IEC 62590

Edition 2.0 2019-08
REDLINE VERSION

INTERNATIONAL STANDARD

colour inside

Railway applications – Fixed installations – Electronic power converters for substations

IEC 62590:2019-08 RLV(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 45.060.01

ISBN 978-2-8322-7357-9

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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RAILWAY APPLICATIONS – FIXED INSTALLATIONS – ELECTRONIC POWER CONVERTERS FOR SUBSTATIONS

FOREWORD

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International Standard IEC 62590 has been prepared by IEC technical committee 9: Electrical equipment and systems for railways.

This standard is based on EN 50328.

This second edition cancels and replaces the first edition published in 2010. This edition constitutes a technical revision.

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

a) Incorporation of DC converters.
b) Correction of the clearances and withstand voltages due to erroneous use of PD in former edition.
c) Adaption to current ISO/IEC directive part 2, adaption of structure, adaption of vocabulary, removal of unused term and abbreviations.

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

FDIS	Report on voting
9/2502/FDIS	9/2516/RVD

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

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

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

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- withdrawn,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

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INTRODUCTION

Semiconductor converters for traction power supply differ from other converters for industrial use due to special electrical service conditions and due to the large range of load variation and the peculiar characteristics of the load.

For these reasons IEC 60146-1-1 does not fully cover the requirements of railway applications and the decision was taken to have a specific standard for this use.

Converter transformers for fixed installations of railway applications are covered by ~~EN 50329~~ IEC 62695.

Harmonization of the rated values and tests of the whole converter group are covered by IEC 62589.

**RAILWAY APPLICATIONS – FIXED INSTALLATIONS –
ELECTRONIC POWER CONVERTERS FOR SUBSTATIONS**

1 Scope

This document specifies the requirements for the performance of all fixed installations electronic power converters, using controllable and/or non-controllable electronic valves, intended for traction power supply.

The devices can be controlled by means of current, voltage or light. Non-bistable devices are assumed to be operated in the switched mode.

This document applies to fixed installations of the following electric traction systems:

- railways,
- guided mass transport systems such as: tramways, light rail systems, elevated and underground railways, mountain railways, trolleybusses.

This document does not apply to:

- cranes, transportable platforms and similar transportation equipment on rails,
- suspended cable cars,
- funicular railways.

This document applies to diode rectifiers, controlled rectifiers, DC converters, inverters and frequency converters.

The equipment covered in this document is the converter itself.

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*~~

IEC 60050-811:~~1991~~2017, *International electrotechnical vocabulary – Part 811: Electric traction*

IEC 60146 (all parts), *Semiconductor convertors*

IEC TR 60146-1-2:~~1991~~2011, *Semiconductor converters – General requirements and line commutated converters – Part 1-2: Application guide*

IEC 60529:1989, *Degrees of protection provided by enclosures (IP Code)*

IEC 60721 (all parts), *Classification of environmental conditions*

IEC 60721-3-3:1994, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 3: Stationary use at*

weatherprotected locations
AMD1:1995
AMD2:1996

IEC 60721-3-4:1995, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 4: Stationary use at non-weatherprotected locations*
AMD1:1996

IEC 60850:~~2007~~2014, *Railway applications – Supply voltages of traction systems*

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

IEC 61000-2-12:2003, *Electromagnetic compatibility (EMC) – Part 2-12: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public medium-voltage power supply systems*

IEC 61992-7-1:2006, *Railway applications – Fixed installations – DC switchgear – Part 7-1: Measurement, control and protection devices for specific use in DC traction systems – Application guide*

IEC 62236 (all parts), *Railway applications – Electromagnetic compatibility*

IEC 62236-5:~~2008~~2018, *Railway applications – Electromagnetic compatibility – Part 5: Emission and immunity of fixed power supply installations and apparatus*

IEC 62497-1:2010, *Railway applications – Insulation coordination – Part 1: Basic requirements – Clearances and creepage distances for all electrical and electronic equipment*

~~EN 50329:2003, *Railway applications – Fixed installations – Traction transformers*~~

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.~~

~~The policy adopted is as follows:~~

~~a) when a suitable IEV definition exists, the term and the reference are given without repeating the text;~~

~~b) when an existing IEV definition needs amplification or additional information, the term, the reference and the additional text are given;~~

~~c) when no IEV definition exists, the term and the text are given.~~

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

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

NOTE An alphabetical index is given in Annex C.

3.1 Semiconductor devices and combinations

3.1.1
semiconductor device
device whose essential characteristics are due to the flow of charge carriers within a semiconductor

[SOURCE: IEC 60050-521: 2002, 521-04-01, modified – note omitted]

3.1.2
(valve device) stack
a 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]

3.1.3
(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

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

3.1.4
electronic power converter
operative unit for power conversion comprising one or more assemblies of semiconductor devices

Note 1 to entry: The transformers are described in IEC 62695

[SOURCE: IEC 60050-551:1998, 551-12-01, modified – "electronic" has been omitted. "electronic valve devices, transformers and filters if necessary and auxiliaries if any" has been replaced with "assemblies of semiconductor devices". The note 1 to entry has been omitted.]

3.1.5
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

3.1.6
system control equipment
equipment associated with a converter equipment or system which performs automatic adjustment of the output characteristics as a function of a controlled quantity

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

Note 1 to entry: Depending on the mode of operation a principal arm may act as an auxiliary arm or vice versa.

[SOURCE: IEC 60050-551:1998, 551-15-02]

3.2.3
converter connection
the electrical arrangement of valve arms and other components essential for the function of the main power circuit of a converter

[SOURCE: IEC 60050-551:1998, 551-15-10]

~~**3.2.4**~~
~~**basic converter connection**~~
~~[IEV 551-15-11]~~

~~**3.2.5**~~
~~**single-way connection (of a converter)**~~
~~[IEV 551-15-12]~~

~~**3.2.6**~~
~~**double-way connection (of a converter)**~~
~~[IEV 551-15-13]~~

3.2.4
uniform connection
a connection with either all principal arms controllable or all principal arms non-controllable

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

3.2.5
non-uniform connection
a connection with both controllable and non-controllable principal arms

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

~~**3.2.9**~~
~~**series connection**~~
~~connection in which two or more converters are connected in such a way that their voltages add~~

~~**3.2.10**~~
~~**boost and buck connection**~~
~~series connection in which the converters are controlled independently~~

~~[IEV 551-15-21, modified]~~

3.2.6
parallel connection <for converters>
connection in which two or more converters are connected in such a way that their currents add

3.3 Controllability of converter arms ~~and quadrants of operation~~

~~**3.3.1**~~
~~**controllable arm**~~
~~**converter arm including controllable semiconductor element(s) as valve device(s)**~~

~~**3.3.2**~~
~~**non-controllable arm**~~
~~converter arm including non-controllable semiconductor element(s) as valve device(s)~~

~~**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~~

~~**3.3.4**~~
~~**one quadrant converter**~~
~~[IEV 551-12-34]~~

~~**3.3.5**~~
~~**two quadrant (single) converter**~~
~~[IEV 551-12-35]~~

~~**3.3.6**~~
~~**four quadrant (double) converter**~~
~~[IEV 551-12-36]~~

~~**3.3.7**~~
~~**reversible converter**~~
~~[IEV 551-12-37]~~

~~**3.3.8**~~
~~**single converter**~~
~~[IEV 551-12-38]~~

~~**3.3.9**~~
~~**double converter**~~
~~[IEV 551-12-39]~~

~~**3.3.10**~~
~~**converter section of a double converter**~~
~~[IEV 551-12-40]~~

3.3.1
controllable valve device
a valve device the current path of which is bistably controlled in its conducting direction

[SOURCE: IEC 60050-551:1998, 551-14-03]

3.4 Commutation, quenching and commutation circuitry

3.4.1
commutation
~~transfer of current from one conducting arm to the next to conduct in sequence, without interruption of the d.c. current. During a finite interval of time both arms are conducting simultaneously~~

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

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

3.4.2
quenching
the termination of current flow in an arm without commutation

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

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

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

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

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

~~**3.4.5**~~
~~**external commutation**~~
~~[IEV 551-16-11]~~

3.4.5
line commutation
an external commutation where the commutating voltage is supplied by the line

Note 1 to entry: In the text commutated is used instead of commutation.

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

3.4.6
load commutation
an external commutation where the commutating voltage is taken from a load other than the line

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

3.4.7
self commutation
a commutation where the commutating voltage is supplied by components within the converter or the electronic switch

Note 1 to entry: In the text commutated is used instead of commutation

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

3.5 Commutation characteristics

~~**3.5.1**~~
~~**commutation circuit**~~
~~[IEV 551-16-03]~~

3.5.1
commutating voltage
the voltage which causes the current to commutate

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

~~**3.5.3**~~
~~**commutation inductance**~~
~~total inductance included in the commutation circuit, in series with the commutating voltage~~

~~[IEV 551-16-07, modified]~~

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

3.5.2
angle of overlap
u
duration of the commutation interval between a pair of principal arms, expressed in angular measure, where the two arms carry current

[SOURCE: IEC 60050-551:1998, 551-16-05, modified – "duration of", "between a pair of principal arms," and ",where the two arms carry current" have been added.]

~~**3.5.5**~~
~~**commutation notch**~~

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

~~[IEV 551-16-06, modified]~~

~~**3.5.6**~~
~~**commutation repetitive transient**~~
~~voltage oscillation associated with the commutation notch~~

3.5.3
commutating group
a group of principal arms which commutate cyclically among themselves without intermediate commutation of the current to other principal arms

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

3.5.4
commutation number
q
number of commutations from one principal arm to another, occurring during one period of the alternating voltage in each commutating group

[SOURCE: IEC 60050-551:1998, 551-17-03, modified – "during one elementary period" has been replaced with "occurring during one period of the alternating voltage".]

3.5.5
pulse number
p
number of non-simultaneous symmetrical direct or indirect commutations from one principal arm to another, during one period of the alternating voltage

[SOURCE: IEC 60050-551:1998, 551-17-01, modified – "which occur during one elementary period" has been replaced with "during one period of the alternating voltage".]

3.5.6
trigger delay angle
α
time expressed in angular measure by which the trigger pulse is delayed with respect to the reference instant (see Figure 1)

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

For AC controllers it is the zero crossing instant of the supply voltage.

For AC controllers with inductive load, 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 – The end of the definition "in the case of phase control" has been removed. The note 1 to entry has been changed.]

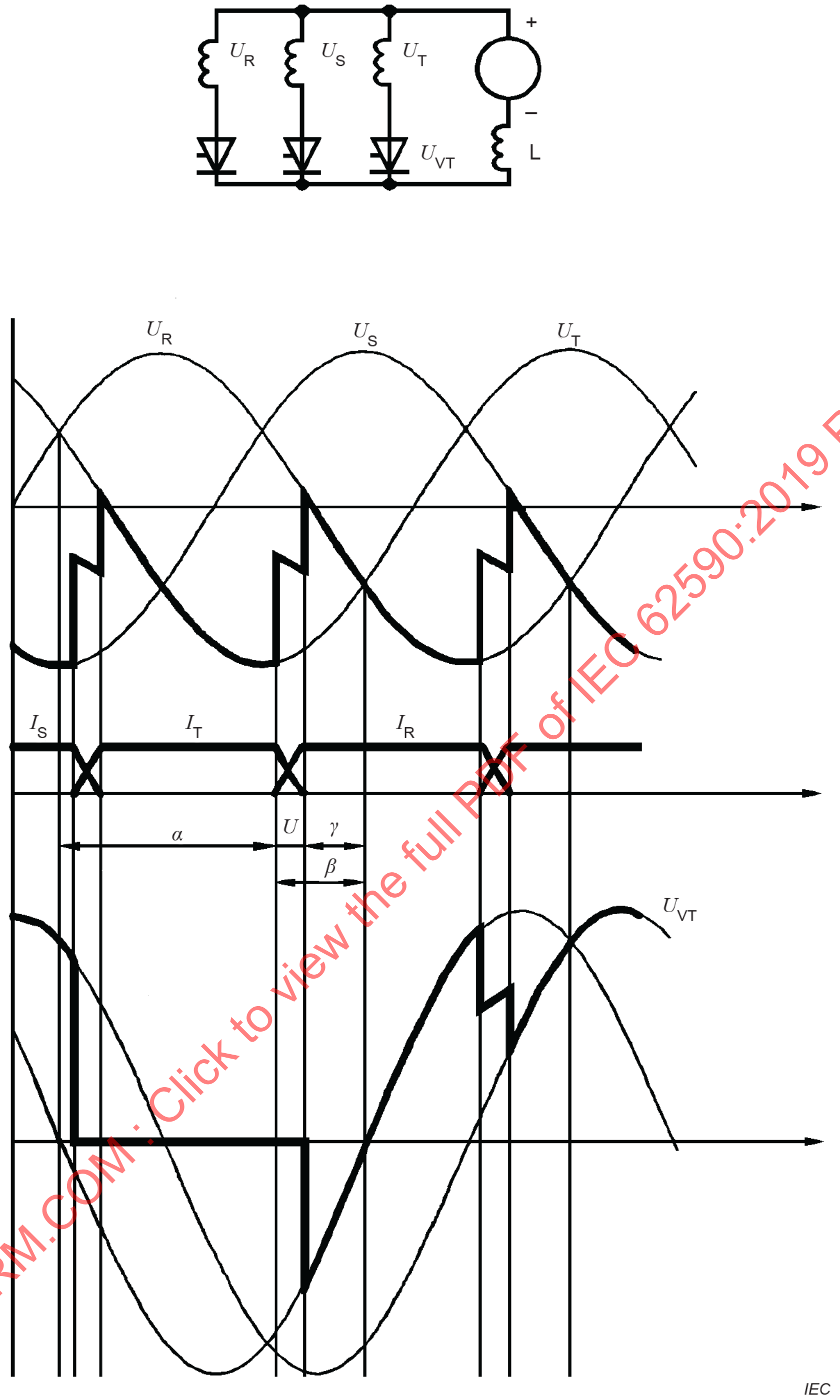


Figure 1 – Illustration of angles

3.5.7
trigger advance angle
β
(see Figure 1)

the 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]

~~**3.5.12**~~
~~**inherent delay angle α_p**~~
~~delay angle which occurs in some converter connections under certain operating conditions even if no phase control is applied~~

~~[IEV 551-16-35, modified]~~

3.5.8
extinction angle
γ
time, expressed in angular measure, between the moment when the current of the arm falls to zero and the moment when the arm is required to withstand steeply rising off-state voltage

3.6 Rated values

3.6.1
rated value
~~numerical value for the electrical, thermal, mechanical and environmental rating assigned to the quantities which define the operation of a converter group in the conditions specified in accordance with this Standard and on which the supplier's guarantees and tests are based~~

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

[SOURCE: IEC 60050-151:2001, 151-16-08]

3.6.2
rated frequency <for converters>
f_N
frequency on either side of the converter for the conversion of which the converter group is designed to operate

3.6.3
nominal voltage <for converters>
U_n
voltage by which a converter is designated

Note 1 to entry: The standardized values of nominal voltages are given in IEC 60850.

3.6.4
rated insulation voltage
U_{Nm}
rated value of the RMS withstand voltage ~~value~~ assigned by the manufacturer to the equipment or to a part of it, characterizing the specified ~~permanent~~ (long-term) withstand capability of its insulation

Note 1 to entry: Standardized values of rated insulation voltages are given in IEC 62497.

[SOURCE: IEC 60050-312: 2014, 312-06-02, modified – note 1 to entry removed]

3.6.5
rated AC voltage on the supply side of a converter
U_{Nv}
RMS value of the no-load voltage between vectorially consecutive commutating phase terminals of a commutating group

3.6.6
rated AC voltage on the traction side of a converter
U_{Nt}
RMS value of the no-load voltage on the traction side of a frequency converter

3.6.7
rated direct voltage
U_{Nd}
specified value of the direct voltage between the DC terminals of the converter assembly at basic direct current

Note 1 to entry: This value is the mean value of the direct voltage.

Note 2 to entry: A converter may have more than one rated voltage or a rated direct voltage range.

Note 3 to entry: The rated direct voltage of a converter depends on the characteristics of the transformer and a guaranteed value of rated direct voltage is valid only together with the transformer (see IEC 62589).

3.6.8
basic service current on the supply side of a converter
I_{Bv}
RMS value of the AC current, containing all harmonics, on the supply side of a converter at basic current on the DC side

Note 1 to entry: For polyphase equipment, this value is computed from the basic direct current on the basis of rectangular shaped currents, 120° conducting, of the converter elements. For single phase equipment, the basis of calculation must be specified.

3.6.9
rated current on the traction side of a frequency converter
I_{Nt}
RMS value of the AC current on the traction side of a frequency converter under rated conditions

3.6.10
basic current <for converters>
I_B
mean value of the current for specified load and service conditions

3.6.11
basic direct current
I_{Bd}
mean value of the direct current for specified load and service conditions

Note 1 to entry: Together with a duty class I_{Bd} is considered as the 1,0 p.u. value, to which other values of I_d are compared.

3.7 Load capabilities

3.7.1
duty class
tabled representation of current capability and test values for standard design converters in terms of current values and duration selected to represent a characteristic group of practical applications~~. The current values are expressed in per unit of the basic direct current I_{Bd}~~

Note 1 to entry: The current values are expressed in per unit of the basic direct current I_B.

3.7.2
load cycle
~~representation of the conventional current demand to a special design converter showing the repetitive variation of the load within a specified time period. The current values are expressed in A or in per unit of I_{bd}~~

conventional representation of the current demand to a converter group

Note 1 to entry: The current values are expressed in A or in per unit of I_B.

Note 2 to entry: The load cycle shows the repetitive variation of the loads with time and, hence, the overloads and underloads the converter group is expected to carry, as well as, for the transformers, the duration and intervals assumed.

[SOURCE: IEC 60050-881: 2017, 811-28-38 modified – The note 1 to entry has been changed.]

3.7.3
rated DC power
~~product of the nominald.c. voltage U_n and the basic direct current I_{bd}~~

delivered power at working point of basic direct current I_{Bd}

3.7.4
power efficiency
ratio of the output power to the input power of the converter

3.8 Specific voltages, currents and factors

3.8.1
ideal no-load direct voltage
U_{di}
theoretical no-load mean direct voltage of a converter, assuming no reduction by phase control, no voltage drop in the assemblies and no voltage rise at small loads

[SOURCE: IEC 60050-551:1998, 551-17-15, modified – "mean" has been added. "AC/DC" has been removed. "no threshold voltages of electronic valve devices" has been replaced with "no voltage drop in the assemblies".]

3.8.2
controlled ideal no-load direct voltage
$U_{di\alpha}$
~~theoretical no-load mean direct voltage of a converter, when the direct voltage is reduced by phase control, assuming no voltage drop in the assemblies and no voltage rise at small loads~~

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~~]

3.8.3
conventional no-load direct voltage
U_{d0}
mean value of the direct voltage which would be obtained by extrapolating the direct voltage/current characteristic for continuous direct current back to zero current

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 – “from the region of continuous flow of direct current to zero current at zero trigger delay angle, i.e. without phase control” has been replaced with “for continuous direct current back to zero current“.]

~~3.8.4~~
~~**controlled conventional no-load direct voltage** $U_{d0\alpha}$~~
~~conventional no-load mean direct voltage obtained when extrapolating the direct voltage/ current characteristic, corresponding to a delay angle a, back to zero current~~

~~[IEV 551-17-18, modifed]~~

3.8.4
real no-load direct voltage
U_{d00}
actual mean direct voltage at zero direct current

[SOURCE: IEC 60050-551:1998, 551-17-19]

3.8.5
ideal crest no-load voltage
U_{iM}
no-load voltage between the end terminals of an arm neglecting internal and external voltage surge and voltage drop in valves

3.8.6
transition current
mean direct current of a converter connection when the direct current of the commutating groups becomes intermittent when decreasing the current

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

3.8.7
direct voltage drop
difference between the conventional no-load direct voltage and the direct voltage at basic direct current, at the same current delay angle, excluding the correction effect of stabilizing means if any

~~[IEV 551-17-21, modified]~~

Note 1 to entry: The nature of the DC circuit (for example capacitors, ~~back e.m.f. load~~ voltage sources) can affect the voltage drop significantly. Where this is the case, special consideration is required.

3.8.8
total power factor
λ

$$\lambda = \frac{\text{active power}}{\text{apparent power}}$$

3.8.9
power factor of the fundamental wave or displacement factor
cos φ_1

$$\cos\varphi_1 = \frac{\text{active power of the fundamental wave}}{\text{apparent power of the fundamental wave}}$$

~~3.8.11~~
~~deformation factor ν~~

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

3.9 Definitions related to virtual junction temperature

3.9.1
thermal resistance
R_{th}
~~quotient of the temperature difference between two specified points or regions and the heat flow between these two points or regions under conditions of thermal equilibrium~~

~~NOTE For most cases, the heat flow can be assumed to be equal to the power dissipation.~~

quotient of the difference between the virtual temperature of the device and the temperature of a stated external reference point, by the steady state power dissipation in the device

[SOURCE: IEC 60050-521:2002, 521-05-13]

3.9.2
transient thermal impedance
Z_{th}
quotient of the variation of the temperature difference, reached at the end of a time interval between the virtual junction temperature and the temperature at a specified external reference point and the step function change of power dissipation at the beginning of the same time interval causing the change of temperature

Note 1 to entry: The transient thermal impedance is given in a characteristic curve as a function of the time interval.

3.9.3
virtual junction temperature
Θ_j
calculated temperature within the semiconductor material which is based on a simplified representation of the thermal and electrical behaviour of a semiconductor device

3.10 Cooling

3.10.1
cooling medium
liquid (for example water) or gas (for example air) which removes the heat from the equipment

3.10.2
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

3.10.3
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

3.10.4
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

3.10.5
natural circulation <for converters>
convection
method of circulating the cooling medium or heat transfer agent which uses the change of volumetric mass (density) with temperature

3.10.6
forced circulation
forced cooling
method of circulating the cooling medium or heat transfer agent by means of blower(s), fan(s) or pump(s)

~~3.10.7~~
~~mixed circulation~~
~~method of circulating the cooling medium or heat transfer agent, which uses alternately natural and forced circulation~~

3.10.7
thermal equilibrium ~~temperature~~
steady-state temperature condition 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.

3.11 Electromagnetic compatibility and harmonic distortion

3.11.1
electrical disturbance
any variation of an electrical quantity, beyond specified limits, which can be the cause of a loss of performance or an interruption of service or damage

3.11.2
immunity level <for converters>
specified value of an electrical disturbance below which a converter is designed to meet the required performances or continue operation or avoid damage

3.11.3
~~(total)~~ harmonic distortion
a type of non-linearity distortion characterized by the production of output components with frequencies which are integral multiples of the frequency of the sinusoidal input signal

~~[IEV 551-17-06]~~

[SOURCE: IEC 60050-702:1992,702-07-61]

4 Symbols

d_{xtB} inductive direct voltage drop due to converter transformer referred to U_{di}

e_{xB} inductive component of the relative short-circuit voltage of the converter transformer corresponding to the basic current on the supply side of the transformer

f_N rated frequency

g number of sets of commutating groups between which I_{Bd} is divided

h order of harmonic

I_{Bd} basic direct current

I_{Bv} basic service current on the supply side of a converter

I_d direct current (any defined value)

I_{Nt} rated current on the traction side of a frequency converter

I_v current on the supply side of a converter

K coupling factor

p pulse number

P active power

q commutation number

s number of series connected commutating groups

u angle of overlap (commutation angle)

U_a power frequency withstand voltage

U_{Bdx} total inductive direct voltage drop at basic direct current

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_{iM} ideal crest no-load voltage

U_n nominal voltage

U_{Nd} rated direct voltage

U_{Ni} impulse voltage

U_{Nm} rated insulation voltage

U_{Nt} rated AC voltage on the traction side of a frequency converter

U_{Nv} rated AC voltage on the supply side of a converter

U_{v0} no-load phase to phase voltage

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

~~ν deformation factor~~

$\varphi 1$ displacement angle for the fundamental component of I_{Bv}

5 Operation of semiconductor power equipment and valve devices

5.1 Classification of traction supply power converters and valves

5.1.1 Types of traction supply power converters

a) AC to DC conversion:

1) diode rectifier;
2) controlled rectifier.

b) DC to AC conversion:
1) inverter.

c) AC to AC conversion:
1) direct frequency converter;
2) DC link frequency converter:
i) supply side;
ii) traction side.

d) DC to DC conversion
1) chopper, i.e. direct DC to DC converter;

NOTE For example, such converters are used inside stationary energy storage system defined in IEC 62924.

2) indirect DC to DC converter.

For the information required see Annex A.

5.1.2 Purpose of conversion

A converter changes or controls one or more characteristics such as:

a) frequency ~~(including zero frequency)~~,
b) voltage,
c) number of phases,
~~d) flow of reactive power,~~
~~e) quality of load power.~~
d) active power flow,
e) reactive power flow,
f) power quality parameters.

5.1.3 Classification of semiconductor valve devices

Semiconductor valves can be turned off either by commutation implying that the current of the valve is transferred to another valve or by quenching if the current of the valve falls to zero.

Valves used in traction supply power converters can be divided into the following categories:

a) non-controllable valve with a conductive forward and a blocking reverse characteristic (diode);
b) valve with a controllable forward and a blocking reverse characteristic (e.g. reverse blocking thyristor);
c) valve with a controllable forward and a conductive reverse characteristic (e.g. reverse conducting thyristor);
d) valve with a controllable forward and / or reverse characteristic which can be turned on and/or off via a signal applied to the gate (e.g. gate turn-off thyristor, insulated gate bipolar transistor);
e) valve with controllable forward and reverse characteristic (e.g. bi-directional thyristors).

5.2 Basic calculation factors for line commutated converters

5.2.1 Voltage

The ideal no-load direct voltage U_{di} is obtained from the voltage between two commutating phases U_{v0}, the commutation number *q* and the number of series-connected commutating groups *s*, between terminals on DC side, by the formula:

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

a) uniform connection

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

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

b) non-uniform connections

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

5.2.2 Voltage characteristics and transition current

At the transition current value, the voltage/current characteristic bends as shown in Figure 2. The transition current can be obtained, for example in case of interphase transformer connection, because the direct current decreases below the critical value where the interphase transformer becomes ineffective.

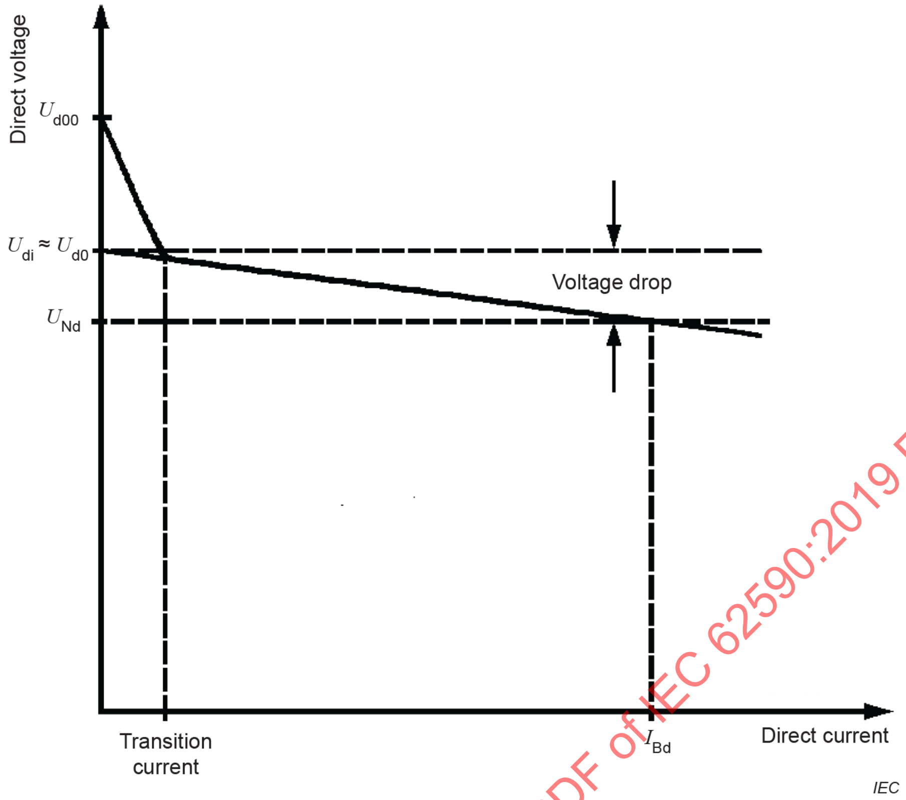


Figure 2 – Voltage ~~drop~~ regulation

6 Service conditions

6.1 Code of identification of cooling method

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

6.1.1 Letter symbols to be used

6.1.1.1 Cooling medium or heat transfer agent (see Table 1)

Table 1 – Letter symbols for cooling mediums and heat transfer agents

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-phase cooling	P

6.1.1.2 Method of circulation (see Table 2)

Table 2 – Letter symbols for methods of circulation

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

Forced, moving device incorporated	F
Vapour cooling	V

6.1.2 Arrangement of letter symbols

6.1.2.1 Direct cooling

The first letter indicates the cooling medium (6.1.1.1), the second the circulation method (6.1.1.2).

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

6.1.2.2 Indirect cooling

The code includes four symbols.

The first two letters indicate:

a) the heat transfer agent (6.1.1.1),
b) the circulation method of the heat transfer agent (6.1.1.2).

The last two letters indicate:

c) the cooling medium (6.1.1.1),
d) the circulation method of the cooling medium (6.1.1.2).

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

6.1.2.3 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 air temperature.

Therefore, the complete code shall include:

a) for direct cooling: two groups of letters separated by a stroke.

EXAMPLE 1 AN/AF: converter with natural direct air cooling and possibilities for forced direct air cooling;

b) for indirect cooling: two groups of letter symbols separated by a stroke.

EXAMPLE 2 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.

6.2 Environmental conditions

6.2.1 Ambient air circulation

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 converters mounted in an enclosure, the ambient for the converters (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. Cubicle or cabinet mounted assemblies shall comply with the overload conditions at maximum temperature of the outside air.

6.2.2 Normal service conditions

6.2.2.1 General

The following limits shall apply unless otherwise specified.

6.2.2.2 Storage and transport temperatures

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

These limits apply with cooling liquid removed.

6.2.2.3 Operation including off-load periods

6.2.2.3.1 Temperatures of cooling air

	Minimum	Maximum
a) Extreme values	–5 °C	+40 °C
b) Daily average		+35 °C
c) Yearly average		+25 °C

6.2.2.3.2 Relative humidity of the ambient air

a) Minimum: 15 %.

b) Maximum: standard design converters are designed for the case where no condensation can occur. If condensation is to be provided for, the case shall be treated as special service condition (see 6.2.3).

6.2.2.3.3 Dust and solid particles content

Standard design equipment is indoor equipment, pollution degree 3A. (Refer to Table A.4 of IEC 62497-1:2010.)

Any condition exceeding PD 3A shall be specified by the purchaser as special service condition.

6.2.2.3.4 Vibrations

~~The equipment shall be suitable for installation in the vicinity of a rail track. Foundations shall be designed to dampen the main effects of the passage of the trains. Nevertheless a limited vibration or limited shocks can affect the equipment, which shall be capable of operating satisfactorily when subjected to conventional sinusoidal vibrations at 10 Hz, separately applied and having the following characteristics:~~

	~~Peak acceleration~~	~~Duration~~
~~Vertical acceleration:~~	~~5 m/s²~~	~~30 s~~
~~Horizontal acceleration:~~	~~5 m/s²~~	~~30 s~~

Standard mechanical environment class for indoor equipment is 3M1 according to IEC 60721-3-3:1994+AMD1:1995+AMD2:1996 and for outdoor equipment 4M1 according to IEC 60721-3-4:1995+AMD1:1996.

Any condition differing from the above shall be agreed between purchaser and supplier.

6.2.2.4 Altitude

With regard to the use of air as cooling medium or heat transfer agent, altitudes up to 1 000 m are considered as normal. If a converter is to be used at an altitude above 1 000 m but is tested at normal altitude, the current capability shall be decreased by 1 % for each 100 m by which the altitude of use exceeds 1 000 m in the case of natural air-cooling, and by 1,5 % for forced air-cooling.

With regard to the dielectric properties of air, altitudes up to 2 000 m are considered as normal (refer to IEC 62497-1).

6.2.3 Special service conditions

The service conditions are assumed to be those listed under normal service conditions. The following list gives examples of special service conditions that shall be subject to a special agreement between purchaser and supplier:

a) special mechanical stresses, for example shocks and vibrations;
b) foreign particles in the ambient air, for example abnormal dirt or dust;
c) salt air (for example proximity to the sea);
d) high values of relative humidity and/or temperature similar to those associated with tropical climatic conditions;
e) other special service conditions not covered by this list or service conditions exceeding the specified limits of normal service conditions.

In case special service conditions are required, the service conditions listed in IEC 60721 should preferably be used.

6.3 Electrical service conditions

6.3.1 General

For network conditions concerning the AC supply network reference shall be made to the publications of IEC TC 77 and its subcommittees.

For network conditions concerning the traction supply network reference shall be made to IEC 62236-5, to IEC 62497-1 and to IEC 60850.

Information on prospective conditions of coexistence between supply systems, disturbing loads and sensitive apparatus (mostly low current control equipment, other power converters, power capacitors and sensitive lines such as used for communications, signalling and control) is essential during the early stages of the design of an installation (notably: ratio of short-circuit power to apparent power, presence of capacitors or other converters).

Guidance on calculation methods will be found in IEC TR 60146-1-2.

6.3.2 Limiting values as basis of rating

Unless otherwise specified, the converter shall be designed to operate under the service conditions specified by the following limiting values.

6.3.2.1 Three-phase AC supply network

6.3.2.1.1 Frequency

	Variation
Range	± 2 % of f_N
Rate of change	± 1 %/s

6.3.2.1.2 Voltage

	Variation
Steady state	+10 % / –10 % of U_N
Short time (0,5 to 30 cycles)	+15 % / –15 %

6.3.2.1.3 Harmonics in supply voltage

Refer to IEC 61000-2-12 and IEC 61000-2-4.

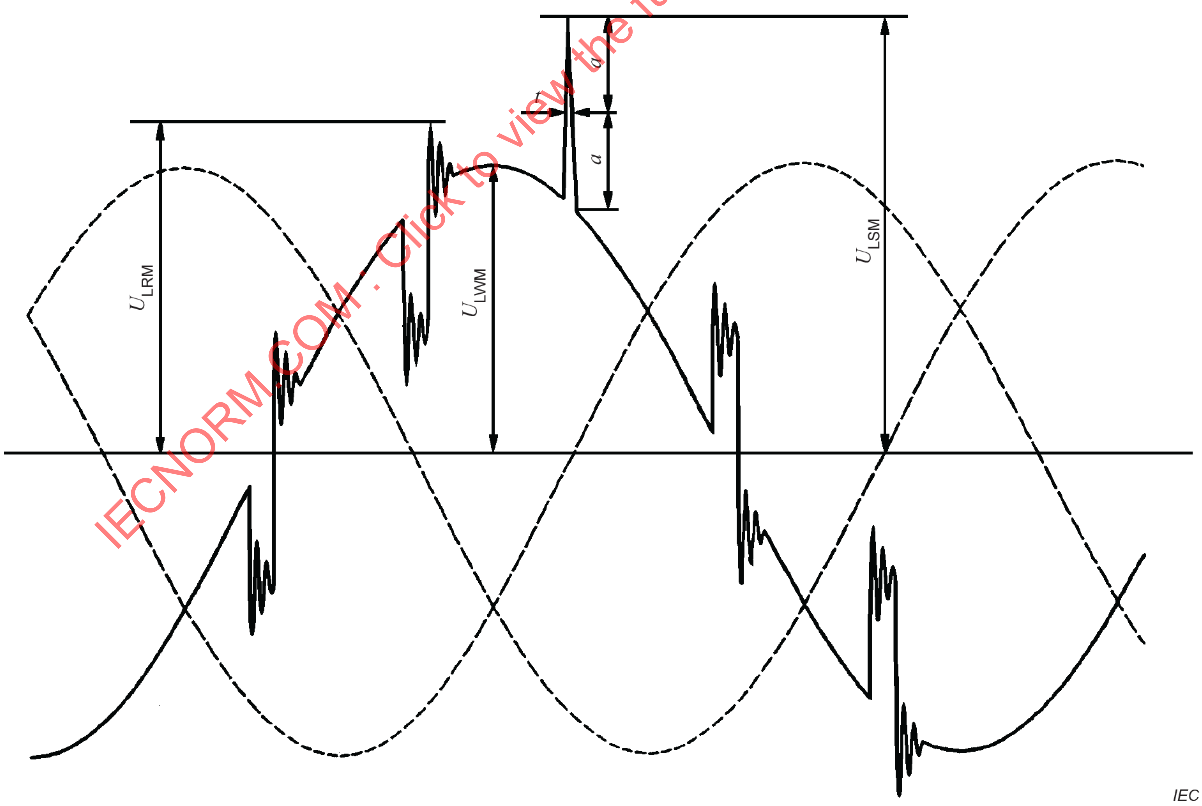
NOTE A harmonic distortion of the AC supply voltage can cause overloads:

– in 12 pulse rectifiers and their transformers due to unbalanced load sharing,
– in two parallel 6 pulse rectifiers with separate transformers due to unbalanced load sharing,
– in capacitive circuits of converters.

6.3.2.1.4 Repetitive and non-repetitive transients

On request the following characteristics shall be specified as far as possible (see Figure 3):

a) transient energy available at the converter terminals (J);
b) rise time, (from 0,1 to 0,9 p.u. peak value) (µs);
c) peak value U_{LRM}/U_{LWM} (p.u.);
d) peak value U_{LSM}/U_{LWM} (p.u.);
e) duration above 50 % (t) (µs).



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

Figure 3 – AC voltage waveform

6.3.2.2 Single-phase AC traction supply voltage

6.3.2.2.1 Frequency

The frequency range according to IEC 60850 applies.

6.3.2.2.2 Voltage

The voltage ranges according to IEC 60850 apply.

6.3.2.2.3 Harmonics

Refer to IEC 61000-2-4.

6.3.2.2.4 Repetitive and non-repetitive transients

Refer to 6.3.2.1.4.

6.3.3 DC traction supply voltage

The ~~frequency~~ voltage range according to IEC 60850 applies.

7 Converter equipment and assemblies

7.1 Losses and efficiency

7.1.1 General

The power efficiency may be determined by calculation of internal losses or by measurement of AC and DC power at basic load conditions. If the purchaser requires measurement of the losses this shall be mentioned in the procurement specification.

The admissible tolerance for losses is + 10 % of the guaranteed value.

7.1.2 Included losses

The following losses shall be included when determining the power efficiency:

a) internal losses in the assembly such as losses in semiconductor valve devices, in fuses, potential dividers, current balancing means, capacitor resistor damping circuits and voltage surge ~~diverters~~ arresters;

b) losses in transductors, ~~interbridge reactors~~ interphase transformers (if supplied as part of the converter), current limiting and balancing reactors between transformer and thyristor or diode assemblies;

c) power absorbed by auxiliaries such as fans or pumps and relays unless otherwise specified;

d) losses due to circulating currents;

e) power consumed in trigger equipment, if any.

7.2 Power factor

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

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

For pulse numbers higher than six the difference between the total power factor λ and the displacement factor cos φ_1 is small, but for lower pulse number the difference is significant.

Unless otherwise stated in the contract, for multi-phase converters supplying inductive load the manufacturer guarantees shall be given on the displacement factor cos φ_1.

NOTE 1 In such cases calculation is adequate to get reliable figures of the displacement factor under the condition of symmetrical control.

When exact calculations of the displacement factor or of the total power factor are required, knowledge of many parameters is necessary, including the line impedance. For such calculations refer to IEC TR 60146-1-2.

NOTE 2 For the power factor of diode rectifiers see Annex C of IEC 62589:2010.

~~6.5 Direct voltage harmonic content~~

~~For perfectly balanced supply voltages, trigger delay angles, etc., the frequency of the direct current and direct voltage harmonic content is given by:~~

$$f_{h,dc} = k \times p \times f_N \qquad k = \text{integer } (1...n)$$

~~An unbalanced supply voltage causes a negative sequence voltage. The negative sequence voltage produces an additional harmonic component at a frequency $2 \times f_N$, which cannot be cancelled by an appropriate design of the converter unless a large smoothing reactance or d.c. output filter is added.~~

~~Refer to IEC 60146-1-2 for more information.~~

7.3 Electromagnetic compatibility (EMC)

Traction supply converters shall cope with the requirements for immunity and emission stated in the IEC 62236 series.

Additional requirements, if any, shall be mentioned by the purchaser in the procurement specification.

Cable routing of AC and DC power cables, auxiliary and control cables, filtering etc., where such are installed by the purchaser or third parties shall be in accordance with any instructions provided by the supplier of the converter and with the requirements of IEC 62236-5.

Immunity and emission tests of the converter group can be done only together with the transformer(s) as test of the whole substation. These tests are not subject of this document.

Control and protection devices shall be tested separately according to their product standards.

7.4 Rated values for converters

7.4.1 General

Rated values of a converter shall be given either as standard design values for standard design converters or as closely as possible according to the load that it is intended to serve for special design converters. The ratings of the converter are not valid if the load is changed to a load for which the converter is not intended.

7.4.2 Current values

7.4.2.1 Current values to be specified

Each converter equipment shall have an assigned value for the basic direct current together with specified current capabilities according to a duty class or a load cycle. The standardized duty classes according to Table 3 should be preferably used. For other types of duty, duty classes defined by the purchaser or load cycles according to 7.4.2.3 apply.

NOTE For converters which are operated not continuously but repeatedly, a load cycle is applied not a duty class. DC to DC converters are examples of these devices.

Table 3 – Standardized duty classes

Duty class	Current capabilities for converters (relative values in per unit of I_{Bd})	Typical applications	Note
I	1,0 p.u. continuously	Frequency converters for mainline railways	
V	a) 1,0 p.u. continuously b) 1,5 p.u. 2 h – after a) c) 2,0 p.u. 1 min – after a)	Mass rapid transit Trolleybusses	Alternatively after thermal equilibrium of a)
VI	a) 1,0 p.u. continuously b) 1,5 p.u. 2 h – after a) c) 3,0 p.u. 1 min – after a)	Mainline railways Mass rapid transit Light rail systems	Alternatively after thermal equilibrium of a)
VII	a) 1,0 p.u. continuously b) 1,5 p.u. 2 h – after a) c) 4,5 p.u. 15 s – after a)	Minor railways Light rail systems Tramways	Alternatively after thermal equilibrium of a)
VIII	a) 1,0 p.u. continuously b) 1,5 p.u. 2 h – after a) c) 2,0 p.u. 1 min – after b)	Mass rapid transit	Cumulative
IX	a) 1,0 p.u. continuously b) 1,5 p.u. 2 h – after a) c) 3,0 p.u. 5 min – after b)	Mainline railways	Cumulative
JP	a) 1,0 p.u. continuously b) 1,2 p.u. 2 h – after a) c) 3,0 p.u. 1 min – after b)	Mainline railways	Cumulative
NOTE For further information see figures in IEC 62695:2014, Annex A.			

The purchaser of a converter shall specify the basic direct current and the duty class.

If for a given application no suitable standardized duty class can be found in Table 3, the purchaser shall specify a load cycle or duty class.

Independently of the duty class or load cycle, the converter and its constituent assemblies shall be able to carry the short circuit current according to 7.4.2.4.

~~NOTE~~ Unlike many other electrical components, semiconductor devices can be irreparably damaged, even within a very short time of operation in excess of their rated values. Selecting the rated direct current and the duty class or load cycle of a converter this should be taken into account.

The supplier shall show the short time current and overload current capability of the converter in a graph in logarithmic scale for overcurrent durations between 0,01 s and 10 000 s. Base current shall be I_{Bd}.

7.4.2.2 Duty classes

Duty classes specify current capabilities and test conditions for converters in terms of current values and durations. Table 3 contains standardized duty classes and gives guidance for the selection for different types of railways and their typical ratio between the basic current and the short time currents.

The basic current of a converter is valid only for the defined duty class. If a converter is designed to operate at different duty classes, a separate basic current shall be given for each duty class.

NOTE The duty class can be chosen either from the recommendations given in Table 3 or from the results of a digital simulation and network calculation, giving the expected RMS current and the time dependent overload characteristics for the intended use of the converter.

A duty class defined by the purchaser shall be called class X.

7.4.2.3 Load cycles

Load cycles specify the repetitive current demand to a converter for a given application.

The purchaser shall specify the current values and respective durations of the required load cycle.

Unless otherwise specified the quadratic mean of the load current over the duration T of the load cycle is assumed to be the basic direct current of the converter for the specific load cycle.

$$I_{Bd} = \sqrt{\frac{1}{T}\int_{T} I_d^2 dt}$$

The supplier shall calculate the capability of a converter to carry the specified currents of the load cycle. Annex B gives guidance for this calculation.

If the purchaser demands a specific type test for a load cycle this shall be mentioned in the procurement specification.

7.4.2.4 Short-time withstand capability

The supplier shall state the short-time withstand current capability of the converter.

If not otherwise agreed between purchaser and supplier the short-time withstand current capability shall be stated for a short circuit:

– after continuous operation at basic current I_{Bd} , and

– for a short circuit duration of 0,15 s, and

– with a factor of 1,6 between sustained current and peak value.

NOTE Refer to Annex B of IEC 62589:2010 for calculation of the short circuit current for a given application.

Controlled converters with a current limiting characteristic need not have a short-time withstand current capability. They shall be equipped with protection devices able to detect short-circuits in the switchgear or the contact line system which possibly cannot be detected by standard AC or DC overcurrent feeder protection devices in the case of current limitation.

7.4.3 Capability for unsymmetrical load of a 12-pulse converter in parallel connection

For a 12-pulse converter in parallel connection (connection No. 9) an unsymmetrical load sharing between the two three-phase bridges of up to ± 5 % of I_{Bd} shall be considered as normal condition.

~~NOTE~~ The following items can cause unsymmetrical load sharing between the two three-phase bridges and should be taken into account when determining the converter rating:

– harmonic distortion of the AC supply voltage exceeding the values according to IEC 61000-2-12;
– different impedance voltages of the transformer secondary windings;
– no-load voltage imbalances in the transformer;
– different lengths of the cables between transformer and converter;
– unequal number of converters with different transformer connections in a substation.

7.4.4 Semiconductor device failure conditions

The purchaser shall specify if semiconductor device fuses are required.

The purchaser shall specify the required immunity level in case of a failure of one or more series or parallel connected semiconductor devices per arm.

When a disturbance from any origin does not exceed the immunity level specified the corresponding performance shall be maintained. Table 4 defines the immunity levels.

Table 4 – Semiconductor device failure conditions

Immunity level		Consequence	
Redundancy	R	No immediate consequence, full performance maintained	Warning signal
Functional	F	Reduced performance (reduced current capability)	Warning signal or tripping signal
Tripping	T	Interruption of service due to protection devices	Tripping signal
Damage	D	Interruption of service due to damage	Tripping signal

7.5 Mechanical characteristics

7.5.1 General

Converters may be either enclosed or not enclosed. Frames and enclosures, if any, shall be metallic.

Converters and relevant enclosures shall be designed so that normal service, inspection and maintenance operations, replacement of diodes, fuses, and valve device assemblies, earthing of cables or busbars and voltage tests can be carried out easily and safely.

All materials used shall be of the quality and of the class most suitable for working under the conditions specified. Special attention is to be paid to its ability to withstand moisture and fire. Unless fire behaviour Class F0 is allowed, materials used shall be metallic or of the self-extinguishing type.

The selection of materials shall be such that corrosion due to atmospheric and electrolytic effects are minimized.

~~European~~ Rules concerning noxious or toxic materials shall be observed.

7.5.2 Earthing

To ensure safety during maintenance works, all parts of the main circuit to which access is required or provided shall be capable of being earthed through suitable means. This does not apply to those parts, which are withdrawable or removable and which become accessible after being separated from the enclosure.

A withdrawable part, however, shall not be removable from the enclosure unless capacitors on it have been discharged to safe values.

For DC traction power supply systems the purchaser shall specify in the enquiry how to earth the converter enclosure or frame according to 6.5.8 of IEC 61992-7-1:2006.

NOTE In DC traction supply systems, "earthing" means either connection to earth or connection to the return circuit, depending on the earthing requirements of the DC system.

The metallic parts of the enclosures or frames shall be connected to a suitable earthing terminal, placed in an accessible position, in order to allow the connection to the main earth system of the substation. The earthing terminal shall be suitably protected against corrosion.

7.5.3 Degree of protection

The purchaser shall specify the degree of protection according to IEC 60529.

Inspection windows and ventilating openings shall provide at least the degree of protection specified for the enclosure.

NOTE 1 If not otherwise agreed between purchaser and supplier, for converter enclosures the degree of protection is assumed to be valid for doors and walls of the enclosure.

Due to the specific requirements of converters for cooling and for connection of AC and DC cables or busbars IP 00 is considered as normal degree of protection for the bottom and the top of the enclosure.

NOTE 2 For indoor converters normally no degree of protection is provided against ingress of water.

7.6 Insulation coordination

For insulation coordination of electric traction system IEC 62497-1 is applicable.

For circuits directly connected to the railway overvoltage category OV3 and pollution degree PD 3A is used. All values define the insulation between the main circuit and the environment including other circuits and frame of the equipment.

Table 5 – Insulation levels for AC/DC and DC converters

Nominal voltage U_n kV	Rated insulation voltage U_{Nm} kV	Power frequency withstand voltage U_a kV		Impulse voltage 1,2 µs/50 µs U_{Ni} kV		Clearance clearance mm	
0,6	0,9	2,8		6		5,5	
0,75	1,2	3,6		8		8	
0,75	1,8	4,6		10		11	
1,5	2,3	5,5		12		14	
1,5	3,0	6,9		15		18	
3,0	3,6	OV 3	11,5	OV 3	25	OV 3	33
		OV 4	14,0	OV 4	30	OV 4	40
3,0	4,8	OV 3	14,0	OV 3	30	OV 3	40
		OV 4	18,5	OV 4	40	OV 4	60
3,0	6,5	OV 3	18,5	OV 3	40	OV 3	60
		OV 4	23,0	OV 4	50	OV 4	75

7.7 Specifics of line commutated rectifiers

7.7.1 Electrical connections

Standard design converters for traction power supply usually are converters each individually connected to a transformer for single phase ($p = 2$) or three-phase ($p = 6$ or 12) AC supply.

Twelve-pulse converters and dual six-pulse converters require two secondary windings in the transformer with 30 electrical degree shifted connections, normally star and delta connected or two separate transformers with different vector groups.

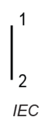
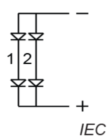
NOTE Higher pulse numbers can be achieved by using transformers with appropriate phase shifting and connecting several six-pulse or twelve-pulse converters in series or parallel. For traction power supply pulse numbers up to 24 p are used.

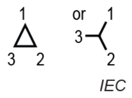
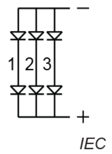
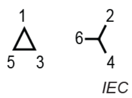
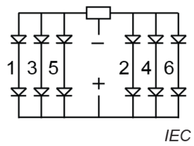
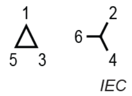
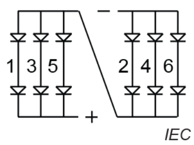
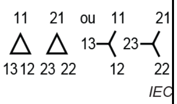
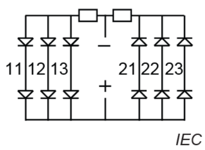
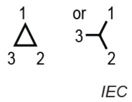
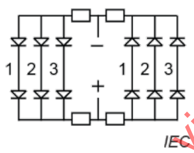
For converters subject to special agreement between the purchaser, the supplier and possibly the electricity supply companies because of their rating or special requirements or mode of operation, refer to IEC TR 60146-1-2, which also gives other converter connections for particular applications.

Table 6 gives conventional values of some calculation factors for the most used connections of converters. For other connections IEC TR 60146-1-2 assists.

The connection numbers are the same as used in the IEC 60146 series.

Table 6 – Connections and calculation factors for line commutated converters

Con-nection No.	Transformer connection valve side	Valve connection	*p*	*q*	Current factor on the AC. side I_v/I_d	$\frac{U_{di}}{U_{v0}}$	$\frac{U_{iM}}{U_{di}}$	$\frac{d_{xtB}}{e_{xB}}$
7			2	2	1	0,9 $\left(\frac{2\sqrt{2}}{\pi}\right)$	1,57 $\left(\frac{\pi}{2}\right)$	0,707 $\left(\frac{1}{\sqrt{2}}\right)$

Con-nection No.	Transformer connection valve side	Valve connection	*p*	*q*	Current factor on the AC. side I_v/I_d	$\frac{U_{di}}{U_{v0}}$	$\frac{U_{iM}}{U_{di}}$	$\frac{d_{xtB}}{e_{xB}}$
8			6	3	0,816 $\left(\sqrt{\frac{2}{3}}\right)$	1,35 $\left(\frac{3\sqrt{2}}{\pi}\right)$	1,05 $\left(\frac{\pi}{3}\right)$	0,5
9			12	3	0,408 $\left(\frac{1}{\sqrt{6}}\right)$	1,35 $\left(\frac{3\sqrt{2}}{\pi}\right)$	1,05 $\left(\frac{\pi}{3}\right)$	0,26
12			12	3	0,816 $\left(\sqrt{\frac{2}{3}}\right)$	2,7 $\left(\frac{6\sqrt{2}}{\pi}\right)$	0,524 $\left(\frac{\pi}{6}\right)$	0,26
18			6	3	0,816 $\left(\sqrt{\frac{2}{3}}\right)$	1,35 $\left(\frac{3\sqrt{2}}{\pi}\right)$	1,05 $\left(\frac{\pi}{3}\right)$	0,5
19			6	3	0,816 $\left(\sqrt{\frac{2}{3}}\right)$	1,35 $\left(\frac{3\sqrt{2}}{\pi}\right)$	1,05 $\left(\frac{\pi}{3}\right)$	0,5

~~NOTE Connection no. 9 with interbridge reactor is used together with converter transformers equipped with two secondary windings at low leakage magnetic flux and a coupling factor K > 0,9 (see EN 50329).~~

~~Connection no. 9 can be used without interbridge reactor if K < 0,2 i.e.~~

- ~~a three-windings transformer with non-coupled secondary windings, or~~
- ~~a four-windings transformer, or~~
- ~~two separate three-phase transformers with different vector groups~~

~~are used. In this case d_{xtB}/e_{xB} is 0,5.~~

NOTE Connection No. 9 can be used with or without interphase transformer. Details are described in IEC 62695. The factor d_{xtB}/e_{xB} can vary between 0,26 and 0,5 depending on the coupling factor defined in IEC 62695.

7.7.2 Calculation factors

7.7.2.1 Current factor on the AC side

The quotient of the RMS value I_v of the current on the AC side and the direct current I_d is indicated in Table 6 on the assumption of smooth direct current and rectangular waveshape of the alternating currents.

7.7.2.2 Voltage drop

Table 6 gives the ratio:

$$\frac{d_{xtB}}{e_{xB}}$$

between the direct inductive voltage drop d_{xtB} at basic current due to the transformer commutating reactance, referred to U_{di} and the inductive component e_{xB} of the transformer impedance voltage at basic service current on the supply side of the converter group for the whole equipment expressed in per cent of rated alternating voltage.

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

For all other connections with p = 12 or higher, the ratio between d_{xtB} and e_{xB} depend on the repartition of the reactances in the transformer between primary and secondary. The external characteristic can be represented graphically.

NOTE The voltage drop of diode rectifier groups depends mainly on the characteristics of the converter transformer. Therefore this document does not contain information regarding to voltage drop. For requirements concerning voltage drop see IEC 62589.

If the purchaser requires provisions against the voltage rise at currents below the transition current, he shall mention this in the tender specification.

7.7.3 Direct voltage harmonic content

For perfectly balanced supply voltages, trigger delay angles, etc., the frequency of the direct current and direct voltage harmonic content is given by:

$$f_{h,dc} = k \times p \times f_N \qquad k = \text{integer } (1\ldots n)$$

An unbalanced supply voltage causes a negative sequence voltage. The negative sequence voltage produces an additional harmonic component at a frequency $2 \times f_N$, which cannot be cancelled by an appropriate design of the converter unless a large smoothing reactance or DC output filter is added.

Refer to IEC TR 60146-1-2 for more information.

8 Tests

8.1 General

8.1.1 Overview

For the terminology for testing procedures refer to IEC 60050-811.

8.1.2 Performance of tests

Whenever practicable the tests shall be performed in electrical conditions equivalent to those in real service. Where it is not practicable, the assemblies and equipment respectively shall be tested under such conditions as to allow the specified performance to be proved.

Components of the converter are assumed to be tested separately.

Unless otherwise agreed at the time of the contract, the AC supply and test voltages shall be at rated frequency.

NOTE When the purchaser or his representative desires to witness factory tests, this should be specified in the procurement specification.

8.1.3 Test schedule

The tests, unless otherwise agreed, shall comprise all the following items marked "X", which are applicable to the assembly assemblies or converter units prefabricated in a factory (see Table 7).

For converters assembled on site only commissioning tests apply.

The tests marked "(x)" shall only be performed if specifically agreed in the contract.

Table 7 – Summary of tests

Test	Type test	Routine test	Optional test	Specification subclause
Insulation test	X	X		8.2.1
Light load functional test	X	X		8.2.2
Load test	X	(x) [a]		8.2.3
Power loss determination	X [a]	(x) [ba]		8.2.4
Temperature rise test	X			8.2.5
Checking of auxiliary devices	X	X		8.2.6
Checking the properties of the control equipment	X	X		8.2.7
Checking the protective devices	X	X		8.2.8
Short-time withstand current test			(x)	8.2.9
EMC tests	X			8.2.10
Additional tests			(x)	8.2.11

[a] For self-commutated converters the load test shall be carried out as routine test.

[ba] Only if power loss determination by measurement is required, see 3.3.1 7.1.1.

8.2 Test specifications

8.2.1 Insulation tests

8.2.1.1 General

Insulation tests shall be carried out to verify the correct state of insulation of a completely assembled unit. In general, they shall be carried out as an AC power frequency voltage test.

During insulation tests the main terminals of the converter, as well as the anode, cathode and gate terminals of all power semiconductor devices, shall be connected together. This does not apply, however, to auxiliaries for which, in case of an insulation fault, voltage can pass on to accessible parts not connected to the enclosure or from the side of higher voltage to the side of lower voltage. These are, for example auxiliary transformers, measuring equipment, pulse transformers and instrument transformers.

Switching devices in main circuits shall be closed or by-passed.

Auxiliaries not metallically connected to the main circuits (for example system control equipment, fan motors) shall be connected with the frame or enclosure during the insulation test according to 8.2.1.2.

In the power frequency withstand voltage test, the test voltage at the frequency as available in the test facility or with the rated frequency, but not exceeding 100 Hz, shall comply with 8.2.1.3.

If an alternating test voltage cannot be applied due to EMC filter components, which cannot easily be disconnected, a direct test voltage may be used having the same value as the crest value of the test voltage given in 8.2.1.3.

In routine tests on assemblies, it is sufficient to apply the full test voltage of 8.2.1.3 for 60 s. Gradual increase of the test voltage may be omitted.

The test has failed if a breakdown or flashover occurs.

Before the test and 1 min after the test, the insulation resistance shall be measured by applying a direct voltage of at least 500 V. The insulation resistance shall be more than 1 000 Ω/V.The measurement of the insulation resistance is not necessary for routine tests.

Earthing resistors and surge arresters, if any, shall be disconnected during the insulation tests.

If a liquid is used as heat transfer agent, the insulation test shall be performed with the liquid present.

Impulse withstand voltage tests are only required for converters with U_{Nm} > 2 500 V. By agreement between purchaser and supplier the impulse voltage test may be substituted by a power frequency withstand voltage test U_{ac} (see IEC 62497-1). In this test the voltage shall be applied for 5 s.

8.2.1.2 Insulation tests of converter equipment and assemblies arranged in a single enclosure

Each circuit of the converter shall be subjected to an insulation test against the enclosure and against any other circuits which are electrically separate from the circuit section under test. The test voltage shall be selected according to 8.2.1.3 with U_{Nm} being determined for the circuit under test.

The test voltage shall be applied between the circuit under test and the frame or enclosure to which the terminals of any other circuits shall be connected for the purpose of this test.

8.2.1.3 Test voltages and clearances ~~and creepage distances~~

8.2.1.3.1 Test voltages and clearances ~~and creepage distances~~ for AC/AC frequency converters

Test voltages, clearances and creepage distances according to Table 5 apply only to devices connected directly to the traction voltage. The dielectric properties of converters isolated from the traction voltage through transformers may be agreed between purchaser and supplier.

The tests according to 8.2.1.2 shall be performed with a test voltage with an RMS value and a peak value according to IEC 62497-1.

For clearances and creepage distances refer to IEC 62497-1.

8.2.1.3.2 Test voltages and clearances for AC/DC converters

The insulation tests shall be performed with test voltages according to Table 8.

NOTE AC/DC converters means rectifiers as well as inverters according to IEC 60050-551: 551-12-01. Converting DC to AC is therefore included.

Table 8 – Insulation levels for AC/DC and DC converters

Nominal voltage U_n kV	Rated insulation voltage U_{Nm} kV	Power frequency withstand voltage U_a kV
0,6	0,9	2,8
0,75	1,2 / 1,8	3,6 / 4,6
1,5	2,3 / 3,0	5,5 / 6,9
3,0	3,6 / 4,8 / 6,5	11,5 / 14 / 18,5

The test voltage applies under the conditions of Clause 6. For other conditions IEC 62497-1 has to be used. The test voltage has to be applied between the main circuit and all other circuits including frame.

8.2.1.3.3 Test voltages and clearances for DC converters

Test voltages and clearances according to Table 8 apply only to devices connected directly to the traction voltage. The dielectric properties of converters isolated from the traction voltage through transformers may be agreed between purchaser and supplier.

The tests according to 8.2.1.2 shall be performed with a test voltage with an RMS value and a peak value according to IEC 62497-1.

For clearances and creepage distances refer to IEC 62497-1.

~~7.2.1.3.2 Test voltages, clearances and creepage distances for a.c./d.c. converters~~

~~Isolating distances shall be designed in accordance with the requirements for isolating distances specified in IEC 62497-1. The insulation tests shall be performed with test voltages according to Table 7.~~

~~The clearances in Table 7 are minimum clearances between phase or pole and earth.~~

~~Table 7 – Insulation levels for a.c./d.c. converters~~

~~Nominal voltage~~ ~~U_n~~ ~~kV~~	~~Rated insulation voltage~~ ~~U_{Nm}~~ ~~kV~~	~~Power frequency withstand voltage~~ ~~U_a~~ ~~kV~~		~~Impulse voltage 1,2 µs/50 µs~~ ~~U_{Ni}~~ ~~kV~~		~~Clearance~~ ~~mm~~	
~~0,6~~	~~0,9~~	~~2,8~~		~~not applicable~~		~~10~~	
~~0,75~~	~~1,2~~	~~3,6~~		~~not applicable~~		~~14~~	
~~0,75~~	~~1,8~~	~~4,6~~		~~not applicable~~		~~18~~	
~~1,5~~	~~2,3~~	~~5,5~~		~~not applicable~~		~~22~~	
~~1,5~~	~~3,0~~	~~9,2~~		~~not applicable~~		~~36~~	
~~3,0~~	~~3,6~~	~~OV 3~~	~~11,5~~	~~OV 3~~	~~25~~	~~OV 3~~	~~45~~
		~~OV 4~~	~~14,0~~	~~OV 4~~	~~30~~	~~OV 4~~	~~54~~
~~3,0~~	~~4,8~~	~~OV 3~~	~~14,0~~	~~OV 3~~	~~30~~	~~OV 3~~	~~54~~
		~~OV 4~~	~~18,5~~	~~OV 4~~	~~40~~	~~OV 4~~	~~72~~
~~3,0~~	~~6,5~~	~~OV 3~~	~~18,5~~	~~OV 3~~	~~40~~	~~OV 3~~	~~72~~
		~~OV 4~~	~~23,0~~	~~OV 4~~	~~50~~	~~OV 4~~	~~91~~

~~NOTE For rated insulation voltages up to 3 kV the values are taken assuming that the overvoltage category OV 3 as defined in IEC 62497-1 is used. For rated insulation voltages of 3 kV or higher OV 4 is used.~~

8.2.2 Light load functional test

The light load functional test is carried out at a sufficient load to verify that all parts of the main circuit and the auxiliary circuits operate properly.

For the routine test, the converter shall be connected to the rated supply voltage(s).

For self-commutated converters the light load functional test and a load test may be combined.

If series connected semiconductor devices are used in the arms of the converter, the voltage sharing shall be checked to be within the design limits.

8.2.3 Load test

The test is carried out to verify that the equipment will operate satisfactorily at basic current.

The DC terminals shall be bonded together via a measuring shunt or a similar device. An AC voltage of sufficient value shall be connected to the AC. terminals of the converter to cause basic direct current to flow.

During the test, the control equipment, if any, and auxiliaries shall be supplied separately with their rated voltage.

By proper coordination of control, if any, and of applied AC. voltage, basic direct current shall be circulated through the DC. terminals.

If parallel connected devices are used in the arms, the current sharing shall be checked to be within the design limits.

The load test and the temperature-rise test may be combined.

For self-commutated converters the load test shall be carried out as routine test.

8.2.4 Power loss determination

If the power loss determination shall be done by measurement and not by calculation (see 7.1.1), the methods for power loss measurement given in Clause 4 of IEC TR 60146-1-2:2011 may be used.

8.2.5 Temperature-rise test

8.2.5.1 General

The temperature-rise of the converter shall be determined under test conditions given for the load test, 8.2.3, under the cooling conditions, which are least favourable. If the test is conducted at a lower ambient temperature than the maximum specified, corrections ~~shall~~ have to be made. The temperature-rise test is not limited to the main circuit.

The temperature-rise test shall be conducted for a duty class at basic current and the overload currents for the duration indicated in the duty class or load cycle.

For diode rectifiers a simplified test with a short circuit at the DC side and a low AC voltage may be used. In this case in order to correct the losses of the elements with sinusoidal waveshape of the current at 180° conduction versus those with rectangular waveshape at 120° conduction, the test current shall be increased by 10 %.

Example: 1,0 p.u. is becoming 1,1 p.u, 1,5 p.u. is becoming 1,65 p.u. and 3 p.u. is becoming 3,3 p.u. for overload class VI.

The temperature-rise at potential highest temperature points accessible on the semiconductor devices shall be recorded. The rise of virtual junction temperature shall be calculated and based on the temperature measurements in order to show that the assembly is capable of carrying the specified duty class or load cycle without exceeding maximum virtual junction temperature for the devices. The actual current sharing between parallel valve devices shall be taken into account.

The temperatures of busbars, insulation material, cables and control and protection devices shall not exceed their admissible limits (absence of permanent damage).

The temperature-rise above ambient temperature at continuous current shall be taken when temperature readings have reached a steady state. Variations of less than 1 K/h, with a maximum test duration of 8 h, shall be considered conditions fulfilling the required steady state conditions.

Temporary connections to the main circuit shall be made so that no heat is removed from the converter assembly nor supplied during the test. The temperature-rise is measured at the main circuit terminals and at the temporary connections, 1 m away from the terminals. The temperature-rise difference shall not exceed 5 K.

In those cases where parallel redundancy of semiconductor devices is provided, the redundant devices with the potential lowest temperature-rise shall be excluded in order to check that the remaining devices do not exceed the maximum allowable temperature.

In those cases where series redundancy of semiconductor devices is provided, all devices shall be included.

The maximum virtual junction temperature, measured and corrected by calculation, shall not exceed the admissible maximum junction temperature given by the manufacturer of the semiconductor device.

8.2.5.2 Ambient air and cooling medium temperature

8.2.5.2.1 Ambient air temperature

The ambient air temperature shall be 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.

8.2.5.2.2 Cooling medium temperature for air cooling

The average temperature shall be measured outside the equipment at points 50 mm from the inlet to the equipment.

NOTE For the evaluation of the fraction of heat which is radiated, the ambient air temperature is that described in 8.2.5.2.1.

8.2.5.2.3 Cooling medium temperature for liquid cooling

The temperature shall be measured in the liquid pipe 100 mm upstream from the liquid inlet.

8.2.5.2.4 Temperature of heat transfer agent

The heat transfer agent temperature shall be measured at a point to be specified by the manufacturer.

8.2.6 Checking of auxiliary devices

The function of auxiliary devices such as contactors, pumps, sequencing equipment, fans, etc., shall be checked.

8.2.7 Checking of the properties of the control equipment

It is not feasible to verify the properties of the control equipment under all those load conditions which can prevail in real operation. However, it is recommended that trigger equipment shall be checked under real load conditions as far as possible. When this cannot be done on the manufacturers premises, it may be performed after installation by agreement with the user.

When practicable, the checking of control equipment may be restricted to a check under two load conditions as specified by 8.2.2 and 8.2.3 respectively.

In either case the static and dynamic properties of the control equipment shall be checked. This shall include checking that the equipment operates satisfactorily for all values of supply voltages within the ranges of variation for which it is designed.

In type tests the function of the auxiliary circuits shall be tested at maximum and minimum values of the supply voltage.

In the case the semiconductor power converter is equipped with automatic control equipment, for example constant voltage control or constant current control, checking of the properties may be replaced by other means such as simulation and stability analysis by agreement between purchaser and supplier.

8.2.8 Checking of the protective devices

Checking of the protective devices shall be done as far as possible without stressing the components of the equipment above their rated values.

Due to the wide variety of protective devices and their combinations, it is not possible to state any general rules for the checking of these devices. However, if a system control equipment is designed to protect the converter from overloads, its ability in this respect shall be checked.

Routine tests shall be performed to check the operation of protective devices. It is, however, not intended that the operation of devices such as fuses, etc., where the operation is based on destruction of the operating component, shall be checked.

8.2.9 Short-time withstand current test

The short-time withstand current test is a supplementary test. The test is carried out to verify the short-time withstand current carrying capability (see 7.4.2.4) of the converter for the specified current and duration. This subclause applies to tests of the converter without its intended transformer.

The short-time withstand current test shall be made under test conditions as given for the load test in 8.2.3.

The converter shall be preheated as described in 8.2.5. When the junction temperature of that semiconductor device, which was found to be the hottest during the temperature-rise test, has reached the temperature, measured as steady-state temperature at I_{Bd}, the short-time current shall be applied to the converter within 1 s.

After the short-time withstand current test all semiconductor devices and fuses shall operate properly. Busbars, insulating material and other mechanical parts shall not be damaged. In order to verify the proper function of the converter, a light load functional test according to 8.2.2 shall be carried out.

In thoses cases where parallel redundancy of semiconductor devices is provided, the redundant devices shall be excluded in order to check that the remaining devices are able to carry the short-time current.

8.2.10 EMC test

Basic immunity test according to IEC 62236-5 shall be made.

8.2.11 Additional tests

Specifications and procedures for any additional tests, for example vibration, voltage drift, audible noise shall be agreed between purchaser and supplier.

9 Marking

9.1 Rating plate

Each converter equipment (see Clause 1) which is delivered as an integrally assembled unit and each assembly which is delivered separately shall bear the following markings on the rating plate:

a) manufacturer's or supplier's indication;
b) indication of the type of equipment (5.1.1);
c) the number of this document;
d) manufacturer's type designation;
e) serial number;
f) number of input phases or indication "DC";
g) rated input voltage (rated direct voltage in the case of inverters);
h) rated input frequency, if any;
i) number of output phases or indication "DC";
j) nominal DC voltage;
k) basic direct current;
l) duty class or designation of the load cycle;
m) short circuit capability;
n) rated output frequency, if any;
o) range of output voltage (if the output voltage is adjustable);
p) cooling method;
q) type of connection.

Further items which may be added if appropriate:

r) cooling requirements (temperature, flow rate of cooling medium);
s) overall weight, weight of cooling fluid, if any;
t) degree of protection (IP-Code);

u) displacement factor under rated conditions;

v) output characteristic curve symbol.

9.2 Main circuit terminals

The marking of the main circuit input and output terminals shall express the sequence of phases (if to be observed) and the polarity of DC terminals.

Annex A
(informative)

Information required

A.1 General

This annex gives a summary of the information which should be exchanged between purchaser and supplier.

A.2 Diode rectifiers

A.2.1 Procurement specification

A.2.1.1 General

The following items should be included, where applicable, within the specification issued by the purchaser in order to provide the precise technical requirements.

NOTE The characteristics are only used where they specifically apply.

A.2.1.2 Characteristics and functional requirements

a) type of equipment (see 5.1.1);
b) nominal DC voltage;
c) rated AC voltage on the supply side;
d) rated insulation voltage;
e) insulation requirements differing from those defined as normal (if any);
f) basic direct current;
g) duty class or designation of a load cycle;
h) short circuit capability of the converter or breaking time of the high voltage circuit breaker;
i) rated DC power;
j) converter connection (see 7.7);
k) diode failure immunity level (see 7.4.4);
l) requirement of diode fuses;
m) requirements for diode or diode fuse failure monitoring device;
n) requirement for diode temperature monitoring;
o) data of the rectifier transformer;
p) requirements and data of voltage and/or current measuring devices;
q) rated voltage of auxiliary circuits;
r) cooling method;
s) safety related interlocks;
t) requirement of provisions against the voltage rise below the transition current.

A.2.1.3 Special service conditions

Environmental and electrical service conditions differing from those defined as normal (see 6.2 and 6.3).

A.2.1.4 Mechanical requirements

a) IP code required (according to IEC 60529);

b) requirement of fixed or withdrawable equipment;
   arrangement of AC and DC connections;
   type and number of AC and DC cables, busbars or busducts;
c) padlocking requirements;
d) earthing and bonding facilities;
e) earthing method of the enclosure or frame of the converter (see 7.5.2);
f) maximum dimensions of the converter at site;
g) details of arrangement for transport and delivery to site;
h) details of site installation.

A.2.1.5 Tests

Tests differing from those specified in 8.1.2 as routine tests.

A.2.2 Supplier's tender specification

NOTE The characteristics are only used where they specifically apply.

A.2.2.1 Identification

a) name of the manufacturer or trademark;
b) type of equipment (see 5.1.1);
c) type designation;
d) reference to the National Standard corresponding with this document, which the manufacturer declares compliance with.

A.2.2.2 Characteristics

a) nominal DC voltage;
b) basic direct current;
c) duty class or suitability of the converter for a specified load cycle (see 7.4.2);
d) overcurrent curve (see 7.4.2.1);
e) peak reverse voltage of diodes;
f) losses;
g) power efficiency;
h) cooling method;
i) dimensions of the converter assembly;
j) space requirements for maintenance;
k) necessity of rear access;
l) weight of the complete assembly;
m) confirmation of compliance with the purchaser's requirements (see A.2.1) and a list of any non-compliances;
n) requirement of special tools for repair or maintenance.

A.2.3 Information and data to be given by the supplier during the delivery stage

a) circuit and schematic diagrams of all circuits;
b) demand of cooling medium (e.g. air);
c) method of fixing of the converter assembly to floor;
d) operation and maintenance manuals.

A.3 Controlled converters and inverters

A.3.1 Procurement specification

A.3.1.1 General

The following items should be included, where applicable, within the specification issued by the purchaser in order to provide the technical requirements for the performance of the converter.

It is assumed that a controlled converter can be supplied only as a whole converter group including transformer and filters under the overall responsibility of the converter supplier.

NOTE The characteristics are only used where they specifically apply.

A.3.1.2 Characteristics and functional requirements

a) type of equipment (see 5.1.1);
b) nominal DC voltage;
c) rated insulation voltage;
d) insulation requirements differing from those defined as normal;
e) rated AC voltage on the supply side of the converter group;
f) conventional no-load direct voltage;
g) rated direct voltage;
h) basic direct current;
i) duty class or designation of a load cycle;
j) requirements for current limiting;
k) rated DC power;
l) requirements concerning AC and DC harmonic content;
m) rated voltage of auxiliary circuits;
n) cooling method;
o) safety related interlocks.

A.3.1.3 Special service conditions

Environmental and electrical service conditions differing from those defined as normal (see 6.2 and 6.3).

A.3.1.4 Mechanical requirements

a) IP code required (according to IEC 60529);
b) arrangement of AC and DC connections;
c) padlocking requirements;
d) earthing and bonding facilities;
e) earthing method of the enclosure or frame of the converter (see 7.5.2);
f) maximum dimensions of the converter at site;
g) details of arrangement for transport and delivery to site.

A.3.1.5 Tests

Tests differing from those specified in 8.1.2 as routine tests.

A.3.2 Supplier's tender specification

NOTE The characteristics are only used where they specifically apply.

A.3.2.1 Identification

a) name of the manufacturer or trademark;

b) type of equipment (see 5.1.1);

c) type designation;

d) reference to the National Standard corresponding with this document, which the manufacturer declares compliance with.

A.3.2.2 Characteristics

a) nominal voltage;

b) basic direct current;

c) duty class or suitability of the converter for a specified load cycle (see 7.4.2);

d) overcurrent curve (see 7.4.2.1);

e) losses;

f) power efficiency;

g) cooling method;

h) dimensions of the converter assembly;

i) space requirements for maintenance;

j) necessity of rear access;

k) weight of the complete assembly;

l) confirmation of compliance with the purchaser's requirements (see A.3.1) and a list of any non-compliances;

m) requirement of special tools for repair or maintenance.

A.3.2.3 Information and data to be given by the supplier during the delivery stage

a) circuit and schematic diagrams of all circuits;

b) demand of cooling medium (e.g. air);

c) method of fixing of the converter assembly to floor;

d) operation and maintenance manuals.

A.4 Frequency converters (direct and DC link converters)

A.4.1 Procurement specification

A.4.1.1 General

The following items should be included, where applicable, within the specification issued by the purchaser in order to provide the precise technical requirements.

It is assumed that a frequency converter can be supplied only as a whole converter group including transformers and filters under the overall responsibility of the converter supplier.

A.4.1.2 Characteristics and functional requirements

a) type of equipment (see 5.1.1);

b) nominal AC voltage, 1 phase;

c) rated AC voltage, 3 phase;

d) rated frequencies, 1 phase and 3 phase;

e) rated insulation voltages;
f) insulation requirements differing from those defined as normal;
g) nominal active and/or reactive power at working point, 1 phase;
h) requirements on reactive power characteristic, 3 phase;
i) duty class or designation of a load cycle;
j) maximum and minimum short circuit power, 1 phase and 3 phase;
k) existing harmonic content in AC voltages, 1 phase and 3 phase;
l) limits for additional harmonic generation, 1 phase and 3 phase;
m) resonance frequencies or network impedances [Z(f)], 1 phase and 3 phase;
n) requirements and data of voltage and current measuring devices;
o) requirements on control and regulation functions;
p) safety related interlocks.

A.4.1.3 Service conditions

Environmental conditions differing from those defined as normal (see 6.2).

A.4.1.4 Mechanical requirements

a) IP code required (according to IEC 60529);
b) padlocking requirements;
c) earthing and bonding facilities;
d) details of site installation;
e) details of arrangement for transport and delivery to site;
f) maximum dimensions of the converter at site.

A.4.1.5 Tests

Tests of components should be agreed upon in accordance to appropriate standards.

Tests for the converter groups should be defined during the tendering process.

A.4.2 Supplier's tender specification

NOTE The characteristics are only used where they specifically apply.

A.4.2.1 Identification

a) name of the manufacturer or trademark;
b) type of equipment (see 5.1.1);
c) type designation if applicable;
d) reference to the National Standard corresponding with this document, which the manufacturer declares compliance with.

A.4.2.2 Characteristics

a) nominal voltage, 1 phase, 3 phase and DC;
b) rated current, 1 phase, 3 phase and DC;
c) rated frequencies, 1 phase, 3 phase;
d) data and requirements of converter transformers, 1 phase and 3 phase;
e) duty class or load cycle at 1 phase;
f) losses;
g) power efficiency;

h) cooling method;
i) rated voltage and power demand of auxiliary and control circuits;
j) dimensions of the converter assembly;
k) space requirements for maintenance;
l) weight of the complete assembly;
m) confirmation of compliance with the purchaser's requirements (see A.4.1) and a list of any non-compliances;
n) requirement of special tools for repair or maintenance.

A.4.2.3 Information and data to be given by the supplier during the delivery stage

a) circuit and schematic diagrams of all circuits;
b) dimension drawings of main components and total converter group;
c) demand of cooling medium (e.g. air);
d) method of fixing of the converter assembly to floor;
e) operation and maintenance manuals, including safety instructions and information on transport, packing, assembly and commissioning.

A.5 DC converters

A.5.1 Procurement specification

A.5.1.1 General

The following items should be included, where applicable, within the specification issued by the purchaser in order to provide the technical requirements for the performance of the converter.

It is assumed that a DC converter can be supplied only as a whole converter group under the overall responsibility of the converter supplier.

NOTE The characteristics are only used where they specifically apply.

A.5.1.2 Characteristics and functional requirements

a) type of equipment (see 5.1.1);
b) nominal input DC voltage (DC bus side);
c) nominal output DC voltage (the other side, e.g. an energy storage unit);
d) rated insulation voltage;
e) insulation requirements differing from those defined as normal;
f) rated direct voltage;
g) basic direct current;
h) duty class or designation of a load cycle;
i) requirements for current limiting;
j) rated DC power;
k) requirements concerning DC harmonic content;
l) rated voltage of auxiliary circuits;
m) cooling method;
n) safety related interlocks.

A.5.1.3 Special service conditions

Environmental and electrical service conditions differing from those defined as normal (see 6.2 and 6.3).

A.5.1.4 Mechanical requirements

a) IP code required (according to IEC 60529);
b) padlocking requirements;
c) earthing and bonding facilities;
d) earthing method of the enclosure or frame of the converter (see 7.5.2);
e) maximum dimensions of the converter at site;
f) details of arrangement for transport and delivery to site.

A.5.1.5 Tests

Tests of components should be agreed upon in accordance to appropriate standards.

Tests for the converter groups should be defined during the tendering process.

A.5.2 Supplier’s tender specification

NOTE The characteristics are only used where they specifically apply.

A.5.2.1 Identification

a) name of the manufacturer or trademark;
b) type of equipment (see 5.1.1);
c) type designation if applicable;
d) reference to the National Standard corresponding with this document, which the manufacturer declares compliance with.

A.5.2.2 Characteristics

a) nominal voltage;
b) basic direct current;
c) duty class or suitability of the converter for a specified load cycle (see 7.4.2);
d) overcurrent curve (if needed, see 7.4.2.1);
e) losses;
f) power efficiency;
g) cooling method;
h) dimensions of the converter assembly;
i) space requirements for maintenance;
j) necessity of rear access;
k) weight of the complete assembly;
l) confirmation of compliance with the purchaser's requirements (see A.5.1) and a list of any non-compliances;
m) requirement of special tools for repair or maintenance.

A.5.2.3 Information and data to be given by the supplier during the delivery stage

a) circuit and schematic diagrams of all circuits;

b) demand of cooling medium (e.g. air);

c) method of fixing of the converter assembly to floor;

d) operation and maintenance manuals.

Annex B
(informative)

Determination of the current capability through calculation of the virtual junction temperature

B.1 General

The calculation of the virtual junction temperature is the basis for determination of current capability of converters.

A method for calculating virtual junction temperature is shown in Clauses B.3 to B.6.

The method is valid under the following assumptions:

a) the virtual junction temperature to be calculated depends only on power dissipation of the power semiconductor device under consideration. In other terms, each power semiconductor has its own heat transfer path to the cooling medium, really or virtually independent from the heat transfer paths of other power dissipating elements of the stack or assembly;

NOTE 1 This does not hold true for example in those ~~four quadrant~~ bidirectional assemblies in which power semiconductors belonging to forward and reverse sections share the same cooling bodies.

b) thermal resistance and transient thermal impedance between the virtual junction and the reference point are independent from the temperature, i.e. a linear relationship exists between the temperature rise and the power dissipation;

NOTE 2 This condition is generally not satisfied in the case of convection cooling.

c) semiconductor losses are mainly conduction losses; turn-on, turn-off and voltage dependent losses. The voltage dependent losses might have to be considered particularly in the case of self-commutated converters or heavy current line commutated converters.

B.2 Approximation of the shape of power pulses applied to the semiconductor device

The equivalent power losses with rectangular waveshape pulses are selected to have:

a) the same peak value as the actual power pulse,

b) a pulse duration adjusted to give the same average value as the actual power pulses.

This method for approximation the power losses is applicable:

c) within a period of the supply frequency, i.e. equal to the conduction period of one converter circuit element,

d) for the case when the load of a converter is cyclic with a period up to several minutes.

For case c)

$$t_1 = \frac{P_{avg}}{\hat{P}} \times T_N$$

For case d)

$$t_p = \frac{P_M}{\hat{P}_{avg}} \times T$$

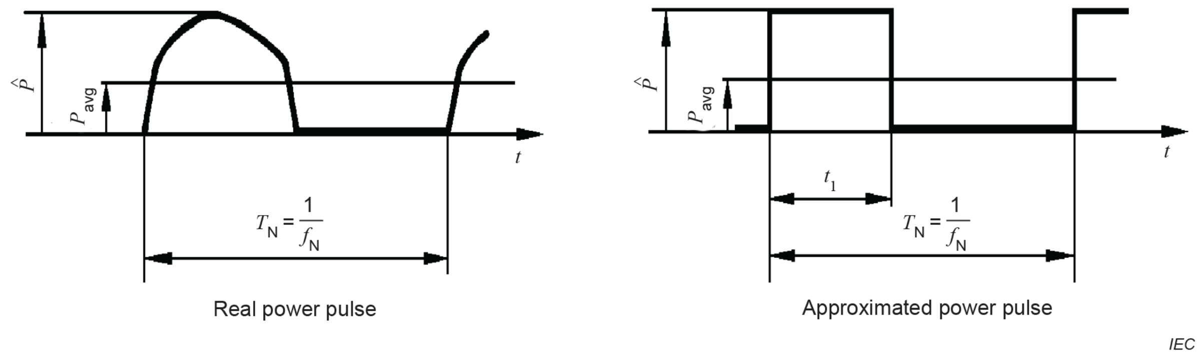


Figure B.1a

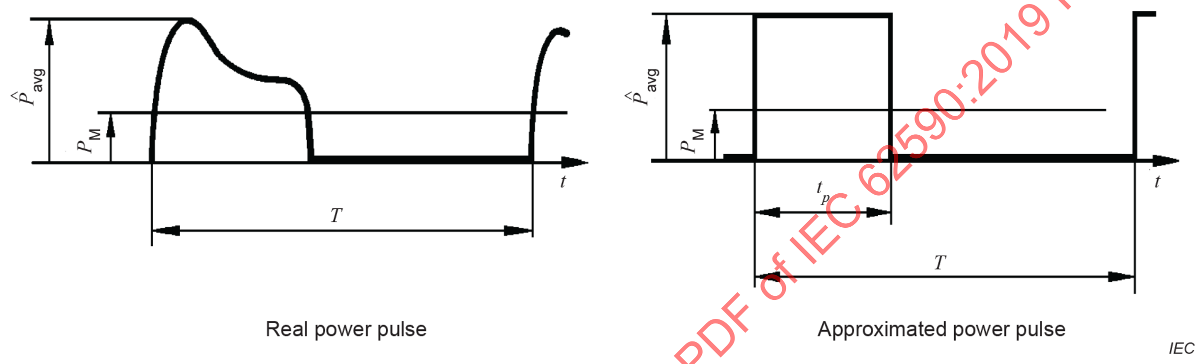


Figure B.1b

Figure B.1 – Approximation of the shape of power pulses

In some cases, especially for pulse duration longer than 1 s and for real power loss pulses with shapes considerably diverging from rectangular wave form, it can be necessary to make up the approximated power pulse by several rectangular pulses of different amplitudes and durations to obtain a more accurate result. It is recommended that each of these pulses should be selected to have the same duration and the same average value as the section of the real power loss pulse it is substituting. (see figure B.1a and B.1b).

B.3 Superposition method for the calculation of temperature

The method is based on the application of a transient thermal impedance curve. It is assumed that the power losses are represented as square wave pulses approximated according to Clause B.2.

The temperature difference Θ_n between two specified points A and B at the time t_n is given as the sum of temperature contributions from all power steps ΔP_v preceeding the time t_n.

$$\Theta_n = \sum_{\nu=1}^{n-1} \Delta P_v \times Z_{nv}$$

A positive power step gives a positive temperature contribution and a negative power step gives a negative temperature contribution.

The method is exemplified in Table B.1.

B.4 Calculation of virtual junction temperature for continuous load

B.4.1 General

In this case the virtual junction temperature varies with time with a frequency determined by the alternating line voltage.

The power loss approximated by the method given in Clause B.2 and the virtual junction temperature versus time is given by the following diagram (Figure B.2).

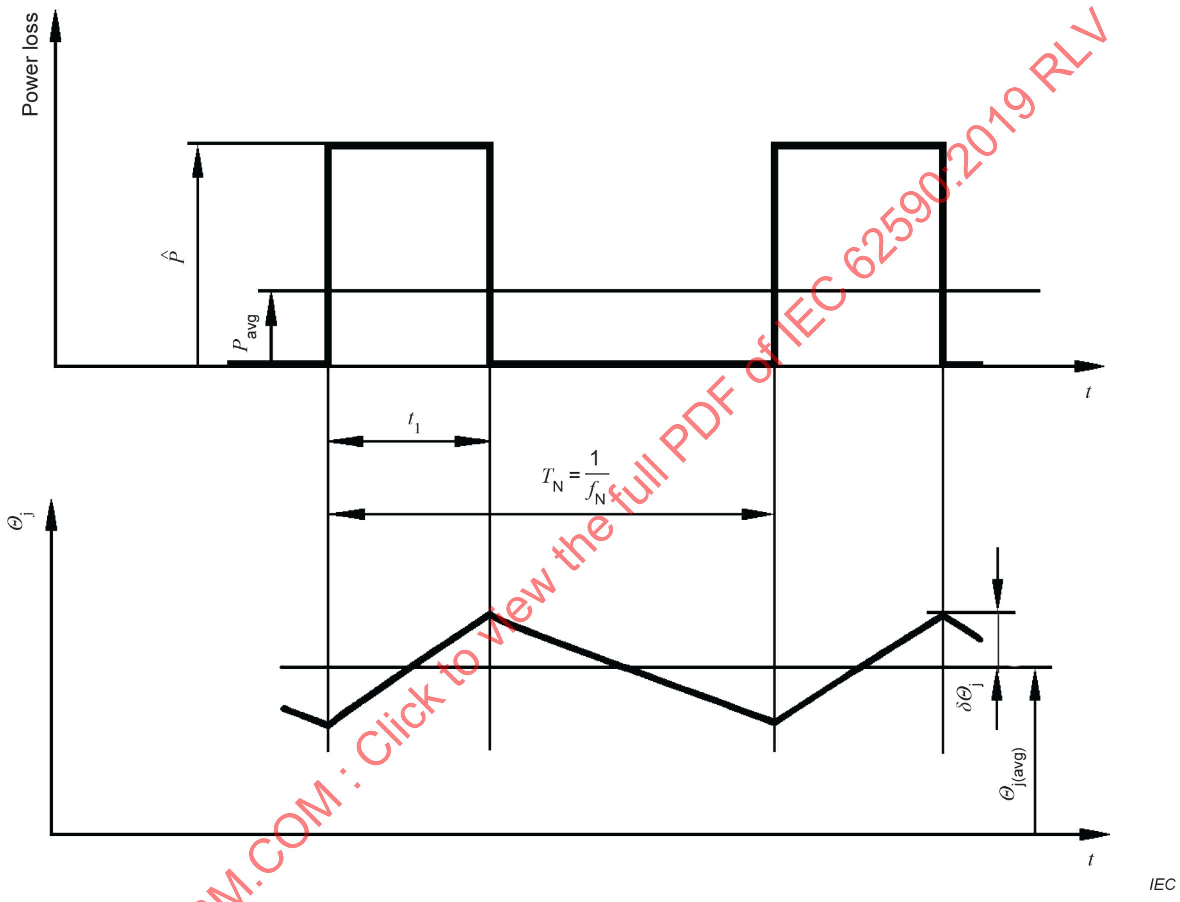


Figure B.2 – Calculation of the virtual junction temperature for continuous load

B.4.2 Calculation of mean value of virtual junction temperature

The mean value of the virtual junction temperature is given by the formula:

$$\Theta_{j(avg)} = \Theta_x + P_{avg} \times R_{th}$$

B.4.3 Calculation of maximum instantaneous virtual junction temperature

The maximum instantaneous virtual junction temperature within one cycle is calculated by the formula:

$$\Theta_j = \Theta_{j(avg)} + \delta\Theta_j$$

An accurate value of the temperature excursion $\delta\Theta_j$ can be calculated by the power pulse superposition method described in Clause B.3.

$$\delta\Theta_j = \frac{T_{1N}}{t_1} \times P_{avg} \left[\sum_{\nu=1}^{\frac{n}{2}} \times Z_n \times (2\nu - 1) - \sum_{\nu=1}^{\frac{n-2}{2}} \times Z_n \times 2\nu \right] - P_{avg} \times R_{th}$$

As $\delta\Theta_j$ normally is small compared to $\delta\Theta_{j(avg)}$the following approximated formula is recommended:

$$\delta\Theta_j = \frac{T_{1N}}{t_1} \times P_{avg} - \left[Z_{t1} - Z_T + \left(1 - \frac{t_1}{T}\right) \times Z_{(t_1+T)} \right]$$

B.5 Calculation of virtual junction temperature for cyclic loads

In this case, the virtual junction temperature varies with time at a frequency determined by the load variations but also with a higher frequency determined by the alternating voltage as described in Clause B.4 (see Figure B.3).

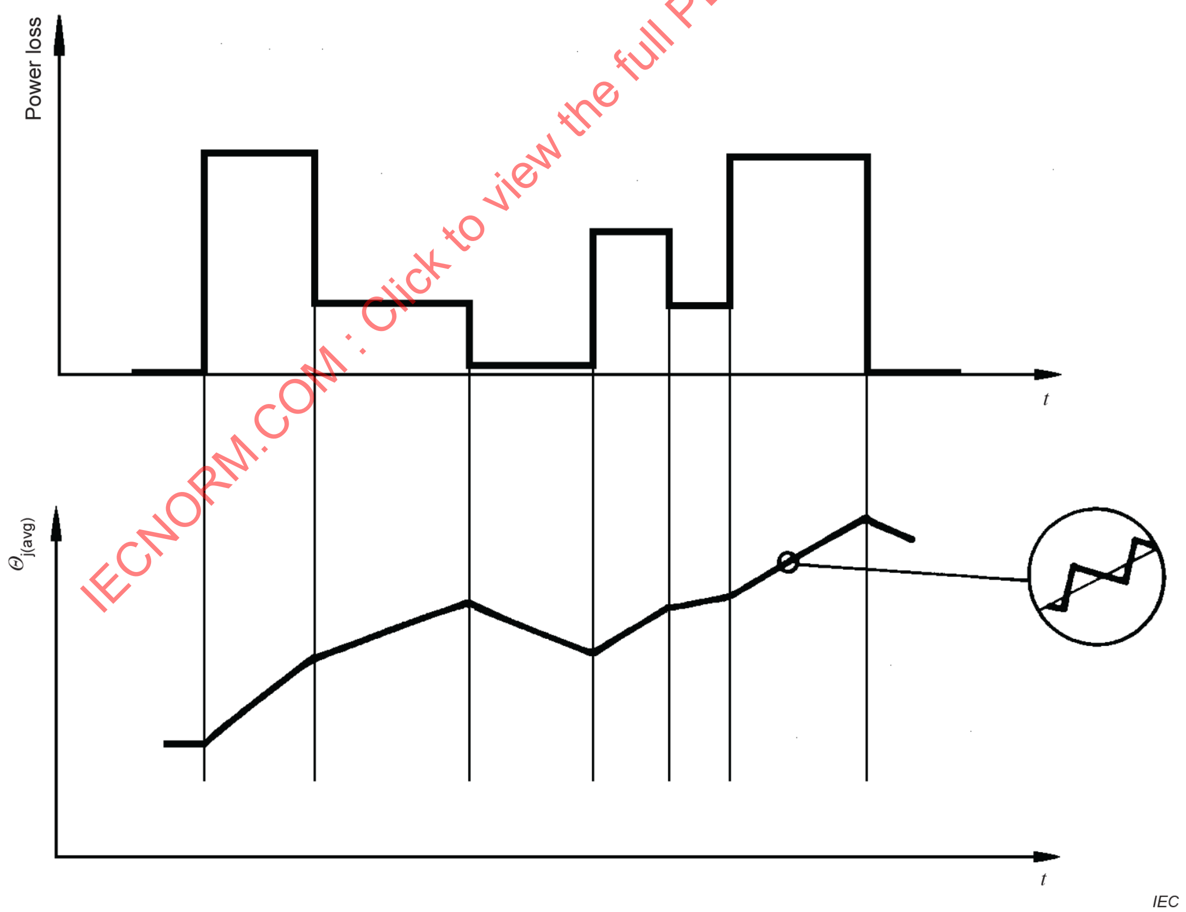


Figure B.3 – Calculation of the virtual junction temperature for cyclic load

The temperature excursion caused by the heating up of the junction during the conduction period and the cooling down during the low-load or no-load period is calculated in the same way as for continuous load according to B.4.2. The mean value of the virtual junction temperature averaged over one cycle of the supply frequency at a certain time in the load cycle is calculated according to the method given in B.4.1.

The mean virtual junction temperature at the time t_n is thus given by:

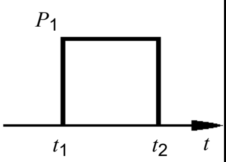
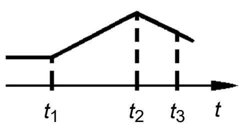
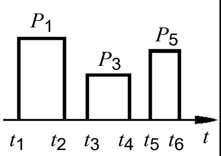
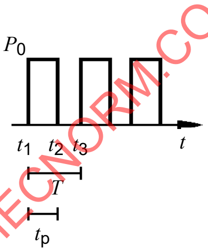
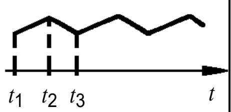
$$\Theta_{j(avg)n} = \Theta_x + \sum_{\nu=1}^{n-1} \Delta P_\nu \times Z_{n\nu}$$

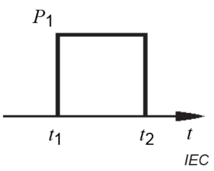
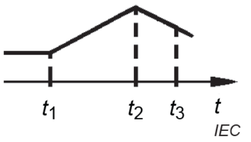
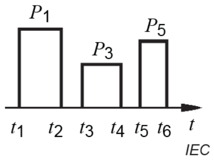
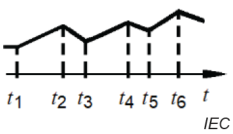
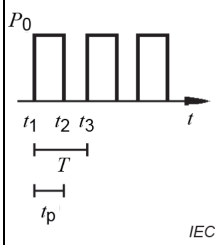
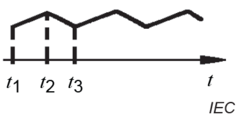
The maximum instantaneous value of virtual junction temperature at the time t_n is given by:

$$\Theta_j = \Theta_{j(avg)} + \delta\Theta_j$$

B.6 Examples for typical applications

Table B.1 – Examples for typical applications

Load condition	Power loss diagram	Mean virtual junction temperature diagram	Calculation formulae
Single load pulse			$\Theta_{j(avg)2} = \Theta_x + P_1 \times Z_{21}$ $\Theta_{j(avg)3} = \Theta_x + P_1 \times Z_{31} - P_1 \times Z_{32}$
Sequence of load pulses			$\Theta_{j(avg)2} = \Theta_x + P_1 \times Z_{21}$ $\Theta_{j(avg)4} = \Theta_x + P_1 \times Z_{41} - P_1 \times Z_{42} + P_3 \times Z_{43}$ $\Theta_{j(avg)6} = \Theta_x + P_1 \times Z_{61} - P_1 \times Z_{62} + P_3 \times Z_{63} -$ $- P_3 \times Z_{64} + P_5 \times Z_{65}$
Long sequence of equal amplitude load pulses			n = even: $\Theta_{j(avg)n} = \Theta_x + \sum_{\upsilon=1}^{\frac{n}{2}} P_0 \times Z_{n(2\upsilon-1)} - \sum_{\upsilon=1}^{\frac{n}{2}-1} P_0 \times Z_{n(2\upsilon)}$ n = odd: $\Theta_{j(avg)n} = \Theta_x + \sum_{\upsilon=1}^{\frac{n-1}{2}} P_0 \times Z_{n(2\upsilon-1)} - \sum_{\upsilon=1}^{\frac{n-1}{2}} P_0 \times Z_{n(2\upsilon)}$ or approximated: $\Theta_{j(avg)n} = \Theta_x + P_0 \times$ $\times \left[Z_{t_p} - Z_T + \left(1 - \frac{t_p}{T}\right) \times Z_{(T+t_p)} + \frac{t_p}{T} \times R_T \right]$

Load condition	Power loss diagram	Mean virtual junction temperature diagram	Calculation formulae
Single load pulse			$\Theta_{j(avg)2} = \Theta_x + P_1 \times Z_{21}$ $\Theta_{j(avg)3} = \Theta_x + P_1 \times Z_{31} - P_1 \times Z_{32}$
Sequence of load pulses			$\Theta_{j(avg)2} = \Theta_x + P_1 \times Z_{21}$ $\Theta_{j(avg)4} = \Theta_x + P_1 \times Z_{41} - P_1 \times Z_{42} + P_3 \times Z_{43}$ $\Theta_{j(avg)6} = \Theta_x + P_1 \times Z_{61} - P_1 \times Z_{62} + P_3 \times Z_{63} - - P_3 \times Z_{64} + P_5 \times Z_{65}$
Long sequence of equal amplitude load pulses			n = even: $\Theta_{j(avg)n} = \Theta_x + \sum_{\upsilon=1}^{\frac{n}{2}} P_0 \times Z_{n(2\upsilon-1)} - \sum_{\upsilon=1}^{\frac{n}{2}-1} P_0 \times Z_{n(2\upsilon)}$ n = odd: $\Theta_{j(avg)n} = \Theta_x + \sum_{\upsilon=1}^{\frac{n-1}{2}} P_0 \times Z_{n(2\upsilon-1)} - \sum_{\upsilon=1}^{\frac{n-1}{2}} P_0 \times Z_{n(2\upsilon)}$ or approximated: $\Theta_{j(avg)n} = \Theta_x + P_0 \times$ $\times \left[Z_{t_p} - Z_T + \left(1 - \frac{t_p}{T}\right) \times Z_{(T+t_p)} + \frac{t_p}{T} \times R_T \right.$

Annex C
(informative)

Index of definitions

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(valve device) assembly	60050-551-14-13	3.1.3
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basic direct current I_{Bd}		3.6.11
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~~commutation inductance~~	~~60050-551-16-07~~	~~3.5.3~~
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Term	IEC	Subclause
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~~single way connection (of a converter)~~	~~60050-551-15-12~~	~~3.2.5~~
system control equipment		3.1.6
thermal equilibrium ~~temperature~~		3.10.7
thermal resistance R_{th}		3.9.1
total power factor λ		3.8.8
transient thermal impedance Z_{th}		3.9.2
transition current	60050-551-17-20	3.8.6
trigger advance angle β	60050-551-16-34	3.5.7
trigger delay angle α	60050-551-16-33	3.5.6
trigger equipment ~~(gating equipment)~~		3.1.5
~~two quadrant (single) converter~~	~~60050-551-12-35~~	~~3.3.5~~
uniform connection	60050-551-15-15	3.2.4
virtual junction temperature Θ_j		3.9.3

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IEC 62695:2014, *Railway applications – Fixed installations – Traction transformers*

~~[1] To be published.~~

IEC 62590

Edition 2.0 2019-08

INTERNATIONAL STANDARD

Railway applications – Fixed installations – Electronic power converters for substations

IEC 62590:2019-08(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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RAILWAY APPLICATIONS – FIXED INSTALLATIONS – ELECTRONIC POWER CONVERTERS FOR SUBSTATIONS

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 62590 has been prepared by IEC technical committee 9: Electrical equipment and systems for railways.

This standard is based on EN 50328.

This second edition cancels and replaces the first edition published in 2010. This edition constitutes a technical revision.

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

a) Incorporation of DC converters.
b) Correction of the clearances and withstand voltages due to erroneous use of PD in former edition.
c) Adaption to current ISO/IEC directive part 2, adaption of structure, adaption of vocabulary, removal of unused term and abbreviations.

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

FDIS	Report on voting
9/2502/FDIS	9/2516/RVD

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

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

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

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

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

Semiconductor converters for traction power supply differ from other converters for industrial use due to special electrical service conditions and due to the large range of load variation and the peculiar characteristics of the load.

For these reasons IEC 60146-1-1 does not fully cover the requirements of railway applications and the decision was taken to have a specific standard for this use.

Converter transformers for fixed installations of railway applications are covered by IEC 62695.

Harmonization of the rated values and tests of the whole converter group are covered by IEC 62589.

RAILWAY APPLICATIONS – FIXED INSTALLATIONS – ELECTRONIC POWER CONVERTERS FOR SUBSTATIONS

1 Scope

This document specifies the requirements for the performance of all fixed installations electronic power converters, using controllable and/or non-controllable electronic valves, intended for traction power supply.

The devices can be controlled by means of current, voltage or light. Non-bistable devices are assumed to be operated in the switched mode.

This document applies to fixed installations of the following electric traction systems:

- railways,
- guided mass transport systems such as: tramways, light rail systems, elevated and underground railways, mountain railways, trolleybusses.

This document does not apply to:

- cranes, transportable platforms and similar transportation equipment on rails,
- suspended cable cars,
- funicular railways.

This document applies to diode rectifiers, controlled rectifiers, DC converters, inverters and frequency converters.

The equipment covered in this document is the converter itself.

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 60050-811:2017, *International electrotechnical vocabulary – Part 811: Electric traction*

IEC 60146 (all parts), *Semiconductor convertors*

IEC TR 60146-1-2:2011, *Semiconductor converters – General requirements and line commutated converters – Part 1-2: Application guide*

IEC 60529:1989, *Degrees of protection provided by enclosures (IP Code)*

IEC 60721 (all parts), *Classification of environmental conditions*

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

IEC 61000-2-12:2003, *Electromagnetic compatibility (EMC) – Part 2-12: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public medium-voltage power supply systems*

IEC 61992-7-1:2006, *Railway applications – Fixed installations – DC switchgear – Part 7-1: Measurement, control and protection devices for specific use in DC traction systems – Application guide*

IEC 62236 (all parts), *Railway applications – Electromagnetic compatibility*

IEC 62236-5:2018, *Railway applications – Electromagnetic compatibility – Part 5: Emission and immunity of fixed power supply installations and apparatus*

IEC 62497-1:2010, *Railway applications – Insulation coordination – Part 1: Basic requirements – Clearances and creepage distances for all electrical and electronic equipment*

3 Terms and definitions

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

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

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

NOTE An alphabetical index is given in Annex C.

3.1 Semiconductor devices and combinations

3.1.1
semiconductor device
device whose essential characteristics are due to the flow of charge carriers within a semiconductor

[SOURCE: IEC 60050-521: 2002, 521-04-01, modified – note omitted]

3.1.2
(valve device) stack
a 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]

3.1.3
(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

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

3.1.4
electronic power converter
operative unit for power conversion comprising one or more assemblies of semiconductor devices

Note 1 to entry: The transformers are described in IEC 62695

[SOURCE: IEC 60050-551:1998, 551-12-01, modified – "electronic" has been omitted. "electronic valve devices, transformers and filters if necessary and auxiliaries if any" has been replaced with "assemblies of semiconductor devices". The note 1 to entry has been omitted.]

3.1.5
trigger 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

3.1.6
system control equipment
equipment associated with a converter equipment or system which performs automatic adjustment of the output characteristics as a function of a controlled quantity

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

Note 1 to entry: Depending on the mode of operation a principal arm may act as an auxiliary arm or vice versa.

[SOURCE: IEC 60050-551:1998, 551-15-02]

3.2.3
converter connection
the electrical arrangement of valve arms and other components essential for the function of the main power circuit of a converter

[SOURCE: IEC 60050-551:1998, 551-15-10]

3.2.4
uniform connection
a connection with either all principal arms controllable or all principal arms non-controllable

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

3.2.5
non-uniform connection
a connection with both controllable and non-controllable principal arms

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

3.2.6
parallel connection <for converters>
connection in which two or more converters are connected in such a way that their currents add

3.3 Controllability of converter arms

3.3.1
controllable valve device
a valve device the current path of which is bistably controlled in its conducting direction

[SOURCE: IEC 60050-551:1998, 551-14-03]

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

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

3.4.2
quenching
the termination of current flow in an arm without commutation

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

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

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

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

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

3.4.5
line commutation
an external commutation where the commutating voltage is supplied by the line

Note 1 to entry: In the text commutated is used instead of commutation.

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

3.4.6
load commutation
an external commutation where the commutating voltage is taken from a load other than the line

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

3.4.7
self commutation
a commutation where the commutating voltage is supplied by components within the converter or the electronic switch

Note 1 to entry: In the text commutated is used instead of commutation

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

3.5 Commutation characteristics

3.5.1
commutating voltage
the voltage which causes the current to commutate

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

3.5.2
angle of overlap
u
duration of the commutation interval between a pair of principal arms, expressed in angular measure, where the two arms carry current

[SOURCE: IEC 60050-551:1998, 551-16-05, modified – "duration of", "between a pair of principal arms," and ",where the two arms carry current" have been added.]

3.5.3
commutating group
a group of principal arms which commutate cyclically among themselves without intermediate commutation of the current to other principal arms

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

3.5.4
commutation number
q
number of commutations from one principal arm to another, occurring during one period of the alternating voltage in each commutating group

[SOURCE: IEC 60050-551:1998, 551-17-03, modified – "during one elementary period" has been replaced with "occurring during one period of the alternating voltage".]

3.5.5
pulse number
p
number of non-simultaneous symmetrical direct or indirect commutations from one principal arm to another, during one period of the alternating voltage

[SOURCE: IEC 60050-551:1998, 551-17-01, modified – "which occur during one elementary period" has been replaced with "during one period of the alternating voltage".]

3.5.6
trigger delay angle
α
time expressed in angular measure by which the trigger pulse is delayed with respect to the reference instant (see Figure 1)

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

For AC controllers it is the zero crossing instant of the supply voltage.

For AC controllers with inductive load, 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 – The end of the definition "in the case of phase control" has been removed. The note 1 to entry has been changed.]

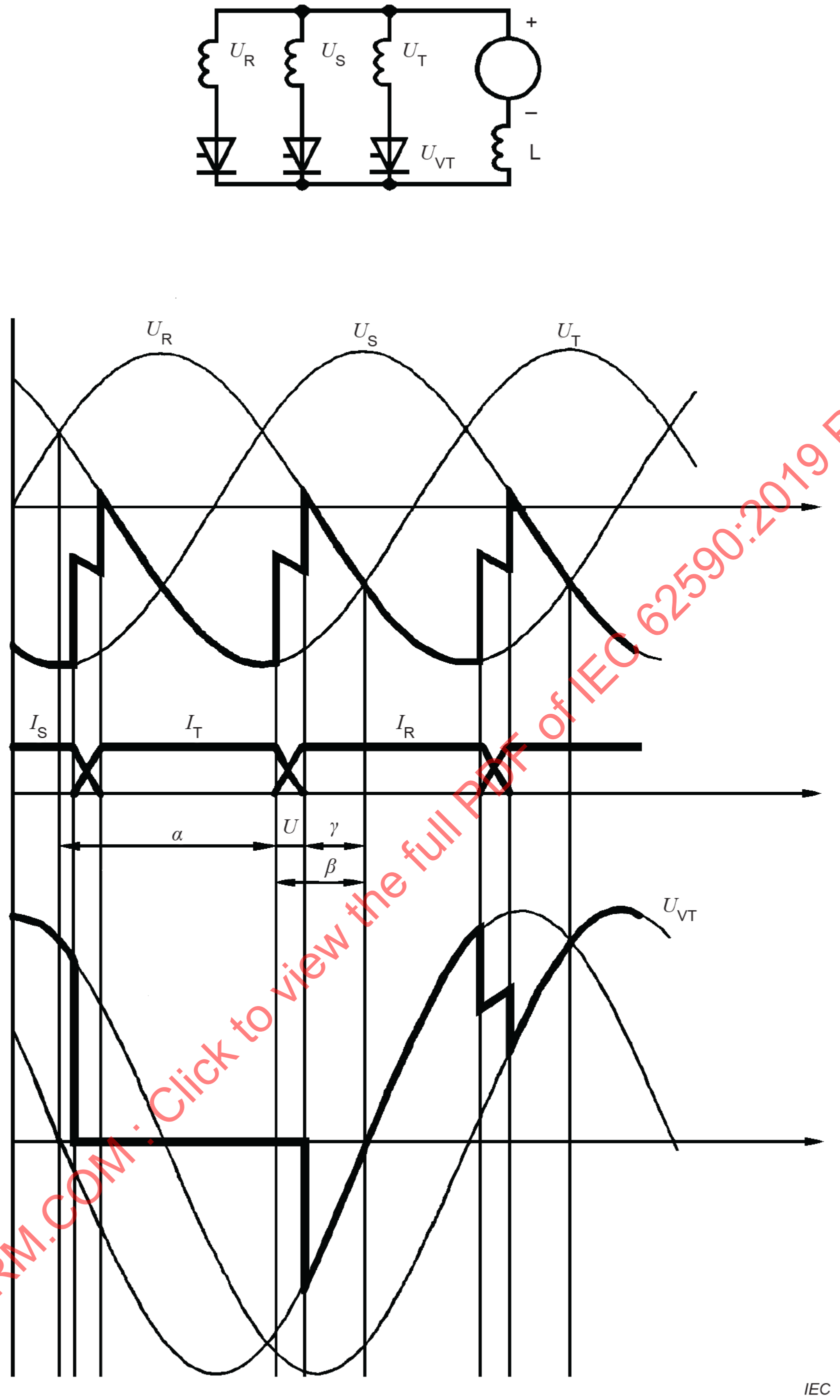


Figure 1 – Illustration of angles

3.5.7
trigger advance angle
β
(see Figure 1)

the 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]

3.5.8
extinction angle
γ
time, expressed in angular measure, between the moment when the current of the arm falls to zero and the moment when the arm is required to withstand steeply rising off-state voltage

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

[SOURCE: IEC 60050-151:2001, 151-16-08]

3.6.2
rated frequency <for converters>
f_N
frequency on either side of the converter for the conversion of which the converter group is designed to operate

3.6.3
nominal voltage <for converters>
U_n
voltage by which a converter is designated

Note 1 to entry: The standardized values of nominal voltages are given in IEC 60850.

3.6.4
rated insulation voltage
U_{Nm}
rated value of the RMS withstand voltage 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: Standardized values of rated insulation voltages are given in IEC 62497.

[SOURCE: IEC 60050-312:2014, 312-06-02, modified – note 1 to entry removed]

3.6.5
rated AC voltage on the supply side of a converter
U_{Nv}
RMS value of the no-load voltage between vectorially consecutive commutating phase terminals of a commutating group

3.6.6
rated AC voltage on the traction side of a converter
U_{Nt}
RMS value of the no-load voltage on the traction side of a frequency converter

3.6.7
rated direct voltage
U_{Nd}
specified value of the direct voltage between the DC terminals of the converter assembly at basic direct current

Note 1 to entry: This value is the mean value of the direct voltage.

Note 2 to entry: A converter may have more than one rated voltage or a rated direct voltage range.

Note 3 to entry: The rated direct voltage of a converter depends on the characteristics of the transformer and a guaranteed value of rated direct voltage is valid only together with the transformer (see IEC 62589).

3.6.8
basic service current on the supply side of a converter
$I_{\mathbf{Bv}}$
RMS value of the AC current, containing all harmonics, on the supply side of a converter at basic current on the DC side

Note 1 to entry: For polyphase equipment, this value is computed from the basic direct current on the basis of rectangular shaped currents, 120° conducting, of the converter elements. For single phase equipment, the basis of calculation must be specified.

3.6.9
rated current on the traction side of a frequency converter
$I_{\mathbf{Nt}}$
RMS value of the AC current on the traction side of a frequency converter under rated conditions

3.6.10
basic current <for converters>
$I_{\mathbf{B}}$
mean value of the current for specified load and service conditions

3.6.11
basic direct current
$I_{\mathbf{Bd}}$
mean value of the direct current for specified load and service conditions

Note 1 to entry: Together with a duty class I_{Bd} is considered as the 1,0 p.u. value, to which other values of I_d are compared.

3.7 Load capabilities

3.7.1
duty class
tabled representation of current capability and test values for standard design converters in terms of current values and duration selected to represent a characteristic group of practical applications

Note 1 to entry: The current values are expressed in per unit of the basic direct current I_B.

3.7.2
load cycle
conventional representation of the current demand to a converter group

Note 1 to entry: The current values are expressed in A or in per unit of I_B.

Note 2 to entry: The load cycle shows the repetitive variation of the loads with time and, hence, the overloads and underloads the converter group is expected to carry, as well as, for the transformers, the duration and intervals assumed.

[SOURCE: IEC 60050-881: 2017, 811-28-38 modified – The note 1 to entry has been changed.]

3.7.3
rated DC power
delivered power at working point of basic direct current I_{Bd}

3.7.4
power efficiency
ratio of the output power to the input power of the converter

3.8 Specific voltages, currents and factors

3.8.1
ideal no-load direct voltage
U_{di}
theoretical no-load mean direct voltage of a converter, assuming no reduction by phase control, no voltage drop in the assemblies and no voltage rise at small loads

[SOURCE: IEC 60050-551:1998, 551-17-15, modified – "mean" has been added. "AC/DC" has been removed. "no threshold voltages of electronic valve devices" has been replaced with "no voltage drop in the assemblies".]

3.8.2
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]

3.8.3
conventional no-load direct voltage
U_{d0}
mean value of the direct voltage which would be obtained by extrapolating the direct voltage/current characteristic for continuous direct current back to zero current

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 – "from the region of continuous flow of direct current to zero current at zero trigger delay angle, i.e. without phase control" has been replaced with "for continuous direct current back to zero current".]

3.8.4
real no-load direct voltage
U_{d00}
actual mean direct voltage at zero direct current

[SOURCE: IEC 60050-551:1998, 551-17-19]

3.8.5
ideal crest no-load voltage
U_{iM}
no-load voltage between the end terminals of an arm neglecting internal and external voltage surge and voltage drop in valves

3.8.6
transition current
mean direct current of a converter connection when the direct current of the commutating groups becomes intermittent when decreasing the current

[SOURCE: IEC 60050-551:1998, 551-17-20, modified – "commutation" has been replaced with "commutating"]

3.8.7
direct voltage drop
difference between the conventional no-load direct voltage and the direct voltage at basic direct current, at the same current delay angle, excluding the correction effect of stabilizing means if any

Note 1 to entry: The nature of the DC circuit (for example capacitors, voltage sources) can affect the voltage drop significantly. Where this is the case, special consideration is required.

3.8.8
total power factor
λ

$$\lambda = \frac{\text{active power}}{\text{apparent power}}$$

3.8.9
power factor of the fundamental wave or displacement factor
cos φ_1

$$\cos \varphi_1 = \frac{\text{active power of the fundamental wave}}{\text{apparent power of the fundamental wave}}$$

3.9 Definitions related to virtual junction temperature

3.9.1
thermal resistance
R_{th}
quotient of the difference between the virtual temperature of the device and the temperature of a stated external reference point, by the steady state power dissipation in the device

[SOURCE: IEC 60050-521:2002, 521-05-13]

3.9.2
transient thermal impedance
Z_{th}
quotient of the variation of the temperature difference, reached at the end of a time interval between the virtual junction temperature and the temperature at a specified external reference point and the step function change of power dissipation at the beginning of the same time interval causing the change of temperature

Note 1 to entry: The transient thermal impedance is given in a characteristic curve as a function of the time interval.

3.9.3
virtual junction temperature
Θ_j
calculated temperature within the semiconductor material which is based on a simplified representation of the thermal and electrical behaviour of a semiconductor device

3.10 Cooling

3.10.1
cooling medium
liquid (for example water) or gas (for example air) which removes the heat from the equipment

3.10.2
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

3.10.3
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

3.10.4
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

3.10.5
natural circulation <for converters>
convection
method of circulating the cooling medium or heat transfer agent which uses the change of volumetric mass (density) with temperature

3.10.6
forced circulation
forced cooling
method of circulating the cooling medium or heat transfer agent by means of blower(s), fan(s) or pump(s)

3.10.7
thermal equilibrium
steady-state temperature condition 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.

3.11 Electromagnetic compatibility and harmonic distortion

3.11.1
electrical disturbance
any variation of an electrical quantity, beyond specified limits, which can be the cause of a loss of performance or an interruption of service or damage

3.11.2
immunity level <for converters>
specified value of an electrical disturbance below which a converter is designed to meet the required performances or continue operation or avoid damage

3.11.3
harmonic distortion
a type of non-linearity distortion characterized by the production of output components with frequencies which are integral multiples of the frequency of the sinusoidal input signal

[SOURCE: IEC 60050-702:1992,702-07-61]

4 Symbols

d_{xtB} inductive direct voltage drop due to converter transformer referred to U_{di}

e_{xB}	inductive component of the relative short-circuit voltage of the converter transformer corresponding to the basic current on the supply side of the transformer
f_N	rated frequency
g	number of sets of commutating groups between which I_{Bd} is divided
h	order of harmonic
I_{Bd}	basic direct current
I_{Bv}	basic service current on the supply side of a converter
I_d	direct current (any defined value)
I_{Nt}	rated current on the traction side of a frequency converter
I_v	current on the supply side of a converter
K	coupling factor
p	pulse number
P	active power
q	commutation number
s	number of series connected commutating groups
u	angle of overlap (commutation angle)
U_a	power frequency withstand voltage
U_{Bdx}	total inductive direct voltage drop at basic direct current
U_d	direct voltage (any defined value)
U_{d0}	conventional no-load direct voltage
U_{d00}	real no-load direct voltage
U_{di}	ideal no-load direct voltage
$U_{di\alpha}$	controlled ideal no-load direct voltage
U_{iM}	ideal crest no-load voltage
U_n	nominal voltage
U_{Nd}	rated direct voltage
U_{Ni}	impulse voltage
U_{Nm}	rated insulation voltage
U_{Nt}	rated AC voltage on the traction side of a frequency converter
U_{Nv}	rated AC voltage on the supply side of a converter
U_{v0}	no-load phase to phase voltage
α	trigger delay angle
β	trigger advance angle
γ	extinction angle
λ	total power factor
$\varphi 1$	displacement angle for the fundamental component of I_{Bv}

5 Operation of semiconductor power equipment and valve devices

5.1 Classification of traction supply power converters and valves

5.1.1 Types of traction supply power converters

a) AC to DC conversion:
   1) diode rectifier;
   2) controlled rectifier.
b) DC to AC conversion:
   1) inverter.
c) AC to AC conversion:
   1) direct frequency converter;
   2) DC link frequency converter:
      i) supply side;
      ii) traction side.
d) DC to DC conversion
   1) chopper, i.e. direct DC to DC converter;

      NOTE For example, such converters are used inside stationary energy storage system defined in IEC 62924.

   2) indirect DC to DC converter.

For the information required see Annex A.

5.1.2 Purpose of conversion

A converter changes or controls one or more characteristics such as:

a) frequency,
b) voltage,
c) number of phases,
d) active power flow,
e) reactive power flow,
f) power quality parameters.

5.1.3 Classification of semiconductor valve devices

Semiconductor valves can be turned off either by commutation implying that the current of the valve is transferred to another valve or by quenching if the current of the valve falls to zero.

Valves used in traction supply power converters can be divided into the following categories:

a) non-controllable valve with a conductive forward and a blocking reverse characteristic (diode);
b) valve with a controllable forward and a blocking reverse characteristic (e.g. reverse blocking thyristor);
c) valve with a controllable forward and a conductive reverse characteristic (e.g. reverse conducting thyristor);
d) valve with a controllable forward and / or reverse characteristic which can be turned on and/or off via a signal applied to the gate (e.g. gate turn-off thyristor, insulated gate bipolar transistor);
e) valve with controllable forward and reverse characteristic (e.g. bi-directional thyristors).

5.2 Basic calculation factors for line commutated converters

5.2.1 Voltage

The ideal no-load direct voltage U_{di} is obtained from the voltage between two commutating phases U_{v0}, the commutation number *q* and the number of series-connected commutating groups *s*, between terminals on DC side, by the formula:

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

a) uniform connection

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

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

b) non-uniform connections

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

5.2.2 Voltage characteristics and transition current

At the transition current value, the voltage/current characteristic bends as shown in Figure 2. The transition current can be obtained, for example in case of interphase transformer connection, because the direct current decreases below the critical value where the interphase transformer becomes ineffective.

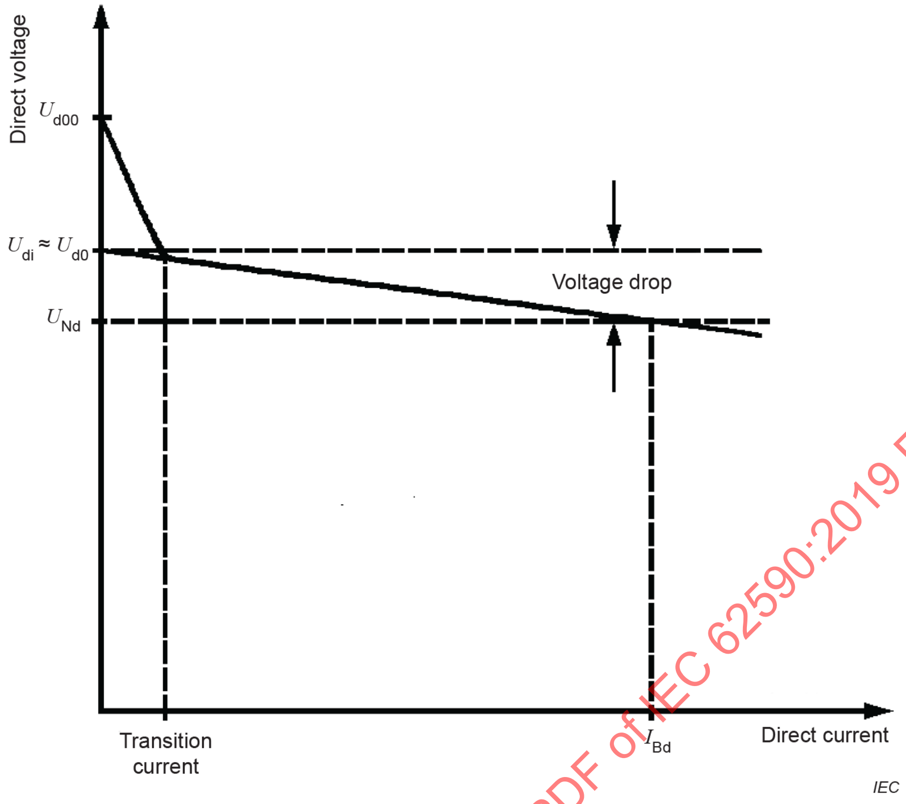


Figure 2 – Voltage regulation

6 Service conditions

6.1 Code of identification of cooling method

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

6.1.1 Letter symbols to be used

6.1.1.1 Cooling medium or heat transfer agent (see Table 1)

Table 1 – Letter symbols for cooling mediums and heat transfer agents

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-phase cooling	P

6.1.1.2 Method of circulation (see Table 2)

Table 2 – Letter symbols for methods of circulation

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

Forced, moving device incorporated	F
Vapour cooling	V

6.1.2 Arrangement of letter symbols

6.1.2.1 Direct cooling

The first letter indicates the cooling medium (6.1.1.1), the second the circulation method (6.1.1.2).

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

6.1.2.2 Indirect cooling

The code includes four symbols.

The first two letters indicate:

a) the heat transfer agent (6.1.1.1),
b) the circulation method of the heat transfer agent (6.1.1.2).

The last two letters indicate:

c) the cooling medium (6.1.1.1),
d) the circulation method of the cooling medium (6.1.1.2).

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

6.1.2.3 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 air temperature.

Therefore, the complete code shall include:

a) for direct cooling: two groups of letters separated by a stroke.

   EXAMPLE 1 AN/AF: converter with natural direct air cooling and possibilities for forced direct air cooling;

b) for indirect cooling: two groups of letter symbols separated by a stroke.

   EXAMPLE 2 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.

6.2 Environmental conditions

6.2.1 Ambient air circulation

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 converters mounted in an enclosure, the ambient for the converters (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. Cubicle or cabinet mounted assemblies shall comply with the overload conditions at maximum temperature of the outside air.

6.2.2 Normal service conditions

6.2.2.1 General

The following limits shall apply unless otherwise specified.

6.2.2.2 Storage and transport temperatures

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

These limits apply with cooling liquid removed.

6.2.2.3 Operation including off-load periods

6.2.2.3.1 Temperatures of cooling air

	Minimum	Maximum
a) Extreme values	–5 °C	+40 °C
b) Daily average		+35 °C
c) Yearly average		+25 °C

6.2.2.3.2 Relative humidity of the ambient air

a) Minimum: 15 %.

b) Maximum: standard design converters are designed for the case where no condensation can occur. If condensation is to be provided for, the case shall be treated as special service condition (see 6.2.3).

6.2.2.3.3 Dust and solid particles content

Standard design equipment is indoor equipment, pollution degree 3A. (Refer to Table A.4 of IEC 62497-1:2010.)

Any condition exceeding PD 3A shall be specified by the purchaser as special service condition.

6.2.2.3.4 Vibrations

Standard mechanical environment class for indoor equipment is 3M1 according to IEC 60721-3-3:1994+AMD1:1995+AMD2:1996 and for outdoor equipment 4M1 according to IEC 60721-3-4:1995+AMD1:1996.

Any condition differing from the above shall be agreed between purchaser and supplier.

6.2.2.4 Altitude

With regard to the use of air as cooling medium or heat transfer agent, altitudes up to 1 000 m are considered as normal. If a converter is to be used at an altitude above 1 000 m but is tested at normal altitude, the current capability shall be decreased by 1 % for each 100 m by which the altitude of use exceeds 1 000 m in the case of natural air-cooling, and by 1,5 % for forced air-cooling.

With regard to the dielectric properties of air, altitudes up to 2 000 m are considered as normal (refer to IEC 62497-1).

6.2.3 Special service conditions

The service conditions are assumed to be those listed under normal service conditions. The following list gives examples of special service conditions that shall be subject to a special agreement between purchaser and supplier:

a) special mechanical stresses, for example shocks and vibrations;
b) foreign particles in the ambient air, for example abnormal dirt or dust;
c) salt air (for example proximity to the sea);
d) high values of relative humidity and/or temperature similar to those associated with tropical climatic conditions;
e) other special service conditions not covered by this list or service conditions exceeding the specified limits of normal service conditions.

In case special service conditions are required, the service conditions listed in IEC 60721 should preferably be used.

6.3 Electrical service conditions

6.3.1 General

For network conditions concerning the AC supply network reference shall be made to the publications of IEC TC 77 and its subcommittees.

For network conditions concerning the traction supply network reference shall be made to IEC 62236-5, to IEC 62497-1 and to IEC 60850.

Information on prospective conditions of coexistence between supply systems, disturbing loads and sensitive apparatus (mostly low current control equipment, other power converters, power capacitors and sensitive lines such as used for communications, signalling and control) is essential during the early stages of the design of an installation (notably: ratio of short-circuit power to apparent power, presence of capacitors or other converters).

Guidance on calculation methods will be found in IEC TR 60146-1-2.

6.3.2 Limiting values as basis of rating

Unless otherwise specified, the converter shall be designed to operate under the service conditions specified by the following limiting values.

6.3.2.1 Three-phase AC supply network

6.3.2.1.1 Frequency

	Variation
Range	± 2 % of f_N
Rate of change	± 1 %/s

6.3.2.1.2 Voltage

	Variation
Steady state	+10 % / –10 % of U_N
Short time (0,5 to 30 cycles)	+15 % / –15 %

6.3.2.1.3 Harmonics in supply voltage

Refer to IEC 61000-2-12 and IEC 61000-2-4.

NOTE A harmonic distortion of the AC supply voltage can cause overloads:

- in 12 pulse rectifiers and their transformers due to unbalanced load sharing,
- in two parallel 6 pulse rectifiers with separate transformers due to unbalanced load sharing,
- in capacitive circuits of converters.

6.3.2.1.4 Repetitive and non-repetitive transients

On request the following characteristics shall be specified as far as possible (see Figure 3):

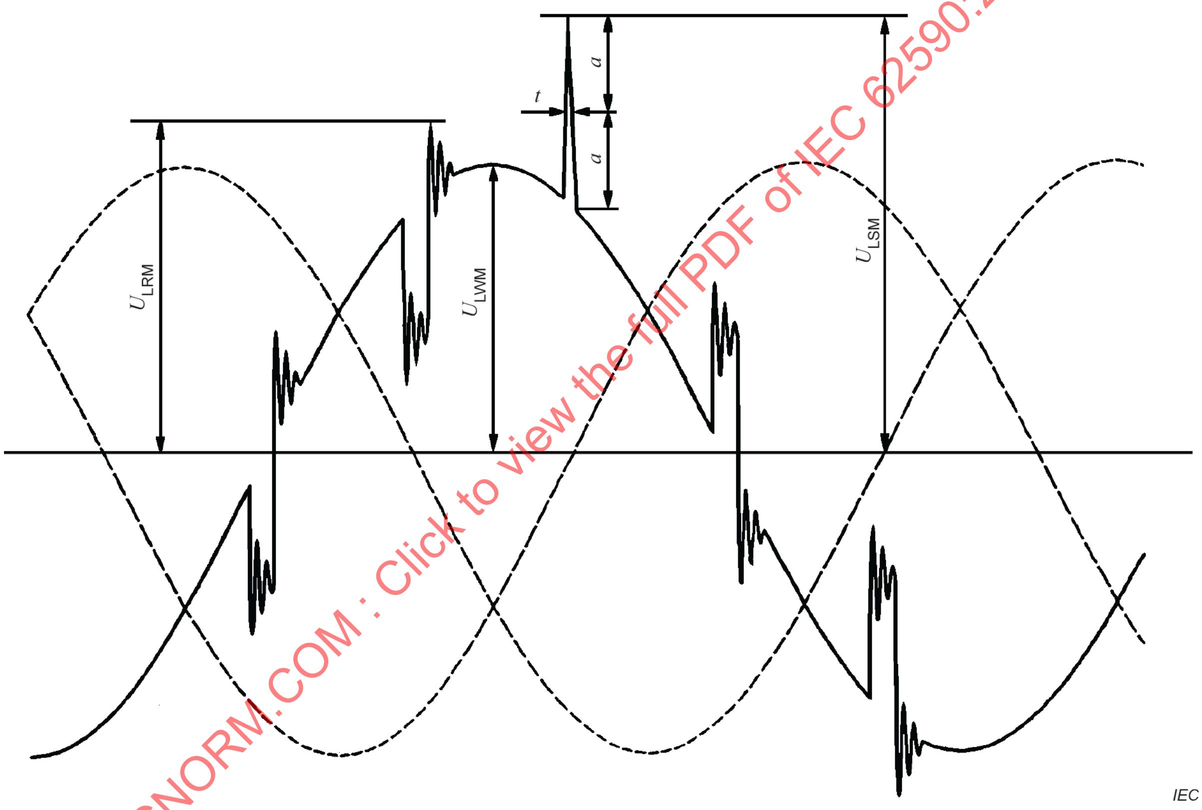
a) transient energy available at the converter terminals (J);

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

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

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

e) duration above 50 % (t) (μs).



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

Figure 3 – AC voltage waveform

6.3.2.2 Single-phase AC traction supply voltage

6.3.2.2.1 Frequency

The frequency range according to IEC 60850 applies.

6.3.2.2.2 Voltage

The voltage ranges according to IEC 60850 apply.

6.3.2.2.3 Harmonics

Refer to IEC 61000-2-4.

6.3.2.2.4 Repetitive and non-repetitive transients

Refer to 6.3.2.1.4.

6.3.3 DC traction supply voltage

The voltage range according to IEC 60850 applies.

7 Converter equipment and assemblies

7.1 Losses and efficiency

7.1.1 General

The power efficiency may be determined by calculation of internal losses or by measurement of AC and DC power at basic load conditions. If the purchaser requires measurement of the losses this shall be mentioned in the procurement specification.

The admissible tolerance for losses is + 10 % of the guaranteed value.

7.1.2 Included losses

The following losses shall be included when determining the power efficiency:

a) internal losses in the assembly such as losses in semiconductor valve devices, in fuses, potential dividers, current balancing means, capacitor resistor damping circuits and voltage surge arresters;
b) losses in transductors, interphase transformers (if supplied as part of the converter), current limiting and balancing reactors between transformer and thyristor or diode assemblies;
c) power absorbed by auxiliaries such as fans or pumps and relays unless otherwise specified;
d) losses due to circulating currents;
e) power consumed in trigger equipment, if any.

7.2 Power factor

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

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

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

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

NOTE 1 In such cases calculation is adequate to get reliable figures of the displacement factor under the condition of symmetrical control.

When exact calculations of the displacement factor or of the total power factor are required, knowledge of many parameters is necessary, including the line impedance. For such calculations refer to IEC TR 60146-1-2.

NOTE 2 For the power factor of diode rectifiers see Annex C of IEC 62589:2010.

7.3 Electromagnetic compatibility (EMC)

Traction supply converters shall cope with the requirements for immunity and emission stated in the IEC 62236 series.

Additional requirements, if any, shall be mentioned by the purchaser in the procurement specification.

Cable routing of AC and DC power cables, auxiliary and control cables, filtering etc., where such are installed by the purchaser or third parties shall be in accordance with any instructions provided by the supplier of the converter and with the requirements of IEC 62236-5.

Immunity and emission tests of the converter group can be done only together with the transformer(s) as test of the whole substation. These tests are not subject of this document.

Control and protection devices shall be tested separately according to their product standards.

7.4 Rated values for converters

7.4.1 General

Rated values of a converter shall be given either as standard design values for standard design converters or as closely as possible according to the load that it is intended to serve for special design converters. The ratings of the converter are not valid if the load is changed to a load for which the converter is not intended.

7.4.2 Current values

7.4.2.1 Current values to be specified

Each converter equipment shall have an assigned value for the basic direct current together with specified current capabilities according to a duty class or a load cycle. The standardized duty classes according to Table 3 should be preferably used. For other types of duty, duty classes defined by the purchaser or load cycles according to 7.4.2.3 apply.

NOTE For converters which are operated not continuously but repeatedly, a load cycle is applied not a duty class. DC to DC converters are examples of these devices.

Table 3 – Standardized duty classes

Duty class	Current capabilities for converters (relative values in per unit of I_{Bd})	Typical applications	Note
I	1,0 p.u. continuously	Frequency converters for mainline railways	
V	a) 1,0 p.u. continuously b) 1,5 p.u. 2 h – after a) c) 2,0 p.u. 1 min – after a)	Mass rapid transit Trolleybusses	Alternatively after thermal equilibrium of a)
VI	a) 1,0 p.u. continuously b) 1,5 p.u. 2 h – after a) c) 3,0 p.u. 1 min – after a)	Mainline railways Mass rapid transit Light rail systems	Alternatively after thermal equilibrium of a)
VII	a) 1,0 p.u. continuously b) 1,5 p.u. 2 h – after a) c) 4,5 p.u. 15 s – after a)	Minor railways Light rail systems Tramways	Alternatively after thermal equilibrium of a)
VIII	a) 1,0 p.u. continuously b) 1,5 p.u. 2 h – after a) c) 2,0 p.u. 1 min – after b)	Mass rapid transit	Cumulative
IX	a) 1,0 p.u. continuously b) 1,5 p.u. 2 h – after a) c) 3,0 p.u. 5 min – after b)	Mainline railways	Cumulative
JP	a) 1,0 p.u. continuously b) 1,2 p.u. 2 h – after a) c) 3,0 p.u. 1 min – after b)	Mainline railways	Cumulative
NOTE For further information see figures in IEC 62695:2014, Annex A.			

The purchaser of a converter shall specify the basic direct current and the duty class.

If for a given application no suitable standardized duty class can be found in Table 3, the purchaser shall specify a load cycle or duty class.

Independently of the duty class or load cycle, the converter and its constituent assemblies shall be able to carry the short circuit current according to 7.4.2.4.

Unlike many other electrical components, semiconductor devices can be irreparably damaged, even within a very short time of operation in excess of their rated values. Selecting the rated direct current and the duty class or load cycle of a converter this should be taken into account.

The supplier shall show the short time current and overload current capability of the converter in a graph in logarithmic scale for overcurrent durations between 0,01 s and 10 000 s. Base current shall be I_{Bd}.

7.4.2.2 Duty classes

Duty classes specify current capabilities and test conditions for converters in terms of current values and durations. Table 3 contains standardized duty classes and gives guidance for the selection for different types of railways and their typical ratio between the basic current and the short time currents.

The basic current of a converter is valid only for the defined duty class. If a converter is designed to operate at different duty classes, a separate basic current shall be given for each duty class.

NOTE The duty class can be chosen either from the recommendations given in Table 3 or from the results of a digital simulation and network calculation, giving the expected RMS current and the time dependent overload characteristics for the intended use of the converter.

A duty class defined by the purchaser shall be called class X.

7.4.2.3 Load cycles

Load cycles specify the repetitive current demand to a converter for a given application.

The purchaser shall specify the current values and respective durations of the required load cycle.

Unless otherwise specified the quadratic mean of the load current over the duration T of the load cycle is assumed to be the basic direct current of the converter for the specific load cycle.

$$I_{Bd} = \sqrt{\frac{1}{T}\int_{T} I_{d}^{2}\mathrm{d}t}$$

The supplier shall calculate the capability of a converter to carry the specified currents of the load cycle. Annex B gives guidance for this calculation.

If the purchaser demands a specific type test for a load cycle this shall be mentioned in the procurement specification.

7.4.2.4 Short-time withstand capability

The supplier shall state the short-time withstand current capability of the converter.

If not otherwise agreed between purchaser and supplier the short-time withstand current capability shall be stated for a short circuit:

- after continuous operation at basic current I_{Bd} , and
- for a short circuit duration of 0,15 s, and
- with a factor of 1,6 between sustained current and peak value.

NOTE Refer to Annex B of IEC 62589:2010 for calculation of the short circuit current for a given application.

Controlled converters with a current limiting characteristic need not have a short-time withstand current capability. They shall be equipped with protection devices able to detect short-circuits in the switchgear or the contact line system which possibly cannot be detected by standard AC or DC overcurrent feeder protection devices in the case of current limitation.

7.4.3 Capability for unsymmetrical load of a 12-pulse converter in parallel connection

For a 12-pulse converter in parallel connection (connection No. 9) an unsymmetrical load sharing between the two three-phase bridges of up to ± 5 % of I_{Bd} shall be considered as normal condition.

The following items can cause unsymmetrical load sharing between the two three-phase bridges and should be taken into account when determining the converter rating:

- harmonic distortion of the AC supply voltage exceeding the values according to IEC 61000-2-12;
- different impedance voltages of the transformer secondary windings;
- no-load voltage imbalances in the transformer;
- different lengths of the cables between transformer and converter;

– unequal number of converters with different transformer connections in a substation.

7.4.4 Semiconductor device failure conditions

The purchaser shall specify if semiconductor device fuses are required.

The purchaser shall specify the required immunity level in case of a failure of one or more series or parallel connected semiconductor devices per arm.

When a disturbance from any origin does not exceed the immunity level specified the corresponding performance shall be maintained. Table 4 defines the immunity levels.

Table 4 – Semiconductor device failure conditions

Immunity level		Consequence	
Redundancy	R	No immediate consequence, full performance maintained	Warning signal
Functional	F	Reduced performance (reduced current capability)	Warning signal or tripping signal
Tripping	T	Interruption of service due to protection devices	Tripping signal
Damage	D	Interruption of service due to damage	Tripping signal

7.5 Mechanical characteristics

7.5.1 General

Converters may be either enclosed or not enclosed. Frames and enclosures, if any, shall be metallic.

Converters and relevant enclosures shall be designed so that normal service, inspection and maintenance operations, replacement of diodes, fuses, and valve device assemblies, earthing of cables or busbars and voltage tests can be carried out easily and safely.

All materials used shall be of the quality and of the class most suitable for working under the conditions specified. Special attention is to be paid to its ability to withstand moisture and fire. Unless fire behaviour Class F0 is allowed, materials used shall be metallic or of the self-extinguishing type.

The selection of materials shall be such that corrosion due to atmospheric and electrolytic effects are minimized.

Rules concerning noxious or toxic materials shall be observed.

7.5.2 Earthing

To ensure safety during maintenance works, all parts of the main circuit to which access is required or provided shall be capable of being earthed through suitable means. This does not apply to those parts, which are withdrawable or removable and which become accessible after being separated from the enclosure.

A withdrawable part, however, shall not be removable from the enclosure unless capacitors on it have been discharged to safe values.

For DC traction power supply systems the purchaser shall specify in the enquiry how to earth the converter enclosure or frame according to 6.5.8 of IEC 61992-7-1:2006.

NOTE In DC traction supply systems, "earthing" means either connection to earth or connection to the return circuit, depending on the earthing requirements of the DC system.

The metallic parts of the enclosures or frames shall be connected to a suitable earthing terminal, placed in an accessible position, in order to allow the connection to the main earth system of the substation. The earthing terminal shall be suitably protected against corrosion.

7.5.3 Degree of protection

The purchaser shall specify the degree of protection according to IEC 60529.

Inspection windows and ventilating openings shall provide at least the degree of protection specified for the enclosure.

NOTE 1 If not otherwise agreed between purchaser and supplier, for converter enclosures the degree of protection is assumed to be valid for doors and walls of the enclosure

Due to the specific requirements of converters for cooling and for connection of AC and DC cables or busbars IP 00 is considered as normal degree of protection for the bottom and the top of the enclosure.

NOTE 2 For indoor converters normally no degree of protection is provided against ingress of water.

7.6 Insulation coordination

For insulation coordination of electric traction system IEC 62497-1 is applicable.

For circuits directly connected to the railway overvoltage category OV3 and pollution degree PD 3A is used. All values define the insulation between the main circuit and the environment including other circuits and frame of the equipment.

Table 5 – Insulation levels for AC/DC and DC converters

Nominal voltage U_n kV	Rated insulation voltage U_{Nm} kV	Power frequency withstand voltage U_a kV		Impulse voltage 1,2 µs/50 µs U_{Ni} kV		Clearance clearance mm	
0,6	0,9	2,8		6		5,5	
0,75	1,2	3,6		8		8	
0,75	1,8	4,6		10		11	
1,5	2,3	5,5		12		14	
1,5	3,0	6,9		15		18	
3,0	3,6	OV 3	11,5	OV 3	25	OV 3	33
		OV 4	14,0	OV 4	30	OV 4	40
3,0	4,8	OV 3	14,0	OV 3	30	OV 3	40
		OV 4	18,5	OV 4	40	OV 4	60
3,0	6,5	OV 3	18,5	OV 3	40	OV 3	60
		OV 4	23,0	OV 4	50	OV 4	75

7.7 Specifics of line commutated rectifiers

7.7.1 Electrical connections

Standard design converters for traction power supply usually are converters each individually connected to a transformer for single phase (p = 2) or three-phase (p = 6 or 12) AC supply.

Twelve-pulse converters and dual six-pulse converters require two secondary windings in the transformer with 30 electrical degree shifted connections, normally star and delta connected or two separate transformers with different vector groups.

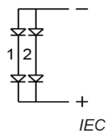
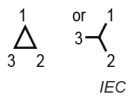
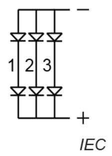
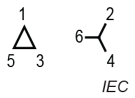
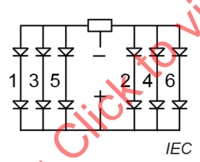
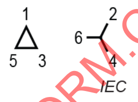
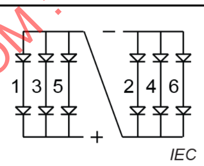
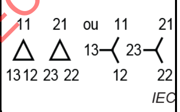
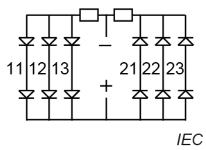
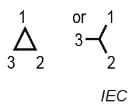
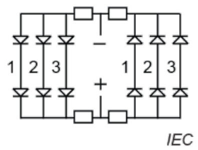
NOTE Higher pulse numbers can be achieved by using transformers with appropriate phase shifting and connecting several six-pulse or twelve-pulse converters in series or parallel. For traction power supply pulse numbers up to 24 p are used.

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

Table 6 gives conventional values of some calculation factors for the most used connections of converters. For other connections IEC TR 60146-1-2 assists.

The connection numbers are the same as used in the IEC 60146 series.

Table 6 – Connections and calculation factors for line commutated converters

Connection No.	Transformer connection valve side	Valve connection	*p*	*q*	Current factor on the AC. side I_v/I_d	$\frac{U_{di}}{U_{v0}}$	$\frac{U_{iM}}{U_{di}}$	$\frac{d_{xtB}}{e_{xB}}$
7			2	2	1	0,9 $\left(\frac{2\sqrt{2}}{\pi}\right)$	1,57 $\left(\frac{\pi}{2}\right)$	0,707 $\left(\frac{1}{\sqrt{2}}\right)$
8			6	3	0,816 $\left(\sqrt{\frac{2}{3}}\right)$	1,35 $\left(\frac{3\sqrt{2}}{\pi}\right)$	1,05 $\left(\frac{\pi}{3}\right)$	0,5
9			12	3	0,408 $\left(\frac{1}{\sqrt{6}}\right)$	1,35 $\left(\frac{3\sqrt{2}}{\pi}\right)$	1,05 $\left(\frac{\pi}{3}\right)$	0,26
12			12	3	0,816 $\left(\sqrt{\frac{2}{3}}\right)$	2,7 $\left(\frac{6\sqrt{2}}{\pi}\right)$	0,524 $\left(\frac{\pi}{6}\right)$	0,26
18			6	3	0,816 $\left(\sqrt{\frac{2}{3}}\right)$	1,35 $\left(\frac{3\sqrt{2}}{\pi}\right)$	1,05 $\left(\frac{\pi}{3}\right)$	0,5
19			6	3	0,816 $\left(\sqrt{\frac{2}{3}}\right)$	1,35 $\left(\frac{3\sqrt{2}}{\pi}\right)$	1,05 $\left(\frac{\pi}{3}\right)$	0,5

NOTE Connection No. 9 can be used with or without interphase transformer. Details are described in IEC 62695. The factor d_{xtB}/e_{xB} can vary between 0,26 and 0,5 depending on the coupling factor defined in IEC 62695.

7.7.2 Calculation factors

7.7.2.1 Current factor on the AC side

The quotient of the RMS value I_v of the current on the AC side and the direct current I_d is indicated in Table 6 on the assumption of smooth direct current and rectangular waveshape of the alternating currents.

7.7.2.2 Voltage drop

Table 6 gives the ratio:

$$\frac{d_{xtB}}{e_{xB}}$$

between the direct inductive voltage drop d_{xtB} at basic current due to the transformer commutating reactance, referred to U_{di} and the inductive component e_{xB} of the transformer impedance voltage at basic service current on the supply side of the converter group for the whole equipment expressed in per cent of rated alternating voltage.

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

For all other connections with p = 12 or higher, the ratio between d_{xtB} and e_{xB} depend on the repartition of the reactances in the transformer between primary and secondary. The external characteristic can be represented graphically.

NOTE The voltage drop of diode rectifier groups depends mainly on the characteristics of the converter transformer. Therefore this document does not contain information regarding to voltage drop. For requirements concerning voltage drop see IEC 62589.

If the purchaser requires provisions against the voltage rise at currents below the transition current, he shall mention this in the tender specification.

7.7.3 Direct voltage harmonic content

For perfectly balanced supply voltages, trigger delay angles, etc., the frequency of the direct current and direct voltage harmonic content is given by:

$$f_{h,dc} = k \times p \times f_N \qquad k = \text{integer } (1...n)$$

An unbalanced supply voltage causes a negative sequence voltage. The negative sequence voltage produces an additional harmonic component at a frequency $2 \times f_N$, which cannot be cancelled by an appropriate design of the converter unless a large smoothing reactance or DC output filter is added.

Refer to IEC TR 60146-1-2 for more information.

8 Tests

8.1 General

8.1.1 Overview

For the terminology for testing procedures refer to IEC 60050-811.

8.1.2 Performance of tests

Whenever practicable the tests shall be performed in electrical conditions equivalent to those in real service. Where it is not practicable, the assemblies and equipment respectively shall be tested under such conditions as to allow the specified performance to be proved.

Components of the converter are assumed to be tested separately.

Unless otherwise agreed at the time of the contract, the AC supply and test voltages shall be at rated frequency.

When the purchaser or his representative desires to witness factory tests, this should be specified in the procurement specification.

8.1.3 Test schedule

The tests, unless otherwise agreed, shall comprise all the following items marked "X", which are applicable to the assemblies or converter units prefabricated in a factory (see Table 7).

For converters assembled on site only commissioning tests apply.

The tests marked "(x)" shall only be performed if specifically agreed in the contract.

Table 7 – Summary of tests

Test	Type test	Routine test	Optional test	Specification subclause
Insulation test	X	X		8.2.1
Light load functional test	X	X		8.2.2
Load test	X	(x)		8.2.3
Power loss determination	X [a]	(x) [a]		8.2.4
Temperature rise test	X			8.2.5
Checking of auxiliary devices	X	X		8.2.6
Checking the properties of the control equipment	X	X		8.2.7
Checking the protective devices	X	X		8.2.8
Short-time withstand current test			(x)	8.2.9
EMC tests	X			8.2.10
Additional tests			(x)	8.2.11

[a] Only if power loss determination by measurement is required, see 7.1.1.

8.2 Test specifications

8.2.1 Insulation tests

8.2.1.1 General

Insulation tests shall be carried out to verify the correct state of insulation of a completely assembled unit. In general, they shall be carried out as an AC power frequency voltage test.

During insulation tests the main terminals of the converter, as well as the anode, cathode and gate terminals of all power semiconductor devices, shall be connected together. This does not apply, however, to auxiliaries for which, in case of an insulation fault, voltage can pass on to accessible parts not connected to the enclosure or from the side of higher voltage to the side of lower voltage. These are, for example auxiliary transformers, measuring equipment, pulse transformers and instrument transformers.