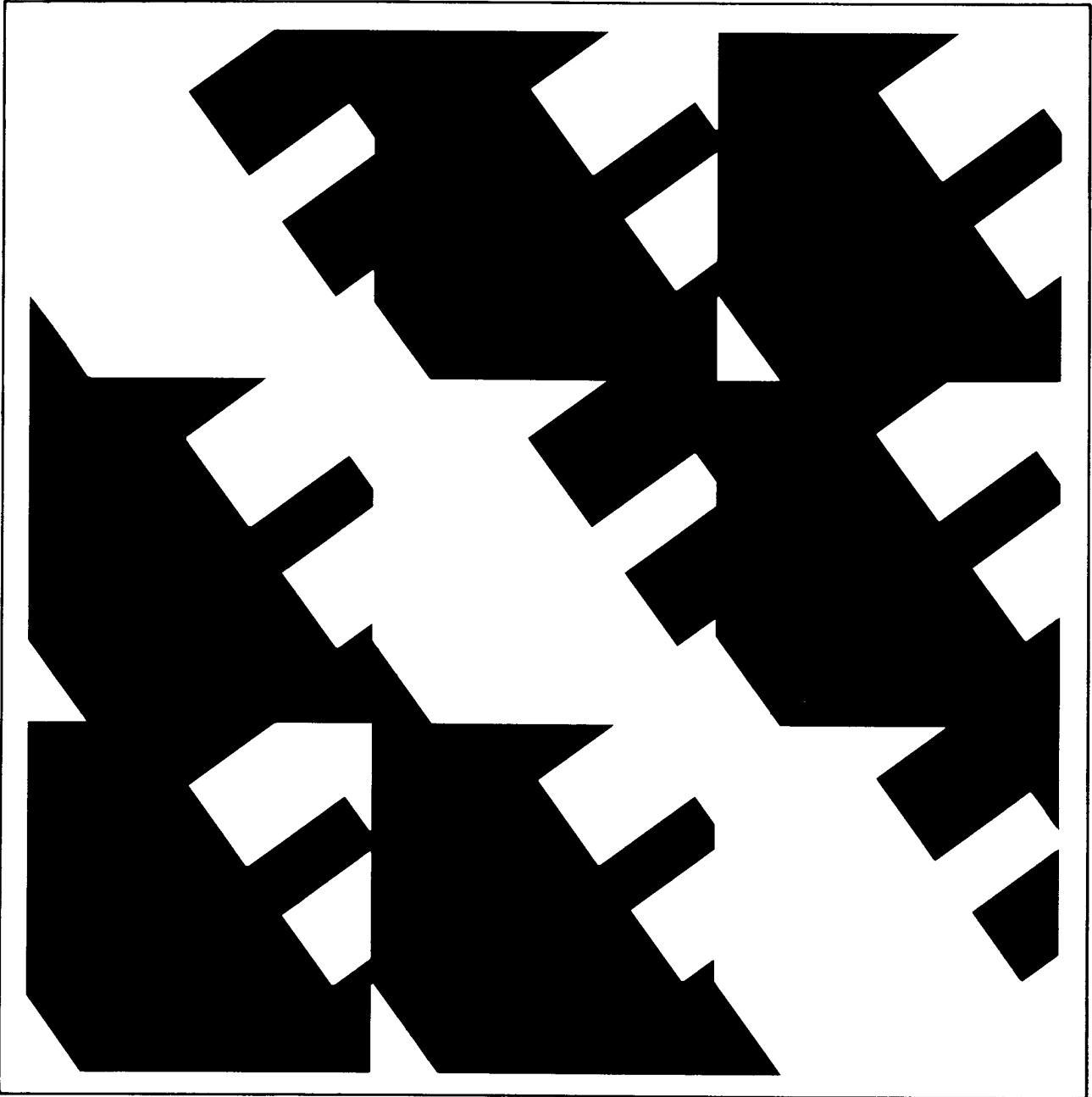




IEEE Guide for Self-Commutated Converters

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Self-Commutated Converters**

Sponsor

**Static Power Converter Committee of the
IEEE Industry Applications Society**

Approved March 13, 1986

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Foreword

(This Foreword is not a part of ANSI/IEEE Std 936-1987, IEEE Guide for Self-Commutated Converters.)

This guide was prepared by the Self-Commutated Converter Subcommittee of the IEEE Static Power Converter Committee, Industry Applications Society. Its purpose is to complement other IEEE standards on static electric power converters and their applications, which mainly concern externally commutated converter circuits. In many applications, a self-commutated converter is linked together with an externally commutated converter in the same system, and often in the same equipment package, such as a rectifier-inverter power supply or an ac drive system. Since the externally commutated portion of such systems is adequately characterized elsewhere, only those characteristics that are particular to the self-commutated converter are included here.

At present, the major industrial applications of self-commutated converters are in adjustable-speed ac drives, uninterruptible power supplies, induction heating supplies, general-purpose ac supplies, choppers for dc traction and for dc power supplies, and power factor correction equipment. The type of conversion includes all combinations of dc or ac input and dc or ac output. This guide is intended to be comprehensive regarding types of conversion and, therefore, includes sections on direct frequency changers, even though that type of equipment is just beginning to find practical application. Because of potentially wide future development, its inclusion here is believed to serve a useful purpose.

However, the guide is not intended to be comprehensive regarding types of applications, because of the wide variety of special conditions that are dependent on the application. General conditions common to most applications are included. Special conditions are better covered in other standards concerning the particular application in detail. Nevertheless, it appeared desirable to cover certain special conditions that are of major concern in one of the most widespread present applications, namely ac adjustable-speed drives. Here, the interaction of the converter and the motor is particularly critical and affects the performance of both. An understanding of the behavior and design of the converter is essential for proper engineering of the drive system. Therefore, descriptions of these interactive effects are presented in the Appendix to guide both the designers and users of inverter drives.

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1. Scope

This guide applies to self-commutated electronic power converters; that is, converters in which commutation is accomplished by components within the converter. In converters using switching devices that have turn-off capability, such as transistors or gate turn-off thyristors, interruption of the current results in a voltage that commutates the current to another branch. In converters using circuit-commutated thyristors, the commutating voltages required to transfer current from one branch to another are normally supplied by capacitors. The type of power conversion may be dc to ac, dc to dc, ac to dc, or ac to ac.

Externally commutated converters, in which commutating voltages are supplied by the ac supply lines, the ac load, or some other ac source outside the converter, are excluded from the scope of this guide except where they may be linked with a self-commutated converter.

2. Definitions

2.1 General. Some of the definitions here have been taken or derived from one of the following sources:

- (1) ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.
- (2) IEC Pub 50-551 (1982), International Electrotechnical Vocabulary, Chapter 551: Power Electronics.

(3) IEC Pub 146 (1973), Semiconductor Convertors: General Requirements and Line-Commutated Convertors (second edition).

(4) IEC Pub 146-2 (1974), Semiconductor Convertors, Part 2: Self-Commutated Convertors.

In the definitions that follow, adjectives that are implicit by virtue of the subject of this guide are often omitted for brevity and clarity (for example, semiconductor, electronic, etc).

2.2 Basic Terms

2.2.1 Converter or Converter Equipment.

An operative unit for electronic power conversion, comprising one or more electronic switching devices and any associated components, such as transformers, filters, commutation aids, controls, and auxiliaries.

2.2.1.1 Externally Commutated Converter. A converter in which the commutating voltages are supplied by the ac supply lines, the ac load, or some other ac source outside the converter.

NOTE: Externally commutated converters are excluded from the scope of this guide, except where they may be linked with a self-commutated converter.

2.2.1.2 Self-Commutated Converter (Forced-Commutated Converter). A converter in which commutation is accomplished by components within the converter.

NOTE: In converters using switching devices that can interrupt or turn off current, such as transistors or gate turn-off thyristors, rejection of the current produces a voltage across the device to commutate the current to another device. In converters using circuit-commutated thyristors, the commutating voltages required to transfer current from one device to another are usually supplied by capacitors.

2.2.2 Rectifier. A converter for conversion from ac to dc.

2.2.3 Inverter. A converter for conversion from dc to ac.

2.2.4 AC Converter. A converter for changing ac power of a given voltage, frequency, and phase number to ac power in which one or more of these parameters are different.

2.2.4.1 Frequency Changer. An ac converter for changing frequency.

2.2.4.2 Direct AC Converter (Cycloconverter). The ac conversion is accomplished directly, without an intermediate link having different power characteristics, such as dc or high-frequency ac.

2.2.4.3 DC-Linked AC Converter. A converter comprising a rectifier and an inverter, with an intermediate dc link.

NOTE: This definition is intended to include only those circuits in which the dc link is readily identified or explicit, and not those circuits having an implicit dc link but no single pair of conductors that can be identified as the dc link.

2.2.4.4 AC-Linked AC Converter. A converter comprising two cascaded frequency changers in which the intermediate link is usually a high-frequency tank circuit.

2.2.5 DC Converter. A converter for changing dc power at a given voltage to dc power at a higher or lower voltage.

2.2.5.1 Direct DC Converter (DC Chopper). The dc conversion is accomplished directly, without an intermediate ac link.

2.2.5.2 AC-Linked DC Converter. A converter comprising an inverter and a rectifier, with an intermediate ac link.

2.3 Converter Circuit Elements

2.3.1 Principal Terminal. A terminal (of a device or circuit element) through which passes the current transmitting the power that is controlled by the device or circuit element. The term is used for distinction from control terminals, monitoring signal terminals, etc.

NOTE: Examples of principal terminals are the anode and cathode of thyristor or diode devices, the collector and emitter of bipolar transistor devices, and the source and drain of field-effect transistor devices.

2.3.2 Converter Switching Element. A part of the converter circuit, bounded by two principal terminals, containing one or more semiconductor devices having the property of controllable or noncontrollable conduction in at least one direction.

2.3.3 Switching Branch. A part of the circuit, including at least one switching element, bounded by two principal terminals.

NOTE: A switching branch may include one or more simultaneously conducting converter switching elements connected together, commutating reactor windings, and other devices intended to protect the semiconductor devices or to assure their proper function, such as voltage and current dividers, snubbers, etc. In the simplest case, a switching branch may consist of only the switching element, which may be a single semiconductor device. The adjective *switching* may be omitted when the context of converter circuits is clear.

2.3.3.1 Principal Branch (Main Branch). A branch involved in the major transfer of energy from one side of the converter to the other.

2.3.3.2 Auxiliary Branch. A branch other than a principal branch.

NOTE: Examples of auxiliary branches are regenerative branches and turn-off branches.

2.3.3.3 Turn-Off Branch. An auxiliary branch intended to take over the current transiently from a previously conducting principal branch.

2.3.3.4 Regenerative Branch. An auxiliary branch intended to transfer energy from the load to the supply side of the converter.

2.3.4 Commutating capacitor. A capacitor that provides commutating voltage for circuit-commutated thyristors in a self-commutated converter.

2.3.5 Commutating Reactor (Commutating Inductor). An inductor having one or more windings that modifies or couples the transient current produced by the commutating voltage.

2.3.6 Snubber. An auxiliary circuit element or combination of elements employed to modify the transient voltage or current of a semiconductor device.

2.3.6.1 Shunt Snubber. Circuit elements, usually including a capacitor, connected in shunt with a switching device to limit the rate of rise of voltage or the peak voltage across the device (or both) when switching from a conducting to a blocking state, or when subjected to an external voltage transient.

2.3.6.2 Series Snubber. Circuit elements, usually including an inductor, connected in series with a switching device to limit the rate of rise or fall of current through the device when switching on or off, respectively.

2.3.6.3 Polarized Snubber. A snubber, including a diode, in which the limiting action depends on the direction of voltage or current.

2.3.7 Clamp. An auxiliary circuit element or combination of elements employed to limit the peak voltage or current of a semiconductor device.

2.3.7.1 Voltage Clamp. A clamp that limits the peak voltage across a semiconductor device.

2.3.7.2 Current Clamp. A clamp that limits the current through a semiconductor device.

2.4 Circuit Properties

2.4.1 Principal Current (of a Converter Switching Element or Branch). The on-state current of the semiconductor devices in a switching element or branch flowing between its principal terminals.

NOTE: The principal current is often referred to as the *current* of the switching element or branch.

2.4.2 Commutation. The transfer of current from one converter switching branch to another.

2.4.2.1 Commutating Voltage. The voltage that causes the current to commute from one switching branch to another.

NOTES: (1) In an externally commutated converter, the commutating voltage is supplied by an ac source outside the converter.

(2) In a self-commutated converter using switching devices that have turn-off capability, such as power transistors or gate turn-off thyristors, the commutating voltage results from the interruption of current in the outgoing device branch.

(3) In a self-commutated converter using circuit-commutated thyristors, the commutating voltage is normally supplied by capacitors.

2.4.2.2 Direct Commutation. A commutation between two principal switching branches without the involvement of other switching branches. In converters using devices such as power transistors or gate turn-off thyristors, this is accomplished by turning off the switch in the outgoing branch and turning on the switch in the incoming branch. In converters using circuit-commutated thyristors, commutating capacitors coupled to the switching branches turn off the outgoing switch when the incoming switch is turned on.

2.4.2.3 Indirect Commutation (Auxiliary Commutation). A commutation between a principal switching branch and an auxiliary switching branch succeeded by a commutation to the next principal switching branch. Indirect commutation is employed in some types of converters using circuit-commu-

tated thyristors, where the auxiliary branch includes a commutating capacitor(s) to turn off the outgoing principal switch when the auxiliary switch is turned on.

NOTE: In some converter circuits, several auxiliary branches may be involved consecutively.

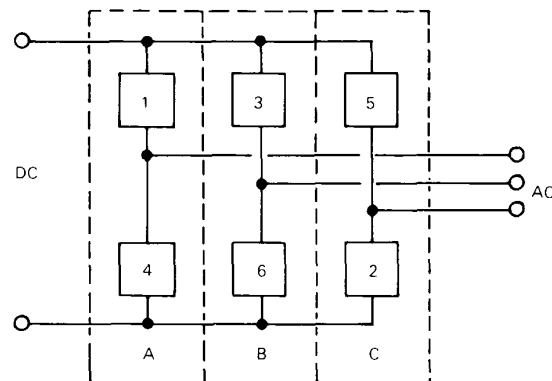
2.4.2.4 Complementary Commutation. Commutation occurs from one to the other of a complementary pair of principal switching branches arranged as a two-pulse group that conduct in alternate but not necessarily equal time intervals. The commutation may be direct or indirect.

NOTE: An example of a converter employing complementary commutation is given in Fig 1.

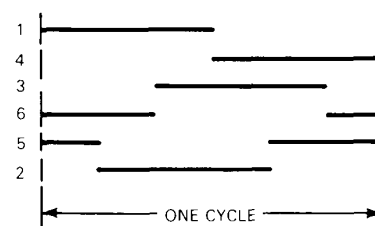
Fig 1

Three-Phase Bridge Converter Employing Complementary Commutation

NOTE: The principal switching branches 1–6 are numbered in the order in which they begin conduction.



(a) Three 2-Pulse Commutating Groups: A, B, C



(b) Conducting Intervals of Principal Switching Branches 1–6

2.4.2.5 Sequential Commutation. Commutation occurs from one to the next of three or more principal switching branches arranged as a multipulse group that conduct in cyclic sequential order for usually (but not always) equal time intervals. The commutation may be direct or indirect.

NOTE: An example of a converter employing a sequential commutation is given in Fig 2.

2.4.3 Pulse Number (of a Group of Principal Branches or of a Complete Converter). The number of nonsimultaneous commutations from one principal branch to another during one cycle of operation, considering the group or the complete converter, respectively.

2.4.4 Time Intervals During Operation

2.4.4.1 Conducting Interval. An interval during which the principal current flows through a switching element.

2.4.4.2 Blocking Interval. An interval

during which voltage is impressed across a switching element in its off-state.

2.4.4.3 Overlap Interval. The time interval during which two commutating converter branches are carrying principal current simultaneously.

2.4.4.4 Commutation Interval. The time interval between the application of commutating voltage to a pair of commutating branches and the cessation of the resulting transient currents.

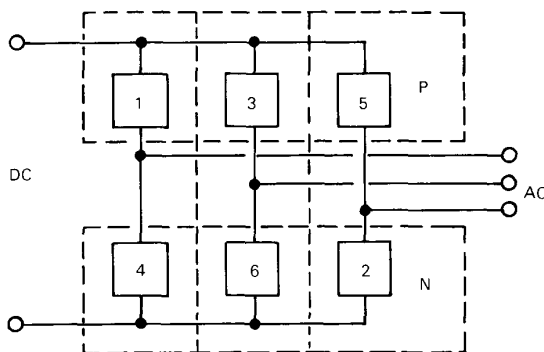
NOTE: The commutation interval is the same as the overlap interval in an externally commutated converter in which the commutating voltage is supplied by the ac line.

2.4.4.5 Turn-Off Time (Applies to Converters that Use Circuit-Commutated Thyristor Devices). The time interval between that instant when the principal current of a thyristor device has been reduced to zero and that instant when the same thyristor device is again subjected to voltage that could cause conduction.

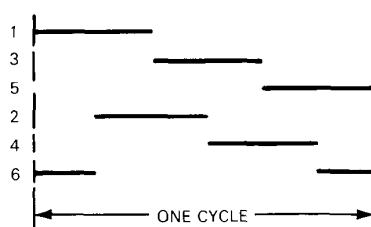
NOTE: For proper operation, the turn-off time, t_o , made available by the action of the circuit must exceed the turn-off time, t_q , required by the thyristor device for recovery of its voltage-blocking ability. Both the available and required turn-off times depend on the operating conditions of the converter. See Fig 3.

Fig 2
Three-Phase Bridge Converter Employing Sequential Commutation

NOTE: The principal switching branches 1–6 are numbered in the order in which they begin conduction.



(a) Two 3-Pulse Commutating Groups: P, N



(b) Conducting Intervals of Principal Switching Branches 1–6

2.5 Characteristics Related to Converter

2.5.1 Efficiency (of Power Conversion). The ratio of active (real) output power and active (real) input power.

NOTE: Both powers are to be taken as the total average power as given by the formula:

$$P = \frac{1}{T} \int_0^T e i \, dt$$

where

T = the period for ac and the ripple period for dc

2.5.2 Ripple Content. The periodic ac function that may be superimposed on a steady zero-frequency (dc) voltage or current.

2.5.3 Harmonic. A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency.

NOTE: For example, a component, the frequency of which is twice the fundamental frequency, is called a second harmonic.

2.5.3.1 Harmonic, Characteristic. Those harmonics produced by semiconductor converter equipment in the course of normal operation. In a six-pulse converter, the characteris-

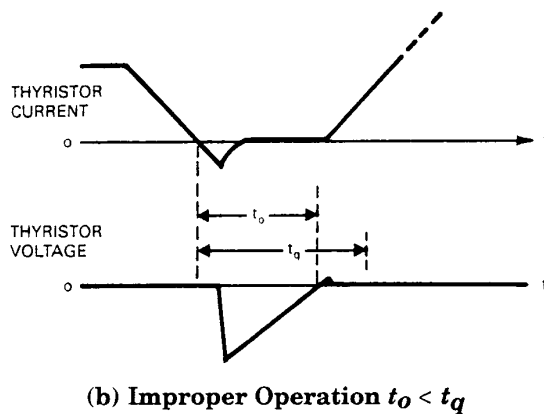
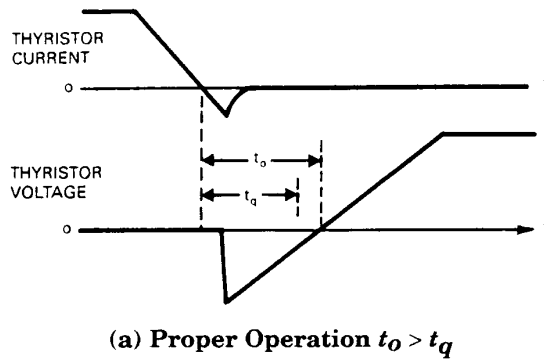


Fig 3
Turn-Off Time for Circuit-Commutated
Thyristors

tic harmonics are the nontriplen odd harmonics, for example, the 5th, 7th, 11th, 13th, etc.

$$h = kq \pm 1$$

where

k = any integer
 q = pulse number

2.5.3.2 Harmonic, Noncharacteristic. Those harmonics which are not produced by semiconductor converter equipment in the course of normal operation. These may be a result of beat frequencies, a demodulation of characteristic harmonics and the fundamental component, unbalance in the ac power system, or unsymmetrical control of the converter.

2.5.3.3 Harmonic Content. The function obtained by subtracting the dc and fundamen-

tal components from a nonsinusoidal periodic function.

2.5.3.4 Harmonic Components. The components of the harmonic content as expressed in terms of the order and rms values of the Fourier series terms describing the periodic function.

2.5.4 Relative Characteristic Factors

2.5.4.1 Relative Harmonic Content. The ratio of the rms value of the harmonic content to the rms value of the total nonsinusoidal periodic function.

2.5.4.2 Relative Fundamental Content. The ratio of the rms value of the fundamental component to the rms value of the total nonsinusoidal periodic function.

2.5.4.3 DC Form Factor. The dc form factor of a periodic function is the ratio of the rms value to the mean value, averaged over a full period of the function.

2.5.4.4 Distortion Factor. The ratio of the rms value of the harmonic content to the rms value of the fundamental quantity.

$$d = \frac{(\text{sum of squares of amplitudes of all harmonics})^{1/2}}{\text{amplitude of fundamental component}}$$

$$= \frac{\sqrt{\sum_{h=2}^{\infty} c_h^2}}{c_1}$$

2.5.4.5 Displacement Power Factor.

The displacement component of power factor; the ratio of the active power of the fundamental wave, in watts, to the apparent power of the fundamental wave, in volt-amperes. It is also equal to $\cos\phi_1$, the cosine of the phase displacement angle between the fundamental component of the voltage and current on the ac side of a converter.

2.5.4.6 Power Factor (Total). The ratio of the total active power in watts to the total apparent power in volt-amperes (the product of rms voltage and rms current) on the ac side of the converter.

NOTE: This definition includes the effect of harmonic components of current and voltage, as well as the effect of phase displacement between current and voltage. If either the voltage or the current is an undistorted sine wave, and d is the distortion factor of the other, then the following relationship is true:

$$\text{total power factor} = \frac{\cos \phi_1}{\sqrt{1 + d^2}}$$