

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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AND LINE COMMUTATED CONVERTERS –****Part 1-1: Specification of basic requirements****FOREWORD**

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

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

This fifth edition introduces four main changes:

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

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

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

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

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

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

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

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

- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

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

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

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

IEC TR 60146-1-2, Application guidelines:

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

SEMICONDUCTOR CONVERTERS – GENERAL REQUIREMENTS AND LINE COMMUTATED CONVERTERS –

Part 1-1: Specification of basic requirements

1 Scope

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

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

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

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

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

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

NOTE 2 For the information on converter transformers, related to this document, see IEC 61378-1.

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

2 Normative references

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

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

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

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

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

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

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

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

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

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

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

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

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

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

3 Terms and definitions

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

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

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

NOTE The policy adopted is as follows:

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

3.1 Semiconductor devices and combinations

3.1.1

semiconductor device

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

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

3.1.2

electronic power switch

electronic switch

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

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

3.1.3

semiconductor switch

electronic power switch with semiconductor valve devices

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

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

3.1.4

non-controllable valve device

rectifier diode

reverse blocking valve device the current path of which conducts in its conducting direction without any control signal being applied

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

3.1.5

thyristor

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

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

Note 2 to entry: The term "thyristor" is used as a generic term to cover the whole range of 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".

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

3.1.6

reverse blocking triode thyristor

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

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

3.1.7

reverse conducting triode thyristor

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

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

3.1.8

bidirectional triode thyristor

triac

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

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

3.1.9**turn-off thyristor**

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

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

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

3.1.10**power transistor**

transistor designed for switching from the on-state to the off-state and vice versa by applying control signals of appropriate polarity to the base or gate terminal

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

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

3.1.11**valve device stack**

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

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

3.1.12**valve device assembly**

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

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

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

3.1.13**electronic valve device**

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

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

3.1.14**semiconductor valve device**

electronic valve device which is a semiconductor device

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

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

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

3.1.15
electronic power conversion
power conversion
conversion

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

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

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

3.1.16
electronic power converter
power converter
converter

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

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

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

3.1.17
trigger equipment
gating equipment

equipment which provides suitable trigger pulses from a control signal for controllable valve devices in a converter or power switch including timing or phase shifting circuits, pulse generating circuits and usually power supply circuits

3.1.18
system control equipment

equipment associated with a power conversion equipment or system which performs automatic adjustment of the converter output characteristics as a function of a controlled quantity

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

3.1.19
semiconductor converter

electronic power converter with semiconductor valve devices

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

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

3.1.20
power conversion equipment
PCE

equipment including the electronic power converter and auxiliaries necessary for operation of the converter itself, or even other parts dedicated to the application, and where these parts cannot be physically separated without preventing the operation of the converter

3.1.21**power conversion system**

system consisting of a power conversion equipment and associated components for the application

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

3.2 Arms and connections**3.2.1****valve arm
arm**

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

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

3.2.2**principal arm**

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

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

3.2.3**auxiliary arm**

valve arm other than a principal arm

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

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

3.2.4**by-pass arm**

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

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

3.2.5**free-wheeling arm**

by-pass arm containing only non-controllable valve devices

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

3.2.6**turn-off arm**

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

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

3.2.7**regenerative arm**

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

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

3.2.8

converter connection

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

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

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

3.2.9

basic converter connection

electrical arrangement of principal arms in a converter

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

3.2.10

single-way connection

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

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

3.2.11

double-way connection

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

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

3.2.12

bridge connection

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

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

3.2.13

uniform connection

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

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

3.2.14

non-uniform connection

connection with both controllable and non-controllable principal arms

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

3.2.15

series connection

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

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

3.2.16**series connection of converters**

series connection in which two or more converters are connected in such a way that their voltages add

3.2.17**boost and buck connection**

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

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

3.3 Controllability of converter arms and quadrants of operation (on DC side)**3.3.1****controllable arm**

converter arm including controllable valve device(s)

3.3.2**non-controllable arm**

converter arm including only no-controllable valve device(s)

3.3.3**quadrant of operation**

<DC side> quadrant of the voltage-current plane defined by the DC voltage polarity and the current direction

3.3.4**one-quadrant converter**

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

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

3.3.5**two-quadrant converter**

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

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

3.3.6**four-quadrant converter**

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

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

3.3.7**reversible converter****bi-directional converter**

converter in which the direction of the power flow is reversible

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

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

3.3.8

single converter

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

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

3.3.9

double converter

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

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

3.3.10

converter section of a double converter

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

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

3.3.11

phase control

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

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

3.3.12

triggering

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

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

3.4 Commutation, quenching and commutation circuitry

3.4.1

commutation

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

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

3.4.2

quenching

termination of current flow in an arm without commutation

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

3.4.3

direct commutation

commutation between two principal arms without transfer through any auxiliary arms

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

3.4.4**indirect commutation**

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

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

3.4.5**external commutation**

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

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

3.4.6**line commutation**

external commutation where the commutating voltage is supplied by the line

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

3.4.7**load commutation**

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

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

3.4.8**machine commutation**

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

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

3.4.9**resonant load commutation**

method of load commutation in which the commutating voltage is supplied by the load, using its resonant property

3.4.10**self-commutation**

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

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

3.4.11**capacitor commutation**

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

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

3.4.12**inductively coupled capacitor commutation**

method of capacitor commutation in which the capacitor circuit is inductively coupled to the commutation circuit

3.4.13**valve device commutation**

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

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

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

3.4.14**valve device quenching**

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

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

3.4.15**external quenching**

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

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

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

3.5 Commutation characteristics**3.5.1****commutation circuit**

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

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

3.5.2**commutation voltage**

voltage which causes the current to commute

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

3.5.3**commutation inductance**

resulting inductance in the commutation circuit

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

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

3.5.4**commutation interval**

time interval in which commutating arms are carrying principal current simultaneously

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

3.5.5**angle of overlap**

μ

commutation interval expressed in angular measure

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

3.5.6

commutation notch

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

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

3.5.7

commutation repetitive transient

voltage oscillation associated with the commutation notch

3.5.8

commutating group

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

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

3.5.9

commutation number

q

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

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

3.5.10

pulse number

p

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

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

3.5.11

trigger delay angle

α

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

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

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

3.5.12

trigger advance angle

β

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

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

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

3.5.13 inherent delay angle

 α_p

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

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

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

3.5.14 extinction angle

 γ

time, expressed in angular measure, between the instant when the current of the arm falls to zero and the instant when the arm is required to withstand steeply rising off-state voltage

3.5.15 hold-off interval

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

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

3.6 Rated values

3.6.1 rated value

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

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

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

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

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

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

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

3.6.2 rated frequency

 f_N

specified frequency on the AC side of a converter

3.6.3 rated voltage on the line side

 U_{LN}

specified RMS value of the voltage between conductors on the line side of the converter

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

3.6.4**rated voltage on the valve side of the transformer** U_{vN}

RMS value of the no-load voltage between vectorially consecutive commutating phase terminals of the valve windings of a commutating group at rated voltage on the line side of the transformer

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

3.6.5**rated current on the line side** I_{LN}

maximum RMS value of the current on the line side of the converter under rated conditions

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

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

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

3.6.6**rated current on the valve side** I_{vN}

maximum RMS value of the current on the valve side of the converter under rated conditions

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

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

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

3.6.7**rated apparent power on the line side** S_{LN}

total apparent power, at the line side terminals, at rated frequency, rated voltage on the line side and rated current on the line side

3.6.8**rated direct voltage** U_{dN}

mean value, at rated DC current, specified by the manufacturer, of the direct voltage between the DC terminals of the assembly or equipment

3.6.9**rated direct current** I_{dN}

mean value of the direct current specified by the manufacturer for specified load and service conditions

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

3.6.10**rated continuous direct current** I_{dMN}

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

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

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

3.6.11

peak maximum direct current

I_{dSMN}

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

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

3.6.12

intermittent peak maximum direct current

I_{dRMN}

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

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

3.6.13

rated current for peak load duty

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

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

3.6.14

rated current for continuous duty with superimposed peak loads

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

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

3.6.15

rated current for repetitive load duty

rated direct current of the assembly or converter, specified as the RMS value of the load current evaluated over the period of the load duty cycle

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

3.6.16

rated DC power

product of the rated direct voltage and the rated direct current

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

3.7 Specific voltages, currents and factors

3.7.1

ideal no-load direct voltage

U_{di}

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

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

3.7.2

controlled ideal no-load direct voltage

$U_{di\alpha}$

theoretical no-load direct voltage of an AC/DC converter corresponding to a specified trigger delay angle assuming no threshold voltages of electronic valve devices and no voltage rise at small loads

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

3.7.3

conventional no-load direct voltage

U_{d0}

mean value of the direct voltage which would be obtained by extrapolating the direct voltage/current characteristic from the region of continuous flow of direct current to zero current at zero trigger delay angle, i.e. without phase control

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

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

3.7.4

controlled conventional no-load direct voltage

$U_{d0\alpha}$

mean value of the direct voltage corresponding to a specified trigger delay angle which would be obtained by extrapolating the direct voltage/current characteristic from the region of continuous flow of direct current to zero current

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

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

3.7.5

real no-load direct voltage

U_{d00}

actual mean direct voltage at zero direct current

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

3.7.6

direct voltage regulation

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

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

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

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

3.7.7

inherent direct voltage regulation

direct voltage regulation excluding the effect of the AC system impedance

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

3.7.8

total direct voltage regulation

direct voltage regulation including the effect of the AC system impedance

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

3.7.9

output voltage tolerance band

specified range of steady-state values of a stabilized output voltage around its nominal or preset value

3.7.10

transition current

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

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

3.7.11

conversion factor

ratio of the fundamental output power or DC output power to the fundamental input power or DC input power

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

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

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

3.7.12

power efficiency

ratio of the output power to the input power of the converter

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

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

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

3.7.13 power factor

λ

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

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

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

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

3.7.14 power factor of the fundamental wave displacement factor

$\cos\varphi_1$

under periodic conditions, ratio of the active power of the fundamental components P_1 to the apparent power of the fundamental components S_1

$$\cos\varphi_1 = \frac{P_1}{S_1}$$

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

3.7.15 deformation factor

ν

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

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

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

3.8 Cooling

3.8.1 cooling medium

liquid (for example water) or gas (for example air) which removes the heat from the equipment

3.8.2 heat transfer agent

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

3.8.3 direct cooling

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

3.8.4 indirect cooling

method of cooling in which a heat transfer agent is used to transfer heat from the part to be cooled to the cooling medium

3.8.5
natural cooling
convection

method of circulating the cooling fluid (cooling medium or heat transfer agent) which uses the change of volumetric mass (density) with temperature

3.8.6
forced cooling

method of circulating the cooling medium or heat transfer agent by means of blower(s), fan(s) or pump(s)

3.8.7
mixed cooling

method of circulating the cooling medium or heat transfer agent, which uses, alternatively, natural and forced circulation

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

3.8.8
equilibrium temperature

steady-state temperature reached by a component of a converter under specified conditions of load and cooling

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

3.8.9
ambient air temperature

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

3.8.10
cooling medium temperature for air and gas cooling

average temperature measured outside the equipment at points 50 mm from the inlet to the equipment

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

3.8.11
cooling medium temperature for liquid cooling

temperature measured in the liquid pipe 100 mm upstream from the liquid inlet

3.8.12
temperature of heat transfer agent

heat transfer agent temperature measured at a point to be specified by the supplier

3.9 Service conditions tolerances and electromagnetic compatibility

3.9.1
electromagnetic compatibility
EMC

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

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

3.9.2**electromagnetic emission
emission**

phenomenon by which electromagnetic energy emanates from a source

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

3.9.3**emission level**

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

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

3.9.4**electromagnetic disturbance**

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

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

3.9.5**electromagnetic disturbance level**

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

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

3.9.6**reference level of generated disturbance of a converter**

assumed level of disturbance produced by a converter, when the actual operating conditions are not known and rated operating conditions are used to calculate or measure the disturbance level

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

3.9.7**immunity to a disturbance**

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

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

3.9.8**immunity level of a converter**

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

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

3.9.9 relative short-circuit power

R_{SC}

ratio of the short-circuit power of the source to the rated apparent power on the line side of the converters

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

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

3.10 Harmonic distortion

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

3.10.1 point of common coupling PCC

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

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

3.10.2 in-plant point of coupling IPC

point on a network inside a system or an installation, electrically nearest to a particular load, at which other loads are, or could be, connected

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

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

3.10.3 fundamental frequency frequency of the fundamental component

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

3.10.4 fundamental component fundamental

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

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

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

3.10.5 reference fundamental component

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

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

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

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

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

3.10.6

reference fundamental frequency

frequency of the reference fundamental component

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

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

3.10.7

harmonic frequency

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

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

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

3.10.8

harmonic component

sinusoidal component of a periodic quantity having a harmonic frequency

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

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

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

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

3.10.9

interharmonic frequency

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

Note 1 to entry: By extension of the harmonic order, the interharmonic order is the ratio of interharmonic frequency to the reference fundamental frequency, this ratio is not an integer (recommended notation: m).

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

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

3.10.10

interharmonic component

sinusoidal component of a periodic quantity having an interharmonic frequency

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

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

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

Note 4 to entry: As stated in IEC 61000-4-7, the time window has a width of 10 fundamental periods (50 Hz systems) or 12 fundamental periods (60 Hz systems), i.e. approximately 200 ms. The difference in frequency between two consecutive interharmonic components is, therefore, approximately 5 Hz. In the case of other fundamental

frequencies, the time window should be selected between 6 fundamental periods (approximately 1 000 ms at 6 Hz) and 18 fundamental periods (approximately 100 ms at 180 Hz).

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

3.10.11

harmonic content

sum of the harmonic components of a periodic quantity

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

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

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

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

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

where

Q represents either current or voltage;

h is the harmonic order;

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

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

3.10.12

total harmonic ratio

total harmonic distortion

THD

ratio of the RMS value of the harmonic content to the RMS value of the fundamental component or the reference fundamental component of an alternating quantity

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

where

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

Q_1 is the RMS value of the fundamental component.

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

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

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

3.10.13**total distortion content**

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

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

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

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

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

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

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

where Q_1 is noted in 3.10.12.

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

3.10.14**total distortion ratio****TDR**

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

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

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

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

3.10.15**total distortion factor****TDF**

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

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

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

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

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

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

3.10.16**individual harmonic ratio****IHR**

ratio of any harmonic component to the fundamental

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

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

3.10.17**partial weighted harmonic ratio****PWHR**

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

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

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

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

3.11 Definitions related to insulation co-ordination**3.11.1****electrical circuit
circuit**

<equipment> current paths of components or assemblies, conductors or terminals connected to each other by electrically conductive connections and insulated from the remaining part of the equipment

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

3.11.2**part of a circuit**

section of a circuit having its own rated insulation voltage

3.11.3**equipotentiality**

state when conductive parts are at a substantially equal electric potential

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

3.11.4**equipotential bonding**

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

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

3.11.5 equipotential bonding system EBS

interconnection of conductive parts providing equipotential bonding between those parts

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

3.11.6 protective equipotential bonding system PEBS

equipotential bonding system providing protective equipotential bonding

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

3.11.7 working voltage

voltage, at rated supply conditions (without tolerances) and worst case operating conditions, which occurs by design in a circuit or across insulation

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

3.11.8 decisive voltage class

calculated voltage range used to determine the classification of protective measures against electric shock

3.11.9 rated insulation voltage

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

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

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

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

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

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

3.11.10 rated impulse voltage

amplitude of the impulse used as reference for the definition and the tests of insulation characteristics of a circuit

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

3.11.11**over-voltage category**

concept used to classify equipment directly energized from the mains supply network

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

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

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

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

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

3.11.12**basic insulation**

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

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

3.11.13**supplementary insulation**

independent insulation applied in addition to basic insulation for fault protection

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

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

3.11.14**double insulation**

insulation comprising both basic insulation and supplementary insulation

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

3.11.15**reinforced insulation**

single insulation of hazardous live parts which provides a degree of protection against electric shock equivalent to double insulation

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

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

3.11.16**protective separation**

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

3.11.17**electrically protective screening
protective screening**

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

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

3.11.18**extra low voltage circuit****ELV circuit**

circuit the voltage of which does not exceed 50 V AC and 120 V DC or the value specified in the relevant product standard

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

3.11.19**protective extra low voltage circuit****PELV circuit**

electrical circuit with the following characteristics:

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

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

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

electrical circuit with the following characteristics:

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

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

3.12 Principal letter symbols and subscripts

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

Table 1 – List of major subscripts

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

Table 2 – Symbols

Symbol	Quantity	Reference to Clause 3 Terms and definitions
d_{xtN}	inductive direct voltage regulation due to converter transformer referred to U_{di}	-
e_{xN}	Inductive component of the relative short-circuit voltage of the converter transformer corresponding to I_{LN}	-
f_N	Rated frequency	3.6.2
g	Number of sets of commutating groups between which I_{dN} is divided	3.6.8
h	Order of harmonic	3.10.6
I_d	Direct current (any defined value)	-
I_{dN}	Rated direct current	3.6.9
I_{dMN}	Rated continuous direct current (maximum value)	3.6.10
I_{dRMN}	Intermittent peak maximum direct current	3.6.12
I_{dSMN}	Peak maximum direct current	3.6.11
I_L	RMS current on line side (of converter or transformer if included)	-
I_{LN}	Rated value of I_L	3.6.5
I_{1LN}	RMS value of the fundamental component of I_{LN}	-
I_{hLN}	RMS value of harmonic order h of I_{LN}	-
I_{vN}	Rated value of current on valve side of transformer	3.6.6
p	Pulse number	3.5.10

Symbol	Quantity	Reference to Clause 3 Terms and definitions
P	Active power	-
P_{LN}	Active power on line side at rated load	-
q	Commutation number	3.5.9
Q_{1LN}	Reactive power on line side at rated load	-
R_{SC}	Relative short-circuit power	3.9.9
s	Number of series connected commutating groups	-
S_{com}	Short-circuit power calculated at the AC terminals of the commutating arms	-
S_{SC}	Short-circuit power of the supply source	-
S_{Cmin}	Minimum short-circuit power of the supply source	-
S_{LN}	Rated apparent power on the line side	3.6.7
S_{1LN}	Value of S_{LN} based on I_{1LN}	-
S_{tN}	Transformer rated apparent power	-
U_d	Direct voltage (any defined value)	-
U_{d0}	Conventional no load direct voltage	3.7.3
$U_{d0\alpha}$	Value of U_{d0} with trigger delay angle α	3.7.4
U_{d00}	Real no-load direct voltage	3.7.5
U_{di}	Ideal no-load direct voltage	3.7.1
U_{dia}	Controlled ideal no-load direct voltage	3.7.2
U_{dN}	Rated direct voltage	3.6.8
U_{dxN}	Total inductive direct voltage regulation at rated direct current	-
U_{hL}	RMS value of harmonic order h of U_L	-
U_{iM}	Ideal crest no-load voltage, appearing between the end terminals of an arm neglecting internal and external voltage surge and voltage drops in valves, at no load. The ratio remains the same at light load current close to the transition current.	-
U_L	Line-to-line voltage on line side of converter or transformer, if any	-
U_{LN}	Rated value of U_L	3.6.3
U_{LRM}	Maximum instantaneous value of U_L including repetitive over-voltage but excluding non-repetitive over-voltages	-
U_{LSM}	Maximum instantaneous value of U_L including non-repetitive over-voltages	-
U_{LWM}	Maximum instantaneous value of U_L excluding transient over-voltages	-
U_M	Maximum of the sinusoidal waveform of the voltage (see 7.2.3.1)	-
U_{v0}	No-load line-to-line voltage on the line side of the converter or on the valve side of the transformer, if any	-
U_{vN}	Rated voltage on the valve side of the transformer	3.6.4
X_{tN}	Inductive voltage drop of the transformer in per unit	-
α	Trigger delay angle	3.5.11
α_p	Inherent delay angle	3.5.13
β	Trigger advance angle	3.5.12
γ	Extinction angle	3.5.14

Symbol	Quantity	Reference to Clause 3 Terms and definitions
δ	Number of commutating groups commutating simultaneously per primary	-
λ	Power factor	3.7.13
μ	Angle of overlap (commutation angle)	3.5.5
ν	Deformation factor	3.7.15
φ_1	Displacement angle of the fundamental component of I_L	3.7.14

4 Operation of semiconductor power equipment and valve devices

4.1 Classification

4.1.1 Semiconductor converter

Semiconductor converters are classified as below.

a) Type of conversion and switching

- 1) AC to DC conversion (rectifier, identified as (power) rectification in IEC 60050-551:1998, 551-11-06);
- 2) DC to AC conversion (inverter, identified as (power) inversion in IEC 60050-551:1998, 551-11-07);
- 3) DC to DC conversion (direct or indirect DC converter, identified as DC (power) conversion in IEC 60050-551:1998, 551-11-09);
- 4) AC to AC conversion (direct or indirect AC converter, identified as AC (power) conversion in IEC 60050-551:1998, 551-11-08);
- 5) switching (periodic or non-periodic).

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

b) Purpose of conversion

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

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

c) Type of valve turn-off

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

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

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

- a) external commutation (or quenching):
 - line commutation (or quenching);
 - load commutation (or quenching);

- b) self commutation (or quenching, see also 4.1.2, Note 2):
 - valve device commutation (or quenching);
 - capacitor commutation (or quenching).

d) Type of DC system

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

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

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

4.1.2 Semiconductor valve devices

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

- a) non-controllable valve device with a conductive forward and a blocking reverse characteristic (rectifier diode);
- b) valve device with a controllable forward switch-on (thyristor). Common name of this type of valve device is "on-switched valve device";
- c) valve device with a controllable forward switch-on and forward switch-off (turn-off thyristor (GTO), integrated gate-commutated thyristors (IGCT), power transistor, insulated gate bipolar transistor (IGBT)). Common name of this type of valve device is "switched valve device";
- d) valve device which is controllable in both directions (for example triac).

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

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

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

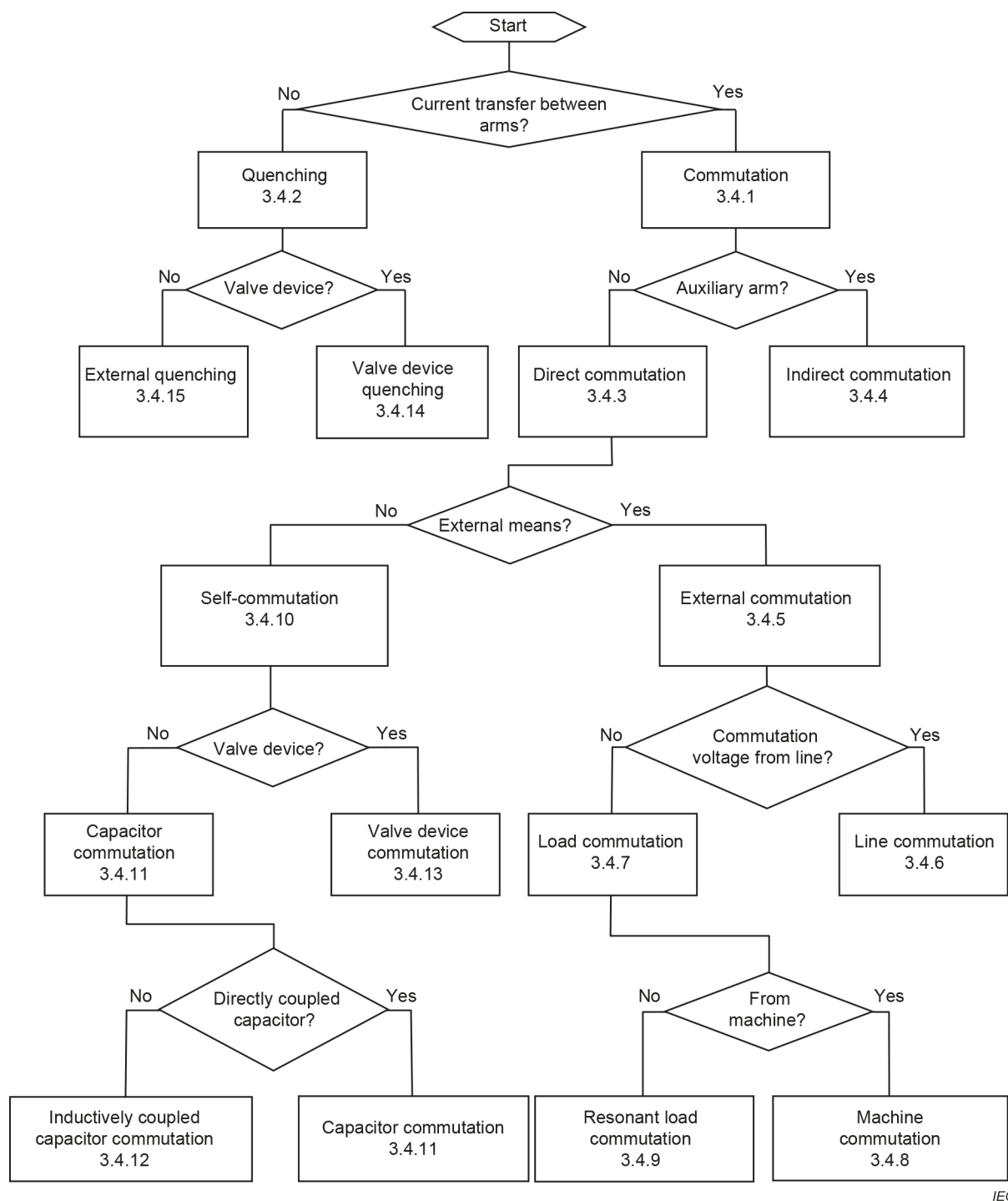
4.2 Basic operation of semiconductor converters

4.2.1 Commutation

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

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

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



IEC

Figure 1 – Types of commutation

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

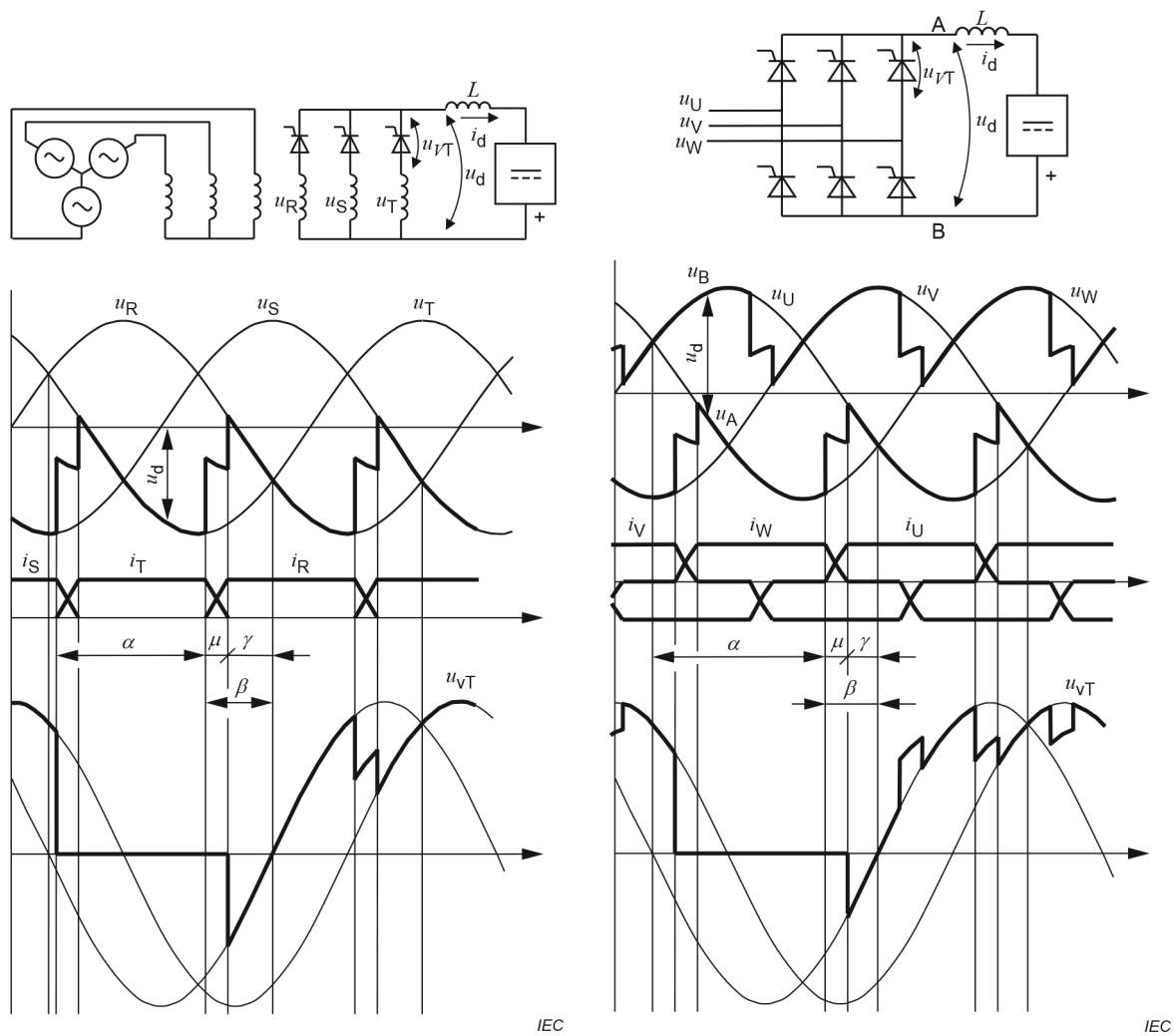


Figure 2 a) – Three phase star connection converter

Figure 2 b) – Three phase bridge converter

Figure 2 – Illustration of angles

4.2.2 Basic calculation factors for line commutated converters

4.2.2.1 Voltage

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

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

The controlled ideal no-load direct voltage U_{dia} 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:

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

2) If the converter load is purely resistive

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

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

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

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

b) Non-uniform connection (half controllable)

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

4.2.2.2 Voltage characteristics and transition current

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

At the transition current value, the voltage/current characteristic bends as is shown in Figure 3. Two examples where this transition between voltage characteristics occurs are

- back e.m.f. loads in which the inductance of the DC circuit cannot maintain direct current over the entire period, and
- in the case of interphase transformer connection, when the direct current decreases below the critical value at which the interphase transformer becomes ineffective.

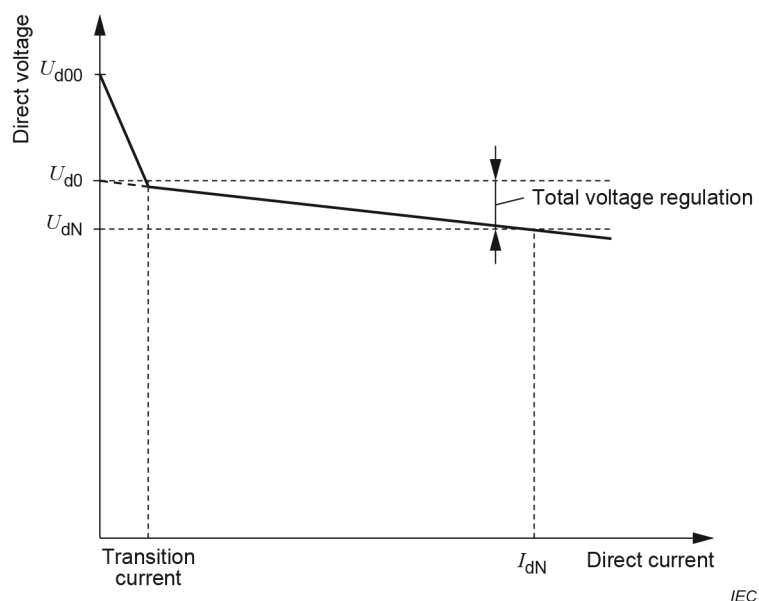


Figure 3 – Voltage regulation

4.2.3 Disturbances and fault conditions

4.2.3.1 Immunity level of a converter

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

Table 3 – Performance criteria

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

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

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

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

- tripping with automatic reset when the disturbance is over;
- tripping without automatic reset (requiring outside intervention for restarting, manual resetting of a circuit-breaker, changing fuse, etc.).

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

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

4.2.3.2 Disturbances and compatibility

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

- IEC 61204-3 for low-voltage switch mode power supplies;
- IEC 61800-3 for adjustable speed electrical power drive systems;
- IEC 62040-2 for uninterruptible power systems (UPS);
- IEC 62310-2 for static transfer systems (STS).

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

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

a) System borne disturbances

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

NOTE 2 Examples of such disturbances are:

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

b) Converter generated disturbances

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

NOTE 3 Examples of such disturbances are:

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

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

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

5 Service conditions

5.1 Code of identification for cooling method

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

a) Direct cooling

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

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

b) Indirect cooling

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

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

c) Mixed cooling method

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

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

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

Table 4 – Cooling medium or heat transfer agent

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

Table 5 – Method of circulation

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

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

5.2 Environmental conditions

5.2.1 Ambient air circulation

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

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

5.2.2 Normal service conditions – Temperatures

The following limits shall apply unless otherwise specified.

a) Storage and transport temperatures

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

These limits apply with cooling liquid removed.

b) Operation including off-load periods, indoor equipment

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

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

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

5.2.3 Other normal service conditions

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

a) Relative humidity of the ambient air for indoor equipment

Minimum: 15 %.

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

b) Altitude

Not higher than 1 000 m

c) Dust and solid particle content for indoor equipment

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

d) Outdoor equipment

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

5.2.4 Unusual service conditions

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

- a) unusual mechanical stresses, for example shocks and vibrations;
- b) cooling water which can cause corrosion or obstruction, for example sea water or hard water;
- c) foreign particles in the ambient air, for example abnormal dirt or dust;
- d) salt air (for example proximity to the sea), high humidity, dripping water or corrosive gases;
- e) exposure to steam or oil vapour;
- f) exposure to explosive mixtures of dust or gases;
- g) exposure to radioactive radiation;
- h) high values of relative humidity and temperature similar to those associated with sub-tropical or tropical climatic conditions;
- i) fluctuations of temperature exceeding 5 K/h and relative humidity changes exceeding 0,05 p.u./h;
- j) altitude more than 1 000 m;
- k) operation at ambient temperatures below +5 °C with water cooling;
- l) operation at ambient temperatures below –5 °C with oil cooling;
- m) other unusual service conditions not covered by this list or service conditions exceeding the specified limits of normal service conditions.

5.3 Characteristics of the load

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

- resistive (W);
- highly inductive (L);
- motor (M);
- battery charging (B);
- capacitive (C);
- regenerative (G).

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

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

- inductive load requiring voltage reversing and/or over-voltage protection, such as DC motor fields, electromagnets, inductors with high X/R ratio;
- energy-storing load such as storage batteries, capacitor banks, electrochemical process cells, inverters;
- hoists, unwinders and other regenerative loads which require means of handling the regenerated energy and protection against mains failure;
- highly variable impedance loads with high rate of current rise.

5.4 Service condition tolerances

5.4.1 Steady state and short time conditions

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

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

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

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

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

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

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

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

Immunity class A	The immunity levels of class A apply to the compatibility levels of class 3 of IEC 61000-2-4:2002 excluding dips and short time interruptions (which are not admissible at most converters) and additional immunity levels defined in Table 7, Table 8 and Table 9.
Immunity class B	The immunity levels of class B apply to the compatibility levels of class 2 of IEC 61000-2-4:2002 excluding dips and short time interruptions (which are not admissible at most converters) and additional immunity levels defined in Table 7, Table 8 and Table 9.
Immunity class C	The immunity levels of class C apply to the compatibility levels of class 1 of IEC 61000-2-4:2002 excluding short time dips (which are not admissible at most converters) and additional immunity levels defined in Table 7, Table 8 and Table 9.

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

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