

Australian Standard™

Semiconductor converters

Part 1.1: General requirements and line commutated converters—Specifications of basic requirements



This Australian Standard was prepared by Committee EL-027, Power Electronics. It was approved on behalf of the Council of Standards Australia on 4 June 2002 and published on 4 July 2002.

The following are represented on Committee EL-027:

Australian Communications Authority
Australian Electrical and Electronic Manufacturers Association
Bureau of Steel Manufacturers of Australia
Electricity Supply Association of Australia
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STANDARDS AUSTRALIA

RECONFIRMATION

OF

AS 60146.1.1—2002-

Semiconductor converters

**Part 1.1: General requirements and line commutated converters—Specifications of
basic requirements**

RECONFIRMATION NOTICE

Technical Committee EL-027 has reviewed the content of this publication and in accordance with Standards Australia procedures for reconfirmation, it has been determined that the publication is still valid and does not require change.

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NOTES

Australian Standard™

Semiconductor converters

Part 1.1: General requirements and line commutated converters—Specifications of basic requirements

Originated as part of AS 1955.1—1977.
Revised and redesignated in part as AS 60146.1.1—2002.

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PREFACE

This Standard was prepared by the Standards Australia Committee EL-027, Power Electronics to partially supersede AS 1955.1—1977, *Semiconductor converters*, Part 1: *General* six months after publication.

The objective of this Standard is to provide system designers, manufacturers and users with performance requirements for all electronic power converters and switches.

This Standard is the first part of a three part Standard; the parts of which are as follows:

AS 60146	Semiconductor converters
AS 60146.1.1	Part 1.1: General requirements and line commutated converters—Specifications of basic requirements (this Standard)
AS 60146.1.2	Part 1.2: General requirements and line commutated converters—Application guide
AS 60146.1.3	Part 1.3: General requirements and line commutated converters—Transformers and reactors

This Standard is technically identical with, and has been reproduced from, IEC 60146-1-1:1991, *Semiconductor converters*, Part 1-1: *General requirements and line commutated converters—Specifications of basic requirements*, including Corrigendum:1993 and Amendment 1:1996 (marked with a marginal bar in the right hand margin). Minor editorial changes have been made to the text such as the use of the word ‘converter’ throughout the document (to standardize spelling across this series of Standards).

A reference to an International Standard identified in the Normative References Clause by strikethrough (~~example~~) is replaced by a reference to the Australian or Australian/New Zealand Standard(s) listed immediately thereafter and identified by shading (**example**). Where the struck-through referenced document and the referenced Australian or Australian/New Zealand Standard are identical, this is indicated in parenthesis after the title of the latter.

In January 1997, the IEC commenced numbering its Standards from 60000 by adding 60000 to the number of each existing Standard. This coordinates IEC numbering with ISO numbering. During the transition period an IEC Standard might be identified by its new number or its old number (for example, IEC 60050 or IEC 50).

As this Standard is reproduced from an International Standard, the following applies:

- (a) Its number does not appear on each page of text and its identity is shown only on the cover and title page.
- (b) In the source text ‘this International Standard’ should read ‘this Australian Standard’.
- (c) A full point should be substituted for a comma when referring to a decimal marker.

The term ‘informative’ has been used in this Standard to define the application of the annex to which it applies. An ‘informative’ annex is only for information and guidance.

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STANDARDS AUSTRALIA

Australian Standard

Semiconductor converters

Part 1.1: General requirements and line commutated converters—
Specifications of basic requirements

Any IEC table, figure or passage of text that is struck-through is not part of this Standard. Any Australian table, figure or passage of text that is added (and identified by shading) is part of this Standard.

Section 1 - General**1.1 Scope and object**

This International Standard specifies the requirements for the performance of all electronic power converters and electronic power switches using controllable and/or non-controllable electronic valves.

The electronic valves mainly comprise semiconductor devices, i.e. diodes and various types of thyristors and transistors, such as reverse blocking or conducting thyristors, turn-off thyristors, triacs and power transistors. The devices may be controlled by means of current, voltage or light. Non-bistable devices are assumed to be operated in the switched mode.

This standard is primarily intended to specify the requirements applicable to line commutated converters for conversion of a.c. power to d.c. power or vice versa. Parts of this standard are applicable also to other types of electronic power converters and should be regarded as a standard for them in so far as it is not in contradiction to additional IEC Standards for particular types of semiconductor converters given in existing or future IEC Publications.

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

The main purposes of this standard are as follows:

Part 1-1, IEC 146-1-1, Specifications of basic requirements.

- to establish basic terms and definitions;
- to specify service conditions which influence the basis of rating;
- to specify test requirements for complete converter equipment and assemblies, standard design, (for special design see IEC 146-1-2);
- to specify basic performance requirements;
- to give application oriented requirements for semiconductor power converters.

Part 1-2, IEC 146-1-2, Application guide

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

Part 1-3, IEC 146-1-3, Transformers and reactors

- to give additional information on characteristics wherein converter transformers differ from ordinary power transformers. In all other respects, the rules specified in IEC 76, shall apply to converter transformers, as far as they are not in contradiction with this standard.

1.2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this international Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below. Members of IEC and ISO maintain registers of currently valid International Standards.

References to International Standards that are struck through in this Clause are replaced by references to equivalent Australian or Australian/New Zealand Standards that are listed immediately thereafter and identified by shading. Any Australian or Australian/New Zealand Standard that is identical to the International Standard it replaces is appropriately identified.

~~IEC 50(151):1978, International Electrotechnical Vocabulary (IEV)- Chapter 151: Electrical and magnetic devices.~~

AS 1852.151, International Electrotechnical Vocabulary (IEV)- Chapter 151: Electrical and magnetic devices. (identical to IEC 50(151):1978)

~~IEC 50(441):1984, International Electrotechnical Vocabulary (IEV)- Chapter 441: Switchgear, controlgear and fuses.~~

AS 1852.441, International Electrotechnical Vocabulary (IEV)- Chapter 441: Switchgear, controlgear and fuses. (identical to IEC 50(441):1984)

~~IEC 50(551):1982, International Electrotechnical Vocabulary (IEV)- Chapter 551: Power Electronics.~~

AS 1852.551, International Electrotechnical Vocabulary Part 551: Power electronics (identical to IEC 50(551):1982)

~~IEC 50(601):1985, International Electrotechnical Vocabulary (IEV)- Chapter 601: Generation, transmission and distribution of electricity. General.~~

AS 1852.601, International Electrotechnical Vocabulary Part 601: Generation, transmission and distribution of electricity—General (identical to IEC 50(601):1985)

~~IEC 76: 1976, Power transformers.~~

AS 2374 Series, Power transformers

~~IEC 555-1:1982, Disturbances in supply systems caused by household appliances and similar electrical equipment—Part 1: Definitions.~~

AS/NZS 61000.3.2, *Electromagnetic compatibility (EMC) Part 3.2: Limits—Limits for harmonic current emissions (equipment input current less than or equal to 16 A per phase)*

IEC 664:1980, *Insulation coordination within low-voltage systems including clearances and creepage distances for equipment.*

IEC 725:1981, *Considerations on reference impedance for use in determining the disturbance characteristics of household appliances and similar electrical equipment.*

Some other IEC publications are quoted for information in Annex B: Bibliography.

1.3 Classification of semiconductor power equipment and valves

1.3.1 Classification of semiconductor power equipment

A general synopsis of IEC Publications, applying to the great variety of types of semiconductor power equipment, requires a classification that can be based on the following characteristics:

- a) Type of conversion and switching:
 - 1) a.c. to d.c. conversion (rectifier);
 - 2) d.c. to a.c. conversion (inverter);
 - 3) d.c. to d.c. conversion (direct or indirect d.c. to d.c. converter);
 - 4) a.c. to a.c. conversion (direct or indirect a.c. to a.c. converter);
 - 5) switching (periodic or non-periodic).
- b) Purpose of conversion: In a power system the converter changes or controls one or more characteristics such as:
 - 1) frequency (including zero frequency);
 - 2) voltage level;
 - 3) number of phases;
 - 4) flow of reactive power;
 - 5) quality of load power.
- c) Type of valve turn-off: (see figure 1). A semiconductor valve 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 fails to zero before another valve is turned on.
 NOTE— Both types of valve turn-off may occur in normal operation; of a.c. to d.c. converters depending on the load. The classification is based on normal operation, full load current.
 The types of valve turn-off can be characterized by the source of the turn-off voltage:
 - 1) external commutation (quenching);
 - 1A) line commutation (quenching);
 - 1B) load commutation (quenching);
 - 2) self commutation (see also 1.3.2. note 2).
- d) Type of d.c. system: Converters connected to at least one d.c. system can usually be wholly or partly classified as current source or voltage source depending on whether the current or the voltage on the d.c. side is smoothed.

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

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

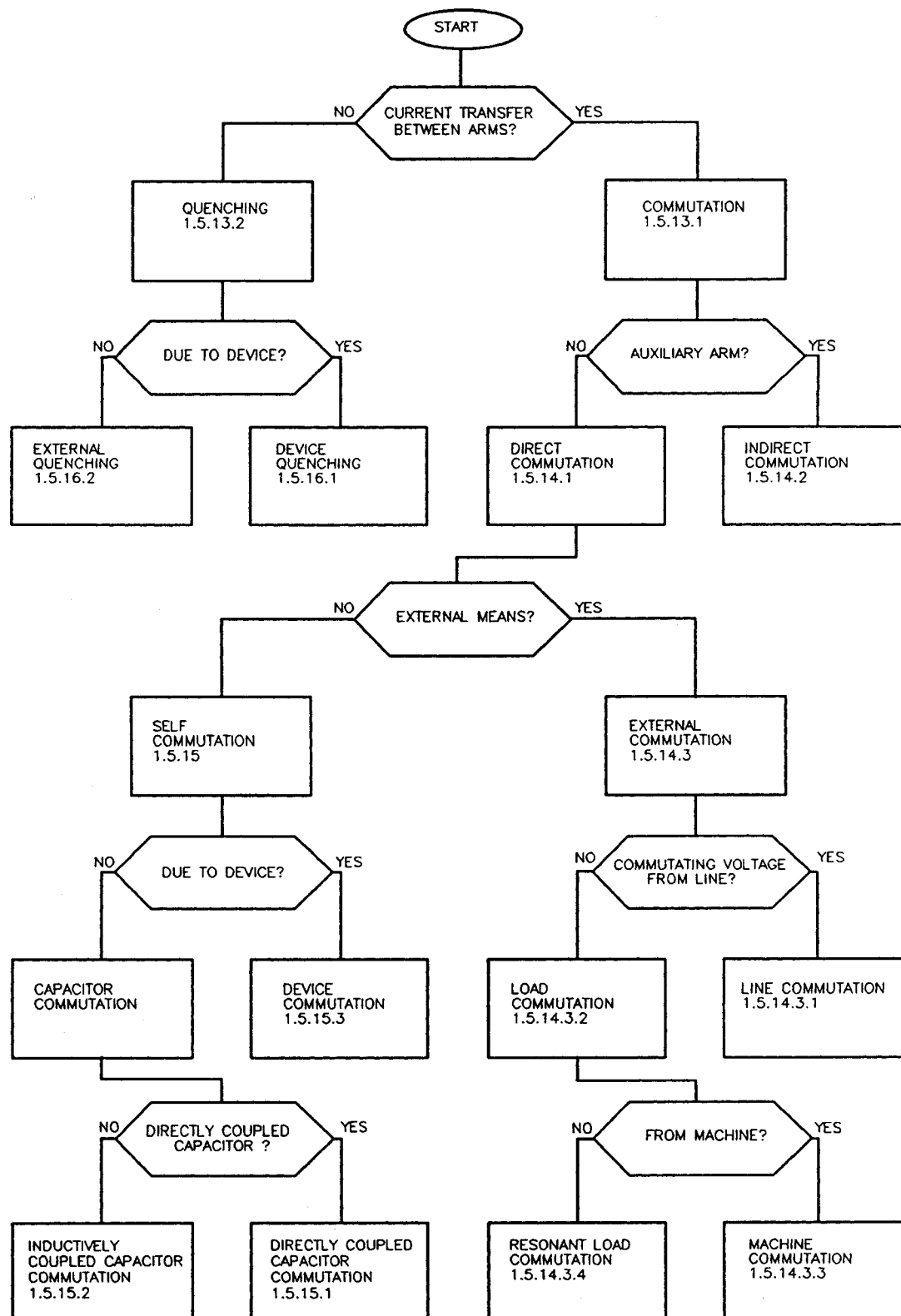


Figure 1- Types of commutation

1.3.2 Classification of semiconductor valves

Valves used in the power circuits of power electronic equipment can be divided into the following categories:

- 1) non controllable valve with a conductive forward and a blocking reverse characteristic (diode valve);
- 2) valve with a controllable forward and a blocking reverse characteristic (for example, reverse blocking thyristor valve);
- 3) valve with a controllable forward and a conductive reverse characteristic (for example, reverse conducting thyristor valve);
- 4) valve which is controllable in both directions (for example triac valve).

NOTES

- 1 A valve is controllable if it can be switched from the blocking to the conducting state by means of a control signal.
- 2 Transistor and turn-off thyristor valves can be turned off by a signal applied to or taken off the gate. Thyristors and triacs do not have this property and must be turned off by main circuit voltages and currents.

1.4 List of principal letter symbols and subscripts

1.4.1 List of subscripts

<i>0</i> (zero)	at no load
<i>c</i>	commutating
<i>C</i>	short-circuit
<i>d</i>	direct current or voltage
<i>f</i>	dependent of frequency
<i>h</i>	pertaining to harmonic component of order <i>h</i>
<i>i</i>	ideal
<i>L</i>	referring to line or source
<i>m</i>	maximum
<i>min</i>	minimum
<i>N</i>	rated value or at rated load
<i>p</i>	inherent
<i>R</i>	repetitive (overvoltage)
<i>r</i>	resistive
<i>S</i>	non-repetitive (overvoltage)
<i>v</i>	valve side
<i>x</i>	inductive
<i>α</i>	controlled value (by delay angle)

1.4.2 List of symbols (self evident symbols are not listed)

d_{xN}	inductive direct voltage regulation due to converter transformer referred to U_{di}
e_{xN}	inductive component of the relative short-circuit voltage of the converter transformer corresponding to I_{LN}
f_N	rated frequency
g	number of sets of commutating groups between which I_{dN} is divided
h	order of harmonic
I_d	direct current (any defined valued)

I_{dN}	rated direct current
I_{dmN}	rated continuous direct current (maximum value)
I_L	r.m.s. current on line side (of converter or transformer if included)
I_{LN}	rated value of I_L
I_{1LN}	r.m.s. value of the fundamental component of I_{LN}
I_{hLN}	r.m.s. value of harmonic order h of I_{LN}
I_{vN}	rated value on valve side of transformer
p	pulse number
P	active power
P_{LN}	power on line side at rated load
q	commutation number
Q_{1LN}	reactive power on line side at rated load
R_{sc}	relative short-circuit power
s	number of series connected commutating groups
S_{com}	short-circuit power calculated at the a.c. terminals of the commutating arms
S_c	short-circuit power of the supply source
S_{Cmin}	minimum value of S_c
S_{LN}	rated apparent power on line side
S_{1LN}	value of S_{LN} based on I_{1LN}
S_{tN}	transformer rated apparent power
u	angle of overlap (commutation angle)
U_d	direct voltage (any defined value)
U_{d0}	conventional no load direct voltage
$U_{d0\alpha}$	value of U_{d0} with trigger delay angle α
U_{d00}	real no-load direct voltage
U_{di}	ideal no-load direct voltage
$U_{di\alpha}$	controlled ideal no-load direct voltage
U_{dN}	rated direct voltage
U_{dxN}	total inductive direct voltage regulation at rated direct current
U_{hL}	r.m.s. value of harmonic order h of U_L
U_{iM}	ideal crest no-load voltage, appearing between the end terminals of an arm neglecting internal and external voltage surge and voltage drops in valves, at no load. The ratio remains the same at light load current close to the transition current.
U_L	line-to-line voltage on line side of converter or transformer, if any
U_{LN}	rated value of U_L
U_{LRM}	maximum instantaneous value of U_L including repetitive overvoltage but excluding non repetitive overvoltages
U_{LSM}	maximum instantaneous value of U_L including non repetitive overvoltages
U_{LWM}	maximum instantaneous value of U_L excluding transient overvoltages
U_M	maximum peak voltage (see 4.2.1.4)
U_{v0}	no-load line-to-line voltage on the line side of the converter or on the valve side of the transformer, is any

U_{vN}	rated voltage on the valve side of the transformer
X_{tN}	inductive voltage drop of the transformer in per unit
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
v	deformation factor
φ_1	displacement angle of the fundamental component of I_L

1.5 Definitions

For the purpose of this International Standard, the following definitions apply. In this standard, IEV definitions are used wherever possible, particularly those in IEC 50(551).

The policy adopted is as follows:

- 1) when a suitable IEV definition exists, the title and reference are given without repeating the text;
- 2) when an existing IEV definition needs amplification or additional information, the title, the reference and the additional text are given;
- 3) when no IEV definition exists, the title and the text are given;
- 4) the definitions appear under:
 - A) for general terms (1.5.1 to 1.5.28);
 - B) for service conditions (1.5.29 to 1.5.30);
 - C) for definitions concerning compatibility (1.5.31 to 1.5.37).

An alphabetical index is given in Annex A (informative)

A) General terms

1.5.1 Semiconductor device (IEV 551-03-05, modified)

Device whose essential characteristics are due to the flow of charge carriers within a semiconductor.

1.5.2 Power semiconductor diode

Two-terminal semiconductor device having an asymmetrical voltage/current characteristic, designed for use in power converter connections.

NOTE- Unless otherwise qualified, this term usually means a device with a voltage current characteristic typical of a single PN junction.

1.5.3 Thyristor

Bi-stable semiconductor device comprising three or more functions which can be switched from the off-state to the on-state.

NOTE- The term 'thyristor' is used as a generic term to cover the whole range of PNP type devices. it may be used by itself for any member of the thyristor family when such use does not result in ambiguity or misunderstanding. In particular, the term 'thyristor' is widely used for reverse blocking triode thyristor, formerly called 'silicon controlled rectifier'.

1.5.4 Reverse blocking triode thyristor

Three-terminal thyristor which does not turn on for negative anode voltage but exhibits a reverse blocking gate.

1.5.5 Reverse conducting triode thyristor

Three-terminal thyristor which does not block for negative anode voltage but conducts large reverse currents at voltages comparable in magnitude to the forward on-state voltages.

1.5.6 Bidirectional triode thyristor (triac)

Three-terminal thyristor having substantially the same switching behaviour in the first and third quadrants of the principal characteristic.

1.5.7 Turn-off thyristor (GTO = Gate Turn Off)

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

1.5.8 Combination of semiconductor devices

1.5.8.1 (Valve device) stack (IEV 551-03-11)

1.5.8.2 (Valve device) assembly (IEV 551-03-12)

1.5.8.3 (Electronic) (power) converter (IEV 551-02-01, modified)

An operative unit for electronic power conversion comprising one or more assemblies together with converter transformer(s), essential switching devices and other auxiliaries, if any. It may include the trigger equipment.

1.5.8.4 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.

1.5.8.5 System control equipment

Equipment associated with a converter equipment or system which performs automatic adjustment of the converter output characteristics as a function of a controlled quantity (for example motor speed, tractive force, etc.).

1.5.9 Converter circuit elements

1.5.9.1 (Circuit) valve (IEV 551-04-01)

1.5.9.2 (Valve) arm (IEV 551-04-04)

1.5.9.3 Principal arm (IEV 551-04-05, modified)

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

1.5.9.4 Auxiliary arm (IEV 551-04-12)

1.5.9.5 By-pass arm (IEV 551-04-13)

1.5.9.6 Free-wheeling arm (IEV 551-04-14)

1.5.9.7 Turn-off arm (IEV 551-04-15)

1.5.9.8 Regenerative arm (IEV 551-04-16)

1.5.10 Converter connection (IEV 551-04-17)

1.5.10.1 Basic converter connection (IEV 551-04-18)

1.5.10.2 Single-way connection (of a converter) (IEV 551-04-21)

1.5.10.3 Double-way connection (of a converter) (IEV 551-04-22)

1.5.10.4 Uniform connection (IEV 551-04-24)

1.5.10.5 Non-uniform connection (IEV 551-04-27)

1.5.10.6 Series connection (IEV 551-04-30, modified)

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

1.5.10.7 Boost and buck connection (IEV 551-04-31, modified)

A series connection in which the converters are controlled independently.

1.5.11 Controllability of converter arms

1.5.11.1 Controllable arm

Converter arm including controllable semiconductor element(s) as valve device(s).

1.5.11.2 Non-controllable arm

Converter arm including no controllable semiconductor element(s) as valve device(s).

1.5.12 Quadrants of operation (on d.c. side)

Each quadrant of the voltage current plane is defined by the d.c. voltage polarity and the current direction.

1.5.12.1 One quadrant converter (IEV 551-02-14)

1.5.12.2 Two quadrant (single) converter (IEV 551-02-15)

1.5.12.3 Four quadrant (double) converter (IEV 551-02-16)

1.5.12.4 Reversible converter (IEV 551-02-17)

1.5.12.4.1 Single converter (IEV 551-02-18)

1.5.12.4.2 Double converter (IEV 551-02-19)

1.5.12.4.3 Converter section of a double converter (IEV 551-02-20)

1.5.13 Commutation and quenching (see figure 1)

1.5.13.1 Commutation (IEV 551-05-01, modified)

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.

1.5.13.2 Quenching (IEV 551-05-02, modified)

The termination of current flow in an arm without commutation.

1.5.14 Type of commutation**1.5.14.1 Direct commutation (IEV 551-05-07)****1.5.14.2 Indirect commutation (IEV 551-05-08)****1.5.14.3 External commutation (IEV 551-05-03)****1.5.14.3.1 Line commutation (IEV 551-05-04)****1.5.14.3.2 Load commutation (IEV 551-05-05)****1.5.14.3.3 Machine commutation**

A method of load commutation in which the commutating voltage is supplied from a machine not included in the source of power.

1.5.14.3.4 Resonant load commutation

A method of load commutation in which the commutating voltage is supplied from the load, taking advantage of its resonant property.

1.5.15 Self commutation (IEV 551-05-06)**1.5.15.1 Directly coupled capacitor commutation**

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

1.5.15.2 Inductively coupled capacitor commutation

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

1.5.15.3 Device commutation

A method of self commutation in which the commutating voltage is produced by the valve device itself.

1.5.16 Type of quenching**1.5.16.1 Device quenching**

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

1.5.16.2 External quenching

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

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

1.5.17 Commutation circuit (IEV 551-05-09)

1.5.17.1 Commutating voltage (IEV 551-05-12)

1.5.17.2 Commutation inductance (IEV 551-05-11, modified)

Total inductance included in the commutation circuit, in series with the commutating voltage.

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

1.5.17.3 Angle of overlap u (IEV 551-05-14, modified)

The duration of the commutation interval between a pair of principal arms, expressed in angular measure, where the two arms carry current.

1.5.17.4 Commutation notch

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

1.5.17.5 Commutation repetitive transient

Voltage oscillation associated with the commutation notch.

1.5.17.6 Commutating group (IEV 551-05-10)

1.5.17.7 Commutation number q (IEV 551-06-03, modified)

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

1.5.17.8 Pulse number p (IEV 551-06-01, modified)

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

1.5.18 Trigger delay angle α (IEV 551-05-29, modified)

The time expressed in angular measure by which the trigger pulse is delayed with respect to the reference instant (see figure 2).

For line, machine or load commutated converters the reference instant is the zero crossing instant of the commutating voltage.

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

For a.c. controllers with inductive load, the trigger delay angle is the sum of the phase shift and the current delay angle.