

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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



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IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

PRICE CODE
CODE PRIX

XD

ICS 29.200; 29.045

ISBN 978-2-88910-061-3

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**SEMICONDUCTOR CONVERTERS –
GENERAL REQUIREMENTS AND LINE COMMUTATED CONVERTERS –****Part 1-1: Specification of basic requirements**

FOREWORD

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

This fourth edition cancels and replaces the third edition published in 1991, Corrigendum 1 (1993) and Amendment 1 (1996). This fourth edition constitutes a technical revision.

This fourth edition introduces five main changes:

- a) re-edition of the whole standard according to the current directives;
- b) correction of definitions and addition of new terms, especially terms concerning EMC, harmonic distortion and insulation co-ordination;
- c) the service condition tolerances have been revised according to the IEC 61000 series;
- d) the insulation tests have been revised considering the insulation co-ordination;
- e) addition of three annexes.

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

FDIS	Report on voting
22/146/FDIS	22/149/RVD

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

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

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

Part 1-1, 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.

Part 1-2, IEC/TR 60146-1-2, Application guide:

- 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.

Part 1-3, IEC 60146-1-3, Transformers and reactors:

- to give additional information on characteristics wherein converter transformers differ from ordinary power transformers. In all other respects, the rules specified in IEC 60076 shall apply to converter transformers, insofar as they are not in contradiction with this International Standard.

A list of all parts of the IEC 60146 series, under the general title: *Semiconductor converters*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

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

SEMICONDUCTOR CONVERTERS – GENERAL REQUIREMENTS AND LINE COMMUTATED CONVERTERS –

Part 1-1: Specification of basic requirements

1 Scope and object

This International Standard 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 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 standard is primarily intended to specify the basic requirements for converters in general and the requirements applicable to line commutated converters for conversion of a.c. power to d.c. power or vice versa. Parts of this standard 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 d.c. motor drives) or include a combination of said characteristics (for example direct d.c. converters for electric rolling stock).

This standard 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. Dedicated product standards for power converters should refer to this International Standard.

NOTE 1 This standard 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.

2 Normative references

The following referenced documents are indispensable for the application 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 – Part 551: Power electronics*

IEC 60050-551-20:2001, *International Electrotechnical Vocabulary – Part 551-20: Power electronics – Harmonic analysis*

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, *Insulation coordination for equipment within low-voltage 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, *Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment with 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, *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, *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, *Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments*

IEC 61000-6-2, *Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity 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, *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 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*

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

3 Terms and definitions

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

The policy adopted is as follows:

- a) when an existing IEV definition needs amplification or additional information, the title, the reference and the additional text are given;
- b) explanations and figures are given in 4.3;
- c) 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]

3.1.2

electronic (power) switch

an operative unit for electronic power switching comprising at least one controllable valve device

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

3.1.3

semiconductor switch

an electronic power switch with semiconductor valve devices

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

NOTE Similar terms are used for electronic switches or power controllers with specific electronic valve devices, for example thyristor controller, transistor switch.

3.1.4

non-controllable valve device

rectifier diode

a 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]

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

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

NOTE 1 Devices having only three layers but having switching characteristics similar to those of four layers thyristors may also be called thyristors.

NOTE 2 The term "thyristor" is used as a generic term to cover the whole range of PNP 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".

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]

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]

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]

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

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

NOTE Also known as gate turn-off thyristor.

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 The structure of the device intrinsically provides the capability of amplification (see IEV 521-04-46)

NOTE 2 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**

a 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]

3.1.12**valve device assembly**

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

NOTE 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]

3.1.13**electronic valve device**

an 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]

3.1.14**semiconductor valve device**

an electronic valve device which is a semiconductor device

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

NOTE 1 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 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.

3.1.15

(electronic) (power) 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

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

NOTE Characteristics include, for example, voltage amplitude, number of phases and frequency, including zero frequency.

3.1.16

(electronic) (power) converter

an operative unit for electronic power conversion, comprising one or more electronic valve devices, and auxiliaries if any

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

NOTE 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 are 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 are included in the converter, for example fans or cooling system.

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]

3.1.19

semiconductor converter

an electronic power converter with semiconductor valve devices

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

NOTE 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.

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]

3.2 Arms and connections

3.2.1

(valve) arm

a part of the circuit of an electronic power converter or switch bounded by any two a.c. or d.c. 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]

3.2.2

principal arm

a 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]

3.2.3

auxiliary arm

any valve arm other than a principal arm

NOTE 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]

3.2.4

by-pass arm

an 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]

3.2.5

free-wheeling arm

a by-pass arm containing only non-controllable valve devices

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

3.2.6

turn-off arm

an 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]

3.2.7

regenerative arm

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

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

3.2.8

converter connection

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

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

NOTE Common practice also uses the term “topology” of the converter with the same sense.

3.2.9

basic converter connection

the electrical arrangement of principal arms in a converter

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

3.2.10

single-way connection (of a converter)

a converter connection such that the current through each of the phase terminals of the a.c. circuit is unidirectional

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

3.2.11

double-way connection (of a converter)

a converter connection such that the current through each of the phase terminals of the a.c. circuit is bidirectional

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

3.2.12

bridge connection

a double-way connection of pairs of arms such that the centre terminals are the phase terminals of the a.c. circuit, and that the outer terminals of like polarity are connected together and are the d.c. terminals

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

3.2.13

uniform connection

a connection with either all principal arms controllable or all principal arms non-controllable

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

3.2.14

non-uniform connection

a connection with both controllable and non-controllable principal arms

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

3.2.15

series connection

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

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

3.2.16

series connection of converters

a 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

a 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]

3.3 Controllability of converter arms and quadrants of operation (on d.c. 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 (on the d.c. side)

quadrant of the voltage current plane defined by the d.c. voltage polarity and the current direction [df 130]

3.3.4

one-quadrant converter

an a.c./d.c. or d.c. converter with one possible direction of d.c. power flow

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

3.3.5

two-quadrant converter

an a.c./d.c. or d.c. converter with two possible directions of d.c. power flow associated with one direction of direct current and two directions of direct voltage or vice versa

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

3.3.6

four-quadrant converter

an a.c./d.c. or d.c. converter with two directions of d.c. power flow, associated with two directions of direct voltage and two directions of direct current

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

3.3.7

reversible converter

bi-directional converter

a converter in which the direction of the power flow is reversible

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

NOTE The term bi-directional converter corresponds to common practice, and provides a better picture of the bi-directional power flow in the converter.

3.3.8

single converter

a current stiff reversible a.c./d.c converter with direct current in one direction

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

3.3.9

double converter

a current stiff reversible a.c./d.c. converter with direct current in both directions

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

3.3.10

converter section of a double converter

that part of a double converter in which the main direct current when viewed from the d.c. terminals always flows in the same direction

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

3.3.11

phase control

the 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]

3.3.12

triggering

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

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

3.4 Commutation, quenching and commutation circuitry

3.4.1

commutation

in an electronic power converter the 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]

3.4.2

quenching

the termination of current flow in an arm without commutation

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

3.4.3

direct commutation

a commutation between two principal arms without transfer through any auxiliary arms

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

3.4.4

indirect commutation

a 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]

3.4.5

external commutation

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

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

3.4.6**line commutation**

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

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

3.4.7**load commutation**

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

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

3.4.8**machine commutation**

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

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

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**

a commutation where the commutating voltage is supplied by components within the converter or the electronic switch

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

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]

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**

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

NOTE Simultaneously the next electronic valve device to conduct is turned on.

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

3.4.14**valve device quenching**

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

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

3.4.15

external quenching

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

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

NOTE External quenching occurs in line-commutated converters under discontinuous conduction operation.

3.5 Commutation characteristics

3.5.1

commutation circuit

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

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

3.5.2

commutation voltage

the voltage which causes the current to commute

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

3.5.3

commutation inductance

the resulting inductance in the commutation circuit

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

NOTE For line or machine commutated converters, the commutation reactance is the impedance of the commutation inductance at the fundamental frequency.

3.5.4

commutation interval

the time interval in which commutating arms are carrying principal current simultaneously

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

3.5.5

angle of overlap

μ

the commutation interval expressed in angular measure

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

NOTE Also known as overlap angle μ .

3.5.6

commutation notch

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

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

3.5.7

commutation repetitive transient

voltage oscillation associated with the commutation notch [df 24]

3.5.8**commutating group**

a group of principal arms which commute cyclically among themselves without intermediate commutation of the current to other principal arms

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

3.5.9**commutation number q**

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

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

3.5.10**pulse number p**

the 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]

3.5.11**trigger delay angle**

α

the 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 With line, machine or load commutated converters the reference instant is the zero crossing instant of the commutating voltage. With a.c. controllers it is the zero crossing instant of the supply voltage. For a.c. 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]

3.5.12**trigger advance angle**

β

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

NOTE 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]

3.5.13**inherent delay angle**

α_p

the current delay angle occurring, even without phase control, caused by multiple overlap

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

NOTE Multiple overlap occurs in line commutated converters at high angles of overlap.

3.5.14**extinction angle**

γ

the 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**

the 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]

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

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

NOTE 1 The quantity may describe electrical, thermal, mechanical, or environmental properties.

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

NOTE 3 The nominal value of a system (for example nominal voltage – IEC 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 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 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.

3.6.2**rated frequency (for converters and their transformers)**

f_N

specified frequency on the a.c. side of a converter [df 142]

3.6.3**rated voltage on the line side (for converters and their transformers)**

U_{LN}

specified r.m.s. value of the voltage between conductors on the line side of the converter [df 146]

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}

r.m.s. 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 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 r.m.s. value of the current on the line side of the converter under rated conditions [df 137]

NOTE 1 It 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 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 The rated line current includes currents supplied to the auxiliary circuits of the converter. It also takes into account the effect of d.c. current ripple and circulating current, if any.

3.6.6

rated current on the valve side (for converters and their transformers)

I_{vN}

maximum r.m.s. value of the current on the valve side of the converter under rated conditions [df 138]

NOTE 1 It 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 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 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 d.c. current, specified by the manufacturer, of the direct voltage between the d.c. 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 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 The rated continuous direct current of an assembly is very often essentially higher than the rated direct current of the corresponding complete equipment.

NOTE 2 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 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 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 The characteristics of the associated maximum direct current I_{dSMN} are parts of the definition of the short time duty.

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 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 r.m.s. value of the load current evaluated over the period of the load duty cycle [df 136]

NOTE The duty class should be specified as a sequence of current values together with their durations.

3.6.16**rated d.c. power**

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

NOTE The measured d.c. power may differ from the rated d.c. 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}**

the theoretical no-load direct voltage of an a.c./d.c. 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]

3.7.2**controlled ideal no-load direct voltage** **$U_{di\alpha}$**

the theoretical no-load direct voltage of an a.c./d.c. 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]

3.7.3**conventional no-load direct voltage** **U_{d0}**

the 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

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

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

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

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

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

3.7.5**real no-load direct voltage** **U_{d00}**

the actual mean direct voltage at zero direct current

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

3.7.6**direct voltage regulation**

the 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

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

NOTE 1 If voltage stabilizing means are used, refer also to 3.7.9.

NOTE 2 The nature of the d.c. 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.

3.7.7**inherent direct voltage regulation**

the direct voltage regulation excluding the effect of the a.c. system impedance

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

3.7.8**total direct voltage regulation**

the direct voltage regulation including the effect of the a.c. system impedance

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

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**

the 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]

3.7.11**conversion factor**

the ratio of the fundamental output power or d.c. output power to the fundamental input power or d.c. input power

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

NOTE 1 The fundamental power (IEV 551-17-08) is the active power determined by the fundamental components of voltage and current.

NOTE 2 For the purposes of this definition, the d.c. power is the product of the mean value of the voltage and mean value of the current.

3.7.12**power efficiency**

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

NOTE 1 In the conversion factor, the power of the a.c. components on the d.c. side is not taken into account. In the power efficiency, it is included in the d.c. power. Therefore, for a.c. to d.c. 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 the maximum power efficiency is 1,0 p.u.

NOTE 2 The conversion factor may be correctly obtained only by measurement of the fundamental a.c. power and d.c. voltage and current. The power efficiency may be correctly obtained either by measurement of a.c. power and d.c. power or by calculation or measurement of internal losses.

NOTE 3 The active power (mean value of the power) on the a.c. side, and the mean value of the power the on the d.c. side are to be considered.

3.7.13**power factor**

λ

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

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

NOTE Under sinusoidal conditions, the power factor is the absolute value of the active factor.

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

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 IEC 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.”

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

$$\nu = \frac{\lambda}{\cos \varphi_1} \quad [\text{df } 44]$$

NOTE Under sinusoidal voltage condition, the deformation factor is equal to the fundamental factor. See Note 2 of 3.10.14.

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 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 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 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

the 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]

3.9.2

(electromagnetic) emission

the phenomenon by which electromagnetic energy emanates from a source

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

3.9.3

emission level of a converter

the 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]

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]

3.9.5

electromagnetic disturbance level

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

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

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 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]

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]

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 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 3 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 of this International Standard.

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.

3.10.1

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.

3.10.2

fundamental frequency

frequency of the fundamental component

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

3.10.3

fundamental component (of a Fourier series)

fundamental

sinusoidal component of the Fourier series of a periodic quantity having the frequency of the quantity itself

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

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

3.10.4

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 If it is clearly stated in a context that the reference fundamental component is used, the word "reference" may be omitted, but this standard does not recommend this practice.

NOTE 2 For practical analysis, an approximation of the periodicity may be necessary.

NOTE 3 In power electronics, often the component having the frequency of the a.c. supply system or of the converter output quantities is chosen as reference fundamental component.

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

3.10.5

reference fundamental frequency

frequency of the reference fundamental component

NOTE If it is clearly stated in a context that the reference fundamental component is used, the word "reference" may be omitted, but this International Standard does not recommend this practice.

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

3.10.6

harmonic frequency

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

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

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

3.10.7

harmonic component

sinusoidal component of a periodic quantity having a harmonic frequency

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

NOTE 1 For brevity, such a component may be referred to simply as a harmonic.

NOTE 2 For practical analysis, an approximation of the periodicity may be necessary.

NOTE 3 The value is normally expressed as an r.m.s. value.

3.10.8**interharmonic frequency**

frequency which is a non-integer multiple of the reference fundamental frequency

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

NOTE 1 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 In the case where " $m < 1$ " the term of sub-harmonic frequency may also be used (see IEV 551-20-10).

3.10.9**interharmonic component**

sinusoidal component of a periodic quantity having an interharmonic frequency

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

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

NOTE 2 For practical analysis, an approximation of the periodicity may be necessary.

NOTE 3 The value is normally expressed as an r.m.s. value.

NOTE 4 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).

3.10.10**harmonic content**

sum of the harmonic components of a periodic quantity

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

NOTE 1 The harmonic content is a time function.

NOTE 2 For practical analysis, an approximation of the periodicity may be necessary.

NOTE 3 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 The r.m.s. value of the distortion content is

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

where

Q represents either current or voltage;

h is the harmonic order;

H is 50 for the purpose of this International Standard. 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.

3.10.11**total harmonic ratio****total harmonic distortion****THD**

ratio of the r.m.s. value of the harmonic content to the r.m.s. value of the fundamental component or the reference fundamental component of an alternating quantity

[IEV 551-20-13] [df 184] [df 185]

NOTE 1 It is preferable to change the term to "total harmonic ratio" for consistency with the naming rule.

NOTE 2 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 3 The total harmonic ratio may be restricted to a certain harmonic order (recommended notation " H "), 50 for the purpose of this International Standard.

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

where, in addition to notations already given in 3.10.10, Q_1 is the r.m.s. value of the fundamental component.

3.10.12

total distortion content

quantity obtained by subtracting from an alternating quantity its fundamental component or its reference fundamental component

[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.

3.10.13

total distortion ratio

TDR

ratio of the r.m.s. value of the total distortion content to the r.m.s. value of the fundamental component or the reference fundamental component of an alternating quantity

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

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

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

3.10.14

total distortion factor

TDF

ratio of the r.m.s. value of the total distortion content to the r.m.s. value of an alternating quantity

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

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

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

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

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

3.10.15**individual harmonic ratio****IHR**

ratio of any harmonic component to the fundamental [df 92]

NOTE 1 In IEC 161-02-20 this term is named “ n^{th} harmonic ratio”. The term here 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 The value of the individual harmonic ratio is $IHR = \frac{Q_h}{Q_1}$

3.10.16**partial weighted harmonic ratio****PWHR**

ratio of the r.m.s. value of a selected group of higher order harmonics, weighted with the harmonic order h , to the r.m.s. 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)”.

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 (of an 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 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]

3.11.4**equipotential bonding**

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

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

3.11.5 equipotential bonding system EBS

interconnection of conductive parts providing equipotential bonding between those parts

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

3.11.6 protective equipotential bonding system PEBS

equipotential bonding system providing protective equipotential bonding

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

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 The working voltage can be d.c. or a.c.. Both the r.m.s. 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

r.m.s. 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

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

NOTE 1 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 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 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 r.m.s. value is the determining value.

NOTE 4 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 r.m.s. value of the working voltage, whichever is the higher.

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 The rated impulse voltage depends either on the result of the insulation co-ordination 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 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 live parts to provide basic protection against electric shock

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

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

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

3.11.14

double insulation

insulation comprising both basic insulation and supplementary insulation

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

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

3.11.15

reinforced insulation

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

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

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

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]

3.11.18

ELV (extra low voltage) circuit

circuit the voltage of which does not exceed 50 V a.c. and 120 V d.c. or the value specified in the relevant product standard

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

3.11.19

PELV (protective extra low voltage) circuit

electrical circuit with the following characteristics:

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

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

3.11.20**SELV (safety extra low voltage) circuit**

electrical circuit with the following characteristics:

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

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

4 Operation of semiconductor power equipment and valve devices**4.1 Classification****4.1.1 Semiconductor converter**

Semiconductor converters can be classified as below.

a) Type of conversion and switching

- 1) a.c. to d.c. conversion (rectifier, identified as (power) rectification in IEV 551-11-06);
- 2) d.c. to a.c. conversion (inverter, identified as (power) inversion in IEV 551-11-07);
- 3) d.c. to d.c. conversion (direct or indirect d.c. converter, identified as d.c. conversion in IEV 551-11-09);
- 4) a.c. to a.c. conversion (direct or indirect a.c. converter, identified as a.c. conversion in IEV 551-11-08);
- 5) switching (periodic or non-periodic).

NOTE 1 Other similar terms are used, e.g. “d.c./d.c. conversion” for d.c. conversion or “a.c./a.c. converter” for a.c. converter.

b) Purpose of conversion

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

- 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 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 d.c. system

Converters connected to at least one d.c. 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 d.c. side is smoothed, in fact of the predominant internal impedance. A thyristor converter is generally a current stiff converter.

For a converter connecting an a.c. system to a d.c. system, rectification implies a power flow from the a.c. to the d.c. 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 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), power transistor). 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 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 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
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
g	number of sets of commutating groups between which I_{dN} is divided
h	order of harmonic
I_d	direct current (any defined value)
I_{dN}	rated direct current
I_{dMN}	rated continuous direct current (maximum value)
I_{dRMN}	intermittent peak maximum direct current
I_{dSMN}	peak maximum direct current
I_L	r.m.s. current on line side (of converter or transformer if included)
I_{LN}	rated value of I_L
I_{1LN}	r.m.s. value of the fundamental component of I_{LN}

Table 2 (continued)

Symbol	Quantity
I_{hLN}	r.m.s. value of harmonic order h of I_{LN}
I_{VN}	rated value of current on valve side of transformer
p	pulse number (see note)
P	active power
P_{LN}	active power on line side at rated load
q	commutation number
Q_{1LN}	reactive power on line side at rated load
R_{SC}	relative short-circuit power
s	number of series connected commutating groups
S_{com}	short-circuit power calculated at the a.c. 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 line side
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
$U_{d0\alpha}$	value of U_{d0} with trigger delay angle α
U_{d00}	real no-load direct voltage
U_{di}	ideal no-load direct voltage
$U_{di\alpha}$	controlled ideal no-load direct voltage
U_{dN}	rated direct voltage
U_{dxN}	total inductive direct voltage regulation at rated direct current
U_{hL}	r.m.s. 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
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
X_{tN}	inductive voltage drop of the transformer in per unit

Table 2 (*continued*)

Symbol	Quantity
α	trigger delay angle
α_p	inherent delay angle
β	trigger advance angle
γ	extinction angle
δ	number of commutating groups commutating simultaneously per primary
λ	total power factor
μ	angle of overlap (commutation angle) NOTE The overlap angle is noted μ in this 4 th 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 .
ν	deformation factor
φ_1	displacement angle of the fundamental component of I_L
NOTE The pulse number p includes the number of phases.	

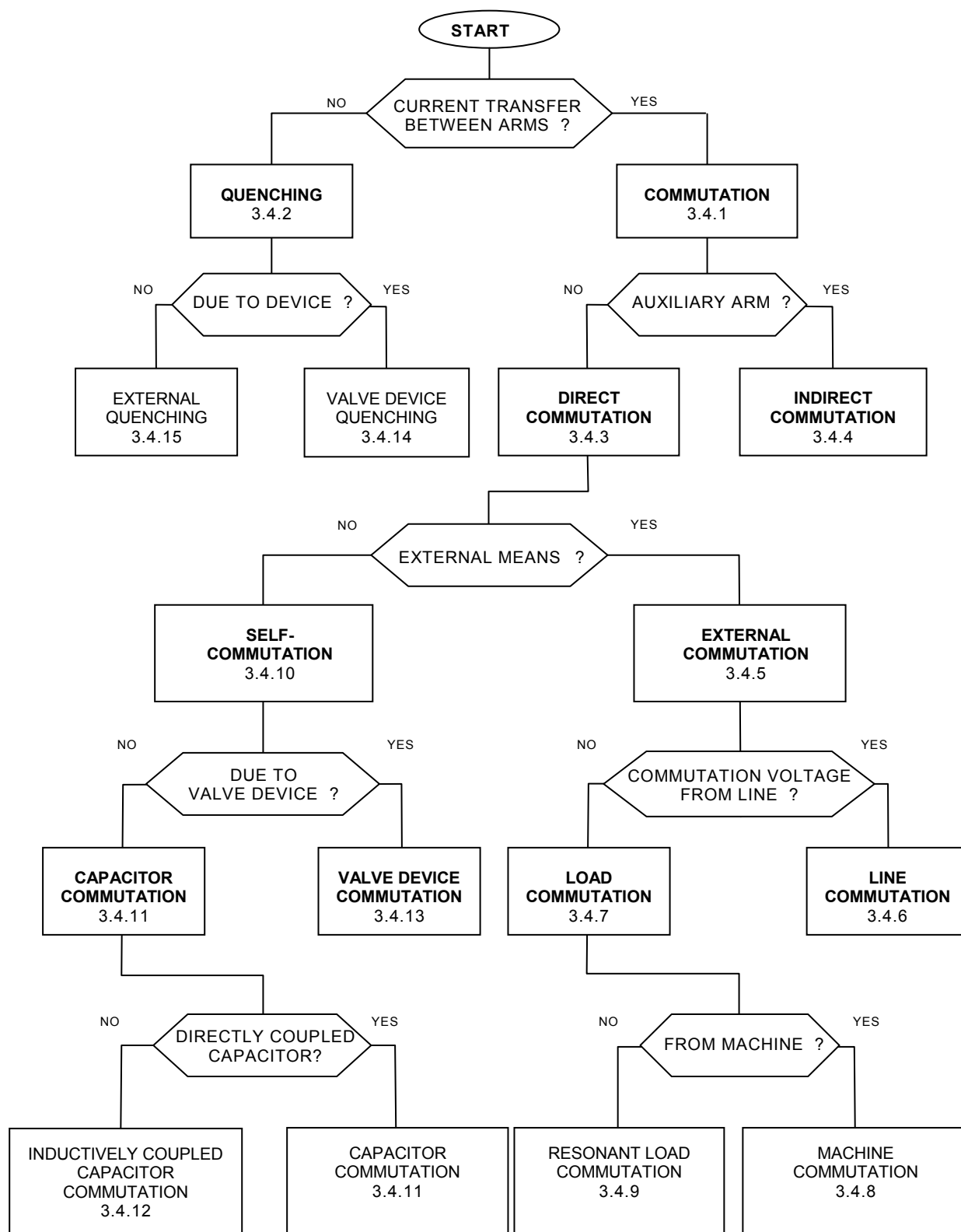
4.3 Basic operation of semiconductor converters

4.3.1 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.



IEC 1144/09

Figure 1 – Types of commutation

The commutation is characterized by the waveforms of voltage and current and by angles, see 3.5.4, 3.5.11, 3.5.12, 3.5.14 and following. 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.

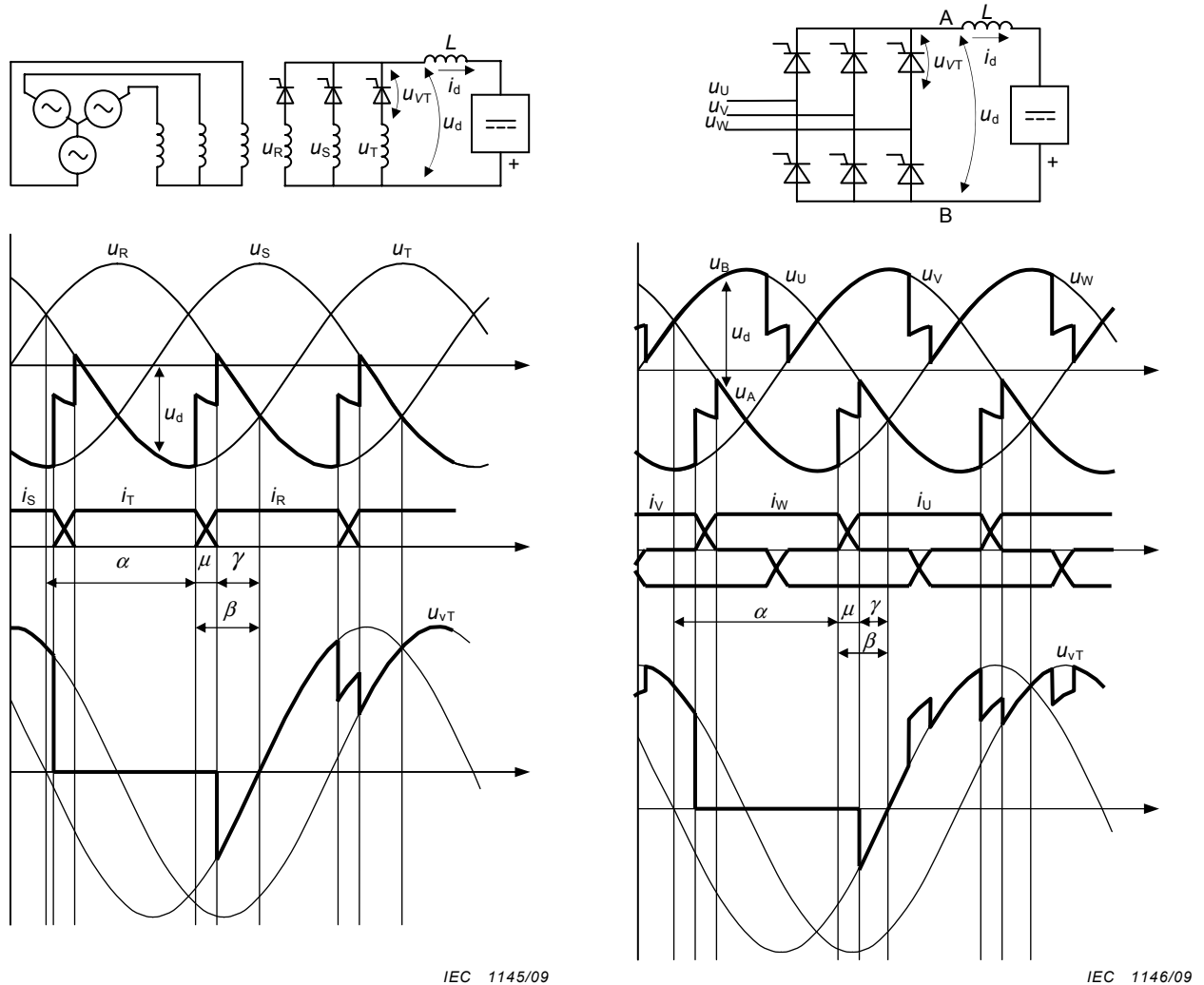


Figure 2a – Three phase star connection converter

Figure 2b – Three phase bridge converter

Figure 2 – Illustration of angles

4.3.2 Basic calculation factors for line commutated converters

4.3.2.1 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 the formula:

$$U_{di} = U_{v0} \times \sqrt{2} \times \frac{p}{\pi} \times \sin \frac{\pi}{p}$$

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:

$$U_{di\alpha} = U_{di} \times \cos \alpha$$

2) If the converter load is purely resistive:

for

$$0 \leq \alpha \leq \frac{\pi}{2} - \frac{\pi}{p}; \quad U_{di\alpha} = U_{di} \times \cos \alpha$$

for

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

b) Non-uniform connection (half controllable)

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

4.3.2.2 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 d.c. voltage only depends on the d.c. 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.

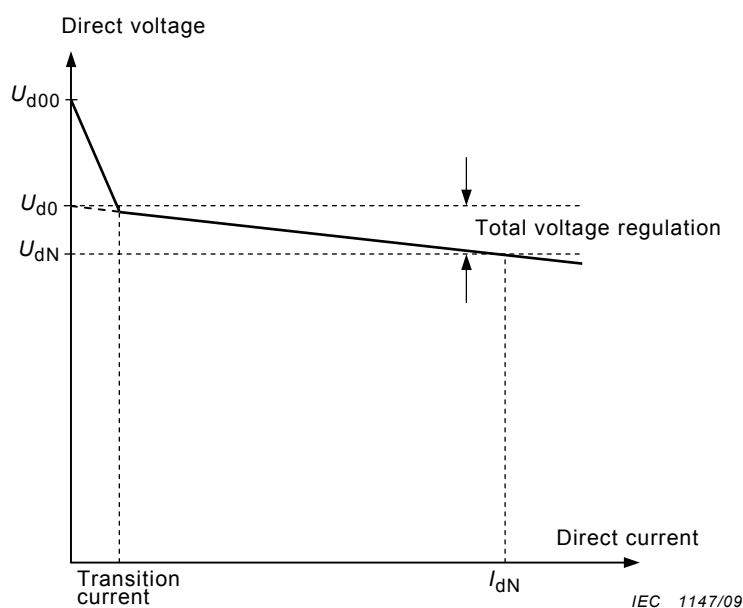


Figure 3 – Voltage regulation

4.3.3 Disturbances and fault conditions

4.3.3.1 Level of immunity 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 Tripping Damage	F T D	No loss of performance No interruption of service due to protective devices 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 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 Automatic resumption of service should consider 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.

4.3.3.2 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:

- IEC 61204-3 for power supply units (PSU);
- IEC 61800-3 for power drive systems (PDS);
- IEC 62040-2 for uninterruptible power systems (UPS);
- IEC 62310-2 for static transfer systems (STS).

NOTE 1 This International Standard 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 system borne low frequency 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.

a) System borne disturbances

Disturbances attributable to a number of causes, 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 inter-harmonic 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 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 r.m.s. value between consecutive steady-states.

NOTE 4 The listed disturbances may be produced by the converter under consideration or by other converters and the actual level may change 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 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 letters 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 the circulation method (refer to Table 5).

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

Example 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 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 suppliers 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) 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).

c) 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 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 d.c. 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; but if the converter improves the disturbance values, the disturbance levels shall exclude the corresponding effects of the converter.

For different a.c. or d.c. connections, different immunity classes or special immunity levels may be specified. If no immunity class is specified, class B 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 this clause correspond to the practice established by the former editions of this standard, before the publication of the IEC 61000-2 series setting up the compatibility levels.

NOTE 1 While IEC 60146 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 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 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 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 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 to frequency and voltage amplitude, Table 8 to voltage unbalance and Table 9 to voltage waveform. Compatibility levels defined in IEC 61000-2-4 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 a.c. voltage connections**

Disturbance	Applicable values of IEC 61000-2-4	Immunity class			Performance criteria ^a
		A	B	C	
Frequency tolerance					
range (%)		±2	B2 = ±2 ^b	±1	F
rate of change (%/s)	–	±2	B1 = ±1 ±1	±1	F
Voltage amplitude tolerance					
a) steady state $\Delta U/U_N$ (%)		+10 / –10	+10 / –10	+10 / –5	F
<i>Compatibility levels IEC 61000-2-4 ^c</i>	<i>Table 1</i>	+10 / –15	±10	±8	
b) short time (0,5 to 30 cycles) up to rated values					
– rectifier operation only (%)	–	±15	+15 / –10	+15 / –10	T
– inverter operation (%)	–	±15	+15 / –10	+15 / –7,5	T
NOTE 1 A decrease in frequency is assumed not to coincide with an increase in line voltage and vice versa.					
NOTE 2 For overload conditions other limits are to be specified separately.					
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 4 Short-time a.c. voltage variations are not expected to occur more frequently than once every 2 h.					
^a For definition of the code, refer to Table 3.					
^b The compatibility level for industrial networks class 2, according to IEC 61000-2-4, is ±1 %					
^c <i>Electromagnetic environment classes 3, 2, 1.</i>					

Table 8 – Immunity levels to voltage unbalance for stiff a.c. voltage connections

Disturbance	Applicable values of IEC 61000-2-4	Immunity class			Performance criteria ^a
		A	B	C	
Voltage unbalance U_{neg}/U_{pos}					
a) steady state (%) <i>Compatibility levels IEC 61000-2-4 ^b (over any 10 min)</i>	<i>Table 1</i>	5 3	5 2	2 2	F
b) short time					
– rectifier operation only (%)	–	8	5	3	T
– inverter operation (%)	–	5	5	2	T
NOTE 1 The higher values specified for short time may lead to, for example, excessive ripple on the d.c. side and uncharacteristic harmonics on the a.c. side.					
NOTE 2 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 <i>Electromagnetic environment classes 3, 2, 1.</i>					

Table 9 – Immunity levels to voltage waveform for stiff a.c. voltage connections

Disturbance	Applicable values of IEC 61000-2-4	Immunity class			Performance criteria ^a
		A	B	C	
Voltage waveform					
a) total harmonic distortion <i>THD</i> (%) <i>Compatibility levels IEC 61000-2-4 ^b</i>	<i>Table 2</i>	25 10	10 8	5 5	F
b) individual harmonic distortion					
steady-state odd (%)		8	6	3	F
even (%)		2	2	1	F
<i>Compatibility levels IEC 61000-2-4 ^b</i>	<i>Table 2</i>	8	6	3	
– order 5 (%)					
– other odd orders					
– excluding multiples of 3	<i>Table 3</i>	See IEC 61000-2-4	See IEC 61000-2-4	See IEC 61000-2-4	
– multiples of 3	<i>Table 4</i>				
– even orders	<i>Table 5</i>				
c) commutation notches (steady state)					
– amplitude (% of U_{LWM})	–	100	40	20	T
– area (% of $U_{LWM} \times \text{degree}$)	–	625	250	125	T
NOTE 1 The area of a notch is approximately constant for a given d.c. current and R_{SC} . The width and depth vary with the trigger delay angle (α).					
NOTE 2 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 <i>Electromagnetic environment classes 3, 2, 1.</i>					