.e. levels of harmonic current are known. But this characteristic is not sufficient to define a filter.

A filter generally consists of equipment which is connected to the network and which presents a very low impedance at the particular frequencies which are filtered. Therefore, the filter absorbs harmonic currents of those particular frequencies. However, there is no discrimination between the harmonic current coming from the PDS, and whose preferred path of low impedance is through the filter (instead of the network of higher impedance), and the harmonic current coming from the existing harmonic voltage on the network. The latter current is only limited by the sum of harmonic impedance of the network and impedance of the filter (see Figure C.4). From this discussion, it can be seen that designing a filter is a rather complex affair which requires the knowledge of the three basic parameters:

- current to be filtered, the origin of which is the PDS (responsibility of the manufacturer of the PDS);
- existing harmonic voltage (compatibility levels could be chosen but would generally lead to overrating of the filter);
- harmonic impedance at the PC (responsibility of the operator of the distribution network, who is the user inside the factory in case of IPC, or the operator of the public distribution network in case of PCC).

The design of such filters requires exchange of information between the system supplier and the user.

It is important to note that knowing the harmonic voltage is of no use if the harmonic impedance is unknown. Often, preliminary measurements of voltages and impedance are needed for a correct rating of the filter.

Finally, the risk of multiple resonances is pointed out for similar reasons which have been developed in C.1.4.4.

C.1.5.2 Passive filter

The most traditional filters are resonant circuits (inductance and capacitors in series) or damped circuits by addition of resistors or more complex structures adding poles and zeros to the impedance of the filter.

A filter presents a very low impedance at a particular frequency which is a multiple of the power frequency. A bank of filters using different resonant circuits in parallel provides filtering of several harmonic orders 5, 7, 11, and 13 for example (see Figure C.4). They also may include high pass circuits. They are designed for a fixed power frequency and, in particular when they are only slightly damped, the effectiveness of the filter is dependent upon the stability of the power frequency.

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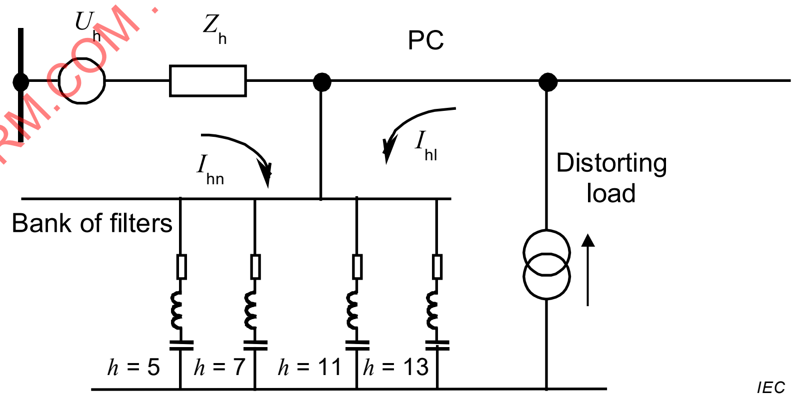

Figure C.4 – Example of passive filter battery

Note that filtering of interharmonics requires damped filters and is only efficient in a narrow band of frequencies.

Two main phenomena are pointed out regarding the risk of resonances.

- A resonance generally exists at a frequency which is a little bit lower than the tuning frequency. It is necessary to verify that this will not affect the ripple control or mains signalling which can be used on the network. It is the responsibility of the user with help from the utility to inform the manufacturer of such possible mains signalling with the characteristics of the carrier frequency.
- Filtering of each PDS multiplies the risk of resonances, and the result can affect a large part of the installation. Generally, only a case by case analysis can get rid of these difficulties, which is the reason why a global compensation should be preferred.

C.1.5.3 Location of the filter

In the case of an individual filter, the filtering equipment should be as close as possible to the distorting PDS.

But with the preferred method of global compensation, the location and structure of the filter should be chosen in regard to the parameters of the installation:

- natural uncoupled sections in the network;
- other distorting PDSs or distorting loads with their distorting characteristics, i.e. conventional harmonic current emission;
- impedances of the distribution network particularly presence of long lengths of cable, or reactive power compensation circuits (see Clause C.2).

C.2 Reactive power and harmonics

C.2.1 Usual installation mitigation methods

As indicated in C.1.1, reactive power compensation and harmonic current filtering techniques are quite linked, so they cannot be correctly applied independently.

Referring to C.1.4.4, the risk of resonance exists as soon as a capacitor is connected to a network which is naturally inductive. Electric cables also introduce capacitances into a network. The following example shows that, with a capacitor compensating reactive power, the harmonic currents at the PCC are increased. Significant harmonic currents also flow to the capacitor.

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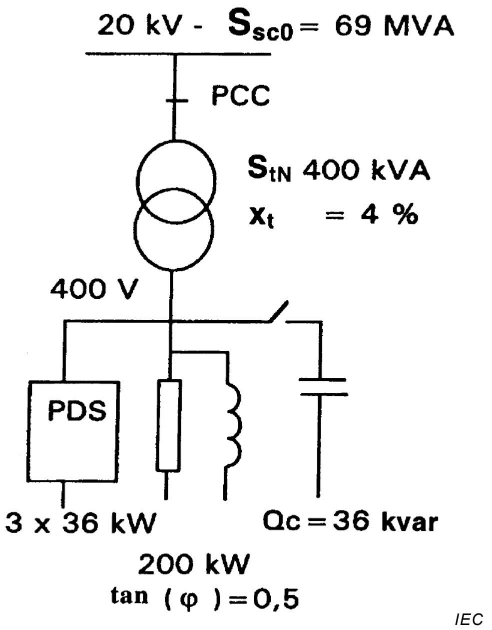
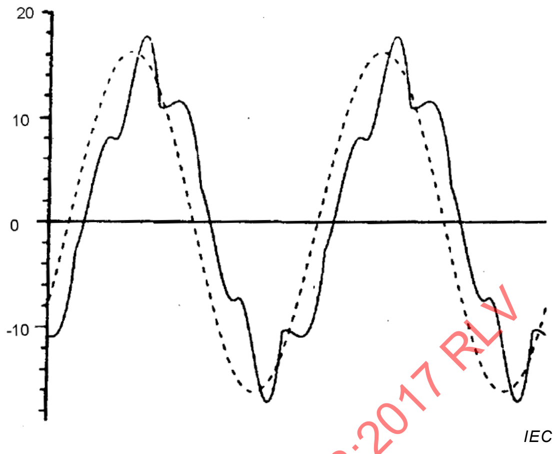


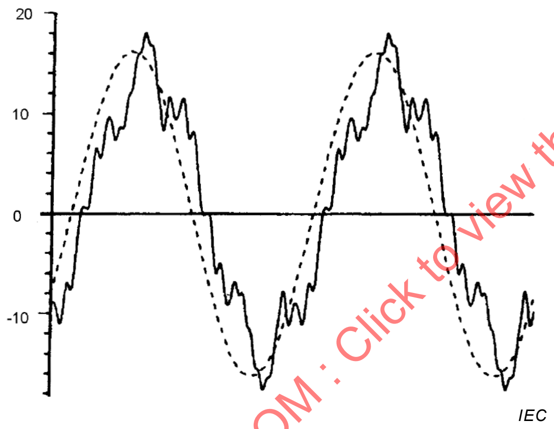
a) Circuit diagram



Solid line – current in amperes

Dashed line – line to neutral voltage in kV

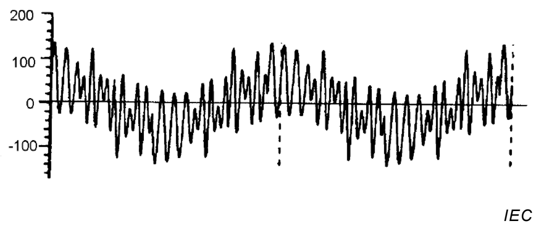
b) Waveforms at PCC when Q_C is not connected



Solid line – current in amperes

Dashed line – line to neutral voltage in kV

c) Waveforms at PCC when Q_C is connected



Solid line – current in amperes

d) Current in Q_C

Figure C.5 – Example of inadequate solution in reactive power compensation

It can be seen in Figure C.5 that the problem is complex with only one capacitor, and increases with the number of capacitors used for compensating reactive power. The multiplication in a network of capacitors for passive filtering and for compensation of reactive power as well, increases the number of possible resonance frequencies. Therefore, global compensation, taking the whole system into account, will show the best results.

Moreover, proceeding separately to reactive power compensation and to filtering increases the risk of over production of reactive power. Actually, efficient passive filtering also produces a significant amount of reactive power. Therefore, considering both phenomena together gives the opportunity to define a better solution by designing optimum equipment for the whole installation.

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C.2.2 Other solutions

C.2.2.1 General

The main drawback of passive filters is often their inability to adapt to network changes and filter component variations (ageing, temperature, etc.). A passive filter is efficient if its impedance at given frequency is very low compared to that of the source. However, in certain cases, compensation becomes difficult if the source (i.e. the network) impedance is low or if the filter frequency characteristics are not accurately tuned to the harmonics generated by the load. But, above all, the most serious problems are series or parallel resonances with the network which can occur.

Consequently, both for the electrical utility and/or the user, other compensation methods can be required to make optimum use of the energy drawn from the network. New solutions, offering better performance, are under consideration and some have already reached the production stage. These solutions are active power filters, and non-polluting PDSs including power factor correction network controls.

C.2.2.2 Active filters

All active filters have been developed based on the active PWM converters. They can be divided into two types, regardless of the configuration topology:

- Power factor correction converters (PFC) normally used for low power applications. These do not have any influence on the active power, or the ability to operate as rectifiers. They work in DC and are in cascade with AC-DC converters;
- Active infeed converters (AIC), often known as active front end (AFE). These are AC-DC converters which can pass active power as well as influencing the reactive power. AICs operate in four quadrants. They can be classified as current source inverters (CSI) or voltage source inverters (VSI). The CSI PWM modulated bridge inverters behave as a source of non-sinusoidal current, and have current harmonics due to non-linear loads. They have an inductance on the DC bus which ensures the circulation of a continuous current in the d.c. link. CSI inverters have a good reliability, but have large losses and require high values of capacitive filters in parallel to the network terminals, to eliminate the unwanted harmonic currents. Furthermore, CSI inverters cannot be used in a multilevel configuration for high power compensation. The other type of AIC converter is the VSI PWM modulated inverter. This converter is more convenient for active power filter applications because it is lighter, cheaper, and extensible to multi-level and multi-phase versions, in order to improve its performance for power factor correction for higher powers and lower switching frequencies. The VSI PWM modulated shunt inverter can be connected to the DC bus through a coupling reactor and an electrolytic capacitor that maintains a constant voltage at its ends and free from ripple. Active filters can be classified taking into account the type of converter, the control scheme and the characteristics of compensation.

From the topological point of view, active filters can be shunt type or series hybrid, the latter intended as a combination of passive and active compensation. The active shunt filters are used to compensate the harmonic currents, reactive power and unbalanced loads.

The shunt active filters compensate current harmonics by injecting equal but opposite harmonic current. In this case, the active filter operates as a current source injecting harmonic components that are 180° out of phase with those generated by the load. As a result, the components of the harmonic currents are eliminated by the active filter; and the current flowing from the source (a.c. generator) remains sinusoidal and in phase with the relative phase to neutral voltage. This principle is applicable to any type of load considered as a source of harmonics. Furthermore, with a control system of this type, the power active filter can also compensate the power factor of the load. The energy distribution system sees the combination of non-linear load and active filter as an ideal resistor.

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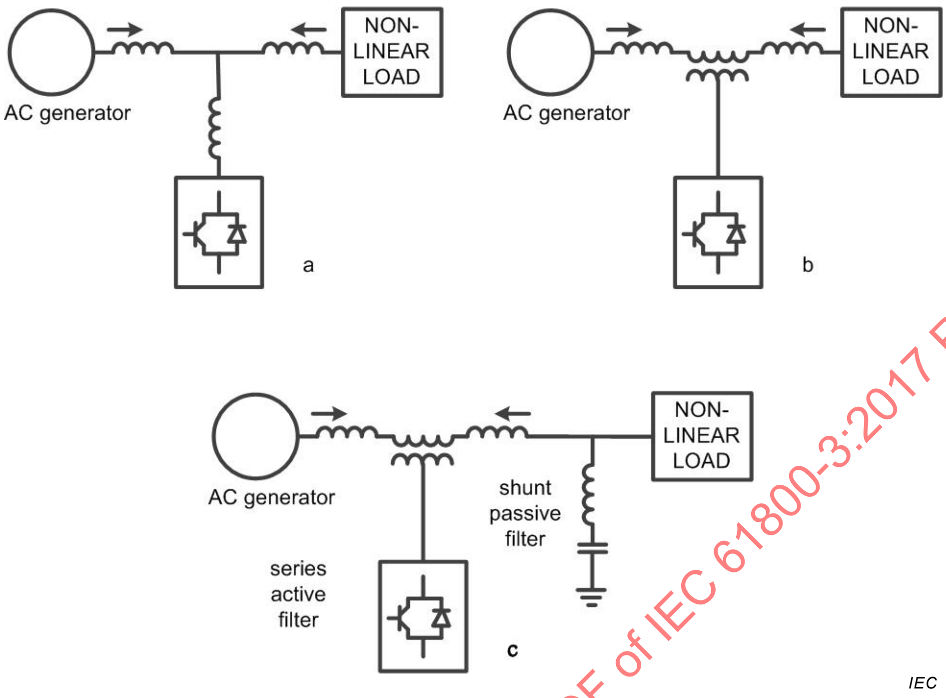
The series type active filters are connected in series between the load and the mains network. The series active filter is frequently connected through a transformer type coupling.



Key

a Shunt connection active filter

b Series connection active filters

c Hybrid active filters

Figure C.6 – VSI PWM active filter topologies

The hybrid configuration is a combination of a series active filter and a shunt passive filter. This topology is suitable for reactive power compensation of high power systems, because the power rating of the active filter as the PFC is a small percentage (about 10 %) of the power rating of the load. Most of the hybrid filter is formed by the shunt passive filter LC, used to compensate the lower order harmonics and reactive power.

The active filter for the compensation of the harmonics and the reduction of the phase shift is located, regardless of the connection, between the network and the non-linear load and is often made by placing a switching converter between the input rectifier and the storage capacitor. The control is carried out so that the input current follows the input voltage. The most widely used type of switching circuit is a boost converter. It does not mean that the converter operates in boost mode, i.e., step-up, but only that the circuit is boost type of circuit.

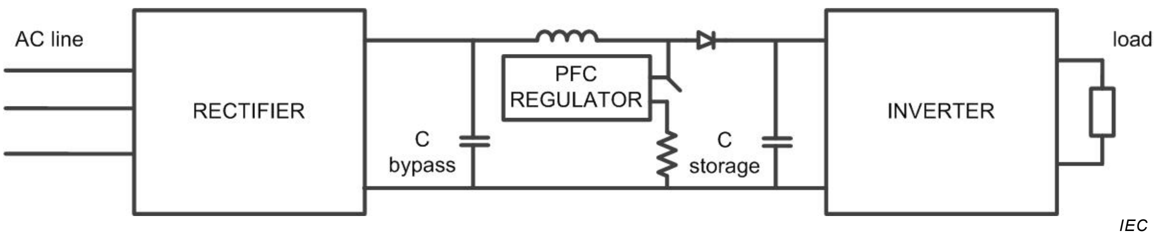


Figure C.7 – Boost mode converter

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The PFC changes a distorted waveform to build a sinusoidal current that is in phase with the input voltage. There are various techniques to achieve a sinusoidal waveform of the input current with low distortion, i.e. with low harmonic content.

In the PFC boost circuit, the inductor is in series with the AC power line. Therefore, the current input to the rectifier block is not a pulse waveform. The use of PFC includes the active regulation of the waveform of the input current I_1, the filtering of the switching frequency, feedback sensing of the current source for the control of the waveform and the feedback control for output voltage regulation.

An active PFC has a higher efficiency and is significantly smaller and lighter than the passive filter. In fact, it can operate at a higher switching frequency than the line frequency, allowing a strong reduction of the size and cost of passive filter elements.

C.2.2.3 Active infeed converter

The term "active infeed converter" (AIC) refers to a power converter placed on the network side with switching components such as IGBTs. The system includes, in addition to the front end, a bank of DC link capacitors and a load side inverter. The front end works as a rectifier, but during a regenerative mode can operate as an inverter feeding the network with recovered energy.

During periods when the energy flows from the network to the load, the converter operates as a rectifier with voltage AC input and voltage DC output. It works as a step-up chopper as the voltage on the DC link might be higher than the peak voltage of AC grid. The requirement of a constant voltage on the DC link is present both in rectifier and inverter operations. The voltage ripple can be reduced by placing the capacitor bank on the DC link.

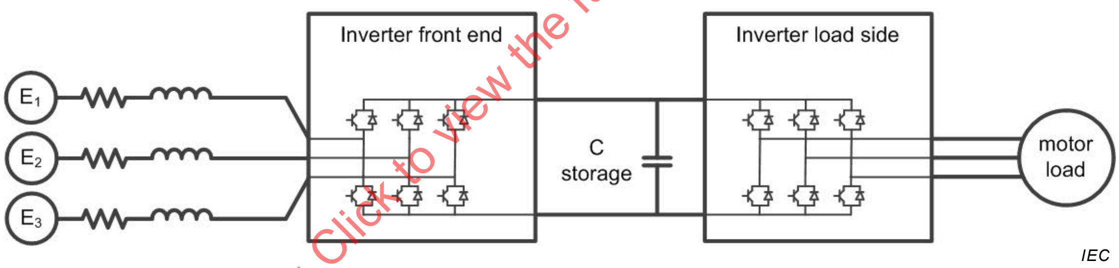

Figure C.8 – Front-End inverter system

Figure C.8 shows the system with the two converters, including the presence of the inductance necessary for boost operations in the line side. Additional filtering may be necessary on the mains side to comply with compatibility levels at the PWM frequency and its harmonics (see IEC 62578). An AIC can be considered as a synchronous voltage source connected in shunt mode and a compensator together with an element that can store energy such as the capacitor in the DC link. Because of its ability to regulate energy, the AIC has some advantages used to maintain compatibility levels required by the network.

These capabilities can be summarized as:

- the maximum achievable compensation is limited only by the value of the maximum permissible current of the switches and the ratio between the AC voltage and the DC link voltage. The AIC can keep the maximum value of volt-amperes reactive compensation and the desired voltage on the DC link even in the presence of severe dips in the mains voltage;
- the AIC can operate over the whole range of current, even with voltage reduced. Sometimes it can tolerate network voltages reduced even by 20 %;

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- by doing so, both with the elimination of harmonics and production of reactive currents, it increases the margin of stability in presence of failure;
- the response time of an AIC, acting as a compensator, can be a fraction of a half cycle (10 ms). By comparison, in the case of controlled thyristors the dynamic response time is as long as 5 to 6 cycles;
- the control strategy allows the AIC to exchange active and reactive power to and from the system to the AC line;
- due to the ability to exchange active power, the AIC can be used to adjust the damping of oscillations in the secondary winding of a transformer.

C.2.2.4 Application

The costs of such systems are or can be an important part of the costs of the distorting loads that they correct (PDSs or others). This should be understood regarding investment, operation and maintenance as well. Note that operation generates costs with increasing losses and also gains with decreasing reactive power consumption. Costs are balanced with the technical objective which does not allow any alternative to "Ensure EMC" (i.e. compliance with compatibility levels).

Another point is that the compensation can be global, local or combined more easily than with passive solutions because of reduction of resonance risks.

Last but not least, these active solutions increase the number of commutating electronic power devices and are responsible for an increase in high-frequency emissions.

The ideal solution does not exist, and all these elements should be considered. However, the definition of the solution of a particular problem should take into account the particular environment of this problem. The particular environment belongs to a generic class, but is refined by the very knowledge of the industrial conditions in each case.

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Annex D
(informative)

Considerations on high-frequency emission

D.1 User guidelines

D.1.1 Expected emission of PDSs

D.1.1.1 PDS and its components

In industrial environments, or public networks which do not supply buildings used for residential purposes, the customers who use PDSs on these networks have a general technical competence and are aware of EMC phenomena.

When selling the components of a PDS, the manufacturer cannot build-in mitigation methods against radio interference, because they are not aware of the EMC boundary conditions of the final installation. Moreover, the user of the components should have a free decision from the economical point of view, to use global or local filtering or screening methods, natural mitigation through distances, or the use of distributed parasitic elements of the existing installation, to achieve electromagnetic compatibility in a case by case manner.

D.1.1.2 Mains terminal disturbance voltage

The methods and values of quantitative judgement to achieve EMC are well-described in the normative part of this document. The level of mains terminal disturbance voltage in the frequency range of 150 kHz up to 30 MHz is important information for the user of an unfiltered PDS, in order to evaluate possible mitigation methods.

The following results are based on measurements made on converters, mainly PDSs, located in various countries in 2012. For an evaluation of the range of emission levels which can usually be expected, the frequency range was divided into the three usual parts (CISPR 11: 0,15 MHz to 0,50 MHz; 0,50 MHz to 5,0 MHz and 5,0 MHz to 30 MHz), and the maximum level from each PDS in every part was recorded as representative of that section. The measurements were made using quasi-peak detectors. Different load conditions (light load and maximum load), different rated input voltages (400 V to 690 V) and different rated powers (75 kVA to 1 000 kVA) were measured.

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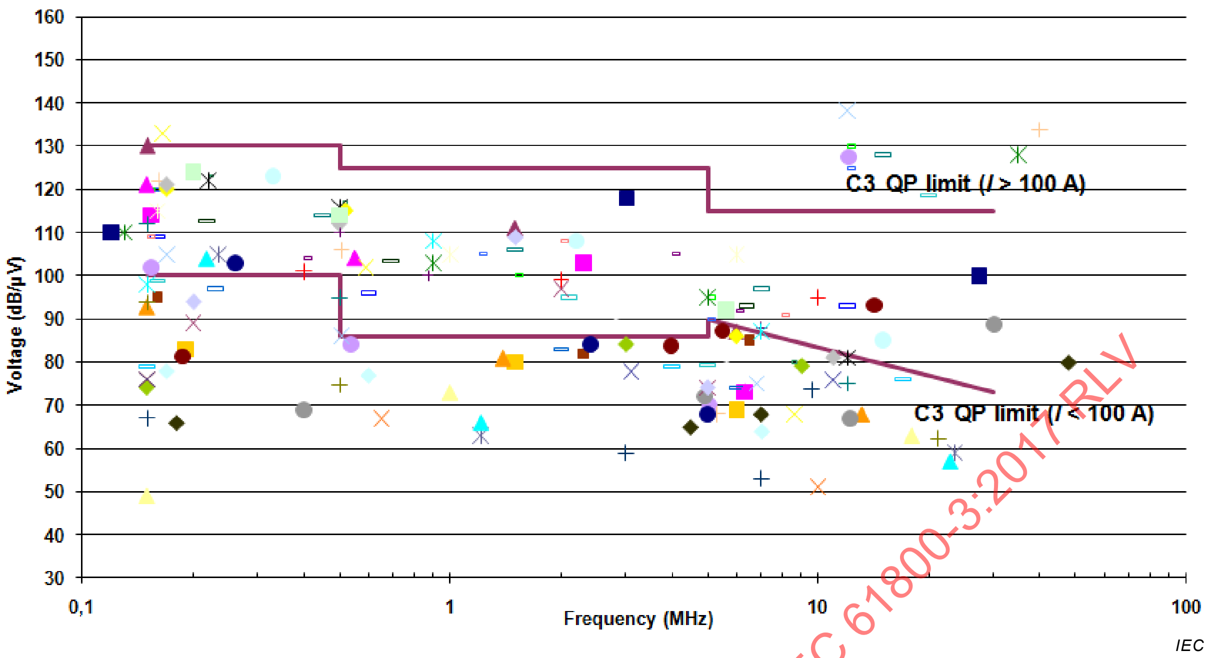

Figure D.1 – Conducted emission of various unfiltered PDSs

In most cases, this equipment is used without interference, but mitigation methods (for example HF filtering) should be taken in the vicinity of a radio-receiver or of a sensitive apparatus, such as for very low-voltage measurements.

D.1.1.3 Radiated disturbances

Measurements related to the radiated emissions have not been deeply investigated due to the lack of complaints in this range. However, what can be expected from the equipment is shown in Figure D.2. The evaluated results represent measurements corrected to peak values at 10 m measuring distance for PDS with or without different applied mitigation methods.

The continuation of the expected disturbance voltage ranges from Figure D.1 in the area above 30 MHz is only a rough approximation with very few representative values, but could show enough data to explain why there is a lack of complaints. As can be seen from this figure, the mean values of radiated emissions above 100 MHz are frequently crossing below the limits of CISPR 11 without mitigation methods.

An analytical approach is not presented in this range. The reason for that is the main sources of radiated emissions in most of the cases are the microprocessors or some active driven power supplies within the equipment and not the main power electronics of the converters at all.

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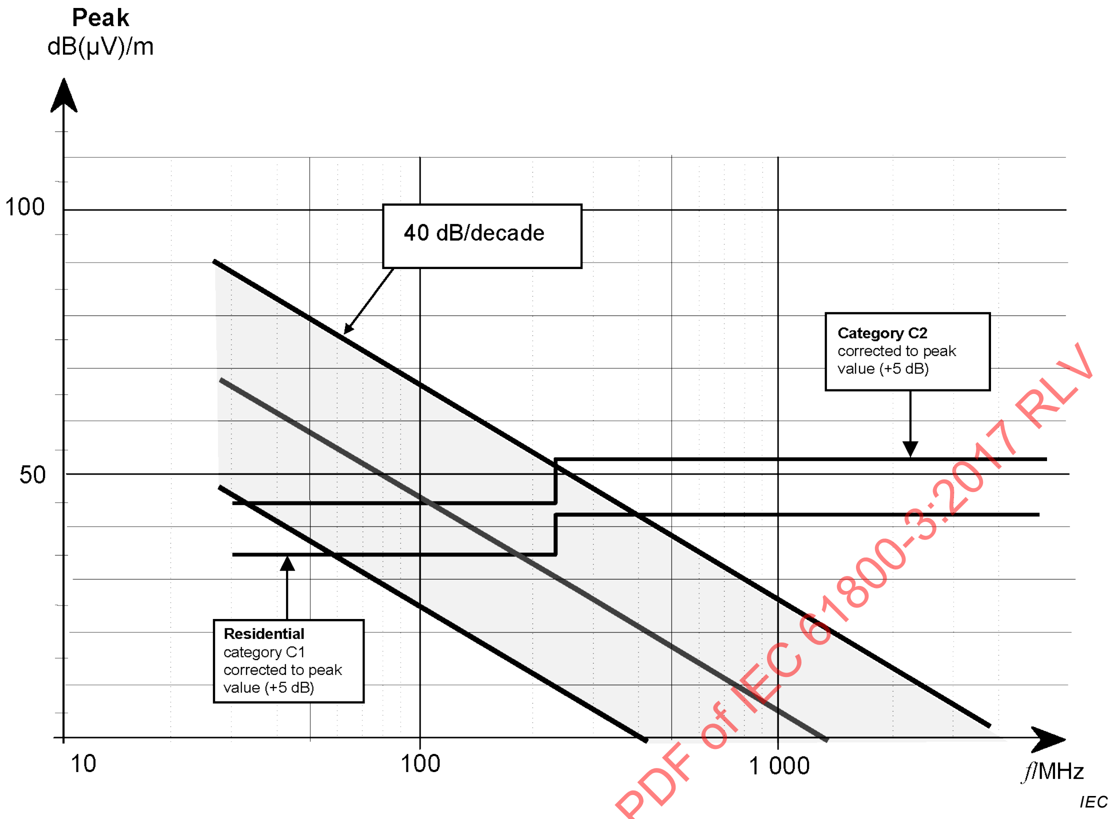

**Figure D.2 – Expected radiated emission of PDS up to rated voltage 400 V
Peak values normalised at 10 m**

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D.1.1.4 Emission from the power interface

The emission from the power interface is mainly due to common mode voltage. The common mode voltage on the power interface can have a high dv/dt. This high dv/dt induces current in the stray capacitance of both the cable and the electrical load (generally, the electrical load consists of the windings of the armature of a motor). These stray currents come back to their source through earth and either the supply network or input filters of the corresponding converter. Therefore, the emission from the power interface is linked with the disturbance voltage which is measured on the power port.

D.1.2 Guidelines

D.1.2.1 Public low-voltage network

The potential effects of the disturbances produced by a PDS depend upon the environment in which the PDS is used.

In some countries, small commercial or light industrial premises can be supplied by a public low-voltage supply which also supplies residential premises. In this system, there is no galvanic isolation between the three-phase input terminals of the PDS in the commercial or light industrial premises and the mains supply sockets in the residential premises.

Where an unsuppressed PDS is directly connected to a public low-voltage supply which supplies residential premises, there is a significant risk of disturbance to radio and television reception. In this environment, it is strongly recommended that the mains input of the PDS be filtered. Therefore, the user should select a PDS which complies with the appropriate limits given in 6.4.

D.1.2.2 Second environment

In an industrial environment, not on a public low-voltage supply, the common practice for many years has been to use unfiltered PDSs. In general, these have worked correctly and have not disturbed other equipment. This has been shown by a general lack of complaints about radio interference in industry. Therefore, they are compatible.

If problems do occur, they are likely to be due to the conducted disturbances from the BDM/CDM. These disturbances propagate along the supply and motor cables and can be coupled into other equipment by conduction, inductive or capacitive coupling, or radiation.

There can be problems if an unfiltered PDS is used in close proximity to particularly sensitive equipment. However, a PDS may not be the only source of disturbance and the sensitive equipment is usually of lower power rating than the PDS. Therefore, improving the immunity of the sensitive equipment can be a more economical solution than filtering the emissions from the PDS.

Problems are usually prevented by following normal installation guidelines, involving segregation of signal and power cables. If these are insufficient, either the immunity of the victim should be increased or the emissions from the PDS should be reduced, depending on which is the most economical solution.

The use of a commercially available EMC filter on the power interface between the BDM/CDM and the motor can lead to problems. It is likely that the capacitors in this filter would be damaged by the fast switching edges present on the BDM/CDM end of this interface.

If a shielded or armoured cable is used for the connection between the BDM/CDM and the motor without the BDM/CDM input being filtered, the coupling from the motor cable will decrease, but the conducted disturbances in the mains supply will increase, due to the capacitance of the armoured cable. Therefore, if a shielded or armoured cable between BDM/CDM and motor is being used to solve an EMC problem, a filter should be connected to the mains input of the BDM/CDM. However, minimising the length of the motor cable will generally assist in reduction of radiated emission of this cable.

Since filtering would cause safety problems in systems which are isolated from earth, the only solution in this case is to ensure that other equipment has sufficient immunity for this environment. In the case of systems in which one live line is connected to earth (known in some countries as "corner grounded" systems), the Y-class (line-to-earth) capacitors should be rated for the full line-to-line voltage.

D.1.2.3 Categories C1 and C3

The manufacturer should provide the information necessary for the user to select the correct emission category and to install the equipment correctly. This information should include clear instructions on the installation of any filters supplied as loose items. If special cables are required, this should also be stated.

Cabinet builders often use insulation withstand tests to check the quality of their wiring. However, an EMC filter is usually less able to withstand this test than the power converter. Therefore, the manufacturer should provide clear instructions on this subject to the user.

If the PDS is unsuppressed or is of a high emission category, the manufacturer should indicate this clearly in the user documentation. In this case, 6.4.1.1 and 6.4.1.3 require that the manufacturer shall provide a warning that the PDS is not to be used in a public low-voltage network which supplies residential premises.

If the PDS generates commutation notches on the input, this should be indicated in the user information.

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In case of problems, the manufacturer should offer (at the cost of the user) the solution necessary to make the PDS comply with a lower emission category.

D.1.2.4 Categories C2 and C4

In this case, the user has the technical competence to apply a correct EMC concept for the installation. The manufacturer should provide information about the emission category of the PDS.

The user will be able to select the correct combination of emission category and mitigation measures to provide the most economical solution for the installation.

D.2 Safety and RFI-filtering in power supply systems

D.2.1 Safety and leakage currents

The RFI-filtering sufficient to meet the emission limits is well-known in the state of the art. It is important to consider that the capacitance values and therefore the energy content and finally the effectiveness of Y-type capacitors used for the filters are limited by the normative requirements of safety standards, such as IEC 60065 in the case of plug-in apparatus. If the leakage current through this RFI-filtering capacitance to earth is too high, the effectiveness of protective measures with RCDs or RCMs within these supply systems can be compromised.

Safety requirements related to leakage current, including requirements for warnings, are given in IEC 61800-5-1.

D.2.2 Safety and RFI-filtering in power supply systems isolated from earth

In complex processes like rolling mills, bar mills or paper mills as well as centrifugal and auxiliary equipment in the sugar industry, crane equipment and chemical industry, it is useful and state of the art to have a distributed IT power supply system. Even if, for example, the motors are installed outside the building and are exposed to high humidity, it may be necessary to continue the process in spite of one insulation fault to earth. This insulation fault is detected via an insulation monitoring device (IMD) which may be combined with an insulation fault location system (IFLS) according IEC 61557-9. This measure allows the whole process to be safely run until the next service interval.

This "process safety philosophy" in industrial installations could be disturbed by a lot of parasitic elements as shown in Figure D.3 for example by capacitances C_{pv} between supply network and earth. The resulting capacitance is the sum of all Y-type capacitances and parasitic capacitances. The sum of all C_{pv} can reach values of several microfarads. Any RFI-filtering system would increase this capacitance-to-earth to an extremely high value because of the large number of Y-type capacitances used (for example n-times the capacitors C_y). With increasing capacitance it would become more and more difficult and finally impossible to detect an insulation fault correctly.

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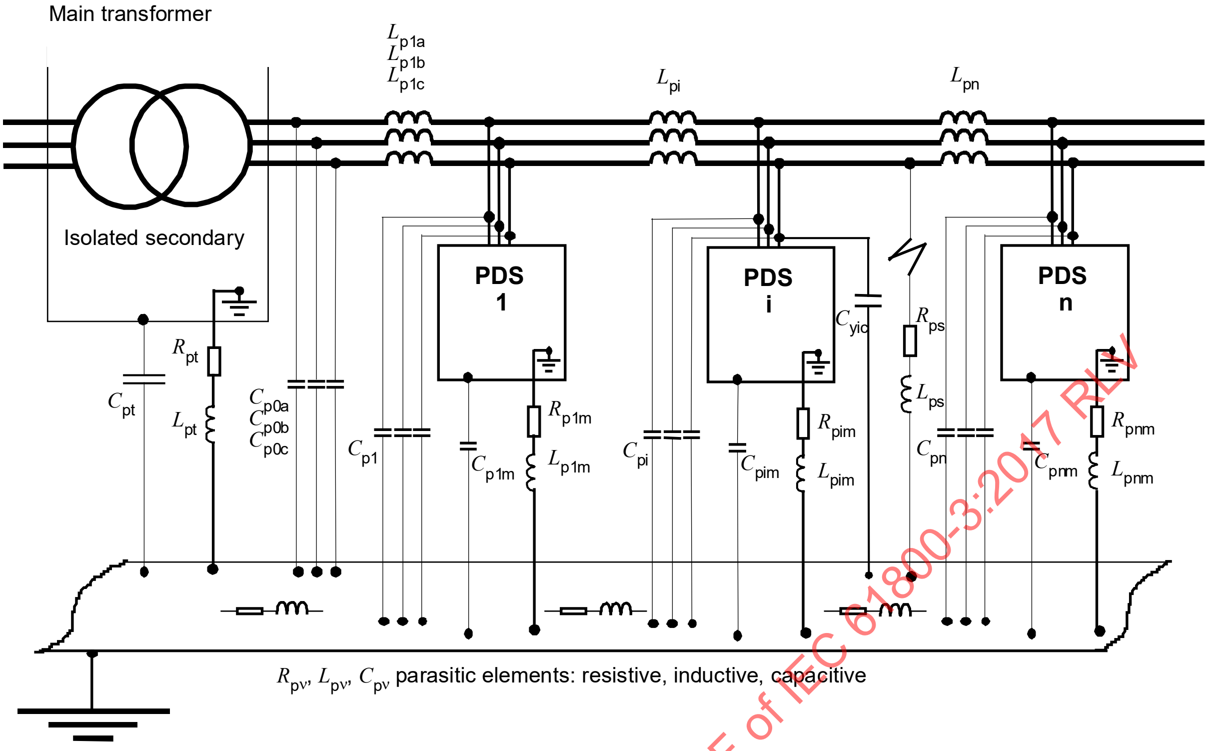

Several PDS are working together in a complex process with distributed isolated power supply.

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Figure D.3 – Safety and filtering

With RFI-filtering devices (C_y), any insulation fault to earth will cause very high current values to flow through the semiconductor switches within the power drive system. This is equivalent to short circuit conditions in the earthing network on any output failure. This would lead to a tripping of function and releasing of electronic emergency protective devices and finally to an undesired process shutdown with unforeseeable economic consequences.

These are the reasons why RFI-filtering is not compatible with isolated networks of distributed processes and therefore is not discussed in the above-mentioned examples. On the other hand, it can be expected that RFI-filtering would not be very effective in these networks. This is because the return path of disturbance current flow to the disturbing source in systems isolated from earth is only capacitive. It will be hard to define or calculate because of resonances with the parasitic line inductances L_{pv}. Finally, an increase of the disturbance currents flowing through some C_y's through this less defined path could lead to interference problems with other equipment working on the same supply system.

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Annex E
(informative)

EMC analysis and EMC plan for PDS of category C4

E.1 General – System EMC analysis applied to PDSs

E.1.1 Electromagnetic environment

E.1.1.1 General

Following the first standardised classification of intended use (see definitions in 3.2), a more detailed and adapted description may be conducted. Various approaches may be used to describe the electromagnetic environment (EM environment). The general characteristics of the environment on which compatibility levels may be based should be defined. If electromagnetic compatibility of systems is to be achieved, the immunity characteristics of equipment should be considered together with installation practices and design, physical separation, filtering, and shielding.

According to the types of PDSs, particular classes of environment can be determined.

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E.1.1.2 General modelling

A system consists of some subsystems. The existing devices (subsystems) can have two functions: emission and/or susceptibility (Figure E.1).

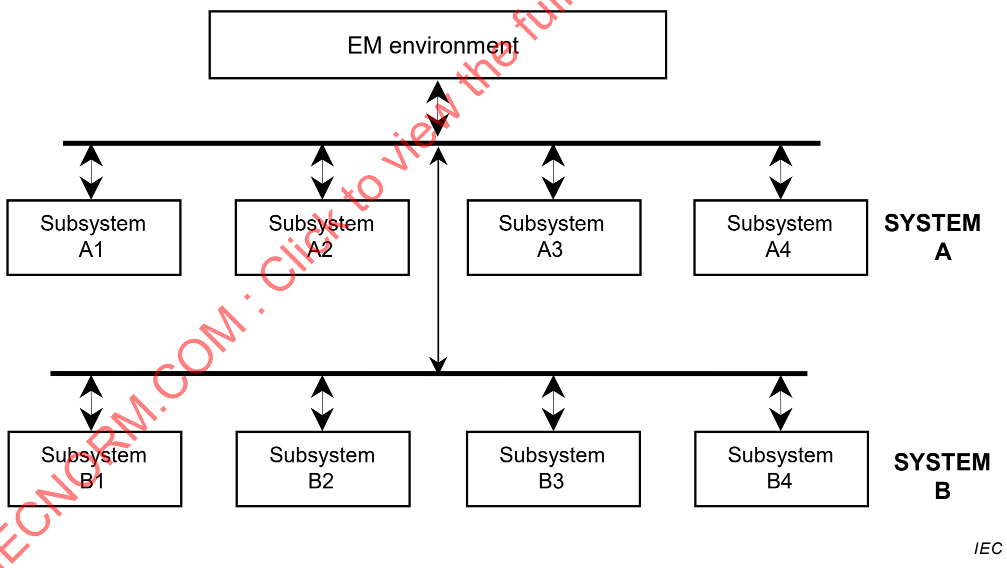

Figure E.1 – Interaction between systems and EM environment

Emitting devices determine the electromagnetic environment. Emission may reach the susceptible devices through various coupling types. General interactions are defined between subsystem i and subsystem j, and subsystem i and the environment. These interactions are defined with a coupling model using various coupling types (common impedance coupling, coupling by induction, and radiation – see Table E.1).

This model helps to define various EMC problems and to define specific limits. Some examples are given in Figure E.1 and Table E.1.

E.1.2 System EMC analysis techniques

E.1.2.1 Zone concept

The system EMC analysis tasks should be performed utilising knowledge of signal characteristics in each subsystem, noise immunity levels of critical circuits, engineering evaluation tests, and consideration of the operational EM environment. Models for sources (transmitters), receivers, antennas, propagation media and coupling paths should be developed as necessary. The objective of the system EMC analysis is to assist in the development of design requirements and procedures to ensure that the drive system meets the EMC requirements.

A zone concept for the drive system should be defined based on the operational electromagnetic environment and the susceptibility of subsystems and equipment. Specific acceptance criteria should be established for each zone prior to each EMC test. These criteria should define the procedure used for the drive system performance during the immunity testing and to detect malfunctions or deviations from specification requirements. The acceptance criteria for a particular subsystem (or equipment) should be included in the applicable EMC test procedure. The zone concept is illustrated in Figure E.2.

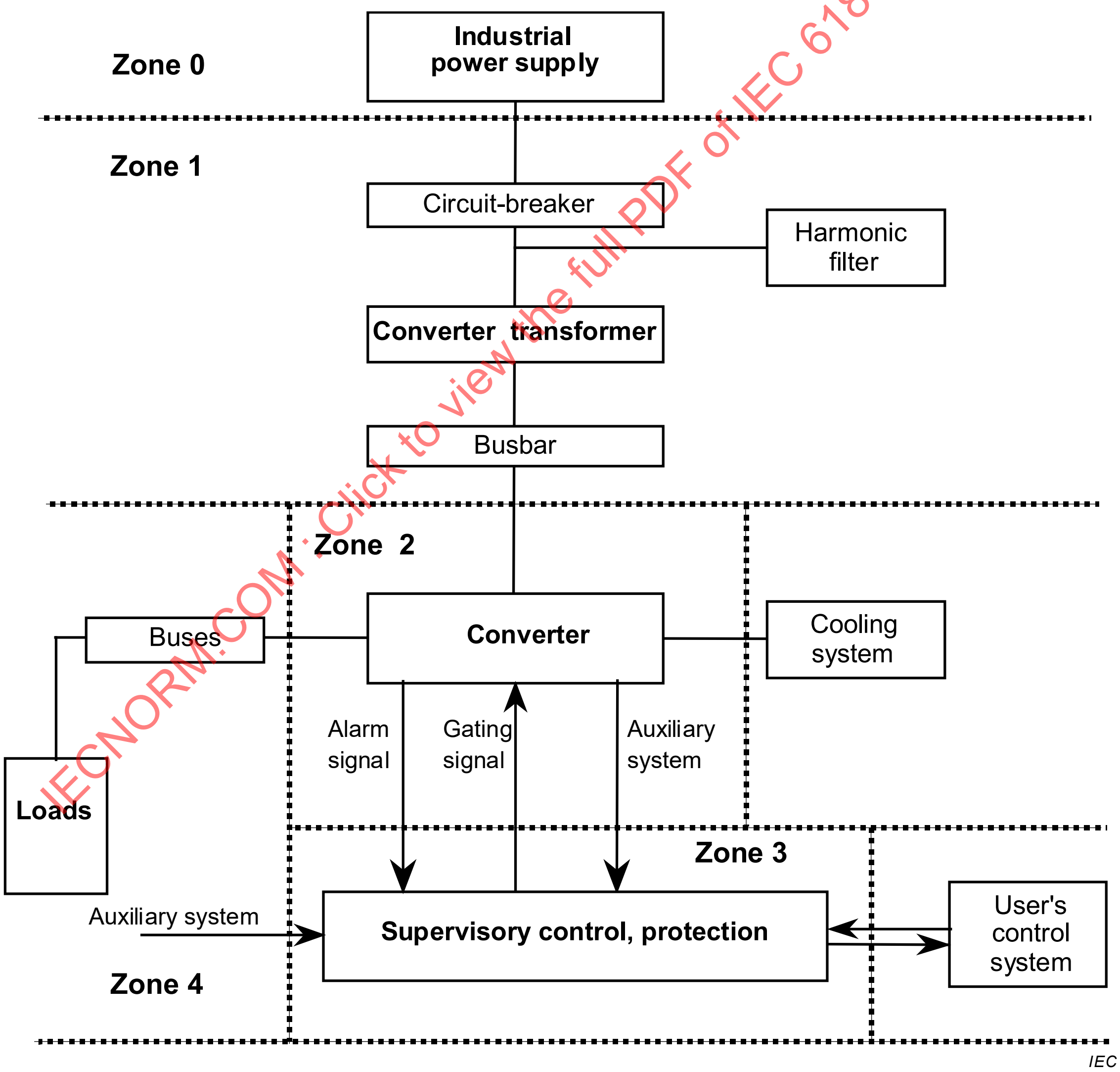

Figure E.2 – Zone concept

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E.1.2.2 Interfaces

Table E.1 gives an example of the power interfaces between the subsystems of the PDS (as shown in Figure E.3), and the types of interference (conducted, radiated).

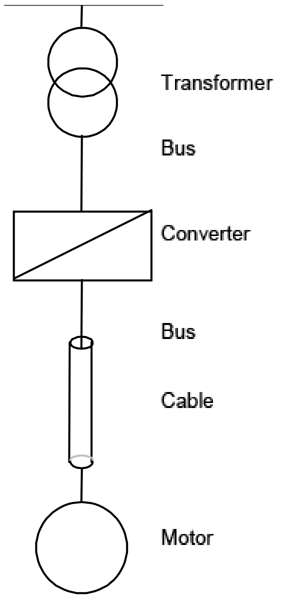

Figure E.3 – Example of drive

Table E.1 – EM interaction between subsystems and environment

	Subsystems as susceptible device				
Subsystems as EM-source	Environment	Trans-former	Converter	Cable	Motor
Environment	N/A	CI	CI Rad.	CI	CI
Transformer	CI E, H, Rad.	N/A	CI	N/A	N/A
Converter	CI Rad.	CI	N/A	CI	N/A
Cable	CI Rad.	Rad.	CI Rad.	N/A	CI
Motor	Rad.	N/A	CI	CI	N/A

NOTE Coupling model:

– common impedance coupling

CI: both resistive and reactive coupling

N/A: not applicable

– coupling by induction

E: electrical field coupling

H: magnetic field coupling

Rad: radiation coupling

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E.1.2.3 Equipment

The electromagnetic characteristics of each equipment (emission, immunity) and the zone to which it belongs should be determined.

In cases where an EMC plan is required according to 6.5.1, the following form can be used.

NOTE This plan is based on IEC TR 61000-5-1.

This EMC plan covers the use of a PDS in a specific installation. The purpose of the plan is to make an EMC analysis at installation level. Based on the EMC analysis, the measures to achieve electromagnetic compatibility will be defined.

E.2 Example of EMC plan

E.2.1 Project data and description

According to 6.5.1, the EMC plan reflects the agreement and the exchange of technical data between the user and the manufacturer. It should define the responsibilities of the manufacturer of the PDS, the installer and the user. The EMC plan is established jointly by all three parties. Any question which is not relevant to the particular application may be omitted.

The EMC plan is divided into two parts:

- E.2 defines the items which should normally be agreed;
- E.3 defines additional items that may be necessary in certain applications.

NOTE The marking N/A is used if the requirement is not applicable. An explanation is provided in such a case.

The example proposed below contains questions, the answers to which can constitute an EMC plan.

Name of manufacturer/supplier
Name of end user
Order No. .... Date

Type of facility (e.g. chemical factory, paper machine)
Application (e.g. pump. fan, conveyor) .....
EMC responsible person(s) ....

E.2.2 Electromagnetic environment analysis

E.2.2.1 Facility data

Installation location

Description of the neighbourhood (next to the second environment in which the PDS is installed)
First environment Second environment
The distance from the building/room of PDS to first environment: .... metres
The distance from the building/room of PDS to the other premises in the second environment: .... metres

Building and room construction

Type (wood, brick, concrete, steel, aluminium, etc.) ....
Reinforcement (steel, etc.) Yes .... No ....
Dedicated room for system Yes .... No.....................

Room layout

Sketch room layout as close to scale as possible. Shows all major equipment: windows, doors, etc.

E.2.2.2 Power and earthing data

Power distribution

Power distribution system for PDS:
Identification of the point of coupling (identification code for distribution panel, switchgear or transformer).......
Type of distribution system (example TN-C, TN-S; TT, IT)
The type of power supply for PDS:
Wye...... Delta .... Number of phases ... Number of wires .....
Earth bus: how and where bonded? ....

Wiring diagram

Draw a single-line diagram of site power distribution system from the main supply transformer to the PDS. Show all transformers, distribution panels, etc. Also indicate nominal voltage, power rating, cable routing and method, number of conductors and approximate length of cables/busbars involved.

E.2.2.3 EMC data

PDS earthing

PDS earth reference? ...... Single point........ Meshed ....
Provide a schematic of equipotential bonding.

PDS shielding

Are shielded cabinets for CDM/BDM used? Yes....... No........
Describe:

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Are shielded cables used? Yes....... No........
Describe:

Other measures used (e.g. container)? Yes....... No........
Describe (consider also motors and cables):

RFI sensitive equipment in facility

Any equipment in the building or near installation location sensitive to RF disturbances?
Yes .... No
Describe: (e.g. process control and measurement, data buses, computers, etc.)

Approximate distance from PDS/cabling of PDS: .... metres
Most likely coupling path for disturbance: Conducted.......... Radiated ......

RFI sensitive equipment outside facility

Any broadcast or communications receiver antennas visible or near facility?
Yes .... No
Describe (e.g. radar, radio/TV broadcast, amateur, microwave or other):
Frequency.......... Distances from the antenna .... metres

Citizen band (CB), walkie-talkies, wireless communication, remote control or clock synchronisation system used on facility?
Yes .... No
Describe:

E.2.3 EMC analysis

E.2.3.1 Identify the most sensitive equipment or systems

Analyse electromagnetic environment constraints to installation.

E.2.3.2 Identify the most likely disturbing parts of PDS

Analyse electromagnetic environment constraints to installation.

E.2.3.3 Are there risks of malfunction of items listed in E.2.3.2, due to disturbances from the PDS?

Yes .... No
Describe:

E.2.4 Establishment of installation rules

E.2.4.1 Earthing

Note the recommendations given by the manufacturer of PDS, when determining the installation rules. To ensure the EMC effectiveness of the earthing, assess the items below:

- earthing system of PDS (single point/meshed);
- equipotential bonding:
  - interconnection of exposed conductive parts;
  - interconnection of metal structures of PDS to the earthing system.
- HF quality of connections:
  - metal-to-metal bonding by fasteners;
  - removal of paint or any other insulating material where necessary.
- describe (EMC solutions).

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E.2.4.2 Cables and wiring

E.2.4.2.1 Cable selection

Note the recommendations given by the manufacturer of PDS, when determining the installation rules. To ensure the EMC effectiveness of cables, assess the items below:

- the signal type (e.g. digital data, PWM to a motor);
- unused conductors;
- type of cable and type of shielding (if any);
- describe (EMC solutions).

E.2.4.2.2 Routing

Note the recommendations given by the manufacturer of PDS, when determining the installation rules. To ensure the EMC effectiveness of cabling, assess the items below:

- separation of high-power and low power, or signal cables;
- minimisation of parallel length;
- segregation distances;
- cable intersection at 90°;
- use of conduits and cable trays as parallel-earthed conductor;
- cable positioning in cable trays;
- earthing of cable trays;
- describe (EMC solutions).

E.2.4.3 Shielding of PDS cabinet

Note the recommendations given by the manufacturer of PDS, when determining the installation rules. To ensure the EMC effectiveness of enclosures, assess the items below:

- continuity of metallic enclosure;
- dimension of slots and openings;
- cable entry through the earth reference plane;
- connection of cable shields to earth reference plane (360° preferred);
- describe (EMC solutions).

E.2.4.4 Dedicated transformer

Note the recommendations given by the manufacturer of PDS, when determining the installation rules. To ensure EMC effectiveness, consider the use of the following:

- dedicated isolation transformer;
- transformer with electrostatic shield;
- describe (size, location).

E.2.4.5 Filtering

Note the recommendations given by the manufacturer of PDS, when determining the installation rules. To ensure EMC effectiveness, consider the use of the following:

- centralised or distributed RFI-filter-configurations;
- signal line filtering;
- filtering power interface if appropriate;

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- describe (EMC solutions)

E.2.4.6 Additional mitigation techniques

Note the recommendations given by the manufacturer of PDS, when determining the installation rules. Are other mitigation techniques necessary? Yes No

Consider the use of the following:

- electrical separation of circuits;
- optical fibres;
- galvanic isolation for data lines (example optocouplers, transformers);
- extra protection for sensitive devices;
- describe (EMC solutions)

E.2.5 Formal result and maintenance

Check that the installation is built according to the defined installation rules.

Do all details follow the defined installation rules? Yes No

Describe any action to correct failings.

Define instructions for maintaining EMC characteristics of the installation (e.g. measures against corrosion, dust which might weaken the contact between the door and the frame, loosening of connections).

Signature(s) by person(s) responsible for EMC:

Date

Signature(s)

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E.3 Example of supplement to EMC plan for particular application

E.3.1 Electromagnetic environment complementary analysis

E.3.1.1 Power distribution from utility substation to facility main supply transformer

The questions in E.3 are related to factors external to the PDS which can be relevant to the EMC performance in a more complex application.

<u>Electrical utility service supplier</u>:

Approximate distance from the nearest utility substation (if known):

Utility service distribution from the substation**:**

overhead lines buried combination

describe

<u>Facility main supply transformer characteristic</u>**:** kVA

input (primary): volts number of phases

type of connection: Delta Wye

other, describe

Output to internal distribution (secondary)

volts number of wires number of phases

Type of connection: Delta Wye

Is the transformer earthed? (describe how and where)

Building earthing electrode consisting of

Earth rod Multiple rods Earth grid Earth plate

Buried conduit Water pipe Building steel

If other, describe

Draw wiring diagram

Draw a single-line diagram of site power distribution system from the utility substation to main supply transformer. Show all transformers, distribution panels, etc.

Earth electrode impedance in ohms (if known)

E.3.1.2 Power distribution from facility main supply transformer to local distribution panel/switch gear/transformer for PDS

The questions in E.3 are related to factors external to the PDS which can be relevant to the EMC performance in a more complex application.

Wiring diagram

Draw a single-line diagram of facility power distribution system from the main supply transformer to the local distribution panel/switchgear/transformer.

Local power distribution panel/switchgear/transformer

Panel/switchgear/transformer identification

Panel construction: how and where bonded

Type of power supply for panel/switchgear/transformer

Wye Delta number of phases

number of wires wire size (phase/neutral/PE): Cu Al

Neutral bus: how and where bonded

Earth bus: how and where bonded

Individual insulated PE wire from PDS or part of PDS

Yes No

Describe

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E.3.2 EMC analysis

E.3.2.1 Frequency plan

RFI survey needed

Yes No

Explain

If yes, issuing a frequency plan/table might clarify the situation. An example is given below in Table E.2.

Table E.2 – Frequency analysis

Equipment	Unit	Frequency	Band-width	Description of frequency source	V	A	Waveform	Type Em	Type Im	Ref. Doc.
Inverter N°1	IGBT-module	5 kHz		Output switching frequency	510		PWM	X		
Inverter N°2	IGBT-module	5 kHz		Output switching frequency	510		PWM	X		
Inverter N°1	Motor control	40 MHz		TTL clock	15		TTL clock	X		
Inverter N°2	Motor control	40 MHz		TTL clock	15		TTL clock	X		
Inverters	Output current sensor	1 kHz		Sampling frequency	0,03				X	
Auxiliary equipment	Power supply	200 kHz		Switching frequency	230		Spike	X		
Cordless telephones									X	
Business radio	Transmitter/ receiver							X	X	
Amateur radio	Transmitter/ receiver	144 MHz							X	

Em: emission

Im: immunity

Ref. doc: reference number of the specification of the item

Risks of malfunction of items listed in above, due to disturbances from the PDS, should be analysed and adequate measures should be defined.

E.3.2.2 EMC testing

List the references of EMC test reports.

Is further specific EMC-testing necessary?

Yes No

If yes, a procedure as follows may be necessary:

- prepare an EMC test plan (refer to EMC analysis);

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- perform EMC tests and write test reports.

Are the test results acceptable?

Yes No

Describe any action to correct failings:

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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ENTRAINEMENTS ELECTRIQUES DE PUISSANCE A VITESSE VARIABLE –

Partie 3: Exigences de CEM et méthodes d'essai spécifiques

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Cette troisième édition annule et remplace la seconde édition parue en 2004 et l'Amendement 1:2011. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) éclaircissement des exigences concernant le rapport d'essai, notamment quand il existe plusieurs autres méthodes d'essai;

b) introduction d'une configuration d'essai plus détaillée pour les mesures des émissions rayonnées, ainsi que d'une distance de mesure de 3 m pour les petits matériels;

c) mises à jour générales des annexes informatives.

Le texte de cette norme est issu des documents suivants:

FDIS	Report on voting
22G/347/FDIS	22G/350/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette norme.

Cette publication a été rédigée selon les Directives ISO/IEC, Partie 2, et le Guide IEC 107.

Une liste de toutes les parties de la série IEC 61800, publiées sous le titre général *Entraînements électriques de puissance à vitesse variable*, peut être consultée sur le site web de l'IEC.

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ENTRAINEMENTS ELECTRIQUES DE PUISSANCE A VITESSE VARIABLE –

Partie 3: Exigences de CEM et méthodes d'essai spécifiques

1 Domaine d'application

La présente partie de l'IEC 61800 spécifie les exigences de compatibilité électromagnétique (CEM) applicables aux entraînements de puissance (PDS, définis en 3.1). Il s'agit d'entraînements à vitesse variable pour moteurs électriques à courant alternatif ou continu. Le présent document spécifie les exigences relatives aux PDS avec convertisseurs ayant des tensions d'entrée et/ou sortie (tensions entre phases) d'une valeur efficace allant jusqu'à 35 kV en courant alternatif.

Les PDS couverts par le présent document sont ceux installés dans des locaux résidentiels, commerciaux et industriels, à l'exception des applications de traction et des véhicules électriques. Les PDS peuvent être connectés à un réseau de distribution industriel ou public. Les réseaux industriels sont alimentés par un transformateur de distribution dédié qui se trouve normalement à proximité ou à l'intérieur du site industriel; ils n'alimentent que des clients industriels. Ces réseaux industriels peuvent aussi être alimentés par leurs propres équipements de génération électrique. Les PDS peuvent, par ailleurs, être aussi raccordés directement au réseau public basse tension qui alimente également des locaux résidentiels et dont le neutre est généralement relié à la terre.

Le domaine d'application de la présente partie de l'IEC 61800, traitant de la CEM, comprend une vaste gamme de PDS qui va de quelques centaines de watts à des centaines de mégawatts. Les PDS font souvent partie intégrante d'un système plus important. L'aspect système n'est pas couvert par le présent document, mais ses annexes informatives fournissent des préconisations.

Les exigences ont été choisies de façon à assurer la CEM des PDS dans les locaux résidentiels, commerciaux et industriels. Les exigences ne peuvent toutefois pas couvrir les cas extrêmes qui peuvent survenir avec une très faible probabilité. Les changements de comportement CEM d'un PDS résultant de conditions de défaut ne sont pas pris en considération.

Le présent document a pour objet de définir les limites et les méthodes d'essai des PDS en fonction de leur utilisation prévue. Il comporte des exigences d'immunité et des exigences concernant les émissions électromagnétiques.

NOTE 1 Les émissions peuvent perturber d'autres équipements électroniques (par exemple les récepteurs radio, appareils de mesure et calculateurs). L'immunité vise à protéger l'équipement contre les perturbations continues et transitoires, conduites et rayonnées, y compris les décharges électrostatiques. Les exigences d'émissions et d'immunité sont homogènes entre elles et avec l'environnement réel du PDS.

Le présent document définit les exigences minimales de CEM auxquelles chaque PDS doit répondre.

Les exigences d'immunité sont données selon des classes d'environnement. Les exigences d'émission basses fréquences sont données selon la nature du réseau d'alimentation. Les exigences d'émission hautes fréquences sont données selon quatre catégories d'utilisation prévue qui couvrent à la fois l'environnement et la mise en fonctionnement.

En tant que norme de produit, le présent document peut être utilisée pour l'évaluation des PDS. Elle peut aussi être utilisée pour l'évaluation des modules d'entraînement principal

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(BDM) ou modules d'entraînement complet (CDM) (voir 3.1), qui peuvent être mis sur le marché séparément.

Le présent document contient

- des exigences relatives à l'évaluation de conformité des produits qui sont mis sur le marché, et
- des règles d'ingénierie recommandées (voir 6.5) pour les cas où les émissions haute fréquence ne peuvent pas être mesurées avant que l'équipement soit mis sur le marché (ces PDS sont définis comme des PDS de la catégorie C4 en 3.2.7).

NOTE 2 La première édition de l'IEC 61800-3 a identifié que l'utilisation prévue pourrait nécessiter des études d'ingénierie pour la mise en service. Cela était établi par le "mode de distribution restreinte". Les équipements qui étaient couverts par le "mode de distribution restreinte" se retrouvent aujourd'hui dans les catégories C2 et C4 (voir 3.2).

Le présent document est conçue comme une norme de produit CEM complète destinée évaluer la conformité CEM des produits des catégories C1, C2 et C3 quand ils sont mis sur le marché (voir définitions 3.2.4 à 3.2.6).

L'émission radiofréquence d'un équipement de catégorie C4 est uniquement mesurée lorsqu'il est installé sur son lieu d'utilisation. L'équipement est alors considéré comme une installation fixe, pour laquelle le présent document donne des règles d'ingénierie et des recommandations techniques en 6.5 et à l'Annexe E, bien qu'elle ne définisse pas de limites d'émission (excepté en cas de plainte).

Le présent document ne spécifie aucune exigence de sécurité pour les équipements, par exemple en matière de protection contre les chocs électriques, de coordination d'isolement et d'essais diélectriques associés, ni concernant un fonctionnement dangereux ou les conséquences dangereuses d'une défaillance. Elle ne couvre pas non plus les conséquences des phénomènes électromagnétiques sur la sécurité et la sécurité fonctionnelle.

Dans des cas spécifiques, par exemple lorsqu'un appareil de grande susceptibilité électromagnétique est utilisé dans le voisinage immédiat d'un PDS, des mesures d'atténuation supplémentaires peuvent devoir être mises en place pour réduire les émissions électromagnétiques à des niveaux inférieurs à ceux spécifiés ou pour augmenter l'immunité de l'appareil très susceptible.

En tant que norme de produit CEM, le présent document prévaut sur tous les aspects spécifiés par les normes génériques, et aucun essai CEM supplémentaire n'est effectué. Lorsqu'un PDS est incorporé dans un équipement couvert par une norme de produit CEM spécifique, la norme CEM pour l'équipement complet s'applique.

2 Références normatives

Les documents suivants sont cités en référence de manière normative, en intégralité ou en partie, dans le présent document et sont indispensables pour son application. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60146-1-1:2009, *Convertisseurs à semiconducteurs – Exigences générales et convertisseurs commutés par le réseau – Partie 1-1: Spécification des exigences de base*

IEC 61000-2-2:2002, *Compatibilité électromagnétique (CEM) – Partie 2-2: Environnement – Niveaux de compatibilité pour les perturbations conduites à basse fréquence et la transmission des signaux sur les réseaux publics d'alimentation basse tension*

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IEC 61000-2-4:2002, *Compatibilité électromagnétique (CEM) – Partie 2-4: Environnement – Niveaux de compatibilité dans les installations industrielles pour les perturbations conduites à basse fréquence*

IEC 61000-3-2:2014, *Compatibilité électromagnétique (CEM) – Partie 3-2: Limites – Limites pour les émissions de courant harmonique (courant appelé par les appareils ≤ 16 A par phase)*

IEC 61000-3-3:2013, *Compatibilité électromagnétique (CEM) – Partie 3-3: Limitation des variations de tension, des fluctuations de tension et du papillotement dans les réseaux publics d'alimentation basse tension pour les matériels ayant un courant assigné ≤ 16 A par phase et non soumis à un raccordement conditionnel*

IEC 61000-3-11:2000, *Compatibilité électromagnétique (CEM) – Partie 3-11: Limitation des variations de tension, des fluctuations de tension et du papillotement dans les réseaux publics d'alimentation basse tension – Equipements ayant un courant appelé ≤ 75 A et soumis à un raccordement conditionnel*

IEC 61000-3-12:2011, *Compatibilité électromagnétique (CEM) – Partie 3-12: Limites – Limites pour les courants harmoniques produits par les appareils connectés aux réseaux publics basse tension ayant un courant appelé > 16 A et ≤ 75 A par phase*

IEC 61000-4-2:2008, *Compatibilité électromagnétique (CEM) – Partie 4-2: Techniques d'essai et de mesure – Essai d'immunité aux décharges électrostatiques*

IEC 61000-4-3:2006, *Compatibilité électromagnétique (CEM) – Partie 4-3: Techniques d'essai et de mesure – Essai d'immunité aux champs électromagnétiques rayonnés aux fréquences radioélectriques*

IEC 61000-4-4:2012, *Compatibilité électromagnétique (CEM) – Partie 4-4: Techniques d'essai et de mesure – Essai d'immunité aux transitoires électriques rapides en salves*

IEC 61000-4-5:2014, *Compatibilité électromagnétique (CEM) – Partie 4-5: Techniques d'essai et de mesure – Essai d'immunité aux ondes de choc*

IEC 61000-4-6:2013, *Compatibilité électromagnétique (CEM) – Partie 4-6: Techniques d'essai et de mesure – Immunité aux perturbations conduites, induites par les champs radioélectriques*

IEC 61000-4-8:2009, *Compatibilité électromagnétique (CEM) – Partie 4-8: Techniques d'essai et de mesure – Essai d'immunité au champ magnétique à la fréquence du réseau*

IEC 61000-4-11:2004, *Compatibilité électromagnétique (CEM) – Partie 4-11: Techniques d'essai et de mesure – Essais d'immunité aux creux de tension, coupures brèves et variations de tension*

IEC 61000-4-13:2002, *Compatibilité électromagnétique (CEM) – Partie 4-13: Techniques d'essai et de mesure – Essais d'immunité basse fréquence aux harmoniques et inter-harmoniques incluant les signaux transmis sur le réseau électrique alternatif*

IEC 61000-4-34:2005, *Compatibilité électromagnétique (CEM) – Partie 4-34: Techniques d'essai et de mesure – Essais d'immunité aux creux de tension, coupures brèves et variations de tension pour matériel ayant un courant d'alimentation de plus de 16 A par phase*

CISPR 11:2015, *Appareils industriels, scientifiques et médicaux – Caractéristiques de perturbations radioélectriques – Limites et méthodes de mesure*
CISPR 11:2015/AMD1:2016

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CISPR 16-1-2:2014, *Spécifications des méthodes et des appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques – Partie 1-2: Appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques – Dispositifs de couplage pour la mesure des perturbations conduites*

CISPR 16-1-4:2010, *Spécifications des méthodes et des appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques – Partie 1-4: Appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques – Antennes et emplacements d'essai pour les mesures des perturbations rayonnées*

CISPR 22, *Appareils de traitement de l'information – Caractéristiques des perturbations radioélectriques – Limites et méthodes de mesure*

CISPR 32:2015, *Compatibilité électromagnétique des équipements multimédia – Exigences d'émission*

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

3.1 Installation et son contenu

La Figure 1 présente les principales parties d'un PDS définies ci-dessous, ainsi que le reste de l'installation.

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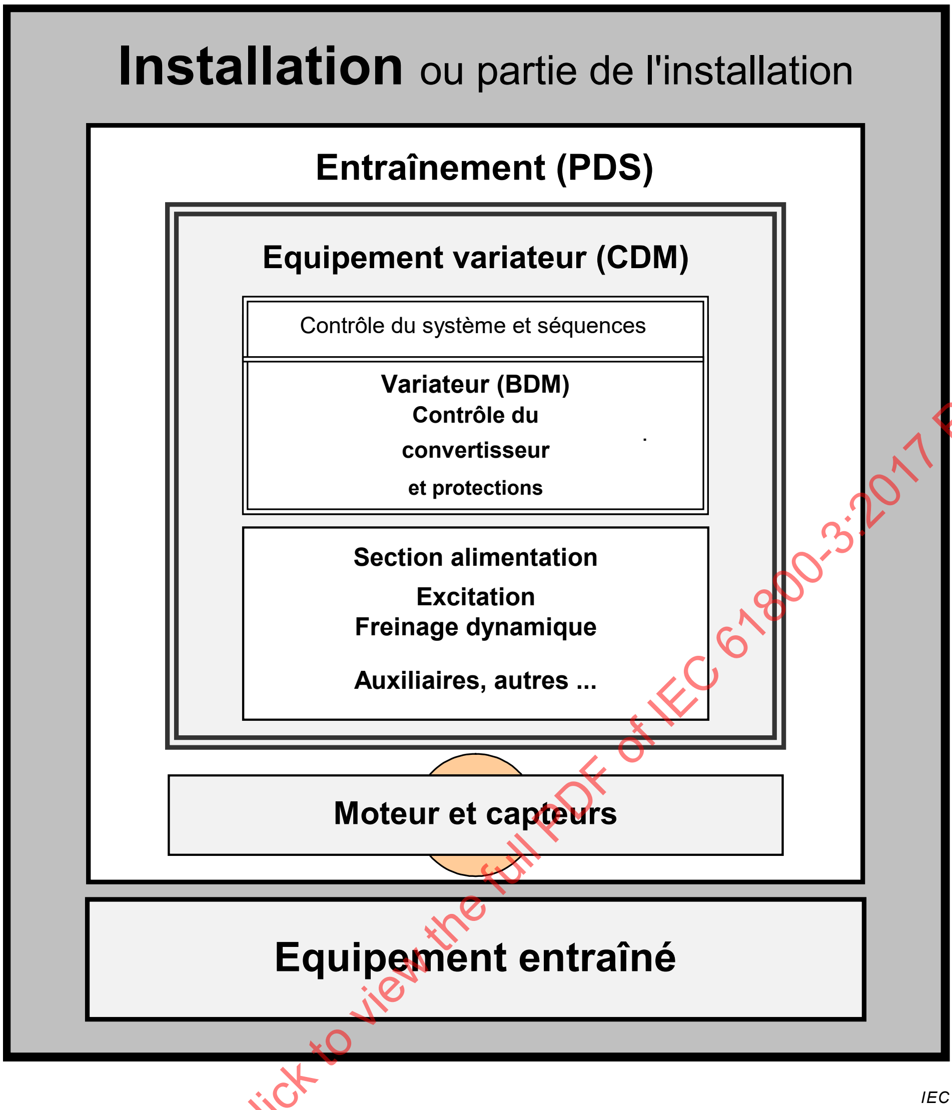

Figure 1 – Installation et son contenu

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3.1.1
module d'entraînement principal
MEP
variateur
BDM
convertisseur électronique de puissance et commande associée, connecté entre une source d'alimentation électrique et un moteur

Note 1 à l'article: Le BDM est capable de transmettre l'énergie de la source d'alimentation électrique au moteur et peut être également capable de transmettre l'énergie produite par le moteur à la source d'alimentation électrique. Le BDM commande tout ou partie des paramètres suivants relatifs à l'énergie transmise au moteur et à celle fournie par celui-ci:

- courant;
- fréquence;
- tension;
- vitesse;
- couple;
- force;
- position.

Note 2 à l'article: L'abréviation "BDM" est dérivée du terme anglais développé correspondant "basic drive module".

3.1.2
module d'entraînement complet
MEC
équipement variateur
CDM
module d'entraînement comprenant, de manière non exhaustive, le BDM et des composants associés, tels que des dispositifs de protection, des transformateurs et des dispositifs auxiliaires

Note 1 à l'article: Le moteur et les capteurs mécaniquement couplés à l'arbre du moteur ne sont pas inclus.

Note 2 à l'article: L'abréviation "CDM" est dérivée du terme anglais développé correspondant "complete drive module".

3.1.3
entraînement électrique de puissance
EEP
entraînement
PDS
système comprenant un ou plusieurs équipements variateurs (CDM) avec un moteur ou plusieurs moteurs

Note 1 à l'article: Tous les capteurs mécaniquement couplés à l'arbre du moteur font également partie du PDS, toutefois, les matériels entraînés ne sont pas inclus

Note 2 à l'article: L'abréviation "PDS" est dérivée du terme anglais développé correspondant "power drive system".

3.1.4
installation
équipement(s) comprenant au moins un PDS et un matériel entraîné

3.1.5
petit matériel
matériel qui est soit placé sur une table, soit monté au mur, soit posé sur le sol, et qui tient à l'intérieur d'un volume d'essai cylindrique imaginaire dont le diamètre ne dépasse pas 1,2 m et dont la hauteur au-dessus du plan au sol ne dépasse pas 1,5 m, y compris ses câbles et d'éventuels équipements auxiliaires

Note 1 à l'article: Cette définition a été modifiée afin de s'adapter à la mesure des émissions rayonnées de l'accès enveloppe.

[SOURCE: CISPR 11:2015, 3.17, modifié – Les expressions "soit monté au mur" et "et d'éventuels équipements auxiliaires" ont été ajoutées, ainsi que la note à l'article.]

3.1.6
équipement à montage mural
CDM/BDM destiné à être installé sur une surface verticale

3.2 Utilisation prévue

3.2.1
plan CEM
procédure d'évaluation de la CEM pour l'installation d'un équipement de catégorie C4 (voir 3.2.7)

3.2.2
premier environnement
environnement comprenant des lieux résidentiels, ou dont l'alimentation électrique est directement fournie sans transformateur intermédiaire, par un réseau public basse tension qui alimente aussi des bâtiments résidentiels

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Note 1 à l'article: Les maisons, appartements, bâtiments commerciaux ou bureaux dans des immeubles résidentiels sont des exemples de locaux du premier environnement.

3.2.3
deuxième environnement
environnement comprenant des lieux autres que ceux qui sont directement alimentés en électricité par un réseau public basse tension qui alimente aussi des bâtiments résidentiels

Note 1 à l'article: Les zones industrielles ou les locaux techniques de tout immeuble alimenté à partir d'un transformateur dédié sont des exemples de locaux du deuxième environnement.

3.2.4
PDS de catégorie C1
PDS de tension assignée inférieure à 1 000 V, prévu pour être utilisé dans le premier environnement

3.2.5
PDS de catégorie C2
PDS de tension assignée inférieure à 1 000 V, qui n'est ni un appareil avec cordon d'alimentation et prise, ni un appareil mobile, et qui, lorsqu'il est utilisé dans le premier environnement, est prévu pour être installé et mis en service uniquement par un professionnel

Note 1 à l'article: Un professionnel est une personne ou une organisation possédant les compétences nécessaires pour l'installation et/ou la mise en service des systèmes d'entraînement de puissance, y compris pour leurs aspects CEM.

3.2.6
PDS de catégorie C3
PDS de tension assignée inférieure à 1 000 V, prévu pour être utilisé dans le deuxième environnement et non prévu pour être utilisé dans le premier environnement

3.2.7
PDS de catégorie C4
PDS de tension assignée égale ou supérieure à 1 000 V, ou de courant assigné égal ou supérieur à 400 A, ou prévu pour être utilisé dans des systèmes complexes du deuxième environnement

3.3 Emplacements, accès et interfaces

3.3.1
in situ
<essai> lieu où l'équipement est installé pour son usage normal par l'utilisateur final

3.3.2
emplacement d'essai
<rayonnement> emplacement satisfaisant aux conditions nécessaires pour effectuer la mesure correcte, dans des conditions définies, des champs électromagnétiques rayonnés par des appareils en essai

[SOURCE: IEC 60050-161:1990, 161-04-28]

3.3.3
accès
point d'un dispositif ou d'un réseau où de l'énergie électromagnétique ou des signaux électromagnétiques peuvent être fournis ou recueillis, ou bien où l'on peut observer ou mesurer des grandeurs

Note 1 à l'article: La Figure 2 montre la diversité des accès d'un entraînement.

[SOURCE: IEC 60050:2002, 131-12-60, modifié – La note à l'article a été remplacée par une nouvelle note.]

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3.3.4
accès enveloppe
limite physique de l'entraînement (PDS) à travers laquelle les champs électromagnétiques peuvent rayonner ou être absorbés

Note 1 à l'article: Voir Figure 2.

3.3.5
accès de mesure et de commande de processus
accès d'entrée/sortie (E/S) d'un conducteur ou d'un câble qui assure la connexion entre le processus et le PDS

3.3.6
accès de puissance
accès par lequel l'entraînement (PDS) est raccordé à l'alimentation de puissance qui alimente aussi d'autres équipements

3.3.7
accès de puissance principal
accès de puissance qui alimente l'entraînement uniquement pour la puissance qui, après conversion électrique, est convertie par le moteur en puissance mécanique

3.3.8
accès de puissance auxiliaire
accès de puissance qui alimente seulement les auxiliaires du PDS, y compris le circuit d'excitation, le cas échéant

3.3.9
interface de signal
borne d'entrée ou de sortie (E/S) pour une ligne de connexion entre le variateur ou l'équipement variateur (BDM/CDM) et une autre partie de l'entraînement (PDS)

Note 1 à l'article: Voirr Figure 2.

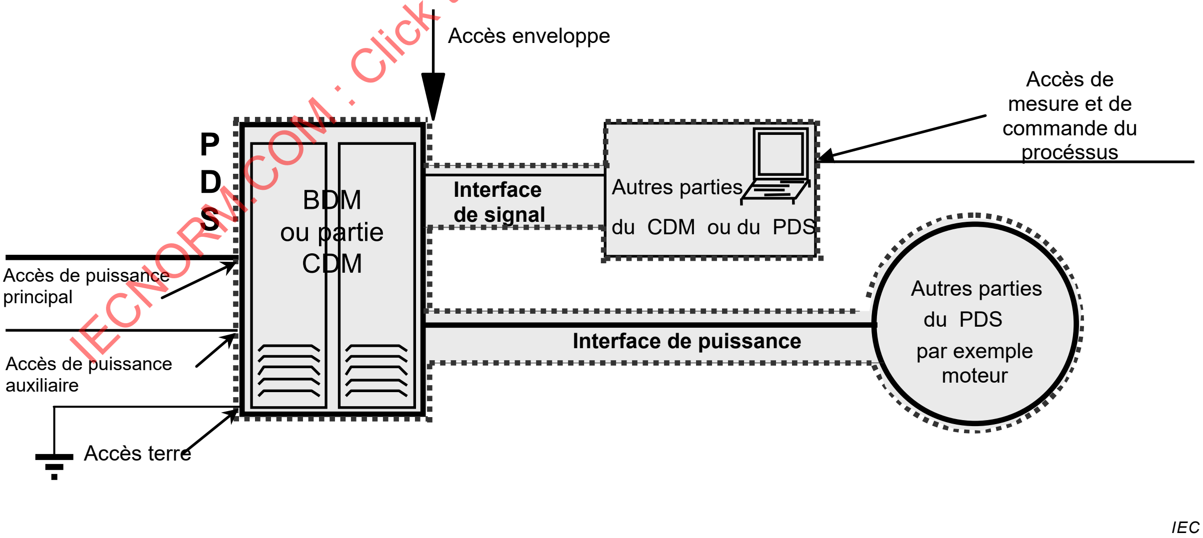

Figure 2 – Interfaces internes d'un PDS et exemples d'accès

3.3.10
interface de puissance
raccordements nécessaires à la distribution de puissance électrique

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Note 1 à l'article: Voir exemples d'interfaces de puissance à la Figure 3 et explications à l'Article E.1.

Note 2 à l'article: Les interfaces de puissance du PDS peuvent prendre différentes formes et avoir différentes extensions.

– A l'intérieur du BDM/CDM

  Une interface de puissance peut être le raccordement destiné à la distribution de la puissance électrique d'une partie du BDM/CDM à une autre partie du BDM/CDM. Une interface de puissance peut être commune à différents composants du PDS. Par exemple, voir Figure 3 et Figure 4.

  La Figure 3 représente une interface de puissance qui distribue la puissance depuis un convertisseur d'entrée (où la puissance est convertie de sa forme disponible sur le réseau en une autre forme, ici en courant continu) aux onduleurs de sortie (où la puissance est convertie d'une forme intermédiaire, ici en courant continu, en une autre forme, ici en courant alternatif, qui peut alimenter directement des moteurs à courant alternatif).

  La Figure 4 représente une interface de puissance qui distribue la puissance du secondaire d'un transformateur (faisant partie du CDM) à chaque BDM.

– A l'intérieur du PDS

  Il est à noter que le raccordement entre l'onduleur et le ou les moteurs est lui aussi une interface de puissance. C'est la dernière interface de puissance avant la conversion en puissance mécanique.

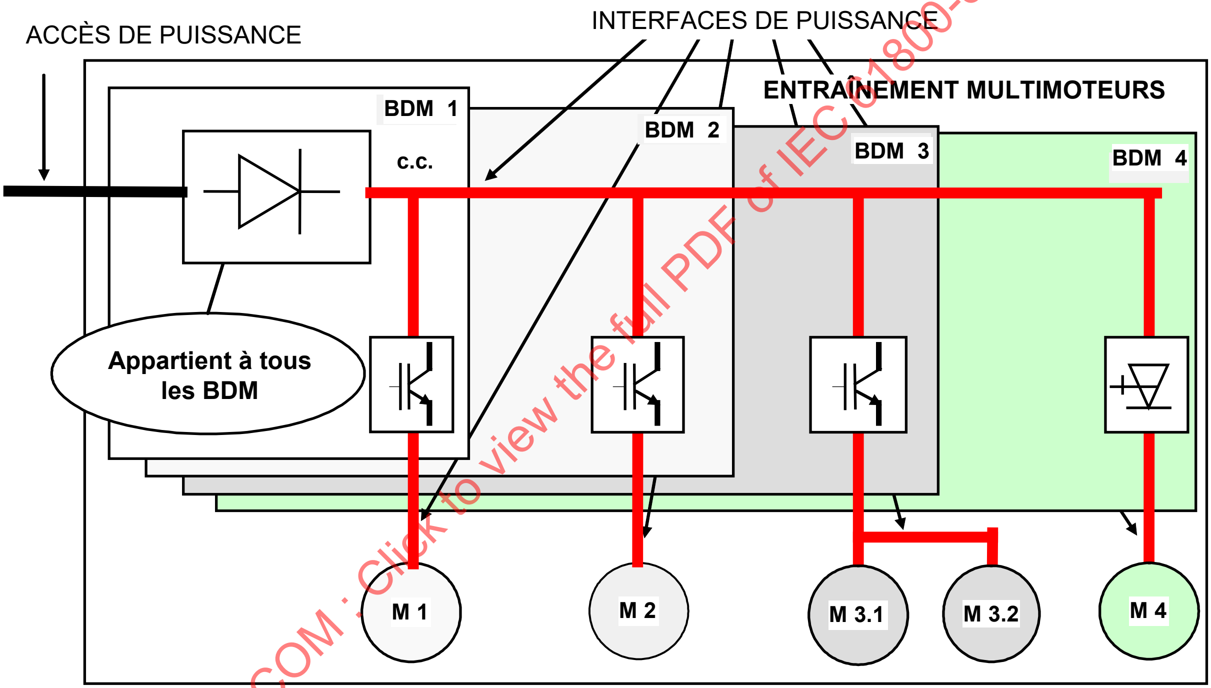

Figure 3 – Interfaces de puissance d'un PDS avec BUS continu commun

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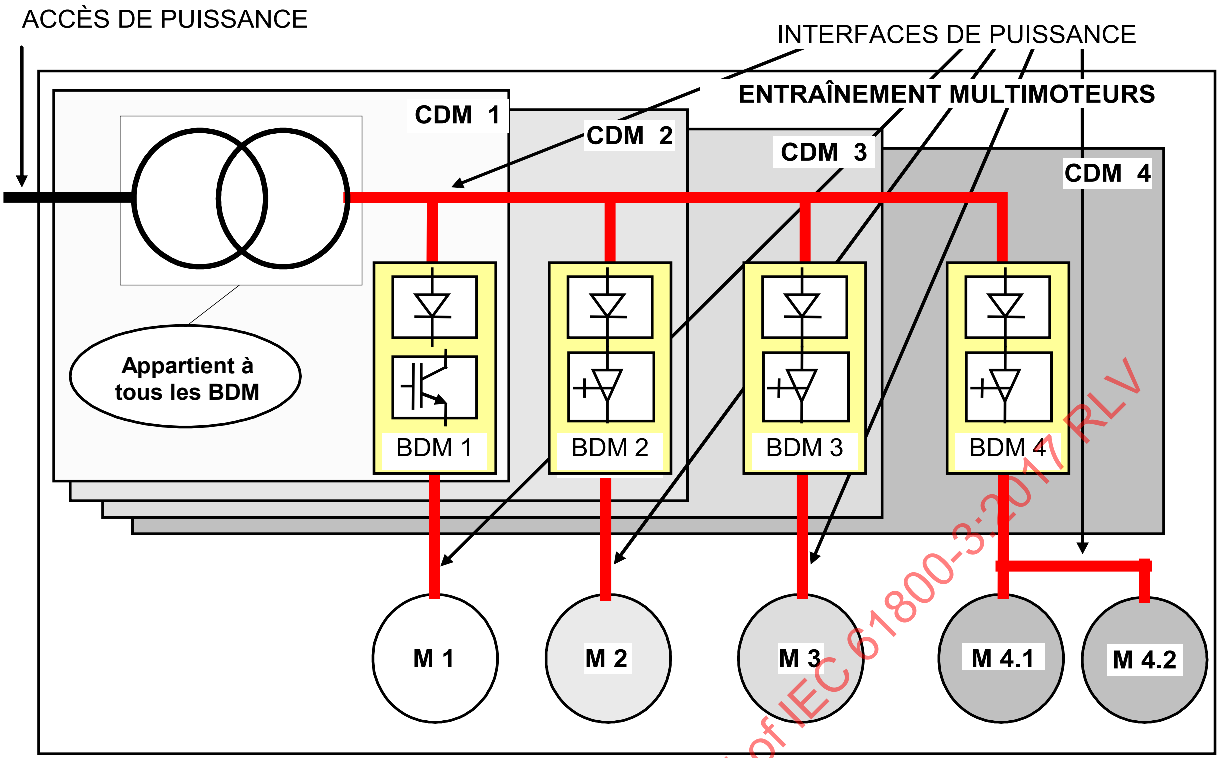

Figure 4 – Interfaces de puissance avec transformateur d'entrée commun

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3.3.11
point de couplage commun
PCC
point électriquement le plus proche d'une charge particulière, situé sur le réseau public de distribution d'énergie, auquel d'autres charges sont ou pourraient être raccordées

[SOURCE: IEC 61000-2-4:2002, 3.1.6]

3.3.12
point de couplage interne
IPC
point électriquement le plus proche d'une charge particulière, situé sur un réseau non public de distribution d'énergie ou à l'intérieur d'une installation, auquel d'autres charges sont ou pourraient être raccordées

Note 1 à l'article: Usuellement l'IPC est le point auquel on étudie la compatibilité électromagnétique.

[SOURCE: IEC 61000-2-4:2002, 3.1.7]

3.3.13
point de couplage
PC
point pouvant être situé sur un réseau public de distribution d'énergie ou sur un réseau non public de distribution d'énergie ou à l'intérieur d'une installation

3.4 Composants du PDS

3.4.1
convertisseur
<du BDM> unité qui change la nature de la puissance électrique fournie par le réseau de distribution en transformant la tension et/ou le courant et/ou la fréquence appliqués au moteur

Note 1 à l'article: Le convertisseur comprend les dispositifs de commutation électroniques et leurs circuits de commutation associés. Il est commandé par des transistors ou des thyristors ou par tout autre composant de commutation puissance à semiconducteur.

Note 2 à l'article: Le convertisseur peut être commuté par le réseau, par la charge ou autocommuté et peut être composé, par exemple, d'un ou de plusieurs redresseurs ou onduleurs.

3.4.2
moteur
moteur électrique
machine électrique destinée à transformer de l'énergie électrique en énergie mécanique

Note 1 à l'article: Pour les besoins du présent document, le moteur inclut tous les capteurs montés destinés à permettre son fonctionnement et interagissant avec le CDM.

[SOURCE: IEC 60050:2001, 151-13-41, modifiée — La note a été ajoutée.]

3.4.3
sous-composant
partie physique d'un équipement qui peut fonctionner séparément, ayant une fonction intrinsèque définie par le constructeur

Note 1 à l'article: Pour les besoins du présent document, un composant de PDS peut être divisé en sous-composants.

Note 2 à l'article: Par exemple l'unité de commande d'un CDM peut être un sous-composant.

3.5 Définitions relatives aux phénomènes

3.5.1
compatibilité électromagnétique
CEM
aptitude d'un appareil ou d'un système à fonctionner dans son environnement électromagnétique de façon satisfaisante et sans produire lui-même des perturbations électromagnétiques intolérables pour tout ce qui se trouve dans cet environnement

[SOURCE: IEC 60050-161:1990, 161-01-07]

3.5.2
courant harmonique total
THC
valeur efficace totale des composantes harmoniques du courant de rangs 2 à 40

$$THC = \sqrt{\sum_{h=2}^{40} I_h^2}$$

[SOURCE: IEC 61000-3-12:2011, 3.1]

3.5.3
taux de distorsion harmonique totale
THD
rapport de la valeur efficace du résidu harmonique à la valeur efficace de la composante fondamentale ou de la composante fondamentale de référence d'une grandeur alternative

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Note 1 à l'article: Le résidu harmonique dépend du choix de la composante fondamentale. En cas d'ambiguïté dans le contexte, on indique de quelle composante il s'agit.

Note 2 à l'article: Le rapport harmonique total THD peut faire l'objet d'une approximation à un certain rang (notation recommandée "H"), 40 pour le présent document.

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

où, en plus des notes à l'article de B.2.2.7,

Q_1 est la valeur efficace de la composante fondamentale.

[SOURCE: IEC 60050-551:2001, 551-20-13, modifiée — Le terme "rapport harmonique total" a été supprimé, la formule a été ajoutée et la Note 1 à l'article a été reformulée. Dans la Note 2 à l'article, la phrase "Les conditions de l'approximation sont alors indiquées" a été supprimée et la partie "(notation recommandée "H"), 40 pour le présent document" a été ajoutée.]

3.5.4
écart de tension
différence entre la tension d'alimentation à un instant donné et la tension d'alimentation déclarée

[SOURCE: IEC 60050-614:2016, 614-01-04]

3.5.5
variation de tension
variation de la valeur efficace ou de la valeur de crête d'une tension entre deux niveaux consécutifs maintenus pendant des durées déterminées, mais non spécifiées

Note 1 à l'article: Le choix entre valeur efficace et valeur de crête dépend de l'application, et il convient de le spécifier.

[SOURCE: IEC 60050-161:1990, 161-08-01, modifiée — La définition a été reformulée.]

3.5.6
fluctuation de tension
suite de variations de tension ou variation permanente de la valeur efficace ou de la valeur de crête d'une tension

Note 1 à l'article: Le choix entre valeur efficace et valeur de crête dépend de l'application, et il convient de le spécifier.

[SOURCE: IEC 60050-161:1990, 161-08-05]

3.5.7
creux de tension
baisse brutale de la tension en un point d'un réseau électrique, suivie d'un rétablissement de la tension après un court laps de temps de quelques périodes à quelques secondes

[SOURCE: IEC 60050-614:2016, 614-01-08, modifiée — Les mots "un réseau d'énergie électrique" ont été remplacés par "un réseau électrique", et les mots "après un court intervalle de temps allant de quelques périodes de la tension sinusoïdale à quelques secondes" par "après un court laps de temps de quelques périodes à quelques secondes".]

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4 Exigences communes

4.1 Conditions générales

Tous les phénomènes concernant les émissions ou l'immunité doivent être pris en considération individuellement. Les limites sont fournies pour des conditions ignorant les effets cumulés de différents phénomènes.

Pour évaluer l'état de la CEM de manière réaliste, une configuration type doit être choisie.

La pratique d'essais pour l'évaluation de l'immunité dépend du PDS particulier, de sa configuration, de ses accès, de sa technologie et de ses conditions de fonctionnement (voir annexes).

4.2 Essais

4.2.1 Conditions

Les normes IEC 60146-1-1 et IEC 61800-2 font la distinction entre les essais de type, les essais de routine et les essais spéciaux. Sauf indication contraire, tous les essais spécifiés dans ce document sont uniquement des essais de type. L'équipement doit satisfaire aux exigences de CEM dans des conditions de fonctionnement normal, comme indiqué dans le manuel d'exploitation dudit équipement lors des mesures via les méthodes d'essai spécifiées dans ce document.

NOTE 1 Pour des raisons de législation locale sur les émissions radio, certains essais d'immunité peuvent être soumis à des conditions qui restreignent le choix des emplacements où ils peuvent être effectués.

Si nécessaire, des mesures de sécurité doivent être prises contre tout effet non recherché sur le processus complet qui pourrait résulter de défaillances au cours d'un quelconque essai CEM.

Pour les essais, le CDM doit être raccordé à un moteur recommandé par le constructeur, à l'aide d'un câble et suivant des règles de mise à la terre définies par ce dernier. Sinon, une charge d'essai passive (résistive ou inductive et résistive) peut être appliquée (par exemple, pour l'évaluation des émissions basses fréquences), si le constructeur le permet.

NOTE 2 Pour les émissions haute fréquence, une charge d'essai passive peut ne pas convenir pour simuler les capacités et les couplages en mode différentiel et en mode commun généralement observés.

La description des essais, les méthodes d'essai, les caractéristiques des essais et les configurations d'essai sont précisées dans les normes référencées et ne sont pas répétées ici. Néanmoins, si des modifications, des exigences et informations complémentaires ou des méthodes d'essais spécifiques sont nécessaires à la réalisation et à la mise en œuvre des essais, alors ils sont précisés dans ce document.

Un nombre de bornes suffisant doit être utilisé pour simuler les conditions de fonctionnement réelles et pour s'assurer que tous les types de bornes susceptibles d'être concernés sont pris en considération. Les essais doivent être effectués à la tension d'alimentation assignée et de façon reproductible.

4.2.2 Rapport d'essai

Les résultats des essais doivent être consignés dans un rapport d'essai. Le rapport doit présenter clairement et sans ambiguïté toutes les informations relatives aux essais reproductibles. Une description fonctionnelle et les critères de qualification détaillés fournis par le constructeur doivent être notés dans le rapport d'essai.

Les modalités retenues pour l'essai doivent être justifiées dans le rapport d'essai. Lorsqu'un paragraphe du présent document propose des méthodes d'essai alternatives, la méthode

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d'essai retenue doit figurer dans le rapport d'essai. Les informations relatives aux méthodes d'essai indiquées dans le Tableau 1 doivent être fournies:

Tableau 1 – Paragraphes contenant des méthodes d'essai alternatives

Paragraphe	Méthodes d'essai
5.1.2	Type d'essai: – essai de performance générale d'un système; ou – essai de performance spéciale d'un système; ou – essai de performance d'un sous-ensemble.
5.2 et paragraphes	Vérification de l'immunité par: – calcul, ou – simulation, ou – essai.
5.3.2	Transitoires rapides en salves pour équipement ≥ 100 A: – couplage direct ou – pince capacitive
5.3.3	Transitoires rapides en salves pour équipement ≥ 100 A: – couplage direct; ou – pince capacitive.
5.3.4	Immunité aux champs électromagnétiques: – essai du PDS; ou – essai des sous-composants.
6.2.1	Vérification des émissions par: – calcul, ou – simulation, ou – essai.
6.3.1.1	Essai sur un emplacement d'essai ou *in situ*
6.3.1.2	Essais d'émissions conduites: – avec réseau fictif d'alimentation du CISPR, ou – avec sonde de tension à haute impédance.
6.3.1.3.3	Emissions rayonnées: distance de mesure

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4.3 Documentation destinée à l'utilisateur

L'établissement des limites et la structure du présent document partent du principe que l'installateur et l'utilisateur sont responsables de suivre les recommandations du constructeur en matière de CEM.

Le constructeur doit fournir la documentation nécessaire à l'installation correcte d'un BDM, d'un CDM ou d'un PDS dans un système ou un processus type dans l'environnement prévu. Ces informations incluent tous les avertissements d'émission exigés en 6.1 et au Tableau 15. Elles incluent également les avertissements demandés en 5.3.2 dans le cas où l'immunité d'un BDM, d'un CDM ou d'un PDS n'est pas adaptée au deuxième environnement.

NOTE 1 Du point de vue de l'émission, un PDS (ou un BDM, ou un CDM) d'une catégorie d'émission faible, telle que C1, peut toujours être utilisé en lieu et place d'un entraînement ayant une catégorie d'émission plus élevée, telle que C3.

NOTE 2 Les catégories d'émission sont indépendantes de l'immunité. Par exemple, l'indication selon laquelle un PDS présente la catégorie d'émission C1 n'implique pas que son niveau d'immunité convienne seulement au premier environnement.

Si des mesures de CEM spéciales sont nécessaires pour respecter les limites exigées, elles doivent être clairement mentionnées dans la documentation l'utilisateur. Il peut s'agir, si le cas est pertinent, des informations suivantes:

- l'impédance maximale et minimale acceptable pour le réseau d'alimentation;
- l'utilisation de câbles blindés ou spéciaux (puissance et/ou commande);
- les exigences de raccordement du blindage des câbles;
- la longueur maximale autorisée des câbles;
- la séparation des câbles;
- l'utilisation d'appareillages externes tels que des filtres;
- le raccordement correct de la terre fonctionnelle.

Lorsque d'autres dispositifs ou exigences de connexion s'appliquent pour des environnements différents, ils doivent également être mentionnés.

La liste de tous les équipements auxiliaires (les options ou améliorations, par exemple) qui peuvent être ajoutés au PDS et qui satisfont aux exigences d'immunité et/ou d'émission doit être disponible.

Ces renseignements peuvent aussi faire partie des rapports d'essais afin de clarifier la composition finale recommandée.

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5 Exigences d'immunité

5.1 Conditions générales

5.1.1 Critères de qualification (critères de performance)

La performance du système est associée aux fonctions déclarées par le constructeur du BDM, du CDM ou du PDS dans leur ensemble.

La performance d'un sous-composant est associée aux fonctions déclarées par le constructeur des sous-composants du BDM, du CDM ou du PDS.

La performance d'un sous-composant peut être soumise à un essai à la place de la performance du système pour démontrer l'immunité (voir 5.1.2). Le rapport d'essai doit préciser quel essai a été appliqué.

Bien que ce document autorise des essais sur des sous-composants (composants du CDM/BDM), elle n'est pas prévue pour être utilisée afin d'évaluer séparément la conformité des sous-composants.

Les critères de qualification doivent être utilisés pour vérifier la tenue d'un PDS aux perturbations externes. Du point de vue de la CEM, toute installation conforme à la Figure 1 doit fonctionner correctement. Le PDS faisant partie de la séquence fonctionnelle d'un processus qui l'englobe, les effets des variations de performances du PDS sur ce processus sont difficilement prévisibles. Toutefois, il convient qu'un plan de CEM (voir Annexe E) traite cet aspect, qui est important pour des systèmes de grande taille.

Les fonctions principales d'un PDS sont la conversion de l'énergie électrique en énergie mécanique et le traitement des informations nécessaires à cette conversion.

Le Tableau 2 classe les effets d'une perturbation donnée en trois critères de qualification (de performance): A, B et C, à la fois pour le PDS et pour ses sous-composants.

Les Paragraphes 5.2 et 5.3 indiquent le critère de qualification exigé pour chaque phénomène.

5.1.2 Choix d'un type de performance

5.1.2.1 Performance générale ou spéciale d'un système

Le critère de "performance générale du système" du Tableau 2 doit être défini conformément à l'application spéciale et à la configuration type du PDS. Le choix des critères relève de la responsabilité du constructeur.

La performance spéciale du système, pour un comportement en générateur de couple, ne doit être soumise à l'essai que lorsque cela est explicitement défini par la spécification du produit. Dans ce cas, la performance en générateur de couple peut être soumise à l'essai de façon directe ou indirecte. L'essai direct utilise un torsiomètre parfaitement immunisé dans ces conditions de CEM pour mesurer les variations de couple.

La performance de couple peut être définie comme la faculté de garder constants le courant ou la vitesse, dans les tolérances spécifiées, lorsqu'une perturbation est appliquée (voir également 5.1.3). Dès lors, un essai de performance en courant peut être effectué comme un essai indirect de performance du couple généré. Pour l'évaluation de la CEM, et sauf accord différent, le courant de sortie du convertisseur de puissance est réputé représenter le couple avec suffisamment de précision. Sinon, pour l'essai indirect, la performance de vitesse fournie peut être utilisée, à condition que l'inertie totale soit spécifiée.

5.1.2.2 Performance d'un sous-ensemble

Il convient de pratiquer des essais de performance des sous-composants lorsqu'un PDS ne peut être mis en service à un emplacement d'essai à cause de limitations dues à la taille du PDS, à la capacité en courant ou en puissance assignée de l'alimentation ou aux conditions de charge. Dans tous les cas, le dispositif d'essai doit être protégé contre le plus haut niveau de perturbation appliqué au PDS ou au sous-composant en essai.

L'essai des fonctions de traitement et d'acquisition des données, y compris pour les accessoires en option s'il y a lieu, ne doit être effectué que lorsque les accès et interfaces concernés sont disponibles sur le PDS. L'essai de performance du sous-composant conforme au Tableau 2, lorsque les fonctions existent, suffit à déterminer la conformité au présent document.

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Tableau 2 – Critères de qualification d'un PDS soumis aux perturbations électromagnétiques

Elément	Critère de qualification (performance)[a]		
	A	**B**	**C**
Performance générale du système	Pas de variation sensible des caractéristiques de fonctionnement Fonctionne comme prévu, dans les tolérances spécifiées	Variations sensibles (visibles ou audibles) des caractéristiques de fonctionnement Autorécupérable	Arrêt, variation des caractéristiques de fonctionnement Déclenchement des dispositifs de protection [b] Non autorécupérable
Performance spéciale du système Comportement du couple généré	Ecart de couple dans les tolérances spécifiées	Ecart de couple temporaire en dehors des tolérances spécifiées Autorécupérable	Perte de couple Non autorécupérable
Performance d'un sous-ensemble Fonctionnement de l'électronique de puissance et de ses circuits de commande	Pas de dysfonctionnement des semiconducteurs de puissance	Dysfonctionnement temporaire qui ne peut pas provoquer l'arrêt intempestif du PDS	Arrêt, déclenchement des dispositifs de protection [b] Aucune perte de programme stocké Aucune perte de programme utilisateur Aucune perte de réglages Non autorécupérable
Performance d'un sous-ensemble Fonctions de traitement et d'acquisition des données	Pas de perturbation de la communication et de l'échange de données avec les matériels externes	Perturbation temporaire de la communication mais pas de message d'erreur des composants internes ou externes qui pourrait provoquer l'arrêt	Erreurs de communication, perte de données et d'informations Aucune perte de programme stocké, aucune perte de programme utilisateur Aucune perte de réglages Non autorécupérable
Performance d'un sous-ensemble Fonctionnement des afficheurs et tableaux de commande	Pas de changement des informations affichées, seulement une légère fluctuation de la luminosité des LED ou un léger mouvement des caractères	Modifications temporaires visibles des informations, illumination intempestive des LED	Arrêt, perte définitive d'informations, ou mode de fonctionnement non autorisé, affichage des informations manifestement erroné Aucune perte de programme stocké, aucune perte de programme utilisateur Aucune perte de réglages

[a] Critères de qualification A, B, C – Les démarrages intempestifs ne sont pas admis. Un démarrage intempestif consiste en un changement non voulu de l'état logique "A L'ARRET" pouvant mettre le moteur en fonctionnement.

[b] Critère de qualification C – La fonction peut être rétablie par une intervention de l'opérateur (réarmement manuel). La fusion des fusibles est admise pour les convertisseurs commutés par le réseau fonctionnant en mode inverseur.

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5.1.3 Conditions pendant l'essai

La charge doit être comprise dans les valeurs spécifiées par le constructeur et la charge réelle doit figurer sur le rapport d'essai.

L'essai de comportement en générateur de couple comme celui des fonctions de détection et de traitement des informations nécessite un équipement d'essai spécial possédant une immunité adaptée contre les couplages parasites des perturbations de l'essai. Le dispositif d'essai ne peut être utilisé que si son immunité peut être prouvée par des mesures de référence. L'évaluation de la perturbation de couple peut être effectuée soit par un torsiomètre, soit par le calcul ou la mesure du courant générant le couple ou par d'autres techniques indirectes. Une charge adaptée et immunisée doit être disponible sur l'emplacement d'essai.

Pour l'essai de performance des fonctions de détection et de traitement des informations, des équipements appropriés pour la simulation de la communication ou de l'évaluation des données doivent être disponibles. Cet équipement doit posséder une immunité suffisante pour fonctionner correctement pendant l'essai.

Le moteur ayant été soumis à l'essai par son constructeur conformément aux normes appropriées, le composant moteur du PDS, à l'exception de ses capteurs, n'a pas à subir d'essai d'immunité de CEM supplémentaire. Le moteur étant connecté au BDM/CDM pendant la durée de l'essai, il n'est pas exigé de procéder à des essais d'immunité de CEM sur le moteur lui-même.

Les essais doivent être effectués sur les accès appropriés, lorsqu'ils existent, y compris ceux des accessoires en option, le cas échéant. Ils doivent être menés selon une méthode bien documentée et reproductible et accès par accès. Toutefois, en présence de plusieurs accès de mesure et de commande de processus ou interfaces de signal ayant une configuration physique (disposition) identique, l'essai d'un seul type d'accès ou d'interface est suffisant.

Les Paragraphes 5.2 et 5.3 présentent les exigences minimales, les essais et les critères de qualification. Les critères de qualification renvoient à 5.1.1.

5.2 Exigences d'immunité de base – perturbations basses fréquences

5.2.1 Principe commun

Les exigences du présent paragraphe doivent être appliquées pour assurer l'immunité d'un PDS contre les perturbations basses fréquences.

Le constructeur peut montrer la conformité aux exigences d'immunité par essai, calcul ou simulation; il doit indiquer la méthode de vérification dans le rapport d'essai. Sauf indication contraire, il suffit de montrer que le circuit de puissance satisfait aux critères de qualification exigés et que les paramètres assignés des circuits d'entrée (filtres, etc.) ne sont pas dépassés.

NOTE 1 Un certain nombre de ces phénomènes ne sont pas exigés par les normes génériques, mais sont importants pour le dimensionnement du circuit de puissance du PDS. Il est difficile de réaliser des essais d'immunité pour beaucoup de ces phénomènes, particulièrement lorsque le courant d'entrée dépasse 16 A ou que la tension d'alimentation dépasse 400 V. Cependant, l'expérience montre depuis de nombreuses années que, avec un circuit de puissance qui fonctionne correctement, l'immunité des commandes et des auxiliaires est généralement suffisante. Ceci est dû au découplage naturel qui existe dans le PDS. Le découplage fourni par les alimentations de puissance et les constantes de temps des processus auxiliaires tels que les ventilations est un exemple d'un tel découplage.

La conformité aux exigences du présent document doit être mentionnée dans la documentation utilisateur. Quand la démonstration de la conformité est faite par des essais, les normes fondamentales applicables dans la série IEC 61000-4 peuvent être prises en considération (voir Article B.7).

NOTE 2 Les conditions de service des alimentations principales et auxiliaires, s'il y a lieu, sont clairement définies dans les conditions de service du PDS des normes appropriées IEC 61800-1, IEC 61800-2 ou IEC 61800-4. Ces conditions de service comprennent les variations de fréquence, la vitesse de variation de la fréquence, les variations de tension, les fluctuations de tension, les déséquilibres de tension d'un réseau, les harmoniques et les encoches de commutation.

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5.2.2 Harmoniques et encoches de commutation/distorsion de tension

5.2.2.1 PDS basse tension (distorsion de tension)

Le PDS, BDM ou CDM doivent supporter les niveaux d'immunité, tout en satisfaisant aux critères de performance donnés aux Tableaux 3, 4 et 5. Il doit être vérifié que ces niveaux ne provoquent pas un dépassement des valeurs assignées des circuits d'entrée (filtres, etc.). L'analyse des encoches de commutation doit être faite dans le domaine temporel. Le constructeur peut vérifier l'immunité par calcul, simulation ou essai conformément à 5.2.1; la méthode de vérification retenue doit figurer dans le rapport d'essai. Si la méthode de vérification retenue est l'essai, elle doit être appliquée à l'aide du PDS avec le moteur raccordé. Pour les équipements assignés en dessous de 16 A par phase, la méthode d'essai de l'IEC 61000-4-13 peut s'appliquer.

NOTE L'analyse dans le domaine fréquentiel de la contribution des encoches de commutation sur la distorsion harmonique totale ne rend pas entièrement compte de certains effets nuisibles (voir Article B.1).

Tableau 3 – Exigences minimales d'immunité en distorsion harmonique totale sur les accès de puissance des PDS basse tension

Phénomène	Premier environnement		Deuxième environnement		Critère de performance (de qualification)
	Document de référence	Niveau	Document de référence	Niveau	
Harmoniques – THD	IEC 61000-2-2	8 %	IEC 61000-2-4 Classe 3	12 %	A

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Tableau 4 – Exigences minimales d'immunité pour les rangs harmoniques individuels sur les accès de puissance des PDS basse tension

Phénomène Rang d'harmonique	Premier environnement		Deuxième environnement		Critère de performance (de qualification)
	Document de référence	Niveau	Document de référence	Niveau	
2	IEC 61000-4-13 Classe 2	3 %	IEC 61000-4-13 Classe 3	5 %	A
3		8 %		9 %	
4		1,5 %		2 %	
5		9 %		12 %	
Rangs pairs $6 \leq h \leq 50$		Aucune exigence		1,5 %	
7		7,5 %		10 %	
9		2,5 %		4 %	
11		5 %		7 %	
13		4,5 %		7 %	
15		Aucune exigence		3 %	
17		3 %		6 %	
19		2 %		6 %	
21		Aucune exigence		2 %	
23		2 %		6 %	
25		2 %		6 %	
27		Aucune exigence		2 %	
29		1,5 %		5 %	
31		1,5 %		3 %	
33		Aucune exigence		2 %	
35		1,5 %		3 %	
37		1,5 %		3 %	
39		Aucune exigence		2 %	

NOTE 1 Pour les rangs harmoniques individuels dans le premier environnement, les niveaux sont ceux de la Classe 2 de l'IEC 61000-4-13 (lesquels correspondent approximativement à 1,5 fois les niveaux de compatibilité de l'IEC 61000-2-4).

NOTE 2 Pour les rangs harmoniques individuels dans le deuxième environnement, les niveaux sont ceux de la Classe 3 de l'IEC 61000-4-13 (lesquels correspondent approximativement à 1,5 fois les niveaux de compatibilité de l'IEC 61000-2-4).

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Tableau 5 – Exigences minimales d'immunité pour les encoches de commutation sur les accès de puissance des PDS basse tension

Phénomène	Premier environnement		Deuxième environnement		Critère de performance (de qualification)
	Document de référence	Niveau	Document de référence	Niveau	
Encoches de commutation	(Aucun)	Aucune exigence	IEC 60146-1-1 Classe B	Profondeur = 40 % Surface totale = 250 en % degrés	A

5.2.2.2 PDS de tension assignée supérieure à 1 000 V (distorsion de tension)

5.2.2.2.1 Accès de puissance principal

Le PDS, le BDM ou le CDM doivent supporter les niveaux d'immunité du Tableau 6. Il doit être vérifié que ces niveaux ne provoquent pas un dépassement des valeurs assignées des circuits d'entrée (filtres, etc.). L'analyse des encoches de commutation doit être faite dans le domaine temporel. Le constructeur peut vérifier l'immunité par calcul, simulation ou essai conformément à 5.2.1; la méthode de vérification retenue doit figurer dans le rapport d'essai.

NOTE L'analyse dans le domaine fréquentiel de la contribution des encoches de commutations à la distorsion harmonique totale ne révèle pas de manière évidente certains types d'effets nuisibles (voir Article B.1).

Tableau 6 – Exigences minimales d'immunité pour les harmoniques et les encoches de commutation/la distorsion de tension sur les accès de puissance principaux des PDS de tension assignée supérieure à 1 000 V

Phénomène	Document de référence	Niveau	Critère de performance (de qualification)
Harmoniques (*THD* et rangs harmoniques individuels)	IEC 61000-2-4 Classe 3	Valeur du niveau de compatibilité	A
Harmoniques transitoires (< 15 s)	IEC 61000-2-4 Classe 2	1,5 fois la valeur des niveaux permanents de compatibilité	A
Encoches de commutation	IEC 60146-1-1	Profondeur = 40 % U_{LWM} (classe B) Surface [a] = 125 en % degrés (classe C)	A
[a] La classe C de l'IEC 60146-1-1 convient pour le primaire du transformateur.			

5.2.2.2.2 Accès de puissance auxiliaire

Les accès de puissance auxiliaires des PDS doivent supporter les niveaux d'immunité pour le deuxième environnement des Tableaux 3, 4 et 5, tout en satisfaisant aux critères de performance donnés dans ces tableaux. Il doit être vérifié que ces niveaux ne provoquent pas un dépassement des valeurs assignées des circuits d'entrée (filtres, etc.). L'analyse des encoches de commutation doit être faite dans le domaine temporel. Le constructeur peut vérifier l'immunité par calcul, simulation ou essai conformément à 5.2.1; la méthode de vérification retenue doit figurer dans le rapport d'essai.

NOTE L'analyse dans le domaine fréquentiel de la contribution des encoches de commutations à la distorsion harmonique totale ne révèle pas de manière évidente certains types d'effets nuisibles (voir Article B.1).

5.2.3 Ecarts de tension, creux de tensions et coupures brèves

5.2.3.1 PDS basse tension (écarts de tension)

Le PDS, le BDM ou le CDM doivent supporter les niveaux d'immunité du Tableau 7. Le constructeur peut vérifier l'immunité par calcul, simulation ou essai conformément à 5.2.1; la méthode de vérification retenue doit figurer dans le rapport d'essai.

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Tableau 7 – Exigences minimales d'immunité pour les écarts de tension, les creux de tension et les coupures brèves sur les accès de puissance des PDS basse tension

Phénomène	Premier environnement			Deuxième environnement			Critère de performance (de qualification)
	Document de référence	Niveau		Document de référence	Niveau		
Ecarts de tension (> 60 s)	IEC 61000-2-2	±10 % [a]		IEC 61000-2-4 Classe 2	±10 % [a]		A [b]
Creux de tension [e]	IEC 61000-4-11 Classe 2 ou IEC 61000-4-34 Classe 2 [f]	Volts restants 0 % 70 %	Cycles 1 25/30 [c]	IEC 61000-4-11 Classe 3 ou IEC 61000-4-34 Classe 3 [f]	Volts restants 0 % 40 % 70 % 80 %	Cycles 1 10/12 [c] 25/30 [c] 250/300 [c]	C [d]
Coupures brèves	IEC 61000-4-11 Classe 2 ou IEC 61000-4-34 Classe 2 [f]	Volts restants 0 %	Cycles 250/ 300 [c]	IEC 61000-4-11 Classe 3 ou IEC 61000-4-34 Classe 3 [f]	Volts restants 0 %	Cycles 250/300 [c]	C [d]

[a] L'"écart de tension" est une variation de la tension d'alimentation par rapport à la tension d'alimentation nominale. Les essais d'écarts de tension pour les PDS triphasés nécessitent d'augmenter ou de diminuer la diminution de la tension des trois phases simultanément.

[b] Lorsque la tension est inférieure à la valeur nominale, les valeurs assignées maximales de puissance de sortie – vitesse et/ou couple – peuvent être réduites parce qu'elles sont fonction de la tension.

[c] "cycles x/y" signifie "x cycles pour l'essai à 50 Hz" et "y cycles pour l'essai à 60 Hz".

[d] La fusion des fusibles est admise pour les convertisseurs commutés par le réseau fonctionnant en mode inverseur.

[e] Accès de puissance de courant assigné ≥ 75 A: la méthode d'essai de chute de tension conforme au 7.5 de l'IEC 61400-21:2008 peut être utilisée.

[f] L'IEC 61000-4-11 s'applique aux équipements ayant un courant assigné inférieur ou égal à 16 A et l'IEC 61000-4-34 s'applique aux équipements ayant un courant assigné supérieur à 16 A.

Un PDS est utilisé pour convertir l'énergie, et un creux de tension représente une perte de l'énergie disponible. Il peut être nécessaire d'opérer un déclenchement pour des raisons de sécurité, même pendant un creux de tension de 30 % à 50 % d'amplitude et d'une durée de 0,3 s.

NOTE 1 Une tension d'entrée décroissante, même pendant quelques millisecondes, peut conduire à la fusion des fusibles lorsqu'elle est appliquée à un convertisseur à thyristor commuté par le réseau fonctionnant en mode générateur.

NOTE 2 L'effet d'un creux de tension (réduction d'énergie) sur le processus ne peut être défini sans connaissance détaillée du processus lui-même. Cet effet est un aspect du système et du dimensionnement, et sera généralement maximal lorsque la demande de puissance (pertes comprises) sur le PDS sera supérieure à la puissance disponible.

Lorsque cela est possible et ne présente pas de danger, le comportement du PDS pendant les coupures brèves peut être vérifié en coupant puis en rétablissant l'alimentation pendant les conditions de fonctionnement normales du PDS (voir B.6.1).

Le constructeur doit indiquer dans la documentation utilisateur les dégradations de performances résultant des creux de tension ou coupures brèves.

NOTE 3 Des améliorations de l'immunité (utilisation d'ASI, générateur de secours, déclassement, etc.) peuvent se traduire par une augmentation sensible de taille et de coût du PDS et peuvent réduire le rendement ou le facteur de puissance. Des manœuvres telles que le redémarrage automatique peuvent avoir des conséquences sur la sécurité et ne sont pas couvertes par le présent document.

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5.2.3.2 PDS de tension assignée supérieure à 1 000 V (écarts de tension)

5.2.3.2.1 Accès de puissance principal

Les accès de puissance principaux des PDS doivent supporter les niveaux d'immunité du Tableau 8. Le constructeur peut vérifier l'immunité par calcul, simulation ou essai conformément à 5.2.1; la méthode de vérification retenue doit figurer dans le rapport d'essai.

Tableau 8 – Exigences minimales d'immunité pour les écarts de tension, les creux de tension et les coupures brèves sur les accès de puissance principaux des PDS de tension assignée supérieure à 1 000 V

Phénomène	Document de référence	Niveau		Critère de performance (de qualification)
Ecarts de tension supérieurs à 1 min	IEC 61000-2-4 Classe 3	±10 %		A [a]
Ecarts de tension inférieurs à 1 min	IEC 61000-2-4 Classe 3	+10 % à –15 %		A [a]
Creux de tension	IEC 61000-4-34 [b]	Volts restants	Cycles	C [d]
		0 %	1	
		40 %	10/12 [c]	
		70 %	25/30 [c]	
		80 %	250/300 [c]	
Coupures brèves	IEC 61000-4-34 [b]	Volts restants	Cycles	C [d]
		0 %	250/300 [c]	

[a] L'"écart de tension" est une variation de la tension d'alimentation par rapport à la tension d'alimentation nominale. Les essais d'écarts de tension pour les PDS triphasés nécessitent d'augmenter ou de diminuer la diminution de la tension des trois phases simultanément.

Concernant les écarts de tension, aucun échelon de tension ne doit dépasser ±12 % de la tension nominale et le temps entre les échelons ne doit pas être inférieur à 2 s.

Lorsque la tension est inférieure à la valeur nominale, les valeurs assignées maximales de puissance de sortie – vitesse et/ou couple – peuvent être réduites parce qu'elles sont fonction de la tension.

[b] Les profondeurs et durées types des creux de tension sont données dans l'IEC TR 61000-2-8.

[c] "cycles x/y" signifie "x cycles pour l'essai à 50 Hz" et "y cycles pour l'essai à 60 Hz".

[d] La fusion des fusibles est admise pour les convertisseurs commutés par le réseau fonctionnant en mode inverseur.

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Le constructeur doit indiquer dans la documentation utilisateur les dégradations de performances résultant des creux de tension ou coupures brèves.

5.2.3.2.2 Accès de puissance auxiliaire

Les accès de puissance auxiliaires des PDS doivent supporter les niveaux d'immunité du Tableau 9. Le constructeur peut vérifier l'immunité par calcul, simulation ou essai; la méthode de vérification retenue doit figurer dans le rapport d'essai.

Tableau 9 – Exigences minimales d'immunité pour les écarts de tension, les creux de tension et les coupures brèves sur les accès de puissance auxiliaires des PDS basse tension

Phénomène	Document de référence	Niveau		Critère de performance (de qualification)
Ecarts de tension supérieurs à 1 min	IEC 61000-2-4 Classe 3	±10 %		A
Ecarts de tension inférieurs à 1 min	IEC 61000-2-4 Classe 3	+10 % à –15 %		A
Creux de tension	IEC 61000-4-11 ou IEC 61000-4-34 [b]	Volts restants	Cycles	C
		0 %	1	
		40 %	10/12 [a]	
		70 %	25/30 [a]	
		80 %	250/300 [a]	
Coupures brèves	IEC 61000-4-11 Classe 3 ou IEC 61000-4-34 Classe 3 [b]	Volts restants	Cycles	C
		0 %	250/300 [a]	

[a] "cycles x/y" signifie "x cycles pour l'essai à 50 Hz" et "y cycles pour l'essai à 60 Hz".

[b] L'IEC 61000-4-11 s'applique aux équipements ayant un courant assigné inférieur ou égal à 16 A et l'IEC 61000-4-34 s'applique aux équipements ayant un courant assigné supérieur à 16 A.

5.2.4 Déséquilibre de tension et variations de fréquence

5.2.4.1 PDS basse tension

La définition et les méthodes d'appréciation d'un déséquilibre de tension sont exposées en B.5.2.

Le PDS, le BDM ou le CDM doivent être conformes aux niveaux d'immunité du Tableau 10. Le constructeur peut vérifier l'immunité par calcul, simulation ou essai; la méthode de vérification retenue doit figurer dans le rapport d'essai. Pendant la vérification, la condition assignée de charge doit être utilisée.

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Tableau 10 – Exigences minimales d'immunité pour le déséquilibre de tension et les variations de fréquence sur les accès de puissance des PDS basse tension

Phénomène	Premier environnement		Deuxième environnement		Critère de performance (de qualification)
	Document de référence	Niveau	Document de référence	Niveau	
Déséquilibre de tension [a]	IEC 61000-2-2	2 % de composante inverse	IEC 61000-2-4 Classe 3	3 % de composante inverse	A[b]
Variations de fréquence	IEC 61000-2-2	± 2 %	IEC 61000-2-4	± 2 % ± 4 % lorsque l'alimentation est distincte des réseaux publics d'alimentation	A
Vitesse de variation de la fréquence		1 %/seconde		± 1 %/s 2 %/s lorsque l'alimentation est distincte des réseaux publics d'alimentation	A

[a] Ne s'applique pas aux PDS monophasés.

[b] En cas d'essai, utiliser une durée d'essai de 30 s ± 5 s.

5.2.4.2 PDS de tension assignée supérieure à 1 000 V

5.2.4.2.1 Accès de puissance principal

La définition et les méthodes d'appréciation d'un déséquilibre de tension sont exposées en B.5.2.

Le PDS, le BDM ou le CDM doivent supporter les niveaux d'immunité du Tableau 11. Le constructeur peut vérifier l'immunité par calcul, simulation ou essai; la méthode de vérification retenue doit figurer dans le rapport d'essai. Pendant la vérification, la condition assignée de charge doit être utilisée.

Tableau 11 – Exigences minimales d'immunité pour le déséquilibre de tension et les variations de fréquence sur les accès de puissance principaux des PDS de tension assignée supérieure à 1 000 V

Phénomène	Document de référence	Niveau	Critère de performance (de qualification)
Déséquilibre de tension	IEC 61000-2-4 Classe 2	2 % de composante inverse	A
Variations de fréquence	IEC 61000-2-4	±2 % ±4 % lorsque l'alimentation est distincte des réseaux publics d'alimentation	A A
Vitesse de variation de la fréquence		±1 %/s 2 %/s lorsque l'alimentation est distincte des réseaux publics d'alimentation	A A

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5.2.4.2.2 Accès de puissance auxiliaire

La définition et les méthodes d'appréciation d'un déséquilibre de tension sont exposées en B.5.2.

Les accès de puissance auxiliaires des PDS doivent supporter les niveaux d'immunité du Tableau 12. Le constructeur peut vérifier l'immunité par calcul, simulation ou essai; la méthode de vérification retenue doit figurer dans le rapport d'essai.

Tableau 12 – Exigences minimales d'immunité pour le déséquilibre de tension et les variations de fréquence sur les accès de puissance auxiliaires des PDS basse tension

Phénomène	Document de référence	Niveau	Critère de performance (de qualification)
Déséquilibre de tension	IEC 61000-2-4 Classe 3	3 % de composante inverse	A
Variations de fréquence	IEC 61000-2-4	±2 % ±4 % lorsque l'alimentation est distincte des réseaux publics d'alimentation	A A

5.2.5 Effets de l'alimentation – Champs magnétiques

Les essais d'immunité conformes à l'IEC 61000-4-8 ne sont pas exigés (voir explication à l'Article A.3).

5.3 Exigences d'immunité de base – perturbations hautes fréquences

5.3.1 Conditions

Le Tableau 13 et le Tableau 14 ci-après exposent les exigences d'immunité minimales pour les essais de perturbations hautes fréquences et les critères de qualification. Les critères de qualification renvoient à 5.1.1. Des explications sont fournies à l'Article A.3.

5.3.2 Premier environnement

Les niveaux du Tableau 13 doivent être appliqués aux PDS destinés à être utilisés dans le premier environnement.

Si le CDM/BDM est conçu pour présenter une immunité conforme au Tableau 13, les instructions d'utilisation doivent comporter un avertissement écrit précisant que le produit n'est pas destiné à être utilisé dans une installation industrielle.

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Tableau 13 – Exigences minimales d'immunité pour les PDS destinés à être utilisés dans le premier environnement

Accès	Phénomène	Norme de base pour la méthode d'essai	Niveau	Critère de performance (de qualification)
Accès enveloppe	ESD (décharge électrostatique)	IEC 61000-4-2	4 kV CD ou 8 kV AD si CD impossible	B
	Champ électromagnétique à radiofréquence, amplitude modulée	IEC 61000-4-3 Voir aussi 5.3.4	80 MHz à 1 000 MHz 3 V/m 80 % AM (1 kHz)	A
	Champ électromagnétique à radiofréquence, amplitude modulée	IEC 61000-4-3 Voir aussi 5.3.4	1,4 GHz à 2,0 GHz 3 V/m 80 % AM (1 kHz)	A
	Champ électromagnétique à radiofréquence, amplitude modulée	IEC 61000-4-3 Voir aussi 5.3.4	2,0 GHz à 2,7 GHz 1 V/m 80 % AM (1 kHz)	A
Accès de puissance accès de puissance auxiliaires en courant continu inférieur à 60 V)	Transitoires rapides en salves	IEC 61000-4-4	1 kV/5 kHz a	B
	Surtension [b] 1,2/50 µs, 8/20 µs	IEC 61000-4-5	1 kV [c] 2 kV [d]	B
	Mode commun de radiofréquence conduite	IEC 61000-4-6 Voir aussi 5.3.4	0,15 MHz à 80 MHz 3 V 80 % AM (1 kHz)	A
Interfaces de puissance	Transitoires rapides en salves e	IEC 61000-4-4	1 kV/5 kHz Pince capacitive	B
Accès des lignes de mesure et de commande de processus et interfaces de signal Accès de puissance auxiliaire en courant continu inférieur à 60 V	Transitoires rapides en salves e	IEC 61000-4-4	0,5 kV/5 kHz Pince capacitive	B
	Mode commun de radiofréquence conduite [e]	IEC 61000-4-6 Voir aussi 5.3.4	0,15 MHz à 80 MHz 3 V 80 % AM (1 kHz)	A

CD: décharge au contact AD: décharge dans l'air AM: modulation d'amplitude

[a] Accès de puissance de courant assigné < 100 A: couplage direct via le réseau de couplage et de découplage. Accès de puissance de courant assigné ≥ 100 A: couplage direct via le réseau de couplage ou la pince capacitative, sans le réseau de découplage. Si une pince capacitive est utilisée, le niveau d'essai doit être de 2 kV/5 kHz. La méthode d'essai retenue doit figurer dans le rapport d'essai.

[b] Ne s'applique qu'aux accès de puissance présentant une consommation de courant < 63 A dans les conditions d'essai à faible charge spécifiées en 5.1.3.

[c] Couplage entre phases.

[d] Couplage phase-terre.

e Applicable seulement aux accès ou aux interfaces destinés à des câbles dont la longueur totale, conformément aux spécifications fonctionnelles données par le constructeur, peut dépasser 3 m.

5.3.3 Deuxième environnement

Les niveaux du Tableau 14 doivent être appliqués aux PDS destinés à être utilisés dans le deuxième environnement. Ceci s'applique également aux accès basse tension, ou aux

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interfaces basse tension (puissance et signaux) des PDS de tension assignée supérieure à 1 000 V.

NOTE Exemples d'accès basse tension et d'interfaces de PDS de tension assignée supérieure à 1 000 V:

Accès enveloppe BT	enveloppe d'auxiliaires, commande et protection;
Accès de puissance BT	Alimentation BT du PDS;
Interfaces de puissance BT	distribution de l'alimentation auxiliaire entre les principaux composants du PDS;
Interfaces de signal BT	interfaces de signal BT dans les principaux composants du PDS;
Accès processus BT	accès signal du PDS

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Tableau 14 – Exigences minimales d'immunité pour les PDS destinés à être utilisés dans le deuxième environnement

Accès	Phénomène	Norme de base pour la méthode d'essai	Niveau	Critère de performance (de qualification)
Accès enveloppe	ESD (Décharge électrostatique)	IEC 61000-4-2	4 kV CD ou 8 kV AD si CD impossible	B
	Champ électromagnétique à radiofréquence, amplitude modulée	IEC 61000-4-3 Voir aussi 5.3.4	80 MHz à 1 000 MHz 10 V/m 80 % AM (1 kHz)	A
	Champ électromagnétique à radiofréquence, amplitude modulée	IEC 61000-4-3 Voir aussi 5.3.4	1,4 GHz à 2,0 GHz 3 V/m 80 % AM (1 kHz)	A
	Champ électromagnétique à radiofréquence, amplitude modulée	IEC 61000-4-3 Voir aussi 5.3.4	2,0 GHz à 2,7 GHz 1 V/m 80 % AM (1 kHz)	A
Accès de puissance (sauf accès de puissance auxiliaires en courant continu inférieur à 60 V)	Transitoires rapides en salves	IEC 61000-4-4	2 kV/5 kHz [a]	B
	Surtension [b] 1,2/50 μs, 8/20 μs	IEC 61000-4-5	1 kV [c] 2 kV [d]	B
	Radiofréquence conduite en mode commun [e]	IEC 61000-4-6 Voir aussi 5.3.4	0,15 MHz à 80 MHz 10 V 80 % AM (1 kHz)	A
Interfaces de puissance	Transitoires rapides en salves [e]	IEC 61000-4-4	2 kV/5 kHz Pince capacitive	B
Interfaces de signaux	Transitoires rapides en salves [e]	IEC 61000-4-4	1 kV/5 kHz Pince capacitive	B
	Radiofréquence conduite en mode commun [e]	IEC 61000-4-6 Voir aussi 5.3.4	0,15 MHz à 80 MHz 10 V 80 % AM (1 kHz)	A
Accès des lignes de mesure et de commande de processus Accès de puissance auxiliaire en courant continu inférieur à 60 V	Transitoires rapides en salves [e]	IEC 61000-4-4	2 kV/5 kHz Pince capacitive	B
	Surtension [f] 1,2/50 μs, 8/20 μs	IEC 61000-4-5	1 kV [d,f]	B
	Radiofréquence conduite en mode commun [e]	IEC 61000-4-6 Voir aussi 5.3.4	0,15 MHz à 80 MHz 10 V 80 % AM (1 kHz)	A
CD: décharge au contact AD: décharge dans l'air AM: modulation d'amplitude				

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[a] Accès de puissance de courant assigné < 100 A: couplage direct via le réseau de couplage et de découplage. Accès de puissance de courant assigné ≥ 100 A: couplage direct via le réseau de couplage ou la pince capacitative, sans le réseau de découplage. Si une pince capacitive est utilisée, le niveau d'essai doit être de 4 kV/5 kHz. La méthode d'essai retenue doit figurer dans le rapport d'essai.

[b] Ne s'applique qu'aux accès de puissance présentant une consommation de courant < 63 A dans les conditions d'essai à faible charge spécifiées en 5.1.3.

[c] Couplage entre phases.

[d] Couplage phase-terre.

[e] Applicable seulement aux accès ou aux interfaces destinés à des câbles dont la longueur totale, conformément aux spécifications fonctionnelles données par le constructeur, peut dépasser 3 m.

[f] Applicable seulement aux accès destinés à des câbles dont la longueur totale, conformément aux spécifications fonctionnelles données par le constructeur, peut dépasser 30 m. Dans le cas d'un câble blindé, un couplage direct est appliqué sur le blindage. Cette exigence d'immunité ne s'applique pas aux bus de communication de terrain ou autres interfaces de signaux pour lesquelles il est difficile, pour des raisons techniques, d'utiliser des dispositifs de protection contre les surtensions. L'essai n'est pas exigé là où le fonctionnement normal de l'équipement en essai (EST) ne peut pas être obtenu à cause de l'influence du réseau de couplage/découplage.

Ces phénomènes ne sont pas significatifs lorsqu'ils sont appliqués aux accès de tension assignée supérieure à 1 000 V. Pour plus de simplicité, ces accès sont appelés accès HT des PDS de tension assignée supérieure à 1 000 V.

NOTE Exemples d'accès et d'interfaces HT de PDS de tension assignée supérieure à 1 000 V:

Accès enveloppe HT	enveloppe du transformateur, partie convertisseur et moteur;
Accès de puissance HT	primaire du transformateur;
Interfaces de puissance HT	distribution du courant HT entre les principaux composants du PDS;
Interfaces de signal HT	interfaces de signal HT dans les principaux composants du PDS

5.3.4 Immunité aux champs électromagnétiques

Lorsque le PDS est

– de tension assignée inférieure ou égale à 500 V,
– de courant assigné inférieur ou égal à 200 A,
– d'un poids total inférieur ou égal à 250 kg, et
– de hauteur, de largeur et de profondeur inférieure ou égale à 1,9 m,

les essais de l'IEC 61000-4-3 et l'IEC 61000-4-6 doivent être effectués (voir 5.3.2 et 5.3.3).

Si le PDS est de taille plus importante ou de calibre supérieur à ce qui est décrit à l'alinéa précédent, le constructeur doit

– effectuer les essais de l'IEC 61000-4-3 et de l'IEC 61000-4-6 sur le PDS, ou
– effectuer les essais des normes IEC 61000-4-3 et IEC 61000-4-6 sur les sous-composants sensibles et faire figurer la méthode d'essai retenue dans le rapport d'essai.

Lorsque la taille du moteur est trop importante pour qu'il soit mis en fonctionnement sur un emplacement d'essai, le moteur peut être remplacé par un autre de taille inférieure à condition que cela ne nuise pas au fonctionnement du CDM/BDM.

5.4 Application des exigences d'immunité – Aspect statistique

Lors du choix du niveau de qualification pour un essai spécifique sur un PDS, il doit être entendu que le résultat de l'essai n'implique qu'une probabilité de performance. Selon le critère de qualification et l'application du PDS, cette probabilité doit être prise en considération en spécifiant le nombre d'impulsions de l'essai ou sa durée.

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Les exigences d'immunité du 5.3 doivent être vérifiées en réalisant un essai de type sur un appareil représentatif. Le constructeur ou le fournisseur doit garantir que le comportement de CEM du produit est maintenu en production par une forme ou une autre de contrôle qualité.

Les résultats des mesures obtenus pour un PDS installé sur son lieu d'utilisation (et non à l'emplacement d'essai) ne doivent s'appliquer qu'à cette installation.

6 Emission

6.1 Généralités sur les exigences d'émission

Les mesures doivent être effectuées pour le mode de fonctionnement produisant le maximum d'émissions dans la bande de fréquences tout en restant compatible avec une application normale.

Le Tableau 15 résume les exigences en fonction de la classification du PDS (voir 3.2).

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Tableau 15 – Résumé des exigences d'émission

Catégorie	Tension perturbatrice Basses fréquences (accès de puissance)	Tension perturbatrice Hautes fréquences (accès de puissance)	Emissions rayonnées (accès enveloppe et autres)
Catégorie C1	Evaluation du produit Exigences: - 6.2.2, - 6.2.3.1 ou 6.2.3.2 ou 6.2.3.3, - 6.2.4, - 6.2.5 Recommandations relatives aux conditions de charge: - B.2.3.3 et B.3.2	Evaluation du produit Limites pour les émissions conduites: - 6.4.1.1, Tableau 16	Evaluation du produit Limites pour les émissions rayonnées: - 6.4.1.3, Tableau 17; Autres exigences d'émission: - 6.4.1.2; - 6.4.1.4
Catégorie C2	Evaluation du produit Exigences: - 6.2.2, - 6.2.3.1 ou 6.2.3.2 ou 6.2.3.3, - 6.2.4, - 6.2.5 Recommandations relatives aux conditions de charge: - B.2.3.3 et B.3.2	Evaluation du produit Limites pour les émissions conduites: - 6.4.1.1, Tableau 16 Avertissement dans les instructions d'utilisation: - 6.4.1.1	Evaluation du produit Limites pour les émissions rayonnées: - 6.4.1.3, Tableau 17; Autres exigences d'émission: - 6.4.1.2; - 6.4.1.4 Avertissement dans les instructions d'utilisation: - 6.4.1.3
Catégorie C3	Evaluation du produit Exigences: - 6.2.2, - 6.2.3.4, - 6.2.4, - 6.2.5 Recommandations relatives aux conditions de charge: - B.2.3.3 et règles générales B.3.3 et B.4	Evaluation du produit Limites pour les émissions conduites: - 6.4.2.2, Tableau 19 Avertissement dans les instructions d'utilisation: - 6.4.2.1	Evaluation du produit Limites pour les émissions rayonnées: - 6.4.2.4, Tableau 20 Autres exigences d'émission: - 6.4.2.3 Avertissement dans les instructions d'utilisation: - 6.4.2.1
Catégorie C4	Règles d'ingénierie Exigences: - 6.2.2, - 6.2.3.4, - 6.2.4, - 6.2.5 Recommandations relatives aux conditions de charge: - B.2.3.3 et règles générales B.3.3 et B.4	Règles d'ingénierie Soit - appliquer les exigences de catégorie C3 ci-dessus, soit - 6.5	Règles d'ingénierie Soit - appliquer les exigences de catégorie C3 ci-dessus, soit - 6.5

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6.2 Limites de base des émissions basse fréquence

6.2.1 Méthode de mise en conformité

La conformité peut se vérifier par calcul, par simulation ou par essai. La méthode de vérification retenue doit figurer dans le rapport d'essai.

6.2.2 Encoches de commutation

Les encoches de commutation sont mesurées au niveau des accès de puissance à l'aide d'un oscilloscope (voir B.1.1). Elles sont produites par des convertisseurs contrôlés commutés par le réseau.

Lorsqu'il est établi que le circuit d'entrée du PDS ne produit pas d'encoches ou ne produit que des encoches d'amplitude négligeable (par exemple dans le cas de redresseurs à diode), l'émission d'encoches peut ne pas être prise en considération.

Dans la pratique, le principal cas dans lequel il convient de tenir compte de l'émission d'encoches de commutation est le cas de convertisseurs à thyristor (commutés par le réseau). Les filtres RFI sont des cas pratiques d'équipements qui peuvent être affectés par les encoches. Ils peuvent être soumis à des surcharges ou surtensions répétées.

NOTE Un redresseur à diodes est un convertisseur non contrôlé commuté par le réseau, qui produit des encoches de commutation d'amplitude négligeable. Certains convertisseurs autocommutés (par exemple, un convertisseur indirect de type onduleur de tension à étage d'entrée actif) peuvent produire des encoches de commutation en fonction du type de modèle MLI.

Lorsque les encoches doivent être prises en considération, le constructeur doit fournir les informations suivantes à l'utilisateur:

- valeur de toutes les réactances de découplage incluses dans le PDS;
- réactances de découplage disponibles qui peuvent être ajoutées en externe pour permettre l'atténuation (voir B.1.2).

Il convient de suivre les recommandations données en B.1.3.

6.2.3 Harmoniques et interharmoniques

6.2.3.1 Réseau public d'alimentation basse tension – Equipement couvert par l'IEC 61000-3-2

Un équipement peut comporter un ou plusieurs PDS, ainsi que d'autres charges.

Lorsqu'un PDS est couvert par l'IEC 61000-3-2, les exigences de cette norme s'appliquent. Lorsqu'un ou plusieurs PDS inclus dans l'équipement sont couverts par l'IEC 61000-3-2, les exigences de cette norme s'appliquent à l'équipement complet, et non aux PDS individuellement. Il incombe au constructeur de l'équipement de définir les limites du système ou du sous-système auquel s'applique l'IEC 61000-3-2, ainsi que la méthode de démonstration de la conformité de l'équipement.

6.2.3.2 Réseau public d'alimentation basse tension – Equipement couvert par l'IEC 61000-3-12

Lorsqu'un PDS est couvert par l'IEC 61000-3-12, les exigences de cette norme s'appliquent. Lorsqu'un ou plusieurs PDS inclus dans l'équipement sont couverts par l'IEC 61000-3-12, les exigences de cette norme s'appliquent à l'équipement complet, et non aux PDS individuellement. Il incombe au constructeur de l'équipement de définir les limites du système ou du sous-système auquel s'applique l'IEC 61000-3-12, ainsi que la méthode de démonstration de la conformité de l'équipement.

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6.2.3.3 Réseau public d'alimentation basse tension – Equipement non couvert par l'IEC 61000-3-2 ou par l'IEC 61000-3-12

Pour un équipement non couvert par l'IEC 61000-3-2 ou par l'IEC 61000-3-12 (courant assigné supérieur à 75 A), des recommandations peuvent être consultées à l'Article B.4.

Le constructeur doit fournir la documentation du PDS ou, sur simple demande, le rapport entre le niveau des harmoniques de courant *THC* dans des conditions assignées de charge et le courant efficace sur l'accès de puissance, ainsi que les courants harmoniques jusqu'au 40^{e} rang. Ces données peuvent s'obtenir par calcul, simulation ou essai.

Pour le calcul ou la simulation, les hypothèses suivantes doivent être retenues: la tension appliquée présente un *THD* inférieur à 1 %, et l'impédance interne du réseau est une inductance pure. Si l'emplacement spécifique du PDS est inconnu, les courants harmoniques doivent être calculés en prenant pour hypothèse que le PDS est relié à un PC doté de la valeur de R_{SI} la plus élevée autorisée par le constructeur du PDS.

$$R_{\mathrm{SI}} = \frac{I_{\mathrm{SC}}}{I_{\mathrm{LN}}}$$

où

I_{SC} est le courant de court-circuit au niveau du PC examiné;

I_{LN} est le courant d'entrée assigné du PDS.

Si le constructeur n'indique pas une valeur maximale de R_{SI}, par hypothèse, une valeur de 250 doit être retenue. Si l'emplacement spécifique du PDS est connu, l'impédance d'alimentation à cet emplacement doit être utilisée.

L'Article A.1 et l'Article A.2 de l'IEC TR 61000-2-6:1995 fournissent un guide de calcul des harmoniques. Des indications pour la sommation d'harmoniques de différentes sources sont également données en 7.4 de l'IEC TR 61000-2-6:1995.

Les effets des interharmoniques sont étudiés en B.4.3. Les méthodes de calcul figurent à l'Annexe C de l'IEC TR 61000-2-6:1995.

6.2.3.4 Réseaux industriels

Lorsqu'un PDS doit être utilisé dans une installation non directement alimentée à partir d'un réseau public basse tension, l'IEC 61000-3-2 et l'IEC 61000-3-12 ne sont pas applicables. Dès lors, il convient de mettre en œuvre une approche raisonnable prenant en considération la totalité de l'installation (voir Article B.4).

NOTE Pour les réseaux de tension supérieure à 1 000 V, la totalité de l'installation peut être soumise à des règles imposées par le distributeur, généralement basées sur l'IEC TR 61000-3-6. Ces règles s'appliquent à l'installation dans sa globalité et non pas à chaque équipement. Elles prennent généralement en considération les courants harmoniques et les distorsions de tension à l'intérieur du système. Le Tableau B.2 fournit une approche efficace et simplifiée.

Dans le cas d'un PDS dont la tension assignée est supérieure à 1 000 V, les émissions harmoniques produites par l'accès de puissance principal et l'accès de puissance auxiliaire doivent être examinées séparément.

6.2.4 Fluctuations de tension

6.2.4.1 Conditions

L'équipement peut comporter un ou plusieurs PDS, ainsi que d'autres charges capables de provoquer des fluctuations de tension.

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NOTE 1 Les fluctuations de tension peuvent être provoquées, par exemple, par des variations fréquentes de la charge d'un PDS, ou par des sous-harmoniques liées à la récupération d'énergie de moteurs asynchrones. Les fluctuations de tension peuvent également être provoquées par des interharmoniques à des fréquences légèrement différentes du fondamental ou des harmoniques prédominantes. L'émission est généralement provoquée par des cycloconvertisseurs ou des onduleurs à source de courant (voir B.4.3 et B.6.2). Les interharmoniques sont couverts par les niveaux de compatibilité indiqués dans l'IEC 61000-2-4 ou dans l'IEC 61000-2-12.

NOTE 2 Les fluctuations de tension dépendent de l'impédance de l'installation et du cycle de service de la charge. Dans certaines applications, l'utilisateur peut réduire les fluctuations de tension en ajustant le cycle de service de la charge par variation du taux d'évolution de la vitesse, ou par d'autres techniques.

La plupart des fluctuations de tension dépendent de l'installation. Par conséquent, il convient que cet aspect du système relève de la responsabilité de l'utilisateur ou de l'installateur. Il convient de ne pas dépasser les niveaux de compatibilité indiqués dans l'IEC 61000-2-4 pour les variations de tension, compte tenu des effets cumulés de l'ensemble des équipements.

6.2.4.2 PDS couvert par l'IEC 61000-3-3 et l'IEC 61000-3-11

Lorsqu'un PDS est couvert par l'IEC 61000-3-3, les exigences de cette norme s'appliquent. Lorsqu'un ou plusieurs PDS inclus dans l'équipement sont couverts par l'IEC 61000-3-3, les exigences de cette norme s'appliquent à l'équipement complet, et non aux PDS individuellement.

Lorsqu'un PDS est couvert par l'IEC 61000-3-11, les exigences de cette norme s'appliquent. Lorsqu'un ou plusieurs PDS inclus dans l'équipement couverts par l'IEC 61000-3-11, les exigences de cette norme s'appliquent à l'équipement complet, et non aux PDS individuellement.

NOTE L'application des limites de fluctuation de tension de l'IEC 61000-3-3 et de l'IEC 61000-3-11 n'est possible que lorsque les caractéristiques de la charge de l'équipement entraîné sont connues. Pour cette raison, seuls le constructeur et/ou l'utilisateur de la machine sont capables de déterminer sa conformité aux limites de fluctuation de tension.

6.2.4.3 PDS non couvert par l'IEC 61000-3-3 et l'IEC 61000-3-11

Pour un équipement non couvert par l'IEC 61000-3-3 et l'IEC 61000-3-11, les émissions de fluctuations de tension dépendent généralement des conditions de charge; le présent document ne peut pas fournir d'exigences.

NOTE Des règlements locaux fournis par les autorités locales peuvent s'appliquer à l'installation complète.

6.2.5 Emissions dans la plage de fréquences comprise entre 2 kHz et 9 kHz

Pour la plage de fréquence entre 2 kHz et 9 kHz, aucune limite n'est spécifiée.

NOTE 1 Le sous-comité 77A de l'IEC travaille actuellement sur les niveaux de compatibilité dans cette plage de fréquence.

NOTE 2 Jusqu'à la spécification de limites dans cette plage de fréquence, des recommandations de conception pour les valeurs d'émission des PDS et des CDM peuvent être consultées dans l'IEC TS 62578:2015, Annexe B.

6.2.6 Emission harmonique en mode commun (tension de mode commun basse fréquence)

La fréquence de commutation du convertisseur du PDS est souvent dans la plage des fréquences audibles et, en particulier, dans la plage des fréquences généralement utilisées par les systèmes de téléphone et de données. Pour éviter tout risque de diaphonie avec les câbles de signal, les instructions d'installation doivent recommander de séparer le câble de l'interface de puissance des câbles de signal, ou bien proposer d'autres méthodes d'atténuation.

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6.3 Conditions liées à la mesure des émissions hautes fréquences

6.3.1 Exigences générales

6.3.1.1 Conditions communes

La vitesse de variation de la tension ou du courant est considérée comme la principale source d'émissions hautes fréquences. Pour ce type de perturbation, les valeurs de d*v*/d*t* les plus élevées ont un impact; elles apparaissent généralement avec des courants de sortie inférieurs au courant assigné du PDS. Ces essais sont donc des essais à faible charge. Les essais doivent être appliqués sur les accès appropriés, lorsqu'ils existent, et doivent être effectués de manière bien définie et reproductible sur chaque accès.

La méthode d'essai doit être conforme au 7.3, au 7.4 et à l'Article 8 du CISPR 11:2015/AMD1:2016. Les exigences relatives à la configuration d'essai du PDS, notamment sur le positionnement du câblage, sont issues du 7.5 du CISPR 11:2015/AMD1:2016, avec une attention particulière accordée à la mise à la terre. 6.3.1.3 ci-après décrit un exemple type de configuration d'essai et de disposition du câblage d'un PDS pour la mesure des perturbations rayonnées avec une distance de séparation de 3 m. La charge et les longueurs de câbles doivent respecter les limites spécifiées par le constructeur. La charge effective et la longueur du câble de l'interface de puissance doivent être indiquées dans le rapport d'essai.

Le rapport d'essai doit indiquer si les essais ont été réalisés sur un emplacement d'essai ou *in situ*.

6.3.1.2 Emissions conduites

L'équipement de mesure pour l'évaluation des émissions de tension perturbatrice hautes fréquences de la borne de puissance réseau (accès de puissance) est soit un réseau fictif d'alimentation (50 Ω/50 µH, voir CISPR 16-1-2 et CISPR 11), lorsqu'il peut être utilisé, soit une sonde de tension à haute impédance conforme au 5.2.1 du CISPR 16-1-2:2014, lorsque le réseau fictif d'alimentation n'est pas applicable. La méthode d'essai retenue doit figurer dans le rapport d'essai. Les dispositifs d'absorption de mode commun (CMAD) ne doivent pas être utilisés dans la configuration d'essai pour la mesure des émissions conduites.

NOTE Un CMAD est un équipement d'essai appliqué sur certains câbles lors de la mesure des émissions rayonnées pour une meilleure reproductibilité (voir 6.3.1.3.4).

Une sonde de tension à haute impédance sans réseau fictif d'alimentation doit être utilisée pour la mesure *in situ* de la tension perturbatrice sur le secteur (voir 7.3.3 du CISPR 11:2015). La même règle peut s'appliquer si le courant d'entrée du PDS est supérieur à 100 A, ou si la tension d'entrée est supérieure ou égale à 500 V, ou si le PDS comprend un convertisseur commuté par le réseau (voir A.4.1.2).

6.3.1.3 Emissions rayonnées

6.3.1.3.1 Type d'emplacement d'essai

Un équipement de la catégorie C1 ou de la catégorie C2 doit être mesuré sur un emplacement d'essai conforme aux exigences du CISPR 16-1-4. La distance de mesure doit figurer dans le rapport d'essai.

Il convient qu'un équipement de catégorie C3 soit soumis à l'essai sur un emplacement d'essai conforme aux exigences du CISPR 16-1-4. Cependant, lorsque cela est impossible pour des raisons pratiques de poids, de taille ou de puissance, les essais peuvent être réalisés dans un emplacement qui ne répond pas entièrement aux exigences concernant les emplacements d'essai. L'utilisation de ces emplacements doit être justifiée dans le rapport d'essai.

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Pour les essais relatifs aux émissions rayonnées sur un emplacement d'essai, le CISPR 11 autorise les sites d'essai en espace libre (OATS) ou les chambres semi-anéchoïques (SAC).

NOTE Les conditions et les exigences d'essai pour la mesure des émissions rayonnées en chambre entièrement anéchoïque (FAR) sont à l'étude par le CISPR/B. Il est prévu qu'elles seront disponibles dans le CISPR 11.

6.3.1.3.2 Volume d'essai

La distance de mesure est prise entre le point de référence (PR) d'étalonnage de l'antenne et les limites du volume d'essai de l'EUT (voir Figures 5 à 7).

Le choix des distances de mesure doit être conforme aux exigences de 6.2.2.3 et 8.3.4 du CISPR 11:2015.

Les limites du volume d'essai de l'EUT correspondent au cylindre imaginaire autour de l'ensemble de la configuration de l'EUT. Cette limite est représentée par l'élément "H" de la Figure 5 et de la Figure 6. Le moteur et tous les câbles doivent se trouver à l'intérieur du cylindre imaginaire, sauf si les câbles en ressortent via un ou plusieurs CMAD. La hauteur du cylindre imaginaire est mesurée à partir du sol, que l'équipement de type EUT soit placé sur une table, monté au mur ou posé au sol.

L'EUT est considéré comme un petit matériel lorsque les limites du volume d'essai de l'EUT sont conformes à la définition en 3.1.5. La limite maximale pour le petit matériel est représentée par l'élément "K" des Figures 5 à 7. Il convient que les dimensions du volume d'essai soient mesurées avec une tolérance de ±0,1 m.

L'utilisation de CMAD est recommandée, car ils contribuent à assurer la reproductibilité des résultats d'essai. Cependant, elle n'est pas obligatoire. Les CMAD servent à définir l'impédance en mode commun et les résonances dans la plage de fréquences au-delà de 30 MHz, améliorant ainsi la reproductibilité.

6.3.1.3.3 Choix de la distance de mesure

Les Paragraphes 6.4.1.3 et 6.4.2.4 définissent les limites d'émission pour les distances d'essais de 10 m et 3 m.

Un petit matériel qui respecte les critères de taille définis en 3.1.5 peut faire l'objet d'un essai à 10 m ou à 3 m. Un matériel qui ne respecte pas ces critères de taille doit faire l'objet d'un essai à 10 m.

Les exigences particulières relatives à la configuration d'essai sont spécifiées en 6.3.1.3.4 à 6.3.1.3.6 pour garantir une meilleure reproductibilité des mesures à 3 m. Quand ces exigences sont également applicables pour les mesures à 10 m, elles améliorent la reproductibilité des mesures à cette distance.

6.3.1.3.4 Auxiliaires et périphériques

Lorsque des équipements auxiliaires ou périphériques ne font pas partie de l'EUT (voir EUT 2, Figures 5 et 6), ils peuvent être placés à l'extérieur du volume d'essai. Cependant, s'ils ne peuvent pas être exclus du volume d'essai maximal en raison de la longueur réduite des câbles d'interconnexion, ou pour d'autres raisons, ces équipements auxiliaires ou périphériques sont placés sur la table d'essai ou sur la plaque isolante.

L'évaluation du rayonnement peut être circonscrite aux seules sections de câble à l'intérieur du volume d'essai, par exemple à l'aide de dispositifs d'absorption de mode commun (CMAD) placés sur les câbles au niveau de leur sortie du volume d'essai. Le CISPR 16-2-3 fournit des préconisations supplémentaires sur l'utilisation de CMAD.

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6.3.1.3.5 Moteur

Pour les émissions rayonnées, des conditions à faible charge sont généralement acceptables pour le fonctionnement du PDS (voir A.2.1 pour plus d'informations sur les conditions de charge).

La puissance assignée du moteur utilisée au cours de l'essai d'émissions rayonnées peut être inférieure à la puissance assignée du CDM. Elle doit cependant être suffisamment importante pour permettre le fonctionnement correct de l'onduleur du CDM.

Le moteur peut être placé à l'intérieur ou à l'extérieur du volume d'essai. Le câble de l'interface de puissance entre le CDM/BDM et le moteur doit être exposé à l'antenne sur une longueur de 0,8 m au moins à l'intérieur du volume d'essai, sauf lorsque la longueur maximale de câble énoncée dans les instructions destinées à l'utilisateur est inférieure.

La position du moteur et la disposition du câblage doivent figurer dans le rapport d'essai.

6.3.1.3.6 Disposition de la configuration des essais relatifs aux émissions rayonnées

Des exemples de dispositions types pour les essais relatifs aux émissions rayonnées sont donnés de la Figure 5 à la Figure 7 ci-dessous.

Si un conducteur de mise à la terre spécial est utilisé (voir "C" de la Figure 7), sa longueur doit être d'au moins 1 m, et il doit être connecté comme indiqué dans la documentation utilisateur.

NOTE 1 Un deuxième conducteur de mise à la terre de protection est un exemple de conducteur de mise à la terre spécial; il peut être utilisé pour assurer la conformité au 4.3.5.5.2 de l'IEC 61800-5-1:2007.

Lorsque le moteur est éloigné du plateau tournant, le câble du moteur peut traverser le plancher de ce plateau (voir ligne en pointillés "A" de la Figure 7). Lorsque le moteur est proche du plateau tournant (voir "F" à la Figure 7) et qu'il l'empêche de tourner, il convient d'accorder une attention particulière à la réalisation des mesures d'émissions rayonnées comme en condition *in situ* (voir A.4.2).

L'utilisation d'un AMN pour les essais relatifs aux émissions rayonnées est recommandée, mais pas obligatoire.

Il convient que les équipements auxiliaires et périphériques qui ne font pas partie de l'EUT soient placés à l'extérieur du volume d'essai. Toutefois, si les câbles de raccordement entre eux et l'EUT ne peuvent pas être allongés suffisamment pour sortir du volume d'essai, ces auxiliaires et périphériques peuvent être placés à l'intérieur du volume d'essai (voir Figure 5 et Figure 6) ou sur la table tournante (voir Figure 7).

Il convient que l'espacement entre toutes les enveloppes (de l'EUT, des périphériques, etc.) soit ≥ 0,1 m. Cette distance est représentée par l'élément "D" dans les Figures 5 à 7.

Pour les cas dans lesquels le câble d'interconnexion est trop long, l'élément "B" des Figures 5 à 7 représente un câble enroulé, comme exigé par en 7.5.2 du CISPR 11:2015. L'excédent de câble est enroulé entre 0,3 m et 0,4 m au milieu de la longueur du câble.

NOTE 2 Le point de référence de l'étalonnage de l'antenne est pris en considération pour déterminer la distance de mesure. Il est représenté par l'élément "RP" des Figures 5 à 7.

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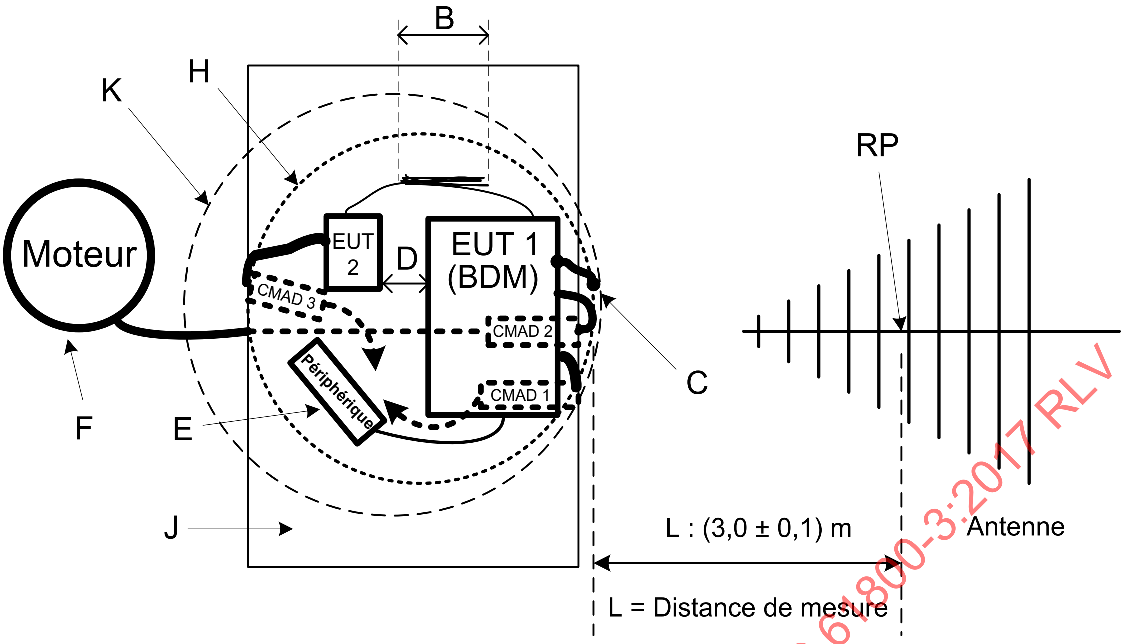

Légende

B L'excédent de câble est enroulé entre 0,3 m et 0,4 m au milieu de la longueur du câble.

C Connexion spéciale de mise à la terre, si la documentation utilisateur en spécifie une.

D Il convient que l'espacement entre les enveloppes soit ≥ 0,1 m.

E Le périphérique ou le dispositif auxiliaire se trouve dans le volume d'essai seulement si les câbles ne peuvent pas être allongés suffisamment pour qu'il soit placé à l'extérieur du volume d'essai.

F Moteur

H Volume d'essai. Il s'agit de la limite du cylindre imaginaire qui englobe la configuration complète de l'EUT (parties BDM/CDM du PDS).

J Table d'essai en matériau isolant, d'une hauteur de 0,8 m ± 0,01 m au-dessus du plan du sol.

K Limite du volume d'essai maximal pour les petits matériels définis en 3.1.5.

L Distance de mesure. Cette distance est mesurée entre le volume d'essai H et le point de référence RP d'étalonnage de l'antenne.

RP Point de référence d'étalonnage de l'antenne

Figure 5 – Exemple de disposition type du câblage pour les mesures à une distance de séparation de 3 m pour un équipement placé sur une table ou à montage mural – vue du dessus

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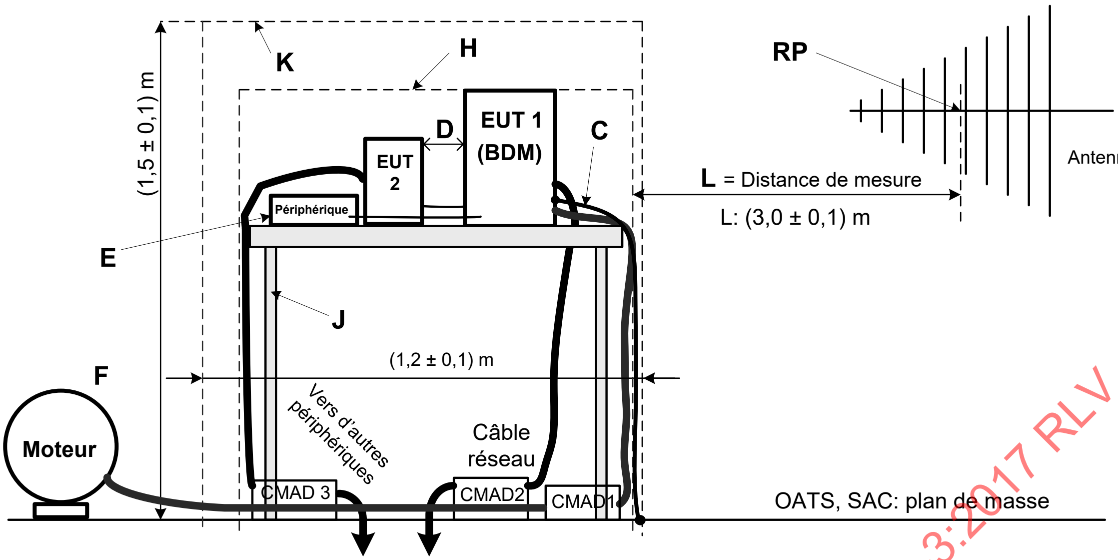

Légende

C Connexion spéciale de mise à la terre, si la documentation utilisateur en spécifie une.

D Il convient que l'espacement entre les enveloppes soit ≥ 0,1 m.

E Le périphérique ou le dispositif auxiliaire se trouve dans le volume d'essai seulement si les câbles ne peuvent pas être allongés suffisamment pour qu'il soit placé à l'extérieur du volume d'essai.

F Moteur

H Volume d'essai. Il s'agit de la limite du cylindre imaginaire qui englobe la configuration complète de l'EUT (parties BDM/CDM du PDS).

J Table d'essai en matériau isolant, d'une hauteur de 0,8 m ± 0,01 m au-dessus du plan du sol.

K Limite du volume d'essai maximal pour les petits matériels définis en 3.1.5.

L Distance de mesure. Cette distance est mesurée entre le volume d'essai H et le point de référence RP d'étalonnage de l'antenne.

RP Point de référence d'étalonnage de l'antenne

Figure 6 – Exemple de disposition type du câblage pour les mesures à une distance de séparation de 3 m pour un équipement placé sur une table ou à montage mural – vue latérale

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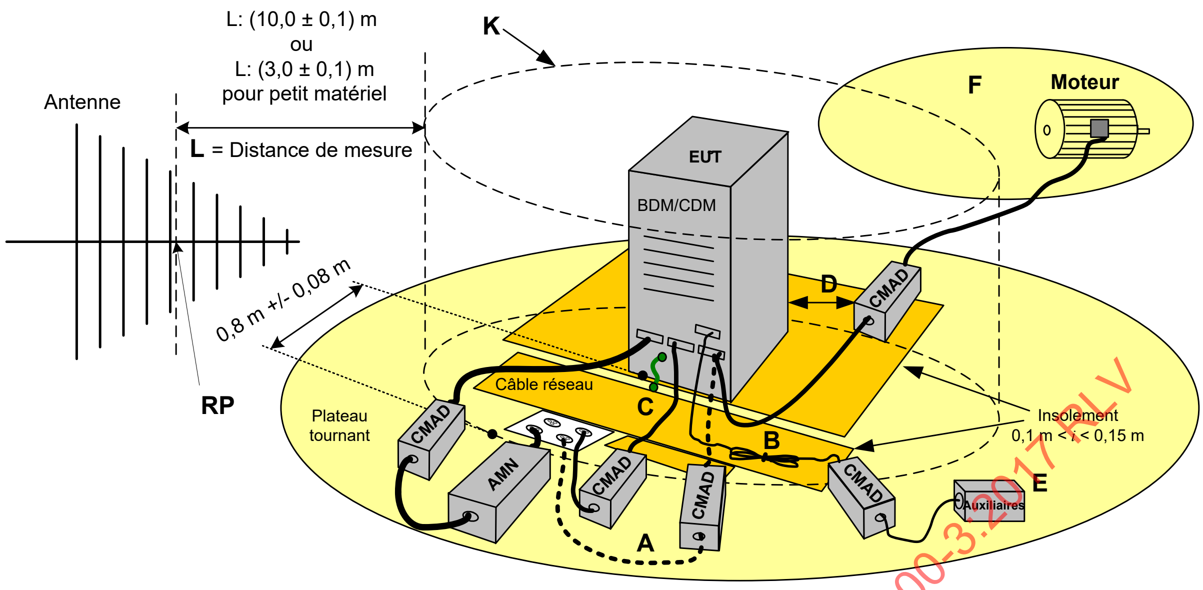

Légende

A La ligne en pointillés représente le trajet du câble du moteur lorsque le moteur est placé loin de la table tournante.

B L'excédent de câble est enroulé entre 0,3 m et 0,4 m au milieu de la longueur du câble.

C Connexion spéciale de mise à la terre, si la documentation utilisateur en spécifie une.

D Il convient que l'espacement entre les enveloppes soit ≥ 0,1 m.

E Le périphérique ou le dispositif auxiliaire se trouve dans le volume d'essai seulement si les câbles ne peuvent pas être allongés suffisamment pour qu'il soit placé à l'extérieur du volume d'essai.

F Moteur

K Limite du volume d'essai maximal pour les petits matériels définis en 3.1.5.

L Distance de mesure. Cette distance est mesurée entre le volume d'essai et le point de référence (RP) d'étalonnage de l'antenne.

RP Point de référence d'étalonnage de l'antenne

Figure 7 – Exemple de configuration type d'essai pour la mesure des perturbations conduites et/ou rayonnées par un PDS placé au sol, vue 3D

6.3.2 Exigences concernant les connexions

Si le PDS est mesuré sur un emplacement d'essai, la configuration d'essai, notamment la longueur et la position des câbles de puissance et de commande, doit être représentative de la ou des applications prévues définies par le constructeur et décrites dans la documentation destinée à l'utilisateur (voir 4.3). La configuration d'essai doit figurer dans le rapport d'essai.

Si le PDS est mesuré *in situ*, la disposition du câble et de la mise à la terre correspondront à celle de l'application.

6.4 Limites de base des émissions hautes fréquences

6.4.1 Equipements de catégorie C1 et C2

6.4.1.1 Tension perturbatrice au niveau des accès de puissance

Les limites de la tension perturbatrice sur les bornes réseau (accès de puissance) sont indiquées au Tableau 16.

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Tableau 16 – Limites de la tension perturbatrice sur les bornes réseau dans la bande de fréquences comprise entre 150 kHz et 30 MHz

	Catégorie C1		Catégorie C2	
Bande de fréquences MHz	Quasi-crête dB(μV)	Moyenne dB(μV)	Quasi-crête dB(μV)	Moyenne dB(μV)
$0{,}15 \le f < 0{,}50$	66 Décroît avec le logarithme de la fréquence jusqu'à 56	56 Décroît avec le logarithme de la fréquence jusqu'à 46	79	66
$0{,}5 \le f \le 5{,}0$	56	46	73	60
$5{,}0 < f < 30{,}0$	60	50	73	60

Lorsqu'un PDS ne respecte pas les limites de la catégorie C1, les instructions d'utilisation doivent contenir l'avertissement suivant:

Avertissement

Dans un environnement résidentiel, ce produit peut provoquer des interférences radio, auquel cas des mesures d'atténuation supplémentaires peuvent être exigées.

NOTE Le filtrage de mode commun en haute fréquence introduit des chemins d'écoulements à la terre par couplage capacitif. Dans le cas d'un système d'alimentation avec neutre isolé de la terre ou avec neutre raccordé à la terre au travers d'une haute impédance ("schéma IT" défini en 312.2.3 de l'IEC 60364-1:2015), ces chemins d'écoulements par couplage capacitif peuvent être dangereux (voir D.2.2).

Pour la plage de fréquence entre 9 kHz et 150 kHz, aucune limite n'est spécifiée.

NOTE 1 Le sous-comité 77A de l'IEC travaille actuellement sur les niveaux de compatibilité dans cette plage de fréquence.

NOTE 2 Jusqu'à la spécification de limites dans cette plage de fréquence, des recommandations de conception pour les valeurs d'émission des PDS et des CDM peuvent être consultées dans l'IEC TS 62578:2015, Annexe B.

6.4.1.2 Accès de mesure et de commande de processus

S'il est prévu de relier un accès de mesure et de commande de processus à un bus de terrain, cet accès doit être conforme aux exigences d'émission conduite de la norme applicable au bus de terrain en question.

S'il est prévu de relier un accès de mesure et de commande de processus à un réseau de télécommunication public, alors cet accès doit être considéré comme un accès de communication. Les exigences d'émissions conduites du CISPR 32, classe B, s'appliquent à cet accès.

6.4.1.3 Rayonnement – Accès enveloppe

Les limites de la perturbation par rayonnement électromagnétique (accès enveloppe, voir définition en 3.3.4 et Figure 2) sont indiquées au Tableau 17.

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Tableau 17 – Limites de la perturbation par rayonnement électromagnétique dans la bande de fréquences comprise entre 30 MHz et 1 000 MHz

	Composante de l'amplitude du champ électrique Quasi-crête dB (µV/m)			
	Distance de mesure de 10 m [a]		Distance de mesure de 3 m [a]	
Bande de fréquences MHz	Catégorie C1	Catégorie C2	Catégorie C1	Catégorie C2
$30 \leq f \leq 230$	30	40	40	50
$230 < f \leq 1\ 000$	37	47	47	57

[a] Concernant le choix de la distance de mesure, voir 6.3.1.3.3.

La distance de mesure doit figurer dans le rapport d'essai.

Lorsqu'un PDS ne respecte pas les limites de la catégorie C1, les instructions d'utilisation doivent contenir l'avertissement suivant:

Avertissement

Dans un environnement résidentiel, ce produit peut provoquer des interférences radio, auquel cas des mesures d'atténuation supplémentaires peuvent être exigées.

6.4.1.4 Emissions de l'interface de puissance

Pour un PDS destiné à fonctionner dans le premier environnement, la limite d'émission doit être obtenue au moyen de l'une des options suivantes.

a) Il n'est pas nécessaire de procéder à des mesures sur l'interface de puissance si la longueur du câble correspondant est inférieure à 2 m, ou si un câble blindé est utilisé. Le blindage doit alors être de bonne qualité en haute fréquence, être continu tout le long du câble et être au moins raccordé sur 360° aux extrémités sur le CDM et sur le moteur.

b) Les émissions doivent être vérifiées par mesure de la tension perturbatrice sur l'interface de puissance du BDM à l'aide de la sonde de tension à haute impédance décrite au 5.2.1 du CISPR 16-1-2:2014. Les limites données au Tableau 18 ci-dessous doivent s'appliquer.

c) Quand les mesures d'atténuation employées ne permettent pas une vérification selon le point b) (par exemple pour des méthodes d'atténuation en mode commun), l'efficacité de ces méthodes d'atténuation doit être vérifiée en réalisant un couplage entre le câble d'alimentation puissance et le câble moteur pendant la mesure de la tension perturbatrice sur la borne d'entrée puissance conformément à 6.4.1.1. Ce couplage doit être réalisé le long du câble, sur la longueur de 1 m séparant l'EUT et l'AMN, en plaçant en parallèle le câble d'alimentation puissance et le câble moteur avec une séparation n'excédant pas 0,10 m et sur une longueur d'au moins 0,60 m.

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Tableau 18 – Limites de la tension perturbatrice sur l'interface de puissance

Bande de fréquences MHz	Mesures effectuées avec le courant assigné de sortie	
	Quasi-crête dB(μV)	**Moyenne** dB(μV)
0,15 ≤ f < 0,5	80	70
0,50 ≤ f < 30	74	64
NOTE Les limites ci-dessus sont dérivées du CISPR 14-1.		

6.4.2 Equipement de catégorie C3

6.4.2.1 Exigence d'information

Si un PDS ne respecte pas les limites des catégories C1 ou C2, les instructions d'utilisation doivent comporter un avertissement indiquant que

- ce type de PDS n'est pas prévu pour être utilisé sur un réseau public basse tension qui alimente des locaux résidentiels, et
- l'utilisation de ce type de réseau peut entraîner un risque d'interférences aux fréquences radio.

Le constructeur doit fournir un guide d'installation et d'utilisation indiquant les appareillages à utiliser pour atténuer ces phénomènes.

6.4.2.2 Tension perturbatrice au niveau des accès de puissance

Les limites de la tension perturbatrice sur les bornes réseau (accès de puissance) des PDS sont indiquées au Tableau 19. Les mêmes limites s'appliquent aux accès de puissance basse tension des PDS de tension assignée supérieure à 1 000 V.

Tableau 19 – Limites de la tension perturbatrice sur les bornes réseau dans la bande de fréquences comprise entre 150 kHz et 30 MHz pour un PDS dans le deuxième environnement – PDS de catégorie C3

Taille du PDS [a]	Bande de fréquences MHz	Quasi-crête dB(μV)	Moyenne dB(μV)
I ≤ 100 A	0,15 ≤ f < 0,50	100	90
	0,5 ≤ f ≤ 5,0	86	76
	5,0 < f < 30,0	90 Décroît avec le logarithme de la fréquence jusqu'à 73	80 Décroît avec le logarithme de la fréquence jusqu'à 60
100 A < I	0,15 ≤ f < 0,50	130	120
	0,5 ≤ f < 5,0	125	115
	5,0 ≤ f < 30,0	115	105
Ces limites ne s'appliquent pas aux accès de puissance qui fonctionnent au-dessus de 1 000 V.			
[a] La taille du PDS fait référence au courant assigné (I) de l'accès.			

Voir aussi Article D.2.

Concernant les PDS au-dessus de 100 A sans transformateur dédié, pour éviter tout risque de diaphonie avec les câbles de signal, les instructions d'installation doivent recommander de séparer le câble de l'interface de puissance des câbles de signal, ou bien proposer d'autres méthodes d'atténuation.

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Pour la plage de fréquence entre 9 kHz et 150 kHz, aucune limite n'est spécifiée.

NOTE 1 Le sous-comité 77A de l'IEC travaille actuellement sur les niveaux de compatibilité dans cette plage de fréquence.

NOTE 2 Jusqu'à la spécification de limites dans cette plage de fréquence, des recommandations de conception pour les valeurs d'émission des PDS et des CDM peuvent être consultées dans l'IEC TS 62578:2015, Annexe B.

6.4.2.3 Accès de mesure et de commande de processus

S'il est prévu de relier un accès de mesure et de commande de processus à un bus de terrain, cet accès doit être conforme aux exigences d'émission conduite de la norme applicable au bus de terrain en question.

S'il est prévu de relier un accès de mesure et de commande de processus à un réseau de télécommunication public, alors cet accès doit être considéré comme un accès de communication. Les exigences d'émission conduite du CISPR 22, classe A, s'appliquent à cet accès.

6.4.2.4 Rayonnement – Accès enveloppe

Les limites de la perturbation par rayonnement électromagnétique (accès enveloppe, voir définition en 3.3.4 et Figure 2) des PDS sont indiquées au Tableau 20.

Tableau 20 – Limites de perturbation par rayonnement électromagnétique dans la bande de fréquences comprise entre 30 MHz et 1 000 MHz pour un PDS dans le deuxième environnement – PDS de catégorie C3

	Composante de l'amplitude du champ électrique Quasi-crête dB (µV/m)	
Bande de fréquences MHz	**Distance de mesure de 10 m [a]**	**Distance de mesure de 3 m [a]**
$30 \leq f \leq 230$	50	60
$230 < f \leq 1\ 000$	60	70
NOTE Dans la prochaine édition de l'IEC 61800-3, l'objectif consistera à harmoniser les valeurs de ce tableau avec le CISPR 11.		
[a] Concernant le choix de la distance de mesure, voir 6.3.1.3.3.		

La distance de mesure doit figurer dans le rapport d'essai.

6.4.2.5 Interface de puissance

Pour un PDS destiné à fonctionner dans le deuxième environnement, les instructions d'installation et d'utilisation doivent contenir toutes les informations nécessaires à l'installation de l'interface de puissance comme exigé en 4.3.

6.5 Règles d'ingénierie

6.5.1 PDS de catégorie C4

Pour les PDS de catégorie C4, la procédure suivante doit être utilisée.

Conditions générales

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Pour des raisons techniques, il existe des applications pour lesquelles il est impossible pour le PDS de respecter les limites du Tableau 19 et du Tableau 20. Ces applications répondent à des valeurs assignées importantes ou à des exigences techniques particulières:

- tension supérieure à 1 000 V;
- courant supérieur à 400 A;
- réseau isolé de la terre ou connecté à la terre par une forte impédance ("schéma IT" défini en 312.2.3 de l'IEC 60364-1:2005);
- lorsque les performances dynamiques demandées seront limitées en raison du filtrage.

Pour l'application des équipements de catégorie C4, l'utilisateur et le constructeur doivent convenir d'un plan de CEM pour respecter les exigences de CEM de l'application prévue (voir Annexe E). Dans ce cas, l'utilisateur définit les caractéristiques de CEM de l'environnement, y compris la totalité de l'installation et le voisinage (voir Figure 8). Le constructeur doit fournir des informations sur les niveaux typiques d'émission du PDS à installer. En cas d'interférences, les exigences et la procédure énoncées en 6.5.2 doivent être appliquées.

NOTE Exemples de mesures d'atténuation couramment utilisées et extraites du plan de CEM: filtrage global, transformateur spécial dédié, séparation des câbles.

Filtrage dans les systèmes d'alimentation IT

L'utilisation de PDS filtrés sur un réseau industriel de distribution, isolé de la terre ou relié par une haute impédance, peut poser un problème de sécurité si les PDS n'ont pas été correctement conçus pour les applications de ce type. Dans le cas des réseaux avec régime IT destinés aux systèmes industriels complexes, aucune limite ne peut être fixée. Les solutions doivent être basées sur la connaissance du système et, à ce titre, ne peuvent être normalisées. Les principales considérations portent sur les conditions de défaut et sur le courant de fuite des filtres.

a) Court-circuit à la terre du côté du moteur du PDS. Si le PDS peut continuer à fonctionner dans cette condition; de hauts niveaux de courant haute fréquence traverseront les condensateurs de filtrage. Cela peut les endommager. Un court-circuit à la terre du côté du moteur du PDS peut provoquer l'application d'une tension de mode commun sur les autres équipements du voisinage.

b) Détection d'un défaut par le contrôleur d'isolement (CPI) conforme à l'IEC 61557-8, en raison d'une augmentation de la capacité à la terre, qui peut entraîner un arrêt non souhaité du processus.

Les solutions reposent sur une analyse au cas par cas.

6.5.2 Limites situées en dehors de celles d'une installation, pour un PDS de catégorie C4 – Exemple de propagation des perturbations

6.5.2.1 Généralités

Pour les PDS installés dans le deuxième environnement, l'utilisateur doit s'assurer que des perturbations excessives ne sont pas induites au voisinage dans les réseaux basse tension, même si la propagation traverse un réseau moyenne tension.

En cas de plaintes concernant des interférences affectant un réseau basse tension avoisinant, ou en cas de litige entre l'utilisateur d'un PDS (par exemple dans l'installation 2 – voir Figure 8), et une victime sur un autre réseau (par exemple dans l'installation 1), il doit tout d'abord être clairement établi que les perturbations provoquées sur l'équipement de la victime (dans l'installation 1) ont lieu durant le fonctionnement du PDS présumé émetteur (installation 2).

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