IEC 60146-1-1

Edition 5.0 2024-03
COMMENTED VERSION

INTERNATIONAL STANDARD

Semiconductor converters – General requirements and line commutated converters –
Part 1-1: Specification of basic requirements

IEC 60146-1-1:2024-03 CMV(en)

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colour inside

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.200, 29.045

ISBN 978-2-8322-8575-6

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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SEMICONDUCTOR CONVERTERS – GENERAL REQUIREMENTS AND LINE COMMUTATED CONVERTERS –

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FOREWORD

This commented version (CMV) of the official standard IEC 60146-1-1:2024 edition 5.0 allows the user to identify the changes made to the previous IEC 60146-1-1:2009 edition 4.0. Furthermore, comments from IEC TC 22 experts are provided to explain the reasons of the most relevant changes, or to clarify any part of the content.

A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text. Experts' comments are identified by a blue-background number. Mouse over a number to display a pop-up note with the comment.

This publication contains the CMV and the official standard. The full list of comments is available at the end of the CMV.

IEC 60146-1-1 has been prepared by IEC technical committee 22: Power electronic systems and equipment. It is an International Standard.

This fifth edition cancels and replaces the fourth edition published in 2009. This fifth edition constitutes a technical revision.

This fifth edition introduces four main changes:

a) re-edition of the whole standard according to the current directives;
b) deletion of safety-related descriptions considering coordination with IEC 62477 series;
c) changes of calculation methods of inductive voltage regulation;
d) changes considering coordination with IEC 61378 series.

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

Draft	Report on voting
22/374/FDIS	22/378/RVD

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

The language used for the development of this International Standard is English.

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

A list of all parts of the IEC 60146 series, under the general title *Semiconductor converters – General requirements and line commutated converters*, can be found on the IEC website.

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

- reconfirmed,
- withdrawn, or
- revised.

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

INTRODUCTION

The main purposes of the IEC 60146-1 series are as follows.

IEC 60146-1-1, Specification of basic requirements:

- to establish basic terms and definitions;
- to specify service conditions which influence the basis of rating;
- to specify test requirements for electronic power converters and assemblies, standard design (for special design, see IEC TR 60146-1-2);
- to specify basic performance requirements;
- to give application oriented requirements for semiconductor power converters.

IEC TR 60146-1-2, Application guidelines:

- to give additional information on test conditions and components (for example: semiconductor valve devices), when required for their use in semiconductor power converters, in addition to or as a modification on existing standards;
- to provide useful reference, calculation factors, formulae and diagrams pertaining to power converter practice.

SEMICONDUCTOR CONVERTERS – GENERAL REQUIREMENTS AND LINE COMMUTATED CONVERTERS –

Part 1-1: Specification of basic requirements

1 Scope ~~and object~~

This part of IEC 60146 specifies the requirements for the performance of all semiconductor power converters and semiconductor power switches using controllable and/or non-controllable electronic valve devices.

The electronic valve devices mainly comprise semiconductor devices, either not controllable (i.e. rectifier diodes) or controllable (i.e. thyristors, triacs, turn-off thyristors and power transistors). The controllable devices ~~may~~ can be reverse blocking or reverse conducting and controlled by means of current, voltage or light. Non-bistable devices are assumed to be operated in the switched mode.

This document is primarily intended to specify the basic requirements for converters in general and the requirements applicable to line commutated converters for conversion of AC power to DC power or vice versa. Parts of this document are also applicable to other types of electronic power converter provided that they do not have their own product standards.

These specific equipment requirements are applicable to semiconductor power converters that either implement power conversion or use commutation (for example semiconductor self-commutated converters) or involve particular applications (for example semiconductor converters for DC motor drives) or include a combination of said characteristics (for example direct DC converters for electric rolling stock).

This document is applicable to all power converters not covered by a dedicated product standard, or if special features are not covered by the dedicated product standard. Generally dedicated product standards for power converters ~~should~~ refer to this document.

NOTE 1 This document is not intended to define EMC requirements. It covers all phenomena and therefore introduces references to dedicated standards which are applicable according to their scope.

NOTE 2 ~~A large part of this standard, particularly for power transformers, is covered in IEC 61378-1.~~ For the information on converter transformers, related to this document, see IEC 61378-1.

NOTE 3 All the terms listed in Clause 3 are not necessarily used in this document, however they are necessary to establish a common understanding in the application of semiconductor converters. 1

2 Normative references

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

~~IEC 60050-101:1998, *International Electrotechnical Vocabulary – Part 101: Mathematics*~~

IEC 60050-551:1998, *International Electrotechnical Vocabulary (IEV) – Part 551: Power electronics*, available at www.electropedia.org

IEC 60050-551-20:2001, *International Electrotechnical Vocabulary (IEV) – Part 551-20: Power electronics – Harmonic analysis,* available at www.electropedia.org

~~IEC 60364-1, *Low-voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions*~~

~~IEC 60529, *Degrees of protection provided by enclosures (IP Code)*~~

IEC 60664-1:~~2007~~2020, *Insulation coordination for equipment within low-voltage supply systems – Part 1: Principles, requirements and tests*

~~IEC 60700-1, *Thyristor valves for high voltage direct current (HVDC) power transmission – Part 1: Electrical testing*~~

~~IEC 61000 (all parts), *Electromagnetic compatibility (EMC)*~~

~~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 61000-3-2:2018, *Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤16 A per phase)*

~~IEC 61000-3-3, *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, *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:~~2004~~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 61000-4-7:2002, *Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto*

IEC 61000-6-1:2016, *Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity standard for residential, commercial and light-industrial environments*

IEC 61000-6-2:2016, *Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity standard for industrial environments*

~~IEC 61000-6-3, *Electromagnetic compatibility (EMC) – Part 6-3: Generic standards – Emission standard for residential, commercial and light-industrial environments*~~

IEC 61000-6-4:2018, *Electromagnetic compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments*

~~IEC 61140, *Protection against electric shock – Common aspects for installation and equipment*~~

~~IEC 61180-1:1992, *High-voltage test techniques for low voltage equipment – Part 1: Definitions, test and procedure requirements*~~

IEC 61204-3, *Low-voltage power supplies, d.c. output – Part 3: Electromagnetic compatibility (EMC)*

IEC 61204-7, *Low voltage power supplies, d.c. output – Part 7: Safety requirements*

IEC 61378-1:2011, *Converter transformers – Part 1: Transformers for industrial applications*

IEC 61800-3, *Adjustable speed electrical power drive systems – Part 3: EMC requirements and specific test methods*

IEC 61800-5-1, *Adjustable speed electrical power drive systems – Part 5-1: Safety requirements – Electrical, thermal and energy*

IEC 61954, *Power electronics for electrical transmission and distribution systems – Testing of thyristor valves for static VAR compensators*

IEC/PAS 61975, *Guide to the specification and design evaluation of a.c. filters for HVDC systems*

IEC 62040-1, *Uninterruptible power systems (UPS) – Part 1: General and safety requirements for UPS*

IEC 62040-2, *Uninterruptible power systems (UPS) – Part 2: Electromagnetic compatibility (EMC) requirements*

IEC 62103, *Electronic equipment for use in power installations*

IEC 62310-1, *Static transfer systems (STS) – Part 1: General and safety requirements*

IEC 62310-2, *Static transfer systems (STS) – Part 2: Electromagnetic compatibility (EMC) requirements*

IEC 62477-1:2022, *Safety requirements for power electronic converter systems and equipment – Part 1: General*

IEC 62477-2:2018, *Safety requirements for power electronic converter systems and equipment – Part 2: Power electronic converters from 1 000 V AC or 1 500 V DC up to 36 kV AC or 54 kV DC* **2**

NOTE Some other IEC publications are quoted for information in the Bibliography.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-551, IEC 60050-551-20, IEC 60664-1 and the following apply.

In this standard, IEV definitions are used wherever possible, particularly those in IEC 60050 (551).

All the terms listed in this clause are not necessarily used in this International Standard, however they are necessary to establish a common understanding in the application of semiconductor converters.

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

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

- IEC Electropedia: available at https://www.electropedia.org

NOTE The policy adopted is as follows:

- when an existing IEC 60050 definition needs amplification or additional information, the title, the reference and the additional text are given;
- explanations and figures are given in 4.2;
- terms used in connection with converter faults are defined in IEC TR 60146-1-2.

~~An alphabetical index is given in the Index of definitions.~~

~~NOTE For easier use of this index, a cross reference numbering is set up, noted [df *n*], in which *n* is the natural integer following the alphabetical order of the definitions.~~

3.1 Semiconductor devices and combinations

3.1.1
semiconductor device
device, the essential electric characteristics of which are due to the flow of charge carriers within one or more semiconductor materials

~~[IEV 151-13-63] [df 164]~~

[SOURCE: IEC 60050-151:2001, 151-13-63]

3.1.2
electronic ~~(~~power~~)~~ switch
electronic switch
operative unit for electronic power switching comprising at least one controllable valve device

~~[IEV 551-13-01] [df 60] [df 123] [df 173]~~

[SOURCE: IEC 60050-551:1998, 551-13-01]

3.1.3
semiconductor switch
electronic power switch with semiconductor valve devices

Note 1 to entry: Similar terms are used for electronic switches or power controllers with specific electronic valve devices, for example thyristor controller, transistor switch.

~~[IEV 551-13-05] [df 165] [df 174]~~

[SOURCE: IEC 60050-551:1998, 551-13-05]

3.1.4
non-controllable valve device
rectifier diode
reverse blocking valve device the current path of which conducts in its conducting direction without any control signal being applied

~~[IEV 551-14-04] [df 45] [df 105] [df 149]~~

[SOURCE: IEC 60050-551:1998, 551-14-04]

3.1.5
thyristor
bi-stable semiconductor device comprising three or more junctions which can be switched from the off-state to the on-state or vice versa

Note 1 to entry: Devices having only three layers but having switching characteristics similar to those of four-layer thyristors may also be called thyristors.

Note 2 to entry: The term "thyristor" is used as a generic term to cover the whole range of PNPN type devices. It may be used by itself for any member of the thyristor family when such use does not result in ambiguity or misunderstanding. In particular, the term "thyristor" is widely used for reverse blocking triode thyristor, formerly called "silicon controlled rectifier".

~~[IEV 521-04-61] [df 178]~~

[SOURCE: IEC 60050-521:2002, 521-04-61, modified – Note 2 to entry added]

3.1.6
reverse blocking triode thyristor
three-terminal thyristor which for negative anode voltage does not switch, but exhibits a reverse blocking state

~~[IEV 521-04-63] [df 158] [df 179] [df 193]~~

[SOURCE: IEC 60050-521:2002, 521-04-63]

3.1.7
reverse conducting triode thyristor
three-terminal thyristor which for negative anode voltage does not switch and conducts large currents at voltages comparable in magnitude to the forward on-state voltage

~~[IEV 521-04-65] [df 159]~~

[SOURCE: IEC 6005-521:2002, 521-04-65]

3.1.8
bidirectional triode thyristor
triac
three-terminal thyristor having substantially the same switching behaviour in the first and third quadrants of the current-voltage characteristic

~~[IEV 521-04-67, modified] [df 11] [df 188]~~

[SOURCE: IEC 60050-521:2002, 521-04-67]

3.1.9
turn-off thyristor
~~**GTO**~~
thyristor which can be switched from the on-state to the off-state and vice versa by applying control signals of appropriate polarity to the gate terminal

~~NOTE Also known as gate turn-off thyristor.~~

Note 1 to entry: The gate turn-off thyristor (GTO) and the integrated gate commutated thyristor (IGCT) are types of turn-off thyristor.

~~[IEV 521-04-68] [df 79] [df 81] [df 195]~~

[SOURCE: IEC 60050-521:2002, 521-04-68, modified – Note to entry added]

3.1.10
power transistor
transistor designed for switching from the on-state to the off-state and vice versa by applying control signals of appropriate polarity to the base or gate terminal ~~[df 124] [df 186]~~

Note 1 to entry: The structure of the device intrinsically provides the capability of amplification (see IEC 60050-521:2002, 521-04-46).

Note 2 to entry: Different technologies of power transistors are used, such as bipolar transistors, insulated gate bipolar transistors (IGBT), metal-oxide-semiconductor field-effect transistors (MOSFET), etc.

3.1.11
valve device stack
single structure of one or more electronic valve devices with its (their) associated mounting(s) and auxiliaries if any

~~[IEV 551-14-12] [df 171] [df 203]~~

[SOURCE: IEC 60050-551:1998, 551-14-12]

3.1.12
valve device assembly
electrically and mechanically combined assembly of electronic valve devices or stacks, complete with all its connections and auxiliaries in its own mechanical structure

Note 1 to entry: Similar terms are applied to stacks or assemblies comprising specific electronic valve devices, for example diode stack (rectifier diodes only), thyristor assembly (thyristors only or in combination with rectifier diodes).

~~[IEV 551-14-13] [df 6] [df 201]~~

[SOURCE: IEC 60050-551:1998, 551-14-13]

3.1.13
electronic valve device
indivisible electronic device for electronic power conversion or electronic power switching, comprising a non-controllable or bistably controlled unidirectionally conducting current path

~~[IEV 551-14-02] [df 61] [df 199]~~

[SOURCE: IEC 60050-551:1998, 551-14-02, modified – Notes to entry deleted]

3.1.14
semiconductor valve device
electronic valve device which is a semiconductor device

Note 1 to entry: Typical semiconductor valve devices are thyristors, rectifier diodes, bipolar transistors, metal-oxide-semiconductor field-effect transistors (MOSFET) and insulated-gate bipolar transistors (IGBT).

Note 2 to entry: Two or more semiconductor valve devices may be integrated on a common semiconductor chip (examples: a thyristor and a rectifier diode in a reverse conducting thyristor, a power switching field effect transistor with its reverse diode) or packaged in a common case (semiconductor power module). These combinations are considered as separate semiconductor valve devices.

~~[IEV 551-14-09] [df 166] [df 200]~~

[SOURCE: IEC 60050-551:1998, 551-14-09, modified – Notes to entry added]

3.1.15
~~(~~electronic~~)~~ ~~(~~power~~)~~ conversion
power conversion
conversion
change of one or more of the characteristics of an electric power system essentially without appreciable loss of power by means of electronic valve devices

Note 1 to entry: Characteristics include, for example, voltage amplitude, number of phases and frequency, including zero frequency.

~~[IEV 551-11-02] [df 32] [df 58] [df 116]~~

[SOURCE: IEC 60050-551:1998, 551-11-02]

3.1.16
~~(~~electronic~~)~~ ~~(~~power~~)~~ converter
power converter
converter
operative unit for electronic power conversion, comprising one or more electronic valve devices, and auxiliaries if any

Note 1 to entry: Converter transformers and filters related to network interfacing in terms of electrical characteristics are excluded from the converter itself. Such devices are part of the system aspect. Any device necessary to the correct operation of the converter itself is included in the converter, for example filters for limitation of the du/dt applied to the valve devices, surge arrestors, etc. Any auxiliary necessary to the correct operation of the converter itself is included in the converter, for example fans or cooling system.

~~[IEV 551-12-01, modified] [df 36] [df 59] [df 119]~~

[SOURCE: IEC 60050-551:1998, 551-12-01, modified, – Words "transformers and filters if necessary" removed from the definition, note to entry replaced, and figure removed]

3.1.17
trigger equipment
gating equipment
equipment which provides suitable trigger pulses from a control signal for controllable valve devices in a converter or power switch including timing or phase shifting circuits, pulse generating circuits and usually power supply circuits ~~[df 80] [df 191]~~

3.1.18
system control equipment
equipment associated with a power conversion equipment or system which performs automatic adjustment of the converter output characteristics as a function of a controlled quantity ~~(for example motor speed, traction force, etc.) [df 26] [df 176]~~

Note 1 to entry: Examples of controlled quantity include motor speed and traction force.

3.1.19
semiconductor converter
electronic power converter with semiconductor valve devices

Note 1 to entry: Similar terms for converters in general or for specific kinds of converters or for converters with other or specific valve devices, for example thyristor converter, transistor inverter.

~~[IEV 551-12-42] [df 37] [df 163]~~

[SOURCE: IEC 60050-551:1998, 551-12-42, modified – Figure removed]

3.1.20
power conversion equipment
PCE
equipment including the electronic power converter and auxiliaries necessary for operation of the converter itself, or even other parts dedicated to the application, and where these parts cannot be physically separated without preventing the operation of the converter ~~[df 33] [df 66] [df 117]~~

3.1.21
power conversion system
system consisting of a power conversion equipment and associated components for the application ~~for example switchgear, reactors or transformers, dedicated filters, etc. [df 35] [df 118] [df 175]~~

Note 1 to entry: Examples of associated components include switchgear, reactors or transformers and dedicated filters.

3.2 Arms and connections

3.2.1
(valve) arm
arm
part of the circuit of an electronic power converter or switch bounded by any two AC or DC terminals and including one or more simultaneously conducting electronic valve devices connected together and other components if any

~~[IEV 551-15-01] [df 5] [df 198]~~

[SOURCE: IEC 60050-551:1998, 551-15-01]

3.2.2
principal arm
valve arm involved in the major transfer of power from one side of the converter or electronic switch to the other

~~[IEV 551-15-02] [df 4] [df 125]~~

[SOURCE: IEC 60050-551:1998, 551-15-02, modified – Note removed]

3.2.3
auxiliary arm
~~any~~ valve arm other than a principal arm

Note 1 to entry: Sometimes an auxiliary arm temporarily fulfils more than one of the following functions: by-pass arm, free-wheeling arm, turn-off arm or regenerative arm.

~~[IEV 551-15-05] [df 3] [df 7]~~

[SOURCE: IEC 60050-551:1998, 551-15-05]

3.2.4
by-pass arm
auxiliary arm providing a conductive path which allows the current to circulate without an interchange of power between source and load

~~[IEV 551-15-06] [df 14]~~

[SOURCE: IEC 60050-551:1998, 551-15-06]

3.2.5
free-wheeling arm
by-pass arm containing only non-controllable valve devices

~~[IEV 551-15-07] [df 75]~~

[SOURCE: IEC 60050-551:1998, 551-15-07]

3.2.6
turn-off arm
auxiliary arm which temporarily takes over the current directly from a conducting valve arm, consisting of one or more latching valve devices which cannot be turned off by a control signal

~~[IEV 551-15-08] [df 194]~~

[SOURCE: IEC 60050-551:1998, 551-15-08]

3.2.7
regenerative arm
valve arm which transfers a part of the power from the load side to the source side

~~[IEV 551-15-09] [df 153]~~

[SOURCE: IEC 60050-551:1998, 551-15-09]

3.2.8
converter connection
electrical arrangement of valve arms and other components essential for the function of the main power circuit of a converter

Note 1 to entry: Common practice also uses the term "topology" of the converter with the same sense.

~~[IEV 551-15-10] [df 38]~~

[SOURCE: IEC 60050-551:1998, 551-15-10, modified – Note to entry added]

3.2.9
basic converter connection
electrical arrangement of principal arms in a converter

~~[IEV 551-15-11] [df 8]~~

[SOURCE: IEC 60050-551:1998, 551-15-11]

3.2.10
single-way connection
<of a converter> converter connection such that the current through each of the phase terminals of the AC circuit is unidirectional

~~[IEV 551-15-12] [df 170]~~

[SOURCE: IEC 60050-551:1998, 551-15-12]

3.2.11
double-way connection
<of a converter> converter connection such that the current through each of the phase terminals of the AC circuit is bidirectional

~~[IEV 551-15-13] [df 52]~~

[SOURCE: IEC 60050-551:1998, 551-15-13]

3.2.12
bridge connection
double-way connection of pairs of arms such that the centre terminals are the phase terminals of the AC circuit, and that the outer terminals of like polarity are connected together and are the DC terminals

~~[IEV 551-15-14] [df 13]~~

[SOURCE: IEC 60050-551:1998, 551-15-14]

3.2.13
uniform connection
connection with either all principal arms controllable or all principal arms non-controllable

~~[IEV 551-15-15] [df 197]~~

[SOURCE: IEC 60050-551:1998, 551-15-15]

3.2.14
non-uniform connection
connection with both controllable and non-controllable principal arms

~~[IEV 551-15-18] [df 106]~~

[SOURCE: IEC 60050-551:1998, 551-15-18]

3.2.15
series connection
connection of two-terminal networks so that they form a single path

~~[IEV 131-12-75] [df 167]~~

[SOURCE: IEC 60050-131:2002, 131-12-75, modified – Notes deleted]

3.2.16
series connection of converters
series connection in which two or more converters are connected in such a way that their voltages add ~~[df 168]~~

3.2.17
boost and buck connection
series connection of two or more converter connections the direct voltages of which may be added or subtracted depending on the control of the individual connections

~~[IEV 551-15-21] [df 12]~~

[SOURCE: IEC 60050-551:1998, 551-15-21]

3.3 Controllability of converter arms and quadrants of operation (on DC side)

3.3.1
controllable arm
converter arm including controllable valve device(s) ~~[df 27]~~

3.3.2
non-controllable arm
converter arm including only no-controllable valve device(s) ~~[df 104]~~

3.3.3
quadrant of operation
<DC side> quadrant of the voltage-current plane defined by the DC voltage polarity and the current direction ~~[df 130]~~

3.3.4
one-quadrant converter
AC/DC or DC converter with one possible direction of DC power flow

~~[IEV 551-12-34] [df 107]~~

[SOURCE: IEC 60050-551:1998, 551-12-34, modified – Figure deleted]

3.3.5
two-quadrant converter
AC/DC or DC converter with two possible directions of DC power flow associated with one direction of direct current and two directions of direct voltage or vice versa

~~[IEV 551-12-35] [df 196]~~

[SOURCE: IEC 60050-551:1998, 551-12-35, modified – Figure deleted]

3.3.6
four-quadrant converter
AC/DC or DC converter with two directions of DC power flow, associated with two directions of direct voltage and two directions of direct current

~~[IEV 551-12-36] [df 74]~~

[SOURCE: IEC 60050-551:1998, 551-12-36, modified – Figure deleted]

3.3.7
reversible converter
bi-directional converter
converter in which the direction of the power flow is reversible

Note 1 to entry: The term "bi-directional converter" corresponds to common practice, and provides a better picture of the bi-directional power flow in the converter.

~~[IEV 551-12-37] [df 10] [df 160]~~

[SOURCE: IEC 60050-551:1998, 551-12-37, modified – Alternative term "bi-directional converter" and note to entry added]

3.3.8
single converter
current stiff reversible AC/DC converter with direct current in one direction

~~[IEV 551-12-38] [df 169]~~

[SOURCE: IEC 60050-551:1998, 551-12-38, modified – Figure deleted]

3.3.9
double converter
current stiff reversible AC/DC converter with direct current in both directions

~~[IEV 551-12-39] [df 50]~~

[SOURCE: IEC 60050-551:1998, 551-12-39]

3.3.10
converter section of a double converter
part of a double converter in which the main direct current when viewed from the DC terminals always flows in the same direction

~~[IEV 551-12-40] [df 39]~~

[SOURCE: IEC 60050-551:1998, 551-12-40]

3.3.11
phase control
process of varying the instant within the cycle at which current conduction in an electronic valve device or valve arm begins

~~[IEV 551-16-23] [df 115]~~

[SOURCE: IEC 60050-551:1998, 551-16-23]

3.3.12
triggering
control action to achieve firing of a latching valve device or an arm consisting of such devices

~~[IEV 551-16-61] [df 192]~~

[SOURCE: IEC 60050-551:1998, 551-16-61]

3.4 Commutation, quenching and commutation circuitry

3.4.1
commutation
<in an electronic power converter> transfer of current from one conducting arm to the next to conduct in sequence, without interruption of the current, both arms conducting simultaneously during a finite time interval

~~[IEV 551-16-01] [df 17]~~

[SOURCE: IEC 60050-551:1998, 551-16-01]

3.4.2
quenching
termination of current flow in an arm without commutation

~~[IEV 551-16-19] [df 131]~~

[SOURCE: IEC 60050-551:1998, 551-16-19]

3.4.3
direct commutation
commutation between two principal arms without transfer through any auxiliary arms

~~[IEV 551-16-09] [df 46]~~

[SOURCE: IEC 60050-551:1998, 551-16-09]

3.4.4
indirect commutation
series of commutations from one principal arm to another or back to the original one by successive commutations via one or more auxiliary arms

~~[IEV 551-16-10] [df 90]~~

[SOURCE: IEC 60050-551:1998, 551-16-10]

3.4.5
external commutation
commutation where the commutating voltage is supplied by a source outside the converter or electronic switch

~~[IEV 551-16-11] [df 70]~~

[SOURCE: IEC 60050-551:1998, 551-16-11]

3.4.6
line commutation
external commutation where the commutating voltage is supplied by the line

~~[IEV 551-16-12] [df 99]~~

[SOURCE: IEC 60050-551:1998, 551-16-12]

3.4.7
load commutation
external commutation where the commutating voltage is taken from a load other than the line

~~[IEV 551-16-13] [df 100]~~

[SOURCE: IEC 60050-551:1998, 551-16-13]

3.4.8
machine commutation
external commutation where the commutating voltage is supplied by a rotating machine

~~[IEV 551-16-14] [df 101]~~

[SOURCE: IEC 60050-551:1998, 551-16-14]

3.4.9
resonant load commutation
method of load commutation in which the commutating voltage is supplied by the load, using its resonant property ~~[df 157]~~

3.4.10
self-commutation
commutation where the commutating voltage is supplied by components within the converter or the electronic switch

~~[IEV 551-16-15] [df 161]~~

[SOURCE: IEC 60050-551:1998, 551-16-15]

3.4.11
capacitor commutation
method of self-commutation in which the commutating voltage is supplied by capacitors included in the commutation circuit

~~[IEV 551-16-17] [df 15]~~

[SOURCE: IEC 60050-551:1998, 551-16-17]

3.4.12
inductively coupled capacitor commutation
method of capacitor commutation in which the capacitor circuit is inductively coupled to the commutation circuit ~~[df 93]~~

3.4.13
valve device commutation
method of self-commutation in which the commutating voltage is created by turning off the conducting electronic valve device by a control signal

Note 1 to entry: Simultaneously the next electronic valve device to conduct is turned on.

~~[IEV 551-16-16] [df 202]~~

[SOURCE: IEC 60050-551:1998, 551-16-16]

3.4.14
valve device quenching
method of quenching in which the quenching is performed by the electronic valve device itself

~~[IEV 551-16-20] [df 204]~~

[SOURCE: IEC 60050-551:1998, 551-16-20]

3.4.15
external quenching
method of quenching in which the quenching results from causes external to the device

Note 1 to entry: External quenching occurs in line-commutated converters under discontinuous conduction operation.

~~[IEV 551-16-21] [df 71]~~

[SOURCE: IEC 60050-551:1998, 551-16-21, modified – Words "electronic valve device" replaced with "device", and note to entry added]

3.5 Commutation characteristics

3.5.1
commutation circuit
circuit consisting of the commutating arms and the source providing the commutating voltage

~~[IEV 551-16-03] [df 18]~~

[SOURCE: IEC 60050-551:1998, 551-16-03]

3.5.2
commutation voltage
voltage which causes the current to commutate

~~[IEV 551-16-02] [df 25]~~

[SOURCE: IEC 60050-551:1998, 551-16-02]

3.5.3
commutation inductance
resulting inductance in the commutation circuit

Note 1 to entry: For line or machine commutated converters, the commutation reactance is the impedance of the commutation inductance at the fundamental frequency.

~~[IEV 551-16-07] [df 20]~~

[SOURCE: IEC 60050-551:1998, 551-16-07, modified – Note to entry added]

3.5.4
commutation interval
time interval in which commutating arms are carrying principal current simultaneously

~~[IEV 551-16-04] [df 21]~~

[SOURCE: IEC 60050-551:1998, 551-16-04]

3.5.5
angle of overlap
μ
commutation interval expressed in angular measure

~~[IEV 551-16-05] [df 2]~~

~~NOTE Also known as overlap angle *μ*.~~

[SOURCE: IEC 60050-551:1998, 551-16-05, modified – Symbol *μ* added]

3.5.6
commutation notch
periodic voltage transient that may appear in the AC side voltage of a line or machine-commutated converter due to the commutation

~~[IEV 551-16-06] [df 22]~~

[SOURCE: IEC 60050-551:1998, 551-16-06]

3.5.7
commutation repetitive transient
voltage oscillation associated with the commutation notch ~~[df 24]~~

3.5.8
commutating group
group of principal arms which commutate cyclically among themselves without intermediate commutation of the current to other principal arms

~~[IEV 551-16-08] [df 19]~~

[SOURCE: IEC 60050-551:1998, 551-16-08]

3.5.9
commutation number
q
number of commutations from one principal arm to another during one elementary period in each commutating group

~~[IEV 551-17-03] [df 23]~~

[SOURCE: IEC 60050-551:1998, 551-17-03, modified – Symbol *q* added]

3.5.10
pulse number
p
number of non-simultaneous symmetrical direct or indirect commutations from one principal arm to another which occur during one elementary period

~~[IEV 551-17-01] [df 129]~~

[SOURCE: IEC 60050-551:1998, 551-17-01, modified – Symbol *p* added]

3.5.11
trigger delay angle
α
time expressed in angular measure by which the trigger pulse is delayed with respect to the reference instant in the case of phase control

Note 1 to entry: With line, machine or load commutated converters the reference instant is the zero crossing instant of the commutating voltage. With AC controllers it is the zero crossing instant of the supply voltage. For AC controllers with inductive loads, the trigger delay angle is the sum of the phase shift and the current delay angle.

~~[IEV 551-16-33] [df 190]~~

[SOURCE: IEC 60050-551:1998, 551-16-33, modified – Symbol *α* added]

3.5.12
trigger advance angle
β
time expressed in angular measure by which the trigger pulse is advanced with respect to the reference instant

Note 1 to entry: With line, machine or load commutated converters the reference instant is the zero crossing instant of the commutating voltage.

~~[IEV 551-16-34] [df 189]~~

[SOURCE: IEC 60050-551:1998, 551-16-34, symbol β added]

3.5.13
inherent delay angle
α_p
current delay angle occurring, even without phase control, caused by multiple overlap

Note 1 to entry: Multiple overlap occurs in line commutated converters at high angles of overlap.

~~[IEV 551-16-35]~~ ~~[df 94]~~

[SOURCE: IEC 60050-551:1998, 551-16-35, modified – Symbol α_p added]

3.5.14
extinction angle
γ
time, expressed in angular measure, between the instant when the current of the arm falls to zero and the instant when the arm is required to withstand steeply rising off-state voltage ~~[df 72]~~

3.5.15
hold-off interval
interval between the instant when the on-state current of a latching valve device has decreased to zero and the instant when the same valve device is subjected to reapplied off-state voltage

~~[IEV 551-16-45]~~ ~~[df 86]~~

[SOURCE: IEC 60050-551:1998, 551-16-45]

3.6 Rated values

3.6.1
rated value
value of a quantity used for specification purposes, established for a specified set of operating conditions of a component, device, equipment or system

Note 1 to entry: The quantity may describe electrical, thermal, mechanical, or environmental properties.

Note 2 to entry: In the case of semiconductor converters, rated values usually apply to a semicondutor valve device, a valve device assembly or a converter.

Note 3 to entry: The nominal value of a system (for example nominal voltage – IEC 60050-601:1985, 601-01-21) is often equal to the corresponding rated value of the equipment, where both values are within the tolerance band of a quantity.

Note 4 to entry: Unlike many other electrical components, semiconductor devices may be irreparably damaged, even within a very short time of operation, in excess of maximum rated values.

Note 5 to entry: Variations of rated values should be specified. Certain of the values assigned are limiting values. These limiting values may be either maximum or minimum values.

~~[IEV 151-16-08]~~ ~~[df 145]~~

[SOURCE: IEC 60050-151:2001, 151-16-08, modified – Notes to entry added]

3.6.2
rated frequency ~~**(for converters and their transformers)**~~
f_N
specified frequency on the AC side of a converter ~~[df 142]~~

3.6.3
rated voltage on the line side (for converters and their transformers)
U_{LN}
specified RMS value of the voltage between conductors on the line side of the converter [df 146]

Note 1 to entry: If the line side transformer winding is provided with taps, the rated value of the voltage of the line side shall refer to a specified tap, which is the principal tap.

3.6.4
rated voltage on the valve side of the transformer (for converters and their transformers)
U_{vN}
RMS value of the no-load voltage between vectorially consecutive commutating phase terminals of the valve windings of a commutating group at rated voltage on the line side of the transformer [df 147]

Note 1 to entry: If no transformer is provided, within the converter case of a directly connected converter, the rated voltage on the valve side is the rated voltage on the line side of the converter.

3.6.5
rated current on the line side (for converters and their transformers)
I_{LN}
maximum RMS value of the current on the line side of the converter under rated conditions [df 137]

Note 1 to entry: The rated current on the line side takes into account rated load and the most onerous combination of all other conditions within their specified ranges, for example line voltage and frequency deviations.

Note 2 to entry: For polyphase equipment, this value is computed from the rated direct current on the basis of rectangular shaped currents of the converter arms. For single phase equipment, the basis of calculation should be specified.

Note 3 to entry: The rated line current includes currents supplied to the auxiliary circuits of the converter. It also takes into account the effect of DC current ripple and circulating current, if any.

3.6.6
rated current on the valve side (for converters and their transformers)
I_{vN}
maximum RMS value of the current on the valve side of the converter under rated conditions [df 138]

Note 1 to entry: The rated current on the valve side takes into account rated load and the most onerous combination of all other conditions within their specified ranges, for example line voltage and frequency deviations.

Note 2 to entry: For polyphase equipment, this value is computed from the rated direct current on the basis of rectangular shaped currents of the converter arms.

Note 3 to entry: For single phase equipment, the basis of calculation should be specified.

3.6.7
rated apparent power on the line side (for converters and their transformers)
S_{LN}
total apparent power, at the line side terminals, at rated frequency, rated voltage on the line side and rated current on the line side [df 132]

3.6.8
rated direct voltage
U_{dN}
mean value, at rated DC current, specified by the manufacturer, of the direct voltage between the DC terminals of the assembly or equipment [df 141]

3.6.9
rated direct current

I_{dN}

mean value of the direct current specified by the manufacturer for specified load and service conditions ~~[df 140]~~

Note 1 to entry: It may be referred to as the 1,0 p.u. value, to which other values of I_{d} are compared.

3.6.10
rated continuous direct current ~~(maximum value)~~

I_{dMN}

mean value of the direct current which an assembly or converter is capable of carrying continuously without damage, for specified service conditions ~~[df 133]~~

Note 1 to entry: The rated continuous direct current of an assembly is very often essentially higher than the rated direct current of the corresponding complete equipment. It is a maximum value.

Note 2 to entry: The rated continuous direct current of an assembly may be limited by parts other than the semiconductor.

3.6.11
peak maximum direct current

I_{dSMN}

mean value of the direct current which an assembly or converter is capable of carrying without damage, for a specified short duration, starting from an undefined duration at the rated current and followed by a no-load period of short duration ~~[df 113]~~

Note 1 to entry: The value and duration of the peak current (peak maximum direct current I_{dSMN}), as well as the minimum time of no-load before again carrying any current, are associated parts of the definition of the peak maximum direct current.

3.6.12
intermittent peak maximum direct current

I_{dRMN}

mean value of the direct current which an assembly or converter is capable of carrying without damage, for a specified short duration and intermittently, starting from any value of current equal or below the rated current, and back to any value of current equal or below the rated current ~~[df 98]~~

Note 1 to entry: The value and duration of the peak current (intermittent peak maximum direct current I_{dRMN}), as well as the minimum time between applications of intermittent peak loads, are associated parts of the definition of the intermittent peak maximum direct current.

3.6.13
rated current for peak load duty ~~(short-time duty)~~

mean value of the direct current which an assembly or converter is capable of carrying for specified duration under specified service conditions, associated with a short-time peak maximum direct current ~~[df 135]~~

Note 1 to entry: The characteristics of the associated maximum direct current I_{dSMN} are parts of the definition of the short-time duty. For details, see 6.4.3.2.

3.6.14
rated current for continuous duty with superimposed peak loads

mean value of the direct current which an assembly or converter is capable of carrying for unlimited duration under specified service conditions and with intermittently applied intermittent peak maximum direct current of specified magnitudes and durations ~~[df 134]~~

Note 1 to entry: The characteristics of the associated intermittent peak maximum direct current I_{dRMN} are parts of the definition of the rated current for continuous duty with superimposed peak loads.

3.6.15
rated current for repetitive load duty (periodic duty)
rated direct current of the assembly or converter, specified as the RMS value of the load current evaluated over the period of the load duty cycle [df 136]

Note 1 to entry: The duty class should be specified as a sequence of current values together with their durations. "repetitive load duty" is also known as "periodic duty". See 6.4.3.2 c).

3.6.16
rated DC power
product of the rated direct voltage and the rated direct current [df 139]

Note 1 to entry: The measured DC power may differ from the rated DC power as defined because of voltage and current ripple.

3.7 Specific voltages, currents and factors

3.7.1
ideal no-load direct voltage
U_{di}
theoretical no-load direct voltage of an AC/DC converter assuming no reduction by phase control, no threshold voltages of electronic valve devices, and no voltage rise at small loads

[IEV 551-17-15] [df 87]

[SOURCE: IEC 60050-551:1998, 551-17-15, modified – Symbol U_{di} added]

3.7.2
controlled ideal no-load direct voltage
$U_{di\alpha}$
theoretical no-load direct voltage of an AC/DC converter corresponding to a specified trigger delay angle assuming no threshold voltages of electronic valve devices and no voltage rise at small loads

[IEV 551-17-16] [df 29]

[SOURCE: IEC 60050-551:1998, 551-17-16, modified – Symbol $U_{di\alpha}$ added]

3.7.3
conventional no-load direct voltage
U_{d0}
mean value of the direct voltage which would be obtained by extrapolating the direct voltage/current characteristic from the region of continuous flow of direct current to zero current at zero trigger delay angle, i.e. without phase control

Note 1 to entry: U_{di} is equal to the sum of U_{d0} and the no-load voltage drop in the assembly.

[IEV 551-17-17] [df 31]

[SOURCE: IEC 60050-551:1998, 551-17-17, modified – Symbol U_{d0} and note to entry added]

3.7.4
controlled conventional no-load direct voltage
$U_{d0\alpha}$
mean value of the direct voltage corresponding to a specified trigger delay angle which would be obtained by extrapolating the direct voltage/current characteristic from the region of continuous flow of direct current to zero current

Note 1 to entry: $U_{di\alpha}$ is equal to the sum of $U_{d0\alpha}$ and the no-load voltage drop in the assembly.

~~[IEV 551-17-18] [df 28]~~

[SOURCE: IEC 60050-551:1998, 551-17-18, modified – Symbol $U_{d0\alpha}$ and note to entry added.]

3.7.5
real no-load direct voltage
U_{d00}
actual mean direct voltage at zero direct current

~~[IEV 551-17-19] [df 148]~~

[SOURCE: IEC 60050-551:1998, 551-17-19, modified – Symbol U_{d00} added]

3.7.6
direct voltage regulation
difference between the conventional no-load direct voltage and the direct voltage at load at the same trigger delay angle excluding the correcting effect of stabilizing means if any

Note 1 to entry: If voltage stabilizing means are used, refer also to 3.7.9.

Note 2 to entry: The nature of the DC circuit (for example capacitors, back e.m.f. load) may affect the voltage change significantly. Where this is the case, special consideration may be required.

~~[IEV 551-17-21] [df 48] [df 154]~~

[SOURCE: IEC 60050-551:1998, 551-17-21, modified – Notes to entry added]

3.7.7
inherent direct voltage regulation
direct voltage regulation excluding the effect of the AC system impedance

~~[IEV 551-17-22] [df 95]~~

[SOURCE: IEC 60050-551:1998, 551-17-22]

3.7.8
total direct voltage regulation
direct voltage regulation including the effect of the AC system impedance

~~[IEV 551-17-23] [df 180]~~

[SOURCE: IEC 60050-551:1998, 551-17-23]

3.7.9
output voltage tolerance band
specified range of steady-state values of a stabilized output voltage around its nominal or preset value ~~[df 108]~~

3.7.10
transition current
mean direct current of a converter connection when the direct current(s) of the commutating group(s) become(s) intermittent when decreasing the current

~~[IEV 551-17-20] [df 187]~~

[SOURCE: IEC 60050-551:1998, 551-17-20 modified – “commutation” replaced with “commutating”]

3.7.11
conversion factor
ratio of the fundamental output power or DC output power to the fundamental input power or DC input power

Note 1 to entry: The fundamental power (IEC 60050-551:1998, 551-17-08) is the active power determined by the fundamental components of voltage and current.

Note 2 to entry: For the purposes of this definition, the DC power is the product of the mean value of the voltage and mean value of the current.

~~[IEV 551-17-10]~~ ~~[df 34]~~

[SOURCE: IEC 60050-551:1998, 551-17-10, modified – Notes to entry added]

3.7.12
power efficiency
ratio of the output power to the input power of the converter ~~[df 120]~~

Note 1 to entry: In the conversion factor, the power ~~of~~ contained in the AC components of the current and voltage on the DC side is not taken into account. In the power efficiency, ~~it~~ the power contained in these AC components of the current and voltage on the DC side is included in the DC power. Therefore, for AC to DC conversion, the conversion factor has a lower value. For a single phase, two-pulse (full wave) converter with resistive load, the theoretical maximum conversion factor is 0,81 p.u., ~~where~~ while the maximum power efficiency is 1,0 p.u.

Note 2 to entry: The conversion factor may be correctly obtained only by measurement of the fundamental ~~a.c. power and d.c. voltage and current~~ component of power on the AC side and zero-frequency components of voltage and current on the DC side. The power efficiency may be correctly obtained either by measurement of root-mean-square values of AC power and DC power or by calculation or measurement of internal losses.

Note 3 to entry: The active power (mean value of the power) on the AC side, and the mean value of the power on the DC side are to be considered.

3.7.13
power factor
λ
ratio of the absolute value of the active power P to the apparent power S, under periodic conditions

$$\lambda = \frac{|P|}{S}$$

Note 1 to entry: Under sinusoidal conditions, the power factor is the absolute value of the active factor.

~~[IEV 131-11-46]~~ ~~[df 121]~~

[SOURCE: IEC 60050-131:2002, 131-11-46, modified – Symbol λ added]

3.7.14
power factor of the fundamental wave
displacement factor
$\cos\varphi_1$
under periodic conditions, ratio of the active power of the fundamental components P_1 to the apparent power of the fundamental components S_1

$$\cos\varphi_1 = \frac{P_1}{S_1}$$ ~~[df 49] [df 122]~~

NOTE IEV 131-11-48 defines the displacement angle as “under sinusoidal conditions, phase difference between the voltage applied to a linear two-terminal element or two-terminal circuit and the electric current in the element or circuit”. A note is added “The cosine of the displacement angle is the active factor.”

Note 1 to entry: For definition on the displacement angle, see IEC 60050-131:2002, 131-11-48.

3.7.15
deformation factor
ν
ratio of the total power factor λ to the displacement factor $\cos\varphi_1$

$$\nu = \frac{\lambda}{\cos\varphi_1}$$

[df 44]

Note 1 to entry: Under sinusoidal voltage condition, the deformation factor is equal to the fundamental factor. See 3.10.14, Note 2 to entry.

3.8 Cooling

3.8.1
cooling medium
liquid (for example water) or gas (for example air) which removes the heat from the equipment [df 40]

3.8.2
heat transfer agent
liquid (for example water) or gas (for example air) within the equipment to transfer the heat from its source to a heat exchanger from where the heat is removed by the cooling medium [df 85]

3.8.3
direct cooling
method of cooling by which the cooling medium is in direct contact with the parts of the equipment to be cooled, i.e. no heat transfer agent is used [df 47]

3.8.4
indirect cooling
method of cooling in which a heat transfer agent is used to transfer heat from the part to be cooled to the cooling medium [df 91]

3.8.5
natural cooling
convection
method of circulating the cooling fluid (cooling medium or heat transfer agent) which uses the change of volumetric mass (density) with temperature [df 30] [df 103]

3.8.6
forced cooling
method of circulating the cooling medium or heat transfer agent by means of blower(s), fan(s) or pump(s) [df 73]

3.8.7
mixed cooling
method of circulating the cooling medium or heat transfer agent, which uses, alternatively, natural and forced circulation [df 102]

Note 1 to entry: Mixed circulation may be used for light load/overload periods or in the case of an emergency.

3.8.8
equilibrium temperature
steady-state temperature reached by a component of a converter under specified conditions of load and cooling – [df 65]

Note 1 to entry: The steady-state temperatures are in general different for different components. The times necessary to establish steady-state are also different and proportional to the thermal time constants.

3.8.9
ambient air temperature
temperature of the air surrounding the power conversion equipment, measured at half the distance from any neighbouring equipment, but not more than 300 mm distance from the enclosure, at middle height of the equipment, protected from direct heat radiation from the equipment

[IEV 441-11-13, modified] [df 1]

3.8.10
cooling medium temperature for air and gas cooling
average temperature measured outside the equipment at points 50 mm from the inlet to the equipment – [df 41]

Note 1 to entry: For the evaluation of the fraction of heat which is radiated, the ambient temperature is that defined under 3.8.9.

3.8.11
cooling medium temperature for liquid cooling
temperature measured in the liquid pipe 100 mm upstream from the liquid inlet – [df 42]

3.8.12
temperature of heat transfer agent
heat transfer agent temperature measured at a point to be specified by the supplier – [df 177]

3.9 Service conditions tolerances and electromagnetic compatibility

3.9.1
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

[IEV 161-01-07] [df 54]

[SOURCE: IEC 60050-161:2018, 161-01-07]

3.9.2
(electromagnetic) emission
emission
phenomenon by which electromagnetic energy emanates from a source

[IEV 161-01-08] [df 57] [df 63]

[SOURCE: IEC 60050-161:2019, 161-01-08, modified – An alternative term “emission” added]

3.9.3
emission level
<converter> level of a given electromagnetic disturbance emitted from a converter operated within specified conditions and measured in a specified way

[IEV 161-03-11, modified] [df 64]

[SOURCE: IEC 60050-161:1990, 161-03-11, modified – Domain "disturbing source" replaced with "converter", and words "particular device, equipement or system" replaced with "converter, operated within specified conditions and measured in a specified way"]

3.9.4
electromagnetic disturbance
~~any~~ electromagnetic phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter

~~[IEV 161-01-05] [df 55]~~

[SOURCE: IEC 60050-161:2018, 161-01-05, modified – Notes to entry deleted]

3.9.5
electromagnetic disturbance level
level of an electromagnetic disturbance existing at a given location, which results from all contributing disturbance sources

~~[IEV 161-03-29] [df 56]~~

[SOURCE: IEC 60050-161:1990, 161-03-29]

3.9.6
reference level of generated disturbance of a converter
assumed level of disturbance produced by a converter, when the actual operating conditions are not known and rated operating conditions are used to calculate or measure the disturbance level ~~[df 152]~~

Note 1 to entry: The level of disturbance generally depends on the supply source impedance, which may not be considered as a characteristic quantity of the converter.

3.9.7
immunity to a disturbance
ability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance

~~[IEV 161-01-20] [df 89]~~

[SOURCE: IEC 60050-161:1990, 161-01-20]

3.9.8
immunity level of a converter
specified value of an electromagnetic disturbance level below which a converter is designed to meet the required performances or continue operation or avoid damage

~~[IEV 161-03-14, modified] [df 88]~~

Note 1 to entry: This definition is specific to the converter. For general concept of immunity level, it is found in IEC 60050-161:1990, 161-03-14.

3.9.9
relative short-circuit power
R_{SC}
ratio of the short-circuit power of the source to the rated apparent power on the line side of the converters ~~[df 156]~~

Note 1 to entry: R_{SC} refers to a given point of the network, for specified operating conditions and specified network configuration.

~~NOTE 2 Since the first edition of IEC 60146-1-1, the reference has been changed from the "fundamental apparent power on the line side of the converters" to the "rated apparent power on the line side of the converters" in order to maintain consistency with definitions adopted in other IEC technical committees (TC77).~~

Note 2 to entry: Within the IEC 61000-3 series, the short-circuit ratio is defined with the short-circuit power of the source at the PCC, instead of short-circuit power of the source at the IPC of use of the converter. The risk of confusion is clarified in Clause B.2.

3.10 Harmonic distortion

~~For the purpose of harmonic definitions, the symbol Q is used to represent a quantity, which in any application is more dedicated (example *U* for voltage, *I* for current). In the other parts of this standard, Q is the symbol used for reactive power (see Table 2). Explanations supporting these definitions are given in Annex A.~~

NOTE Equations in the harmonic definitions below use the symbol Q to represent a quantity. When these equations are used in dedicated applications, Q is replaced by the actual symbol for the quantity, for example U for voltage, I for current. In the other parts of this document, Q is the symbol used for reactive power (see Table 2). Explanations supporting these definitions are given in Annex A.

~~**3.10.1**~~
~~**PC, PCC, IPC**~~
~~**PC, PCC, IPC**~~
~~these definitions are given in IEC 61000-2-4 [df 112]~~

~~NOTE The definitions are :~~
- ~~PC: point of coupling for either of next cases;~~
- ~~PCC (point of common coupling on a public network): point on a public network, electrically nearest to a particular load, at which other loads are, or could be connected;~~
- ~~IPC (in-plant point of coupling): 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.~~

3.10.1
point of common coupling
PCC
point on a public power 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]

3.10.2
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]

3.10.3
fundamental frequency
frequency of the fundamental component

~~[IEV 551-20-03] [df 78]~~

[SOURCE: IEC 60050-551:2001, 551-20-03]

3.10.4
fundamental component
fundamental
<of a Fourier series> sinusoidal component of the Fourier series of a periodic quantity having the frequency of the quantity itself

Note 1 to entry: For practical analysis, an approximation of the periodicity may be necessary.

~~[IEV 551-20-01]~~ ~~[df 76] [df 77]~~

[SOURCE: IEC 60050-551:2001, 551-20-01]

3.10.5
reference fundamental component
sinusoidal component of the Fourier series of a periodic quantity having the frequency to which all other components are referred and which is not the fundamental component

Note 1 to entry: If it is clearly stated in a context that the reference fundamental component is used, the word "reference" may be omitted, but this document does not recommend this practice.

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

Note 3 to entry: In power electronics, often the component having the frequency of the AC supply system or of the converter output quantities is chosen as reference fundamental component.

~~[IEV 551-20-02]~~ ~~[df 150]~~

[SOURCE: IEC 60050-551:2001, 551-20-02]

3.10.6
reference fundamental frequency
frequency of the reference fundamental component

Note 1 to entry: If it is clearly stated in a context that the reference fundamental component is used, the word "reference" may be omitted, but this document does not recommend this practice.

~~[IEV 551-20-04]~~ ~~[df 151]~~

[SOURCE: IEC 60050-551:2001, 551-20-04]

3.10.7
harmonic frequency
frequency which is an integer multiple greater than one of the fundamental frequency or of the reference fundamental frequency

Note 1 to entry: The ratio of the harmonic frequency to the fundamental frequency, or to the reference fundamental frequency, is named "harmonic order" (recommended notation: h).

~~[IEV 551-20-05]~~ ~~[df 84]~~

[SOURCE: IEC 60050-551:2001, 551-20-05, modified – Note to entry added]

3.10.8
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: For practical analysis, an approximation of the periodicity may be necessary.

Note 3 to entry: The value is normally expressed as an RMS value.

~~[IEV 551-20-07]~~ ~~[df 82]~~

[SOURCE: IEC 60050-551:2001, 551-20-07, modified – Notes 1 and 3 to entry added]

3.10.9
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 reference fundamental frequency, this ratio is not an integer (recommended notation: m).

Note 2 to entry: In the case where $m < 1$, the term "sub-harmonic frequency" may also be used (see IEC 60050-551:2001, 551-20-10).

~~[IEV 551-20-06] [df 97]~~

[SOURCE: IEC 60050-551:2001, 551-20-06, modified – Notes to entry added]

3.10.10
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 practical analysis, an approximation of the periodicity may be necessary.

Note 3 to entry: The value is normally expressed as an RMS value.

Note 4 to entry: 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 the 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).

~~[IEV 551-20-08] [df 96]~~

[SOURCE: IEC 60050-551:2001, 551-20-08, modified – Notes 1, 3 and 4 to entry added]

3.10.11
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 distortion content is

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

$$Q_{\mathrm{HC}} = \sqrt{\sum_{h=2}^{h=H} Q_h^{\ 2}}$$

where

Q represents either current or voltage;

h is the harmonic order;

H is 50 for the purpose of this document. It has been 40 for a long time in standards related to power electronics, and should be moved to 50 in line with IEC 61000-2-2 and IEC 61000-2-4.

~~[IEV 551-20-12] [df 83]~~

[SOURCE: IEC 60050-551:2001, 551-20-12, modified – Note 4 to entry added]

3.10.12
total harmonic ratio
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

~~[IEV 551-20-11] [df 181]~~

~~NOTE 1 The total distortion content includes harmonic components and interharmonic components if any.~~

~~NOTE 2 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 The total distortion content is a time function.~~

~~NOTE 4 An alternating quantity (abbreviated as Q) is a periodic quantity with zero d.c. component.~~

~~NOTE 5 The r.m.s. value of the distortion content is~~

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

~~where~~

~~notations come from 3.10.10 and 3.10.11. See also IEV 101-14-54 and IEV 551-20-06.~~

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

where

Q, h, and H are the same as listed in 3.10.11;

Q_1 is the RMS value of the fundamental component.

Note 1 to entry: The harmonic 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.

Note 2 to entry: The total harmonic ratio may be restricted to a certain harmonic order (recommended notation: H), 50 for the purpose of this document.

[SOURCE: IEC 60050-551:2001, 551-20-13, modified – Recommended notation and value added in Note 2 to entry]

3.10.13
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 (symbol Q) is a periodic quantity with zero DC component.

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

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

where

~~notations come from 3.10.10 and 3.10.11. See also IEV 101-14-54 and IEV 551-20-06.~~

Q_1 is noted in 3.10.12.

~~[IEV 551-20-11] [df 181]~~

[SOURCE: IEC 60050-551:2001, 551-20-11, modified – Symbol added in Note 4 to entry. Note 5 to entry added]

3.10.14
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

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

$$D_R = \frac{D_C}{Q_1} = \frac{\sqrt{Q^2 - Q_1^2}}{Q_1}$$

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.

~~[IEV 551-20-14] [df 183]~~

[SOURCE: IEC 60050-551:2001, 551-20-14, modified – Abbreviated term "TDR" and formula in Note 1 to entry added. Note 2 to entry deleted]

3.10.15
total distortion factor
TDF
ratio of the RMS value of the total distortion content to the RMS value of an alternating quantity

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

$$D_F = \frac{D_C}{Q} = \frac{\sqrt{Q^2 - Q_1^2}}{Q}$$

Note 1 to entry: 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 given.

Note 2 to entry: The ratio between TDF and TDR equals the ratio between the RMS value of the fundamental component and the total RMS value. It is the fundamental factor (IEC 60050-161:1990, 161-02-22):

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

$$f_F = \frac{D_F}{D_R} = \frac{Q_1}{Q} \leq 1$$

~~[IEV 551-20-16] [df 182]~~

[SOURCE: IEC 60050-551:2001, 551-20-16, modified – Abbreviated term "TDF", formula in Note 1 to entry, and Note 2 to entry added]

3.10.16
individual harmonic ratio
IHR
ratio of any harmonic component to the fundamental ~~[df 92]~~

Note 1 to entry: In IEC 60050-161:1990, 161-02-20, the individual harmonic ratio is named "n^{th} harmonic ratio". IHR has been chosen for consistency with 3.10.11, and the order index has been chosen as "h" instead of "n", which is frequently used elsewhere, for example for the natural integer list.

Note 2 to entry: The value of the individual harmonic ratio is ~~$IHR = \frac{Q_h}{Q_1}$~~ $Q_{\mathrm{IHR}} = \frac{Q_h}{Q_1}$.

3.10.17
partial weighted harmonic ratio
PWHR
ratio of the RMS value of a selected group of higher order harmonics, weighted with the harmonic order h, to the RMS value of the fundamental

~~[IEC 61000-3-12, definition 3.2, modified] [df 111]~~

~~NOTE 1 The partial weighted harmonic ratio is employed in order to ensure that the effects of the higher order harmonic currents on the results are reduced sufficiently and individual limits need not be specified.~~

~~NOTE 2 In IEC 61000-3-12, this term is defined as "partial weighted harmonic distortion (*PWHD*)" and the orders of harmonics in the group are defined from 14 to 40.~~

~~$$PWHD = \sqrt{\sum_{h=14}^{h=40} h \cdot \left(\frac{Q_h}{Q_1}\right)^2}$$~~

~~In a draft IEC 61000-3-12 2nd edition, the term and definition have been changed to "partial weighted harmonic current (*PWHC*)".~~

$$Q_{\mathrm{PWHR}} = \sqrt{\sum_{h=14}^{h=40} h \times \left(\frac{Q_h}{Q_1}\right)^2}$$

Note 1 to entry: The partial weighted harmonic ratio is employed in order to ensure that the effects of the higher order harmonic currents on the results are reduced sufficiently and individual limits need not be specified.

Note 2 to entry: The similar concept for the harmonic current is shown in IEC 61000-3-12:2011, 3.2.

3.11 Definitions related to insulation co-ordination

~~The definitions of Clause 3 of IEC 60664-1 apply together with the following.~~

3.11.1
~~(electrical)~~ circuit
circuit
<equipment> current paths of components or assemblies, conductors or terminals connected to each other by electrically conductive connections and insulated from the remaining part of the equipment ~~[df 16] [df 53]~~

Note 1 to entry: If parts of the same equipment are conductively connected only via a protective equipotential bonding system, then they are regarded as separate circuits.

3.11.2
part of a circuit
section of a circuit having its own rated insulation voltage ~~[df 110]~~

3.11.3
equipotentiality
state when conductive parts are at a substantially equal electric potential

~~[IEV 195-01-09]~~ ~~[df 69]~~

[SOURCE: IEC 60050-195:2021, 195-01-09]

3.11.4
equipotential bonding
provision of electric connections between conductive parts, intended to achieve equipotentiality

~~[IEV 195-01-10]~~ ~~[df 67]~~

[SOURCE: IEC 60050-195:2021, 195-01-10, modified – Definition reformulated]

3.11.5
equipotential bonding system
EBS
interconnection of conductive parts providing equipotential bonding between those parts

~~[IEV 195-02-22]~~ ~~[df 68]~~

[SOURCE: IEC 60050-195:2021, 195-02-22]

3.11.6
protective equipotential bonding system
PEBS
equipotential bonding system providing protective equipotential bonding

~~[IEV 195-02-23]~~ ~~[df 126]~~

[SOURCE: IEC 60050-195:2021, 195-02-23]

3.11.7
working voltage
voltage, at rated supply conditions (without tolerances) and worst case operating conditions, which occurs by design in a circuit or across insulation ~~[df 205]~~

Note 1 to entry: The working voltage can be DC or AC. Both the RMS and recurring peak values are used.

3.11.8
decisive voltage class
calculated voltage range used to determine the classification of protective measures against electric shock ~~[df 43]~~

3.11.9
rated insulation voltage
RMS voltage value assigned by the manufacturer to the equipment or to a part of it, characterizing the specified (long-term) withstand capability of its insulation

Note 1 to entry: The rated insulation voltage is higher than or equal to the rated voltage of the equipment, or to the rated voltage of the concerned part of the equipment, which is primarily related to functional performance.

Note 2 to entry: The rated insulation voltage refers to the insulation between electric circuits, between live parts and exposed conductive parts and within an electric circuit.

Note 3 to entry: For clearances and solid insulation, the peak value of the voltage occurring across the insulation or clearance is the determining value for the rated insulation voltage. For creepage distances, the RMS value is the determining value.

Note 4 to entry: The rated insulation voltage depends either on the result of the insulation co-ordination investigation for high voltage systems, or on the expectable temporary over-voltage, the over-voltage category, and the RMS value of the working voltage, whichever is the higher.

~~[IEC 60664-1:2007, definition 3.9.1, modified]~~ ~~[df 144]~~

[SOURCE: IEC 60664-1:2020, 3.1.18, modified – Symbol U_i deleted. Words "value of the RMS withstand voltage" replaced with "RMS voltage value". Note 1 to entry clarified, and Notes 2 to 4 to entry added]

3.11.10
rated impulse voltage
amplitude of the impulse used as reference for the definition and the tests of insulation characteristics of a circuit ~~[df 143]~~

Note 1 to entry: The rated impulse voltage depends either on the result of the insulation coordination investigation for high voltage systems, or on the expectable impulse voltages from any origin related to the over-voltage category and on the peak value of the working voltage, whichever is the higher.

3.11.11
over-voltage category
concept used to classify equipment directly energized from the mains supply network ~~[df 109]~~

Note 1 to entry: IEC 60664-1 considers four categories of equipment:

category I: connected to a distribution circuit protected against a defined level of transient over-voltages;

category II: not permanently connected within the installation (any IPC);

category III: permanently connected within the installation (any IPC);

category IV: permanently connected at the origin of the installation (nearest to the PCC).

3.11.12
basic insulation 3
insulation applied to hazardous live parts to provide basic protection against electric shock

~~[IEV 195-06-06, modified]~~ ~~[df 9]~~

[SOURCE: IEC 60050-826:2004, 826-12-14, modified – The definition has been reformulated]

3.11.13
supplementary insulation
independent insulation applied in addition to basic insulation ~~in order to provide basic protection against electric shock in the event of a failure of basic insulation~~

Note 1 to entry: Basic insulation and supplementary insulation are separate, each designed for basic protection against electric shock.

~~[IEC 60664-1:2007, definition 3.17.3, modified]~~ ~~[df 172]~~

[SOURCE: IEC 60664-1: 2020, 3.1.31, modified – The note to entry has been added]

3.11.14
double insulation
insulation comprising both basic insulation and supplementary insulation

~~NOTE Basic and supplementary insulation are separate, each designed for basic protection against electric shock.~~

~~[IEV 826-12-16]~~ ~~[df 51]~~

[SOURCE: IEC 60050-195:2021, 195-06-08]

3.11.15
reinforced insulation
single insulation system, applied to of hazardous live parts, which provides a degree of protection against electric shock equivalent to double insulation under the conditions specified by the relevant IEC standard

Note 1 to entry: Reinforced insulation may comprise several layers which cannot be tested separately as basic insulation or supplementary insulation.

[IEC 60664-1:2007, definition 3.17.5, modified] [df 155]

[SOURCE: IEC 60664-1:2020, 3.1.33]

3.11.16
protective separation
separation between circuits by means of basic and supplementary protection (basic insulation plus supplementary insulation or protective screening) or by an equivalent protective provision (for example reinforced insulation) [df 128]

3.11.17
electrically protective screening
protective screening
separation of circuits from hazardous live parts by means of an interposed conductive screen connected to the means of connection to an external protective earthing conductor [df 127]

separation of electric circuits and/or conductors from hazardous live parts by an electrically protective screen connected to the protective equipotential bonding system and intended to provide protection against electric shock

[SOURCE: IEC 60050-195:2021, 195-06-18, modified – The word "electrically" has been added to "protective screening", and the term "protective shielding" has been deleted]

3.11.18
ELV (extra low voltage) circuit
ELV circuit
circuit the voltage of which does not exceed 50 V AC and 120 V DC or the value specified in the relevant product standard

Note 1 to entry: In this document, the volage range is defined as above for the voltage tests in 7.2.2.2. For general concept of extra-low volage, it is found in IEC 60050-195:2021, 195-05-24.

[IEV 826-12-30, modified] [df 62]

3.11.19
protective extra low voltage circuit
PELV (protective extra low voltage) circuit
electrical circuit with the following characteristics:

- the voltage does not exceed ELV;
- there is a protective separation from circuits other than PELV or SELV;
- there are provisions for earthing the PELV circuit, or its accessible conductive parts, or both

Note 1 to entry: In this document, the PELV circuit is defined as above for the voltage tests in 7.2.2.2. For general concept of PELV system, it is found in IEC 60050-195:2021, 195-06-29.

[IEV 826-12-32, modified] [df 114]

3.11.20
~~SELV (~~safety extra low voltage~~)~~ circuit
SELV circuit
electrical circuit with the following characteristics:

– the voltage does not exceed ELV;
– there is a protective separation from circuits other than SELV or PELV;
– there are no provisions for earthing the SELV circuit, or its accessible conductive parts;
– there is a basic insulation of the SELV circuit from earth and from PELV circuits

Note 1 to entry: In this document, the SELV circuit is defined as above for the voltage tests in 7.2.2. For general concept of SELV system, it is found in IEC 60050-195:2021, 195-06-28.

~~[IEV 826-12-31, modified] [df 162]~~

3.12 Principal letter symbols and subscripts

The principal letter symbols and subscripts are given in Table 1 and Table 2.

Table 1 – List of major subscripts

Subscript	Signification
0 (zero)	At no load
C	Commutating
D	Direct current or voltage
F	Dependent of frequency
H	Pertaining to harmonic component of order h
I	Ideal
L	Referring to line or source
M	Maximum
M	Pertaining to interharmonic component of order m
Min	Minimum
N	Rated value or at rated load
P	Inherent
R	Repetitive (over-voltage or peak current)
R	Resistive
S	Non-repetitive (over-voltage or peak current)
SC	Short-circuit
V	Valve side
X	Inductive
α	Controlled value (by delay angle)

Table 2 – Symbols 4

Symbol	Quantity	Reference to Clause 3 Terms and definitions
d_{xtN}	inductive direct voltage regulation due to converter transformer referred to U_{di}	-
e_{xN}	Inductive component of the relative short-circuit voltage of the converter transformer corresponding to I_{LN}	-
f_N	Rated frequency	3.6.2
g	Number of sets of commutating groups between which I_{dN} is divided	3.6.8
h	Order of harmonic	3.10.6
I_d	Direct current (any defined value)	-
I_{dN}	Rated direct current	3.6.9
I_{dMN}	Rated continuous direct current (maximum value)	3.6.10
I_{dRMN}	Intermittent peak maximum direct current	3.6.12
I_{dSMN}	Peak maximum direct current	3.6.11
I_L	RMS current on line side (of converter or transformer if included)	-
I_{LN}	Rated value of I_L	3.6.5
I_{1LN}	RMS value of the fundamental component of I_{LN}	-
I_{hLN}	RMS value of harmonic order h of I_{LN}	-
I_{vN}	Rated value of current on valve side of transformer	3.6.6
p	Pulse number ~~(see note)~~	3.5.10
P	Active power	-
P_{LN}	Active power on line side at rated load	-
q	Commutation number	3.5.9
Q_{1LN}	Reactive power on line side at rated load	-
R_{SC}	Relative short-circuit power	3.9.9
s	Number of series connected commutating groups	-
S_{com}	Short-circuit power calculated at the AC terminals of the commutating arms	-
S_{SC}	Short-circuit power of the supply source	-
S_{Cmin}	Minimum short-circuit power of the supply source	-
S_{LN}	Rated apparent power on the line side	3.6.7
S_{1LN}	Value of S_{LN} based on I_{1LN}	-
S_{tN}	Transformer rated apparent power	-
U_d	Direct voltage (any defined value)	-
U_{d0}	Conventional no load direct voltage	3.7.3
$U_{d0\alpha}$	Value of U_{d0} with trigger delay angle α	3.7.4
U_{d00}	Real no-load direct voltage	3.7.5
U_{di}	Ideal no-load direct voltage	3.7.1
$U_{di\alpha}$	Controlled ideal no-load direct voltage	3.7.2
U_{dN}	Rated direct voltage	3.6.8
U_{dxN}	Total inductive direct voltage regulation at rated direct current	-

Symbol	Quantity	Reference to Clause 3 Terms and definitions
U_{hL}	RMS value of harmonic order h of U_L	-
U_{iM}	Ideal crest no-load voltage, appearing between the end terminals of an arm neglecting internal and external voltage surge and voltage drops in valves, at no load. The ratio remains the same at light load current close to the transition current.	-
U_L	Line-to-line voltage on line side of converter or transformer, if any	-
U_{LN}	Rated value of U_L	3.6.3
U_{LRM}	Maximum instantaneous value of U_L including repetitive over-voltage but excluding non-repetitive over-voltages	-
U_{LSM}	Maximum instantaneous value of U_L including non-repetitive over-voltages	-
U_{LWM}	Maximum instantaneous value of U_L excluding transient over-voltages	-
U_M	Maximum of the sinusoidal waveform of the voltage (see 7.2.3.1)	-
U_{v0}	No-load line-to-line voltage on the line side of the converter or on the valve side of the transformer, if any	-
U_{vN}	Rated voltage on the valve side of the transformer	3.6.4
Xt_N	Inductive voltage drop of the transformer in per unit	-
α	Trigger delay angle	3.5.11
α_p	Inherent delay angle	3.5.13
β	Trigger advance angle	3.5.12
γ	Extinction angle	3.5.14
δ	Number of commutating groups commutating simultaneously per primary	-
λ	~~total~~ Power factor	3.7.13
μ	Angle of overlap (commutation angle) ~~NOTE The overlap angle is noted μ in this 4th edition of IEC 60146-1-1. It was noted u in the previous editions, which is still the case for edition 3 of IEC/TR 60146-1-2, the application guide. Progress in common printing facilities allow to confirm the current practice μ.~~	3.5.5
ν	Deformation factor	3.7.15
φ_1	Displacement angle of the fundamental component of I_L	3.7.14
~~NOTE The pulse number p includes the number of phases.~~		

4 Operation of semiconductor power equipment and valve devices

4.1 Classification

4.1.1 Semiconductor converter

Semiconductor converters ~~can be~~ are classified as below.

a) Type of conversion and switching

1) AC to DC conversion (rectifier, identified as (power) rectification in ~~IEV~~ IEC 60050-551:1998, 551-11-06);

2) DC to AC conversion (inverter, identified as (power) inversion in ~~IEV~~ IEC 60050-551:1998, 551-11-07);

3) DC to DC conversion (direct or indirect DC converter, identified as DC (power) conversion in ~~IEV~~ IEC 60050-551:1998, 551-11-09);

4) AC to AC conversion (direct or indirect AC converter, identified as AC (power) conversion in ~~IEV~~ IEC 60050-551:1998, 551-11-08);
5) switching (periodic or non-periodic).

NOTE 1 Other similar terms are used, e.g. "DC/DC conversion" for DC conversion or "AC/AC converter" for AC converter.

b) Purpose of conversion

In a power system, the converter changes or controls one or more characteristics such as the following:

1) frequency (including zero frequency);
2) voltage level or current level;
3) number of phases, phase angle;
4) flow of active power;
5) flow of reactive power, waveform;
6) quality of load power.

c) Type of valve turn-off

A semiconductor valve device can be turned off either by commutation, implying that the current of the arm is transferred to another arm, or by quenching, if the current of the arm falls to zero before another arm is turned on. See Figure 1.

NOTE 2 Both types of turn-off ~~may~~ can occur in normal operation of converters depending on the load. The classification is based on normal operation, full load current.

NOTE 3 The types of turn-off can be characterized by the source of the turn-off voltage:

a) external commutation (or quenching):
   – line commutation (or quenching);
   – load commutation (or quenching);
b) self commutation (or quenching, see also 4.1.2, Note 2):
   – valve device commutation (or quenching);
   – capacitor commutation (or quenching).

d) Type of DC system

Converters connected to at least one DC system can usually be wholly or partly classified as current source (current stiff converter) or voltage source (voltage stiff converter) depending on whether the current or the voltage on the DC side is smoothed~~, in fact of~~. The predominant internal impedance of a current stiff converter is high, while the predominant internal impedance of a voltage stiff converter is low. A thyristor converter is generally a current stiff converter.

For a converter connecting an AC system to a DC system, rectification implies a power flow from the AC to the DC side and inversion a power flow in the opposite direction.

For each mode of operation, in a current source system, the current is unidirectional, but the voltage polarity depends on the direction of the power flow. In a voltage source system, the converse applies.

4.1.2 Semiconductor valve devices

Valve devices used in the power circuits of semiconductor converters ~~can be~~ are divided into the following categories:

a) non-controllable valve device with a conductive forward and a blocking reverse characteristic (rectifier diode);
b) valve device with a controllable forward switch-on (thyristor). Common name of this type of valve device is "on-switched valve device";

c) valve device with a controllable forward switch-on and forward switch-off (turn-off thyristor (GTO), integrated gate-commutated thyristors (IGCT), power transistor, insulated gate bipolar transistor (IGBT)). Common name of this type of valve device is "switched valve device";

d) valve device which is controllable in both directions (for example triac).

NOTE 1 A valve device is controllable if it can be switched from the blocking to the conducting state by means of a control signal.

NOTE 2 Power transistors and turn-off thyristors can be turned off by a signal applied to or taken off the gate. Thyristors and triacs do not have this property and ~~must~~ have to be turned off by main circuit voltages and currents.

NOTE 3 Depending on the type of semiconductor valve devices, they can have a conductive or a blocking reverse characteristic. Some of them can have an "only few volts" blocking reverse characteristic.

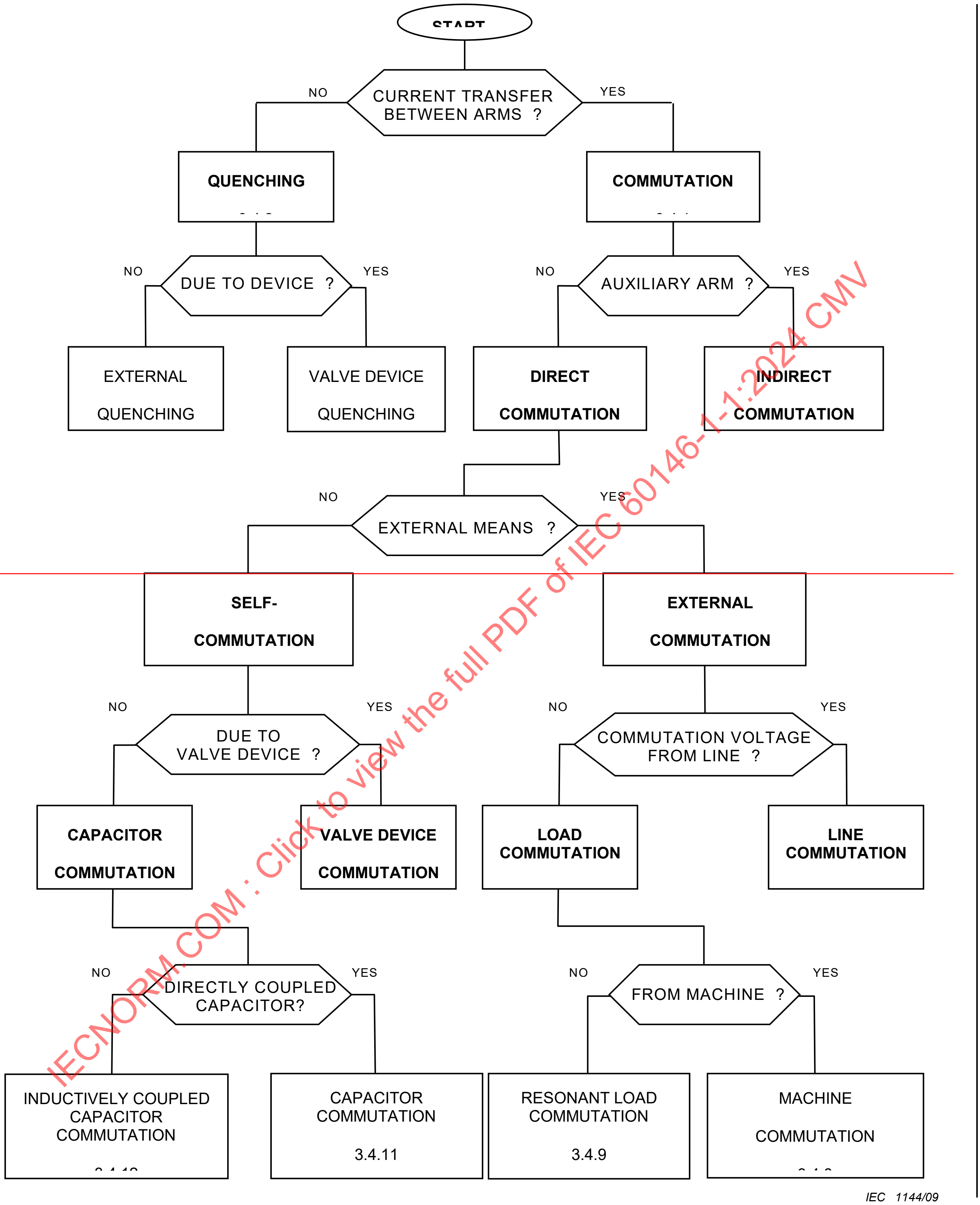
4.2 Basic operation of semiconductor converters

4.2.1 Commutation

Power electronic converters are semiconductor converters which, by means of the commutation or the quenching of the semiconductor valve devices, convert amplitude and/or frequency of the voltage or of the current from one side to the other side of the converter. The commutation or quenching is the basis of the function and the operation of a semiconductor converter. The general performance is moreover defined by the converter connections of the semiconductor valve devices (circuit topology) and their control.

The different types of commutations are defined in 3.4 and the characteristics of commutation in 3.5. The definition differentiates between commutation which is a transfer of current from an arm to another, and quenching which is the termination of the current within an arm.

Figure 1 gives an overview of the different types of commutations.


START
CURRENT TRANSFER BETWEEN ARMS ?
NO
YES
QUENCHING
COMMUTATION
DUE TO DEVICE ?
NO
YES
AUXILIARY ARM ?
NO
YES
EXTERNAL QUENCHING
VALVE DEVICE QUENCHING
DIRECT COMMUTATION
INDIRECT COMMUTATION
EXTERNAL MEANS ?
NO
YES
SELF-COMMUTATION
EXTERNAL COMMUTATION
DUE TO VALVE DEVICE ?
NO
YES
COMMUTATION VOLTAGE FROM LINE ?
NO
YES
CAPACITOR COMMUTATION
VALVE DEVICE COMMUTATION
LOAD COMMUTATION
LINE COMMUTATION
DIRECTLY COUPLED CAPACITOR?
NO
YES
FROM MACHINE ?
NO
YES
INDUCTIVELY COUPLED CAPACITOR COMMUTATION
CAPACITOR COMMUTATION
3.4.11
RESONANT LOAD COMMUTATION
3.4.9
MACHINE COMMUTATION
IEC 1144/09

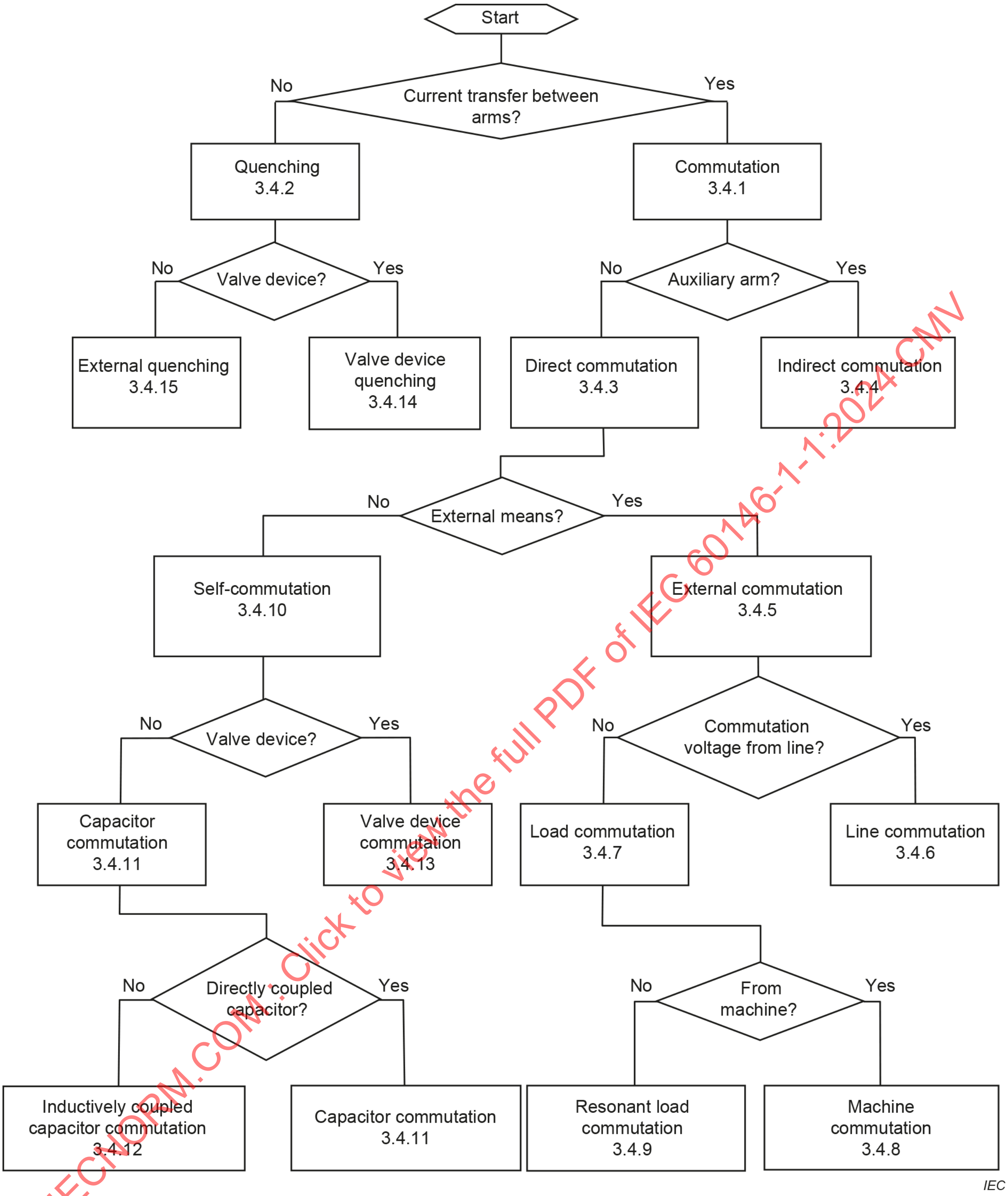


Figure 1 – Types of commutation

The commutation is characterized by the waveforms of voltage and current and by angles (see 3.5.5, 3.5.11, 3.5.12, 3.5.14). Figure 2 illustrates these angles with a simple case of commutating voltages from line. The top trace shows the rectified voltage and the bottom trace shows an anode to cathode voltage. Figure 2 a) and Figure 2 b) are examples for $p = 3$ and $p = 6$, respectively. 5

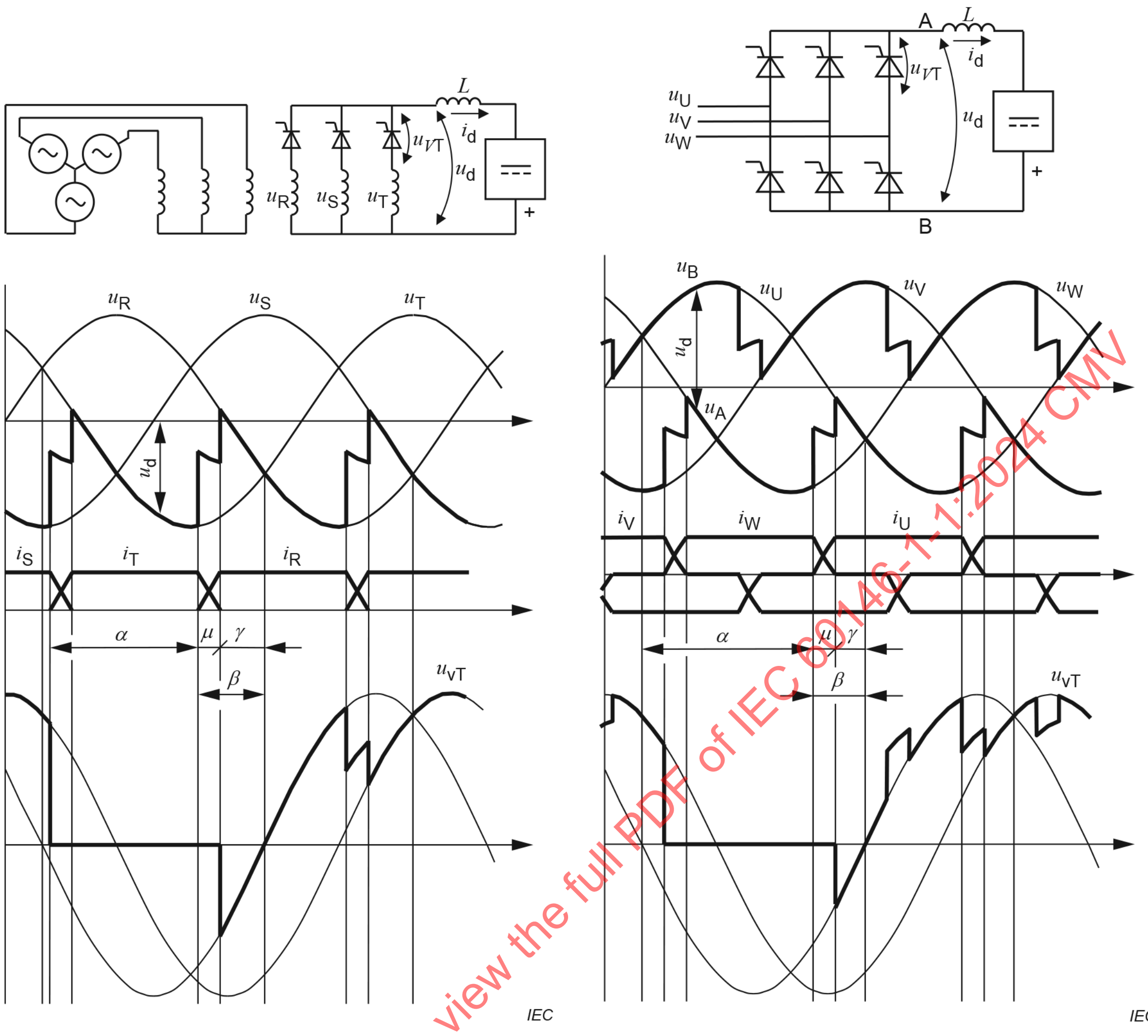


Figure 2 a) – Three phase star connection converter

Figure 2 b) – Three phase bridge converter

Figure 2 – Illustration of angles

4.2.2 Basic calculation factors for line commutated converters

4.2.2.1 Voltage

The ideal no-load direct voltage U_{di} is obtained from the voltage between two commutating phases U_{v0} and the pulse number p by Formula (1):

$$U_{di} = U_{v0} \times \sqrt{2} \times \frac{p}{\pi} \times \sin\frac{\pi}{p} \qquad (1)$$ 6

The controlled ideal no-load direct voltage $U_{di\alpha}$ is calculated for different cases, first for uniform connections (see 3.2.13, example with thyristors), and for non-uniform connections (see 3.2.14, example half with thyristors and half with diodes).

a) Uniform connection (fully controllable)

1) If the direct current is continuous over the entire control range:

$$U_{\mathrm{di}\alpha} = U_{\mathrm{di}} \times \cos \alpha \quad (2)$$

2) If the converter load is purely resistive

For $0 \leq \alpha \leq \frac{\pi}{2} - \frac{\pi}{p}$:

$$U_{\mathrm{di}\alpha} = U_{\mathrm{di}} \times \cos \alpha \quad (3)$$

For $\frac{\pi}{2} - \frac{\pi}{p} \leq \alpha \leq \frac{\pi}{2} + \frac{\pi}{p}$:

$$U_{\mathrm{di}\alpha} = U_{\mathrm{di}} \times \frac{1 - \sin(\alpha - \pi/p)}{2 \sin(\pi/p)} \quad (4)$$

b) Non-uniform connection (half controllable)

$$U_{\mathrm{di}\alpha} = 0{,}5 \times U_{\mathrm{di}} \times (1 + \cos \alpha) \quad (5)$$

4.2.2.2 Voltage characteristics and transition current

Below the value of the transition current (mean value), and during the period where the current is zero (instantaneous value), the DC voltage only depends on the DC circuit and no longer depends on the line side voltage.

At the transition current value, the voltage/current characteristic bends as is shown in Figure 3. ~~Transition current can be obtained, for example in the case of back e.m.f. load because the inductance of the d.c. circuit can not maintain direct current over the entire period or in case of interphase transformer connection, because the direct current decreases below the critical value where the interphase transformer becomes ineffective.~~

Two examples where this transition between voltage characteristics occurs are

– back e.m.f. loads in which the inductance of the DC circuit cannot maintain direct current over the entire period, and

– in the case of interphase transformer connection, when the direct current decreases below the critical value at which the interphase transformer becomes ineffective.

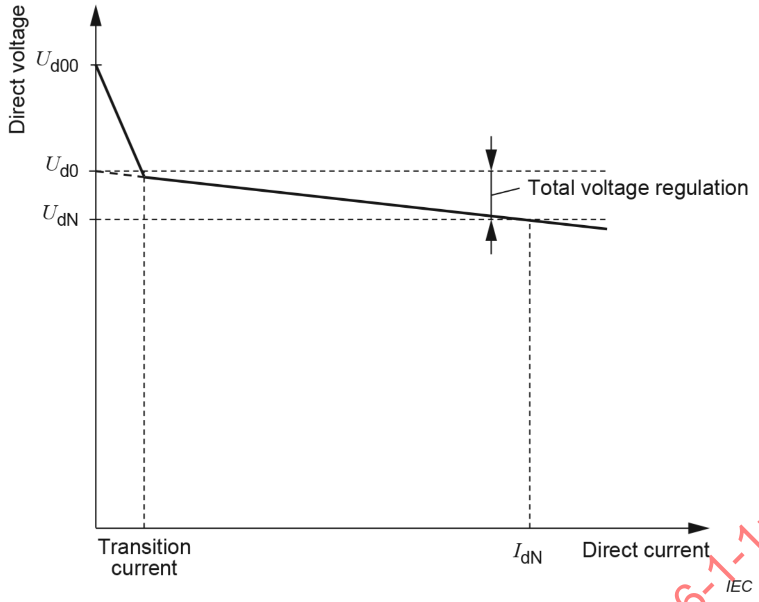


Figure 3 – Voltage regulation

4.2.3 Disturbances and fault conditions

4.2.3.1 Immunity level of a converter

When a disturbance from any origin does not exceed the immunity level specified (see for example Table 7, Table 8 and Table 9), the corresponding performance shall be maintained: no loss of performance, no tripping and no damage. Table 3 defines the levels.

Table 3 – Performance criteria

Immunity level	Symbol	Performance criteria
Functional	F	No loss of performance
Tripping	T	No interruption of service due to protective devices
Damage	D	No permanent damage (fuses excepted)

The functional immunity level (F) of a converter is a combination of all the limiting levels of the various kinds of electromagnetic disturbance level which said converter can withstand without loss of performance.

The tripping immunity level (T) of a converter is a combination of all the limiting levels of the various kinds of electromagnetic disturbance level which said converter can withstand without interruption of service due to protective devices.

The tripping immunity level ~~can be~~ is further divided into two sub-levels:

– tripping with automatic reset when the disturbance is over;

– tripping without automatic reset (requiring outside intervention for restarting, manual resetting of a circuit-breaker, changing fuse, etc.).

NOTE 1 Automatic resumption of service ~~should consider~~ needs consideration of safety aspects according to the application.

The damage immunity level (D) of a converter is a combination of all the limiting levels of the various kinds of electromagnetic disturbance level which said converter can withstand without sustaining permanent damage.

4.2.3.2 Disturbances and compatibility

~~The electromagnetic compatibility (EMC) in general is the object of the IEC 61000 series, and in addition dedicated requirements for some semiconductor converters are stated in product standards:~~

For electromagnetic compatibility (EMC), the semiconductor converters shall comply with IEC 61000-6-1, IEC 61000-6-2 and IEC 61000-6-4 in general unless relevant product standards are provided. EMC standards for semiconductor converters are provided to some products as listed below:

– IEC 61204-3 for ~~power supply units (PSU)~~ low-voltage switch mode power supplies;

– IEC 61800-3 for adjustable speed electrical power drive systems ~~(PDS)~~;

– IEC 62040-2 for uninterruptible power systems (UPS);

– IEC 62310-2 for static transfer systems (STS).

NOTE 1 This document is not intended to define EMC requirements. It covers all phenomena and therefore introduces references to dedicated standards which are applicable according to their scope.

~~Conducted phenomena need to distinguish the systemborne lowfrequency disturbances, in other words disturbances which may exist previous to the coupling of the converter to the electrical system, and the converter generated disturbances, in other words disturbances generated by the converter itself.~~

Conducted phenomena are distinguished between system-borne low-frequency disturbances and converter-generated disturbances.

a) System borne disturbances

Disturbances attributable to a number of causes external to the converter, such as in the case of varying loads on the distribution system, switching transients, changes of configuration in the supply network, for which only statistical values can be specified.

NOTE 2 Examples of such disturbances are:

– overvoltages, switching transients, lightning strokes;
– voltage changes due to motor starting, capacitor switching;
– faults and fault clearing: single phase-to-earth, phase-to-phase;
– quasi-permanent voltage unbalance, to be specified in terms of negative to positive sequence ratio;
– frequency variation and phase displacement;
– ripple-control signals;
– harmonic and interharmonic components of voltage and current.

b) Converter generated disturbances

Disturbances due to the non-linearity of the converter are generated by the operation of the converter.

NOTE 3 Examples of such disturbances are:

– harmonic currents, in terms of order, magnitude and phase relationship, for specified operating conditions, taking into account the average, the "most likely" value and the maximum, occasional value for short durations (for example 1 min);
– commutation notches, to be specified in terms of width, depth, area;
– commutation repetitive transients, to be specified as short impulses in terms of energy, crest value, rate of rise, etc.;
– non-repetitive transients which ~~may~~ can be due to transformer inrush current, internal or external fault clearing, etc.;
– interharmonic components (for example frequency changers);
– voltage dips and swells, to be specified as the difference of RMS value between consecutive steady-states.

NOTE 4 The listed disturbances ~~may be~~ are possibly produced by the converter under consideration or by other converters and the actual level ~~may change~~ changes with the network impedance, at the point at which they are considered.

NOTE 5 For more information, refer to IEC TR 60146-1-2. For example, when many converters with large pulse numbers and phase-shift transformers are used, the harmonic problem ~~may be~~ is possibly alleviated to a point where the voltage changes become the main concern.

5 Service conditions

5.1 Code of identification for cooling method

The cooling method is identified by letter symbols. They are arranged in a code form. The code consists of two letters for direct cooling, and of four letters for indirect cooling.

a) Direct cooling

For direct cooling, the first letter indicates the cooling medium (see 3.8.1 and refer to Table 4), the second letter indicates the circulation method (refer to Table 5).

EXAMPLE 1 AN, air cooled, natural circulation (convection).

b) Indirect cooling

For indirect cooling, the same rule applies first to the two first letters corresponding to the heat transfer agent (see 3.8.2) and secondly to the two last letters corresponding to the cooling medium (see 3.8.1).

EXAMPLE 2 OFAF, converter with forced circulated oil (pump) as heat transfer agent and forced circulated (fan) air as cooling medium.

c) Mixed cooling method

For both cases, direct cooling or indirect cooling, if the circulation is alternatively natural or forced, two groups of symbols, separated by a stroke, shall indicate both possible methods of circulation as used, the first group corresponding with the lower heat flow or the lower ambient temperature.

EXAMPLE 3 For direct cooling: AN/AF, converter with natural direct air cooling and possibilities for forced direct air cooling.

EXAMPLE 4 For indirect cooling: OFAN/OFAF, converter with forced circulated oil as heat transfer agent and natural air as cooling medium, with possibilities for forced air as cooling medium.

Table 4 – Cooling medium or heat transfer agent

Cooling medium or heat transfer agent	Symbol
Mineral oil	O
Dielectric liquid (other than mineral oil or water)	L
Gas	G
Water	W
Air	A
Fluid used for two-state cooling	P

Table 5 – Method of circulation

Method of circulation	Symbol
Natural (convection)	N
Forced, moving device not incorporated	E
Forced, moving device incorporated	F
Vapour cooling	V

NOTE In most cases, the identification code for the cooling method is the same as that now in use for transformers.

5.2 Environmental conditions

5.2.1 Ambient air circulation

Indoor type equipment installed in a room shall be connected to the (unlimited) supply of cooling medium or, if the cooling air is taken from the ambient in the room, provision shall be made to extract the heat from the room, which then ~~can be~~ is considered as an intermediate heat-exchanger between the equipment and the outside air.

For assemblies mounted in a cubicle or cabinet, the ambient for the assemblies (internal air of the cubicle or cabinet) is to be considered as a heat transfer agent and not as a cooling medium. There is some reflection from the cabinet walls, which should be taken into account. Therefore, for the cubicle or cabinet mounted assemblies, a higher ambient temperature has to be specified and the clearance distances shall comply with the supplier's specification.

5.2.2 Normal service conditions – Temperatures

The following limits shall apply unless otherwise specified.

a) Storage and transport temperatures

	Minimum	Maximum
Storage and transport	–25 °C	+55 °C

These limits apply with cooling liquid removed.

b) Operation including off-load periods, indoor equipment

Temperature conditions are defined in Table 6, according to different cases.

Table 6 – Limit of temperature of the cooling medium for indoor equipment

Conditions	Cooling medium	Minimum °C	Maximum °C
Temporary extreme temperatures of the cooling medium	Air	0	40
	Water	+5	30
	Oil	–5	30
Daily average	Air		30
Yearly average	Air		25

5.2.3 Other normal service conditions

Operation including off-load periods are intended under the following limits.

a) Relative humidity of the ambient air for indoor equipment

Minimum: 15 %.

Maximum: standard equipment is designed for the case where no condensation can occur. The case of condensation shall be treated as unusual service conditions (see 5.2.4).

b) Altitude

Not higher than 1 000 m

c) Dust and solid particle content for indoor equipment

Standard equipment is designed for clean air (IEC 60664-1, pollution degree 1). Any other conditions are to be specified by the purchaser as unusual service conditions (see 5.2.4).

d) Outdoor equipment

Operation including off-load periods for outdoor equipment shall be specified by the purchaser.

5.2.4 Unusual service conditions

The service conditions are assumed to be those listed under normal service conditions. The following list is an example of unusual service conditions that shall be subject to special agreement between purchaser and supplier:

a) unusual mechanical stresses, for example shocks and vibrations;

b) cooling water which ~~may~~ can cause corrosion or obstruction, for example sea water or hard water;

c) foreign particles in the ambient air, for example abnormal dirt or dust;

d) salt air (for example proximity to the sea), high humidity, dripping water or corrosive gases;

e) exposure to steam or oil vapour;

f) exposure to explosive mixtures of dust or gases;

g) exposure to radioactive radiation;

h) high values of relative humidity and temperature similar to those associated with sub-tropical or tropical climatic conditions;

i) fluctuations of temperature exceeding 5 K/h and relative humidity changes exceeding 0,05 p.u./h;

j) altitude more than 1 000 m ~~(see IEC/TR 60146-1-2)~~;

k) operation at ambient temperatures below +5 °C with water cooling;

l) operation at ambient temperatures below –5 °C with oil cooling;

m) other unusual service conditions not covered by this list or service conditions exceeding the specified limits of normal service conditions.

5.3 Characteristics of the load

The supplier shall state the type of load for which the converter is designed and for which its rating is valid:

– resistive (W);

– highly inductive (L);

– motor (M);

– battery charging (B);

– capacitive (C);

– regenerative (G).

Conversely, the purchaser shall specify the type and characteristics of the load in the prospective application.

Examples of loads which require to be specified in detail include:

– inductive load requiring voltage reversing and/or over-voltage protection, such as DC motor fields, electromagnets, inductors with high X/R ratio;

– energy-storing load such as storage batteries, capacitor banks, electrochemical process cells, inverters;

– hoists, unwinders and other regenerative loads which require means of handling the regenerated energy and protection against mains failure;

– highly variable impedance loads with high rate of current rise.

5.4 Service condition tolerances

5.4.1 Steady state and short time conditions

Unless otherwise specified, the converter shall be designed to conform to the requirements for immunity to conducted disturbances specified by the following determinations.

Disturbance levels corresponding to the immunity levels include the disturbance effects of the converter; however, if the converter improves the disturbance values, the disturbance levels shall exclude the corresponding effects of the converter.

For different AC or DC connections, different immunity classes or special immunity levels may be specified. If no immunity class is specified, class B in Table 7 shall be assumed to apply.

For connected stiff voltages, the electric service conditions refer to IEC 61000-2-4. IEC 61000-2-2 is also taken into consideration.

For guidance on disturbance effects caused by line-commutated converters, see also IEC TR 60146-1-2.

The immunity classes A, B, C defined in 5.4 correspond to the practice established, before the publication of the IEC 61000-2 series setting up the compatibility levels.

NOTE 1 While the IEC 60146 series establishes immunity classes from the highest immunity to the lowest (A, B, C decreasing immunity), IEC 61000-2-4 sets classes of compatibility levels from the lowest values to the highest (classes 1, 2 and 3 with increasing values of compatibility levels).

NOTE 2 For these low frequency phenomena, the margin between the compatibility levels and the immunity levels ~~may~~ can have significant consequences on the design. This is the responsibility of the manufacturer to define their margin according to the tolerances resulting from their design and according to their manufacturing process. Therefore, there is no margin planned in the standard requirements.

Immunity class A — The immunity levels of class A apply to the compatibility levels of class 3 of IEC 61000-2-4:2002 excluding dips and short time interruptions (which are not admissible at most converters) and additional immunity levels defined in Table 7, Table 8 and Table 9.

Immunity class B — The immunity levels of class B apply to the compatibility levels of class 2 of IEC 61000-2-4:2002 excluding dips and short time interruptions (which are not admissible at most converters) and additional immunity levels defined in Table 7, Table 8 and Table 9.

Immunity class C — The immunity levels of class C apply to the compatibility levels of class 1 of IEC 61000-2-4:2002 excluding short time dips (which are not admissible at most converters) and additional immunity levels defined in Table 7, Table 8 and Table 9.

The defined immunity levels are summarized in Table 7 for frequency and voltage amplitude, Table 8 for voltage unbalance and Table 9 for voltage waveform. Compatibility levels defined in IEC 61000-2-4:2002 are also shown in italics for reference.

Deviations from the defined immunity levels and additional immunity levels should be specified for the individual equipment and application.

Table 7 – Immunity levels to frequency and voltage amplitude for stiff AC voltage connections

Disturbance	Applicable values of IEC 61000-2-4:2002	Immunity class			Performance criteria [a]
		A	B	C	
Frequency tolerance					
Range (%)		±2	B2 = ±2 [b] B1 = ±1	±1	F
Rate of change (%/s)	–	±2	±1	±1	F
Voltage amplitude tolerance					
a) Steady state $\Delta U/U_N$ (%)		+10 to –10	+10 to –10	+10 to –5	F
Compatibility levels IEC 61000-2-4:2002 [c]	Table 1	+10 to –15	±10	±8	
b) Short time (0,5 to 30 cycles) up to rated values					
– Rectifier operation only (%)	–	±15	+15 to –10	+15 to –10	T
– Inverter operation (%)	–	±15	+15 to –10	+15 to –7,5	T

~~NOTE~~ For overload conditions, other limits ~~are to~~ shall be specified separately.

NOTE 1 Compatibility levels defined in IEC 61000-2-4:2002 are shown in italics for reference.

NOTE 2 A decrease in frequency is assumed not to coincide with an increase in line voltage and vice versa.

~~NOTE 3 Within certain limits to be specified, the possible consequence T may be replaced by F, in particular if, by a requirement to be inserted in the specification, the purchaser requires special control arrangements.~~

NOTE 3 Short-time AC voltage variations are not expected to occur more frequently than once every 2 h.

[a] For definition of the code, refer to Table 3. Within certain limits to be specified, the possible consequence T may be replaced by F, in particular if, by a requirement to be inserted in the specification, the purchaser requires special control arrangements.

[b] The compatibility level for industrial networks class 2, according to IEC 61000-2-4:2002, is ±1 %.

[c] Electromagnetic environment classes 3, 2, 1.

Table 8 – Immunity levels to voltage unbalance for stiff AC voltage connections

Disturbance	Applicable values of IEC 61000-2-4:2002	Immunity class			Performance criteria [a]
		A	B	C	
Voltage unbalance factor U_{neg}/U_{pos}					
a) Steady state (%)		5	5	2	F
Compatibility levels IEC 61000-2-4:2002 [b] (over any 10 min)	Table 1	3	2	2	
b) Short time					
– Rectifier operation only (%)	–	8	5	3	T
– Inverter operation (%)	–	5	5	2	T

NOTE 1 Compatibility levels defined in IEC 61000-2-4:2002 are shown in italics for reference.

NOTE 2 The higher values specified for short time ~~may~~ can lead to, for example, excessive ripple on the DC side and uncharacteristic harmonics on the AC side.

NOTE 3 Short-time voltage unbalances are not expected to occur more frequently than once every 2 h.

[a] For definition of the code, refer to Table 3.

[b] Electromagnetic environment classes 3, 2, 1.

Table 9 – Immunity levels to voltage waveform for stiff AC voltage connections

Disturbance	Applicable values of IEC 61000-2-4:2002	Immunity class			Performance criteria [a]
		A	B	C	
Voltage waveform					
a) total harmonic distortion THD (%)		25	10	5	F
Compatibility levels IEC 61000-2-4:2002[b]	Table ~~2~~5	10	8	5	
b) individual harmonic distortion					
steady-state odd (%)		8	6	3	F
even (%)		2	2	1	F
Compatibility levels IEC 61000-2-4:2002[b]					
– order 5 (%)	Table 2	8	6	3	
– other odd orders excluding multiples of 3	Table ~~3~~2	See IEC 61000-2-4:2002 Class 3	See IEC 61000-2-4:2002 Class 2	See IEC 61000-2-4:2002 Class 1	
– multiples of 3	Table ~~4~~3				
– even orders	Table ~~5~~4				
c) commutation notches (steady state)					
– amplitude (% of U_{LWM})	–	100	40	20	T
– area (% of U_{LWM} × degree)	–	625	250	125	T

NOTE 1 Compatibility levels defined in IEC 61000-2-4:2002 are shown in italics for reference.

NOTE 2 The area of a notch is approximately constant for a given DC current and R_{SC}. The width and depth vary with the trigger delay angle (α).

NOTE 3 If several converters are connected to the same converter transformer terminals, the total area of all notches over one period of the fundamental is not expected to exceed four times the area given above for one principal commutation notch.

[a] For definition of the code, refer to Table 3.

[b] Electromagnetic environment classes 3, 2, 1.

5.4.2 Repetitive and non-repetitive transients

A typical waveform of repetitive and non-repetitive transient is shown in Figure 4. The following characteristics shall be specified as far as possible:

a) transient energy available at the converter terminals (J);

b) rise time, (from 0,1 p.u. to 0,9 p.u. peak value) (μs);

c) peak value U_{LRM}/U_{LWM} (p.u.);

d) peak value U_{LSM}/U_{LWM} (p.u.);

e) duration above 50 % of the peak measured from the sine wave ~~(t)~~ (μs).

Item e) describes the duration of the non-repetitive transient voltage denoted by U_{LSM} in Figure 4. The duration is defined by the parameters "a" and "t" in the waveform. "a" shows 50 % of the amplitude of the non-repetitive voltage above the "sine wave", the sinusoidal part in the waveform. "t" is the width of the non-repetitive transient measured at "a" from the sinusoidal part as shown in Figure 4. 7

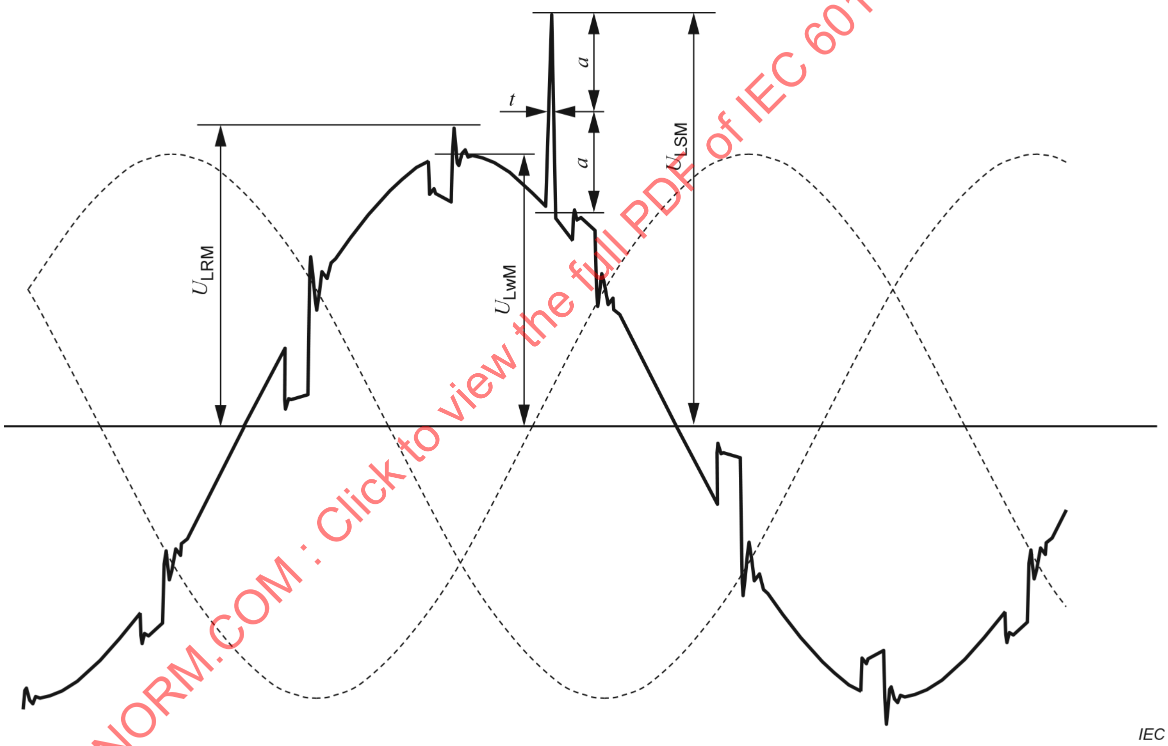


Figure 4 – AC voltage waveform

NOTE For additional information on AC voltage waveforms, see IEC TR 60146-1-2.

6 Power conversion equipment and assemblies

6.1 Electrical connections

a) Standard design converters

Considering the need for simplification in the common case of standard design converters covering the majority of users requirements, two types are considered in Clause 6:

1) converters without transformer;

2) individual transformer converters.

In both cases, single phase and three-phase supplies are considered (p = 2, p = 6) with uniform connection.

In case 2), twelve-pulse converters and dual six-pulse converters require two secondary windings (valve side windings) with star (Y) and delta (D) connections, respectively.

b) Special design converters

For converters subject to special agreement between the purchaser, the supplier and possibly the supply authorities because of their rating or special requirements or mode of operation, refer to IEC TR 60146-1-2:2019, which also gives other types of possible connections for particular applications.

6.2 Calculation factors

6.2.1 Essential variables

Table 10 gives the value of some calculation factors for the most used connections of line commutated converters. IEC TR 60146-1-2 gives the calculation factors also for some other connections. 8

Table 10 consists of 17 columns.

- Column 1 gives a reference number to the connection.
- Column 2 defines the transformer connections on the line side.
- Column 3 defines the transformer connections on the valve side.
- Column 4 shows the converter connections (schematics).
- Column 5 is the pulse number p.
- Column 6 is the commutation number q (on a commutating group).
- Column 7 ~~(this column is free)~~ gives the line side fundamental to dc current factor I_{1L}/I_d.
- Column 8 gives the line side current factor.
- Column 9 gives the valve side current factor.
- Column 10 gives the voltage ratio U_{di}/U_{v0}.
- Column 11 gives the voltage ratio U_{iM}/U_{di}.
- Column 12 gives the parameter for inductive voltage regulation (see Formula (10)).
- Column 13 gives the short-circuit transformer connections for transformer test.
- Column 14 gives the short-circuit transformer connections for transformer test.
- Column 15 gives the short-circuit transformer connections for transformer test.
- Column 16 gives the transformer guaranteed losses ~~for converter operation related to losses under short-circuit conditions (columns 13-14-15)~~.
- Column 17 gives ~~the measurement of e_{xN}, inductive component of the relative short-circuit voltage of the converter transformer corresponding to I_{LN}~~ the transformer guaranteed short-circuit impedance.

a) Voltage ratios

The voltage ratios are:

$$\frac{U_{di}}{U_{v0}} \tag{6}$$

$$\frac{U_{iM}}{U_{di}} \tag{7}$$

regarding the ideal no-load direct voltage, and the ideal crest no-load direct voltage.

b) Line side current factor

The line side current factor is the quotient of the RMS value I'_L of the current on the line side of the converter and the direct current I_d. The line side current factor is indicated in Table 10 on the assumption of smooth direct current, rectangular wave-shape of the alternating currents and on the following voltage ratio for single or double-way connections:

$$\frac{U_L}{U_{v0}} = 1 \tag{8}$$

where

U_L is the phase-to-phase voltage on the line side;

U_{v0} is the voltage between two commutating phases on valve side.

The line side current is approximately:

$$I_L = I'_L \times \frac{U_{v0}}{U_L} \tag{9}$$

The inherent direct voltage regulation is the ratio:

$$\frac{d_{xtN}}{e_{xN}}$$

between the direct voltage regulation d_{xtN} at rated load due to the transformer commutating reactance, referred to U_{di} and the inductive component e_{xN} of the transformer impedance voltage at rated line current I_{LN} for the whole equipment expressed in per cent of rated alternating voltage U_{LN}, the secondaries being short-circuited according to column 17.

The direct inductive voltage regulation d_{xtN} can be calculated using the value of e_{xN} of a three-phase transformer only for connections with a commutating number $q = 3$.

For all other connections with a three-phase transformer, the ratio between d_{xtN} and e_{xN} may depend on the proportions of primary and secondary reactances in the transformer. For these connections, it is recommended to use the method given in IEC/TR 60146-1-2, for determination of d_{xtN}.

NOTE It is assumed that the angle of overlap μ is less than $2\pi / p$, p being the pulse number.

The magnetic circuits corresponding to the connections supplied with 3-phase currents in Table 10 are assumed to have three legs.

Power loss factor: Table 10 gives the relation between power losses in converter operation and on the short-circuit test at rated line current I_{LN} for the whole equipment and according to columns 13, 14 and 15.

c) Nominal inductive voltage regulation

The nominal inductive voltage regulation may be calculated from the value of X_t by means of Formula (10): **9**

$$d_{xtN} = \frac{\delta \times q \times s}{2 \times \pi \times g} \times X_t \times \frac{I_{dN}}{U_{di}} \tag{10}$$

where

g is the number of sets of commutating groups between which I_{dN} is dvided;

I_{dN} is the rated direct current;

q is the commutation number;

s is the number of commutating groups in series;

U_{di} is the ideal no-load direct voltage;

δ is the number of commutating groups commutating simultaneously per primary.

The parameter below used in Formula (10) is listed in Table 10, column 12.

$$\frac{\delta \times q \times s}{g} \tag{11}$$

X_t is the transformer commutating reactance measured according to IEC 61378-1:2011, 7.2.

U_{di} is calculated from U_{v0} with the parameter of Table 10, column 10. In case of the 6-pulse converter, $U_{di} = \frac{3\sqrt{2}}{\pi} U_{v0}$.

For details, see IEC TR 60146-1-2:2019, 4.7.2.4.

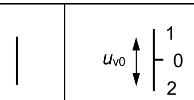
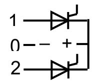
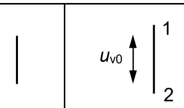
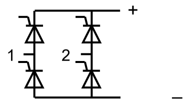
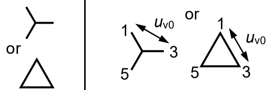
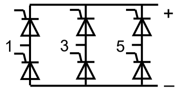
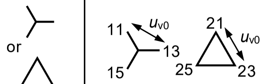
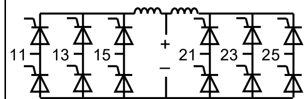
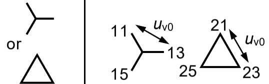
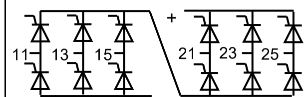
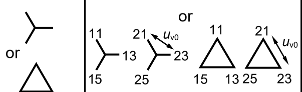
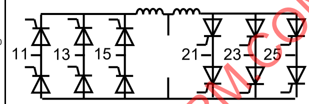
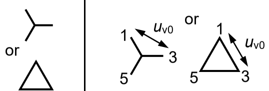
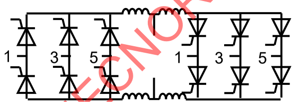
d) Transformer losses and short-circuit impedance **10**

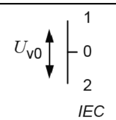
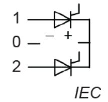
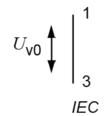
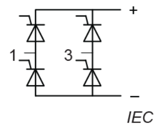
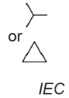
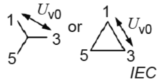
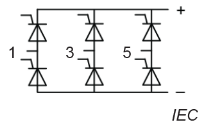
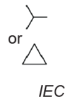
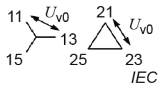
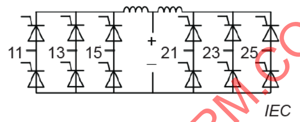
Table 10 gives the transformer guaranteed losses and the transformer guaranteed short-circuit impedance. For details, see IEC TR 60146-1-2:2019, 4.4.7 and 4.4.8, respectively. They are originally defined in the IEC 61378 series, the converter transformer standards.

e) Short-circuit conditions

Usually, the protection of the converter is such that a short-circuit is cleared in the shortest possible time. Some applications, for example converters for railway fixed installations, require the converter to withstand the DC short-circuit current for the breaking time of the output circuit-breaker which can be as long as 150 ms. In such cases, specific calculation ratios take into account the large angle of overlap which introduces multiple commutation. This is covered by dedicated standards (see IEC 62589).

Table 10 – Connections and calculation factors 11

~~No.~~	~~Transformer connection~~ ~~Line side~~	~~Valve side~~	~~Converter connection~~	~~p a~~	~~q a~~		~~Line side current factor b~~ ~~I'_L/I_d~~	~~Valve side current factor c~~ ~~I_v/I_d~~	$\frac{U_{di}}{U_{v0}}$	$\frac{U_{iM}}{U_{di}}$	$\frac{d_{xtN}}{e_{xN}}$	~~Terminals to be short-circuited at transformers loss test~~ ~~A~~	~~B~~	~~C~~	~~Total losses in converter operation~~	~~Terminals to be short-circuited for e_{xN}~~
~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~	~~9~~	~~10~~	~~11~~	~~12~~	~~13~~	~~14~~	~~15~~	~~16~~	~~17~~
~~Single converter, single-way connections~~																
~~1~~				~~2~~	~~2~~		~~0,5~~	~~0,707~~ $\left(\frac{1}{\sqrt{2}}\right)$	~~0,450~~ $\left(\frac{\sqrt{2}}{\pi}\right)$	~~3,14~~ ~~(π)~~	~~0,707~~ $\left(\frac{1}{\sqrt{2}}\right)$	~~0-1~~	~~0-2~~		~~$0,5(P_A+P_B)$~~	~~1-2~~
~~Single converter, uniform double-way connections~~																
~~7~~				~~2~~	~~2~~		~~1~~	~~1~~	~~0,900~~ $\left(\frac{2\sqrt{2}}{\pi}\right)$	~~1,57~~ $\left(\frac{\pi}{2}\right)$	~~0,707~~ $\left(\frac{1}{\sqrt{2}}\right)$	~~1-2~~			~~P_A~~	~~1-2~~
~~8~~				~~6~~	~~3~~		~~0,816~~ $\left(\sqrt{\frac{2}{3}}\right)$	~~0,816~~ $\left(\sqrt{\frac{2}{3}}\right)$	~~1,35~~ $\left(\frac{3\sqrt{2}}{\pi}\right)$	~~1,05~~ $\left(\frac{\pi}{3}\right)$	~~0,500~~	~~1-2-3~~			~~P_A~~	~~1-3-5~~
~~9~~				~~12~~	~~3~~		~~0,789~~ $\left(\frac{1+\sqrt{3}}{2\sqrt{3}}\right)$	~~0,408~~ $\left(\frac{1}{\sqrt{6}}\right)$	~~1,35~~ $\left(\frac{3\sqrt{2}}{\pi}\right)$	~~1,05~~ $\left(\frac{\pi}{3}\right)$	~~0,259~~	~~11-13-15~~	~~21-23-25~~	~~11-13-15 21-23-25~~	~~0,036 (P_A+P_B) + 0,928 P_C~~	~~Average of measurement 1 11-13-15 measurement 2 21-23-25~~
~~12~~				~~12~~	~~3~~		~~1,58~~ $\left(\frac{1+\sqrt{3}}{\sqrt{3}}\right)$	~~0,816~~ $\left(\sqrt{\frac{2}{3}}\right)$	~~2,70~~ $\left(\frac{6\sqrt{2}}{\pi}\right)$	~~0,524~~ $\left(\frac{\pi}{6}\right)$	~~0,259~~	~~11-13-15~~	~~21-23-25~~	~~11-13-15 21-23-25~~	~~0,036 (P_A+P_B) + 0,928 P_C~~	~~Average of measurement 1 11-13-15 measurement 2 21-23-25~~
~~18~~				~~See connection No. 8~~												
~~19~~				~~See connection No. 8~~												

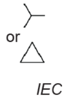
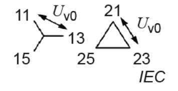
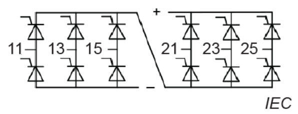
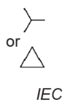
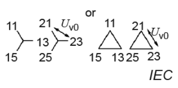
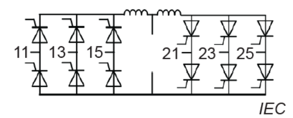
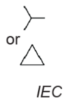
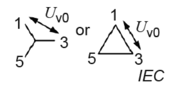
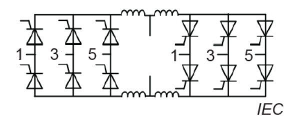
No.	Transformer connection		Converter connection	p [a]	q [a]	Line side fundamental current factor [b,d] I'_{1L} / I_d	Line side current factor [b] I'_L / I_d	Valve side current factor [c] I_v / I_d	$\frac{U_{di}}{U_{v0}}$	$\frac{U_{iM}}{U_{di}}$	$\frac{\delta qs}{g}$	Terminals to be short-circuited for short-circuit measurement [d]			Transformer guaranteed load losses [e]	Transformer guaranteed short-circuit impedance [d]
	Line side	Valve side										A	B	C		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Single converter, single-way connections																
1				2	2	-	0,5	0,707 $\left(\frac{1}{\sqrt{2}}\right)$	0,450 $\left(\frac{\sqrt{2}}{\pi}\right)$	3,14 (π)	2		-	-	-	-
Single converter, uniform double-way connections																
7				2	2	-	1	1	0,900 $\left(\frac{2\sqrt{2}}{\pi}\right)$	1,57 $\left(\frac{\pi}{2}\right)$	4	-	-	-	-	-
8				6	3	$\frac{\sqrt{6}}{\pi}$ $(\approx 0{,}78)$	0,816 $\left(\sqrt{\frac{2}{3}}\right)$	0,816 $\left(\sqrt{\frac{2}{3}}\right)$	1,35 $\left(\frac{3\sqrt{2}}{\pi}\right)$	1,05 $\left(\frac{\pi}{3}\right)$	6	1-3-5			P_A	e_{XA}
9				12	3	$\frac{\sqrt{6}}{\pi}$ $(\approx 0{,}78)$	0,789 $\left(\frac{1+\sqrt{3}}{2\sqrt{3}}\right)$	0,408 $\left(\frac{1}{\sqrt{6}}\right)$	1,35 $\left(\frac{3\sqrt{2}}{\pi}\right)$	1,05 $\left(\frac{\pi}{3}\right)$	3	11-13-15	21-23-25	11-13-15 and 21-23-25	P_C	e_{XA} and e_{XB}

~~NOTE For other connections, see IEC/TR 60146-1-2~~

~~[a] Refer to Table 2.~~

~~[b] Refer to transformer primary.~~

~~[c] Refer to transformer secondary.~~

No.	Transformer connection		Converter connection	p [a]	q [a]	Line side fundamental current factor [b,d] I'_{1L} / I_d	Line side current factor [b] I'_L / I_d	Valve side current factor [c] I_v / I_d	$\frac{U_{di}}{U_{v0}}$	$\frac{U_{iM}}{U_{di}}$	$\frac{\delta qs}{g}$	Terminals to be short-circuited for short-circuit measurement [d]			Transformer guaranteed load losses [e]	Transformer guaranteed short-circuit impedance [d]
	Line side	Valve side										A	B	C		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
12				12	3	$\frac{2\times\sqrt{6}}{\pi}$ (≈ 1,559	1,577 $\left(\frac{1+\sqrt{3}}{\sqrt{3}}\right)$	0,816 $\left(\sqrt{\frac{2}{3}}\right)$	2,70 $\left(\frac{6\sqrt{2}}{\pi}\right)$	0,524 $\left(\frac{\pi}{6}\right)$	12	11-13-15	21-23-25	11-13-15 and 21-23-25	P_C	e_{XA} and e_{XB}
18				See connection no. 8												
19				See connection no. 8												

For other connections, see IEC TR 60146-1-2.

[a] Refer to Table 1.

[b] Refer to transformer primary.

[c] Refer to transformer secondary.

[d] The symbols e_{XA} and e_{XB} in column 17 show the transformer guaranteed short circuit impedance. e_{XA} is the inductive short-circuit impedance obtained by the short-circuit measurement A in column 13. e_{XB} is that obtained by the short-circuit measurement B in column 14. Refer to 4.4.8 of IEC TR 60146-1-2:2019.

[e] IEC 61378-1:2011, Table 1, does not contain the information for the lines 1 and 7. Then, the cells which are not given relevant values are filled with hyphen "-". When the values are necessary, refer to the textbooks for the converter theory. Some information can be obtained from IEC TR 60146-1-2:2019, Annex C.

6.2.2 Losses and efficiency

6.2.2.1 General

The efficiency of converter assemblies or equipment shall be declared as power efficiency.

The efficiency may be determined by a measurement of AC and DC power at normal load conditions or by a measurement of internal losses in a short-circuit test and a light load test or by a calculation of internal losses, at the choice of the supplier.

NOTE The loss evaluation by calculation can be applied for the large converters which practically cannot be tested in the factory or in the laboratory. The loss calculation is performed in such cases based on the actual loss measurement of the assemblies or on the authorized calculation procedures in relevant product standards. A typical example is the HVDC converter, of which loss determination is specified in IEC 61803.

The apparatus included in the determination of the over-all efficiency shall be stated.

In case of doubt as to whether the losses of a component of the power conversion equipment (PCE) should be included or not, when calculating the efficiency, it shall be stated whether the losses in it are included in the declared efficiency. For certain components in the power conversion equipment, 6.2.2.2 and 6.2.2.3 shall be considered.

6.2.2.2 Included losses

The following losses shall be included when determining the efficiency:

a) internal losses in the assembly such as losses in semiconductor valve devices, in fuses, potential dividers, current balancing means, capacitor resistor damping circuits and voltage surge diverters;
b) losses in transformers, transducers, interphase transformers, current limiting and balancing reactors between transformer and thyristor or diode assemblies and the losses of the line side auxiliary transformers and reactors forming part of the equipment and delivered under the same contract;
c) losses due to main connections between transformer and assembly for the case when transformer and assembly are built together and delivered as a unit;
d) power absorbed by auxiliaries such as permanently connected fans or pumps and relays unless otherwise specified;
e) losses in series smoothing reactors, when supplied by the supplier of the PCE;
f) losses due to circulating currents in double converter connections;
g) power consumed by the trigger equipment (see 3.1.17).

6.2.2.3 Not included losses

The following losses shall not be included when determining the efficiency but shall be stated separately if requested and if the apparatus concerned is supplied by the supplier of the PCE:

a) losses due to the main connections between transformer and the assembly when delivered as separate units;
b) losses due to the main connections to circuit-breakers, disconnectors, switches and to the load;
c) losses in circuit-breakers, disconnectors, switches and in control gear other than the items mentioned in 6.2.2.2;
d) losses due to heating and ventilation of the building and in the cooling supply;
e) losses in the series smoothing reactor, when not supplied with PCE;
f) losses in system control equipment (see 3.1.18);
g) losses due to auxiliary apparatus which operate only intermittently.

6.2.3 Power factor

As the line current to a line-commutated converter contains harmonics, it is important to state the kind of power factor meant when a specification for a guaranteed supply power factor is written.

Reference is made to the power factor of the fundamental wave or displacement factor $\cos\varphi_1$, unless otherwise specified (see 3.7.14).

For pulse numbers higher than 6, the difference between the total power factor λ and the displacement factor $\cos\varphi_1$ is small, but for lower pulse number the difference is significant.

Unless otherwise stated in the contract, for multi-phase converters supplying inductive load, the manufacturer guarantees shall be given on the displacement factor $\cos\varphi_1$.

NOTE In such a case, calculation is adequate to get reliable figures of the displacement factor under the condition of symmetrical control.

For converters supplying mainly battery chargers or capacitive loads, the total power factor should be considered is calculated in general. When exact calculations of the displacement factor or of the total power factor are required, knowledge of many parameters is necessary, including line impedance. For such calculations, refer to IEC TR 60146-1-2.

The formulae described in 6.2.3 can be applied on the assumption of smooth direct current and rectangular wave-shape of the alternating current.

When the actual direct current and output direct voltage of a line-commutated converter is known, the following formulae give approximate values:

Active power	$P = U_d \times I_d$	(12)
Fundamental apparent power	$S_1 = U_{di} \times I_d$	(13)
Displacement factor	$\cos\varphi_1 = P/S_1$	(14)
Fundamental reactive power	$Q_1 = \sqrt{S_1^2 - P^2}$	(15)

These formulae normally give sufficient accuracy to calculate $\cos\varphi_1$ and also the amount of capacitors needed to correct the power factor to a specified value.

Refer to IEC TR 60146-1-2 for more details, if required.

6.2.4 Voltage regulation

The following refers to standard design (connection no. 8 in Table 10), line commutated, three-phase, uniform, double-way connection converters with transformer or line reactors. Here, some usual cases are considered.

a) Resistive direct voltage regulation

   Resistive direct voltage regulation U_{dr} is approximated by Formula (16) using losses in components P_r.

$$U_{dr} = \frac{P_r}{I_{dN}} \quad (16)$$

The term "components" includes transformer windings, series reactors, smoothing reactor, diodes, thyristors, fuses, etc.

b) Inductive direct voltage regulation

Assuming nominal voltage at the a.c. terminals of the converter, the inductive voltage regulation is given by:

$$U_{dx} = 0{,}5 \times U_{di} \times \frac{S_{1LN}}{S_{com}} \times \frac{I_d}{I_{dN}}$$

1) Converter with individual transformer

$$S_{com} = \frac{1}{\frac{1}{S_c} + \frac{e_{xN}}{S_{tN}}}$$

2) Converter without individual transformer

The inductance L of the cables and line reactors is introduced instead of the transformer inductance, using the per unit voltage regulation at rated current to calculate S_{com}:

$$S_{com} = \frac{1}{\frac{1}{S_c} + \frac{X_L}{S_{1LN}}}$$

where

$$X_L = \frac{2 \times \pi \times f_N \times L \times S_{1LN}}{U_{LN}^2}$$

For other cases, see IEC/TR 60146-1-2.

The inductive voltage regulation including the effects from the reactances of the supply source and the feeder cable or line is calculated as below based on Formula (10).

$$d_{xtN} = \frac{\delta \times q \times s}{2 \times \pi \times g} \times X_{sum} \times \frac{I_{dN}}{I_{di}} \quad (17)$$ 12

where

X_{sum} = $X_t + X'_L + X'_C$, the sum of the reactances below:

X_t is the commutation reactance of the converter transformer seen from the valve side;

$X'_L = \left(\frac{U_{v0}}{U_L}\right)^2 \times X_L$ is the reactance of the cable or the line seen from the valve side through the converter transformer;

$X'_C = \left(\frac{U_{v0}}{U_L}\right)^2 \times X_C$ is the reactance of the supply source seen from the valve side through the converter transformer.

For other symbols and parameters in Formula (17), refer to the explanations for Formula (10). For details, see IEC TR 60146-1-2:2019, 5.1.3.

c) Influence of other converters

If several converters are fed from the same supply transformer, this usually causes an additional voltage drop. If required by the contract, the detailed calculation may be performed using the rating, type of connection and other particulars of the other converters.

In the simple case of several independent, identical converters, the maximum additional voltage drop may be estimated using the total apparent power of all the converters, assuming the same value of the trigger delay angle α.

d) Twelve-pulse converters

In the case of two series connected six-pulse converters, one fed from a star (Y) and the other from a delta (D) secondary winding, each six-pulse converter is considered separately, neglecting the primary leakage reactance, which is usually much smaller than the secondary reactance for transformers designed for the purpose and adding the individual voltage regulation.

e) Boost and buck connection converters (series connection)

Using the same assumption as above, the voltage regulation depends on the operating point and each six-pulse converter shall be treated separately. The DC voltage and voltage regulation add up (algebraically if one of the converters is in the inverter mode).

This approximate method may also be used for three-phase, double-way non-uniform connections (for example three thyristors, three diodes or six thyristors, six diodes).

6.3 Electromagnetic compatibility

6.3.1 Harmonics

6.3.1.1 General

In this document, the power frequency is taken as the fundamental frequency of the harmonics. For details, see Annex B.

6.3.1.2 Order of harmonics in line current and voltage

Assuming perfect symmetry of the supply voltages, trigger delay angles, transformer ratio for star (Y) and delta (D) windings, the following apply for three-phase uniform connected converters.

The order of characteristic harmonics depends on the pulse number p:

$$h = kp \pm 1 \qquad k = \text{integer } (1 \ldots n) \tag{18}$$

The corresponding frequency is related to the fundamental frequency f_1 by:

$$f_h = h \times f_1 \tag{19}$$

subject to the mains frequency variations.

NOTE 1 Due to small errors in star (Y) and delta (D) winding voltages (integer number of turns), supply voltage unbalance, trigger delay angle error and other manufacturing tolerances, twelve-pulse converters usually produce uncharacteristic harmonics which ~~may~~ can range from 0,05 p.u. to 0,15 p.u. of the value for a six-pulse converter (p = 6) of the same rating.

NOTE 2 Sequential gating or non-uniform, dual six-pulse converters ~~may~~ can produce harmonics up to 1,0 p.u. of the theoretical value for the equivalent six-pulse converter depending on the trigger delay angle and transformer secondary phase shift, if any.

~~Refer to Annex A and to IEC/TR 60146-1-2 for more information.~~

6.3.1.3 Amplification of harmonic currents on the line side

Power capacitors may be used for power factor compensation both of AC motors and line-commutated converters. The resonance between the source impedance and the capacitors (including the cable capacitances, especially for MV systems) may amplify the harmonic currents and voltages. These resonances may be shifted to lower frequencies (below the 5th harmonic) by providing reactors in series with the capacitors.

~~Refer to Annex A and to IEC/TR 60146-1-2 for more information.~~

6.3.1.4 Direct voltage harmonic content

For perfectly balanced supply voltages, trigger delay angles, etc., the frequency of the direct current and the direct voltage harmonic content is given by:

$$f_{h,dc} = k \times p \times f_1 \qquad k = \text{integer } (1 \ldots n) \qquad (20)$$

The negative sequence voltage produces an additional harmonic component at a frequency $2 \times f_1$, which cannot be cancelled by an appropriate design of the converter unless a large smoothing reactance or DC output filter is added.

~~Refer to Annex A and to IEC/TR 60146-1-2 for more information.~~

As a result of the harmonic content of the voltage on the DC side, the DC current also contains ripple. For converters supplying capacitor banks or storage batteries (battery chargers), the counter e.m.f. may be equal to the direct voltage average value, in which case the direct current is discontinuous and an appropriate trigger equipment is required.

6.3.2 Other EMC aspects

Beside harmonics, which represent the main EMC concern for line commutated semiconductor converters, the risk of interference with in-plant low current control and communication lines, or with telephone and communication links shall be considered. The following only gives general advice and it is reminded that, as indicated in 4.2.3.2, all aspects of electromagnetic compatibility (EMC) for certain semiconductor converters are discussed in dedicated standards.

The purchaser ~~shall~~ should specify any special requirements in the enquiry or, failing this, specify the installation site, the type of supply system, the intended use of the converter and all particulars that ~~may~~ can have an influence on the actual electromagnetic compatibility (EMC) requirements.

a) Interference with in-plant, low current control and communication lines

   Cable routing, filtering, feed-back cables and low current cables, etc., where such are installed by the purchaser, ~~shall~~ should be in accordance with any instructions provided by the supplier and also publications by IEC TC 77 and local authorities.

b) Interference with telephone and communication links

~~Standard design industrial converters or special design converters for industrial application are not usually designed to meet the requirements applicable to domestic and similar appliances, particularly as specified in the generic EMC standards for domestic, commercial and light industry applications (IEC 61000-6-1 and IEC 61000-6-3). References are given in the generic EMC standards for industrial applications (IEC 61000-6-2 and IEC 61000-6-4) and in the dedicated product standards, see 4.3.3.2.~~

Standard design industrial converters or special design converters for industrial application are not usually designed to meet the emission requirements applicable to equipment intended for use in residential environments, such as those specified in IEC 61000-6-3. Emission limits are given in the dedicated product EMC standards, see 4.2.3.2. Where no product EMC standard exists, the equipment should comply with the product family standard CISPR 11 or the relevant generic emission standard, such as IEC 61000-6-4 or IEC 61000-6-8.

6.4 Rated values

6.4.1 General

Rated values of a converter shall be given either as standard design values for general purpose converters or as closely as possible according to the load that it is intended to serve. The ratings of the converter are not valid if the load is changed to a load for which the converter is not intended.

In the specification of the converter, the character of the load shall also be specified.

It is noted that this document will not take precedence over a specific product standard. Namely, considering the fact that the load characteristics vary application by application, requirements for a product shall be specified by its appropriate product standards where applicable **13**. For example, requirements for adjustable speed motor drives in applications such as rolling mills, paper mills, mining hoists, etc. are given in ~~IEC publications~~ IEC 61800-2 and IEC TR 61800-6.

6.4.2 Rated output voltage

The rated output voltage shall be the continuous operating voltage assigned by the supplier.

The maximum output voltage shall comply with the dynamic requirements of the intended use or shall be separately specified by the purchaser.

NOTE A line-commutated converter frequently ~~has~~ needs to be designed for a maximum direct voltage higher than the rated direct voltage (for example, in the case of field excitation of DC machines or synchronous machines, it is designed for a multiple of the rated direct voltage) in order to allow a margin for control, voltage regulation, AC line voltage variation compensation. This ~~may~~ can result in a rated apparent power for the converter transformer, which in some cases greatly exceeds the rated output of the converter.

In the absence of such a specification, the rated direct voltage shall be maintained at all values of current up to the rated direct current for the specified limits (see 5.4, service condition tolerances) at the line terminals of the converter.

A line-commutated converter shall perform without service interruption at its rated values, under any operation mode (as rectifier or inverter) and throughout the service condition tolerances. A lower voltage may be negotiated for AC systems subject to heavy fluctuations, with the recommendation that the safe level of inverter operation should be set lower than the expected minimum alternating voltage on line side (see 5.4).

6.4.3 Rated current values

6.4.3.1 Current values to be specified

Each PCE shall have an assigned value for rated current, together with a specified duty class unless the rated current is related to continuous duty (see duty cycle, IEC 60050-151:2001, 151-16-02). Additionally, the assemblies shall have an assigned value for rated continuous current. This assigned value is the rated continuous direct current (maximum value) I_{dMN} (see 3.6.10)

Independently of the duty class for the converter, the converter and its constituent assemblies shall be capable of withstanding fault currents within the limits permitted by the protective equipment (example fuses) as recommended by the converter supplier. This applies to all operating conditions up to and including maximum loading.

Independently of the duty class for the converter, the converter and its constituent assemblies shall be capable of withstanding over-currents of such magnitude and duration as is necessary to allow the automatic load regulating equipment or over-current protective equipment to operate (over current electronic protection).

6.4.3.2 Short-time duty

A rated current ~~can~~ may be defined for continuous and permanent condition as above, or for simple load duty consisting of a constant current associated with a single short duration peak current. Two equivalent methods ~~can~~ may be used. For both cases, requirements of 6.4.3.1 apply.

a) Rated current for peak load duty

   The rated current for peak load duty delivered by the PCE is compatible with a peak load duty, provided the peak is followed by a no load period the duration of which allows the temperature of all parts of the PCE to fall to that correspondent to operation at rated direct current.

   The value of direct current which the PCE can supply to its load for specified duration under specified service conditions, which includes a short-time peak direct current, is the rated current for peak load duty. The duration and magnitude of the peak current (peak maximum direct current I_{dSMN}) and the minimum time of no-load before carrying any current shall be specified, as defined in 3.6.11 and 3.6.13.

b) Rated current for continuous duty with superimposed peak loads

   The rated current for continuous duty with superimposed peak loads delivered by the PCE is compatible with an intermittent peak load duty, provided the minimum time between applications of intermittent peak loads allows the temperature of all parts of the PCE to fall to that corresponding to operation at rated direct current.

   The rated direct current for this duty is the value of direct current which the converter can supply to its load for unlimited duration under specified service conditions and with intermittently applied peak loads (I_{dRMN}) of specified magnitudes and durations. The minimum time between applications of intermittent peak loads shall also be specified (see 3.6.12 and 3.6.14).

c) Rated current for repetitive load duty (periodic duty)

   The rated direct current of the PCE shall be specified as the RMS value of the load current evaluated over the period of the load duty cycle. The duty class shall be preferably specified as a sequence of current values together with their durations, as defined in 3.6.15.

6.5 Duty classes

6.5.1 Principles

6.5 is described assuming the line commutated converter applications, listed in Table 12, as examples where the loads have cyclic variation patterns.

It is noted that this document will not take precedence over a specific product standard. Then, in case where the load of a product has different characteristics from those assumed, appropriate product standards shall be applied. 14

If in practice it is difficult to know the expected load diagrams on which the exact size of a converter depends, conventional diagrams which show constant current values for specified durations may be specified as follows.

A rated current value shall be specified and valid only for a defined duty class. If a converter is designed to operate at different duty classes, separate rated current values have to be given for each duty class.

If no suitable standard duty class can be is found in Table 11, the duty shall be specified based on the agreement between purchaser and supplier. The rated current shall may be the RMS value of the repetitive load duty cycle taken over the most onerous 15 min period, if not otherwise specified.

Table 11 contains standard duty classes, which specify current capabilities in terms of current values and durations.

The current values specified in Table 11 are each individually applicable after temperatures have been reached equivalent to continuous operation at rated current.

For examples of load cycles, see Table 12.

Table 11 – Standard duty classes

Duty class	Rated currents for converters and test conditions for assemblies (relative values in per unit of I_{dN})
I	1,00 p.u. continuously
II	1,00 p.u. continuously 1,50 p.u. 1 min
III	1,00 p.u. continuously 1,50 p.u. 2 min 2,00 p.u. 10 s
IV	1,00 p.u. continuously 1,25 p.u. 2 h 2,00 p.u. 10 s
V	1,00 p.u. continuously 1,50 p.u. 2 h 2,00 p.u. 1 min
VI	1,00 p.u. continuously 1,50 p.u. 2 h 3,00 p.u. 1 min

6.5.2 Selection of duty class and rated current value

Different hypothetical load current diagrams giving assumed typical load conditions for the standard duty classes are given in Table 12 together with an indication of applications for each class.

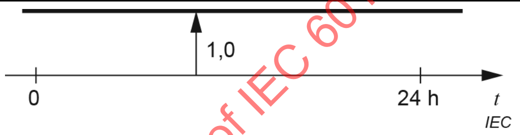
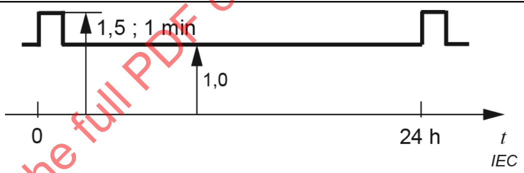
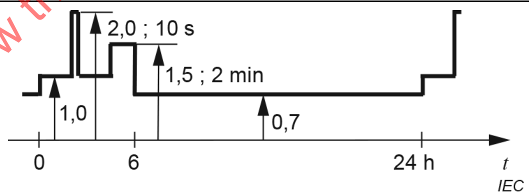
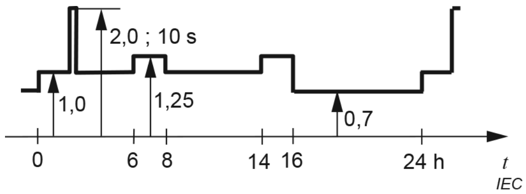
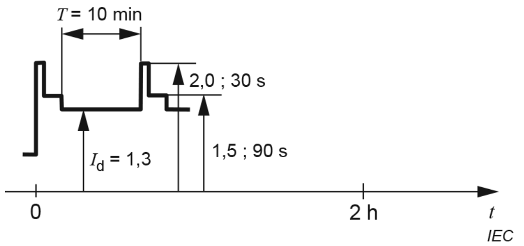
For guidance in determining the rated current of the PCE, the expected load diagram shall be examined and the conditions indicated in Table 12 should not normally be exceeded.

The load conditions specified in Table 12 are less onerous than the rated current values specified in Table 12. This allows for the fact that the peak loads are sometimes concurrent and ensures that rated peak of short duration (5 min and less) can, in almost all practical cases, be safely applied as often as permitted by the longer time specified for the lower rated peak load current, the only restriction being that the time between two consecutive peak currents is at least 20 min. The restriction is due to the fact that the thermal time constant of converter assemblies is normally in the order of 2 min to 20 min, depending on the properties of the cooling system.

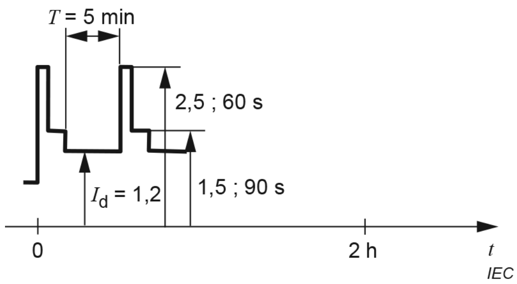
For duty classes IV and V, this will mean that the time periods ~~T_1, T_2, etc.~~ and corresponding current values ~~I_1, I_2~~ may differ considerably without affecting the design of the transformer.

Typical load conditions of duty classes V and VI include recurrent two-step peak currents, as shown in the load diagrams, with interposed intervals of current amplitude I_d (p.u.). The current amplitude I_d (p.u.) and the duration t (min) are specified in the tables and change in the course of the day.

Table 12 – Examples of load cycles as guidance for selection of duty class

<table>
<tr><th>Duty class</th><th>Most typical applications</th><th>Assumed typical load conditions for the duty class
Load current in relation to the rated direct current</th></tr>
<tr><td>I</td><td>Electrochemical processes, etc.</td><td>
</td></tr>
<tr><td>II</td><td>Electrochemical processes, etc.</td><td>
</td></tr>
<tr><td>III</td><td>Light industrial and light traction substation service</td><td>
</td></tr>
<tr><td>IV</td><td>Industrial service, heavy duty</td><td>
</td></tr>
<tr><td>V</td><td>Medium traction substation and mining
I_d = 1,5 p.u. (2 h)</td><td>

<table>
<tr><th></th><th>I_d (p.u.)</th><th>T (min)</th><th>$I_{d,rms}$ (p.u.)[a]</th></tr>
<tr><td>0 h to 2 h</td><td>1,3</td><td>10</td><td>1,36</td></tr>
<tr><td>2 h to 10 h</td><td>0,8</td><td>15</td><td>0,94</td></tr>
<tr><td>10 h to 12 h</td><td>1,3</td><td>10</td><td>1,36</td></tr>
<tr><td>12 h to 24 h</td><td>0,7</td><td>30</td><td>0,79</td></tr>
</table></td></tr>
</table>

Duty class	Most typical applications	Assumed typical load conditions for the duty class Load current in relation to the rated direct current
VI	Heavy traction substation I_d = 1,5 p.u. (2 h)	

	I_d (p.u.)	T (min)	$I_{d,rms}$ (p.u.)[a]
0 h to 2 h	1,2	5	1,50
2 h to 10 h	0,8	6	1,26
10 h to 12 h	1,2	5	1,50
12 h to 24 h	0,7	20	0,93

[a] $I_{d,rms}$ is the RMS value over the load cycle.

6.5.3 Particular remarks for double converters

A double converter may have either a symmetrical load where the loading of the two converter sections is symmetrical in the two directions of current flow or an asymmetrical load where the loading of the two sections is different. For converter section of a double converter, see 3.3.10.

The requirements in 6.4.3 apply also to double converters. In the case of double converters with asymmetrical loading, each section shall be given separate duty cycles.

Special recommendations for double converters intended for adjustable speed motor drives may be found in IEC TR 61800-6.

6.6 Markings

6.6.1 General

Each PCE which is delivered as an integrally assembled unit and each assembly which is delivered separately shall bear the following markings.

a) Clear indication of manufacturer or supplier

   ~~NOTE 1~~ This indication may be given on the rating plate.

b) Indication of the type of equipment

   The type of equipment is according to 3.2 and 3.3.

   ~~NOTE 2~~ This indication may be given on the rating plate. The indication should, for PCE, include the intended mode of operation, for example "adjustable rectifier equipment" or "inverter equipment".

c) Marking of the input and output terminals of the main circuit

   The marking should express sequence of phases (if to be observed) or polarity respectively.

6.6.2 Rating plate

a) Rating plates of equipment and assemblies

   The following information shall be provided with the product. For products not covered by their own dedicated standards, the rating plate shall bear the following indications:

   1) identification reference, manufacturer's type designation and serial number;

   2) number of input phases (including neutral, if connection to it is necessary) or "DC";

   3) rated input voltage (called "rated direct voltage" in the case of inverters);

4) rated input current (called "rated direct current" in the case of inverters);
5) rated input frequency, if any;
6) number of output phases (including neutral, if connection to it is necessary) or "DC";
7) rated output voltage (called "rated direct voltage" in the case of rectifiers);
8) rated output current (called "rated direct current" in the case of rectifiers);
9) rated output frequency, if any;
10) range of output voltage (if the output voltage is adjustable);
11) range of output frequency (if the output frequency is adjustable);
12) character of the load (for example counter e.m.f., inductive, etc.) if so restricted;
13) type of duty or duty class;
14) type of connection including "uniform" or "non-uniform" respectively (for assemblies only);
15) maximum permissible prospective symmetrical RMS short-circuit current of the power source;
16) the reference of this document.

~~NOTE~~ On the rating plate of small equipment (300 kW and less and rated current not exceeding 5 000 A), items 4) and 10) to 13) may be excluded. As stated in the Scope, where a dedicated product standard, or product safety standard defines requirements for the rating plate, this dedicated standard takes precedence.

b) Additional information where appropriate

Some items may be added if appropriate, especially those listed below:

1) cooling method;
2) cooling requirements (temperature, flow rate of cooling medium);
3) over-all mass, mass of cooling fluid, if any;
4) degree of protection;
5) displacement factor under rated conditions;
6) output characteristic curve symbol.

7 Tests for valve device assemblies and power conversion equipment

7.1 General

7.1.1 Methods of testing

Semiconductor converters are frequently integrated in electrical equipment. The electrical equipment includes auxiliaries necessary for operation of the converter itself, or even other parts. It may happen that the semiconductor converter cannot be separated, even for testing. In such a case, the assembly is named "power conversion equipment" (PCE).

It is advisable for economical reasons to confine the performance of tests to those which are considered necessary. This document is therefore arranged so that testing of large equipment can be limited to tests in the manufacturer's works on the separate assemblies that are to be shipped separately.

Other tests such as tests on large, complete equipment or tests on site are to be included if separately specified.

Smaller equipment normally shipped as integral assemblies shall, however, be tested completely before being shipped in accordance with these provisions.

7.1.2 Kinds of tests

Two different kinds of tests are necessary.

a) Type tests

Type tests shall be performed to verify that the design of the product is appropriate to meet the performance requirements specified in this document and/or those specified separately.

~~NOTE~~ Some or all of the type tests may be repeated at specified intervals on a specified number of samples to verify that the quality of the product is maintained.

b) Routine tests

Routine tests shall be performed on each PCE or on its sub-assemblies if they are shipped separately, before delivery to verify that the requirements of this document are met.

7.1.3 Performance of tests

The tests shall be performed in electrical conditions equivalent to those in real service. If this is not practicable, the assemblies and equipment respectively shall be tested under such conditions as to allow the specified performance to be proved.

In equipment tests, the assembly and other items of the equipment may be tested separately if this is more convenient. When tested separately, the stack or assembly shall be supplied from a transformer with a connection equivalent to that specified in the contract.

Unless otherwise agreed at the time of the contract, the AC supply and test voltages shall be at rated frequency except for the insulation test voltage which may be DC or ~~at any convenient frequency (at the supplier's choice between 15 Hz and 100 Hz)~~ in the frequency range introduced in 7.2.2.3.

~~NOTE~~ When the purchaser or their representative desires to witness factory tests, they should so specify in the order. If so agreed before order, the contract may specify that the supplier should provide a report of tests performed on the product.

Reference may be made to type tests, previously performed, on an identical or similar product with test conditions at least equal to the requirements of the contract or of this specification.

The tests, unless otherwise agreed, shall comprise all the following items marked "x" in Table 13, which are applicable to the assembly or converter.

The tests marked "(x)" in Table 13 shall only be performed if specifically agreed in the contract.

Table 13 – Summary of tests

Test	Type test	Routine test	Optional test	Specification subclause
Visual inspection	x	x		
Insulation test	x	x		7.2
Light load and functional test	x	x		7.3.1
Rated current test	x			7.3.2
Over-current capability test			(x)	7.3.3
Measurement of the inherent voltage regulation			(x)	7.3.4
Measurement of ripple voltage and current			(x)	7.3.5
Measurement of harmonic currents			(x)	7.3.6
Power loss determination for assemblies and equipment	x			7.4.1

Temperature rise test	x			7.4.2
Power factor measurement			(x)	7.4.3
Checking of auxiliary devices	x	x		7.5.1
Checking the properties of the control equipment	x	x		7.5.2
Checking the protective devices	x	x		7.5.3
Immunity test			(x)	7.6 a)
Radio frequency radiated and conducted disturbances			(x)	7.6 b)
Measurement of audible noise			(x)	7.7
Additional tests			(x)	7.7

7.2 Insulation tests

7.2.1 General

To demonstrate adequate dielectric strength of the insulation system within the product, tests are to be conducted as type test as well as routine testing. The insulation system is investigated by testing safety critical components and solid insulation by means of three types of tests.

The different types of tests cover different physical phenomena:

- AC or DC voltage test to cover the impact of ~~long-term~~ temporary over voltages from the mains supply;
- impulse voltage test to cover the impact of impulse transient over voltages generated in the mains supply;
- partial discharge testing of solid insulation to cover the impact of impulse over voltages, temporary over voltages, as well as recurring peaks across the insulation.

NOTE Impulse transient over voltages, temporary over voltages, as well as recurring peaks might cause partial discharge inside the insulation material which can lead to its degradation.

Generally, the impulse voltage test and the partial discharge test are specified separately, see 7.2.3.2.

The selection of type test and the corresponding test voltages shall be based on the requirement from IEC 62477-1 or IEC 62477-2, unless the relevant product standards ~~(see in Clause C.5)~~ are provided.

The selection of routine tests and the corresponding test voltages shall be based on the requirement ~~as specified in 7.2, unless a more severe requirement is specified in the relevant standards (see in Clause C.5)~~ from IEC 62477-1 or IEC 62477-2, unless the relevant product standards are provided.

7.2.2 introduces the routine insulation tests. If any inconsistency is found with the IEC 62477 series, then the requirements in IEC 62477-1 or IEC 62477-2 shall take precedence.

For the relationship between the IEC 60146 series and the IEC 62477 series, see Annex B. **15**

7.2.2 Routine insulation tests of power conversion equipment

7.2.2.1 AC or DC voltage test

If possible, an AC or DC voltage test shall be performed on the final assembly to ensure that the manufacturing process has not affected the insulation coordination of the product. Test voltage shall be according to Table 14 or Table 15, as appropriate.

~~The test voltages in Table 14 or Table 15 are for type testing of basic insulation only. For routine testing, they cover verification of basic, supplementary, double and reinforced insulation (see definitions 3.11.12, 3.11.13, 3.11.14 and 3.11.15).~~

The test voltages in Table 14 or Table 15 cover routine testing of basic, supplementary, double and reinforced insulation in addition to type testing of basic insulation (see definitions 3.11.12, 3.11.13, 3.11.14 and 3.11.15).

NOTE ~~It should be reminded that~~ The withstand voltage of double or reinforced insulation is ~~twice~~ higher than the withstand voltage of basic insulation. However, in order to prevent damage to the solid insulation by partial discharge, routine testing uses only one level of test voltage for basic, supplementary, double and reinforced insulation, assuming that the validity of the different systems has been duly verified by type tests.

~~Type testing of double and reinforced insulation is performed with higher test voltages depending on the rated insulation voltage.~~

Functional insulation is not considered unless specified by the purchaser according to 7.2.3.2.

Terminals, open contacts on switches and semiconductor valve devices, etc. shall be bridged where necessary in order to create a continuous circuit for the voltage test on the equipment. Before testing, semiconductors and other vulnerable components within a circuit may be disconnected and/or their terminals bridged to avoid damage occurring to them during the test.

Wherever practicable, individual components forming part of the insulation under test, for example capacitors of high frequency filters, should not be disconnected or bridged before the test. In this case, it is recommended to use the DC test voltage specified in Table 14 or Table 15.

Where the equipment is covered totally or partly by a non-conductive accessible surface, a conductive foil to which the test voltage is applied shall be wrapped around this surface for testing. In this case, the insulation test between a circuit and non-conductive accessible surface may be performed as a sample test instead of a routine test. If a complete covering of the housing with a metal foil is not possible, a partial covering shall be applied at those spots which are considered relevant with regard to protection.

Printed circuit boards and modules with multipoint connectors may be withdrawn, disconnected or replaced by dummies during the AC or DC voltage test.

This does not apply, however, to auxiliaries for which, in case of a dielectric breakdown, voltage may pass on to accessible parts not connected to the housing or from the side of higher voltage to the side of lower voltage. These are, for example, auxiliary transformers, measuring equipment, pulse transformers and instrument transformers, the insulation stress of which is equal to that of the main circuit.

Switchgear and control gear in main circuits shall be closed or by-passed. Auxiliaries not galvanically connected to the main circuits (for example system control equipment, fan motors) shall be connected with the housing during the AC or DC voltage test. During these tests, units with housings consisting of insulating material shall be covered with metal foil. The foil is regarded as housing when performing these tests.

7.2.2.2 Performing the voltage test

The test shall be applied as follows:

- test (1) between accessible conductive part (connected to earth) and each circuit sequentially (except PELV or SELV);
- test (2) between accessible surface (non-conductive or conductive but not connected to earth) and each circuit sequentially (except PELV or SELV);

– test (3) between each considered circuit sequentially and the other adjacent circuits connected together;

– test (4) between PELV or SELV circuit and each adjacent circuit sequentially.

~~NOTE 1~~ Either the adjacent circuit or the PELV or SELV circuit may be earthed for this test.

~~It is necessary to test basic insulation between PELV and SELV circuits, but it is not necessary to test functional insulation between adjacent PELV or adjacent SELV circuits.~~

NOTE 1 It is described above to test basic insulation between PELV and SELV circuits. For test of functional insulation between adjacent PELV or adjacent SELV circuits, see 7.2.2.1, third paragraph.

NOTE 2 PELV/SELV circuits and other circuits of higher voltage are separated from chassis (earth) by basic insulation. It is typically impossible to test double or reinforced insulation separating low-voltage circuits from high-voltage circuits in a fully-assembled equipment without overstressing the basic insulation. For this reason, the test voltage for basic insulation is used for double or reinforced insulation as well.

7.2.2.3 Duration of the AC or DC voltage test

The voltage test shall be performed with a sinusoidal voltage ~~at 50 Hz or 60 Hz~~ of which frequency is in the range from 45 Hz to 65 Hz. If the circuit contains capacitors, the test may be performed with a DC voltage of a value equal to the peak value of the specified AC voltage.

The duration of the test shall be 1 min for type test and at least 1 s for the routine test. The test voltage may be applied with increasing and/or decreasing ramp voltage but the full voltage shall be maintained for the specified duration.

~~A voltage source with a short-circuit current of at least 0,1 A according to 5.2.2.2 of IEC 61180-1 shall be used for this test.~~

For the detailed requirements of the test procedures and test circuits, refer to IEC 61180:2016, Clauses 5 and 6. **16**

The test is successfully passed if no electrical breakdown occurs during the test.

7.2.2.4 Test voltages **17**

AC or DC test voltages for equipment directly connected to low voltage mains are given in Table 14.

~~For type testing of circuits with protective separation, and between circuits and accessible surfaces (non-conductive or conductive but not connected to protective earth) these voltages shall be multiplied by 2.~~

~~NOTE 1 The above rule is the result of the latest standardization work and is in line with the latest published standard related to a similar application (see IEC 61800-5-1).~~

~~NOTE 2 With U being the rated insulation voltage, the a.c. test voltage equals [U + 1 200] V.~~

In Table 14, with U being the rated insulation voltage, for U between 0 V and 1 000 V, the AC test voltage equals (U + 1 200) V and the DC test voltage equals $\sqrt{2}\frac{3\sqrt{2}}{\pi} \times (U + 1\,200)$ V.

Table 14 – AC or DC test voltages for equipment directly connected to low voltage mains

Rated insulation voltage V (see 3.11.9)	Test voltages V	
	AC (RMS)	DC
≤ 50	1 250	1 770
100	1300	1 840
150	1 350	1 910
300	1 500	2 120
600	1 800	2 550
1 000	2 200	3 110
NOTE Interpolation is permitted.		

For higher voltage equipment, above 1 000 V AC and directly connected to high voltage mains, AC or DC test voltages are given in Table 15 (see 7.2.2.1 and Note 1).

For type testing circuits with protective separation, and between circuits and accessible surfaces (non-conductive or conductive but not connected to protective earth) these voltages shall be multiplied by 1,6.

NOTE 3 The above rule is the result of the latest standardization work and is in line with the latest published standard related to a similar application (see IEC 61800-5-1).

NOTE 4 With *U* being the rated insulation voltage, the a.c. test voltage can be approached by:

– [2,7 × *U* + 300] V for *U* between 1 000 V and 7 200 V;

– [1,8 × *U* + 7 200] V for *U* between 7 200 V and 36 000 V.

For the test voltages in Table 15, the explanations are given below.

With U being the rated insulation voltage, for U between 1 000 V and 7 200 V, the AC test voltage equals (2,7 × U + 300) V and the DC test voltage equals $\sqrt{2}\frac{3\sqrt{2}}{\pi}$ × (2,7 × U + 300) V.

For U between 7 200 V and 36 000 V, the AC test voltage equals (1,8 × U + 7 200) V and the DC test voltage equals $\sqrt{2}\frac{3\sqrt{2}}{\pi}$ × (1,8 × U + 7 200) V.

Table 15 – AC or DC test voltages for equipment directly connected to high voltage mains

Rated insulation voltage V (see 3.11.9)	Test voltages V	
	AC (RMS)	DC
> 1 000	3 000	4 250
3 600	10 000	14 150
7 200	20 000	28 300
12 000	28 000	39 600
17 500	38 000	53 700
24 000	50 000	70 700
36 000	70 000	99 000
NOTE Interpolation is permitted.		

For equipment not directly connected to the mains, the AC test voltages may be are given in dedicated product standards (example IEC 61800-5-1 related to power drive systems) IEC 62477-1:2022, Table 29. Unless otherwise specified, the test voltage shall be agreed between purchaser and supplier. The principle should be to define AC test voltage with an RMS value not less than 1,15 times the total voltage used for designing the blocking capability of the semiconductor devices which are the most exposed to over-voltages within the circuit. Where DC voltage is used, the level of the test voltage should not be less than 1,63 times the total voltage used for designing the blocking state of the most exposed semiconductor valve devices to over-voltages within the circuit.

NOTE The word "total" means that, in case of semiconductor valve devices mounted in series, the total voltage is the sum of the voltages used for each semiconductor valve device, excluding the tolerance for voltage sharing between the different devices.

For type testing circuits with protective separation, and between circuits and accessible surfaces (non-conductive or conductive but not connected to protective earth) these voltages should be multiplied by 2 for working voltages up to and including 1 000 V and by 1,6 for higher working voltages.

7.2.3 Additional tests

7.2.3.1 Insulation resistance

One minute after the AC or DC voltage test, the insulation resistance is to be measured by applying a direct voltage of a least 500 V. The insulation resistance should be not less than 1 MΩ for voltage values of $U_M / \sqrt{2}$ not exceeding 1 000 V.

For higher values of $U_M / \sqrt{2}$, the insulation resistance should exceed 1 000 Ω/V. The measurement of the insulation resistance is not necessary for routine tests.

Grounding resistors, if any, shall be disconnected during the insulation tests.

If water is used as a heat transfer agent, the insulation resistance test may be performed in two steps, without and with water. In the first case, the insulation level shall meet the specified value, while in the latter case it has to be specified separately.

7.2.3.2 Agreed tests

Insulation tests other than those prescribed specified in this document shall be performed only if agreed upon prior to order.

For high voltage converters 3,6 kV to 36 kV, when the assembly is connected to the AC line without a converter transformer, an impulse test may be performed in addition to the AC or DC voltage test if specified separately.

7.3 Functional test

7.3.1 Light load test and functional test

The light load test and functional test are carried out as follows.

a) Light load test

The light load test is carried out to verify that all parts of the electrical circuit and the cooling of the equipment operate properly together with the main circuit.

For the routine test, the converter is connected to rated input voltage. For the type test, the function of the equipment is also tested at maximum and minimum values of the input voltage. If series-connected semiconductor devices are used in the arms of the converter, the voltage sharing shall be checked. For a high voltage converter, this part of the light load test could be conducted at a lower voltage than rated. For low current equipment ($I_{dN} \leq 5$ A), the test is not necessary.

b) Functional test

The test load is chosen in such a manner that the required proof of performance is given. During the test, it should be verified that the control equipment, auxiliaries, protection equipment and main circuit are operating properly together. This could be achieved in different ways depending on the type of equipment.

7.3.2 Rated current test

The test is carried out to verify that the equipment will operate satisfactorily at rated current.

The DC terminals shall be short-circuited directly or with a reactor, and an alternating voltage of sufficient value, to cause at least the rated continuous direct current to flow, shall be connected to the AC terminals of the converter. During the test, the control equipment, if any, and auxiliaries have to be supplied separately with rated voltage.

By proper co-ordination of control, if any, and applied alternating voltage, rated continuous current shall be caused to flow through the DC terminals and operation shall be checked. If parallel connected devices are used in the arms, the current division shall be checked.

When it is more convenient, the current test may be replaced by a full load test at rated alternating voltage.

7.3.3 Over-current capability test

The over-current capability test is a load test. Specified values of short time over-current or starting up sequences of actual load are to be applied for the time interval specified. Specified values of voltage and current are to be recorded. If this is a factory type test, then it shall be carried out in accordance with 6.4.3 and 6.5. The over-current capability test is performed according to the second paragraph of rated current test (7.3.2).

7.3.4 Measurement of the inherent voltage regulation

The converter shall be supplied with rated alternating voltage. Transducer control current, delay angle, etc., shall be set at a specified value and direct voltage and direct current measured while the direct current is varied.

7.3.5 Measurement of ripple voltage and current

The measurements of superposed AC voltage, superposed AC current, noise voltage or noise current on the DC side, if necessary, shall be specified separately.

NOTE DC ripple and AC unbalance of input or output of the equipment ~~should be taken into account~~ are noted in measurement.

7.3.6 Measurement of harmonic currents

The determination of harmonic currents on the AC side, if necessary, shall be specified separately.

Harmonic emission may be determined by either:

- direct measurement, or
- calculation by validated simulation.

For converters included in low voltage equipment of rated input current greater than 16 A and less than or equal to 75 A, IEC 61000-3-12 gives the requirements for a simulation to be validated.

When a measurement is specified as a special test, the measurement methods and conditions shall comply either with the relevant standard: IEC 61000-3-2, IEC 61000-3-12 according to the AC rated current, or shall be agreed for higher values of rated current. In the latter case, it ~~can~~ may be agreed to perform the measurement on the test premises of the manufacturer under defined conditions (example short-circuit on the DC side), or once installed at the customer site. ~~Clause A.4 indicates the basic conditions.~~

The measurement of harmonic currents shall be performed

- with measuring instruments and methods complying with IEC 61000-4-7,
- disregarding individual harmonic currents below 1 % of the reference fundamental current, and
- recording the characteristics of the voltage source used to perform the measurement (voltage level and tolerance, frequency and tolerance, R_{sc} and impedance, voltage unbalance in case of multiphase systems, harmonic voltages under no load conditions).

Results of the measurements shall be interpreted taking into account the characteristics of the source.

Harmonic voltage measurement depends on the whole installation and on the network itself and is outside the scope of this document.

7.4 Losses, temperature and power factor

7.4.1 Power loss determination for assemblies and equipment

7.4.1.1 General

Losses in the assembly and equipment may be determined either by calculations based on measurements or by direct measurements. Power loss of indirectly cooled converters may be evaluated by measurement of the heat removed by the heat transfer agent (using the calorimetric method) and estimation of heat flow through the housing of the converter.

When loss measurement cannot be performed under actual service conditions (rated load), the following methods ~~can~~ may be applied.

The power losses of the converter shall be measured during a light load test (minimum load possible) and a short-circuit test. The total losses of the converter are the sum of the light load losses and short-circuit losses from the tests.

The method is valid under the following assumptions and conditions.

a) The losses in the semiconductor valve devices in service, due to switching losses, off-state and reverse current, are normally negligible.
b) The forward voltage drop in the semiconductor valve devices ~~can~~ may be represented by a constant component plus a resistive component directly proportional to the current.
c) The losses in service due to forward current are taken to be equal to those that would exist at the same value of direct current and with rectangular current waveform in the converter arms in the case of polyphase connections.
d) Saturable or non-saturable reactors built into the assembly and carrying valve side phase current or converter circuit currents may be included in the measuring circuits. The bias of saturable reactors should be adjusted to the value that will be required in normal operation to supply rated direct voltage at rated direct current and rated voltage on the line side.
e) For those load conditions for which efficiency is specified, the efficiency may be determined by measuring input and output power or by segregated loss tests.
f) For those load conditions for which a conversion factor is specified, this may be determined by measuring AC power and DC output.
g) Increase of power losses due to existing line distortion or due to load increase is not considered here.

7.4.1.2 Methods of measurement

The methods of measurement prescribed here are based on the foregoing assumptions. The test or tests may be performed in the normal ambient temperature prevailing in the supplier's premises. Forward loss measurements shall be made when all parts of the converter assembly have reached stable temperature carrying the rated direct current.

~~When the converter transformer is included in the power loss measurement, the load losses shall be corrected to a reference temperature of specified limit temperature rise plus 20 K (Class A and B insulation) by increasing the value of *P* by 0,001 2 p.u. for each K by which the transformer temperature during the measurement is below the reference value. For this purpose, the transformer temperature shall be taken as the average oil temperature in oil-immersed transformers or the mean winding temperature in air-cooled transformers (see also IEC/TR 60146-1-2).~~

When the converter transformer is included in the power loss measurement, the measurement shall be in accordance with the converter transformer standard.IEC 61378:2011. **18**

NOTE It is possible the transformer losses need to be corrected considering its temperature characteristics.

7.4.1.3 Test circuits

Guidance on connections which may be used for test purposes is given in IEC TR 60146-1-2.

In all cases, the losses that will occur in service in voltage dividing resistors, damping circuits and surge arrestors, if any, are to be calculated and added.

7.4.2 Temperature rise test

The temperature rise of the converter shall be determined under test conditions given for the current test under the cooling conditions, which are least favourable. If the test is conducted at a lower temperature than the maximum specified, corrections have to be made. The temperature rise test is not limited to the main circuit.

Whenever possible, the temperature rise test should be conducted at rated load conditions.

In other cases, the test shall be conducted according to 7.3.2 and by adding temperature rise due to switching losses.

The temperature rise shall be measured at a specified point and the result shall be used to verify the design of the cooling system.

If the converter is rated for other than continuous load duty, the transient thermal impedance shall be measured for the main circuit components and for the cooling system. The test shall be performed for several of the components including those operating at the highest temperature.

The temperature rise at a specified point on the semiconductor valve devices shall be recorded. The rise of virtual junction temperature shall be calculated and based on the temperature measurements in order to show that the assembly is capable of carrying the specified load duty without exceeding maximum virtual junction temperature for the devices taking into account the actual current sharing between parallel valve devices.

7.4.3 Power factor measurements

As a rule, power factor measurements need not be carried out. However, if a power factor measurement is required, it shall be determined as the displacement factor $\cos\varphi_1$ (see 3.7.14) in accordance with 6.2.3.

7.5 ~~Auxiliaries~~ Auxiliary device and control equipment

7.5.1 Checking of auxiliary devices

The function of auxiliary devices such as contactors, pumps, sequencing equipment, fans, etc., shall be checked. If convenient, this ~~can~~ may be done in conjunction with the light load test.

7.5.2 Checking the properties of the control equipment

It is not feasible to verify the properties of the control equipment under all those load conditions which may prevail in real operation. However, it is recommended that trigger equipment should be checked under real load conditions as far as possible. When this cannot be done on the manufacturer's premises, it may be performed after installation by agreement with the user.

When practicable, the checking of control equipment may be restricted to a check under two load conditions as specified by 7.3.1 a) and 7.3.2 respectively.

In either case, the static and dynamic properties of the control equipment shall be checked. This shall include checking that the equipment operates satisfactorily for all values of supply voltages within the range of variation for which it is designed.

7.5.3 Checking the protective devices

Checking of the protective devices shall be carried out as far as possible without stressing the components of the equipment above their rated values.

Due to the wide variety of protective devices and their combinations, it is not possible to state any general rules for the checking of these devices. However, if a system control equipment is designed to protect the converter from current overloads, its ability in this respect shall be checked.

If type tests to check the effectiveness of fuse protection are considered to be necessary, they shall be specified separately with conditions for tests.

Routine tests shall be performed to check the operation of protective devices. It is, however, not intended that the operation of devices such as fuses, etc., where the operation is based on destruction of the operating component, shall be checked.

7.6 EMC tests

There are two aspects concerning EMC tests as follows.

a) Immunity test

Checking of the immunity level of the converter shall be treated as an optional type test if so agreed in the contract. The test shall, as far as possible, be in accordance with the specified electrical service conditions.

~~NOTE 1 Conditions for performing immunity tests may be subject to legal conditions. Any optional type test agreed in a contract cannot break the local laws where the test is to be performed.~~

~~NOTE 2 The immunity level of incoming wires other than the main lines may also be included in the test.~~

NOTE 1 National regulations relating to the prevention of radio interference are likely to restrict the ability to perform certain immunity tests outside an EMC shielded room.

NOTE 2 Effective immunity tests usually include tests on auxiliary and control ports as well as on the main power port.

b) Radio frequency radiated and conducted disturbances

The requirements for radio frequency radiated and conducted disturbances may be the subject of a separate specification and should then be specified for actual loads. The separate specification may be constituted by national regulations.

NOTE 3 The disturbances from a complete equipment ~~may~~ can differ from the disturbances produced by functional units. For example, the radio-frequency disturbances produced by a variable speed drive system including converter and motor are very different to the disturbances produced by a converter on its own.

~~NOTE 4 The separate specification may be constituted by national regulations.~~

7.7 Measurement of audible noise and additional tests

Test procedures and limits shall be specified separately for the measurement of audible noise.

NOTE Audible noise of a complete PCE ~~may~~ can differ considerably from the values of individual functional units. Room conditions – resonance and reflection – will cause differences from calculated or measured values.

Specification and procedures for any additional tests, if necessary, for example vibration, shock, environmental, drift, shall be specified separately.

7.8 Tolerances

If guarantees are given, they shall always refer to rated values and rated conditions. It is not intended that guarantees shall necessarily be given upon all or any of the items shown below, but when such guarantees are given, they may be given either without tolerances or with tolerances, as may be specified. Either of these practices complies with this specification.

If guarantees are given with tolerances, the values stated in Table 16 shall apply. If the guaranteed values are given without tolerances, they are maximum or minimum values, as the case may be.

Table 16 – Tolerances

Subclause	Item	Tolerance
7.4.1	Assembly losses	+0,1 p.u. of the guaranteed value
7.4.1.2	Losses of transformer and reactor	+0,1 p.u. of the total guaranteed value
7.4.1.2	Efficiency of the PCE	~~Efficiency tolerance corresponding to +0,2 p.u. of the losses with a maximum consequence on the efficiency limited to –0,002 p.u. [a]~~ ~~(which means efficiency at least [x – 0,2] %)~~ Efficiency tolerance shall be the stricter of the values below [a] 1) value corresponding to +0,2 p.u. of the losses 2) –0,002 p.u. (-0,2 %) Namely, efficiency shall be at least [x – 0,2] %, where x is the guaranteed value. 19
7.4.3	Calculated displacement factor	$-0,2 \times (1 - \cos\varphi_1)$
7.3.4	Inductive direct voltage drop U_{dx}, due to the transformer	±0,1 p.u. of guaranteed value
7.3.4	Inherent voltage regulation	±0,15 p.u. of guaranteed regulation
	Measured direct voltages above 10 V [b]	$\pm (1 + 0,02\ U_{dN})$
	Measured direct voltages below or equal to 10 V [b]	$\pm 0,1\ U_{dN}$

[a] With the readings of loss measurements:

P for the output power and P_L for the losses, the first criterion provides a condition to the tolerance of the losses ΔP_L.

$\Delta P_L < 0,2 P_L$

The efficiency η is given by

$\eta = P / (P + P_L)$

The tolerance for the efficiency $\Delta\eta$, corresponding to the tolerance ΔP_L is approximately given by

$\Delta\eta = [(P_L + \Delta P_L) / (P + P_L + \Delta P_L)] - [(P_L) / (P + P_L)] \approx [\Delta P_L / P]$

~~Therefore, the second criterion for the tolerance on P_L corresponds to:~~

~~$\Delta P_L < 0,002 P$~~

Therefore, the second criterion for the efficiency tolerance provides the other condition to ΔP_L.

$\Delta P_L \approx [\Delta\eta \times P] < 0,002P$

In summary, for efficiency calculation, tolerance of the losses ΔP_L complies with the stricter of the following two conditions:

$\Delta P_L < 0,2 P_L$

$\Delta P_L < 0,002 P$

For information, the first criterion implies the efficiency tolerance as approximately $0,2 P_L / P$.

[b] For equipment provided with automatic control of an output quantity, the tolerance on the controlled quantity shall be specified.

Annex A 20
(normative)

Harmonics and interhamonics

A.1 Non-sinusoidal voltages and currents

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

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

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

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

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

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

In order that the result of the DFT, applied to a function considered as periodic (see Clause A.3), is the same as the result of a Fourier series analysis, the fundamental frequency f_f is made an integer multiple of the basic frequency (this requires the sampling frequency to be an exact integer multiple of the basic frequency [$f_s = M \times f_b$]). The synchronous sampling is essential. Loss of synchronism can change the spectrum result, making extra lines appear and changing amplitudes of true lines.

A.2 Definitions

There have been two different approaches to establish a set of definitions related to harmonics. The first approach considered the frequency as primary source of the set of definitions and started with the definition of an arbitrary reference, giving it the name of fundamental frequency (3.2.1 of IEC 61000-2-2 and 3.2.1 of IEC 61000-2-4):

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

For the purposes of IEC 60146-1-1, the fundamental frequency is the same as the power frequency supplying the converter, or supplied by the converter according to the case which is considered.

[IEV 101-14-50, modified]

NOTE 1 In the case of a periodic function, the fundamental frequency is generally equal to the frequency of the function itself.

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

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

The second approach defines the harmonic components as the result of the Fourier analysis; frequencies are therefore a consequence (IEV 551-20-01 and IEV 551-20-02). However, this approach meets a practical difficulty illustrated in Clause A.4. It should also be reminded that interharmonics, of common practice in power electronics, do not exist in the Fourier analysis. Therefore, there was a need to introduce a reference frequency, as arbitrary as in the first approach.

This International Standard follows the IEV approach. It should be noted that there is no contradiction between the two approaches, each having its own merits.

A.3 Basis

The Fourier transform S_F of a time function $f(t)$ is defined by :

$$S_F(\omega) = \int_{-\infty}^{+\infty} f(t) \cdot e^{-j\omega t} \cdot dt$$

and the reverse is:

$$f(t) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} S_F(\omega) \cdot e^{j\omega t} \cdot d\omega$$

Notation:

– F is the variable in the frequency domain,

– F_R is the the arbitrary frequency chosen as fundamental frequency,

It is arbitrarily chosen $F_R = 1 / T$

$\omega = 2\pi F$

h is the per unit variable in the frequency domain

$$h = F / F_R$$

$\omega = 2\pi h F_R$ and $\omega T = 2\pi h$

The application to a periodical function $f(t)$ may be processed in two steps. The first step considers one period $f_0(t)$ (duration T) of the function, applying the Fourier transform:

$$S_{F0}(\omega) = \int_{-\infty}^{+\infty} f_0(t)\ e^{-j\omega t}\ dt$$

in which the per unit variable h can be used

$$h = \omega / (2\pi F_R)$$

The fundamental property of a periodical function (period $T = 1 / F_R$) is applied as a second step:

$$\sum_{n=-\infty}^{+\infty} e^{-j \cdot 2\pi \cdot h \cdot n} = F_R \sum_{n=-\infty}^{+\infty} \delta(h-n)$$

The Fourier transform of the periodical function equals the Fourier transform of one period of the function multiplied by the reverse of the period and made discrete by the multiplication by a series of Dirac distributions centred on the series of relatives integers.

$$S_F(h) = \left\{ \sum_{n=-\infty}^{+\infty} \delta(h-n) \right\} F_R\ S_{F0}(h)$$

Note that $F_R \times S_{F0}(h)$ is an over-estimation of the Fourier series using complex terms. An envelope of the Fourier series with real terms can be established :

$$A_n = 2\ F_R\ S_{F0}(h)$$

A.4 Measurement

The measurement techniques defined in the second edition of IEC 61000-4-7 and the definition of the fundamental frequency in 3.10.2 are consistent for application to all electrotechnical and power electronics items. Other cases need further consideration.

As an illustration, the superposition of a sinusoidal ripple control signal at 175 Hz on a sinusoidal 50 Hz supply voltage may be considered. This results in a periodic voltage having a period of 40 ms and a frequency of 25 Hz. A classical Fourier series analysis of this voltage yields a fundamental component of 25 Hz with zero amplitude and two components with non-zero amplitude, a 2nd harmonic (50 Hz) with amplitude equal to that of the supply voltage and a 7th harmonic (175 Hz) with an amplitude equal to that of the ripple control signal. The definitions in 3.10 avoid the confusion implicit in this approach, and produce a result in line with the common practice of the DFT (as described in IEC 61000-4-7), showing a fundamental at 50 Hz and an interharmonic of order 3,5.

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

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

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

A.1 Non-sinusoidal voltages and currents

The line-side current of a line commutated converter is usually similar to a train of trapezoids as shown in Figure 2. The repetition frequency of the current waveshape is equal to the frequency of the line voltage for commutation. The line voltage for commutation can be distorted such as is shown in Figure 4 unless appropriate countermeasures are taken. The repetition frequency of the distorted voltage waveshape is also equal to the frequency of the line voltage for commutation.

Thus, the current waveshape and the voltage waveshape include the harmonic components, the frequency of which are integer multiples of the frequency of the line voltage for commutation as indicated by Formula (19).

However, when the harmonics are measured in real installations, harmonic components with non-integer multiple of the fundamental frequency can be observed. They are called interharmonics. For harmonic measurement, refer to IEC 61000-4-7.

A.2 Two approaches for definitions related to harmonics

There have been two different approaches to establish a set of definitions related to harmonics. The first approach considered the frequency as primary source of the set of definitions and started with the definition of an arbitrary reference, giving it the name of "fundamental frequency" (IEC 61000-2-2:2002, 3.2.1, and IEC 61000-2-4:2002, 3.2.1).

For the purposes of this document, the fundamental frequency is the same as the power frequency supplying the converter, or supplied by the converter according to the case which is considered.

The definition above is practically reasonable as described below.

In many cases, the line commutated converters are connected to the mains power supply. The commutation voltage is fed by the mains. The frequency of the commutation voltage is the power frequency of the mains. In cases where the line commutated converters provide the power to the loads or to the machines, the frequency of the commutation voltage is determined by the converter. In these cases, the frequency of the commutation voltage is also the power frequency of the feeding lines to the loads or to the machines. As explained in Clause A.1, the frequencies of the harmonic components are the integer multiple of the commutation voltage. Thus, the frequencies of the harmonic components are integer multiple of the power frequency.

The second approach defines the harmonic components as the result of the Fourier analysis; frequencies are therefore a consequence (IEC 60050-551:1998, 551-20-01 and 551-20-02). However, this approach is not superior to the first approach from practical viewpoint.

Annex B
(informative)

Electrical environment – Short-circuit ratio

B.1 Electrical environment specification

The generic aspect of network conditions is developed in the publications of IEC TC 77 and its subcommittees. All EMC considerations are developed in dedicated standards as mentioned in 4.2.3.2. These EMC standards for application of semiconductor converters set requirements for both immunity and emission in the low frequency range and high frequency range and consider conducted phenomena as well as radiated phenomena.

Information on the prospective conditions of coexistence between supply systems, disturbing loads and sensitive apparatus (mostly low current control equipment, other power converters, power capacitors and sensitive lines such as used for communications and control) is essential during the early stages of the design of an installation.

Notably, harmonic emission should be considered relative to the ratio of short-circuit power to apparent power, presence of capacitors or other converters.

Guidance on calculation methods will be found in IEC TR 60146-1-2.

NOTE Such information ~~may not be readily~~ is not possibly available ~~and the approach could be made as follows:~~. In such case, the approach below is taken for example.

Request system information from the appropriate local and national authorities, when the final location of the plant is known. This includes the power, line and radio communication authorities and those responsible for the limitation of disturbance.

Where agreement is necessary with the purchaser to finalize the requirements, the above information ~~should be~~ is used as a basis for discussion and when agreed, used for calculation purposes.

Low frequency conducted emissions are defined relative to the applicable set of standards prepared by IEC subcommittee 77A.

Four standards or Technical Reports deal with harmonic emission:

- IEC 61000-3-2: low voltage equipment with input current ≤ 16 A per phase;
- IEC TS 61000-3-4: Technical Report for low-voltage power supply systems and equipment with rated current greater than 75 A;
- IEC 61000-3-12: equipment connected to public low-voltage systems with input current between 16 A and 75 A per phase (restricted conditions of use);
- IEC TR 61000-3-6: distorting loads in MV and HV power systems.

NOTE 1 IEC 61000-3-2, IEC TS 61000-3-4 and IEC 61000-3-12 apply only to equipment intended to be connected to public low voltage AC distribution systems. This is stated in the scopes of these standards.

Four standards or Technical Reports deal with voltage changes, voltage fluctuations and flicker:

- IEC 61000-3-3: low-voltage equipment with input current ≤ 16 A per phase;
- IEC TS 61000-3-5: low-voltage equipment with input current greater than 75 A;
- IEC 61000-3-11: low-voltage equipment with input current ~~between 16 A and~~ ≤ 75 A (restricted conditions of use);
- IEC TR 61000-3-7: fluctuating loads in MV and HV power systems.

NOTE 2 IEC 61000-3-3, IEC TS 61000-3-5 and IEC 61000-3-11 apply only to equipment intended to be connected to public low voltage AC distribution systems. This is stated in the scopes of these standards.

Guidance for different applications is also provided in the dedicated EMC product standards (see 4.2.3.2).

When neither the final location nor the user is known, for standard converters, the supplier should select the "immunity class" from experience and this should be stated in the specification for the equipment.

The general electrical service condition tolerances are discussed in 5.4.

B.2 Point of coupling of the converter

B.2.1 Systems and installations

A converter is generally a component of a larger system. 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.

Within the installation, a converter is connected at a given point of coupling. The harmonic operating characteristics of the converter depend on the network characteristics at the point of coupling.

For a given installation, the agreed power S_{ST} defines the equivalent reference current I_{TN} (total RMS value):

$$S_{ST} = U_N \times I_{TN} \times \sqrt{3} \quad \text{(B.1)}$$

where

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

I_{TN} is the reference current. ~~Note that~~

NOTE 1 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 2 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., the reference current I_{TN1} is by convention equal to I_{TN}.

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

$$S_{ITA} = U_N \times I_{TNA} \times \sqrt{3} \quad \text{(B.2)}$$

where

U_N is the rated line-to-line voltage at the IPC "α" IPC$_A$. Note that

NOTE 3 I_{TNA} is the rated current of the feeding section of 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) $S_{SCα}$ S_{SCA} defined at the IPC "α" IPC$_A$. This is the responsibility of those in charge of internal power distribution.

B.2.2 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 point of coupling to the rated apparent power of the installation, or of a part of the installation, supplied from this point of coupling (see Figure B.1):

$$R_{SIA} = S_{SCα} / S_{ITA} = I_{SCα} / I_{TNA}$$

$$R_{SIA} = S_{SCA} / S_{ITA} = I_{SCA} / I_{TNA} \quad (B.3)$$

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

NOTE 1 3.9.9 and definition 3.69 of IEC 62103 defines the relative short-circuit power (R_{SC}) as "ratio of the short-circuit power of the source to the rated apparent power on the line side of the converter(s)". R_{SC} 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 rated 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 in-plant point of coupling (IPCα IPC$_A$) 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 2 In Figure B.1, the installation shows a part A with a short-circuit current ratio of the source R_{SIA}. Part A contains a part B, part B has a short-circuit current ratio of the source R_{SIB}, and part A also contains a part C, etc. 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.

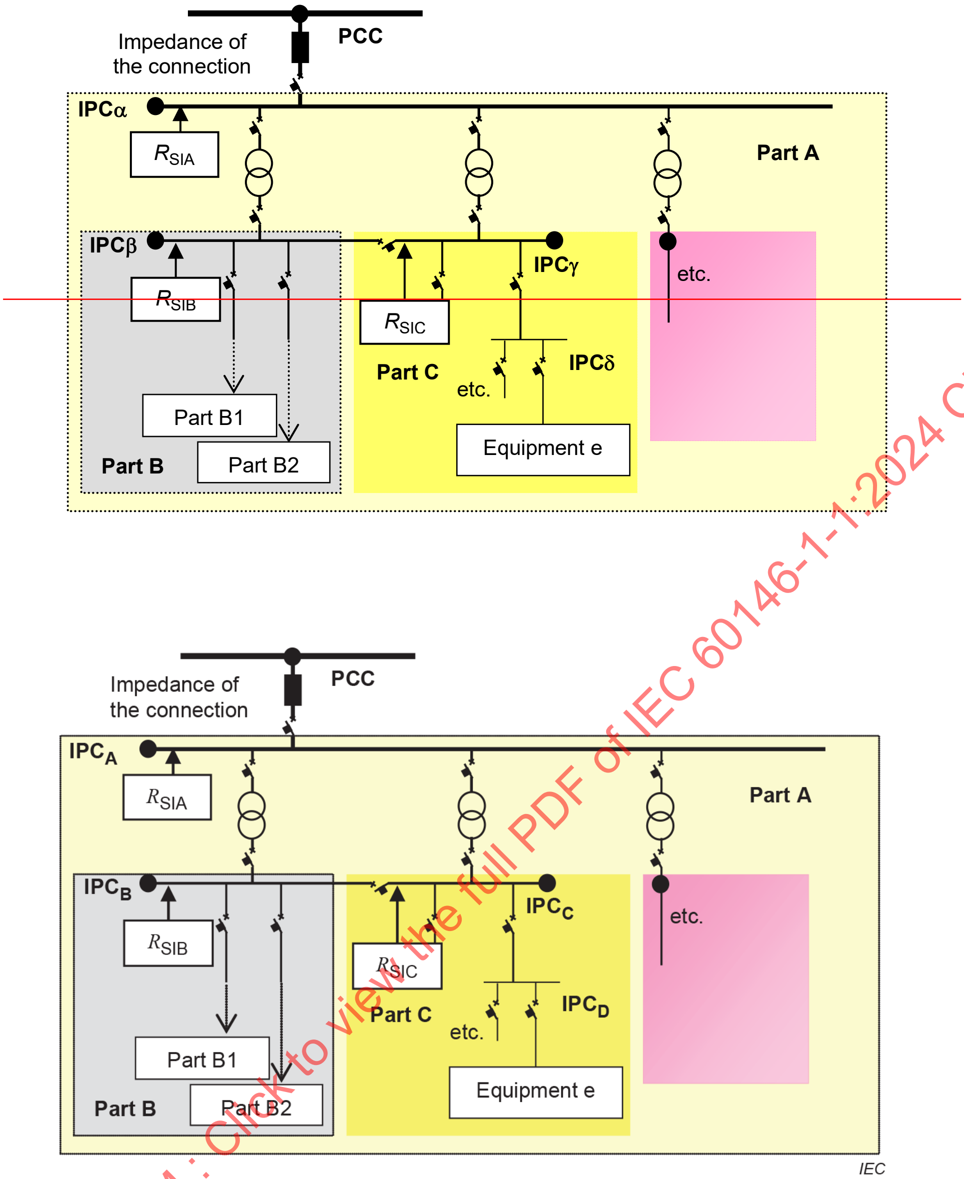


Figure B.1 – PCC, IPC, installation current ratio and R_{SI}

B.2.3 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 TS 61000-3-4 or IEC 61000-3-12):

$$R_{SC} = S_{SC} / S_{Ne} = I_{SC} / I_{LNe} \tag{B.4}$$

NOTE 1 With the example of Figure B.2, R_{SC} can be expressed as a function of the relevant R_{SI}. The piece of equipment (e) is fed from a bus bar (~~IPC$_\delta$~~ IPC$_D$), 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:

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

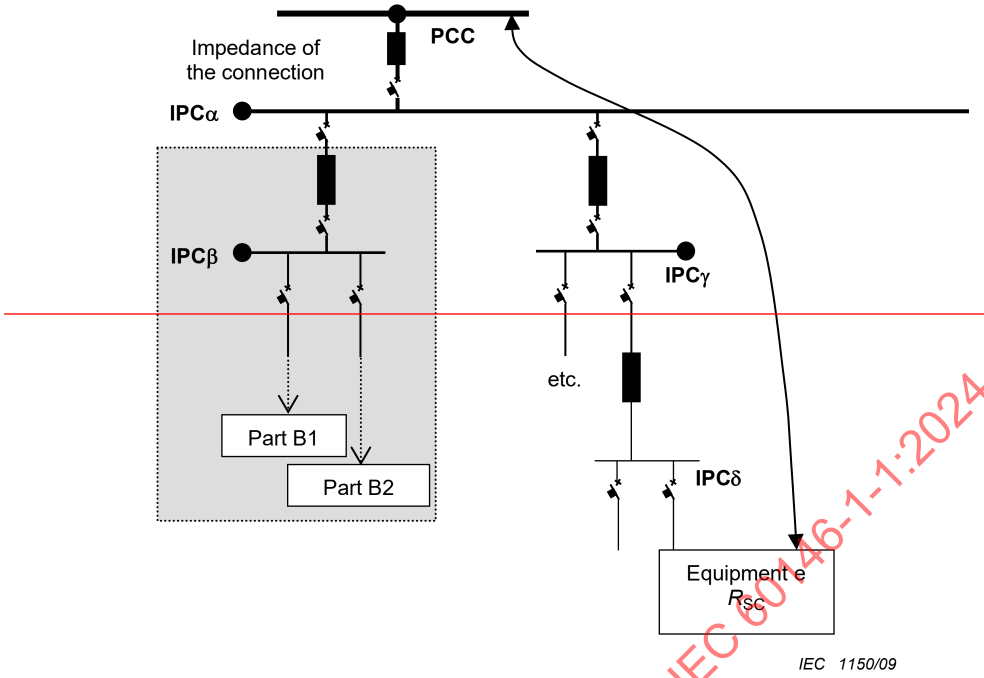
$$R_{\mathrm{SIe}} = S_{\mathrm{SCD}} / S_{\mathrm{ITe}} = I_{\mathrm{SCD}} / I_{\mathrm{LNe}} = (I_{\mathrm{SCD}} / I_{\mathrm{SC}}) \times (I_{\mathrm{SC}} / I_{\mathrm{LNe}}) = (S_{\mathrm{SCD}} / S_{\mathrm{SC}}) \times (R_{\mathrm{SCe}}) \qquad \text{(B.5)}$$

or

$$R_{\mathrm{SCe}} = (S_{\mathrm{SC}} / S_{\mathrm{SC}\delta}) \times R_{\mathrm{SIe}}$$

$$R_{\mathrm{SCe}} = (S_{\mathrm{SC}} / S_{\mathrm{SCD}}) \times R_{\mathrm{SIe}} \qquad \text{(B.6)}$$

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



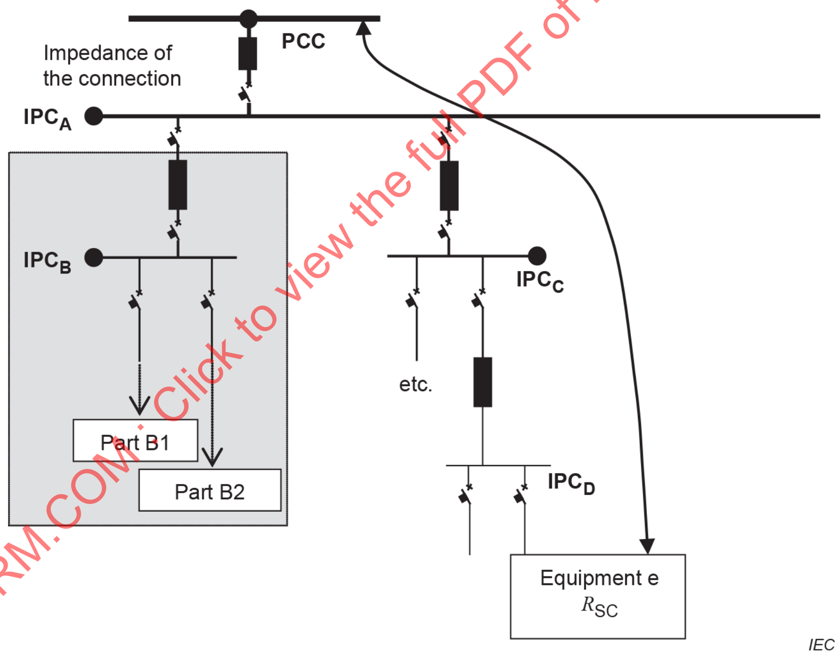


Figure B.2 – PCC, IPC, installation current ratio and R_{SC}

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

Annex C
(normative)

Protection against electric shock and energy hazards

C.1 General

Considerations to ensure safety of semiconductor converters, and more generally of power conversion equipment (PCE) during installation, normal operating conditions and maintenance for the expected lifetime of the PCE needs to be addressed during the design and construction of the PCE. Also consideration should be given to minimize hazards resulting from reasonably foreseeable misuse.

Protection against thermal hazards and electric shock is to be maintained in single fault conditions as well as under normal conditions.

The necessary evaluations include (but are not limited to) insulation coordination, determination and performance of tests, circuit analysis in case of failure and information to be delivered to the user. For clarity, the terms defined in 3.11 should be used in reporting investigations or tests.

C.2 Insulation coordination

The insulation coordination is the basis to provide protection against electric shock. It covers clearance and creepage distances, solid insulation, enclosure or screens, protection circuits. It addresses printed circuit boards (or printed wiring boards PWBs), sub-assemblies and components.

a) Clearance and creepage distances

Evaluation of clearance and creepage distances on PWB, components and sub-assemblies ensures that functional, basic, supplementary, double and reinforced insulation is appropriate.

The clearance and creepage distances are determined upon the voltage stress across the evaluated circuits, due to over-voltage category, temporary over-voltage and working voltage across the circuits investigated.

NOTE IEC 60664-1 defines the rules to be applied to low voltage equipment up to 1 000 V a.c. and 1 500 V d.c.

b) Solid insulation

Evaluation of solid insulation used in components and sub-assemblies shall be based on the voltage stress due to voltage category, temporary over-voltage and working voltage across the circuits.

The evaluation also takes into account mechanical and environmental stress.

c) Enclosure

Evaluation of enclosure that provides protection against direct contact to dangerous live parts shall confirm compliance with the requirements in IEC 60529 for the appropriate IP-code. The appropriate IP code shall be specified.

d) Direct contact

~~Evaluation of circuits, components and sub-assemblies that provide protection in case of direct contact demonstrates the appropriate level of protective separation, limited voltage and/or protective impedance.~~

~~e) Indirect contact~~

~~Evaluation of enclosure and circuits that provide protection against indirect contact demonstrates that the measures taken are appropriate according to insulation class I, class II or class III equipment as defined in IEC 61140.~~

~~C.3 System voltage~~

~~The rated insulation voltage (see 3.11.9) is assigned by the manufacturer to the equipment or to a part of it, according to the voltage stress it can withstand.~~

~~The voltage stress to be withstood is related to the system used to supply the equipment which includes over-voltage category, temporary over-voltage and working voltage across the circuits investigated.~~

~~The system voltage is defined according to the earthing system as described in IEC 60364-1.~~

~~NOTE 1 Three basic types of earthing system are described.~~

~~TN system: has one point directly earthed, the exposed conductive parts of the installation being connected to that point by protective conductors. Three types of TN system, TN-C, TN-S and TN-C-S, are defined according to the arrangement of the neutral and protective conductors;~~

~~TT system: has one point directly earthed, the exposed conductive parts of the installation being connected to earth electrodes electrically independent of the earth electrodes of the power system;~~

~~IT system: has all live parts isolated from earth or one point connected to earth through an impedance, the exposed conductive parts of the installation being earthed independently or collectively to the earthing system.~~

~~In TN and TT systems, the system voltage is the r.m.s. value of the rated voltage between a phase and earth.~~

~~NOTE 2 A corner-earthed system is a TN system with one phase earthed, in which the system voltage is the r.m.s. value of the rated voltage between a non-earthed phase and earth (i.e. the phase-phase voltage).~~

~~In three-phase IT systems, and for determination of impulse voltage, the system voltage is the r.m.s. value of the rated voltage between a phase and an artificial neutral point (an imaginary junction of equal impedances from each phase).~~

~~NOTE 3 For most systems, this is equivalent to dividing the phase-to-phase voltage by √3.~~

~~In three-phase IT systems, and for determination of temporary overvoltage, the system voltage is the r.m.s. value of the rated voltage between phases.~~

~~In single-phase IT systems, the system voltage is the r.m.s. value of the rated voltage between phases.~~

~~For equipment directly connected to high voltage mains, the system voltage is the r.m.s. value of the rated voltage between phases.~~

~~NOTE 4 In all cases, when the supply voltage is rectified a.c., the system voltage is the r.m.s. value of the source a.c. before rectification, taking into account the supply earthing system.~~

~~NOTE 5 Voltages generated within the converter by the secondaries of transformers providing galvanic isolation from the supply mains are also considered to be system voltages for the determination of impulse voltages.~~

~~NOTE 6 For converters having series-connected diode bridges (12-pulse, 18-pulse, etc.), the system voltage is the sum of the a.c. voltages at the diode bridges.~~

C.4 Requirements for tests, analysis and information

Identification of all characteristics: environmental conditions, system voltage, over-voltage category etc. as well as conducting tests are performed to verify that environmental impact (temperature, dust, water etc.) on the converter subassemblies and components does not lead to any thermal or electric shock hazard.

Circuit analysis and test identifies and evaluates components (including insulation systems) whose failure, due to an open circuit or short-circuit, would result in a thermal or electric shock hazard.

Information should be provided to the purchaser by means of labelling and user manual, in order to enable safe installation, maintenance and operation, including relevant caution and warnings located on the equipment.

C.5 Relevant references

This standard does not give more requirements for the safety evaluation of the PCE as this is covered by other safety standards. The relevant safety requirements are determined by the specific product or product family standards.

The following safety product or product family standards set up the requirements for different applications:

– IEC 61204-7 for power supply units (PSU);
– IEC 61800-5-1 for power drive systems (PDS);
– IEC 62040-1 for uninterruptible power systems (UPS), IEC 62310-1 for static transfer systems (STS);
– IEC 60700-1 for high voltage applications like d.c. transmission systems (HVDC) and IEC/PAS 61975 regarding their installation, IEC 61954 for static var compensators (SVC);
– IEC 62103 for other products not covered by a product standard.

NOTE Future IEC 62477 related to safety requirements for power semiconductor converter systems is under consideration within IEC.

Annex C
(informative)

Introduction to safety standards for power conversion equipment 21

C.1 General

Annex C briefly introduces the safety standards of the IEC 62477 series for power electronics converter systems (PECS) and equipment. Annex C also clarifies that this edition of IEC 60146-1-1 was revised considering good coordination with the IEC 62477 series.

NOTE PECS is defined in IEC 62477-1. Annex C interprets PCE as equivalent to power conversion equipment.

C.2 Brief introduction to IEC 62477 series with reference to IEC 60146 series

IEC 62477-1 and IEC 62477-2 cover the safety requirements for the power conversion equipment while the IEC 60146-1-1 and IEC TR 60146-1-2 mainly cover the basic performance requirement. The IEC 62477 series is in the same position as the IEC 60146 series, which can be applied to the converters not covered by product standards.

C.3 Purposes or intentions of IEC 60146 series and IEC 62477 series

The purposes or intentions of the standards are listed in Table C.1. Some additional explanations are added in parentheses in Table C.1 for making the differences clear between two series.

From Table C.1, it is pointed out that the IEC 60146 series focus on basic requirements to operations and performances of the power conversion equipment while the IEC 62477 series focus on the safety requirements.

Table C.1 – Comparison on purposes or intentions between two standards

IEC 60146-1-1	IEC 62477-1
To establish basic terms and definitions (for operations and performance of the line-commutated converters) To specify basic performance requirements To specify test requirements (for basic operations and performances) of the line commutated converters To specify service conditions which influences the basis of ratings	To establish common terminology for safety aspects relating to PECS To establish minimum requirements for the coordination of safety aspects of interrelated parts within PECS To establish common basis for minimum safety requirements for the PEC portion of products that contain PEC To specify requirements to reduce safety risks during use and operation and during service and maintenance where specifically stated

The requirements related to safety were deleted from this revision of IEC 60146-1-1. This edition of IEC 60146-1-1 refers to the IEC 62477 series for relevant guidance on safety.

Careful consideration has been made for test requirements during revision of IEC 60146-1-1. The test requirements related to safety have been deleted and now IEC 60146-1-1 only includes the test requirement for basic operations and performances of the power electronics converter.

IEC 60146-1-1 also considers that the power electronics products covered by this edition comply with fundamental IEC standards like IEC 60364-1 or IEC 60529.

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IEC 60071-2, *Insulation co-ordination – Part 2: Application guidelines*

IEC 60076-1, *Power transformers – Part 1: General*

IEC TR 60146-1-2:~~1991~~2019, *Semiconductor converters – General requirements and line commutated converters – Part 1-2: Application guidelines*

~~IEC 60146-1-3, *Semiconductor convertors – General requirements and line commutated convertors – Part 1-3: Transformers and reactors*~~

IEC 60146-2, *Semiconductor converters – Part 2: Self-commutated semiconductor converters including direct d.c. converters*

~~IEC 60146-6, *Semiconductor convertors – Part 6: Application guide for the protection of semiconductor convertors against overcurrent by fuses*~~

IEC 60364-1, *Low-voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC TR 60664-2-1, *Insulation coordination for equipment within low-voltage systems – Part 2-1: Application guide –* ~~*Dimensioning procedure worksheets and dimensioning examples*~~ *Explanation of the application of the IEC 60664 series, dimensioning examples and dielectric testing*

IEC TR 60664-2-2, *Insulation coordination for equipment within low-voltage systems – Part 2-2: Interface considerations – Application guide*

IEC 60664-3, *Insulation coordination for equipment within low-voltage systems – Part 3: Use of coating, potting or moulding for protection against pollution*

IEC 60664-4, *Insulation coordination for equipment within low-voltage systems – Part 4: Consideration of high-frequency voltage stress*

~~IEC 60664-5, *Insulation coordination for equipment within low-voltage systems – Part 5: Comprehensive method for determining clearances and creepage distances equal to or less than 2 mm*~~

IEC TR 60725, *Consideration of reference impedances and public supply network impedances for use in determining the disturbance characteristics of electrical equipment having a rated current ≤75 A per phase*

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

IEC~~/TR~~ TS 61000-3-5, *Electromagnetic compatibility (EMC) – Part 3-5: Limits – Limitation of voltage fluctuations and flicker in low-voltage power supply systems for equipment with rated current greater than* ~~*16*~~ *75 A*

IEC TR 61000-3-6, *Electromagnetic compatibility (EMC) – Part 3-6: Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems*

IEC TR 61000-3-7, *Electromagnetic compatibility (EMC) – Part 3-7: Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems*

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IEC 61378-1, *Convertor transformers – Part 1: Transformers for industrial applications*

IEC 61378-2, *Convertor transformers – Part 2: Transformers for HVDC applications*

IEC 61439-1, *Low-voltage switchgear and controlgear assemblies – Part 1: General rules*

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IEC 62040-2:2016, *Uninterruptible power systems (UPS) – Part 2: Electromagnetic compatibility (EMC) requirements*

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IEC 62310-2:2006, *Static transfer systems (STS) – Part 2: Electromagnetic compatibility (EMC) requirements*

IEC 62477, *Safety requirements for power semiconductor converter systems – Part 1: General*[1]

IEC 62589, *Railway applications – Fixed installations – Harmonisation of the rated values for converter groups and tests on converter groups*[2]

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[1] Under consideration

[2] In preparation

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Index of definitions

List of comments

1 The note reminds the first purpose listed in Introduction. The note clarifies that this document has a mission to develop common understanding on power electronics technology by listing key terms and definitions.

2 For the safety standards, IEC 62477 series are referred instead of IEC 62103.

3 Terms and definitions related to safety insulation are in coordination with IEC 62477-1:2022.

4 For better readability, Table 2 is provided with references to Clause 3.

5 For better understandings, Figures 2 a) and 2 b) are provided with supplemental explanation.

6 For clear identification, the formulae are provided with numbers.

7 For better understandings, Figure 4 is provided with supplemental explanations especially for item e).

8 Contents of Table 10 are replaced with those in Table 1 of IEC TR 60146-1-2:2019, which was revised considering the coordination with the converter transformer standard, IEC 61378-1:2011.

9 The formula for nominal inductive voltage regulation is replaced with Formula (10). The formula in the previous edition was derived based on the r.m.s. value of the rectangular current waveform while the latest converter transformer standard, IEC 61378-1:2011, is based on the fundamental frequency component.

In addition, the previous formula is not popular and could not be found in general textbooks of the power electronics. Then, this edition takes Formula (10).

For details, see IEC 60146-1-2:2019, Subclause 4.7.2.4 and Annex C.

10 The transformer loss and the transformer guaranteed short-circuit impedance are changed in Table 10 to keep good coordination with IEC 61378-1:2011.

11 Contents of Table 10 are replaced with those in Table 1 of IEC TR 60146-1-2:2019, which was revised considering the coordination with the converter transformer standard, IEC 61378-1:2011.

12 The formula for the inductive direct voltage regulation is replaced with Formula (17). The formula in the previous edition used the short circuit ratio and seemed to be difficult to understand. Formula (17) is based on the reactance which is consistent with Formula (10).

For details, see IEC 60146-1-2:2019, Subclause 5.1.3.

13 This document explicitly declares its position to the product standards.

14 This edition clearly declares its scope for the duty class. It also clarifies the procedure for the case where an appropriate duty class cannot be found in this document.

15 For Subclause 7.2, this document explicitly declares its position to IEC 62477-1 and IEC 62477-2 for keeping good coordination among standards.

16 The reference for the test procedures is changed to the latest standard.

17 In Subclause 7.2.2.4, the formulae of test voltage are added for better understandings.

18 For transformer losses, this document changes the description simply to refer IEC 61378-1: 2011 considering good coordination between the standards.

19 For the efficiency tolerance requirement, descriptions are simplified by explicitly showing two criteria. Notation "a" is provided with supplemental explanations for better understandings.

20 Annex A is made compact. Descriptions are largely changed clearly to provide reasons for supporting the preference of the harmonics definition in this document.

21 Annex C is completely replaced with descriptions on relationship between this document and the safety standard IEC 62477 series.

IEC 60146-1-1

Edition 5.0 2024-03

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Semiconductor converters – General requirements and line commutated converters – Part 1-1: Specification of basic requirements

Convertisseurs à semiconducteurs – Exigences générales et convertisseurs commutés par le réseau – Partie 1-1: Spécification des exigences de base

IEC 60146-1-1:2024-03(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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SEMICONDUCTOR CONVERTERS – GENERAL REQUIREMENTS AND LINE COMMUTATED CONVERTERS –

Part 1-1: Specification of basic requirements

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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IEC 60146-1-1 has been prepared by IEC technical committee 22: Power electronic systems and equipment. It is an International Standard.

This fifth edition cancels and replaces the fourth edition published in 2009. This fifth edition constitutes a technical revision.

This fifth edition introduces four main changes:

a) re-edition of the whole standard according to the current directives;
b) deletion of safety-related descriptions considering coordination with IEC 62477 series;
c) changes of calculation methods of inductive voltage regulation;
d) changes considering coordination with IEC 61378 series.

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

Draft	Report on voting
22/374/FDIS	22/378/RVD

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

The language used for the development of this International Standard is English.

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

A list of all parts of the IEC 60146 series, under the general title *Semiconductor converters – General requirements and line commutated converters*, can be found on the IEC website.

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

- reconfirmed,
- withdrawn, or
- revised.

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

INTRODUCTION

The main purposes of the IEC 60146-1 series are as follows.

IEC 60146-1-1, Specification of basic requirements:

- to establish basic terms and definitions;
- to specify service conditions which influence the basis of rating;
- to specify test requirements for electronic power converters and assemblies, standard design (for special design, see IEC TR 60146-1-2);
- to specify basic performance requirements;
- to give application oriented requirements for semiconductor power converters.

IEC TR 60146-1-2, Application guidelines:

- to give additional information on test conditions and components (for example: semiconductor valve devices), when required for their use in semiconductor power converters, in addition to or as a modification on existing standards;
- to provide useful reference, calculation factors, formulae and diagrams pertaining to power converter practice.

SEMICONDUCTOR CONVERTERS – GENERAL REQUIREMENTS AND LINE COMMUTATED CONVERTERS –

Part 1-1: Specification of basic requirements

1 Scope

This part of IEC 60146 specifies the requirements for the performance of all semiconductor power converters and semiconductor power switches using controllable and/or non-controllable electronic valve devices.

The electronic valve devices mainly comprise semiconductor devices, either not controllable (i.e. rectifier diodes) or controllable (i.e. thyristors, triacs, turn-off thyristors and power transistors). The controllable devices can be reverse blocking or reverse conducting and controlled by means of current, voltage or light. Non-bistable devices are assumed to be operated in the switched mode.

This document is primarily intended to specify the basic requirements for converters in general and the requirements applicable to line commutated converters for conversion of AC power to DC power or vice versa. Parts of this document are also applicable to other types of electronic power converter provided that they do not have their own product standards.

These specific equipment requirements are applicable to semiconductor power converters that either implement power conversion or use commutation (for example semiconductor self-commutated converters) or involve particular applications (for example semiconductor converters for DC motor drives) or include a combination of said characteristics (for example direct DC converters for electric rolling stock).

This document is applicable to all power converters not covered by a dedicated product standard, or if special features are not covered by the dedicated product standard. Generally dedicated product standards for power converters refer to this document.

NOTE 1 This document is not intended to define EMC requirements. It covers all phenomena and therefore introduces references to dedicated standards which are applicable according to their scope.

NOTE 2 For the information on converter transformers, related to this document, see IEC 61378-1.

NOTE 3 All the terms listed in Clause 3 are not necessarily used in this document, however they are necessary to establish a common understanding in the application of semiconductor converters.

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 60050-551:1998, *International Electrotechnical Vocabulary (IEV) – Part 551: Power electronics*, available at www.electropedia.org

IEC 60050-551-20:2001, *International Electrotechnical Vocabulary (IEV) – Part 551-20: Power electronics – Harmonic analysis,* available at www.electropedia.org

IEC 60664-1:2020, *Insulation coordination for equipment within low-voltage supply systems – Part 1: Principles, requirements and tests*

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

IEC 61000-3-2:2018, *Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤16 A per phase)*

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 61000-4-7:2002, *Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto*

IEC 61000-6-1:2016, *Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity standard for residential, commercial and light-industrial environments*

IEC 61000-6-2:2016, *Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity standard for industrial environments*

IEC 61000-6-4:2018, *Electromagnetic compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments*

IEC 61378-1:2011, *Converter transformers – Part 1: Transformers for industrial applications*

IEC 62477-1:2022, *Safety requirements for power electronic converter systems and equipment – Part 1: General*

IEC 62477-2:2018, *Safety requirements for power electronic converter systems and equipment – Part 2: Power electronic converters from 1 000 V AC or 1 500 V DC up to 36 kV AC or 54 kV DC*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-551, IEC 60050-551-20, IEC 60664-1 and the following apply.

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

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

NOTE The policy adopted is as follows:

– when an existing IEC 60050 definition needs amplification or additional information, the title, the reference and the additional text are given;

– explanations and figures are given in 4.2;

– terms used in connection with converter faults are defined in IEC TR 60146-1-2.

3.1 Semiconductor devices and combinations

3.1.1
semiconductor device
device, the essential electric characteristics of which are due to the flow of charge carriers within one or more semiconductor materials

[SOURCE: IEC 60050-151:2001, 151-13-63]

3.1.2
electronic power switch
electronic switch
operative unit for electronic power switching comprising at least one controllable valve device

[SOURCE: IEC 60050-551:1998, 551-13-01]

3.1.3
semiconductor switch
electronic power switch with semiconductor valve devices

Note 1 to entry: Similar terms are used for electronic switches or power controllers with specific electronic valve devices, for example thyristor controller, transistor switch.

[SOURCE: IEC 60050-551:1998, 551-13-05]

3.1.4
non-controllable valve device
rectifier diode
reverse blocking valve device the current path of which conducts in its conducting direction without any control signal being applied

[SOURCE: IEC 60050-551:1998, 551-14-04]

3.1.5
thyristor
bi-stable semiconductor device comprising three or more junctions which can be switched from the off-state to the on-state or vice versa

Note 1 to entry: Devices having only three layers but having switching characteristics similar to those of four-layer thyristors may also be called thyristors.

Note 2 to entry: The term "thyristor" is used as a generic term to cover the whole range of PNPN type devices. It may be used by itself for any member of the thyristor family when such use does not result in ambiguity or misunderstanding. In particular, the term "thyristor" is widely used for reverse blocking triode thyristor, formerly called "silicon controlled rectifier".

[SOURCE: IEC 60050-521:2002, 521-04-61, modified – Note 2 to entry added]

3.1.6
reverse blocking triode thyristor
three-terminal thyristor which for negative anode voltage does not switch, but exhibits a reverse blocking state

[SOURCE: IEC 60050-521:2002, 521-04-63]

3.1.7
reverse conducting triode thyristor
three-terminal thyristor which for negative anode voltage does not switch and conducts large currents at voltages comparable in magnitude to the forward on-state voltage

[SOURCE: IEC 6005-521:2002, 521-04-65]

3.1.8
bidirectional triode thyristor
triac
three-terminal thyristor having substantially the same switching behaviour in the first and third quadrants of the current-voltage characteristic

[SOURCE: IEC 60050-521:2002, 521-04-67]

3.1.9
turn-off thyristor
thyristor which can be switched from the on-state to the off-state and vice versa by applying control signals of appropriate polarity to the gate terminal

Note 1 to entry: The gate turn-off thyristor (GTO) and the integrated gate commutated thyristor (IGCT) are types of turn-off thyristor.

[SOURCE: IEC 60050-521:2002, 521-04-68, modified – Note to entry added]

3.1.10
power transistor
transistor designed for switching from the on-state to the off-state and vice versa by applying control signals of appropriate polarity to the base or gate terminal

Note 1 to entry: The structure of the device intrinsically provides the capability of amplification (see IEC 60050-521:2002, 521-04-46).

Note 2 to entry: Different technologies of power transistors are used, such as bipolar transistors, insulated gate bipolar transistors (IGBT), metal-oxide-semiconductor field-effect transistors (MOSFET), etc.

3.1.11
valve device stack
single structure of one or more electronic valve devices with its (their) associated mounting(s) and auxiliaries if any

[SOURCE: IEC 60050-551:1998, 551-14-12]

3.1.12
valve device assembly
electrically and mechanically combined assembly of electronic valve devices or stacks, complete with all its connections and auxiliaries in its own mechanical structure

Note 1 to entry: Similar terms are applied to stacks or assemblies comprising specific electronic valve devices, for example diode stack (rectifier diodes only), thyristor assembly (thyristors only or in combination with rectifier diodes).

[SOURCE: IEC 60050-551:1998, 551-14-13]

3.1.13
electronic valve device
indivisible electronic device for electronic power conversion or electronic power switching, comprising a non-controllable or bistably controlled unidirectionally conducting current path

[SOURCE: IEC 60050-551:1998, 551-14-02, modified – Notes to entry deleted]

3.1.14
semiconductor valve device
electronic valve device which is a semiconductor device

Note 1 to entry: Typical semiconductor valve devices are thyristors, rectifier diodes, bipolar transistors, metal-oxide-semiconductor field-effect transistors (MOSFET) and insulated-gate bipolar transistors (IGBT).

Note 2 to entry: Two or more semiconductor valve devices may be integrated on a common semiconductor chip (examples: a thyristor and a rectifier diode in a reverse conducting thyristor, a power switching field effect transistor with its reverse diode) or packaged in a common case (semiconductor power module). These combinations are considered as separate semiconductor valve devices.

[SOURCE: IEC 60050-551:1998, 551-14-09, modified – Notes to entry added]

3.1.15
electronic power conversion
power conversion
conversion
change of one or more of the characteristics of an electric power system essentially without appreciable loss of power by means of electronic valve devices

Note 1 to entry: Characteristics include, for example, voltage amplitude, number of phases and frequency, including zero frequency.

[SOURCE: IEC 60050-551:1998, 551-11-02]

3.1.16
electronic power converter
power converter
converter
operative unit for electronic power conversion, comprising one or more electronic valve devices, and auxiliaries if any

Note 1 to entry: Converter transformers and filters related to network interfacing in terms of electrical characteristics are excluded from the converter itself. Such devices are part of the system aspect. Any device necessary to the correct operation of the converter itself is included in the converter, for example filters for limitation of the du/dt applied to the valve devices, surge arrestors, etc. Any auxiliary necessary to the correct operation of the converter itself is included in the converter, for example fans or cooling system.

[SOURCE: IEC 60050-551:1998, 551-12-01, modified, – Words "transformers and filters if necessary" removed from the definition, note to entry replaced, and figure removed]

3.1.17
trigger equipment
gating equipment
equipment which provides suitable trigger pulses from a control signal for controllable valve devices in a converter or power switch including timing or phase shifting circuits, pulse generating circuits and usually power supply circuits

3.1.18
system control equipment
equipment associated with a power conversion equipment or system which performs automatic adjustment of the converter output characteristics as a function of a controlled quantity

Note 1 to entry: Examples of controlled quantity include motor speed and traction force.

3.1.19
semiconductor converter
electronic power converter with semiconductor valve devices

Note 1 to entry: Similar terms for converters in general or for specific kinds of converters or for converters with other or specific valve devices, for example thyristor converter, transistor inverter.

[SOURCE: IEC 60050-551:1998, 551-12-42, modified – Figure removed]

3.1.20
power conversion equipment
PCE
equipment including the electronic power converter and auxiliaries necessary for operation of the converter itself, or even other parts dedicated to the application, and where these parts cannot be physically separated without preventing the operation of the converter

3.1.21
power conversion system
system consisting of a power conversion equipment and associated components for the application

Note 1 to entry: Examples of associated components include switchgear, reactors or transformers and dedicated filters.

3.2 Arms and connections

3.2.1
valve arm
arm
part of the circuit of an electronic power converter or switch bounded by any two AC or DC terminals and including one or more simultaneously conducting electronic valve devices connected together and other components if any

[SOURCE: IEC 60050-551:1998, 551-15-01]

3.2.2
principal arm
valve arm involved in the major transfer of power from one side of the converter or electronic switch to the other

[SOURCE: IEC 60050-551:1998, 551-15-02, modified – Note removed]

3.2.3
auxiliary arm
valve arm other than a principal arm

Note 1 to entry: Sometimes an auxiliary arm temporarily fulfils more than one of the following functions: by-pass arm, free-wheeling arm, turn-off arm or regenerative arm.

[SOURCE: IEC 60050-551:1998, 551-15-05]

3.2.4
by-pass arm
auxiliary arm providing a conductive path which allows the current to circulate without an interchange of power between source and load

[SOURCE: IEC 60050-551:1998, 551-15-06]

3.2.5
free-wheeling arm
by-pass arm containing only non-controllable valve devices

[SOURCE: IEC 60050-551:1998, 551-15-07]

3.2.6
turn-off arm
auxiliary arm which temporarily takes over the current directly from a conducting valve arm, consisting of one or more latching valve devices which cannot be turned off by a control signal

[SOURCE: IEC 60050-551:1998, 551-15-08]

3.2.7
regenerative arm
valve arm which transfers a part of the power from the load side to the source side

[SOURCE: IEC 60050-551:1998, 551-15-09]

3.2.8
converter connection
electrical arrangement of valve arms and other components essential for the function of the main power circuit of a converter

Note 1 to entry: Common practice also uses the term "topology" of the converter with the same sense.

[SOURCE: IEC 60050-551:1998, 551-15-10, modified – Note to entry added]

3.2.9
basic converter connection
electrical arrangement of principal arms in a converter

[SOURCE: IEC 60050-551:1998, 551-15-11]

3.2.10
single-way connection
<of a converter> converter connection such that the current through each of the phase terminals of the AC circuit is unidirectional

[SOURCE: IEC 60050-551:1998, 551-15-12]

3.2.11
double-way connection
<of a converter> converter connection such that the current through each of the phase terminals of the AC circuit is bidirectional

[SOURCE: IEC 60050-551:1998, 551-15-13]

3.2.12
bridge connection
double-way connection of pairs of arms such that the centre terminals are the phase terminals of the AC circuit, and that the outer terminals of like polarity are connected together and are the DC terminals

[SOURCE: IEC 60050-551:1998, 551-15-14]

3.2.13
uniform connection
connection with either all principal arms controllable or all principal arms non-controllable

[SOURCE: IEC 60050-551:1998, 551-15-15]

3.2.14
non-uniform connection
connection with both controllable and non-controllable principal arms

[SOURCE: IEC 60050-551:1998, 551-15-18]

3.2.15
series connection
connection of two-terminal networks so that they form a single path

[SOURCE: IEC 60050-131:2002, 131-12-75, modified – Notes deleted]

3.2.16
series connection of converters
series connection in which two or more converters are connected in such a way that their voltages add

3.2.17
boost and buck connection
series connection of two or more converter connections the direct voltages of which may be added or subtracted depending on the control of the individual connections

[SOURCE: IEC 60050-551:1998, 551-15-21]

3.3 Controllability of converter arms and quadrants of operation (on DC side)

3.3.1
controllable arm
converter arm including controllable valve device(s)

3.3.2
non-controllable arm
converter arm including only no-controllable valve device(s)

3.3.3
quadrant of operation
<DC side> quadrant of the voltage-current plane defined by the DC voltage polarity and the current direction

3.3.4
one-quadrant converter
AC/DC or DC converter with one possible direction of DC power flow

[SOURCE: IEC 60050-551:1998, 551-12-34, modified – Figure deleted]

3.3.5
two-quadrant converter
AC/DC or DC converter with two possible directions of DC power flow associated with one direction of direct current and two directions of direct voltage or vice versa

[SOURCE: IEC 60050-551:1998, 551-12-35, modified – Figure deleted]

3.3.6
four-quadrant converter
AC/DC or DC converter with two directions of DC power flow, associated with two directions of direct voltage and two directions of direct current

[SOURCE: IEC 60050-551:1998, 551-12-36, modified – Figure deleted]

3.3.7
reversible converter
bi-directional converter
converter in which the direction of the power flow is reversible

Note 1 to entry: The term "bi-directional converter" corresponds to common practice, and provides a better picture of the bi-directional power flow in the converter.

[SOURCE: IEC 60050-551:1998, 551-12-37, modified – Alternative term "bi-directional converter" and note to entry added]

3.3.8
single converter
current stiff reversible AC/DC converter with direct current in one direction

[SOURCE: IEC 60050-551:1998, 551-12-38, modified – Figure deleted]

3.3.9
double converter
current stiff reversible AC/DC converter with direct current in both directions

[SOURCE: IEC 60050-551:1998, 551-12-39]

3.3.10
converter section of a double converter
part of a double converter in which the main direct current when viewed from the DC terminals always flows in the same direction

[SOURCE: IEC 60050-551:1998, 551-12-40]

3.3.11
phase control
process of varying the instant within the cycle at which current conduction in an electronic valve device or valve arm begins

[SOURCE: IEC 60050-551:1998, 551-16-23]

3.3.12
triggering
control action to achieve firing of a latching valve device or an arm consisting of such devices

[SOURCE: IEC 60050-551:1998, 551-16-61]

3.4 Commutation, quenching and commutation circuitry

3.4.1
commutation
<in an electronic power converter> transfer of current from one conducting arm to the next to conduct in sequence, without interruption of the current, both arms conducting simultaneously during a finite time interval

[SOURCE: IEC 60050-551:1998, 551-16-01]

3.4.2
quenching
termination of current flow in an arm without commutation

[SOURCE: IEC 60050-551:1998, 551-16-19]

3.4.3
direct commutation
commutation between two principal arms without transfer through any auxiliary arms

[SOURCE: IEC 60050-551:1998, 551-16-09]

3.4.4
indirect commutation
series of commutations from one principal arm to another or back to the original one by successive commutations via one or more auxiliary arms

[SOURCE: IEC 60050-551:1998, 551-16-10]

3.4.5
external commutation
commutation where the commutating voltage is supplied by a source outside the converter or electronic switch

[SOURCE: IEC 60050-551:1998, 551-16-11]

3.4.6
line commutation
external commutation where the commutating voltage is supplied by the line

[SOURCE: IEC 60050-551:1998, 551-16-12]

3.4.7
load commutation
external commutation where the commutating voltage is taken from a load other than the line

[SOURCE: IEC 60050-551:1998, 551-16-13]

3.4.8
machine commutation
external commutation where the commutating voltage is supplied by a rotating machine

[SOURCE: IEC 60050-551:1998, 551-16-14]

3.4.9
resonant load commutation
method of load commutation in which the commutating voltage is supplied by the load, using its resonant property

3.4.10
self-commutation
commutation where the commutating voltage is supplied by components within the converter or the electronic switch

[SOURCE: IEC 60050-551:1998, 551-16-15]

3.4.11
capacitor commutation
method of self-commutation in which the commutating voltage is supplied by capacitors included in the commutation circuit

[SOURCE: IEC 60050-551:1998, 551-16-17]

3.4.12
inductively coupled capacitor commutation
method of capacitor commutation in which the capacitor circuit is inductively coupled to the commutation circuit

3.4.13
valve device commutation
method of self-commutation in which the commutating voltage is created by turning off the conducting electronic valve device by a control signal

Note 1 to entry: Simultaneously the next electronic valve device to conduct is turned on.

[SOURCE: IEC 60050-551:1998, 551-16-16]

3.4.14
valve device quenching
method of quenching in which the quenching is performed by the electronic valve device itself

[SOURCE: IEC 60050-551:1998, 551-16-20]

3.4.15
external quenching
method of quenching in which the quenching results from causes external to the device

Note 1 to entry: External quenching occurs in line-commutated converters under discontinuous conduction operation.

[SOURCE: IEC 60050-551:1998, 551-16-21, modified – Words "electronic valve device" replaced with "device", and note to entry added]

3.5 Commutation characteristics

3.5.1
commutation circuit
circuit consisting of the commutating arms and the source providing the commutating voltage

[SOURCE: IEC 60050-551:1998, 551-16-03]

3.5.2
commutation voltage
voltage which causes the current to commutate

[SOURCE: IEC 60050-551:1998, 551-16-02]

3.5.3
commutation inductance
resulting inductance in the commutation circuit

Note 1 to entry: For line or machine commutated converters, the commutation reactance is the impedance of the commutation inductance at the fundamental frequency.

[SOURCE: IEC 60050-551:1998, 551-16-07, modified – Note to entry added]

3.5.4
commutation interval
time interval in which commutating arms are carrying principal current simultaneously

[SOURCE: IEC 60050-551:1998, 551-16-04]

3.5.5
angle of overlap
μ
commutation interval expressed in angular measure

[SOURCE: IEC 60050-551:1998, 551-16-05, modified – Symbol μ added]

3.5.6
commutation notch
periodic voltage transient that may appear in the AC side voltage of a line or machine-commutated converter due to the commutation

[SOURCE: IEC 60050-551:1998, 551-16-06]

3.5.7
commutation repetitive transient
voltage oscillation associated with the commutation notch

3.5.8
commutating group
group of principal arms which commutate cyclically among themselves without intermediate commutation of the current to other principal arms

[SOURCE: IEC 60050-551:1998, 551-16-08]

3.5.9
commutation number
q
number of commutations from one principal arm to another during one elementary period in each commutating group

[SOURCE: IEC 60050-551:1998, 551-17-03, modified – Symbol q added]

3.5.10
pulse number
p
number of non-simultaneous symmetrical direct or indirect commutations from one principal arm to another which occur during one elementary period

[SOURCE: IEC 60050-551:1998, 551-17-01, modified – Symbol p added]

3.5.11
trigger delay angle
α
time expressed in angular measure by which the trigger pulse is delayed with respect to the reference instant in the case of phase control

Note 1 to entry: With line, machine or load commutated converters the reference instant is the zero crossing instant of the commutating voltage. With AC controllers it is the zero crossing instant of the supply voltage. For AC controllers with inductive loads, the trigger delay angle is the sum of the phase shift and the current delay angle.

[SOURCE: IEC 60050-551:1998, 551-16-33, modified – Symbol α added]

3.5.12
trigger advance angle
β
time expressed in angular measure by which the trigger pulse is advanced with respect to the reference instant

Note 1 to entry: With line, machine or load commutated converters the reference instant is the zero crossing instant of the commutating voltage.

[SOURCE: IEC 60050-551:1998, 551-16-34, symbol β added]

3.5.13
inherent delay angle
α_p
current delay angle occurring, even without phase control, caused by multiple overlap

Note 1 to entry: Multiple overlap occurs in line commutated converters at high angles of overlap.

[SOURCE: IEC 60050-551:1998, 551-16-35, modified – Symbol α_p added]

3.5.14
extinction angle
γ
time, expressed in angular measure, between the instant when the current of the arm falls to zero and the instant when the arm is required to withstand steeply rising off-state voltage

3.5.15
hold-off interval
interval between the instant when the on-state current of a latching valve device has decreased to zero and the instant when the same valve device is subjected to reapplied off-state voltage

[SOURCE: IEC 60050-551:1998, 551-16-45]

3.6 Rated values

3.6.1
rated value
value of a quantity used for specification purposes, established for a specified set of operating conditions of a component, device, equipment or system

Note 1 to entry: The quantity may describe electrical, thermal, mechanical, or environmental properties.

Note 2 to entry: In the case of semiconductor converters, rated values usually apply to a semicondutor valve device, a valve device assembly or a converter.

Note 3 to entry: The nominal value of a system (for example nominal voltage – IEC 60050-601:1985, 601-01-21) is often equal to the corresponding rated value of the equipment, where both values are within the tolerance band of a quantity.

Note 4 to entry: Unlike many other electrical components, semiconductor devices may be irreparably damaged, even within a very short time of operation, in excess of maximum rated values.

Note 5 to entry: Variations of rated values should be specified. Certain of the values assigned are limiting values. These limiting values may be either maximum or minimum values.

[SOURCE: IEC 60050-151:2001, 151-16-08, modified – Notes to entry added]

3.6.2
rated frequency
f_N
specified frequency on the AC side of a converter

3.6.3
rated voltage on the line side
U_{LN}
specified RMS value of the voltage between conductors on the line side of the converter

Note 1 to entry: If the line side transformer winding is provided with taps, the rated value of the voltage of the line side shall refer to a specified tap, which is the principal tap.

3.6.4
rated voltage on the valve side of the transformer
U_{vN}
RMS value of the no-load voltage between vectorially consecutive commutating phase terminals of the valve windings of a commutating group at rated voltage on the line side of the transformer

Note 1 to entry: If no transformer is provided, within the converter case of a directly connected converter, the rated voltage on the valve side is the rated voltage on the line side of the converter.

3.6.5
rated current on the line side
I_{LN}
maximum RMS value of the current on the line side of the converter under rated conditions

Note 1 to entry: The rated current on the line side takes into account rated load and the most onerous combination of all other conditions within their specified ranges, for example line voltage and frequency deviations.

Note 2 to entry: For polyphase equipment, this value is computed from the rated direct current on the basis of rectangular shaped currents of the converter arms. For single phase equipment, the basis of calculation should be specified.

Note 3 to entry: The rated line current includes currents supplied to the auxiliary circuits of the converter. It also takes into account the effect of DC current ripple and circulating current, if any.

3.6.6
rated current on the valve side
I_{vN}
maximum RMS value of the current on the valve side of the converter under rated conditions

Note 1 to entry: The rated current on the valve side takes into account rated load and the most onerous combination of all other conditions within their specified ranges, for example line voltage and frequency deviations.

Note 2 to entry: For polyphase equipment, this value is computed from the rated direct current on the basis of rectangular shaped currents of the converter arms.

Note 3 to entry: For single phase equipment, the basis of calculation should be specified.

3.6.7
rated apparent power on the line side
S_{LN}
total apparent power, at the line side terminals, at rated frequency, rated voltage on the line side and rated current on the line side

3.6.8
rated direct voltage
U_{dN}
mean value, at rated DC current, specified by the manufacturer, of the direct voltage between the DC terminals of the assembly or equipment

3.6.9
rated direct current
I_{dN}
mean value of the direct current specified by the manufacturer for specified load and service conditions

Note 1 to entry: It may be referred to as the 1,0 p.u. value, to which other values of I_d are compared.

3.6.10
rated continuous direct current
I_{dMN}
mean value of the direct current which an assembly or converter is capable of carrying continuously without damage, for specified service conditions

Note 1 to entry: The rated continuous direct current of an assembly is very often essentially higher than the rated direct current of the corresponding complete equipment. It is a maximum value.

Note 2 to entry: The rated continuous direct current of an assembly may be limited by parts other than the semiconductor.

3.6.11
peak maximum direct current
I_{dSMN}
mean value of the direct current which an assembly or converter is capable of carrying without damage, for a specified short duration, starting from an undefined duration at the rated current and followed by a no-load period of short duration

Note 1 to entry: The value and duration of the peak current (peak maximum direct current I_{dSMN}), as well as the minimum time of no-load before again carrying any current, are associated parts of the definition of the peak maximum direct current.

3.6.12
intermittent peak maximum direct current
I_{dRMN}
mean value of the direct current which an assembly or converter is capable of carrying without damage, for a specified short duration and intermittently, starting from any value of current equal or below the rated current, and back to any value of current equal or below the rated current

Note 1 to entry: The value and duration of the peak current (intermittent peak maximum direct current I_{dRMN}), as well as the minimum time between applications of intermittent peak loads, are associated parts of the definition of the intermittent peak maximum direct current.

3.6.13
rated current for peak load duty
mean value of the direct current which an assembly or converter is capable of carrying for specified duration under specified service conditions, associated with a short-time peak maximum direct current

Note 1 to entry: The characteristics of the associated maximum direct current I_{dSMN} are parts of the definition of the short-time duty. For details, see 6.4.3.2.

3.6.14
rated current for continuous duty with superimposed peak loads
mean value of the direct current which an assembly or converter is capable of carrying for unlimited duration under specified service conditions and with intermittently applied intermittent peak maximum direct current of specified magnitudes and durations

Note 1 to entry: The characteristics of the associated intermittent peak maximum direct current I_{dRMN} are parts of the definition of the rated current for continuous duty with superimposed peak loads.

3.6.15
rated current for repetitive load duty
rated direct current of the assembly or converter, specified as the RMS value of the load current evaluated over the period of the load duty cycle

Note 1 to entry: The duty class should be specified as a sequence of current values together with their durations. "repetitive load duty" is also known as "periodic duty". See 6.4.3.2 c).

3.6.16
rated DC power
product of the rated direct voltage and the rated direct current

Note 1 to entry: The measured DC power may differ from the rated DC power as defined because of voltage and current ripple.

3.7 Specific voltages, currents and factors

3.7.1
ideal no-load direct voltage
U_{di}
theoretical no-load direct voltage of an AC/DC converter assuming no reduction by phase control, no threshold voltages of electronic valve devices, and no voltage rise at small loads

[SOURCE: IEC 60050-551:1998, 551-17-15, modified – Symbol U_{di} added]

3.7.2
controlled ideal no-load direct voltage
$U_{di\alpha}$
theoretical no-load direct voltage of an AC/DC converter corresponding to a specified trigger delay angle assuming no threshold voltages of electronic valve devices and no voltage rise at small loads

[SOURCE: IEC 60050-551:1998, 551-17-16, modified – Symbol $U_{di\alpha}$ added]

3.7.3
conventional no-load direct voltage
U_{d0}
mean value of the direct voltage which would be obtained by extrapolating the direct voltage/current characteristic from the region of continuous flow of direct current to zero current at zero trigger delay angle, i.e. without phase control

Note 1 to entry: U_{di} is equal to the sum of U_{d0} and the no-load voltage drop in the assembly.

[SOURCE: IEC 60050-551:1998, 551-17-17, modified – Symbol U_{d0} and note to entry added]

3.7.4
controlled conventional no-load direct voltage
$U_{d0\alpha}$
mean value of the direct voltage corresponding to a specified trigger delay angle which would be obtained by extrapolating the direct voltage/current characteristic from the region of continuous flow of direct current to zero current

Note 1 to entry: $U_{di\alpha}$ is equal to the sum of $U_{d0\alpha}$ and the no-load voltage drop in the assembly.

[SOURCE: IEC 60050-551:1998, 551-17-18, modified – Symbol $U_{d0\alpha}$ and note to entry added.]

3.7.5
real no-load direct voltage
U_{d00}
actual mean direct voltage at zero direct current

[SOURCE: IEC 60050-551:1998, 551-17-19, modified – Symbol U_{d00} added]

3.7.6
direct voltage regulation
difference between the conventional no-load direct voltage and the direct voltage at load at the same trigger delay angle excluding the correcting effect of stabilizing means if any

Note 1 to entry: If voltage stabilizing means are used, refer also to 3.7.9.

Note 2 to entry: The nature of the DC circuit (for example capacitors, back e.m.f. load) may affect the voltage change significantly. Where this is the case, special consideration may be required.

[SOURCE: IEC 60050-551:1998, 551-17-21, modified – Notes to entry added]

3.7.7
inherent direct voltage regulation
direct voltage regulation excluding the effect of the AC system impedance

[SOURCE: IEC 60050-551:1998, 551-17-22]

3.7.8
total direct voltage regulation
direct voltage regulation including the effect of the AC system impedance

[SOURCE: IEC 60050-551:1998, 551-17-23]

3.7.9
output voltage tolerance band
specified range of steady-state values of a stabilized output voltage around its nominal or preset value

3.7.10
transition current
mean direct current of a converter connection when the direct current(s) of the commutating group(s) become(s) intermittent when decreasing the current

[SOURCE: IEC 60050-551:1998, 551-17-20 modified – “commutation” replaced with “commutating”]

3.7.11
conversion factor
ratio of the fundamental output power or DC output power to the fundamental input power or DC input power

Note 1 to entry: The fundamental power (IEC 60050-551:1998, 551-17-08) is the active power determined by the fundamental components of voltage and current.

Note 2 to entry: For the purposes of this definition, the DC power is the product of the mean value of the voltage and mean value of the current.

[SOURCE: IEC 60050-551:1998, 551-17-10, modified – Notes to entry added]

3.7.12
power efficiency
ratio of the output power to the input power of the converter

Note 1 to entry: In the conversion factor, the power contained in the AC components of the current and voltage on the DC side is not taken into account. In the power efficiency, the power contained in these AC components of the current and voltage on the DC side is included in the DC power. Therefore, for AC to DC conversion, the conversion factor has a lower value. For a single phase, two-pulse (full wave) converter with resistive load, the theoretical maximum conversion factor is 0,81 p.u., while the maximum power efficiency is 1,0 p.u.

Note 2 to entry: The conversion factor may be correctly obtained only by measurement of the fundamental component of power on the AC side and zero-frequency components of voltage and current on the DC side. The power efficiency may be correctly obtained either by measurement of root-mean-square values of AC power and DC power or by calculation or measurement of internal losses.

Note 3 to entry: The active power (mean value of the power) on the AC side, and the mean value of the power on the DC side are to be considered.

3.7.13
power factor
λ
ratio of the absolute value of the active power P to the apparent power S, under periodic conditions

$$\lambda = \frac{|P|}{S}$$

Note 1 to entry: Under sinusoidal conditions, the power factor is the absolute value of the active factor.

[SOURCE: IEC 60050-131:2002, 131-11-46, modified – Symbol λ added]

3.7.14
power factor of the fundamental wave
displacement factor
$\cos\varphi_1$
under periodic conditions, ratio of the active power of the fundamental components P_1 to the apparent power of the fundamental components S_1

$$\cos\varphi_1 = \frac{P_1}{S_1}$$

Note 1 to entry: For definition on the displacement angle, see IEC 60050-131:2002, 131-11-48.

3.7.15
deformation factor
ν
ratio of the total power factor λ to the displacement factor $\cos\varphi_1$

$$\nu = \frac{\lambda}{\cos\varphi_1}$$

Note 1 to entry: Under sinusoidal voltage condition, the deformation factor is equal to the fundamental factor. See 3.10.14, Note 2 to entry.

3.8 Cooling

3.8.1
cooling medium
liquid (for example water) or gas (for example air) which removes the heat from the equipment

3.8.2
heat transfer agent
liquid (for example water) or gas (for example air) within the equipment to transfer the heat from its source to a heat exchanger from where the heat is removed by the cooling medium

3.8.3
direct cooling
method of cooling by which the cooling medium is in direct contact with the parts of the equipment to be cooled, i.e. no heat transfer agent is used

3.8.4
indirect cooling
method of cooling in which a heat transfer agent is used to transfer heat from the part to be cooled to the cooling medium

3.8.5
natural cooling
convection
method of circulating the cooling fluid (cooling medium or heat transfer agent) which uses the change of volumetric mass (density) with temperature

3.8.6
forced cooling
method of circulating the cooling medium or heat transfer agent by means of blower(s), fan(s) or pump(s)

3.8.7
mixed cooling
method of circulating the cooling medium or heat transfer agent, which uses, alternatively, natural and forced circulation

Note 1 to entry: Mixed circulation may be used for light load/overload periods or in the case of an emergency.

3.8.8
equilibrium temperature
steady-state temperature reached by a component of a converter under specified conditions of load and cooling

Note 1 to entry: The steady-state temperatures are in general different for different components. The times necessary to establish steady-state are also different and proportional to the thermal time constants.

3.8.9
ambient air temperature
temperature of the air surrounding the power conversion equipment, measured at half the distance from any neighbouring equipment, but not more than 300 mm distance from the enclosure, at middle height of the equipment, protected from direct heat radiation from the equipment

3.8.10
cooling medium temperature for air and gas cooling
average temperature measured outside the equipment at points 50 mm from the inlet to the equipment

Note 1 to entry: For the evaluation of the fraction of heat which is radiated, the ambient temperature is that defined under 3.8.9.

3.8.11
cooling medium temperature for liquid cooling
temperature measured in the liquid pipe 100 mm upstream from the liquid inlet

3.8.12
temperature of heat transfer agent
heat transfer agent temperature measured at a point to be specified by the supplier

3.9 Service conditions tolerances and electromagnetic compatibility

3.9.1
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 60050-161:2018, 161-01-07]

3.9.2
electromagnetic emission
emission
phenomenon by which electromagnetic energy emanates from a source

[SOURCE: IEC 60050-161:2019, 161-01-08, modified – An alternative term “emission” added]

3.9.3
emission level
<converter> level of a given electromagnetic disturbance emitted from a converter operated within specified conditions and measured in a specified way

[SOURCE: IEC 60050-161:1990, 161-03-11, modified – Domain "disturbing source" replaced with "converter", and words "particular device, equipement or system" replaced with "converter, operated within specified conditions and measured in a specified way"]

3.9.4
electromagnetic disturbance
electromagnetic phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter

[SOURCE: IEC 60050-161:2018, 161-01-05, modified – Notes to entry deleted]

3.9.5
electromagnetic disturbance level
level of an electromagnetic disturbance existing at a given location, which results from all contributing disturbance sources

[SOURCE: IEC 60050-161:1990, 161-03-29]

3.9.6
reference level of generated disturbance of a converter
assumed level of disturbance produced by a converter, when the actual operating conditions are not known and rated operating conditions are used to calculate or measure the disturbance level

Note 1 to entry: The level of disturbance generally depends on the supply source impedance, which may not be considered as a characteristic quantity of the converter.

3.9.7
immunity to a disturbance
ability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance

[SOURCE: IEC 60050-161:1990, 161-01-20]

3.9.8
immunity level of a converter
specified value of an electromagnetic disturbance level below which a converter is designed to meet the required performances or continue operation or avoid damage

Note 1 to entry: This definition is specific to the converter. For general concept of immunity level, it is found in IEC 60050-161:1990, 161-03-14.

3.9.9
relative short-circuit power
R_{SC}
ratio of the short-circuit power of the source to the rated apparent power on the line side of the converters

Note 1 to entry: R_{SC} refers to a given point of the network, for specified operating conditions and specified network configuration.

Note 2 to entry: Within the IEC 61000-3 series, the short-circuit ratio is defined with the short-circuit power of the source at the PCC, instead of short-circuit power of the source at the IPC of use of the converter. The risk of confusion is clarified in Clause B.2.

3.10 Harmonic distortion

NOTE Equations in the harmonic definitions below use the symbol Q to represent a quantity. When these equations are used in dedicated applications, Q is replaced by the actual symbol for the quantity, for example U for voltage, I for current. In the other parts of this document, Q is the symbol used for reactive power (see Table 2). Explanations supporting these definitions are given in Annex A.

3.10.1
point of common coupling
PCC
point on a public power 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]

3.10.2
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]

3.10.3
fundamental frequency
frequency of the fundamental component

[SOURCE: IEC 60050-551:2001, 551-20-03]

3.10.4
fundamental component
fundamental
<of a Fourier series> sinusoidal component of the Fourier series of a periodic quantity having the frequency of the quantity itself

Note 1 to entry: For practical analysis, an approximation of the periodicity may be necessary.

[SOURCE: IEC 60050-551:2001, 551-20-01]

3.10.5
reference fundamental component
sinusoidal component of the Fourier series of a periodic quantity having the frequency to which all other components are referred and which is not the fundamental component

Note 1 to entry: If it is clearly stated in a context that the reference fundamental component is used, the word "reference" may be omitted, but this document does not recommend this practice.

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

Note 3 to entry: In power electronics, often the component having the frequency of the AC supply system or of the converter output quantities is chosen as reference fundamental component.

[SOURCE: IEC 60050-551:2001, 551-20-02]

3.10.6
reference fundamental frequency
frequency of the reference fundamental component

Note 1 to entry: If it is clearly stated in a context that the reference fundamental component is used, the word "reference" may be omitted, but this document does not recommend this practice.

[SOURCE: IEC 60050-551:2001, 551-20-04]

3.10.7
harmonic frequency
frequency which is an integer multiple greater than one of the fundamental frequency or of the reference fundamental frequency

Note 1 to entry: The ratio of the harmonic frequency to the fundamental frequency, or to the reference fundamental frequency, is named "harmonic order" (recommended notation: h).

[SOURCE: IEC 60050-551:2001, 551-20-05, modified – Note to entry added]

3.10.8
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: For practical analysis, an approximation of the periodicity may be necessary.

Note 3 to entry: The value is normally expressed as an RMS value.

[SOURCE: IEC 60050-551:2001, 551-20-07, modified – Notes 1 and 3 to entry added]

3.10.9
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 reference fundamental frequency, this ratio is not an integer (recommended notation: m).

Note 2 to entry: In the case where $m < 1$, the term "sub-harmonic frequency" may also be used (see IEC 60050-551:2001, 551-20-10).

[SOURCE: IEC 60050-551:2001, 551-20-06, modified – Notes to entry added]

3.10.10
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 practical analysis, an approximation of the periodicity may be necessary.

Note 3 to entry: The value is normally expressed as an RMS value.

Note 4 to entry: 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 the 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 – Notes 1, 3 and 4 to entry added]

3.10.11
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 distortion content is

$$Q_{\mathrm{HC}} = \sqrt{\sum_{h=2}^{h=H} {Q_h}^2}$$

where

Q represents either current or voltage;

h is the harmonic order;

H is 50 for the purpose of this document. It has been 40 for a long time in standards related to power electronics, and should be moved to 50 in line with IEC 61000-2-2 and IEC 61000-2-4.

[SOURCE: IEC 60050-551:2001, 551-20-12, modified – Note 4 to entry added]

3.10.12
total harmonic ratio
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

$$D_{\mathrm{H}} = \sqrt{\sum_{h=2}^{h=H} \left(\frac{Q_h}{Q_1}\right)^2} = \frac{Q_{\mathrm{HC}}}{Q_1}$$

where

Q, h, and H are the same as listed in 3.10.11;

Q_1 is the RMS value of the fundamental component.

Note 1 to entry: The harmonic 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.

Note 2 to entry: The total harmonic ratio may be restricted to a certain harmonic order (recommended notation: H), 50 for the purpose of this document.

[SOURCE: IEC 60050-551:2001, 551-20-13, modified – Recommended notation and value added in Note 2 to entry]

3.10.13
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 (symbol Q) is a periodic quantity with zero DC component.

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

$$D_{\mathrm{C}} = \sqrt{Q^2 - Q_1^2}$$

where Q_1 is noted in 3.10.12.

[SOURCE: IEC 60050-551:2001, 551-20-11, modified – Symbol added in Note 4 to entry. Note 5 to entry added]

3.10.14
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

$$D_{\mathrm{R}} = \frac{D_{\mathrm{C}}}{Q_1} = \frac{\sqrt{Q^2 - Q_1^2}}{Q_1}$$

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.

[SOURCE: IEC 60050-551:2001, 551-20-14, modified – Abbreviated term "TDR" and formula in Note 1 to entry added. Note 2 to entry deleted]

3.10.15
total distortion factor
TDF
ratio of the RMS value of the total distortion content to the RMS value of an alternating quantity

$$D_{\mathrm{F}} = \frac{D_{\mathrm{C}}}{Q} = \frac{\sqrt{Q^2 - Q_1^2}}{Q}$$

Note 1 to entry: 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 given.

Note 2 to entry: The ratio between TDF and TDR equals the ratio between the RMS value of the fundamental component and the total RMS value. It is the fundamental factor (IEC 60050-161:1990, 161-02-22):

$$f_{\mathrm{F}} = \frac{D_{\mathrm{F}}}{D_{\mathrm{R}}} = \frac{Q_1}{\mathrm{Q}} \leq 1$$

[SOURCE: IEC 60050-551:2001, 551-20-16, modified – Abbreviated term "TDF", formula in Note 1 to entry, and Note 2 to entry added]

3.10.16
individual harmonic ratio
IHR
ratio of any harmonic component to the fundamental

Note 1 to entry: In IEC 60050-161:1990, 161-02-20, the individual harmonic ratio is named "n^{th} harmonic ratio". IHR has been chosen for consistency with 3.10.11, and the order index has been chosen as "h" instead of "n", which is frequently used elsewhere, for example for the natural integer list.

Note 2 to entry: The value of the individual harmonic ratio is $Q_{\mathrm{IHR}} = \dfrac{Q_h}{Q_1}$.

3.10.17
partial weighted harmonic ratio
PWHR
ratio of the RMS value of a selected group of higher order harmonics, weighted with the harmonic order h, to the RMS value of the fundamental

$$Q_{\mathrm{PWHR}} = \sqrt{\sum_{h=14}^{h=40} h \times \left(\frac{Q_h}{Q_1}\right)^2}$$

Note 1 to entry: The partial weighted harmonic ratio is employed in order to ensure that the effects of the higher order harmonic currents on the results are reduced sufficiently and individual limits need not be specified.

Note 2 to entry: The similar concept for the harmonic current is shown in IEC 61000-3-12:2011, 3.2.

3.11 Definitions related to insulation co-ordination

3.11.1
electrical circuit
circuit
<equipment> current paths of components or assemblies, conductors or terminals connected to each other by electrically conductive connections and insulated from the remaining part of the equipment

Note 1 to entry: If parts of the same equipment are conductively connected only via a protective equipotential bonding system, then they are regarded as separate circuits.

3.11.2
part of a circuit
section of a circuit having its own rated insulation voltage

3.11.3
equipotentiality
state when conductive parts are at a substantially equal electric potential

[SOURCE: IEC 60050-195:2021, 195-01-09]

3.11.4
equipotential bonding
provision of electric connections between conductive parts, intended to achieve equipotentiality

[SOURCE: IEC 60050-195:2021, 195-01-10, modified – Definition reformulated]

3.11.5
equipotential bonding system
EBS
interconnection of conductive parts providing equipotential bonding between those parts

[SOURCE: IEC 60050-195:2021, 195-02-22]

3.11.6
protective equipotential bonding system
PEBS
equipotential bonding system providing protective equipotential bonding

[SOURCE: IEC 60050-195:2021,195-02-23]

3.11.7
working voltage
voltage, at rated supply conditions (without tolerances) and worst case operating conditions, which occurs by design in a circuit or across insulation

Note 1 to entry: The working voltage can be DC or AC. Both the RMS and recurring peak values are used.

3.11.8
decisive voltage class
calculated voltage range used to determine the classification of protective measures against electric shock

3.11.9
rated insulation voltage
RMS voltage value assigned by the manufacturer to the equipment or to a part of it, characterizing the specified (long-term) withstand capability of its insulation

Note 1 to entry: The rated insulation voltage is higher than or equal to the rated voltage of the equipment, or to the rated voltage of the concerned part of the equipment, which is primarily related to functional performance.

Note 2 to entry: The rated insulation voltage refers to the insulation between electric circuits, between live parts and exposed conductive parts and within an electric circuit.

Note 3 to entry: For clearances and solid insulation, the peak value of the voltage occurring across the insulation or clearance is the determining value for the rated insulation voltage. For creepage distances, the RMS value is the determining value.

Note 4 to entry: The rated insulation voltage depends either on the result of the insulation co-ordination investigation for high voltage systems, or on the expectable temporary over-voltage, the over-voltage category, and the RMS value of the working voltage, whichever is the higher.

[SOURCE: IEC 60664-1:2020, 3.1.18, modified – Symbol U_i deleted. Words "value of the RMS withstand voltage" replaced with "RMS voltage value". Note 1 to entry clarified, and Notes 2 to 4 to entry added]

3.11.10
rated impulse voltage
amplitude of the impulse used as reference for the definition and the tests of insulation characteristics of a circuit

Note 1 to entry: The rated impulse voltage depends either on the result of the insulation coordination investigation for high voltage systems, or on the expectable impulse voltages from any origin related to the over-voltage category and on the peak value of the working voltage, whichever is the higher.

3.11.11
over-voltage category
concept used to classify equipment directly energized from the mains supply network

Note 1 to entry: IEC 60664-1 considers four categories of equipment:

category I: connected to a distribution circuit protected against a defined level of transient over-voltages;

category II: not permanently connected within the installation (any IPC);

category III: permanently connected within the installation (any IPC);

category IV: permanently connected at the origin of the installation (nearest to the PCC).

3.11.12
basic insulation
insulation applied to hazardous live parts to provide basic protection against electric shock

[SOURCE: IEC 60050-826:2004, 826-12-14, modified – The definition has been reformulated]

3.11.13
supplementary insulation
independent insulation applied in addition to basic insulation for fault protection

Note 1 to entry: Basic insulation and supplementary insulation are separate, each designed for basic protection against electric shock.

[SOURCE: IEC 60664-1: 2020, 3.1.31, modified – The note to entry has been added]

3.11.14
double insulation
insulation comprising both basic insulation and supplementary insulation

[SOURCE: IEC 60050-195:2021, 195-06-08]

3.11.15
reinforced insulation
single insulation of hazardous live parts which provides a degree of protection against electric shock equivalent to double insulation

Note 1 to entry: Reinforced insulation may comprise several layers which cannot be tested separately as basic insulation or supplementary insulation.

[SOURCE: IEC 60664-1:2020, 3.1.33]

3.11.16
protective separation
separation between circuits by means of basic and supplementary protection (basic insulation plus supplementary insulation or protective screening) or by an equivalent protective provision (for example reinforced insulation)

3.11.17
electrically protective screening
protective screening
separation of electric circuits and/or conductors from hazardous live parts by an electrically protective screen connected to the protective equipotential bonding system and intended to provide protection against electric shock

[SOURCE: IEC 60050-195:2021, 195-06-18, modified – The word "electrically" has been added to "protective screening", and the term "protective shielding" has been deleted]

3.11.18
extra low voltage circuit
ELV circuit
circuit the voltage of which does not exceed 50 V AC and 120 V DC or the value specified in the relevant product standard

Note 1 to entry: In this document, the volage range is defined as above for the voltage tests in 7.2.2.2. For general concept of extra-low volage, it is found in IEC 60050-195:2021, 195-05-24.

3.11.19
protective extra low voltage circuit
PELV circuit
electrical circuit with the following characteristics:

– the voltage does not exceed ELV;
– there is a protective separation from circuits other than PELV or SELV;
– there are provisions for earthing the PELV circuit, or its accessible conductive parts, or both

Note 1 to entry: In this document, the PELV circuit is defined as above for the voltage tests in 7.2.2.2. For general concept of PELV system, it is found in IEC 60050-195:2021, 195-06-29.

3.11.20
safety extra low voltage circuit
SELV circuit
electrical circuit with the following characteristics:

– the voltage does not exceed ELV;
– there is a protective separation from circuits other than SELV or PELV;
– there are no provisions for earthing the SELV circuit, or its accessible conductive parts;
– there is a basic insulation of the SELV circuit from earth and from PELV circuits

Note 1 to entry: In this document, the SELV circuit is defined as above for the voltage tests in 7.2.2. For general concept of SELV system, it is found in IEC 60050-195:2021, 195-06-28.

3.12 Principal letter symbols and subscripts

The principal letter symbols and subscripts are given in Table 1 and Table 2.

Table 1 – List of major subscripts

Subscript	Signification
0 (zero)	At no load
C	Commutating
D	Direct current or voltage
F	Dependent of frequency
H	Pertaining to harmonic component of order h
I	Ideal
L	Referring to line or source
M	Maximum
M	Pertaining to interharmonic component of order m
Min	Minimum
N	Rated value or at rated load
P	Inherent
R	Repetitive (over-voltage or peak current)
R	Resistive
S	Non-repetitive (over-voltage or peak current)
SC	Short-circuit
V	Valve side
X	Inductive
α	Controlled value (by delay angle)

Table 2 – Symbols

Symbol	Quantity	Reference to Clause 3 Terms and definitions
d_{xtN}	inductive direct voltage regulation due to converter transformer referred to U_{di}	-
e_{xN}	Inductive component of the relative short-circuit voltage of the converter transformer corresponding to I_{LN}	-
f_{N}	Rated frequency	3.6.2
g	Number of sets of commutating groups between which I_{dN} is divided	3.6.8
h	Order of harmonic	3.10.6
I_{d}	Direct current (any defined value)	-
I_{dN}	Rated direct current	3.6.9
I_{dMN}	Rated continuous direct current (maximum value)	3.6.10
I_{dRMN}	Intermittent peak maximum direct current	3.6.12
I_{dSMN}	Peak maximum direct current	3.6.11
I_{L}	RMS current on line side (of converter or transformer if included)	-
I_{LN}	Rated value of I_{L}	3.6.5
I_{1LN}	RMS value of the fundamental component of I_{LN}	-
I_{hLN}	RMS value of harmonic order h of I_{LN}	-
I_{vN}	Rated value of current on valve side of transformer	3.6.6
p	Pulse number	3.5.10

Symbol	Quantity	Reference to Clause 3 Terms and definitions
P	Active power	-
P_{LN}	Active power on line side at rated load	-
q	Commutation number	3.5.9
Q_{1LN}	Reactive power on line side at rated load	-
R_{SC}	Relative short-circuit power	3.9.9
s	Number of series connected commutating groups	-
S_{com}	Short-circuit power calculated at the AC terminals of the commutating arms	-
S_{SC}	Short-circuit power of the supply source	-
S_{Cmin}	Minimum short-circuit power of the supply source	-
S_{LN}	Rated apparent power on the line side	3.6.7
S_{1LN}	Value of S_{LN} based on I_{1LN}	-
S_{tN}	Transformer rated apparent power	-
U_{d}	Direct voltage (any defined value)	-
U_{d0}	Conventional no load direct voltage	3.7.3
$U_{d0\alpha}$	Value of U_{d0} with trigger delay angle α	3.7.4
U_{d00}	Real no-load direct voltage	3.7.5
U_{di}	Ideal no-load direct voltage	3.7.1
$U_{di\alpha}$	Controlled ideal no-load direct voltage	3.7.2
U_{dN}	Rated direct voltage	3.6.8
U_{dxN}	Total inductive direct voltage regulation at rated direct current	-
U_{hL}	RMS value of harmonic order h of U_{L}	-
U_{iM}	Ideal crest no-load voltage, appearing between the end terminals of an arm neglecting internal and external voltage surge and voltage drops in valves, at no load. The ratio remains the same at light load current close to the transition current.	-
U_{L}	Line-to-line voltage on line side of converter or transformer, if any	-
U_{LN}	Rated value of U_{L}	3.6.3
U_{LRM}	Maximum instantaneous value of U_{L} including repetitive over-voltage but excluding non-repetitive over-voltages	-
U_{LSM}	Maximum instantaneous value of U_{L} including non-repetitive over-voltages	-
U_{LWM}	Maximum instantaneous value of U_{L} excluding transient over-voltages	-
U_{M}	Maximum of the sinusoidal waveform of the voltage (see 7.2.3.1)	-
U_{v0}	No-load line-to-line voltage on the line side of the converter or on the valve side of the transformer, if any	-
U_{vN}	Rated voltage on the valve side of the transformer	3.6.4
Xt_{N}	Inductive voltage drop of the transformer in per unit	-
α	Trigger delay angle	3.5.11
α_{p}	Inherent delay angle	3.5.13
β	Trigger advance angle	3.5.12
γ	Extinction angle	3.5.14

Symbol	Quantity	Reference to Clause 3 Terms and definitions
δ	Number of commutating groups commutating simultaneously per primary	-
λ	Power factor	3.7.13
μ	Angle of overlap (commutation angle)	3.5.5
ν	Deformation factor	3.7.15
φ_1	Displacement angle of the fundamental component of I_L	3.7.14

4 Operation of semiconductor power equipment and valve devices

4.1 Classification

4.1.1 Semiconductor converter

Semiconductor converters are classified as below.

a) Type of conversion and switching
   1) AC to DC conversion (rectifier, identified as (power) rectification in IEC 60050-551:1998, 551-11-06);
   2) DC to AC conversion (inverter, identified as (power) inversion in IEC 60050-551:1998, 551-11-07);
   3) DC to DC conversion (direct or indirect DC converter, identified as DC (power) conversion in IEC 60050-551:1998, 551-11-09);
   4) AC to AC conversion (direct or indirect AC converter, identified as AC (power) conversion in IEC 60050-551:1998, 551-11-08);
   5) switching (periodic or non-periodic).

   NOTE 1 Other similar terms are used, e.g. "DC/DC conversion" for DC conversion or "AC/AC converter" for AC converter.

b) Purpose of conversion

   In a power system, the converter changes or controls one or more characteristics such as the following:
   1) frequency (including zero frequency);
   2) voltage level or current level;
   3) number of phases, phase angle;
   4) flow of active power;
   5) flow of reactive power, waveform;
   6) quality of load power.

c) Type of valve turn-off

   A semiconductor valve device can be turned off either by commutation, implying that the current of the arm is transferred to another arm, or by quenching, if the current of the arm falls to zero before another arm is turned on. See Figure 1.

   NOTE 2 Both types of turn-off can occur in normal operation of converters depending on the load. The classification is based on normal operation, full load current.

   NOTE 3 The types of turn-off can be characterized by the source of the turn-off voltage:

   a) external commutation (or quenching):
      – line commutation (or quenching);
      – load commutation (or quenching);

b) self commutation (or quenching, see also 4.1.2, Note 2):
   – valve device commutation (or quenching);
   – capacitor commutation (or quenching).

d) Type of DC system

   Converters connected to at least one DC system can usually be wholly or partly classified as current source (current stiff converter) or voltage source (voltage stiff converter) depending on whether the current or the voltage on the DC side is smoothed. The predominant internal impedance of a current stiff converter is high, while the predominant internal impedance of a voltage stiff converter is low. A thyristor converter is generally a current stiff converter.

   For a converter connecting an AC system to a DC system, rectification implies a power flow from the AC to the DC side and inversion a power flow in the opposite direction.

   For each mode of operation, in a current source system, the current is unidirectional, but the voltage polarity depends on the direction of the power flow. In a voltage source system, the converse applies.

4.1.2 Semiconductor valve devices

Valve devices used in the power circuits of semiconductor converters are divided into the following categories:

a) non-controllable valve device with a conductive forward and a blocking reverse characteristic (rectifier diode);
b) valve device with a controllable forward switch-on (thyristor). Common name of this type of valve device is "on-switched valve device";
c) valve device with a controllable forward switch-on and forward switch-off (turn-off thyristor (GTO), integrated gate-commutated thyristors (IGCT), power transistor, insulated gate bipolar transistor (IGBT)). Common name of this type of valve device is "switched valve device";
d) valve device which is controllable in both directions (for example triac).

NOTE 1 A valve device is controllable if it can be switched from the blocking to the conducting state by means of a control signal.

NOTE 2 Power transistors and turn-off thyristors can be turned off by a signal applied to or taken off the gate. Thyristors and triacs do not have this property and have to be turned off by main circuit voltages and currents.

NOTE 3 Depending on the type of semiconductor valve devices, they can have a conductive or a blocking reverse characteristic. Some of them can have an "only few volts" blocking reverse characteristic.

4.2 Basic operation of semiconductor converters

4.2.1 Commutation

Power electronic converters are semiconductor converters which, by means of the commutation or the quenching of the semiconductor valve devices, convert amplitude and/or frequency of the voltage or of the current from one side to the other side of the converter. The commutation or quenching is the basis of the function and the operation of a semiconductor converter. The general performance is moreover defined by the converter connections of the semiconductor valve devices (circuit topology) and their control.

The different types of commutations are defined in 3.4 and the characteristics of commutation in 3.5. The definition differentiates between commutation which is a transfer of current from an arm to another, and quenching which is the termination of the current within an arm.

Figure 1 gives an overview of the different types of commutations.

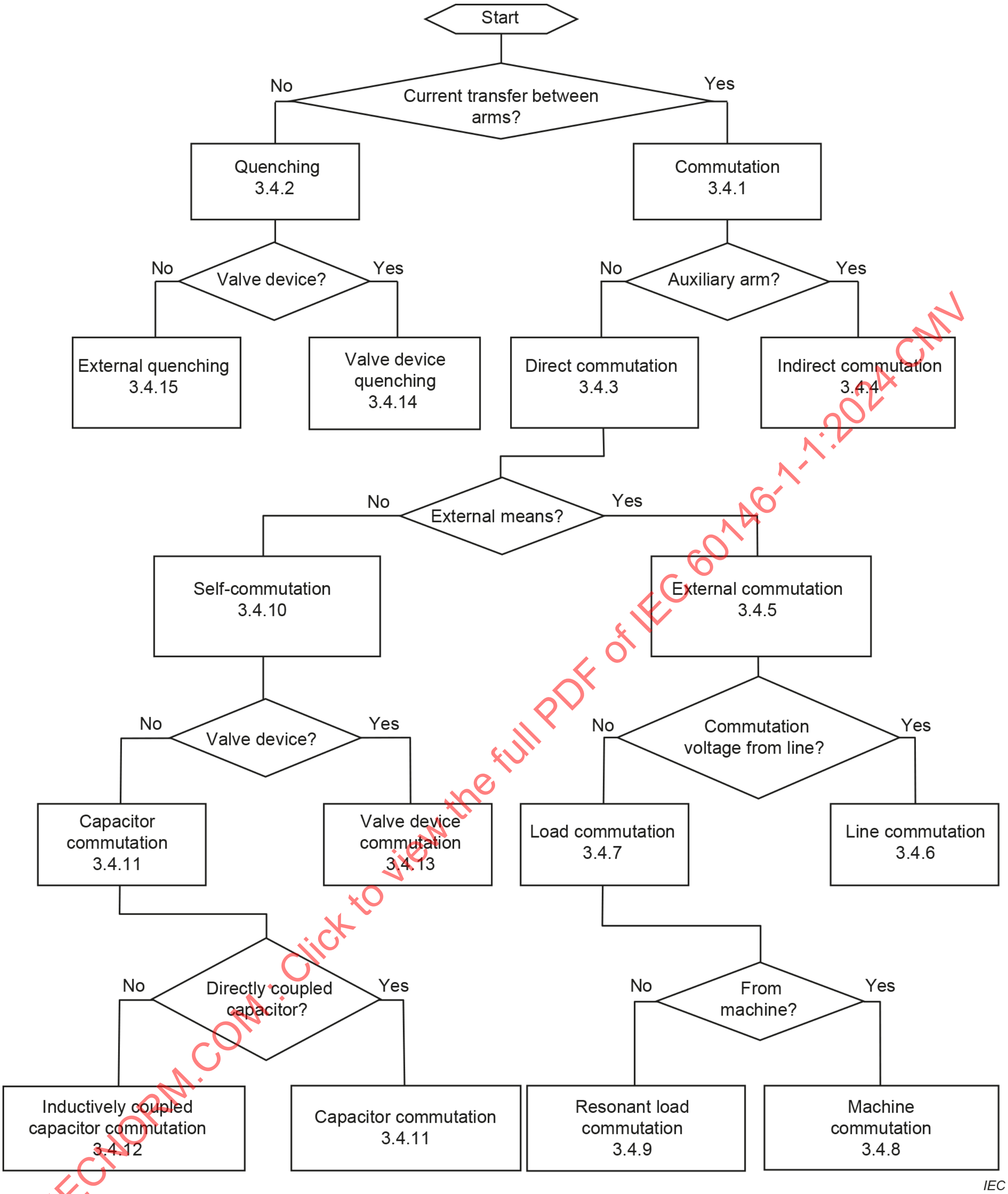


Figure 1 – Types of commutation

The commutation is characterized by the waveforms of voltage and current and by angles (see 3.5.5, 3.5.11, 3.5.12, 3.5.14). Figure 2 illustrates these angles with a simple case of commutating voltages from line. The top trace shows the rectified voltage and the bottom trace shows an anode to cathode voltage. Figure 2 a) and Figure 2 b) are examples for p = 3 and p = 6, respectively.

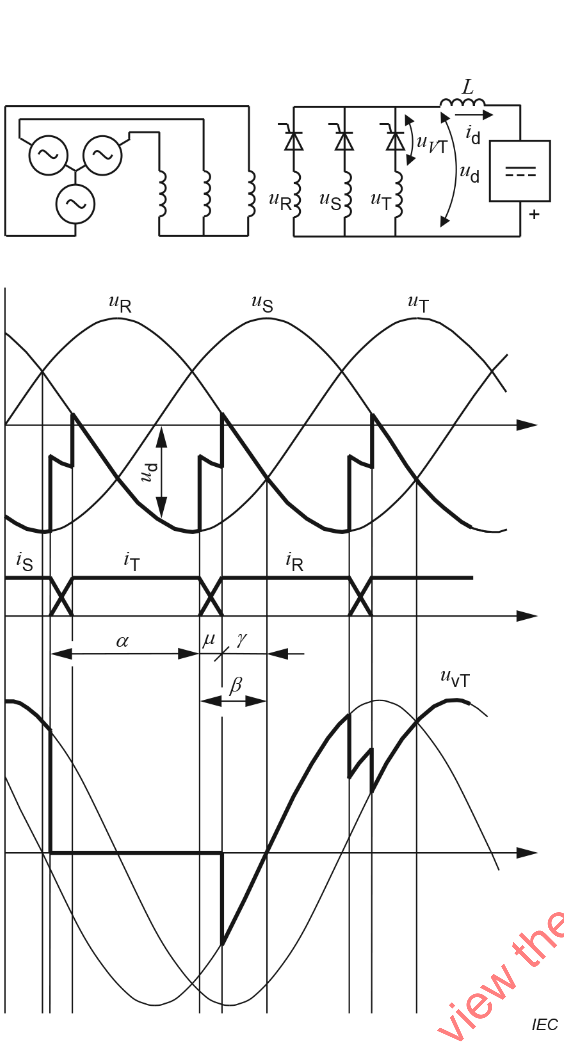


Figure 2 a) – Three phase star connection converter

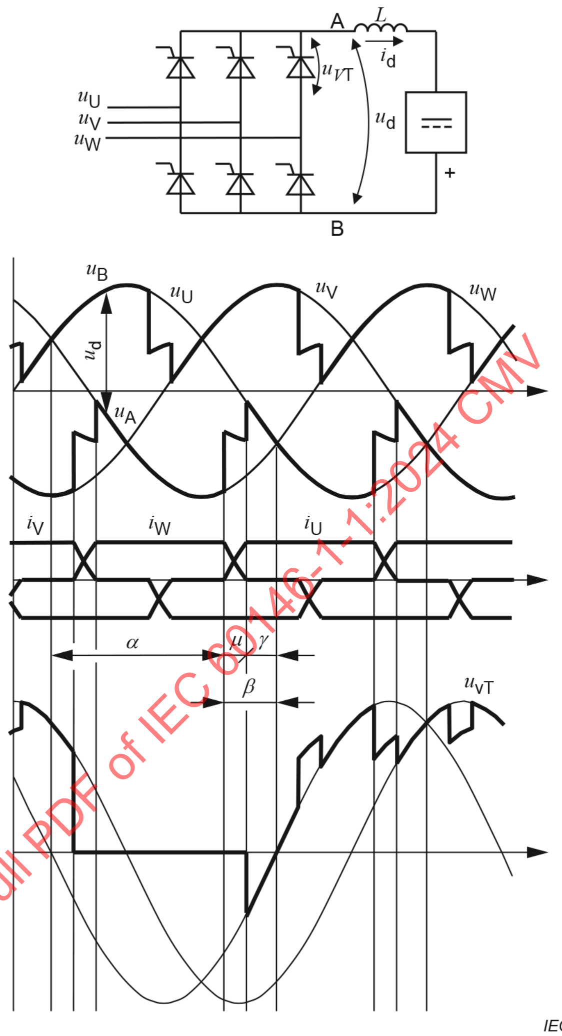


Figure 2 b) – Three phase bridge converter

Figure 2 – Illustration of angles

4.2.2 Basic calculation factors for line commutated converters

4.2.2.1 Voltage

The ideal no-load direct voltage U_{di} is obtained from the voltage between two commutating phases U_{v0} and the pulse number p by Formula (1):

$$U_{di} = U_{v0} \times \sqrt{2} \times \frac{p}{\pi} \times \sin\frac{\pi}{p} \qquad (1)$$

The controlled ideal no-load direct voltage $U_{di\alpha}$ is calculated for different cases, first for uniform connections (see 3.2.13, example with thyristors), and for non-uniform connections (see 3.2.14, example half with thyristors and half with diodes).

a) Uniform connection (fully controllable)

1) If the direct current is continuous over the entire control range:

$$U_{di\alpha} = U_{di} \times \cos \alpha \tag{2}$$

2) If the converter load is purely resistive

For $0 \leq \alpha \leq \frac{\pi}{2} - \frac{\pi}{p}$:

$$U_{di\alpha} = U_{di} \times \cos \alpha \tag{3}$$

For $\frac{\pi}{2} - \frac{\pi}{p} \leq \alpha \leq \frac{\pi}{2} + \frac{\pi}{p}$:

$$U_{di\alpha} = U_{di} \times \frac{1 - \sin (\alpha - \pi / p)}{2 \sin (\pi / p)} \tag{4}$$

b) Non-uniform connection (half controllable)

$$U_{di\alpha} = 0{,}5 \times U_{di} \times (1 + \cos \alpha) \tag{5}$$

4.2.2.2 Voltage characteristics and transition current

Below the value of the transition current (mean value), and during the period where the current is zero (instantaneous value), the DC voltage only depends on the DC circuit and no longer depends on the line side voltage.

At the transition current value, the voltage/current characteristic bends as is shown in Figure 3. Two examples where this transition between voltage characteristics occurs are

– back e.m.f. loads in which the inductance of the DC circuit cannot maintain direct current over the entire period, and

– in the case of interphase transformer connection, when the direct current decreases below the critical value at which the interphase transformer becomes ineffective.

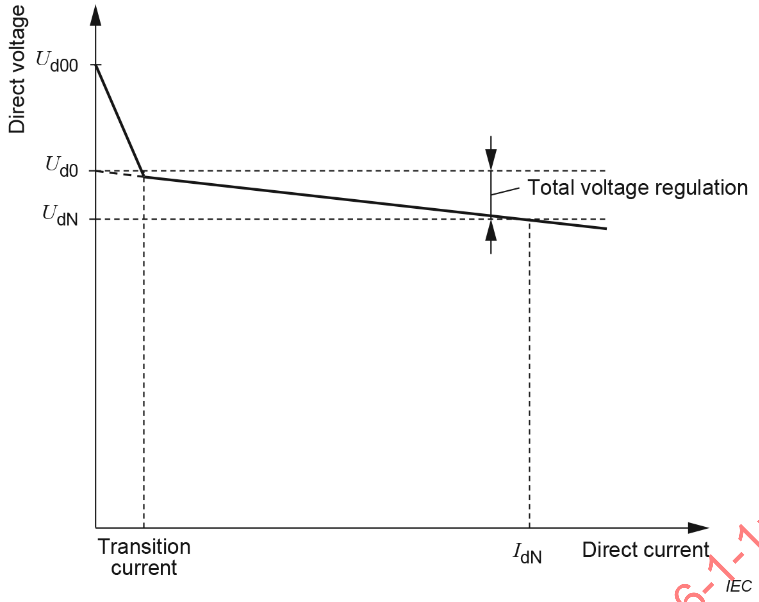


Figure 3 – Voltage regulation

4.2.3 Disturbances and fault conditions

4.2.3.1 Immunity level of a converter

When a disturbance from any origin does not exceed the immunity level specified (see for example Table 7, Table 8 and Table 9), the corresponding performance shall be maintained: no loss of performance, no tripping and no damage. Table 3 defines the levels.

Table 3 – Performance criteria

Immunity level	Symbol	Performance criteria
Functional	F	No loss of performance
Tripping	T	No interruption of service due to protective devices
Damage	D	No permanent damage (fuses excepted)

The functional immunity level (F) of a converter is a combination of all the limiting levels of the various kinds of electromagnetic disturbance level which said converter can withstand without loss of performance.

The tripping immunity level (T) of a converter is a combination of all the limiting levels of the various kinds of electromagnetic disturbance level which said converter can withstand without interruption of service due to protective devices.

The tripping immunity level is further divided into two sub-levels:

– tripping with automatic reset when the disturbance is over;
– tripping without automatic reset (requiring outside intervention for restarting, manual resetting of a circuit-breaker, changing fuse, etc.).

NOTE 1 Automatic resumption of service needs consideration of safety aspects according to the application.

The damage immunity level (D) of a converter is a combination of all the limiting levels of the various kinds of electromagnetic disturbance level which said converter can withstand without sustaining permanent damage.

4.2.3.2 Disturbances and compatibility

For electromagnetic compatibility (EMC), the semiconductor converters shall comply with IEC 61000-6-1, IEC 61000-6-2 and IEC 61000-6-4 in general unless relevant product standards are provided. EMC standards for semiconductor converters are provided to some products as listed below:

– IEC 61204-3 for low-voltage switch mode power supplies;
– IEC 61800-3 for adjustable speed electrical power drive systems;
– IEC 62040-2 for uninterruptible power systems (UPS);
– IEC 62310-2 for static transfer systems (STS).

NOTE 1 This document is not intended to define EMC requirements. It covers all phenomena and therefore introduces references to dedicated standards which are applicable according to their scope.

Conducted phenomena are distinguished between system-borne low-frequency disturbances and converter-generated disturbances.

a) System borne disturbances

Disturbances attributable to a number of causes external to the converter, such as in the case of varying loads on the distribution system, switching transients, changes of configuration in the supply network, for which only statistical values can be specified.

NOTE 2 Examples of such disturbances are:

– overvoltages, switching transients, lightning strokes;
– voltage changes due to motor starting, capacitor switching;
– faults and fault clearing: single phase-to-earth, phase-to-phase;
– quasi-permanent voltage unbalance, to be specified in terms of negative to positive sequence ratio;
– frequency variation and phase displacement;
– ripple-control signals;
– harmonic and interharmonic components of voltage and current.

b) Converter generated disturbances

Disturbances due to the non-linearity of the converter are generated by the operation of the converter.

NOTE 3 Examples of such disturbances are:

– harmonic currents, in terms of order, magnitude and phase relationship, for specified operating conditions, taking into account the average, the "most likely" value and the maximum, occasional value for short durations (for example 1 min);
– commutation notches, to be specified in terms of width, depth, area;
– commutation repetitive transients, to be specified as short impulses in terms of energy, crest value, rate of rise, etc.;
– non-repetitive transients which can be due to transformer inrush current, internal or external fault clearing, etc.;
– interharmonic components (for example frequency changers);
– voltage dips and swells, to be specified as the difference of RMS value between consecutive steady-states.

NOTE 4 The listed disturbances are possibly produced by the converter under consideration or by other converters and the actual level changes with the network impedance, at the point at which they are considered.

NOTE 5 For more information, refer to IEC TR 60146-1-2. For example, when many converters with large pulse numbers and phase-shift transformers are used, the harmonic problem is possibly alleviated to a point where the voltage changes become the main concern.

5 Service conditions

5.1 Code of identification for cooling method

The cooling method is identified by letter symbols. They are arranged in a code form. The code consists of two letters for direct cooling, and of four letters for indirect cooling.

a) Direct cooling

For direct cooling, the first letter indicates the cooling medium (see 3.8.1 and refer to Table 4), the second letter indicates the circulation method (refer to Table 5).

EXAMPLE 1 AN, air cooled, natural circulation (convection).

b) Indirect cooling

For indirect cooling, the same rule applies first to the two first letters corresponding to the heat transfer agent (see 3.8.2) and secondly to the two last letters corresponding to the cooling medium (see 3.8.1).

EXAMPLE 2 OFAF, converter with forced circulated oil (pump) as heat transfer agent and forced circulated (fan) air as cooling medium.

c) Mixed cooling method

For both cases, direct cooling or indirect cooling, if the circulation is alternatively natural or forced, two groups of symbols, separated by a stroke, shall indicate both possible methods of circulation as used, the first group corresponding with the lower heat flow or the lower ambient temperature.

EXAMPLE 3 For direct cooling: AN/AF, converter with natural direct air cooling and possibilities for forced direct air cooling.

EXAMPLE 4 For indirect cooling: OFAN/OFAF, converter with forced circulated oil as heat transfer agent and natural air as cooling medium, with possibilities for forced air as cooling medium.

Table 4 – Cooling medium or heat transfer agent

Cooling medium or heat transfer agent	Symbol
Mineral oil	O
Dielectric liquid (other than mineral oil or water)	L
Gas	G
Water	W
Air	A
Fluid used for two-state cooling	P

Table 5 – Method of circulation

Method of circulation	Symbol
Natural (convection)	N
Forced, moving device not incorporated	E
Forced, moving device incorporated	F
Vapour cooling	V

NOTE In most cases, the identification code for the cooling method is the same as that now in use for transformers.

5.2 Environmental conditions

5.2.1 Ambient air circulation

Indoor type equipment installed in a room shall be connected to the (unlimited) supply of cooling medium or, if the cooling air is taken from the ambient in the room, provision shall be made to extract the heat from the room, which then is considered as an intermediate heat-exchanger between the equipment and the outside air.

For assemblies mounted in a cubicle or cabinet, the ambient for the assemblies (internal air of the cubicle or cabinet) is to be considered as a heat transfer agent and not as a cooling medium. There is some reflection from the cabinet walls, which should be taken into account. Therefore, for the cubicle or cabinet mounted assemblies, a higher ambient temperature has to be specified and the clearance distances shall comply with the supplier's specification.

5.2.2 Normal service conditions – Temperatures

The following limits shall apply unless otherwise specified.

a) Storage and transport temperatures

	Minimum	Maximum
Storage and transport	–25 °C	+55 °C

These limits apply with cooling liquid removed.

b) Operation including off-load periods, indoor equipment

Temperature conditions are defined in Table 6, according to different cases.

Table 6 – Limit of temperature of the cooling medium for indoor equipment

Conditions	Cooling medium	Minimum °C	Maximum °C
Temporary extreme temperatures of the cooling medium	Air	0	40
	Water	+5	30
	Oil	–5	30
Daily average	Air		30
Yearly average	Air		25

5.2.3 Other normal service conditions

Operation including off-load periods are intended under the following limits.

a) Relative humidity of the ambient air for indoor equipment

Minimum: 15 %.

Maximum: standard equipment is designed for the case where no condensation can occur. The case of condensation shall be treated as unusual service conditions (see 5.2.4).

b) Altitude

Not higher than 1 000 m

c) Dust and solid particle content for indoor equipment

Standard equipment is designed for clean air (IEC 60664-1, pollution degree 1). Any other conditions are to be specified by the purchaser as unusual service conditions (see 5.2.4).

d) Outdoor equipment

Operation including off-load periods for outdoor equipment shall be specified by the purchaser.

5.2.4 Unusual service conditions

The service conditions are assumed to be those listed under normal service conditions. The following list is an example of unusual service conditions that shall be subject to special agreement between purchaser and supplier:

a) unusual mechanical stresses, for example shocks and vibrations;
b) cooling water which can cause corrosion or obstruction, for example sea water or hard water;
c) foreign particles in the ambient air, for example abnormal dirt or dust;
d) salt air (for example proximity to the sea), high humidity, dripping water or corrosive gases;
e) exposure to steam or oil vapour;
f) exposure to explosive mixtures of dust or gases;
g) exposure to radioactive radiation;
h) high values of relative humidity and temperature similar to those associated with sub-tropical or tropical climatic conditions;
i) fluctuations of temperature exceeding 5 K/h and relative humidity changes exceeding 0,05 p.u./h;
j) altitude more than 1 000 m;
k) operation at ambient temperatures below +5 °C with water cooling;
l) operation at ambient temperatures below –5 °C with oil cooling;
m) other unusual service conditions not covered by this list or service conditions exceeding the specified limits of normal service conditions.

5.3 Characteristics of the load

The supplier shall state the type of load for which the converter is designed and for which its rating is valid:

– resistive (W);
– highly inductive (L);
– motor (M);
– battery charging (B);
– capacitive (C);
– regenerative (G).

Conversely, the purchaser shall specify the type and characteristics of the load in the prospective application.

Examples of loads which require to be specified in detail include:

– inductive load requiring voltage reversing and/or over-voltage protection, such as DC motor fields, electromagnets, inductors with high X/R ratio;
– energy-storing load such as storage batteries, capacitor banks, electrochemical process cells, inverters;
– hoists, unwinders and other regenerative loads which require means of handling the regenerated energy and protection against mains failure;
– highly variable impedance loads with high rate of current rise.

5.4 Service condition tolerances

5.4.1 Steady state and short time conditions

Unless otherwise specified, the converter shall be designed to conform to the requirements for immunity to conducted disturbances specified by the following determinations.

Disturbance levels corresponding to the immunity levels include the disturbance effects of the converter; however, if the converter improves the disturbance values, the disturbance levels shall exclude the corresponding effects of the converter.

For different AC or DC connections, different immunity classes or special immunity levels may be specified. If no immunity class is specified, class B in Table 7 shall be assumed to apply.

For connected stiff voltages, the electric service conditions refer to IEC 61000-2-4. IEC 61000-2-2 is also taken into consideration.

For guidance on disturbance effects caused by line-commutated converters, see also IEC TR 60146-1-2.

The immunity classes A, B, C defined in 5.4 correspond to the practice established, before the publication of the IEC 61000-2 series setting up the compatibility levels.

NOTE 1 While the IEC 60146 series establishes immunity classes from the highest immunity to the lowest (A, B, C decreasing immunity), IEC 61000-2-4 sets classes of compatibility levels from the lowest values to the highest (classes 1, 2 and 3 with increasing values of compatibility levels).

NOTE 2 For these low frequency phenomena, the margin between the compatibility levels and the immunity levels can have significant consequences on the design. This is the responsibility of the manufacturer to define their margin according to the tolerances resulting from their design and according to their manufacturing process. Therefore, there is no margin planned in the standard requirements.

Immunity class A: The immunity levels of class A apply to the compatibility levels of class 3 of IEC 61000-2-4:2002 excluding dips and short time interruptions (which are not admissible at most converters) and additional immunity levels defined in Table 7, Table 8 and Table 9.

Immunity class B: The immunity levels of class B apply to the compatibility levels of class 2 of IEC 61000-2-4:2002 excluding dips and short time interruptions (which are not admissible at most converters) and additional immunity levels defined in Table 7, Table 8 and Table 9.

Immunity class C: The immunity levels of class C apply to the compatibility levels of class 1 of IEC 61000-2-4:2002 excluding short time dips (which are not admissible at most converters) and additional immunity levels defined in Table 7, Table 8 and Table 9.

The defined immunity levels are summarized in Table 7 for frequency and voltage amplitude, Table 8 for voltage unbalance and Table 9 for voltage waveform. Compatibility levels defined in IEC 61000-2-4:2002 are also shown in italics for reference.

Deviations from the defined immunity levels and additional immunity levels should be specified for the individual equipment and application.

Table 7 – Immunity levels to frequency and voltage amplitude for stiff AC voltage connections

Disturbance	Applicable values of IEC 61000-2-4:2002	Immunity class			Performance criteria [a]
		A	B	C	
Frequency tolerance					
Range (%)		±2	B2 = ±2 [b] B1 = ±1	±1	F
Rate of change (%/s)	–	±2	±1	±1	F
Voltage amplitude tolerance					
a) Steady state $\Delta U/U_N$ (%)		+10 to –10	+10 to –10	+10 to –5	F
Compatibility levels IEC 61000-2-4:2002 [c]	Table 1	+10 to –15	±10	±8	
b) Short time (0,5 to 30 cycles) up to rated values					
– Rectifier operation only (%)	–	±15	+15 to –10	+15 to –10	T
– Inverter operation (%)	–	±15	+15 to –10	+15 to –7,5	T

For overload conditions, other limits shall be specified separately.

NOTE 1 Compatibility levels defined in IEC 61000-2-4:2002 are shown in italics for reference.

NOTE 2 A decrease in frequency is assumed not to coincide with an increase in line voltage and vice versa.

NOTE 3 Short-time AC voltage variations are not expected to occur more frequently than once every 2 h.

[a] For definition of the code, refer to Table 3. Within certain limits to be specified, the possible consequence T may be replaced by F, in particular if, by a requirement to be inserted in the specification, the purchaser requires special control arrangements.

[b] The compatibility level for industrial networks class 2, according to IEC 61000-2-4:2002, is ±1 %.

[c] Electromagnetic environment classes 3, 2, 1.

Table 8 – Immunity levels to voltage unbalance for stiff AC voltage connections

Disturbance	Applicable values of IEC 61000-2-4:2002	Immunity class			Performance criteria [a]
		A	B	C	
Voltage unbalance factor U_{neg}/U_{pos}					
a) Steady state (%)		5	5	2	F
Compatibility levels IEC 61000-2-4:2002 [b] (over any 10 min)	Table 1	3	2	2	
b) Short time					
– Rectifier operation only (%)	–	8	5	3	T
– Inverter operation (%)	–	5	5	2	T

NOTE 1 Compatibility levels defined in IEC 61000-2-4:2002 are shown in italics for reference.

NOTE 2 The higher values specified for short time can lead to, for example, excessive ripple on the DC side and uncharacteristic harmonics on the AC side.

NOTE 3 Short-time voltage unbalances are not expected to occur more frequently than once every 2 h.

[a] For definition of the code, refer to Table 3.

[b] Electromagnetic environment classes 3, 2, 1.

Table 9 – Immunity levels to voltage waveform for stiff AC voltage connections

Disturbance	Applicable values of IEC 61000-2-4:2002	Immunity class			Performance criteria [a]
		A	B	C	
Voltage waveform					
a) total harmonic distortion THD (%)		25	10	5	F
Compatibility levels IEC 61000-2-4:2002[b]	*Table 5*	*10*	*8*	*5*	
b) individual harmonic distortion					
steady-state odd (%)		8	6	3	F
even (%)		2	2	1	F
Compatibility levels IEC 61000-2-4:2002[b]					
– *order 5 (%)*	*Table 2*	*8*	*6*	*3*	
– *other odd orders excluding multiples of 3*	*Table 2*	*See IEC 61000-2-4:2002 Class 3*	*See IEC 61000-2-4:2002 Class 2*	*See IEC 61000-2-4:2002 Class 1*	
– *multiples of 3*	*Table 3*				
– *even orders*	*Table 4*				
c) commutation notches (steady state)					
– amplitude (% of U_{LWM})	–	100	40	20	T
– area (% of U_{LWM} × degree)	–	625	250	125	T

NOTE 1 Compatibility levels defined in IEC 61000-2-4:2002 are shown in italics for reference.

NOTE 2 The area of a notch is approximately constant for a given DC current and R_{SC}. The width and depth vary with the trigger delay angle (α).

NOTE 3 If several converters are connected to the same converter transformer terminals, the total area of all notches over one period of the fundamental is not expected to exceed four times the area given above for one principal commutation notch.

[a] For definition of the code, refer to Table 3.

[b] Electromagnetic environment classes 3, 2, 1.

5.4.2 Repetitive and non-repetitive transients

A typical waveform of repetitive and non-repetitive transient is shown in Figure 4. The following characteristics shall be specified as far as possible:

a) transient energy available at the converter terminals (J);

b) rise time, (from 0,1 p.u. to 0,9 p.u. peak value) (µs);

c) peak value U_{LRM}/U_{LWM} (p.u.);

d) peak value U_{LSM}/U_{LWM} (p.u.);

e) duration above 50 % of the peak measured from the sine wave (µs).

Item e) describes the duration of the non-repetitive transient voltage denoted by U_{LSM} in Figure 4. The duration is defined by the parameters "a" and "t" in the waveform. "a" shows 50 % of the amplitude of the non-repetitive voltage above the "sine wave", the sinusoidal part in the waveform. "t" is the width of the non-repetitive transient measured at "a" from the sinusoidal part as shown in Figure 4.

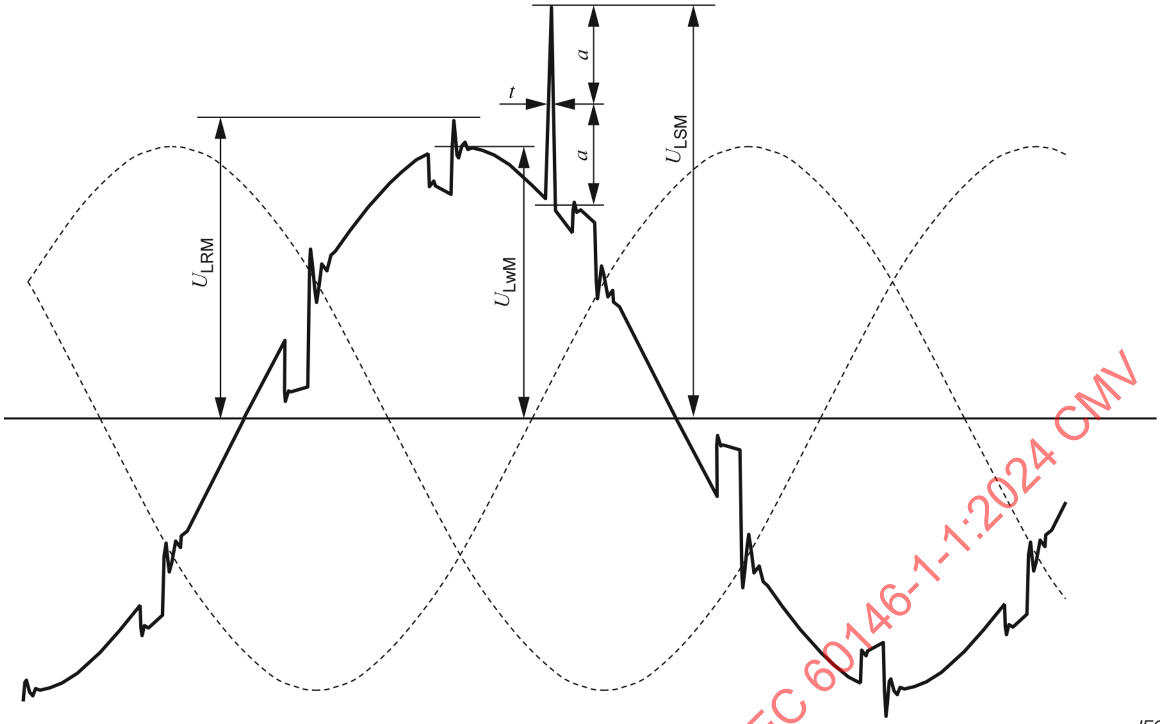


Figure 4 – AC voltage waveform

NOTE For additional information on AC voltage waveforms, see IEC TR 60146-1-2.

6 Power conversion equipment and assemblies

6.1 Electrical connections

a) Standard design converters

Considering the need for simplification in the common case of standard design converters covering the majority of users requirements, two types are considered in Clause 6:

1) converters without transformer;

2) individual transformer converters.

In both cases, single phase and three-phase supplies are considered (p = 2, p = 6) with uniform connection.

In case 2), twelve-pulse converters and dual six-pulse converters require two secondary windings (valve side windings) with star (Y) and delta (D) connections, respectively.

b) Special design converters

For converters subject to special agreement between the purchaser, the supplier and possibly the supply authorities because of their rating or special requirements or mode of operation, refer to IEC TR 60146-1-2:2019, which also gives other types of possible connections for particular applications.

6.2 Calculation factors

6.2.1 Essential variables

Table 10 gives the value of some calculation factors for the most used connections of line commutated converters. IEC TR 60146-1-2 gives the calculation factors also for some other connections.

Table 10 consists of 17 columns.

- Column 1 gives a reference number to the connection.
- Column 2 defines the transformer connections on the line side.
- Column 3 defines the transformer connections on the valve side.
- Column 4 shows the converter connections (schematics).
- Column 5 is the pulse number p.
- Column 6 is the commutation number q (on a commutating group).
- Column 7 gives the line side fundamental to dc current factor I_{1L}/I_d.
- Column 8 gives the line side current factor.
- Column 9 gives the valve side current factor.
- Column 10 gives the voltage ratio U_{di}/U_{v0}.
- Column 11 gives the voltage ratio U_{iM}/U_{di}.
- Column 12 gives the parameter for inductive voltage regulation (see Formula (10)).
- Column 13 gives the short-circuit transformer connections for transformer test.
- Column 14 gives the short-circuit transformer connections for transformer test.
- Column 15 gives the short-circuit transformer connections for transformer test.
- Column 16 gives the transformer guaranteed losses.
- Column 17 gives the transformer guaranteed short-circuit impedance.

a) Voltage ratios

The voltage ratios are:

$$\frac{U_{di}}{U_{v0}} \tag{6}$$

$$\frac{U_{iM}}{U_{di}} \tag{7}$$

regarding the ideal no-load direct voltage, and the ideal crest no-load direct voltage.

b) Line side current factor

The line side current factor is the quotient of the RMS value I'_L of the current on the line side of the converter and the direct current I_d. The line side current factor is indicated in Table 10 on the assumption of smooth direct current, rectangular wave-shape of the alternating currents and on the following voltage ratio for single or double-way connections:

$$\frac{U_L}{U_{v0}} = 1 \tag{8}$$

where

U_L is the phase-to-phase voltage on the line side;

U_{v0} is the voltage between two commutating phases on valve side.

The line side current is approximately:

$$I_L = I'_L \times \frac{U_{v0}}{U_L} \quad (9)$$

c) Nominal inductive voltage regulation

The nominal inductive voltage regulation may be calculated from the value of X_t by means of Formula (10):

$$d_{xtN} = \frac{\delta \times q \times s}{2 \times \pi \times g} \times X_t \times \frac{I_{dN}}{U_{di}} \quad (10)$$

where

g is the number of sets of commutating groups between which I_{dN} is dvided;

I_{dN} is the rated direct current;

q is the commutation number;

s is the number of commutating groups in series;

U_{di} is the ideal no-load direct voltage;

δ is the number of commutating groups commutating simultaneously per primary.

The parameter below used in Formula (10) is listed in Table 10, column 12.

$$\frac{\delta \times q \times s}{g} \quad (11)$$

X_t is the transformer commutating reactance measured according to IEC 61378-1:2011, 7.2.

U_{di} is calculated from U_{v0} with the parameter of Table 10, column 10. In case of the 6-pulse converter, $U_{di} = \frac{3\sqrt{2}}{\pi} U_{v0}$.

For details, see IEC TR 60146-1-2:2019, 4.7.2.4.

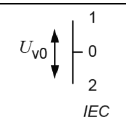
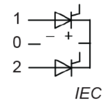
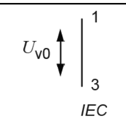
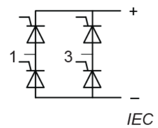
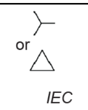
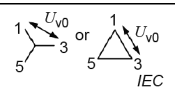
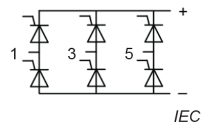
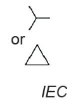
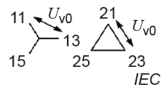
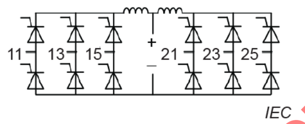
d) Transformer losses and short-circuit impedance

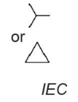
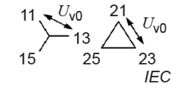
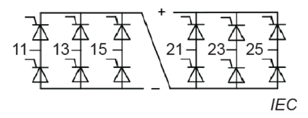
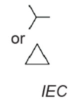
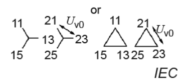
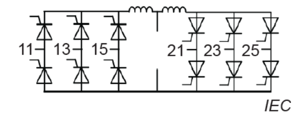
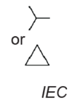
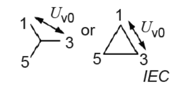
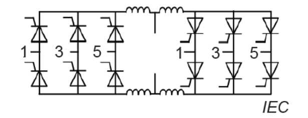
Table 10 gives the transformer guaranteed losses and the transformer guaranteed short-circuit impedance. For details, see IEC TR 60146-1-2:2019, 4.4.7 and 4.4.8, respectively. They are originally defined in the IEC 61378 series, the converter transformer standards.

e) Short-circuit conditions

Usually, the protection of the converter is such that a short-circuit is cleared in the shortest possible time. Some applications, for example converters for railway fixed installations, require the converter to withstand the DC short-circuit current for the breaking time of the output circuit-breaker which can be as long as 150 ms. In such cases, specific calculation ratios take into account the large angle of overlap which introduces multiple commutation. This is covered by dedicated standards (see IEC 62589).

Table 10 – Connections and calculation factors

No.	Transformer connection		Converter connection	p [a]	q [a]	Line side fundamental current factor [b,d] I'_{1L} / I_d	Line side current factor [b] I'_L / I_d	Valve side current factor [c] I_v / I_d	$\frac{U_{di}}{U_{v0}}$	$\frac{U_{iM}}{U_{di}}$	$\frac{\delta qs}{g}$	Terminals to be short-circuited for short-circuit measurement [d]			Transformer guaranteed load losses [e]	Transformer guaranteed short-circuit impedance [d]
	Line side	Valve side										A	B	C		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Single converter, single-way connections																
1				2	2	-	0,5	0,707 $\left(\frac{1}{\sqrt{2}}\right)$	0,450 $\left(\frac{\sqrt{2}}{\pi}\right)$	3,14 (π)	2		-	-	-	-
Single converter, uniform double-way connections																
7				2	2	-	1	1	0,900 $\left(\frac{2\sqrt{2}}{\pi}\right)$	1,57 $\left(\frac{\pi}{2}\right)$	4	-	-	-	-	-
8				6	3	$\frac{\sqrt{6}}{\pi}$ $(\approx 0{,}78)$	0,816 $\left(\sqrt{\frac{2}{3}}\right)$	0,816 $\left(\sqrt{\frac{2}{3}}\right)$	1,35 $\left(\frac{3\sqrt{2}}{\pi}\right)$	1,05 $\left(\frac{\pi}{3}\right)$	6	1-3-5			P_A	e_{XA}
9				12	3	$\frac{\sqrt{6}}{\pi}$ $(\approx 0{,}78)$	0,789 $\left(\frac{1+\sqrt{3}}{2\sqrt{3}}\right)$	0,408 $\left(\frac{1}{\sqrt{6}}\right)$	1,35 $\left(\frac{3\sqrt{2}}{\pi}\right)$	1,05 $\left(\frac{\pi}{3}\right)$	3	11-13-15	21-23-25	11-13-15 and 21-23-25	P_C	e_{XA} and e_{XB}

No.	Transformer connection		Converter connection	p [a]	q [a]	Line side fundamental current factor [b,d] I'_{1L} / I_d	Line side current factor [b] I'_L / I_d	Valve side current factor [c] I_v / I_d	$\frac{U_{di}}{U_{v0}}$	$\frac{U_{iM}}{U_{di}}$	$\frac{\delta qs}{g}$	Terminals to be short-circuited for short-circuit measurement [d]			Transformer guaranteed load losses [e]	Transformer guaranteed short-circuit impedance [d]
	Line side	Valve side										A	B	C		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
12				12	3	$\frac{2\times\sqrt{6}}{\pi}$ $(\approx 1{,}559$	1,577 $\left(\frac{1+\sqrt{3}}{\sqrt{3}}\right)$	0,816 $\left(\sqrt{\frac{2}{3}}\right)$	2,70 $\left(\frac{6\sqrt{2}}{\pi}\right)$	0,524 $\left(\frac{\pi}{6}\right)$	12	11-13-15	21-23-25	11-13-15 and 21-23-25	P_C	e_{XA} and e_{XB}
18				See connection no. 8												
19				See connection no. 8												

For other connections, see IEC TR 60146-1-2.

[a] Refer to Table 1.

[b] Refer to transformer primary.

[c] Refer to transformer secondary.

[d] The symbols e_{xA} and e_{xB} in column 17 show the transformer guaranteed short circuit impedance. e_{xA} is the inductive short-circuit impedance obtained by the short-circuit measurement A in column 13. e_{xB} is that obtained by the short-circuit measurement B in column 14. Refer to 4.4.8 of IEC TR 60146-1-2:2019.

[e] IEC 61378-1:2011, Table 1, does not contain the information for the lines 1 and 7. Then, the cells which are not given relevant values are filled with hyphen "-". When the values are necessary, refer to the textbooks for the converter theory. Some information can be obtained from IEC TR 60146-1-2:2019, Annex C.

6.2.2 Losses and efficiency

6.2.2.1 General

The efficiency of converter assemblies or equipment shall be declared as power efficiency.

The efficiency may be determined by a measurement of AC and DC power at normal load conditions or by a measurement of internal losses in a short-circuit test and a light load test or by a calculation of internal losses, at the choice of the supplier.

NOTE The loss evaluation by calculation can be applied for the large converters which practically cannot be tested in the factory or in the laboratory. The loss calculation is performed in such cases based on the actual loss measurement of the assemblies or on the authorized calculation procedures in relevant product standards. A typical example is the HVDC converter, of which loss determination is specified in IEC 61803.

The apparatus included in the determination of the over-all efficiency shall be stated.

In case of doubt as to whether the losses of a component of the power conversion equipment (PCE) should be included or not, when calculating the efficiency, it shall be stated whether the losses in it are included in the declared efficiency. For certain components in the power conversion equipment, 6.2.2.2 and 6.2.2.3 shall be considered.

6.2.2.2 Included losses

The following losses shall be included when determining the efficiency:

a) internal losses in the assembly such as losses in semiconductor valve devices, in fuses, potential dividers, current balancing means, capacitor resistor damping circuits and voltage surge diverters;
b) losses in transformers, transducers, interphase transformers, current limiting and balancing reactors between transformer and thyristor or diode assemblies and the losses of the line side auxiliary transformers and reactors forming part of the equipment and delivered under the same contract;
c) losses due to main connections between transformer and assembly for the case when transformer and assembly are built together and delivered as a unit;
d) power absorbed by auxiliaries such as permanently connected fans or pumps and relays unless otherwise specified;
e) losses in series smoothing reactors, when supplied by the supplier of the PCE;
f) losses due to circulating currents in double converter connections;
g) power consumed by the trigger equipment (see 3.1.17).

6.2.2.3 Not included losses

The following losses shall not be included when determining the efficiency but shall be stated separately if requested and if the apparatus concerned is supplied by the supplier of the PCE:

a) losses due to the main connections between transformer and the assembly when delivered as separate units;
b) losses due to the main connections to circuit-breakers, disconnectors, switches and to the load;
c) losses in circuit-breakers, disconnectors, switches and in control gear other than the items mentioned in 6.2.2.2;
d) losses due to heating and ventilation of the building and in the cooling supply;
e) losses in the series smoothing reactor, when not supplied with PCE;
f) losses in system control equipment (see 3.1.18);
g) losses due to auxiliary apparatus which operate only intermittently.

6.2.3 Power factor

As the line current to a line-commutated converter contains harmonics, it is important to state the kind of power factor meant when a specification for a guaranteed supply power factor is written.

Reference is made to the power factor of the fundamental wave or displacement factor $\cos\varphi_1$, unless otherwise specified (see 3.7.14).

For pulse numbers higher than 6, the difference between the total power factor λ and the displacement factor $\cos\varphi_1$ is small, but for lower pulse number the difference is significant.

Unless otherwise stated in the contract, for multi-phase converters supplying inductive load, the manufacturer guarantees shall be given on the displacement factor $\cos\varphi_1$.

NOTE In such a case, calculation is adequate to get reliable figures of the displacement factor under the condition of symmetrical control.

For converters supplying mainly battery chargers or capacitive loads, the total power factor is calculated in general. When exact calculations of the displacement factor or of the total power factor are required, knowledge of many parameters is necessary, including line impedance. For such calculations, refer to IEC TR 60146-1-2.

The formulae described in 6.2.3 can be applied on the assumption of smooth direct current and rectangular wave-shape of the alternating current.

When the actual direct current and output direct voltage of a line-commutated converter is known, the following formulae give approximate values:

Active power $$P = U_d \times I_d \qquad (12)$$

Fundamental apparent power $$S_1 = U_{di} \times I_d \qquad (13)$$

Displacement factor $$\cos\varphi_1 = P/S_1 \qquad (14)$$

Fundamental reactive power $$Q_1 = \sqrt{S_1^2 - P^2} \qquad (15)$$

These formulae normally give sufficient accuracy to calculate $\cos\varphi_1$ and also the amount of capacitors needed to correct the power factor to a specified value.

Refer to IEC TR 60146-1-2 for more details, if required.

6.2.4 Voltage regulation

The following refers to standard design (connection no. 8 in Table 10), line commutated, three-phase, uniform, double-way connection converters with transformer or line reactors. Here, some usual cases are considered.

a) Resistive direct voltage regulation

Resistive direct voltage regulation U_{dr} is approximated by Formula (16) using losses in components P_r.

$$U_{dr} = \frac{P_r}{I_{dN}} \quad (16)$$

The term "components" includes transformer windings, series reactors, smoothing reactor, diodes, thyristors, fuses, etc.

b) Inductive direct voltage regulation

The inductive voltage regulation including the effects from the reactances of the supply source and the feeder cable or line is calculated as below based on Formula (10).

$$d_{xtN} = \frac{\delta \times q \times s}{2 \times \pi \times g} \times X_{sum} \times \frac{I_{dN}}{I_{di}} \quad (17)$$

where

X_{sum} = X_t + X'_L + X'_C, the sum of the reactances below:

X_t is the commutation reactance of the converter transformer seen from the valve side;

$X'_L = \left(\frac{U_{v0}}{U_L}\right)^2 \times X_L$ is the reactance of the cable or the line seen from the valve side through the converter transformer;

$X'_C = \left(\frac{U_{v0}}{U_L}\right)^2 \times X_C$ is the reactance of the supply source seen from the valve side through the converter transformer.

For other symbols and parameters in Formula (17), refer to the explanations for Formula (10). For details, see IEC TR 60146-1-2:2019, 5.1.3.

c) Influence of other converters

If several converters are fed from the same supply transformer, this usually causes an additional voltage drop. If required by the contract, the detailed calculation may be performed using the rating, type of connection and other particulars of the other converters.

In the simple case of several independent, identical converters, the maximum additional voltage drop may be estimated using the total apparent power of all the converters, assuming the same value of the trigger delay angle α.

d) Twelve-pulse converters

In the case of two series connected six-pulse converters, one fed from a star (Y) and the other from a delta (D) secondary winding, each six-pulse converter is considered separately, neglecting the primary leakage reactance, which is usually much smaller than the secondary reactance for transformers designed for the purpose and adding the individual voltage regulation.

e) Boost and buck connection converters (series connection)

Using the same assumption as above, the voltage regulation depends on the operating point and each six-pulse converter shall be treated separately. The DC voltage and voltage regulation add up (algebraically if one of the converters is in the inverter mode).

This approximate method may also be used for three-phase, double-way non-uniform connections (for example three thyristors, three diodes or six thyristors, six diodes).

6.3 Electromagnetic compatibility

6.3.1 Harmonics

6.3.1.1 General

In this document, the power frequency is taken as the fundamental frequency of the harmonics. For details, see Annex B.

6.3.1.2 Order of harmonics in line current and voltage

Assuming perfect symmetry of the supply voltages, trigger delay angles, transformer ratio for star (Y) and delta (D) windings, the following apply for three-phase uniform connected converters.

The order of characteristic harmonics depends on the pulse number p:

$$h = kp \pm 1 \qquad k = \text{integer } (1 \ldots n) \tag{18}$$

The corresponding frequency is related to the fundamental frequency f_1 by:

$$f_h = h \times f_1 \tag{19}$$

subject to the mains frequency variations.

NOTE 1 Due to small errors in star (Y) and delta (D) winding voltages (integer number of turns), supply voltage unbalance, trigger delay angle error and other manufacturing tolerances, twelve-pulse converters usually produce uncharacteristic harmonics which can range from 0,05 p.u. to 0,15 p.u. of the value for a six-pulse converter (p = 6) of the same rating.

NOTE 2 Sequential gating or non-uniform, dual six-pulse converters can produce harmonics up to 1,0 p.u. of the theoretical value for the equivalent six-pulse converter depending on the trigger delay angle and transformer secondary phase shift, if any.

6.3.1.3 Amplification of harmonic currents on the line side

Power capacitors may be used for power factor compensation both of AC motors and line-commutated converters. The resonance between the source impedance and the capacitors (including the cable capacitances, especially for MV systems) may amplify the harmonic currents and voltages. These resonances may be shifted to lower frequencies (below the 5th harmonic) by providing reactors in series with the capacitors.

6.3.1.4 Direct voltage harmonic content

For perfectly balanced supply voltages, trigger delay angles, etc., the frequency of the direct current and the direct voltage harmonic content is given by:

$$f_{h,dc} = k \times p \times f_1 \qquad k = \text{integer } (1 \ldots n) \tag{20}$$

The negative sequence voltage produces an additional harmonic component at a frequency 2 × f_1, which cannot be cancelled by an appropriate design of the converter unless a large smoothing reactance or DC output filter is added.

As a result of the harmonic content of the voltage on the DC side, the DC current also contains ripple. For converters supplying capacitor banks or storage batteries (battery chargers), the counter e.m.f. may be equal to the direct voltage average value, in which case the direct current is discontinuous and an appropriate trigger equipment is required.

6.3.2 Other EMC aspects

Beside harmonics, which represent the main EMC concern for line commutated semiconductor converters, the risk of interference with in-plant low current control and communication lines, or with telephone and communication links shall be considered. The following only gives general advice and it is reminded that, as indicated in 4.2.3.2, all aspects of electromagnetic compatibility (EMC) for certain semiconductor converters are discussed in dedicated standards.

The purchaser should specify any special requirements in the enquiry or, failing this, specify the installation site, the type of supply system, the intended use of the converter and all particulars that can have an influence on the actual electromagnetic compatibility (EMC) requirements.

a) Interference with in-plant, low current control and communication lines

   Cable routing, filtering, feed-back cables and low current cables, etc., where such are installed by the purchaser, should be in accordance with any instructions provided by the supplier and also publications by IEC TC 77 and local authorities.

b) Interference with telephone and communication links

   Standard design industrial converters or special design converters for industrial application are not usually designed to meet the emission requirements applicable to equipment intended for use in residential environments, such as those specified in IEC 61000-6-3. Emission limits are given in the dedicated product EMC standards, see 4.2.3.2. Where no product EMC standard exists, the equipment should comply with the product family standard CISPR 11 or the relevant generic emission standard, such as IEC 61000-6-4 or IEC 61000-6-8.

6.4 Rated values

6.4.1 General

Rated values of a converter shall be given either as standard design values for general purpose converters or as closely as possible according to the load that it is intended to serve. The ratings of the converter are not valid if the load is changed to a load for which the converter is not intended.

In the specification of the converter, the character of the load shall also be specified.

It is noted that this document will not take precedence over a specific product standard. Namely, considering the fact that the load characteristics vary application by application, requirements for a product shall be specified by its appropriate product standards where applicable. For example, requirements for adjustable speed motor drives in applications such as rolling mills, paper mills, mining hoists, etc. are given in IEC 61800-2 and IEC TR 61800-6.

6.4.2 Rated output voltage

The rated output voltage shall be the continuous operating voltage assigned by the supplier.

The maximum output voltage shall comply with the dynamic requirements of the intended use or shall be separately specified by the purchaser.

NOTE A line-commutated converter frequently needs to be designed for a maximum direct voltage higher than the rated direct voltage (for example, in the case of field excitation of DC machines or synchronous machines, it is designed for a multiple of the rated direct voltage) in order to allow a margin for control, voltage regulation, AC line voltage variation compensation. This can result in a rated apparent power for the converter transformer, which in some cases greatly exceeds the rated output of the converter.

In the absence of such a specification, the rated direct voltage shall be maintained at all values of current up to the rated direct current for the specified limits (see 5.4, service condition tolerances) at the line terminals of the converter.

A line-commutated converter shall perform without service interruption at its rated values, under any operation mode (as rectifier or inverter) and throughout the service condition tolerances. A lower voltage may be negotiated for AC systems subject to heavy fluctuations, with the recommendation that the safe level of inverter operation should be set lower than the expected minimum alternating voltage on line side (see 5.4).

6.4.3 Rated current values

6.4.3.1 Current values to be specified

Each PCE shall have an assigned value for rated current, together with a specified duty class unless the rated current is related to continuous duty (see duty cycle, IEC 60050-151:2001, 151-16-02). Additionally, the assemblies shall have an assigned value for rated continuous current. This assigned value is the rated continuous direct current (maximum value) I_{dMN} (see 3.6.10)

Independently of the duty class for the converter, the converter and its constituent assemblies shall be capable of withstanding fault currents within the limits permitted by the protective equipment (example fuses) as recommended by the converter supplier. This applies to all operating conditions up to and including maximum loading.

Independently of the duty class for the converter, the converter and its constituent assemblies shall be capable of withstanding over-currents of such magnitude and duration as is necessary to allow the automatic load regulating equipment or over-current protective equipment to operate (over current electronic protection).

6.4.3.2 Short-time duty

A rated current may be defined for continuous and permanent condition as above, or for simple load duty consisting of a constant current associated with a single short duration peak current. Two equivalent methods may be used. For both cases, requirements of 6.4.3.1 apply.

a) Rated current for peak load duty

   The rated current for peak load duty delivered by the PCE is compatible with a peak load duty, provided the peak is followed by a no load period the duration of which allows the temperature of all parts of the PCE to fall to that correspondent to operation at rated direct current.

   The value of direct current which the PCE can supply to its load for specified duration under specified service conditions, which includes a short-time peak direct current, is the rated current for peak load duty. The duration and magnitude of the peak current (peak maximum direct current I_{dSMN}) and the minimum time of no-load before carrying any current shall be specified, as defined in 3.6.11 and 3.6.13.

b) Rated current for continuous duty with superimposed peak loads

   The rated current for continuous duty with superimposed peak loads delivered by the PCE is compatible with an intermittent peak load duty, provided the minimum time between applications of intermittent peak loads allows the temperature of all parts of the PCE to fall to that corresponding to operation at rated direct current.

   The rated direct current for this duty is the value of direct current which the converter can supply to its load for unlimited duration under specified service conditions and with intermittently applied peak loads (I_{dRMN}) of specified magnitudes and durations. The minimum time between applications of intermittent peak loads shall also be specified (see 3.6.12 and 3.6.14).

c) Rated current for repetitive load duty (periodic duty)

The rated direct current of the PCE shall be specified as the RMS value of the load current evaluated over the period of the load duty cycle. The duty class shall be preferably specified as a sequence of current values together with their durations, as defined in 3.6.15.

6.5 Duty classes

6.5.1 Principles

6.5 is described assuming the line commutated converter applications, listed in Table 12, as examples where the loads have cyclic variation patterns.

It is noted that this document will not take precedence over a specific product standard. Then, in case where the load of a product has different characteristics from those assumed, appropriate product standards shall be applied.

If in practice it is difficult to know the expected load diagrams on which the exact size of a converter depends, conventional diagrams which show constant current values for specified durations may be specified as follows.

A rated current value shall be specified and valid only for a defined duty class. If a converter is designed to operate at different duty classes, separate rated current values have to be given for each duty class.

If no suitable standard duty class is found in Table 11, the duty shall be specified based on the agreement between purchaser and supplier. The rated current may be the RMS value of the repetitive load duty cycle taken over the most onerous 15 min period, if not otherwise specified.

Table 11 contains standard duty classes, which specify current capabilities in terms of current values and durations.

The current values specified in Table 11 are each individually applicable after temperatures have been reached equivalent to continuous operation at rated current.

For examples of load cycles, see Table 12.

Table 11 – Standard duty classes

Duty class	Rated currents for converters and test conditions for assemblies (relative values in per unit of I_{dN})
I	1,00 p.u. continuously
II	1,00 p.u. continuously 1,50 p.u. 1 min
III	1,00 p.u. continuously 1,50 p.u. 2 min 2,00 p.u. 10 s
IV	1,00 p.u. continuously 1,25 p.u. 2 h 2,00 p.u. 10 s
V	1,00 p.u. continuously 1,50 p.u. 2 h 2,00 p.u. 1 min
VI	1,00 p.u. continuously 1,50 p.u. 2 h 3,00 p.u. 1 min

6.5.2 Selection of duty class and rated current value

Different hypothetical load current diagrams giving assumed typical load conditions for the standard duty classes are given in Table 12 together with an indication of applications for each class.

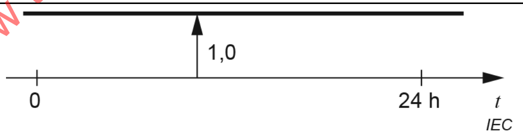
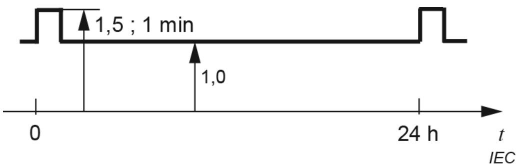
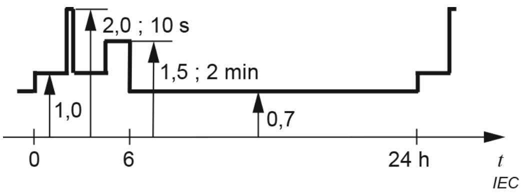
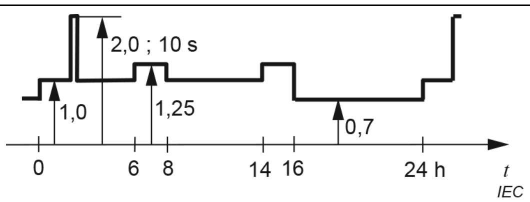
For guidance in determining the rated current of the PCE, the expected load diagram shall be examined.

The load conditions specified in Table 12 are less onerous than the rated current values specified in Table 12. This allows for the fact that the peak loads are sometimes concurrent and ensures that rated peak of short duration (5 min and less) can, in almost all practical cases, be safely applied as often as permitted by the longer time specified for the lower rated peak load current, the only restriction being that the time between two consecutive peak currents is at least 20 min. The restriction is due to the fact that the thermal time constant of converter assemblies is normally in the order of 2 min to 20 min, depending on the properties of the cooling system.

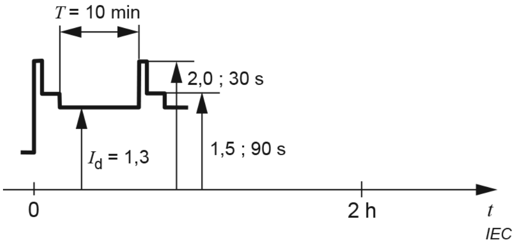
For duty classes IV and V, this will mean that the time periods and corresponding current values may differ considerably without affecting the design of the transformer.

Typical load conditions of duty classes V and VI include recurrent two-step peak currents, as shown in the load diagrams, with interposed intervals of current amplitude I_d (p.u.). The current amplitude I_d (p.u.) and the duration t (min) are specified in the tables and change in the course of the day.

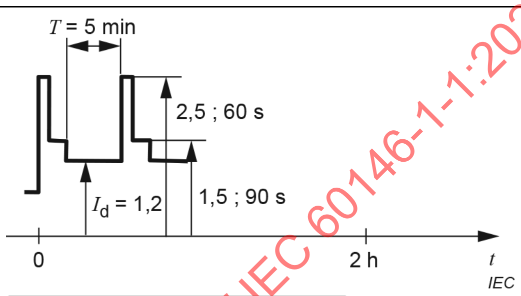
Table 12 – Examples of load cycles as guidance for selection of duty class

Duty class	Most typical applications	Assumed typical load conditions for the duty class Load current in relation to the rated direct current
I	Electrochemical processes, etc.	
II	Electrochemical processes, etc.	
III	Light industrial and light traction substation service	
IV	Industrial service, heavy duty	

<table>
<tr><th>Duty class</th><th>Most typical applications</th><th>Assumed typical load conditions for the duty class
Load current in relation to the rated direct current</th></tr>
<tr><td>V</td><td>Medium traction substation and mining

I_d = 1,5 p.u. (2 h)</td><td>

<table>
<tr><th></th><th>I_d (p.u.)</th><th>T (min)</th><th>$I_{d,rms}$ (p.u.)[a]</th></tr>
<tr><td>0 h to 2 h</td><td>1,3</td><td>10</td><td>1,36</td></tr>
<tr><td>2 h to 10 h</td><td>0,8</td><td>15</td><td>0,94</td></tr>
<tr><td>10 h to 12 h</td><td>1,3</td><td>10</td><td>1,36</td></tr>
<tr><td>12 h to 24 h</td><td>0,7</td><td>30</td><td>0,79</td></tr>
</table></td></tr>
<tr><td>VI</td><td>Heavy traction substation

I_d = 1,5 p.u. (2 h)</td><td>

<table>
<tr><th></th><th>I_d (p.u.)</th><th>T (min)</th><th>$I_{d,rms}$ (p.u.)[a]</th></tr>
<tr><td>0 h to 2 h</td><td>1,2</td><td>5</td><td>1,50</td></tr>
<tr><td>2 h to 10 h</td><td>0,8</td><td>6</td><td>1,26</td></tr>
<tr><td>10 h to 12 h</td><td>1,2</td><td>5</td><td>1,50</td></tr>
<tr><td>12 h to 24 h</td><td>0,7</td><td>20</td><td>0,93</td></tr>
</table></td></tr>
<tr><td colspan="3">[a] $I_{d,rms}$ is the RMS value over the load cycle.</td></tr>
</table>

6.5.3 Particular remarks for double converters

A double converter may have either a symmetrical load where the loading of the two converter sections is symmetrical in the two directions of current flow or an asymmetrical load where the loading of the two sections is different. For converter section of a double converter, see 3.3.10.

The requirements in 6.4.3 apply also to double converters. In the case of double converters with asymmetrical loading, each section shall be given separate duty cycles.

Special recommendations for double converters intended for adjustable speed motor drives may be found in IEC TR 61800-6.

6.6 Markings

6.6.1 General

Each PCE which is delivered as an integrally assembled unit and each assembly which is delivered separately shall bear the following markings.

a) Clear indication of manufacturer or supplier

   This indication may be given on the rating plate.

b) Indication of the type of equipment

   The type of equipment is according to 3.2 and 3.3.

   This indication may be given on the rating plate. The indication should, for PCE, include the intended mode of operation, for example "adjustable rectifier equipment" or "inverter equipment".

c) Marking of the input and output terminals of the main circuit

   The marking should express sequence of phases (if to be observed) or polarity respectively.

6.6.2 Rating plate

a) Rating plates of equipment and assemblies

   The following information shall be provided with the product. For products not covered by their own dedicated standards, the rating plate shall bear the following indications:

   1) identification reference, manufacturer's type designation and serial number;
   2) number of input phases (including neutral, if connection to it is necessary) or "DC";
   3) rated input voltage (called "rated direct voltage" in the case of inverters);
   4) rated input current (called "rated direct current" in the case of inverters);
   5) rated input frequency, if any;
   6) number of output phases (including neutral, if connection to it is necessary) or "DC";
   7) rated output voltage (called "rated direct voltage" in the case of rectifiers);
   8) rated output current (called "rated direct current" in the case of rectifiers);
   9) rated output frequency, if any;
   10) range of output voltage (if the output voltage is adjustable);
   11) range of output frequency (if the output frequency is adjustable);
   12) character of the load (for example counter e.m.f., inductive, etc.) if so restricted;
   13) type of duty or duty class;
   14) type of connection including "uniform" or "non-uniform" respectively (for assemblies only);
   15) maximum permissible prospective symmetrical RMS short-circuit current of the power source;
   16) the reference of this document.

   On the rating plate of small equipment (300 kW and less and rated current not exceeding 5 000 A), items 4) and 10) to 13) may be excluded. As stated in the Scope, where a dedicated product standard, or product safety standard defines requirements for the rating plate, this dedicated standard takes precedence.

b) Additional information where appropriate

   Some items may be added if appropriate, especially those listed below:

   1) cooling method;
   2) cooling requirements (temperature, flow rate of cooling medium);
   3) over-all mass, mass of cooling fluid, if any;
   4) degree of protection;
   5) displacement factor under rated conditions;
   6) output characteristic curve symbol.

7 Tests for valve device assemblies and power conversion equipment

7.1 General

7.1.1 Methods of testing

Semiconductor converters are frequently integrated in electrical equipment. The electrical equipment includes auxiliaries necessary for operation of the converter itself, or even other parts. It may happen that the semiconductor converter cannot be separated, even for testing. In such a case, the assembly is named "power conversion equipment" (PCE).

It is advisable for economical reasons to confine the performance of tests to those which are considered necessary. This document is therefore arranged so that testing of large equipment can be limited to tests in the manufacturer's works on the separate assemblies that are to be shipped separately.

Other tests such as tests on large, complete equipment or tests on site are to be included if separately specified.

Smaller equipment normally shipped as integral assemblies shall, however, be tested completely before being shipped in accordance with these provisions.

7.1.2 Kinds of tests

Two different kinds of tests are necessary.

a) Type tests

Type tests shall be performed to verify that the design of the product is appropriate to meet the performance requirements specified in this document and/or those specified separately.

Some or all of the type tests may be repeated at specified intervals on a specified number of samples to verify that the quality of the product is maintained.

b) Routine tests

Routine tests shall be performed on each PCE or on its sub-assemblies if they are shipped separately, before delivery to verify that the requirements of this document are met.

7.1.3 Performance of tests

The tests shall be performed in electrical conditions equivalent to those in real service. If this is not practicable, the assemblies and equipment respectively shall be tested under such conditions as to allow the specified performance to be proved.

In equipment tests, the assembly and other items of the equipment may be tested separately if this is more convenient. When tested separately, the stack or assembly shall be supplied from a transformer with a connection equivalent to that specified in the contract.

Unless otherwise agreed at the time of the contract, the AC supply and test voltages shall be at rated frequency except for the insulation test voltage which may be DC or in the frequency range introduced in 7.2.2.3.

When the purchaser or their representative desires to witness factory tests, they should so specify in the order. If so agreed before order, the contract may specify that the supplier should provide a report of tests performed on the product.

Reference may be made to type tests, previously performed, on an identical or similar product with test conditions at least equal to the requirements of the contract or of this specification.

The tests, unless otherwise agreed, shall comprise all the following items marked "x" in Table 13, which are applicable to the assembly or converter.

The tests marked "(x)" in Table 13 shall only be performed if specifically agreed in the contract.

Table 13 – Summary of tests

Test	Type test	Routine test	Optional test	Specification subclause
Visual inspection	x	x		
Insulation test	x	x		7.2
Light load and functional test	x	x		7.3.1
Rated current test	x			7.3.2
Over-current capability test			(x)	7.3.3
Measurement of the inherent voltage regulation			(x)	7.3.4
Measurement of ripple voltage and current			(x)	7.3.5
Measurement of harmonic currents			(x)	7.3.6
Power loss determination for assemblies and equipment	x			7.4.1
Temperature rise test	x			7.4.2
Power factor measurement			(x)	7.4.3
Checking of auxiliary devices	x	x		7.5.1
Checking the properties of the control equipment	x	x		7.5.2
Checking the protective devices	x	x		7.5.3
Immunity test			(x)	7.6 a)
Radio frequency radiated and conducted disturbances			(x)	7.6 b)
Measurement of audible noise			(x)	7.7
Additional tests			(x)	7.7

7.2 Insulation tests

7.2.1 General

To demonstrate adequate dielectric strength of the insulation system within the product, tests are to be conducted as type test as well as routine testing. The insulation system is investigated by testing safety critical components and solid insulation by means of three types of tests.

The different types of tests cover different physical phenomena:

– AC or DC voltage test to cover the impact of temporary over voltages from the mains supply;

– impulse voltage test to cover the impact of impulse transient over voltages generated in the mains supply;

– partial discharge testing of solid insulation to cover the impact of impulse over voltages, temporary over voltages, as well as recurring peaks across the insulation.

NOTE Impulse transient over voltages, temporary over voltages, as well as recurring peaks might cause partial discharge inside the insulation material which can lead to its degradation.

Generally, the impulse voltage test and the partial discharge test are specified separately, see 7.2.3.2.

The selection of type test and the corresponding test voltages shall be based on the requirement from IEC 62477-1 or IEC 62477-2, unless the relevant product standards are provided.

The selection of routine tests and the corresponding test voltages shall be based on the requirement from IEC 62477-1 or IEC 62477-2, unless the relevant product standards are provided.

7.2.2 introduces the routine insulation tests. If any inconsistency is found with the IEC 62477 series, then the requirements in IEC 62477-1 or IEC 62477-2 shall take precedence.

For the relationship between the IEC 60146 series and the IEC 62477 series, see Annex B.

7.2.2 Routine insulation tests of power conversion equipment

7.2.2.1 AC or DC voltage test

If possible, an AC or DC voltage test shall be performed on the final assembly to ensure that the manufacturing process has not affected the insulation coordination of the product. Test voltage shall be according to Table 14 or Table 15, as appropriate.

The test voltages in Table 14 or Table 15 cover routine testing of basic, supplementary, double and reinforced insulation in addition to type testing of basic insulation (see definitions 3.11.12, 3.11.13, 3.11.14 and 3.11.15).

NOTE The withstand voltage of double or reinforced insulation is higher than the withstand voltage of basic insulation. However, in order to prevent damage to the solid insulation by partial discharge, routine testing uses only one level of test voltage for basic, supplementary, double and reinforced insulation, assuming that the validity of the different systems has been duly verified by type tests.

Functional insulation is not considered unless specified by the purchaser according to 7.2.3.2.

Terminals, open contacts on switches and semiconductor valve devices, etc. shall be bridged where necessary in order to create a continuous circuit for the voltage test on the equipment. Before testing, semiconductors and other vulnerable components within a circuit may be disconnected and/or their terminals bridged to avoid damage occurring to them during the test.

Wherever practicable, individual components forming part of the insulation under test, for example capacitors of high frequency filters, should not be disconnected or bridged before the test. In this case, it is recommended to use the DC test voltage specified in Table 14 or Table 15.

Where the equipment is covered totally or partly by a non-conductive accessible surface, a conductive foil to which the test voltage is applied shall be wrapped around this surface for testing. In this case, the insulation test between a circuit and non-conductive accessible surface may be performed as a sample test instead of a routine test. If a complete covering of the housing with a metal foil is not possible, a partial covering shall be applied at those spots which are considered relevant with regard to protection.

Printed circuit boards and modules with multipoint connectors may be withdrawn, disconnected or replaced by dummies during the AC or DC voltage test.

This does not apply, however, to auxiliaries for which, in case of a dielectric breakdown, voltage may pass on to accessible parts not connected to the housing or from the side of higher voltage to the side of lower voltage. These are, for example, auxiliary transformers, measuring equipment, pulse transformers and instrument transformers, the insulation stress of which is equal to that of the main circuit.

Switchgear and control gear in main circuits shall be closed or by-passed. Auxiliaries not galvanically connected to the main circuits (for example system control equipment, fan motors) shall be connected with the housing during the AC or DC voltage test. During these tests, units with housings consisting of insulating material shall be covered with metal foil. The foil is regarded as housing when performing these tests.

7.2.2.2 Performing the voltage test

The test shall be applied as follows:

– test (1) between accessible conductive part (connected to earth) and each circuit sequentially (except PELV or SELV);
– test (2) between accessible surface (non-conductive or conductive but not connected to earth) and each circuit sequentially (except PELV or SELV);
– test (3) between each considered circuit sequentially and the other adjacent circuits connected together;
– test (4) between PELV or SELV circuit and each adjacent circuit sequentially.

Either the adjacent circuit or the PELV or SELV circuit may be earthed for this test.

NOTE 1 It is described above to test basic insulation between PELV and SELV circuits. For test of functional insulation between adjacent PELV or adjacent SELV circuits, see 7.2.2.1, third paragraph.

NOTE 2 PELV/SELV circuits and other circuits of higher voltage are separated from chassis (earth) by basic insulation. It is typically impossible to test double or reinforced insulation separating low-voltage circuits from high-voltage circuits in a fully-assembled equipment without overstressing the basic insulation. For this reason, the test voltage for basic insulation is used for double or reinforced insulation as well.

7.2.2.3 Duration of the AC or DC voltage test

The voltage test shall be performed with a sinusoidal voltage of which frequency is in the range from 45 Hz to 65 Hz. If the circuit contains capacitors, the test may be performed with a DC voltage of a value equal to the peak value of the specified AC voltage.

The duration of the test shall be 1 min for type test and at least 1 s for the routine test. The test voltage may be applied with increasing and/or decreasing ramp voltage but the full voltage shall be maintained for the specified duration.

For the detailed requirements of the test procedures and test circuits, refer to IEC 61180:2016, Clauses 5 and 6.

The test is successfully passed if no electrical breakdown occurs during the test.

7.2.2.4 Test voltages

AC or DC test voltages for equipment directly connected to low voltage mains are given in Table 14.

In Table 14, with U being the rated insulation voltage, for U between 0 V and 1 000 V, the AC test voltage equals (U + 1 200) V and the DC test voltage equals $\sqrt{2}\frac{3\sqrt{2}}{\pi} \times (U + 1\,200)$ V.

Table 14 – AC or DC test voltages for equipment directly connected to low voltage mains

Rated insulation voltage V (see 3.11.9)	Test voltages V	
	AC (RMS)	DC
≤ 50	1 250	1 770
100	1300	1 840
150	1 350	1 910
300	1 500	2 120
600	1 800	2 550
1 000	2 200	3 110
Interpolation is permitted.		

For higher voltage equipment, above 1 000 V AC and directly connected to high voltage mains, AC or DC test voltages are given in Table 15 (see 7.2.2.1).

For the test voltages in Table 15, the explanations are given below.

With U being the rated insulation voltage, for U between 1 000 V and 7 200 V, the AC test voltage equals (2,7 × U + 300) V and the DC test voltage equals $\sqrt{2}\frac{3\sqrt{2}}{\pi}$ × (2,7 × U + 300) V.

For U between 7 200 V and 36 000 V, the AC test voltage equals (1,8 × U + 7 200) V and the DC test voltage equals $\sqrt{2}\frac{3\sqrt{2}}{\pi}$ × (1,8 × U + 7 200) V.

Table 15 – AC or DC test voltages for equipment directly connected to high voltage mains

Rated insulation voltage V (see 3.11.9)	Test voltages V	
	AC (RMS)	DC
> 1 000	3 000	4 250
3 600	10 000	14 150
7 200	20 000	28 300
12 000	28 000	39 600
17 500	38 000	53 700
24 000	50 000	70 700
36 000	70 000	99 000
Interpolation is permitted.		

For equipment not directly connected to the mains, the AC test voltages are given in IEC 62477-1:2022, Table 29. Unless otherwise specified, the test voltage shall be agreed between purchaser and supplier. The principle should be to define AC test voltage with an RMS value not less than 1,15 times the total voltage used for designing the blocking capability of the semiconductor devices which are the most exposed to over-voltages within the circuit. Where DC voltage is used, the level of the test voltage should not be less than 1,63 times the total voltage used for designing the blocking state of the most exposed semiconductor valve devices to over-voltages within the circuit.

NOTE The word "total" means that, in case of semiconductor valve devices mounted in series, the total voltage is the sum of the voltages used for each semiconductor valve device, excluding the tolerance for voltage sharing between the different devices.

7.2.3 Additional tests

7.2.3.1 Insulation resistance

One minute after the AC or DC voltage test, the insulation resistance is to be measured by applying a direct voltage of a least 500 V. The insulation resistance should be not less than 1 MΩ for voltage values of $U_M / \sqrt{2}$ not exceeding 1 000 V.

For higher values of $U_M / \sqrt{2}$, the insulation resistance should exceed 1 000 Ω/V. The measurement of the insulation resistance is not necessary for routine tests.

Grounding resistors, if any, shall be disconnected during the insulation tests.

If water is used as a heat transfer agent, the insulation resistance test may be performed in two steps, without and with water. In the first case, the insulation level shall meet the specified value, while in the latter case it has to be specified separately.

7.2.3.2 Agreed tests

Insulation tests other than those specified in this document shall be performed only if agreed upon prior to order.

For high voltage converters 3,6 kV to 36 kV, when the assembly is connected to the AC line without a converter transformer, an impulse test may be performed in addition to the AC or DC voltage test if specified separately.

7.3 Functional test

7.3.1 Light load test and functional test

The light load test and functional test are carried out as follows.

a) Light load test

The light load test is carried out to verify that all parts of the electrical circuit and the cooling of the equipment operate properly together with the main circuit.

For the routine test, the converter is connected to rated input voltage. For the type test, the function of the equipment is also tested at maximum and minimum values of the input voltage. If series-connected semiconductor devices are used in the arms of the converter, the voltage sharing shall be checked. For a high voltage converter, this part of the light load test could be conducted at a lower voltage than rated. For low current equipment ($I_{dN} \leq 5$ A), the test is not necessary.

b) Functional test

The test load is chosen in such a manner that the required proof of performance is given. During the test, it should be verified that the control equipment, auxiliaries, protection equipment and main circuit are operating properly together. This could be achieved in different ways depending on the type of equipment.

7.3.2 Rated current test

The test is carried out to verify that the equipment will operate satisfactorily at rated current.

The DC terminals shall be short-circuited directly or with a reactor, and an alternating voltage of sufficient value, to cause at least the rated continuous direct current to flow, shall be connected to the AC terminals of the converter. During the test, the control equipment, if any, and auxiliaries have to be supplied separately with rated voltage.

By proper co-ordination of control, if any, and applied alternating voltage, rated continuous current shall be caused to flow through the DC terminals and operation shall be checked. If parallel connected devices are used in the arms, the current division shall be checked.

When it is more convenient, the current test may be replaced by a full load test at rated alternating voltage.

7.3.3 Over-current capability test

The over-current capability test is a load test. Specified values of short time over-current or starting up sequences of actual load are to be applied for the time interval specified. Specified values of voltage and current are to be recorded. If this is a factory type test, then it shall be carried out in accordance with 6.4.3 and 6.5. The over-current capability test is performed according to the second paragraph of rated current test (7.3.2).

7.3.4 Measurement of the inherent voltage regulation

The converter shall be supplied with rated alternating voltage. Transducer control current, delay angle, etc., shall be set at a specified value and direct voltage and direct current measured while the direct current is varied.

7.3.5 Measurement of ripple voltage and current

The measurements of superposed AC voltage, superposed AC current, noise voltage or noise current on the DC side, if necessary, shall be specified separately.

NOTE DC ripple and AC unbalance of input or output of the equipment are noted in measurement.

7.3.6 Measurement of harmonic currents

The determination of harmonic currents on the AC side, if necessary, shall be specified separately.

Harmonic emission may be determined by either:

- direct measurement, or
- calculation by validated simulation.

For converters included in low voltage equipment of rated input current greater than 16 A and less than or equal to 75 A, IEC 61000-3-12 gives the requirements for a simulation to be validated.

When a measurement is specified as a special test, the measurement methods and conditions shall comply either with the relevant standard: IEC 61000-3-2, IEC 61000-3-12 according to the AC rated current, or shall be agreed for higher values of rated current. In the latter case, it may be agreed to perform the measurement on the test premises of the manufacturer under defined conditions (example short-circuit on the DC side), or once installed at the customer site.

The measurement of harmonic currents shall be performed

- with measuring instruments and methods complying with IEC 61000-4-7,
- disregarding individual harmonic currents below 1 % of the reference fundamental current, and
- recording the characteristics of the voltage source used to perform the measurement (voltage level and tolerance, frequency and tolerance, R_{sc} and impedance, voltage unbalance in case of multiphase systems, harmonic voltages under no load conditions).

Results of the measurements shall be interpreted taking into account the characteristics of the source.

Harmonic voltage measurement depends on the whole installation and on the network itself and is outside the scope of this document.

7.4 Losses, temperature and power factor

7.4.1 Power loss determination for assemblies and equipment

7.4.1.1 General

Losses in the assembly and equipment may be determined either by calculations based on measurements or by direct measurements. Power loss of indirectly cooled converters may be evaluated by measurement of the heat removed by the heat transfer agent (using the calorimetric method) and estimation of heat flow through the housing of the converter.

When loss measurement cannot be performed under actual service conditions (rated load), the following methods may be applied.

The power losses of the converter shall be measured during a light load test (minimum load possible) and a short-circuit test. The total losses of the converter are the sum of the light load losses and short-circuit losses from the tests.

The method is valid under the following assumptions and conditions.

a) The losses in the semiconductor valve devices in service, due to switching losses, off-state and reverse current, are normally negligible.
b) The forward voltage drop in the semiconductor valve devices may be represented by a constant component plus a resistive component directly proportional to the current.
c) The losses in service due to forward current are taken to be equal to those that would exist at the same value of direct current and with rectangular current waveform in the converter arms in the case of polyphase connections.
d) Saturable or non-saturable reactors built into the assembly and carrying valve side phase current or converter circuit currents may be included in the measuring circuits. The bias of saturable reactors should be adjusted to the value that will be required in normal operation to supply rated direct voltage at rated direct current and rated voltage on the line side.
e) For those load conditions for which efficiency is specified, the efficiency may be determined by measuring input and output power or by segregated loss tests.
f) For those load conditions for which a conversion factor is specified, this may be determined by measuring AC power and DC output.
g) Increase of power losses due to existing line distortion or due to load increase is not considered here.

7.4.1.2 Methods of measurement

The methods of measurement prescribed here are based on the foregoing assumptions. The test or tests may be performed in the normal ambient temperature prevailing in the supplier's premises. Forward loss measurements shall be made when all parts of the converter assembly have reached stable temperature carrying the rated direct current.

When the converter transformer is included in the power loss measurement, the measurement shall be in accordance with the converter transformer standard.IEC 61378:2011.

NOTE It is possible the transformer losses need to be corrected considering its temperature characteristics.

7.4.1.3 Test circuits

Guidance on connections which may be used for test purposes is given in IEC TR 60146-1-2.

In all cases, the losses that will occur in service in voltage dividing resistors, damping circuits and surge arrestors, if any, are to be calculated and added.

7.4.2 Temperature rise test

The temperature rise of the converter shall be determined under test conditions given for the current test under the cooling conditions, which are least favourable. If the test is conducted at a lower temperature than the maximum specified, corrections have to be made. The temperature rise test is not limited to the main circuit.

Whenever possible, the temperature rise test should be conducted at rated load conditions.

In other cases, the test shall be conducted according to 7.3.2 and by adding temperature rise due to switching losses.

The temperature rise shall be measured at a specified point and the result shall be used to verify the design of the cooling system.

If the converter is rated for other than continuous load duty, the transient thermal impedance shall be measured for the main circuit components and for the cooling system. The test shall be performed for several of the components including those operating at the highest temperature.

The temperature rise at a specified point on the semiconductor valve devices shall be recorded. The rise of virtual junction temperature shall be calculated and based on the temperature measurements in order to show that the assembly is capable of carrying the specified load duty without exceeding maximum virtual junction temperature for the devices taking into account the actual current sharing between parallel valve devices.

7.4.3 Power factor measurements

As a rule, power factor measurements need not be carried out. However, if a power factor measurement is required, it shall be determined as the displacement factor $\cos\varphi_1$ (see 3.7.14) in accordance with 6.2.3.

7.5 Auxiliary device and control equipment

7.5.1 Checking of auxiliary devices

The function of auxiliary devices such as contactors, pumps, sequencing equipment, fans, etc., shall be checked. If convenient, this may be done in conjunction with the light load test.

7.5.2 Checking the properties of the control equipment

It is not feasible to verify the properties of the control equipment under all those load conditions which may prevail in real operation. However, it is recommended that trigger equipment should be checked under real load conditions as far as possible. When this cannot be done on the manufacturer's premises, it may be performed after installation by agreement with the user.

When practicable, the checking of control equipment may be restricted to a check under two load conditions as specified by 7.3.1 a) and 7.3.2 respectively.

In either case, the static and dynamic properties of the control equipment shall be checked. This shall include checking that the equipment operates satisfactorily for all values of supply voltages within the range of variation for which it is designed.

7.5.3 Checking the protective devices

Checking of the protective devices shall be carried out as far as possible without stressing the components of the equipment above their rated values.

Due to the wide variety of protective devices and their combinations, it is not possible to state any general rules for the checking of these devices. However, if a system control equipment is designed to protect the converter from current overloads, its ability in this respect shall be checked.

If type tests to check the effectiveness of fuse protection are considered to be necessary, they shall be specified separately with conditions for tests.

Routine tests shall be performed to check the operation of protective devices. It is, however, not intended that the operation of devices such as fuses, etc., where the operation is based on destruction of the operating component, shall be checked.

7.6 EMC tests

There are two aspects concerning EMC tests as follows.

a) Immunity test

   Checking of the immunity level of the converter shall be treated as an optional type test if so agreed in the contract. The test shall, as far as possible, be in accordance with the specified electrical service conditions.

   NOTE 1 National regulations relating to the prevention of radio interference are likely to restrict the ability to perform certain immunity tests outside an EMC shielded room.

   NOTE 2 Effective immunity tests usually include tests on auxiliary and control ports as well as on the main power port.

b) Radio frequency radiated and conducted disturbances

   The requirements for radio frequency radiated and conducted disturbances may be the subject of a separate specification and should then be specified for actual loads. The separate specification may be constituted by national regulations.

   NOTE 3 The disturbances from a complete equipment can differ from the disturbances produced by functional units. For example, the radio-frequency disturbances produced by a variable speed drive system including converter and motor are very different to the disturbances produced by a converter on its own.

7.7 Measurement of audible noise and additional tests

Test procedures and limits shall be specified separately for the measurement of audible noise.

NOTE Audible noise of a complete PCE can differ considerably from the values of individual functional units. Room conditions – resonance and reflection – will cause differences from calculated or measured values.

Specification and procedures for any additional tests, if necessary, for example vibration, shock, environmental, drift, shall be specified separately.

7.8 Tolerances

If guarantees are given, they shall always refer to rated values and rated conditions. It is not intended that guarantees shall necessarily be given upon all or any of the items shown below, but when such guarantees are given, they may be given either without tolerances or with tolerances, as may be specified. Either of these practices complies with this specification.

If guarantees are given with tolerances, the values stated in Table 16 shall apply. If the guaranteed values are given without tolerances, they are maximum or minimum values, as the case may be.

Table 16 – Tolerances

Subclause	Item	Tolerance
7.4.1	Assembly losses	+0,1 p.u. of the guaranteed value
7.4.1.2	Losses of transformer and reactor	+0,1 p.u. of the total guaranteed value
7.4.1.2	Efficiency of the PCE	Efficiency tolerance shall be the stricter of the values below [a] 1) value corresponding to +0,2 p.u. of the losses 2) –0,002 p.u. (-0,2 %) Namely, efficiency shall be at least [x – 0,2] %, where x is the guaranteed value.
7.4.3	Calculated displacement factor	$-0{,}2 \times (1 - \cos\varphi_1)$
7.3.4	Inductive direct voltage drop U_{dx}, due to the transformer	±0,1 p.u. of guaranteed value
7.3.4	Inherent voltage regulation	±0,15 p.u. of guaranteed regulation
	Measured direct voltages above 10 V [b]	$\pm (1 + 0{,}02\ U_{dN})$
	Measured direct voltages below or equal to 10 V [b]	$\pm 0{,}1\ U_{dN}$

[a] With the readings of loss measurements:
P for the output power and P_L for the losses, the first criterion provides a condition to the tolerance of the losses ΔP_L.

$\Delta P_L < 0{,}2 P_L$

The efficiency η is given by

$\eta = P / (P + P_L)$

The tolerance for the efficiency $\Delta\eta$, corresponding to the tolerance ΔP_L is approximately given by

$\Delta\eta = [(P_L + \Delta P_L) / (P + P_L + \Delta P_L)] - [(P_L) / (P + P_L)] \approx [\Delta P_L / P]$

Therefore, the second criterion for the efficiency tolerance provides the other condition to ΔP_L.

$\Delta P_L \approx [\Delta\eta \times P] < 0{,}002P$

In summary, for efficiency calculation, tolerance of the losses ΔP_L complies with the stricter of the following two conditions:

$\Delta P_L < 0{,}2 P_L$

$\Delta P_L < 0{,}002P$

For information, the first criterion implies the efficiency tolerance as approximately $0{,}2P_L / P$.

[b] For equipment provided with automatic control of an output quantity, the tolerance on the controlled quantity shall be specified.

Annex A
(normative)

Harmonics and interhamonics

A.1 Non-sinusoidal voltages and currents

The line-side current of a line commutated converter is usually similar to a train of trapezoids as shown in Figure 2. The repetition frequency of the current waveshape is equal to the frequency of the line voltage for commutation. The line voltage for commutation can be distorted such as is shown in Figure 4 unless appropriate countermeasures are taken. The repetition frequency of the distorted voltage waveshape is also equal to the frequency of the line voltage for commutation.

Thus, the current waveshape and the voltage waveshape include the harmonic components, the frequency of which are integer multiples of the frequency of the line voltage for commutation as indicated by Formula (19).

However, when the harmonics are measured in real installations, harmonic components with non-integer multiple of the fundamental frequency can be observed. They are called interharmonics. For harmonic measurement, refer to IEC 61000-4-7.

A.2 Two approaches for definitions related to harmonics

There have been two different approaches to establish a set of definitions related to harmonics. The first approach considered the frequency as primary source of the set of definitions and started with the definition of an arbitrary reference, giving it the name of "fundamental frequency" (IEC 61000-2-2:2002, 3.2.1, and IEC 61000-2-4:2002, 3.2.1).

For the purposes of this document, the fundamental frequency is the same as the power frequency supplying the converter, or supplied by the converter according to the case which is considered.

The definition above is practically reasonable as described below.

In many cases, the line commutated converters are connected to the mains power supply. The commutation voltage is fed by the mains. The frequency of the commutation voltage is the power frequency of the mains. In cases where the line commutated converters provide the power to the loads or to the machines, the frequency of the commutation voltage is determined by the converter. In these cases, the frequency of the commutation voltage is also the power frequency of the feeding lines to the loads or to the machines. As explained in Clause A.1, the frequencies of the harmonic components are the integer multiple of the commutation voltage. Thus, the frequencies of the harmonic components are integer multiple of the power frequency.

The second approach defines the harmonic components as the result of the Fourier analysis; frequencies are therefore a consequence (IEC 60050-551:1998, 551-20-01 and 551-20-02). However, this approach is not superior to the first approach from practical viewpoint.

Annex B
(informative)

Electrical environment – Short-circuit ratio

B.1 Electrical environment specification

The generic aspect of network conditions is developed in the publications of IEC TC 77 and its subcommittees. All EMC considerations are developed in dedicated standards as mentioned in 4.2.3.2. These EMC standards for application of semiconductor converters set requirements for both immunity and emission in the low frequency range and high frequency range and consider conducted phenomena as well as radiated phenomena.

Information on the prospective conditions of coexistence between supply systems, disturbing loads and sensitive apparatus (mostly low current control equipment, other power converters, power capacitors and sensitive lines such as used for communications and control) is essential during the early stages of the design of an installation.

Notably, harmonic emission should be considered relative to the ratio of short-circuit power to apparent power, presence of capacitors or other converters.

Guidance on calculation methods will be found in IEC TR 60146-1-2.

NOTE Such information is not possibly available. In such case, the approach below is taken for example.

Request system information from the appropriate local and national authorities, when the final location of the plant is known. This includes the power, line and radio communication authorities and those responsible for the limitation of disturbance.

Where agreement is necessary with the purchaser to finalize the requirements, the above information is used as a basis for discussion and when agreed, used for calculation purposes.

Low frequency conducted emissions are defined relative to the applicable set of standards prepared by IEC subcommittee 77A.

Four standards or Technical Reports deal with harmonic emission:

– IEC 61000-3-2: low voltage equipment with input current ≤ 16 A per phase;
– IEC TS 61000-3-4: Technical Report for low-voltage power supply systems and equipment with rated current greater than 75 A;
– IEC 61000-3-12: equipment connected to public low-voltage systems with input current between 16 A and 75 A per phase (restricted conditions of use);
– IEC TR 61000-3-6: distorting loads in MV and HV power systems.

NOTE 1 IEC 61000-3-2, IEC TS 61000-3-4 and IEC 61000-3-12 apply only to equipment intended to be connected to public low voltage AC distribution systems. This is stated in the scopes of these standards.

Four standards or Technical Reports deal with voltage changes, voltage fluctuations and flicker:

– IEC 61000-3-3: low-voltage equipment with input current ≤ 16 A per phase;
– IEC TS 61000-3-5: low-voltage equipment with input current greater than 75 A;
– IEC 61000-3-11: low-voltage equipment with input current ≤ 75 A (restricted conditions of use);
– IEC TR 61000-3-7: fluctuating loads in MV and HV power systems.

NOTE 2 IEC 61000-3-3, IEC TS 61000-3-5 and IEC 61000-3-11 apply only to equipment intended to be connected to public low voltage AC distribution systems. This is stated in the scopes of these standards.

Guidance for different applications is also provided in the dedicated EMC product standards (see 4.2.3.2).

When neither the final location nor the user is known, for standard converters, the supplier should select the "immunity class" from experience and this should be stated in the specification for the equipment.

The general electrical service condition tolerances are discussed in 5.4.

B.2 Point of coupling of the converter

B.2.1 Systems and installations

A converter is generally a component of a larger system. 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.

Within the installation, a converter is connected at a given point of coupling. The harmonic operating characteristics of the converter depend on the network characteristics at the point of coupling.

For a given installation, the agreed power S_{ST} defines the equivalent reference current I_{TN} (total RMS value):

$$S_{ST} = U_N \times I_{TN} \times \sqrt{3} \quad \text{(B.1)}$$

where

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

I_{TN} is the reference current.

NOTE 1 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 2 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., the reference current I_{TN1} is by convention equal to I_{TN}.

The agreed internal power S_{ITA}, for an installation at a defined IPC$_A$ (in-plant point of coupling) defines the equivalent reference current I_{TNA} (total RMS value) for the part A of the installation fed from IPC$_A$:

$$S_{ITA} = U_N \times I_{TNA} \times \sqrt{3} \quad \text{(B.2)}$$

where

U_N is the rated line-to-line voltage at the IPC_A.

NOTE 3 I_{TNA} is the rated current of the feeding section of 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_{SCA} defined at the IPC_A. This is the responsibility of those in charge of internal power distribution.

B.2.2 Short-circuit ratio of the source in the installation

R_{SI} is the ratio of the short-circuit power of the source at a defined point of coupling to the rated apparent power of the installation, or of a part of the installation, supplied from this point of coupling (see Figure B.1):

$$R_{SIA} = S_{SCA} / S_{ITA} = I_{SCA} / I_{TNA} \quad \text{(B.3)}$$

The subscript "A" indicates the considered part of the installation.

NOTE 1 3.9.9 defines the relative short-circuit power (R_{SC}) as "ratio of the short-circuit power of the source to the rated apparent power on the line side of the converter(s)". R_{SC} refers to a given point of the network, for specified operating conditions and specified network configuration."

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.

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 in-plant point of coupling (IPC_A) of the part of the installation to its rated current.

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 2 In Figure B.1, the installation shows a part A with a short-circuit current ratio of the source R_{SIA}. Part A contains a part B, part B has a short-circuit current ratio of the source R_{SIB}, and part A also contains a part C, etc. 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.

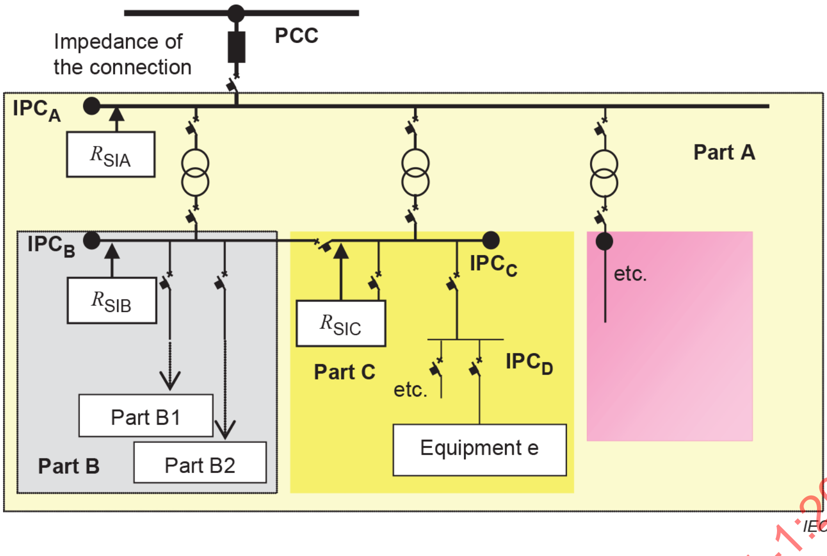


Figure B.1 – PCC, IPC, installation current ratio and R_{SI}

B.2.3 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 TS 61000-3-4 or IEC 61000-3-12):

$$R_{SC} = S_{SC} / S_{Ne} = I_{SC} / I_{LNe} \quad \text{(B.4)}$$

NOTE 1 With the example of Figure B.2, R_{SC} can be expressed as a function of the relevant R_{SI}. The piece of equipment (e) is fed from a bus bar (IPC_D), 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:

$$R_{SIe} = S_{SCD} / S_{ITe} = I_{SCD} / I_{LNe} = (I_{SCD} / I_{SC}) \times (I_{SC} / I_{LNe}) = (S_{SCD} / S_{SC}) \times (R_{SCe}) \quad \text{(B.5)}$$

or

$$R_{SCe} = (S_{SC} / S_{SCD}) \times R_{SIe} \quad \text{(B.6)}$$

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

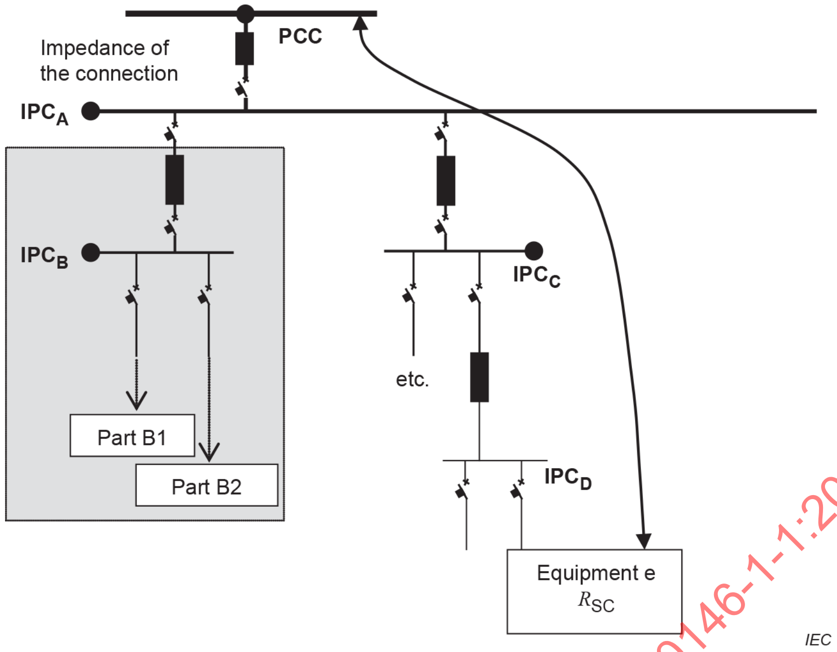


Figure B.2 – PCC, IPC, installation current ratio and R_{SC}

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

Annex C
(informative)

Introduction to safety standards for power conversion equipment

C.1 General

Annex C briefly introduces the safety standards of the IEC 62477 series for power electronics converter systems (PECS) and equipment. Annex C also clarifies that this edition of IEC 60146-1-1 was revised considering good coordination with the IEC 62477 series.

NOTE PECS is defined in IEC 62477-1. Annex C interprets PCE as equivalent to power conversion equipment.

C.2 Brief introduction to IEC 62477 series with reference to IEC 60146 series

IEC 62477-1 and IEC 62477-2 cover the safety requirements for the power conversion equipment while the IEC 60146-1-1 and IEC TR 60146-1-2 mainly cover the basic performance requirement. The IEC 62477 series is in the same position as the IEC 60146 series, which can be applied to the converters not covered by product standards.

C.3 Purposes or intentions of IEC 60146 series and IEC 62477 series

The purposes or intentions of the standards are listed in Table C.1. Some additional explanations are added in parentheses in Table C.1 for making the differences clear between two series.

From Table C.1, it is pointed out that the IEC 60146 series focus on basic requirements to operations and performances of the power conversion equipment while the IEC 62477 series focus on the safety requirements.

Table C.1 – Comparison on purposes or intentions between two standards

IEC 60146-1-1	IEC 62477-1
To establish basic terms and definitions (for operations and performance of the line-commutated converters) To specify basic performance requirements To specify test requirements (for basic operations and performances) of the line commutated converters To specify service conditions which influences the basis of ratings	To establish common terminology for safety aspects relating to PECS To establish minimum requirements for the coordination of safety aspects of interrelated parts within PECS To establish common basis for minimum safety requirements for the PEC portion of products that contain PEC To specify requirements to reduce safety risks during use and operation and during service and maintenance where specifically stated

The requirements related to safety were deleted from this revision of IEC 60146-1-1. This edition of IEC 60146-1-1 refers to the IEC 62477 series for relevant guidance on safety.

Careful consideration has been made for test requirements during revision of IEC 60146-1-1. The test requirements related to safety have been deleted and now IEC 60146-1-1 only includes the test requirement for basic operations and performances of the power electronics converter.

IEC 60146-1-1 also considers that the power electronics products covered by this edition comply with fundamental IEC standards like IEC 60364-1 or IEC 60529.

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

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IEC TR 61800-6, *Adjustable speed electrical power drive systems – Part 6: Guide for determination of types of load duty and corresponding current ratings*

IEC 61803:2020, *Determination of power losses in high-voltage direct current (HVDC) converter stations with line-commutated converters*

IEC 62040-2:2016, *Uninterruptible power systems (UPS) – Part 2: Electromagnetic compatibility (EMC) requirements*

IEC 62068, *Electrical insulating materials and systems – General method of evaluation of electrical endurance under repetitive voltage impulses*

IEC 62310-2:2006, *Static transfer systems (STS) – Part 2: Electromagnetic compatibility (EMC) requirements*

IEC 62589, *Railway applications – Fixed installations – Harmonisation of the rated values for converter groups and tests on converter groups*

IEC/IEEE 60076-57-129, *Power transformers – Part 57-129: Transformers for HVDC applications*

IEEE 519, *IEEE Recommended practices and Requirements for Harmonic Control in Electrical Power Systems*

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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CONVERTISSEURS À SEMICONDUCTEURS – EXIGENCES GÉNÉRALES ET CONVERTISSEURS COMMUTÉS PAR LE RÉSEAU –

Partie 1-1: Spécification des exigences de base

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9) L'IEC attire l'attention sur le fait que la mise en application du présent document peut entraîner l'utilisation d'un ou de plusieurs brevets. L'IEC ne prend pas position quant à la preuve, à la validité et à l'applicabilité de tout droit de propriété revendiqué à cet égard. À la date de publication du présent document, l'IEC n'avait pas reçu notification qu'un ou plusieurs brevets pouvaient être nécessaires à sa mise en application. Toutefois, il y a lieu d'avertir les responsables de la mise en application du présent document que des informations plus récentes sont susceptibles de figurer dans la base de données de brevets, disponible à l'adresse https://patents.iec.ch. L'IEC ne saurait être tenue pour responsable de ne pas avoir identifié de tels droits de brevet.

L'IEC 60146-1-1 a été établie par le comité d'études 22 de l'IEC: Systèmes et équipements électroniques de puissance. Il s'agit d'une Norme internationale.

Cette cinquième édition annule et remplace la quatrième édition parue en 2009. Cette cinquième édition constitue une révision technique.

Cette cinquième édition introduit quatre modifications principales:

a) réédition de l'ensemble de la norme conformément aux directives en vigueur;
b) suppression des descriptions relatives à la sécurité, pour prendre en compte la coordination avec la série IEC 62477;
c) modifications des méthodes de calcul de la variation inductive de tension;
d) modifications pour prendre en compte la coordination avec la série IEC 61378.

Le texte de cette Norme internationale est issu des documents suivants:

Projet	Rapport de vote
22/374/FDIS	22/378/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à son approbation.

La langue employée pour l'élaboration de cette Norme internationale est l'anglais.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2, il a été développé selon les Directives ISO/IEC, Partie 1 et les Directives ISO/IEC, Supplément IEC, disponibles sous www.iec.ch/members_experts/refdocs. Les principaux types de documents développés par l'IEC sont décrits plus en détail sous www.iec.ch/publications.

Une liste de toutes les parties de la série IEC 60146, publiées sous le titre général *Convertisseurs à semiconducteurs – Exigences générales et convertisseurs commutés par le réseau*, se trouve sur le site Web de l'IEC.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site Web de l'IEC sous webstore.iec.ch dans les données relatives au document recherché. À cette date, le document sera

- reconduit,
- supprimé, ou
- révisé.

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INTRODUCTION

Les principaux objectifs de la série IEC 60146-1 sont les suivants.

IEC 60146-1-1, Spécification des exigences de base:

- stipuler les termes de base et leurs définitions;
- spécifier les conditions de service qui ont une influence sur le dimensionnement;
- spécifier les exigences d'essai applicables aux convertisseurs et ensembles électroniques de puissance, ainsi qu'aux convertisseurs normaux (pour les convertisseurs spéciaux, voir l'IEC TR 60146-1-2);
- spécifier les exigences de fonctionnement de base;
- fournir les exigences d'emploi applicables aux convertisseurs de puissance à semiconducteurs.

IEC TR 60146-1-2, Lignes directrices d'application:

- apporter des informations supplémentaires relatives aux conditions d'essai et aux composants (par exemple: valves à semiconducteurs), lorsque ces informations sont exigées pour leur utilisation dans les convertisseurs de puissance à semiconducteurs, pour compléter ou modifier les normes existantes;
- fournir les références utiles, les coefficients de calcul, les formules et les diagrammes utilisés dans la pratique des convertisseurs de puissance.

CONVERTISSEURS À SEMICONDUCTEURS – EXIGENCES GÉNÉRALES ET CONVERTISSEURS COMMUTÉS PAR LE RÉSEAU –

Partie 1-1: Spécification des exigences de base

1 Domaine d’application

La présente partie de l’IEC 60146 spécifie les exigences relatives aux caractéristiques de fonctionnement de tous les convertisseurs de puissance à semiconducteurs, ainsi que des commutateurs de puissance à semiconducteurs utilisant des valves électroniques, commandables et/ou non commandables.

Les valves électroniques comprennent principalement des dispositifs à semiconducteurs, non commandables (c’est-à-dire des diodes de redressement) ou commandables (c’est-à-dire des thyristors, triacs, thyristors blocables et transistors de puissance). Les dispositifs commandables peuvent être à blocage inverse ou à conduction inverse et commandés par un courant, une tension ou par la lumière. Les dispositifs qui ne sont pas bistables sont présumés être utilisés en mode commuté.

Le présent document est prévu en premier lieu pour spécifier les exigences de base applicables aux convertisseurs en général, ainsi que les exigences applicables aux convertisseurs commutés par le réseau, pour la conversion de puissance alternative en puissance continue ou vice versa. Certaines parties du présent document s’appliquent également à d’autres types de convertisseurs électroniques de puissance, sous réserve qu’il n’existe pas de normes de produit qui leur soient propres.

Ces exigences spécifiques relatives aux équipements s’appliquent aux convertisseurs de puissance à semiconducteurs qui, soit mettent en œuvre différents modes de conversion, soit utilisent différents types de commutation (par exemple convertisseurs autocommutés à semiconducteurs), soit correspondent à des applications particulières (par exemple convertisseurs à semiconducteurs pour moteurs à courant continu), voire englobent diverses propriétés spécifiques (par exemple convertisseurs directs en courant continu pour matériel roulant à traction électrique).

Le présent document s’applique à tous les convertisseurs de puissance non couverts par une norme de produit spécifique, ou si ladite norme ne couvre pas des caractéristiques particulières. Généralement, les normes de produit spécifiques aux convertisseurs de puissance font référence au présent document.

NOTE 1 Le présent document n’est pas destiné à définir des exigences de CEM. Il couvre tous les phénomènes et introduit par conséquent des références aux normes spécifiques applicables conformément à leur domaine d’application.

NOTE 2 Pour les informations relatives aux transformateurs de conversion, relatives au présent document, voir l’IEC 61378-1.

NOTE 3 Tous les termes cités dans l’Article 3 ne sont pas nécessairement utilisés dans le présent document. Ils sont toutefois nécessaires pour établir une compréhension commune de l’application des convertisseurs à semiconducteurs.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu’ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60050-551:1998, *Vocabulaire Électrotechnique International – Partie 551: Électronique de puissance*, disponible à l'adresse www.electropedia.org

IEC 60050-551-20:2001, *Vocabulaire Électrotechnique International – Partie 551-20: Électronique de puissance – Analyse harmonique*, disponible à l'adresse www.electropedia.org

IEC 60664-1:2020, *Coordination de l'isolement des matériels dans les réseaux d'énergie électrique à basse tension – Partie 1: Principes, exigences et essais*

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 61000-3-2:2018, *Compatibilité électromagnétique (CEM) – Partie 3-2: Limites – Limites pour les émissions de courant harmonique (courant appelé par les appareils ≤ 16 A par phase)*

IEC 61000-3-12:2011, *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 61000-4-7:2002, *Compatibilité électromagnétique (CEM) – Partie 4-7: Techniques d'essai et de mesure – Guide général relatif aux mesures d'harmoniques et d'interharmoniques, ainsi qu'à l'appareillage de mesure, applicable aux réseaux d'alimentation et aux appareils qui y sont raccordés*

IEC 61000-6-1:2016, *Compatibilité électromagnétique (CEM) – Partie 6-1: Normes génériques – Norme d'immunité pour les environnements résidentiels, commerciaux et de l'industrie légère*

IEC 61000-6-2:2016, *Compatibilité électromagnétique (CEM) – Partie 6-2: Normes génériques – Norme d'immunité pour les environnements industriels*

IEC 61000-6-4:2018, *Compatibilité électromagnétique (CEM) – Partie 6-4: Normes génériques – Norme sur l'émission pour les environnements industriels*

IEC 61378-1:2011, *Transformateurs de conversion – Partie 1: Transformateurs pour applications industrielles*

IEC 62477-1:2022, *Exigences de sécurité applicables aux systèmes et matériels électroniques de conversion de puissance – Partie 1: Généralités*

IEC 62477-2:2018, *Exigences de sécurité applicables aux systèmes et matériels électroniques de conversion de puissance – Partie 2: Convertisseurs électroniques de puissance entre 1 000 V en courant alternatif ou 1 500 V en courant continu et 36 kV en courant alternatif ou 54 kV en courant continu*

3 Termes et définitions

Pour les besoins du présent document, les termes et les définitions de l'IEC 60050-551, l'IEC 60050-551-20, l'IEC 60664-1 ainsi que les 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:

- ISO Online browsing platform: disponible à l'adresse https://www.iso.org/obp
- IEC Electropedia: disponible à l'adresse https://www.electropedia.org

NOTE La méthode adoptée est la suivante:

– lorsqu'une définition existante de l'IEC 60050 nécessite de plus amples précisions ou des informations supplémentaires, le titre, la référence et le texte ajouté sont fournis;

– des explications et des figures sont fournies en 4.2;

– les termes associés aux défauts et défaillances de convertisseurs sont définis dans l'IEC TR 60146-1-2.

3.1 Dispositifs à semiconducteurs et combinaisons

3.1.1
dispositif à semiconducteur
dispositif dont les caractéristiques électriques essentielles sont dues au déplacement de porteurs de charge dans un ou plusieurs matériaux semiconducteurs

[SOURCE: IEC 60050-151:2001, 151-13-63]

3.1.2
interrupteur électronique de puissance
interrupteur électronique
ensemble fonctionnel comprenant au moins une valve électronique commandable, assurant la commande (ouverture et fermeture) électronique d'un circuit de puissance

[SOURCE: IEC 60050-551:1998, 551-13-01]

3.1.3
interrupteur à semiconducteurs
interrupteur électronique de puissance comportant des valves électroniques à semiconducteurs

Note 1 à l'article: On utilise des termes similaires pour des interrupteurs électroniques ou des contrôleurs de puissance comportant des valves électroniques particulières, par exemple contrôleur à thyristors ou interrupteur à transistor.

[SOURCE: IEC 60050-551:1998, 551-13-05]

3.1.4
valve non commandable
diode de redressement
valve bloquante en inverse dont le trajet de courant conduit dans le sens de conduction sans intervention d'aucun signal de commande

[SOURCE: IEC 60050-551:1998, 551-14-04]

3.1.5
thyristor
dispositif à semiconducteurs bistable, comprenant trois jonctions ou plus, qui peut être commuté de l'état bloqué à l'état passant ou vice versa

Note 1 à l'article: Les dispositifs ayant seulement trois couches mais possédant des caractéristiques de commutation similaires à celles des thyristors à quatre couches peuvent aussi être appelés thyristors.

Note 2 à l'article: Le terme "thyristor" est utilisé de manière générale pour désigner tout dispositif de type PNPN. Il peut être utilisé seul pour tout élément de la famille des thyristors lorsqu'un tel usage ne prête pas à confusion ou à malentendu. En particulier, le terme "thyristor" est couramment employé pour le thyristor triode bloqué en inverse, antérieurement désigné par "redresseur commandé au silicium".

[SOURCE: IEC 60050-521:2002, 521-04-61, modifié – La Note 2 à l'article a été ajoutée]

3.1.6
thyristor triode bloqué en inverse
thyristor à trois bornes qui pour une tension d'anode négative ne commute pas, mais présente un état bloqué en inverse

[SOURCE: IEC 60050-521:2002, 521-04-63]

3.1.7
thyristor triode passant en inverse
thyristor à trois bornes qui pour une tension d'anode négative ne commute pas et conduit de forts courants à des tensions d'amplitude comparable à celle de la tension directe à l'état passant

[SOURCE: IEC 6005-521:2002, 521-04-65]

3.1.8
thyristor triode bidirectionnel
triac
thyristor à trois bornes présentant sensiblement le même comportement en commutation dans le premier et le troisième quadrants de la caractéristique principale

[SOURCE: IEC 60050-521:2002, 521-04-67]

3.1.9
thyristor blocable
thyristor qui peut être commuté de l'état passant à l'état bloqué et vice versa en appliquant des signaux de commande, de polarité appropriée, à la borne de gâchette

Note 1 à l'article: Le thyristor à blocage par la gâchette (GTO, Gate Turn-Off thyristor) et le thyristor intégré commuté par la gâchette (IGCT, Integrated Gate-Commutated Thyristor) sont des types de thyristors blocables.

[SOURCE: IEC 60050-521:2002, 521-04-68, modifié – La Note à l'article a été ajoutée]

3.1.10
transistor de puissance
transistor conçu pour commuter de l'état passant à l'état bloqué et vice versa en appliquant des signaux de commande, de polarité appropriée, à la base ou à la borne de gâchette

Note 1 à l'article: La structure intrinsèque du dispositif est capable de fournir une amplification (voir l'IEC 60050-521:2002, 521-04-46).

Note 2 à l'article: Différentes techniques de transistors de puissance sont utilisées telles que les transistors bipolaires, transistors bipolaires à grille isolée (IGBT, Insulated Gate Bipolar Transistor), transistors à effet de champ métal-oxyde-semiconducteurs (MOSFET, Metal-Oxide-Semiconductor Field-Effect Transistor), etc.

3.1.11
bloc de valves
groupement unitaire d'une ou de plusieurs valves électroniques avec les dispositifs de montage et accessoires éventuels correspondants

[SOURCE: IEC 60050-551:1998, 551-14-12]

3.1.12
ensemble de valves
assemblage électrique et mécanique de valves électroniques ou de blocs de valves, comprenant tous ses moyens de raccordement et ses accessoires à l'intérieur de sa propre structure mécanique

Note 1 à l'article: Des termes similaires sont utilisés pour des blocs ou des ensembles comprenant des valves électroniques particulières, par exemple bloc de diodes (composé uniquement de diodes de redressement), ensemble de thyristors (composé de thyristors seuls ou combinés avec des diodes de redressement).

[SOURCE: IEC 60050-551:1998, 551-14-13]

3.1.13
valve électronique
dispositif électronique indivisible assurant la conversion électronique de puissance ou l'ouverture et la fermeture électronique d'un circuit électrique de puissance unique, comportant un trajet conducteur unidirectionnel, non commandable ou commandable de façon bistable

[SOURCE: IEC 60050-551:1998, 551-14-02, modifié – Les Notes à l'article ont été supprimées]

3.1.14
valve à semiconducteurs
valve électronique constituée d'un dispositif à semiconducteurs

Note 1 à l'article: Exemples typiques de valves à semiconducteurs: thyristors, diodes de redressement, transistors bipolaires, transistors à effet de champ métal-oxyde-semiconducteurs (MOSFET) et transistors bipolaires à grille isolée (IGBT).

Note 2 à l'article: Plusieurs valves à semiconducteurs peuvent être intégrées sur une pastille de semiconducteur (exemples: un thyristor et une diode de redressement dans un thyristor passant en inverse, un transistor de commutation de puissance à effet de champ avec sa diode inverse) ou assemblées dans un même boîtier (module de puissance à semiconducteur). Tous ces ensembles sont considérés comme des valves à semiconducteurs séparées.

[SOURCE: IEC 60050-551:1998, 551-14-09, modifié – Les Notes à l'article ont été ajoutées]

3.1.15
conversion électronique de puissance
conversion de puissance
conversion
changement d'une ou de plusieurs caractéristiques d'un système électrique de puissance essentiellement sans perte de puissance notable, au moyen de valves électroniques

Note 1 à l'article: Ces caractéristiques sont par exemple, l'amplitude de tension, le nombre de phases et la fréquence, y compris la fréquence nulle.

[SOURCE: IEC 60050-551:1998, 551-11-02]

3.1.16
convertisseur électronique de puissance
convertisseur de puissance
convertisseur
ensemble fonctionnel assurant la conversion électronique de puissance, constitué d'une ou de plusieurs valves électroniques et éventuellement d'accessoires

Note 1 à l'article: Les transformateurs et les filtres de conversion associés au réseau interfaçant en matière de caractéristiques électriques sont exclus du convertisseur proprement dit. Ces dispositifs font partie intégrante du système. Tout dispositif nécessaire au bon fonctionnement du convertisseur à proprement parler est intégré au convertisseur, par exemple les filtres utilisés pour limiter le rapport du/dt appliqué aux valves, les suppresseurs de surtensions, etc. Tout accessoire nécessaire pour le bon fonctionnement du convertisseur à proprement parler est intégré au convertisseur, par exemple ventilateurs ou système de refroidissement.

[SOURCE: IEC 60050-551:1998, 551-12-01, modifié – L'expression "de transformateurs et de filtres si nécessaire" a été supprimée de la définition, la Note à l'article a été remplacée et la figure a été supprimée]

3.1.17
dispositif de commande
dispositif à gâchette
dispositif qui fournit à partir d'un signal de commande les impulsions d'amorçage appropriées à des valves commandables d'un convertisseur ou interrupteur de puissance et qui comporte des circuits temporisateurs ou déphaseurs, des circuits générateurs d'impulsions et, en règle générale, des circuits d'alimentation

3.1.18
équipement de commande d'un système
équipement associé à un équipement ou à un système convertisseur de puissance qui assure le réglage automatique des caractéristiques de sortie du convertisseur en fonction d'une grandeur contrôlée

Note 1 à l'article: La vitesse d'un moteur et la force de traction constituent des exemples de grandeur contrôlée.

3.1.19
convertisseur à semiconducteurs
convertisseur électronique de puissance comportant des valves électroniques à semiconducteurs

Note 1 à l'article: On utilise des termes similaires pour les convertisseurs en général ou pour des types particuliers de convertisseurs et pour des convertisseurs comportant des valves électroniques particulières ou spéciales, par exemple: convertisseur à thyristors, onduleur à transistors.

[SOURCE: IEC 60050-551:1998, 551-12-42, modifié – La figure a été supprimée]

3.1.20
équipement de conversion de puissance
PCE
équipement comprenant le convertisseur électronique de puissance et les accessoires nécessaires pour le fonctionnement du convertisseur proprement dit, voire d'autres éléments spécifiques à l'application, et où ces éléments ne peuvent pas être séparés physiquement sans empêcher le convertisseur de fonctionner

Note 1 à l'article: L'abréviation "PCE" est dérivée du terme anglais développé correspondant "Power Conversion Equipment".

3.1.21
système de conversion de puissance
système comprenant un équipement de conversion de puissance et des composants associés nécessaires à l'application

Note 1 à l'article: L'appareillage de commutation, les bobines d'inductance ou les transformateurs et les filtres spécifiques constituent des exemples de composants associés.

3.2 Bras et connexions

3.2.1
bras de valve
bras
partie du circuit d'un convertisseur ou d'un interrupteur électronique de puissance limitée par deux bornes à courant alternatif ou à courant continu quelconques, et comprenant une ou plusieurs valves électroniques conduisant simultanément, connectées entre elles et éventuellement à d'autres constituants

[SOURCE: IEC 60050-551:1998, 551-15-01]

3.2.2
bras principal
bras de valve concerné par le transfert principal de puissance entre les deux côtés du convertisseur ou de l'interrupteur électronique

[SOURCE: IEC 60050-551:1998, 551-15-02, modifié – La Note à l'article a été supprimée]

3.2.3
bras auxiliaire
bras de valve autre qu'un bras principal

Note 1 à l'article: Quelquefois un bras auxiliaire remplit temporairement plusieurs des fonctions suivantes: bras de shuntage, bras de roue libre, bras d'extinction ou bras de retour.

[SOURCE: IEC 60050-551:1998, 551-15-05]

3.2.4
bras de shuntage
bras auxiliaire fournissant un trajet conducteur permettant la circulation du courant sans échange de puissance entre la source et la charge

[SOURCE: IEC 60050-551:1998, 551-15-06]

3.2.5
bras de roue libre
bras de shuntage ne contenant que des valves non commandables

[SOURCE: IEC 60050-551:1998, 551-15-07]

3.2.6
bras d'extinction
bras auxiliaire destiné à dériver temporairement et sans intermédiaire le courant d'un bras de valve en conduction consistant en une ou plusieurs valves à accrochage ne pouvant être bloquées par un signal de commande

[SOURCE: IEC 60050-551:1998, 551-15-08]

3.2.7
bras de retour
bras de valve destiné à transférer une partie de la puissance de la charge vers la source

[SOURCE: IEC 60050-551:1998, 551-15-09]

3.2.8
montage de convertisseur
disposition électrique de bras de valve et d’autres composants essentiels pour le fonctionnement du circuit de puissance principal d’un convertisseur

Note 1 à l’article: La pratique courante utilise également le terme "topologie" du convertisseur avec la même signification.

[SOURCE: IEC 60050-551:1998, 551-15-10, modifié – La Note à l’article a été ajoutée]

3.2.9
montage de base d’un convertisseur
disposition électrique des bras principaux d’un convertisseur

[SOURCE: IEC 60050-551:1998, 551-15-11]

3.2.10
montage à simple voie
<d’un convertisseur> montage convertisseur dans lequel chaque borne de phase du circuit à courant alternatif est parcourue par un courant unidirectionnel

[SOURCE: IEC 60050-551:1998, 551-15-12]

3.2.11
montage à double voie
<d’un convertisseur> montage convertisseur dans lequel chaque borne de phase du circuit à courant alternatif est parcourue par un courant bidirectionnel

[SOURCE: IEC 60050-551:1998, 551-15-13]

3.2.12
montage en pont
montage de paires de bras à double voie dans lequel les bornes centrales sont les bornes de phase du circuit à courant alternatif, et les bornes extérieures de même polarité sont reliées ensemble et sont les bornes à courant continu

[SOURCE: IEC 60050-551:1998, 551-15-14]

3.2.13
montage homogène
montage dont les bras principaux sont ou bien tous commandables ou bien tous non commandables

[SOURCE: IEC 60050-551:1998, 551-15-15]

3.2.14
montage hétérogène
montage mixte
montage constitué par des bras principaux en partie commandables et en partie non commandables

[SOURCE: IEC 60050-551:1998, 551-15-18]

3.2.15
montage en série
montage de plusieurs bipôles de façon qu’ils forment un seul chemin

[SOURCE: IEC 60050-131:2002, 131-12-75, modifié – Les Notes à l’article ont été supprimées]

3.2.16
montage en série de convertisseurs
montage en série dans lequel deux convertisseurs ou plus sont connectés de manière telle que leurs tensions s’ajoutent

3.2.17
montage survolteur/dévolteur
montage en série de plusieurs convertisseurs dont les tensions continues s’ajoutent ou se soustraient, suivant l’arrangement de leurs connexions individuelles

[SOURCE: IEC 60050-551:1998, 551-15-21]

3.3 Commandabilité des bras de convertisseurs et quadrants de fonctionnement (côté courant continu)

3.3.1
bras commandable
bras de convertisseur comprenant une ou plusieurs valves commandables

3.3.2
bras non commandable
bras de convertisseur ne comprenant que des valves non commandables

3.3.3
quadrant de fonctionnement
<côté courant continu> quadrant du plan tension/courant défini par la polarité de la tension continue et le sens du courant

3.3.4
convertisseur à un quadrant
convertisseur alternatif/continu ou convertisseur de courant continu à un seul sens de circulation de la puissance en courant continu

[SOURCE: IEC 60050-551:1998, 551-12-34, modifié – La figure a été supprimée]

3.3.5
convertisseur à deux quadrants
convertisseur alternatif/continu ou convertisseur de courant continu à deux sens possibles de circulation de la puissance en courant continu associés à une direction du courant continu et à deux directions de la tension continue ou vice versa

[SOURCE: IEC 60050-551:1998, 551-12-35, modifié – La figure a été supprimée]

3.3.6
convertisseur à quatre quadrants
convertisseur alternatif/continu ou convertisseur de courant continu à deux sens possibles de circulation de la puissance en courant continu associés à deux directions de la tension continue et à deux directions du courant continu

[SOURCE: IEC 60050-551:1998, 551-12-36, modifié – La figure a été supprimée]

3.3.7
convertisseur réversible
convertisseur bidirectionnel
convertisseur dans lequel le sens de circulation de la puissance peut être inversé

Note 1 à l'article: Le terme "convertisseur bidirectionnel" correspond à la pratique courante, et fournit une meilleure description du sens de circulation du courant bidirectionnel dans le convertisseur.

[SOURCE: IEC 60050-551:1998, 551-12-37, modifié – Le terme en variante "convertisseur bidirectionnel" et la Note à l'article ont été ajoutés]

3.3.8
convertisseur simple
convertisseur réversible alternatif/continu unidirectionnel pour le courant continu

[SOURCE: IEC 60050-551:1998, 551-12-38, modifié – La figure a été supprimée]

3.3.9
convertisseur double
convertisseur réversible alternatif/continu bidirectionnel pour le courant continu

[SOURCE: IEC 60050-551:1998, 551-12-39]

3.3.10
section convertisseur d'un convertisseur double
partie d'un convertisseur double dans laquelle le courant continu principal circule toujours dans le même sens lorsqu'il est vu depuis les bornes côté continu

[SOURCE: IEC 60050-551:1998, 551-12-40]

3.3.11
commande de phase
processus consistant à faire varier l'instant de la période à partir duquel commence la conduction de courant dans une valve électronique ou dans un bras de valve

[SOURCE: IEC 60050-551:1998, 551-16-23]

3.3.12
commande d'amorçage
commande qui provoque l'amorçage d'une valve à accrochage ou d'un bras composé de telles valves

[SOURCE: IEC 60050-551:1998, 551-16-61]

3.4 Commutation, extinction et circuits de commutation

3.4.1
commutation
<dans un convertisseur électronique de puissance> transfert du courant d'un bras conducteur dans le bras suivant sans interruption du courant, les deux bras conduisant simultanément pendant un intervalle de temps fini

[SOURCE: IEC 60050-551:1998, 551-16-01]

3.4.2
extinction sans commutation
interruption de la conduction du courant dans un bras sans commutation

[SOURCE: IEC 60050-551:1998, 551-16-19]

3.4.3
commutation directe
commutation entre deux bras principaux, sans transfert à travers un ou plusieurs bras auxiliaires

[SOURCE: IEC 60050-551:1998, 551-16-09]

3.4.4
commutation indirecte
suite de commutations d'un bras principal à un autre, ou de retour au même bras principal, au moyen de commutations successives par l'intermédiaire d'un ou de plusieurs bras auxiliaires

[SOURCE: IEC 60050-551:1998, 551-16-10]

3.4.5
commutation externe
commutation dans laquelle la tension de commutation est fournie par une source extérieure au convertisseur ou à l'interrupteur électronique

[SOURCE: IEC 60050-551:1998, 551-16-11]

3.4.6
commutation par le réseau
commutation externe dans laquelle la tension de commutation est fournie par le réseau

[SOURCE: IEC 60050-551:1998, 551-16-12]

3.4.7
commutation par la charge
commutation externe dans laquelle la tension de commutation est fournie par une charge autre que celle du réseau

[SOURCE: IEC 60050-551:1998, 551-16-13]

3.4.8
commutation par machine
commutation externe dans laquelle la tension de commutation est fournie par une machine tournante

[SOURCE: IEC 60050-551:1998, 551-16-14]

3.4.9
commutation par la charge résonante
méthode de commutation par la charge dans laquelle la tension de commutation est fournie par la charge, en utilisant sa résonance

3.4.10
commutation autonome
commutation dans laquelle la tension de commutation est fournie par des composants inclus dans le convertisseur ou l'interrupteur électronique

[SOURCE: IEC 60050-551:1998, 551-16-15]

3.4.11
commutation par condensateur
méthode de commutation autonome dans laquelle la tension de commutation est fournie par des condensateurs inclus dans le circuit de commutation

[SOURCE: IEC 60050-551:1998, 551-16-17]

3.4.12
commutation capacitive à couplage inductif
méthode de commutation capacitive dans laquelle le circuit des condensateurs est couplé par induction au circuit de commutation

3.4.13
commutation par extinction forcée
méthode de commutation autonome dans laquelle la tension de commutation est fournie par le blocage de la valve électronique conductrice par un signal de commande

Note 1 à l'article: La valve suivante est amorcée simultanément.

[SOURCE: IEC 60050-551:1998, 551-16-16]

3.4.14
extinction par valve
méthode d'extinction sans commutation dans laquelle l'extinction est produite par la valve électronique elle-même

[SOURCE: IEC 60050-551:1998, 551-16-20]

3.4.15
extinction externe
méthode d'extinction sans commutation dans laquelle l'extinction résulte de causes externes à la valve

Note 1 à l'article: Dans les convertisseurs commutés par le réseau, l'extinction externe se produit en régime de conduction discontinue.

[SOURCE: IEC 60050-551:1998, 551-16-21, modifié – L'expression "valve électronique" a été remplacée par "valve" et la Note à l'article a été ajoutée]

3.5 Caractéristiques de commutation

3.5.1
circuit de commutation
circuit constitué par les bras commutants et la source fournissant la tension de commutation

[SOURCE: IEC 60050-551:1998, 551-16-03]

3.5.2
tension de commutation
tension qui provoque la commutation de courant

[SOURCE: IEC 60050-551:1998, 551-16-02]

3.5.3
inductance de commutation
inductance totale comprise dans le circuit de commutation

Note 1 à l'article: Pour les convertisseurs commutés par le réseau ou par machine, la réactance de commutation est l'impédance de l'inductance de commutation à la fréquence fondamentale.

[SOURCE: IEC 60050-551:1998, 551-16-07, modifié – La Note à l'article a été ajoutée]

3.5.4
intervalle de commutation
intervalle de temps au cours duquel les bras commutants conduisent simultanément le courant principal

[SOURCE: IEC 60050-551:1998, 551-16-04]

3.5.5
angle d'empiètement
μ
durée de la commutation exprimée en mesure angulaire

[SOURCE: IEC 60050-551:1998, 551-16-05, modifié – Le symbole μ a été ajouté]

3.5.6
encoche de commutation
transitoire périodique de tension qui peut apparaître sur la tension alternative d'un convertisseur commuté par le réseau ou par machine, du fait de la commutation

[SOURCE: IEC 60050-551:1998, 551-16-06]

3.5.7
transitoire répétitif de commutation
oscillation de tension associée à l'encoche de commutation

3.5.8
groupe commutant
groupe de bras principaux qui commutent cycliquement entre eux sans commutation intermédiaire du courant vers d'autres bras principaux

[SOURCE: IEC 60050-551:1998, 551-16-08]

3.5.9
indice de commutation
q
nombre de commutations d'un bras principal à un autre pendant une période élémentaire dans chaque groupe commutant

[SOURCE: IEC 60050-551:1998, 551-17-03, modifié – Le symbole q a été ajouté]

3.5.10
indice de pulsation
p
nombre de commutations non simultanées et symétriques directes ou indirectes d'un bras principal à un autre qui se produisent pendant une période élémentaire

[SOURCE: IEC 60050-551:1998, 551-17-01, modifié – Le symbole p a été ajouté]

angle de retard de l'ordre d'amorçage
α
dans le cas de la commande de phase, durée exprimée en mesure angulaire pendant laquelle l'impulsion d'amorçage est retardée par rapport à un instant de référence

Note 1 à l'article: Pour les convertisseurs commutés par le réseau, par machine ou par la charge, l'instant de référence est l'instant de passage par zéro de la tension de commutation. Pour les gradateurs, c'est l'instant de passage par zéro de la tension d'alimentation. Pour les gradateurs associés à des charges inductives, l'angle de retard de l'ordre d'amorçage est la somme du déphasage et de l'angle de retard à l'amorçage.

[SOURCE: IEC 60050-551:1998, 551-16-33, modifié – Le symbole α a été ajouté]

3.5.11
angle d'avance de l'ordre d'amorçage
β
durée exprimée en mesure angulaire pendant laquelle l'impulsion d'amorçage est avancée par rapport à l'instant de référence

Note 1 à l'article: Pour les convertisseurs commutés par le réseau, par machine ou par la charge, l'instant de référence est l'instant de passage par zéro de la tension de commutation.

[SOURCE: IEC 60050-551:1998, 551-16-34, modifié – Le symbole β a été ajouté]

3.5.12
angle de retard propre
α_p
angle de retard à l'amorçage apparaissant, même en l'absence de commande de phase, et provoqué par empiètement multiple

Note 1 à l'article: L'empiètement multiple se produit sur des convertisseurs à commutation par le réseau, pour des valeurs élevées de l'angle d'empiètement.

[SOURCE: IEC 60050-551:1998, 551-16-35, modifié – Le symbole α_p a été ajouté]

3.5.13
angle d'extinction
γ
durée, exprimée en mesure angulaire, entre l'instant d'extinction du courant de bras et l'instant où il est exigé que le bras supporte un front raide de montée de la tension

3.5.14
intervalle de suppression
intervalle entre l'instant où le courant de conduction dans une valve à accrochage s'annule et l'instant où cette même valve est appelée à supporter à nouveau une tension directe à l'état bloqué

[SOURCE: IEC 60050-551:1998, 551-16-45]

3.6 Valeurs assignées

3.6.1
valeur assignée
valeur d'une grandeur, utilisée à des fins de spécification, correspondant à un ensemble spécifié de conditions de fonctionnement d'un composant, dispositif, matériel ou système

Note 1 à l'article: La grandeur peut décrire des propriétés électriques, thermiques, mécaniques ou environnementales.

Note 2 à l'article: Dans le cas des convertisseurs à semiconducteurs, les valeurs assignées s'appliquent habituellement à une valve à semiconducteurs, un ensemble de valves ou un convertisseur.

Note 3 à l'article: La valeur nominale d'un réseau (par exemple tension nominale, IEC 60050-601:1985, 601-01-21) est souvent égale à la valeur assignée correspondante du matériel lorsque les deux valeurs sont dans les limites de tolérance d'une grandeur.

Note 4 à l'article: À la différence de nombreux autres composants électriques, les dispositifs à semiconducteurs peuvent être détruits même pour un temps très court de fonctionnement si des valeurs maximales assignées sont dépassées.

Note 5 à l'article: Il convient que les variations des valeurs assignées soient spécifiées. Certaines valeurs assignées sont des valeurs limites. Ces valeurs limites peuvent être soit maximales soit minimales.

[SOURCE: IEC 60050-151:2001, 151-16-08, modifié – Les Notes à l'article ont été ajoutées]

3.6.2
fréquence assignée
f_{N}
fréquence spécifiée du côté courant alternatif du convertisseur

3.6.3
tension assignée côté réseau
U_{LN}
valeur efficace spécifiée de la tension entre les conducteurs côté réseau du convertisseur

Note 1 à l'article: Si l'enroulement du transformateur côté réseau comporte des prises, la valeur assignée de la tension côté réseau doit correspondre à une prise spécifiée qui est en fait la prise principale.

3.6.4
tension assignée côté valve du transformateur
U_{vN}
valeur efficace de la tension à vide entre les bornes de phases de commutation, vectoriellement successives, de l'enroulement du transformateur côté valve pour la tension assignée côté réseau dudit transformateur

Note 1 à l'article: Si le convertisseur ne comporte pas de transformateur, au sein de l'enveloppe d'un convertisseur pour raccordement direct, la tension assignée côté valve est la tension assignée côté réseau du convertisseur.

3.6.5
courant assigné côté réseau
I_{LN}
valeur efficace maximale du courant du convertisseur côté réseau dans les conditions assignées

Note 1 à l'article: Le courant assigné côté réseau tient compte de la charge assignée et de la combinaison la plus sévère de toutes les autres conditions dans leurs gammes spécifiées, par exemple variations de la tension et de la fréquence du réseau.

Note 2 à l'article: Pour les équipements polyphasés, cette valeur est calculée d'après le courant continu assigné sur la base d'ondes rectangulaires de courant dans les bras du convertisseur. Il convient de spécifier la base de calcul dans le cas des équipements monophasés.

Note 3 à l'article: Le courant assigné de réseau comprend les courants fournis aux circuits auxiliaires du convertisseur. Il tient compte également de l'effet de l'ondulation du courant continu et du courant de circulation, s'il y a lieu.

3.6.6
courant assigné côté valve
I_{vN}
valeur efficace maximale du courant du convertisseur côté valve dans les conditions assignées

Note 1 à l'article: Le courant assigné côté valve tient compte de la charge assignée et de la combinaison la plus sévère de toutes les autres conditions dans leurs gammes spécifiées, par exemple variations de la tension et de la fréquence du réseau.

Note 2 à l'article: Pour les équipements polyphasés, cette valeur est calculée d'après le courant continu assigné sur la base d'ondes rectangulaires de courant dans les bras du convertisseur.

Note 3 à l'article: Il convient de spécifier la base de calcul dans le cas des équipements monophasés.

3.6.7
puissance apparente assignée côté réseau
S_{LN}
puissance apparente totale aux bornes côté réseau à la fréquence assignée, à la tension assignée côté réseau et au courant assigné côté réseau

3.6.8
tension continue assignée
U_{dN}
valeur moyenne, spécifiée par le fabricant, de la tension continue entre les bornes à courant continu de l'ensemble ou de l'équipement, pour le courant continu assigné

3.6.9
courant continu assigné
I_{dN}
valeur moyenne du courant continu spécifiée par le fabricant pour des conditions de charge et de service déterminées

Note 1 à l'article: Cette valeur peut être désignée comme la valeur 1,0 p.u., à laquelle d'autres valeurs de I_d sont comparées.

3.6.10
courant continu permanent assigné
I_{dMN}
valeur moyenne du courant continu qu'un ensemble ou un convertisseur est capable de supporter en régime permanent sans dommage et pour des conditions de service spécifiées

Note 1 à l'article: Le courant continu permanent assigné d'un ensemble est très souvent nettement plus élevé que le courant continu assigné de l'équipement complet correspondant. Il s'agit d'une valeur maximale.

Note 2 à l'article: Le courant continu permanent assigné d'un ensemble peut être limité par d'autres composants que le semiconducteur.

3.6.11
courant continu maximal de crête
I_{dSMN}
valeur moyenne du courant continu qu'un ensemble ou un convertisseur est capable de supporter sans dommage, pendant une courte durée spécifiée, en commençant par une durée non définie à la valeur de courant assignée, suivi d'une période temporaire à vide

Note 1 à l'article: La valeur et la durée du courant de pointe (courant continu maximal de crête I_{dSMN}), ainsi que la durée minimale de fonctionnement à vide avant de supporter tout nouveau courant, participent à la définition du courant continu maximal de crête.

3.6.12
courant continu maximal de crête intermittent
I_{dRMN}
valeur moyenne du courant continu qu'un ensemble ou un convertisseur est capable de supporter sans dommage, pendant une courte durée spécifiée et de façon intermittente, en commençant par toute valeur de courant inférieure ou égale à la valeur de courant assignée, puis en revenant à toute valeur de courant inférieure ou égale à la valeur de courant assignée

Note 1 à l'article: La valeur et la durée du courant de pointe (courant continu maximal de crête intermittent I_{dRMN}), ainsi que la durée minimale entre les applications de charges de crête intermittentes participent à la définition du courant continu maximal de crête intermittent.

3.6.13
courant assigné pour le service de charge de pointe
valeur moyenne du courant continu qu'un ensemble ou un convertisseur est capable de supporter, pendant une durée spécifiée et dans des conditions de service déterminées, associée à la valeur de courant continu maximale de crête pendant une courte durée

Note 1 à l'article: Les caractéristiques du courant continu maximal associé I_{dSMN} participent à la définition du service temporaire. Pour plus d'informations, voir 6.4.3.2.

3.6.14
courant assigné pour service continu avec surcharges de crête
valeur moyenne du courant continu qu'un ensemble ou un convertisseur est capable de supporter, pendant une durée illimitée et dans des conditions de service spécifiées, avec un courant continu maximal de crête intermittent d'amplitudes et de durées spécifiées

Note 1 à l'article: Les caractéristiques du courant continu maximal de crête intermittent associé I_{dRMN} participent à la définition du courant assigné pour un service continu avec application de surcharges de crête.

3.6.15
courant assigné pour un service de charge répétitive
courant continu assigné de l'ensemble ou du convertisseur, spécifié comme la valeur efficace du courant de charge, calculée sur la période du cycle de charge

Note 1 à l'article: Il convient de spécifier la classe de service sous la forme d'une suite de valeurs de courants en spécifiant leurs durées. Un "service de charge répétitive" est également désigné sous l'appellation "service périodique". Voir 6.4.3.2 c).

3.6.16
puissance assignée côté courant continu
produit de la tension continue assignée et du courant continu assigné

Note 1 à l'article: Du fait de l'ondulation du courant et de la tension, la puissance mesurée côté courant continu peut différer de la puissance assignée côté courant continu telle que définie.

3.7 Tensions, courants et facteurs spécifiques

3.7.1
tension continue fictive à vide
U_{di}
tension à vide théorique d'un convertisseur alternatif-continu en supposant qu'il n'y a ni réduction de tension par réglage de phase, ni tensions de seuil des valves électroniques, ni remontée de tension aux faibles charges

[SOURCE: IEC 60050-551:1998, 551-17-15, modifié – Le symbole U_{di} a été ajouté]

3.7.2
tension continue fictive à vide avec réglage
$U_{di\alpha}$
tension à vide théorique d'un convertisseur alternatif/continu correspondant à un angle de retard spécifié de l'ordre d'amorçage en supposant qu'il n'y a ni tensions de seuil des valves électroniques, ni remontée de tension aux faibles charges

[SOURCE: IEC 60050-551:1998, 551-17-16, modifié – Le symbole $U_{di\alpha}$ a été ajouté]

3.7.3
tension continue conventionnelle à vide
U_{d0}
valeur moyenne de la tension continue que l'on obtiendrait en extrapolant la partie de la courbe caractéristique tension/courant correspondant à la conduction continue du courant redressé jusqu'à l'axe des ordonnées (courant nul) à angle de retard de l'ordre d'amorçage nul, c'est-à-dire sans réglage de phase

Note 1 à l'article: U_{di} est égale à la somme de U_{d0} et de la chute de tension à vide dans l'ensemble.

[SOURCE: IEC 60050-551:1998, 551-17-17, modifié – Le symbole U_{d0} et la Note à l'article ont été ajoutés]

3.7.4
tension continue conventionnelle à vide avec réglage
$U_{d0\alpha}$
valeur moyenne de la tension continue correspondant à un angle de retard de l'ordre d'amorçage spécifié, que l'on obtiendrait en extrapolant la partie de la courbe caractéristique tension/courant correspondant à la conduction continue du courant redressé jusqu'à l'axe des ordonnées (courant nul)

Note 1 à l'article: $U_{di\alpha}$ est égale à la somme de $U_{d0\alpha}$ et de la chute de tension à vide dans l'ensemble.

[SOURCE: IEC 60050-551:1998, 551-17-18, modifié – Le symbole $U_{d0\alpha}$ et la Note à l'article ont été ajoutés.]

3.7.5
tension continue réelle à vide
U_{d00}
valeur moyenne de la tension continue effective pour un courant continu nul

[SOURCE: IEC 60050-551:1998, 551-17-19, modifié – Le symbole U_{d00} a été ajouté]

3.7.6
chute de tension continue
différence entre la tension continue conventionnelle à vide et la tension continue en charge, pour un même angle de retard de l'ordre d'amorçage ne tenant pas compte de l'effet correctif d'une stabilisation éventuelle de tension

Note 1 à l'article: Si l'on utilise un dispositif de régulation de tension, se reporter également à 3.7.9.

Note 2 à l'article: La nature du circuit à courant continu (par exemple condensateurs, charge électromotrice de retour) peut influencer notablement la variation de tension. Lorsque tel est le cas, une attention toute particulière peut être exigée.

[SOURCE: IEC 60050-551:1998, 551-17-21, modifié – Les Notes à l'article ont été ajoutées]

3.7.7
chute propre de tension intrinsèque
variation de tension continue ne tenant pas compte de l'effet de l'impédance du réseau à courant alternatif

[SOURCE: IEC 60050-551:1998, 551-17-22]

3.7.8
chute totale de tension continue
variation de tension continue tenant compte de l'effet de l'impédance du réseau à courant alternatif

[SOURCE: IEC 60050-551:1998, 551-17-23]

3.7.9
plage de tolérances de la tension de sortie
plage spécifiée des valeurs, en régime établi, d'une tension de sortie stabilisée autour de sa valeur nominale ou de sa valeur de réglage

3.7.10
courant critique
valeur moyenne du courant continu d'un montage convertisseur au-dessous de laquelle le courant continu des groupes commutants devient intermittent, lorsqu'on fait décroître le courant

[SOURCE: IEC 60050-551:1998, 551-17-20 modifié – Cette modification ne concerne que la version anglaise]

3.7.11
facteur de conversion
rapport de la puissance de sortie fondamentale ou de la puissance de sortie en courant continu à la puissance d'entrée fondamentale ou à la puissance d'entrée en courant continu

Note 1 à l'article: La puissance fondamentale (IEC 60050-551:1998, 551-17-08) constitue la puissance active déterminée par les composantes fondamentales de la tension et du courant.

Note 2 à l'article: Pour les besoins de la présente définition, la puissance en courant continu constitue le produit de la valeur moyenne de la tension et de la valeur moyenne du courant.

[SOURCE: IEC 60050-551:1998, 551-17-10, modifié – Les Notes à l'article ont été ajoutées]

3.7.12
rendement
rapport de la puissance de sortie à la puissance d'entrée du convertisseur

Note 1 à l'article: Dans le facteur de conversion, la puissance des composantes alternatives du courant et de la tension côté courant continu n'est pas prise en compte. Dans le rendement, la puissance de ces composantes alternatives du courant et de la tension côté courant continu est incluse dans la puissance côté courant continu. Par conséquent, le facteur de conversion a une valeur inférieure pour la conversion du courant alternatif en courant continu. Pour un convertisseur monophasé à deux impulsions (et à deux alternances), avec charge résistive, la valeur maximale théorique du facteur de conversion est 0,81 p.u., où 1,0 p.u. représente le rendement maximal.

Note 2 à l'article: Le facteur de conversion ne peut être obtenu correctement que par la mesure de la composante fondamentale de la puissance côté courant alternatif et des composantes à fréquence nulle de tension et de courant côté courant continu. Le rendement peut être obtenu correctement, soit par la mesure des valeurs efficaces de la puissance côté courant continu et de la puissance côté courant alternatif, soit par le calcul ou la mesure des pertes internes.

Note 3 à l'article: Il faut tenir compte de la puissance active (valeur moyenne de la puissance) côté courant alternatif, et de la valeur moyenne de la puissance côté courant continu.

3.7.13
facteur de puissance
λ
rapport de la valeur absolue de la puissance active P à la puissance apparente S, en régime périodique

$$\lambda = \frac{|P|}{S}$$

Note 1 à l'article: En régime sinusoïdal, le facteur de puissance est la valeur absolue du facteur de puissance active.

[SOURCE: IEC 60050-131:2002, 131-11-46, modifié – Le symbole λ a été ajouté]

3.7.14
facteur de puissance de l'onde fondamentale
facteur de déphasage tension-courant
$\cos\varphi_1$
en régime périodique, rapport de la puissance active des composantes fondamentales P_1 à la puissance apparente des composantes fondamentales S_1

$$\cos\varphi_1 = \frac{P_1}{S_1}$$

Note 1 à l'article: Pour la définition du déphasage tension-courant, voir l'IEC 60050-131:2002, 131-11-48.

3.7.15
facteur de déformation
ν
rapport du facteur de puissance total λ sur le facteur de déphasage tension-courant $\cos\varphi_1$

$$\nu = \frac{\lambda}{\cos\varphi_1}$$

Note 1 à l'article: Lorsque la tension est sinusoïdale, le facteur de déformation équivaut au facteur fondamental. Voir la Note 2 à l'article en 3.10.14.

3.8 Refroidissement

3.8.1
milieu de refroidissement
liquide (par exemple eau) ou gaz (par exemple air) qui absorbe la chaleur produite par l'équipement

3.8.2
fluide réfrigérant
liquide (par exemple eau) ou gaz (par exemple air) inclus dans l'équipement destiné à transporter la chaleur de la source vers un échangeur d'où la chaleur est extraite par le milieu de refroidissement

3.8.3
refroidissement direct
mode de refroidissement dans lequel le milieu de refroidissement est en contact direct avec les parties de l'équipement à refroidir, c'est-à-dire n'utilisant pas de fluide réfrigérant

3.8.4
refroidissement indirect
mode de refroidissement dans lequel un fluide réfrigérant est utilisé pour transporter la chaleur depuis la partie à refroidir jusqu'au milieu de refroidissement

3.8.5
refroidissement naturel
convection
mode de circulation du fluide de refroidissement (milieu de refroidissement ou fluide réfrigérant), utilisant la variation de masse volumique (densité) avec la température

3.8.6
refroidissement forcé
mode de circulation du milieu de refroidissement ou du fluide réfrigérant utilisant un ou des souffleurs, ventilateurs ou pompes

3.8.7
refroidissement mixte
mode de circulation du milieu de refroidissement ou du fluide réfrigérant, utilisant la circulation naturelle ou la circulation forcée suivant les circonstances

Note 1 à l'article: La circulation mixte peut être appliquée à faible charge ou en surcharge ou dans le cas de fonctionnement de secours.

3.8.8
température d'équilibre
température de régime permanent atteinte par un composant du convertisseur dans des conditions spécifiées de charge et de refroidissement

Note 1 à l'article: Les températures de régime permanent sont en général différentes pour des composants différents. Les temps nécessaires pour atteindre le régime permanent (stabilisation) sont également différents et augmentent avec les constantes de temps thermiques.

3.8.9
température de l'air ambiant
température de l'air environnant l'équipement de conversion de puissance, mesurée à mi-distance de tout équipement voisin, mais pas à plus de 300 mm de l'enceinte, à mi-hauteur de celle-ci, en un point abrité du rayonnement thermique direct de l'équipement

3.8.10
température du milieu de refroidissement pour refroidissement par air et par gaz
température moyenne mesurée à l'extérieur de l'équipement en des points distants de 50 mm de l'entrée de l'équipement

Note 1 à l'article: Pour l'évaluation de la proportion de chaleur rayonnée, la température ambiante est celle définie en 3.8.9.

3.8.11
température du milieu de refroidissement pour refroidissement par liquide
température mesurée dans la canalisation à 100 mm en amont de l'entrée du liquide

3.8.12
température du fluide réfrigérant
température du fluide réfrigérant mesurée en un point qui est à définir par le fournisseur

3.9 Tolérances relatives aux conditions de service et compatibilité électromagnétique

3.9.1
compatibilité électromagnétique
CEM
aptitude d'un équipement ou d'un système à fonctionner dans son environnement électromagnétique de façon satisfaisante et sans produire lui-même des perturbations électromagnétiques intolérables pour tout ce qui se trouve dans cet environnement

[SOURCE: IEC 60050-161:2018, 161-01-07]

3.9.2
émission électromagnétique
émission
processus par lequel une source fournit de l'énergie électromagnétique vers l'extérieur

[SOURCE: IEC 60050-161:2019, 161-01-08, modifié – Le terme en variante "émission" a été ajouté]

3.9.3
niveau d'émission
<d'un convertisseur> niveau d'une perturbation électromagnétique donnée, émise par un convertisseur utilisé dans des conditions déterminées et mesurée selon une méthode spécifique

[SOURCE: IEC 60050-161:1990, 161-03-11, modifié – Le domaine "d'une source perturbatrice" a été remplacé par "d'un convertisseur" et l'expression "par un dispositif, un appareil ou un système particulier et mesurée d'une manière spécifiée" a été remplacée par "par un convertisseur utilisé dans des conditions déterminées et mesurée selon une méthode spécifique"]

3.9.4
perturbation électromagnétique
phénomène électromagnétique susceptible de dégrader le fonctionnement d'un dispositif, d'un équipement ou d'un système, ou d'affecter défavorablement la matière vivante ou inerte

[SOURCE: IEC 60050-161:2018, 161-01-05, modifié – Les Notes à l'article ont été supprimées]

3.9.5
niveau de perturbation électromagnétique
niveau d'une perturbation électromagnétique existant à un endroit donné et résultant de la contribution de toutes les sources de perturbation

[SOURCE: IEC 60050-161:1990, 161-03-29]

3.9.6
niveau de référence de la perturbation produite par un convertisseur
niveau estimé de la perturbation produite par un convertisseur lorsque les conditions réelles de service ne sont pas connues et que les conditions assignées de service sont utilisées pour calculer ou mesurer le niveau de perturbation

Note 1 à l'article: Le niveau de perturbation dépend généralement de l'impédance de la source d'alimentation, qui ne peut être considérée comme une grandeur propre du convertisseur.

3.9.7
immunité à une perturbation
aptitude d'un dispositif, d'un appareil ou d'un système à fonctionner sans dégradation en présence d'une perturbation électromagnétique

[SOURCE: IEC 60050-161:1990, 161-01-20]

3.9.8
niveau d'immunité d'un convertisseur
valeur spécifiée d'un niveau de perturbation électromagnétique en dessous duquel un convertisseur est destiné à satisfaire aux performances exigées, à continuer de fonctionner ou à prévenir tout dommage

Note 1 à l'article: Cette définition est propre au convertisseur. Une description du concept générique de niveau d'immunité est donnée dans l'IEC 60050-161:1990, 161-03-14.

3.9.9
puissance de court-circuit relative
R_{SC}
rapport de la puissance de court-circuit de la source à la puissance apparente assignée côté réseau des convertisseurs

Note 1 à l'article: R_{SC} se rapporte à un point donné du réseau, pour des conditions spécifiées de fonctionnement et pour une configuration spécifiée du réseau.

Note 2 à l'article: La série IEC 61000-3 définit le rapport de court-circuit comme la puissance de court-circuit de la source au PCC, et non comme la puissance de court-circuit de la source à l'IPC d'utilisation du convertisseur. Le risque de confusion est clarifié à l'Article B.2.

3.10 Distorsion harmonique

NOTE Les équations dans les définitions ci-dessous relatives aux distorsions harmoniques utilisent le symbole Q pour représenter une grandeur. Lorsque ces équations sont utilisées dans des applications spécifiques, Q est remplacé par le symbole réel de la grandeur, par exemple U pour la tension, I pour l'intensité. Dans les autres parties du présent document, Q est le symbole utilisé pour la puissance réactive (voir Tableau 2). Les explications à l'appui de ces définitions sont données à l'Annexe A.

3.10.1
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

Note 1 à l'article: L'abréviation "PCC" est dérivée du terme anglais développé correspondant "Point of Common Coupling".

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

3.10.2
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.

Note 2 à l'article: L'abréviation "IPC" est dérivée du terme anglais développé correspondant "In-plant Point of Coupling".

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

3.10.3
fréquence fondamentale
fréquence de la composante fondamentale

[SOURCE: IEC 60050-551:2001, 551-20-03]

3.10.4
composante fondamentale
fondamental
<d'une série de Fourier> composante sinusoïdale de la décomposition en série de Fourier d'une grandeur périodique dont la fréquence est la fréquence de la grandeur elle-même

Note 1 à l'article: Pour l'analyse pratique, il peut être nécessaire de procéder à une approximation de la périodicité.

[SOURCE: IEC 60050-551:2001, 551-20-01]

3.10.5
composante fondamentale de référence
composante sinusoïdale de la décomposition en série de Fourier d'une grandeur périodique dont la fréquence est celle à laquelle toutes les autres composantes sont référencées et qui n'est pas la composante fondamentale

Note 1 à l'article: Lorsqu'il est clairement établi dans le contexte qu'il est question de la composante fondamentale de référence, on peut omettre le qualificatif "de référence", mais ce document ne recommande pas cet usage.

Note 2 à l'article: Pour l'analyse pratique, il peut être nécessaire de procéder à une approximation de la périodicité.

Note 3 à l'article: En électronique de puissance, la composante à la fréquence du réseau d'alimentation à courant alternatif ou à la fréquence des grandeurs de sortie du convertisseur est souvent choisie comme composante fondamentale de référence.

[SOURCE: IEC 60050-551:2001, 551-20-02]

3.10.6
fréquence fondamentale de référence
fréquence de la composante fondamentale de référence

Note 1 à l'article: Lorsqu'il est clairement établi dans le contexte qu'il est question de la composante fondamentale de référence, on peut omettre le qualificatif "de référence", mais ce document ne recommande pas cet usage.

[SOURCE: IEC 60050-551:2001, 551-20-04]

3.10.7
fréquence harmonique
fréquence qui est un multiple entier supérieur à 1 de la fréquence fondamentale, ou de la fréquence fondamentale de référence

Note 1 à l'article: Le rapport de la fréquence harmonique à la fréquence fondamentale, ou à la fréquence fondamentale de référence, est appelé rang harmonique (notation recommandée: h).

[SOURCE: IEC 60050-551:2001, 551-20-05, modifié – La Note à l'article a été ajoutée]

3.10.8
composante harmonique
composante sinusoïdale d'une grandeur périodique dont la fréquence est une fréquence harmonique

Note 1 à l'article: Par souci de concision, cette composante peut simplement être désignée comme un harmonique.

Note 2 à l'article: Pour l'analyse pratique, il peut être nécessaire de procéder à une approximation de la périodicité.

Note 3 à l'article: La valeur est normalement exprimée comme une valeur efficace.

[SOURCE: IEC 60050-551:2001, 551-20-07, modifié – Les Notes 1 et 3 à l'article ont été ajoutées]

3.10.9
fréquence interharmonique
fréquence qui est un multiple non entier de la fréquence fondamentale de référence

Note 1 à l'article: Par extension du rang harmonique, le rang interharmonique désigne le rapport de la fréquence interharmonique à la fréquence fondamentale de référence. Ce rapport n'est pas un entier (notation recommandée: m).

Note 2 à l'article: Lorsque $m < 1$, le terme "fréquence sous-harmonique" peut également être employé (voir l'IEC 60050-551:2001, 551-20-10).

[SOURCE: IEC 60050-551:2001, 551-20-06, modifié – Les Notes à l'article ont été ajoutées]

3.10.10
composante interharmonique
composante sinusoïdale d'une grandeur périodique dont la fréquence est une fréquence interharmonique

Note 1 à l'article: Par souci de concision, cette composante peut simplement être désignée comme un interharmonique.

Note 2 à l'article: Pour l'analyse pratique, il peut être nécessaire de procéder à une approximation de la périodicité.

Note 3 à l'article: La valeur est normalement exprimée comme une valeur efficace.

Note 4 à l'article: Comme indiqué dans l'IEC 61000-4-7, la fenêtre temporelle a une largeur de 10 périodes fondamentales (systèmes de 50 Hz) ou de 12 périodes fondamentales (systèmes de 60 Hz), c'est-à-dire approximativement 200 ms. La différence de fréquence entre deux composantes interharmoniques consécutives est donc d'environ 5 Hz. Dans le cas d'autres fréquences fondamentales, il convient de choisir la fenêtre temporelle entre 6 périodes fondamentales (environ 1 000 ms à 6 Hz) et 18 périodes fondamentales (environ 100 ms à 180 Hz).

[SOURCE: IEC 60050-551:2001, 551-20-08, modifié – Les Notes 1, 3 et 4 à l'article ont été ajoutées]

3.10.11
résidu harmonique
somme des composantes harmoniques d'une grandeur périodique

Note 1 à l'article: Le résidu harmonique est une fonction du temps.

Note 2 à l'article: Pour l'analyse pratique, il peut être nécessaire de procéder à une approximation de la périodicité.

Note 3 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 4 à l'article: La valeur efficace du résidu de distorsion est:

$$Q_{\mathrm{HC}} = \sqrt{\sum_{h=2}^{h=H} {Q_h}^2}$$

où

Q représente le courant ou la tension;

h est le rang harmonique;

H est égal à 50 pour les besoins du présent document. Cette valeur a été longtemps égale à 40 dans les normes associées à l'électronique de puissance. Il convient désormais qu'elle soit égale à 50 conformément à l'IEC 61000-2-2 et à l'IEC 61000-2-4.

[SOURCE: IEC 60050-551:2001, 551-20-12, modifié – La Note 4 à l'article a été ajoutée]

3.10.12
rapport harmonique total
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

$$D_{\mathrm{H}} = \sqrt{\sum_{h=2}^{h=H} \left(\frac{Q_h}{Q_1}\right)^2} = \frac{Q_{\mathrm{HC}}}{Q_1}$$

où

Q, h, et H sont identiques aux valeurs énumérées en 3.10.11;

Q_1 désigne la valeur efficace de la composante fondamentale.

Note 1 à l'article: Le rapport 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 peut faire l'objet d'une approximation à un certain rang (notation recommandée: H), à savoir 50 pour les besoins du présent document.

Note 3 à l'article: L'abréviation "THD" est dérivée du terme anglais développé correspondant "Total Harmonic Distortion".

[SOURCE: IEC 60050-551:2001, 551-20-13, modifié – La notation recommandée et une valeur ont été ajoutées à la Note 2 à l'article]

3.10.13
résidu total de distorsion
grandeur obtenue en soustrayant d'une grandeur alternative sa composante fondamentale ou sa composante fondamentale de référence

Note 1 à l'article: Le résidu total de distorsion comporte les composantes harmoniques et, s'il y en a, les composantes interharmoniques.

Note 2 à l'article: Le résidu total de distorsion dépend du choix de la composante fondamentale. En cas d'ambiguïté dans le contexte on indique de quelle composante il s'agit.

Note 3 à l'article: Le résidu total de distorsion est une fonction du temps.

Note 4 à l'article: Une grandeur alternative (symbole Q) est une grandeur périodique dont la composante continue est nulle.

Note 5 à l'article: La valeur efficace du résidu de distorsion est:

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

où Q_1 est détaillé en 3.10.12.

[SOURCE: IEC 60050-551:2001, 551-20-11, modifié – Un symbole a été ajouté à la Note 4 à l'article. La Note 5 à l'article a été ajoutée]

3.10.14
rapport total de distorsion
TDR
rapport de la valeur efficace du résidu total de distorsion à la valeur efficace de la composante fondamentale ou de la composante fondamentale de référence d'une grandeur alternative

$$D_R = \frac{D_C}{Q_1} = \frac{\sqrt{Q^2 - Q_1^2}}{Q_1}$$

Note 1 à l'article: Le rapport total de distorsion 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: L'abréviation "TDR" est dérivée du terme anglais développé correspondant "Total Distortion Ratio".

[SOURCE: IEC 60050-551:2001, 551-20-14, modifié – L'abréviation "TDR" et la formule dans la Note 1 à l'article ont été ajoutées. La Note 2 à l'article a été supprimée]

3.10.15
facteur total de distorsion
TDF
rapport de la valeur efficace du résidu total de distorsion à la valeur efficace d'une grandeur alternative

$$D_F = \frac{D_C}{Q} = \frac{\sqrt{Q^2 - Q_1^2}}{Q}$$

Note 1 à l'article: Le facteur total de distorsion 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 entre TDF et TDR équivaut au rapport de la valeur efficace de la composante fondamentale sur la valeur efficace totale. Il s'agit du taux de fondamental défini dans l'IEC 60050-161:1990, 161-02-22.

Note 3 à l'article: L'abréviation "TDF" est dérivée du terme anglais développé correspondant "Total Distortion Factor".

$$f_F = \frac{D_F}{D_R} = \frac{Q_1}{\mathrm{Q}} \leq 1$$

[SOURCE: IEC 60050-551:2001, 551-20-16, modifié – L'abréviation "TDF", la formule dans la Note 1 à l'article et la Note 2 à l'article ont été ajoutées]

3.10.16
rapport harmonique individuel
IHR
rapport entre une composante harmonique et la valeur du fondamental

Note 1 à l'article: Dans l'IEC 60050-161:1990, 161-02-20, le rapport harmonique individuel est nommé le " taux du $n^{\text{ième}}$ harmonique". IHR a été choisi pour des raisons de cohérence avec la définition 3.10.11, et l'indice de rang a été désigné par le symbole "h" en lieu et place du symbole "n" qui est souvent employé dans d'autres documents, par exemple pour la liste des entiers naturels.

Note 2 à l'article: La valeur du rapport harmonique individuel est $Q_{\text{IHR}} = \frac{Q_h}{Q_1}$

Note 3 à l'article: L'abréviation "IHR" est dérivée du terme anglais développé correspondant "Individual Harmonic Ratio".

3.10.17
rapport harmonique pondéré partiel
PWHR
rapport de la valeur efficace d'un groupe choisi d'harmoniques de rang supérieur, pondérés avec le rang harmonique h, à la valeur efficace du fondamental

$$Q_{\text{PWHR}} = \sqrt{\sum_{h=14}^{h=40} h \times \left(\frac{Q_h}{Q_1}\right)^2}$$

Note 1 à l'article: Le rapport harmonique pondéré partiel est utilisé afin de s'assurer que les effets des courants d'harmoniques de rang supérieur sur les résultats sont réduits de manière suffisante et qu'il n'est pas nécessaire de spécifier des limites individuelles.

Note 2 à l'article: Un concept similaire concernant le courant harmonique est donné dans l'IEC 61000-3-12:2011, 3.2.

Note 3 à l'article: L'abréviation "PWR" est dérivée du terme anglais développé correspondant "Partial Weighted Harmonic Ratio".

3.11 Définitions relatives à la coordination de l'isolement

3.11.1
circuit électrique
circuit
<d'un équipement> trajectoires de courant de composants ou d'ensembles, conducteurs ou bornes raccordés entre eux par des connexions électriquement conductrices et isolés de la partie restante de l'équipement

Note 1 à l'article: Si des parties du même équipement sont raccordées par conduction uniquement au moyen d'un réseau équipotentiel de protection, elles sont alors considérées comme des circuits distincts.

3.11.2
partie d'un circuit
section d'un circuit ayant sa propre tension d'isolement assignée

3.11.3
équipotentialité
état de parties conductrices ayant un potentiel électrique sensiblement égal

[SOURCE: IEC 60050-195:2021, 195-01-09]

3.11.4
liaison équipotentielle
mise en œuvre de liaisons électriques entre parties conductrices pour réaliser l'équipotentialité

[SOURCE: IEC 60050-195:2021, 195-01-10, modifié – La définition a été reformulée]

3.11.5
réseau équipotentiel
EBS
interconnexion de parties conductrices, permettant d'assurer une liaison équipotentielle entre ces parties

Note 1 à l'article: L'abréviation "EBS" est dérivée du terme anglais développé correspondant "Equipotential Bonding System".

[SOURCE: IEC 60050-195:2021, 195-02-22]

3.11.6
réseau équipotentiel de protection
PEBS
réseau équipotentiel assurant une liaison équipotentielle de protection

Note 1 à l'article: L'abréviation "PEBS" est dérivée du terme anglais développé correspondant "Protective Equipotential Bonding System".

[SOURCE: IEC 60050-195:2021,195-02-23]

3.11.7
tension de service
tension de calcul dans un circuit ou tension d'isolement, dans les conditions d'alimentation assignées (sans tolérances) et dans les conditions de service les plus défavorables

Note 1 à l'article: La tension de service peut être en courant continu ou en courant alternatif. Les valeurs efficaces et les valeurs de crête récurrentes sont utilisées.

3.11.8
classe de tension déterminante
plage de tensions calculée utilisée pour déterminer la classification des mesures de protection contre le choc électrique

3.11.9
tension d'isolement assignée
valeur de tension efficace assignée par le fabricant à l'équipement ou à une partie de ce dernier, qui caractérise la capacité de résistance (à long terme) spécifiée de son isolation

Note 1 à l'article: La tension d'isolement assignée est supérieure ou égale à la tension assignée de l'équipement, ou à la tension assignée de la partie de l'équipement concernée, qui est associée principalement aux performances de fonctionnement.

Note 2 à l'article: La tension d'isolement assignée fait référence à l'isolation entre les circuits électriques, entre les parties actives et les parties conductrices exposées et au sein d'un circuit électrique.

Note 3 à l'article: Pour les distances d'isolement dans l'air et l'isolement sous charge, la valeur de crête de la tension observée dans l'isolement ou la distance d'isolement dans l'air constitue la valeur déterminante de la tension d'isolement assignée. Pour les lignes de fuite, la valeur efficace constitue la valeur déterminante.

Note 4 à l'article: La tension d'isolement assignée dépend du résultat de la recherche de coordination de l'isolement pour les systèmes haute tension, ou de la surtension provisoire prévisible, la catégorie de surtension, et la valeur efficace de la tension de service, selon la plus grande des deux valeurs.

[SOURCE: IEC 60664-1:2020, 3.1.18, modifié – Le symbole U_i a été supprimé. L'expression "valeur de la tension de tenue efficace" a été remplacée par "valeur de tension efficace". La Note 1 à l'article a été clarifiée, et les Notes 2 à 4 à l'article ont été ajoutées]

3.11.10
tension de choc assignée
amplitude de choc utilisée comme référence pour la définition d'un circuit et pour les essais relatifs aux caractéristiques d'isolement d'un circuit

Note 1 à l'article: La tension de choc assignée dépend du résultat de la recherche de coordination de l'isolement pour les systèmes haute tension, ou des tensions de choc prévisibles de toute origine associées à la catégorie de surtension et de la valeur de crête de la tension de service, selon la plus grande des deux valeurs.

3.11.11
catégorie de surtension
concept utilisé pour classer les équipements alimentés directement par le réseau d'alimentation

Note 1 à l'article: L'IEC 60664-1 définit quatre catégories d'équipement:

catégorie I: équipement raccordé à un circuit de distribution protégé contre un niveau défini de surtensions transitoires;

catégorie II: équipement non raccordé de façon permanente à l'installation (tout IPC);

catégorie III: équipement raccordé de façon permanente à l'installation (tout IPC);

catégorie IV: équipement raccordé au point d'origine de l'installation (le plus proche du PCC).

3.11.12
isolation principale
isolation appliquée aux parties actives dangereuses pour assurer une protection principale contre les chocs électriques

[SOURCE: IEC 60050-826:2004, 826-12-14, modifié – La définition a été reformulée]

3.11.13
isolation supplémentaire
isolation indépendante prévue, en plus de l'isolation principale, en tant que protection en cas de défaut

Note 1 à l'article: L'isolation principale et l'isolation supplémentaire sont distinctes, chacune étant destinée à assurer une protection principale contre les chocs électriques.

[SOURCE: IEC 60664-1: 2020, 3.1.31, modifié – La Note à l'article a été ajoutée]

3.11.14
isolation double
isolation comprenant à la fois une isolation principale et une isolation supplémentaire

[SOURCE: IEC 60050-195:2021, 195-06-08]

3.11.15
isolation renforcée
isolation des parties actives dangereuses assurant un degré de protection contre les chocs électriques équivalent à celui d'une double isolation

Note 1 à l'article: L'isolation renforcée peut comporter plusieurs couches qui ne peuvent pas être soumises à l'essai séparément en tant qu'isolation principale ou isolation supplémentaire.

[SOURCE: IEC 60664-1:2020, 3.1.33]

3.11.16
séparation de protection
séparation entre des circuits par le biais d'une protection principale et d'une protection supplémentaire (isolation principale à laquelle s'ajoute une isolation supplémentaire ou un écran de protection) ou d'un moyen de protection équivalent (par exemple isolation renforcée)

3.11.17
protection électrique par écran
protection par écran
séparation de circuits électriques et/ou de conducteurs par rapport aux parties actives dangereuses par un écran de protection électrique relié au réseau équipotentiel de protection et destiné à fournir une protection contre les chocs électriques

[SOURCE: IEC 60050-195:2021, 195-06-18, modifié – L'adjectif "électrique" a été ajouté à "protection par écran"; en langue anglaise, le terme "protective shielding" a été supprimé]

3.11.18
circuit circuit TBTtrès basse tension
circuit dont la tension ne dépasse pas 50 V en courant alternatif et 120 V en courant continu ou la valeur spécifiée dans la norme de produit correspondante

Note 1 à l'article: Dans le présent document, la définition ci-dessus de la plage de tensions s'applique pour les essais de tension donnés en 7.2.2.2. Pour une description du concept générique de très basse tension, voir l'IEC 60050-195:2021, 195-05-24.

3.11.19
circuit de circuit TBTPtrès basse tension de protection
circuit électrique dont les caractéristiques sont les suivantes:

– la tension ne dépasse pas la valeur de la très basse tension;
– il existe une séparation de protection entre les circuits autres que les circuits TBTP ou TBTS;
– il existe des dispositions pour procéder à la mise à la terre du circuit TBTP, ou de ses parties conductrices accessibles, ou de ces deux éléments à la fois

Note 1 à l'article: Dans le présent document, la définition ci-dessus de circuit TBTP s'applique pour les essais de tension donnés en 7.2.2.2. Pour une description du concept générique de très basse tension de protection, voir l'IEC 60050-195:2021, 195-06-29.