

Semiconductor convertors — General requirements and line commutated convertors —

Part 1-1: Specifications of basic requirements

The European Standard EN 60146-1-1:1993, with the incorporation of its amendment A1:1997, has the status of a British Standard

ICS 29.200

Cooperating organizations

The European Committee for Electrotechnical Standardization (CENELEC), under whose supervision this European Standard was prepared, comprises the national committees of the following countries:

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National foreword

This British Standard has been prepared under the direction of the Power Electrical Engineering Standards Policy Committee and is the English language version of EN 60146-1-1:1993 *Semiconductor convertors. General requirements and line commutated convertors — Part 1-1: Specifications of basic requirements*, including Amendment A1:1997, published by the European Committee for Electrotechnical Standardization (CENELEC). It is identical with IEC 60146-1-1:1991, including Amendment 1:1996, published by the International Electrotechnical Commission (IEC).

This British Standard, together with BS EN 60146-1-3, supersedes BS 4417:1969, which is withdrawn.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 48, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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English version

Semiconductor convertors General requirements and line commutated convertors Part 1-1: Specifications of basic requirements

(IEC 60146-1-1:1991 including A1:1996)

Convertisseurs à semiconducteurs
Spécifications communes et convertisseurs
commutés par le réseau
Partie 1-1: Spécifications des clauses
techniques de base
(CEI 60146-1-1:1991 inclut A1:1996)

Halbleiter-Stromrichter Allgemeine
Anforderungen und netzgeführte Stromrichter
Teil 1-1: Festlegung der Grundanforderungen
(IEC 60146-1-1:1991 enthält A1:1996)

This European Standard was approved by CENELEC on 1992-12-09; amendment A1 was approved by CENELEC on 1997-10-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

The CENELEC questionnaire procedure, performed for finding out whether or not the International Standard IEC 146-1-1:1991 could be accepted without textual changes, has shown that no common modifications were necessary for the acceptance as European Standard.

The reference document was submitted to the CENELEC members for formal vote and was approved by CENELEC as EN 60146-1-1 on 9 December 1992.

The following dates were fixed:

- latest date of publication of an identical national standard (dop) 1993-12-01
- latest date of withdrawal of conflicting national standards (dow) 1993-12-01

For products which have complied with the relevant national standard before 1993-12-01, as shown by the manufacturer or by a certification body, this previous standard may continue to apply for production until 1998-12-01.

Annexes designated “normative” are part of the body of the standard. Annexes designated “informative” are given only for information. In this standard, Annex A and Annex B are informative, Annex ZA is normative.

Foreword to A1:1997

The text of the amendment 1:1996 to the International Standard IEC 60146-1-1:1991, prepared by SC 22B, Semiconductor converters, of IEC TC 22, Power electronics, was submitted to the formal vote and was approved by CENELEC as amendment A1 to EN 60146-1-1:1993 on 1997-10-01 without any modification.

The following dates were fixed:

- latest date by which the amendment has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 1998-09-01
- latest date by which the national standards conflicting with the amendment have to be withdrawn (dow) 1998-09-01

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Section 1. General

1.1 Scope and object

This International Standard specifies the requirements for the performance of all electronic power convertors 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 convertors 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 convertors 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 convertors given in existing or future IEC Publications.

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

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 convertors, in addition to or as a modification on existing standards;
- to provide useful reference, calculation factors, formulae and diagrams pertaining to power convertor practice.

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

- to give additional information on characteristics wherein convertor transformers differ from ordinary power transformers. In all other respects, the rules specified in IEC 76, shall apply to convertor 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.

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

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

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

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

IEC 76:1976, *Power transformers*.

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

IEC 664:1980, *Insulation co-ordination 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. convertor);
 - 4) a.c. to a.c. conversion (direct or indirect a.c. to a.c. convertor);
 - 5) switching (periodic or non-periodic).
- b) Purpose of conversion: In a power system the convertor 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 falls 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. convertors 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: Convertors 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 convertor 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.

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).

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

NOTE 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

0 (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
α	controlled value (by delay angle)

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

d_{xtN}	inductive direct voltage regulation due to convertor transformer referred to U_{di}
e_{xN}	inductive component of the relative short-circuit voltage of the convertor transformer corresponding to I_{LN}
f_N	rated frequency
g	number of sets of commutating groups between which I_{dN} is divided
h	order of harmonic
I_d	direct current (any defined value)
I_{dN}	rated direct current
I_{dmN}	rated continuous direct current (maximum value)
I_L	r.m.s. current on line side (of convertor 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_{ILN}	value of S_{LN} based on I_{ILN}
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 convertor 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 convertor or on the valve side of the transformer, if any
U_{vN}	rated voltage on the valve side of the transformer
X_{tN}	inductive voltage drop of the transformer in per unit
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 convertor 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) convertor (IEV 551-02-01, modified)

an operative unit for electronic power conversion comprising one or more assemblies together with convertor 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 convertor 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 convertor equipment or system which performs automatic adjustment of the convertor output characteristics as a function of a controlled quantity (for example motor speed, tractive force, etc.)

1.5.9 Convertor 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 convertor 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 Convertor connection (IEV 551-04-17)

1.5.10.1

basic convertor connection (IEV 551-04-18)

1.5.10.2

single-way connection (of a convertor) (IEV 551-04-21)

1.5.10.3

double-way connection (of a convertor) (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 convertors 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 convertors are controlled independently

1.5.11 Controllability of convertor arms**1.5.11.1****controllable arm**

convertor arm including controllable semiconductor element(s) as valve device(s)

1.5.11.2**non-controllable arm**

convertor 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 convertor (IEV 551-02-14)****1.5.12.2****two quadrant (single) convertor (IEV 551-02-15)****1.5.12.3****four quadrant (double) convertor (IEV 551-02-16)****1.5.12.4 Reversible convertor (IEV 551-02-17)****1.5.12.4.1****single convertor (IEV 551-02-18)****1.5.12.4.2****double convertor (IEV 551-02-19)****1.5.12.4.3****convertor section of a double convertor (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 convertors 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 convertors the commutation reactance is the impedance of the commutation inductance at the fundamental frequency.

1.5.17.3

angle of overlap μ (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 convertor due to commutation

1.5.17.5

commutation repetitive transient

voltage oscillation associated with the commutation notch

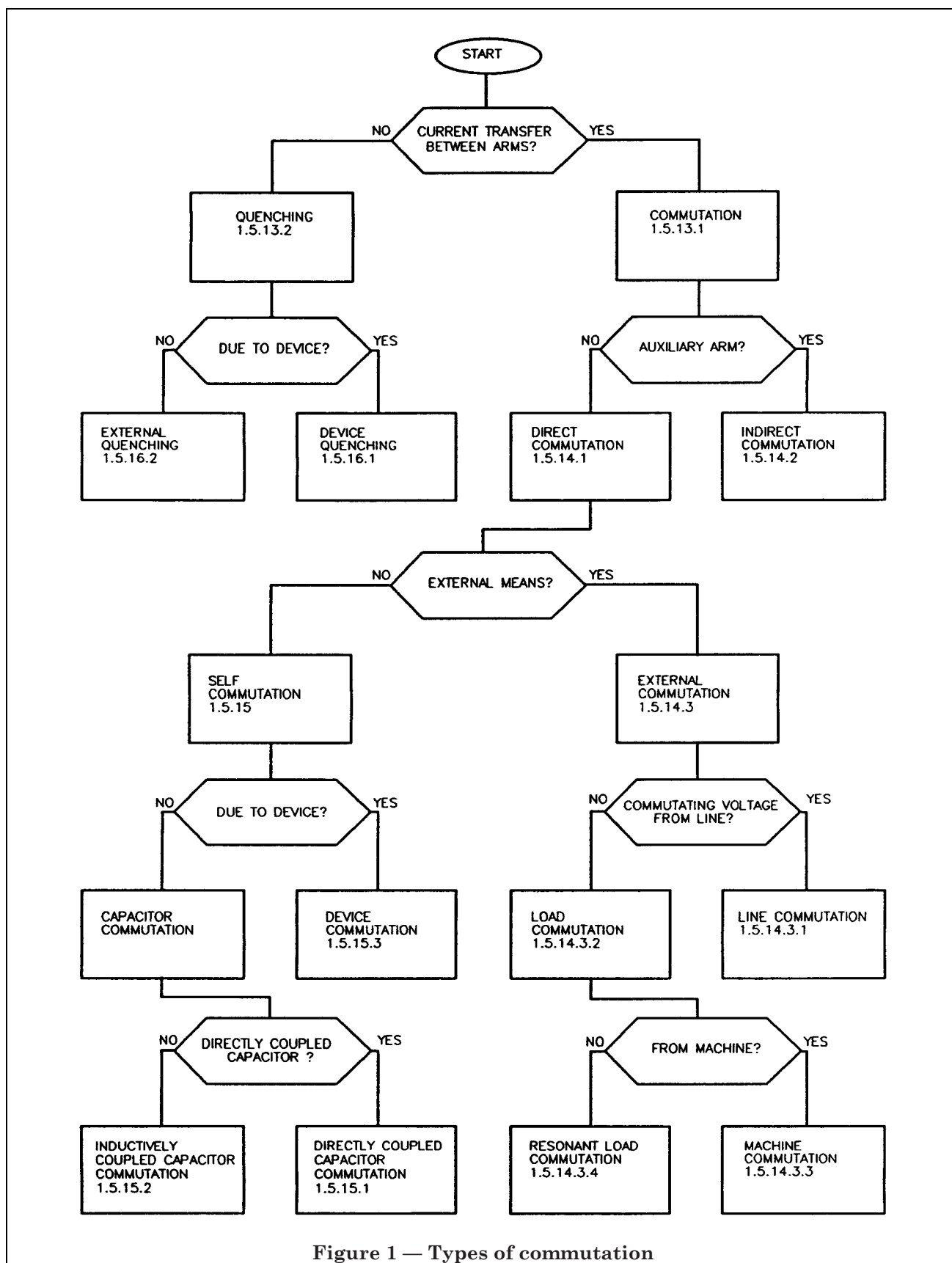


Figure 1 — Types of commutation