

IEEE Standard Practices and Requirements for General Purpose Thyristor DC Drives

Sponsors

**Static Power Converter Committee and
Industrial Drives Committee of the
IEEE Industry Applications Society**

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Foreword

(This Foreword is not a part of IEEE Std 597-1983, IEEE Standard Practices and Requirements for General Purpose Thyristor DC Drives.)

This standard is intended to cover standard practices and requirements for general purpose thyristor DC drives.

The objectives of the standard are:

- (1) Common vocabulary
- (2) Common methods of test and specification
- (3) Recommended code of practice

There are sections on service conditions, operating characteristics, circuits, ratings, and regulators. The Appendixes cover several of the above in more detail.

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IEEE Standard Practices and Requirements for General Purpose Thyristor DC Drives

1. Scope

This standard applies to line-commutated semiconductor power converters for general purpose industrial direct-current motor drives powered from three-phase or single-phase ac supplies.

Reference is also made to a companion standard: IEEE Std 444-1973 [5]¹, which is usually intended for larger drives requiring multi-phase power, normally used in more complex system applications.

2. References

[1] ANSI C34.2-1968 (R1973), American National Standard Practices and Requirements for Semiconductor Power Rectifiers.²

[2] ANSI C57.96-1959, American National Standard Guide for Loading Dry-Type Distribution and Power Transformers (Appendix to ANSI C57.12 Standards).

[3] ANSI/IEEE C57.92-1981, IEEE Guide for Loading Mineral-Oil-Immersed Power Transformers up to and including 100 MVA with 55 °C or 65 °C Average Winding Rise.

[4] ANSI/IEEE Std 100-1977, IEEE Standard Dictionary of Electrical and Electronics Terms.

¹The numbers in brackets correspond to the references listed in Section 2 of this standard.

²ANSI documents are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

[5] ANSI/IEEE Std 444-1973, IEEE Standard Practices and Requirements for Thyristor Converters for Motor Drives; Part I — Converters for DC Motor Armature Supplies (ANSI C34.3-1973).

[6] ANSI/NEMA ICS 3-1978, Industrial Systems.

[7] ANSI/NEMA ICS 3.1-1979, Safety Standards for Construction and Guide for Selection, Installation and Operation of Adjustable-Speed Drive Systems.

[8] ANSI/NEMA ICS 6-1978, Enclosures for Industrial Controls and Systems.

[9] ANSI/NEMA MG1-1978, Motors and Generators.

[10] ANSI/NEMA ST 1-1978 (R1981), Specialty Transformers (Except General-Purpose Type) (ANSI C89.1).

[11] ANSI/NEMA ST 20-1972, Dry-Type Transformers for General Applications (ANSI C89.2).

[12] ANSI/NEMA TR 98-1978, Guide for Loading Oil-Immersed Power Transformers with 65 °C Average Winding Rise.

[13] ANSI/NFPA 70-1981, National Electrical Code.

[14] ANSI/UL 508-1976, Safety Standard for Industrial Control Equipment.

[15] ANSI/IEEE Std 142-1982, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems.

[16] IEEE Std 223-1966, IEEE Standard Definitions of Terms for Thyristors.

[17] IEEE Std 518-1982, IEEE Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources.

[18] IEEE Std 519-1981, IEEE Guide for Harmonic Control and Reactive Compensation of Static Power Converters.

3. Definitions

In this standard the following converter terms are used interchangeably: half wave = single way; full wave = double way.

3.1 Basic Terms

general purpose drives. General purpose drives are designed to be used for any of a variety of industrial applications which can economically utilize standardized functional and performance features, including a selection of standard optional modifications.

line voltage. The ac voltage between the conductors of the supplying power system, expressed in rms units.

crest working line voltage E_{CW} . The highest instantaneous value of the fundamental frequency component of the line voltage excluding all repetitive and nonrepetitive transient voltages, but including line-voltage regulation.

repetitive peak line voltage E_{LRM} . The highest instantaneous value of the line voltage including all repetitive transient voltages, but excluding all nonrepetitive transient voltages.

nonrepetitive peak line voltage E_{LSM} . The highest instantaneous value of any nonrepetitive transient voltage.

load L/R . The effective dc motor time constant of the armature circuit including conductors to the motor.

3.2 Definitions of System Regulator Terms. Terms commonly employed in describing regulator performance are defined below and discussed in Section 8.

command. An input variable established by means external to, and independent of, the automatic feedback control system. It sets, is equivalent to, and is expressed in the same units as the ideal value of the ultimately controlled variable.

control accuracy. The degree of correspondence between the final value and the ideal value of the directly controlled variable.

directly controlled system. That part of the control system which is directly guided or restrained by the control elements to achieve a prescribed value of the directly controlled variable.

directly controlled variable. That variable in a feedback control system whose value is sensed to originate the primary feedback signal.

drift. An undesired but relatively slow change in output over a specified time with a fixed reference input and fixed load, with specified environmental conditions. The specified time is normally after the warm-up period.

NOTE: Drift shall be expressed in percent of the maximum rated value of the variable being measured.

dynamic deviation. The difference between the ideal value and the actual value of a specified variable when the reference input is changing at a specified constant rate and all other transients have expired.

NOTE: Dynamic deviation shall be expressed either as a percentage of the maximum value of the directly controlled variable or, in absolute terms, as the numerical difference between the ideal and the actual values of the directly controlled variable.

feedback controlled system. A control system which operates to achieve prescribed relationships between selected system variables by comparing the functions of those variables and using the difference to effect control.

final value. The steady-state value of a specified variable.

ideal value. The value of a selected variable that results from a perfect system operating from the same command as the actual system under consideration.

indirectly controlled system. That portion of the controlled system in which the indirectly controlled variable is changed in response to changes in the directly controlled variable.

indirectly controlled variable. A variable that is not directly measured for control but that is related to, and influenced by, the directly controlled variable.

initial value. The value of the time response of a system or element at the time a stimulus is applied.

repeat accuracy. A term used to express the degree of consistency of repeat operations under specific conditions.

response time. The time required, following the initiation of a specified stimulus to a system, for an output going in the direction of necessary corrective action to first reach a specified value.

NOTE: The response time shall be expressed in seconds. (See Figs 9 and 10.)

rise time. The time required for the output of a feedback system (other than first order) to make the change from a small specified percentage (often 5 or 10) of the steady-state increment to a large specified percentage (often 90 to 95), either before overshoot or in the absence of overshoot.

NOTE: If the term *rise time* is unqualified, response to a step change is understood, otherwise the pattern and magnitude of the stimulus should be specified.

speed range. The ratio of the rated speed to that minimum operating speed wherein the limits of the deviation band apply.

steady state. The condition of a specified variable at a time when no transients are present.

NOTE: For the purpose of this definition, drift is not considered to be a transient.

steady-state deviation. The system deviation after transients have expired.

NOTE: For the purpose of this definition, drift is not considered to be a transient. (1) Absolute steady-state deviation shall be expressed as the numerical difference between the ideal value and the final value of the directly controlled variable (or another variable if specified); (2) Percent steady-state deviation shall be the difference between the ideal value and the final value, expressed as a percentage of the maximum rated value of the directly controlled variable (or another variable if specified).

system deviation. The difference between the value of a specified variable at any instant and its ideal value.

NOTES: (1) Absolute system deviation at any given point on the time response shall be expressed as the numerical difference between the ideal value and the

final value of the directly controlled variable (or another variable if specified).

(2) Percent steady-state deviation shall be the difference between the ideal value and the final value, expressed as a percentage of the maximum rated value of the directly controlled variable (or another variable if specified).

system overshoot. The largest value of system deviation following the first dynamic crossing of the ideal value in the direction of correction, after the application of a specified stimulus.

transient. That part of the variation in a variable that disappears after transition from one steady-state operating condition to another.

transient deviation. The difference between the value of a specified variable at any instant and its final value (see Figs 9 and 10).

NOTES: (1) Absolute transient deviation shall be expressed as the numerical difference between the instantaneous value and the final value of the directly controlled variable (or another variable if specified).

(2) Percent transient deviation shall be the difference between the instantaneous value and the final value of the directly controlled variable expressed as a percentage of the maximum rated value of the directly controlled variable (or another variable if specified).

transient overshoot. The largest value of transient deviation following the first dynamic crossing of the final value in the direction of correction, after the application of a specified stimulus.

4. Letter Symbols

The following set of letter symbols is used in converter circuit analysis and calculation of converter characteristics in this standard.

4.1 Subscripts

- O = at no load, for example, E_{do}
- d = direct current and voltage
- L = line side of transformer
- s = thyristor side of transformer, phase to neutral

4.2 Letter Symbols

- μ = commutating angle, notch width, angle of overlap
- C_o = distributed ac line capacitance in farads
- di/dt = instantaneous rate of change of current with time
- dv/dt = instantaneous rate of change of voltage with time

E_{CW}	= crest working voltage
E_{do}	= average value of theoretical dc voltage at no load
E_L	= ac system line-to-line voltage
E_{LRM}	= repetitive peak line voltage
E_{LSM}	= nonrepetitive peak line voltage
E_n	= ac system line-to-neutral voltage
E_s	= transformer secondary winding line-to-neutral voltage
f	= frequency of ac power system
i	= instantaneous value of current with time
I_d	= average value of dc load current of the rectifier in amperes
L_C	= line-to-neutral commutation inductance for a set of commutating groups
M	= mutual inductance
p	= pulse number of commutating group
R_G	= grounding resistance
T	= time interval over which rms current is calculated
v	= instantaneous value of voltage as a function of time
X_L	= reactance of supply line in ohms (per line)
X_T	= reactance of transformer in ohms
X_{GC}	= distributed phase-to-ground charging reactance in ohms

5. Thyristor Converter Circuits

5.1 Nomenclature of Typical Circuits. Fig 1 (single phase) and Fig 2 (three phase) show converter circuits with standard diagrams and approved names for circuits typically used for general purpose thyristor power supplies for motor drives. Identifying numbers, where applicable, are taken from ANSI C34.2-1968, Table 1 [1] and IEEE Std 444-1973, Part I, Fig 6(a) [5], and are shown at upper left of circuits in Figs 1 and 2. Tables 1 and 2 show some basic circuits and their current and voltage characteristics. Additional circuit information is provided in Appendix A, Circuit Characteristics.

Thyristor converter circuit nomenclature is based on descriptive names given:

- (1) Number of input line phases
- (2) Configuration of the power transformer connection (if used)

(3) Statement if only half the rectifier elements are controlled

(4) Connection of the thyristor circuit elements (half-wave or full-wave bridge)

(5) Pulse number (This is the number of pulses present in the dc output voltage in one cycle of the supply voltage.)

(6) Presence of a bypass diode, if used

(7) Statement if the output is reversible

5.2 Transformers in the Converter Circuits. (See Section 11 for commercial standards and recommendations for transformers.)

5.2.1 Functions of Power Input Transformers

- (1) Provide ac supply voltage transformation
- (2) Isolate the converter output
- (3) Limit fault currents, and increase commutation impedance
- (4) Provide a center-point connection, where required

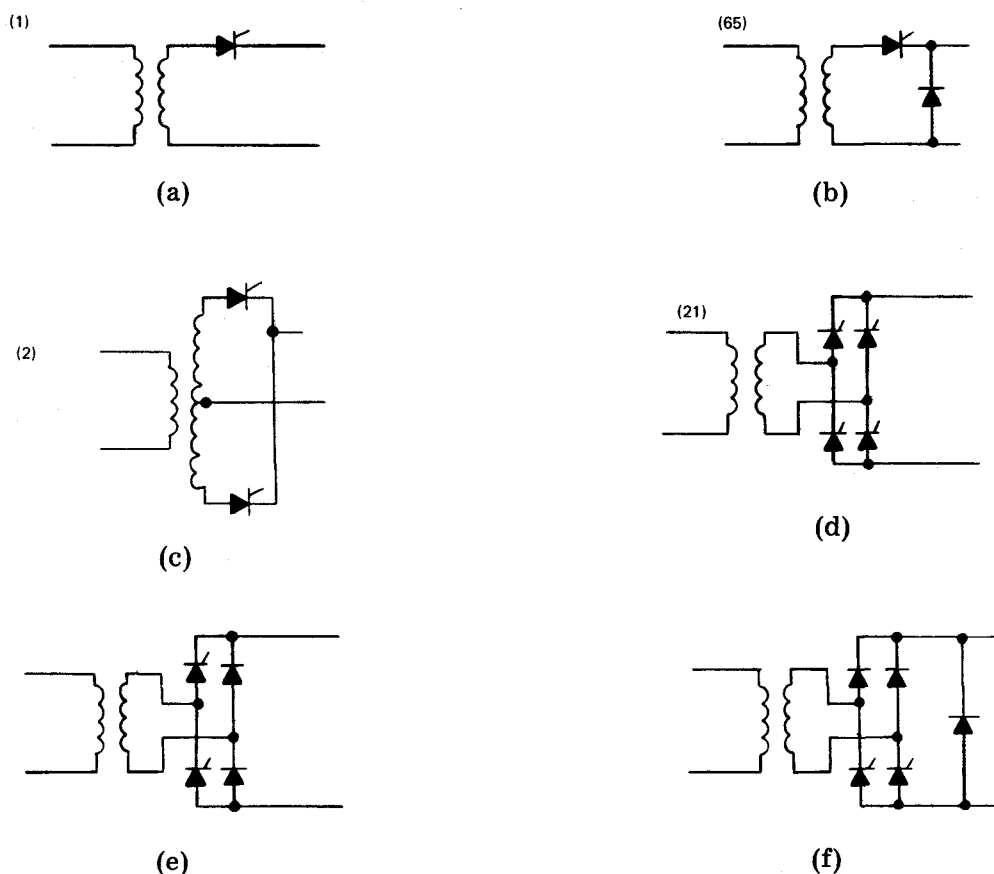
With due consideration to the requirements, many circuits can be used without transformers.

5.2.2 Currents in the Conductors and Transformer Windings. The transformer primary carries alternating current (see item (3) below). The secondary may carry either ac or dc or both as shown in (1) and (2) below.

(1) *Unidirectional Secondary Current.* The single-phase, single-way (half-wave) circuits shown in Figs 1(a) and 1(b) and the three-phase, single-way (half-wave) circuits shown in Figs 2(b) and 2(d), induce flux in one direction only in each leg of the transformer core and so require transformers sized or designed adequately to avoid saturation due to dc flux in the transformer core.

(2) *Bidirectional Secondary Current.* The single-phase, double-way (full-wave) circuits shown in Figs 1(c), 1(d), 1(e), and 1(f), and the three-phase, single-way (half-wave) zig-zag, and double-way (full-wave) circuits shown in Figs 2(a), 2(c), 2(e), 2(f), 2(g), and 2(h), result in cancellation of the dc component of flux in the transformer core.

(3) *RMS Currents.* The total rms currents carried by the transformer windings and the lines shown by Appendix A and in Tables 1 and 2 are based on the assumption of sufficient motor armature inductance to result in continuous motor current with negligible ripple. The total rms current is greater than the rms value of fundamental-frequency current because total rms current includes the effect of harmonic currents.



NOTE: Numbers in parenthesis indicate circuit numbers from [1].

Fig 1

Single-Phase Converter Circuits

- (a) Single Phase, Single Way (Half Wave), One Pulse (b) Single Phase, Single Way (Half Wave), One Pulse with Bypass Diode (c) Single Phase, Center Tap, Double Way (Full Wave), Two Pulse
(d) Single-Phase, Double-Way (Full-Wave), Fully-Controlled Bridge, Two Pulse
(e) Single-Phase, Double-Way (Full-Wave), Half-Controlled Bridge, Two Pulse
(f) Single-Phase, Double-Way (Full-Wave), Half-Controlled Bridge, Two Pulse, With Bypass Diode

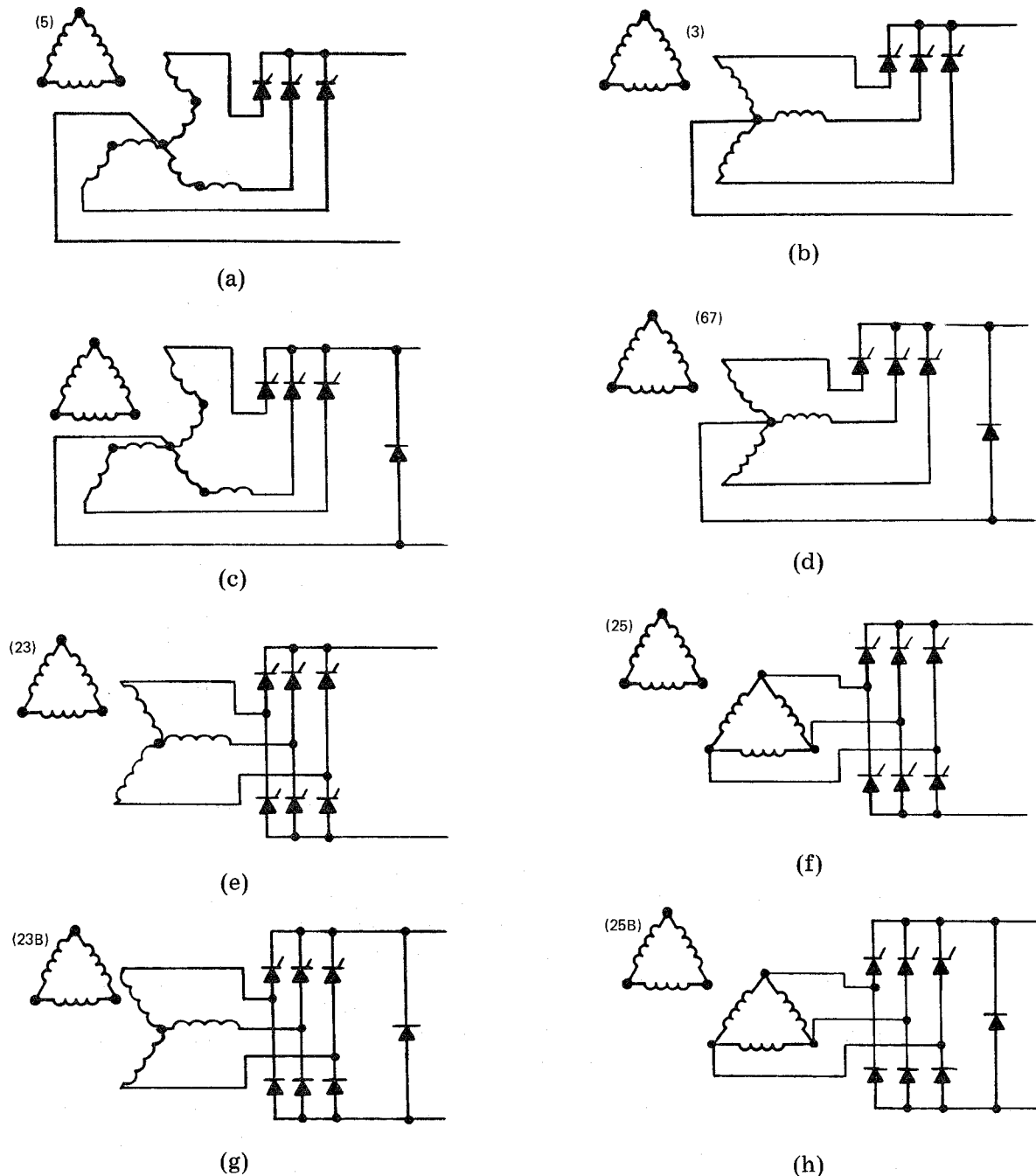
5.3 Load Current Ripple and Form Factor. Ripple in the direct current, which is particularly significant with single-phase circuits, increases rms current in the motor armature and transformer windings. The heating effect on the load is increased in proportion to the direct current form factor, which is the ratio of rms output current to the average direct current which produces motor torque.

Tables 1 and 2 show the dc output form factor for typical load L/R time constants.

5.4 Operating Quadrants. The operating quadrants are a graphical display of energy flow in a converter system as illustrated in Fig 3. The

four possible modes of energy flow are represented by the four quadrants relating the converter output voltage and current.

5.4.1 Single Quadrant. The circuits illustrated by Figs 1 and 2 are capable of operation with output current in one direction only. Those circuits with bypass diode paths [see Figs 1(b), 1(e), 1(f), and 2(c), 2(d), 2(g), 2(h)] are capable of operation with power flow only in the direction from ac to dc, and therefore with only one output voltage polarity. This corresponds only to Quadrant I of Fig 3. The remaining circuits [Figs 1(a), 1(c), 1(d) and 2(a), 2(b), 2(e), 2(f)] can transmit power from dc to ac by operation with reverse voltage in Quadrant IV (for



NOTES: (1) Numbers in parenthesis indicate circuit numbers from [1] and [15].
(2) Thyristors in (g) and (h) may be either in the positive or the negative leg.

Fig 2

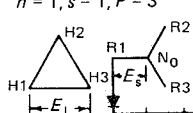
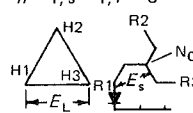
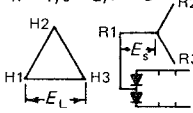
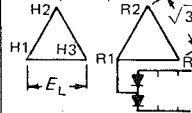
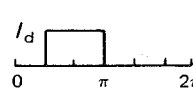
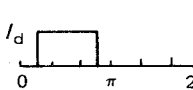
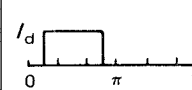
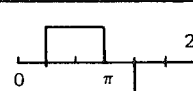
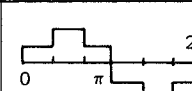
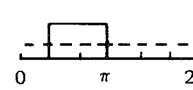
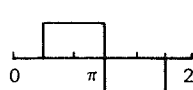
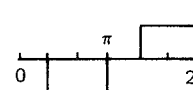
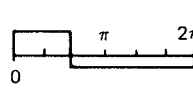
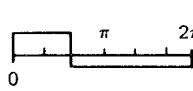
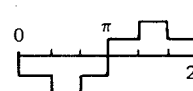
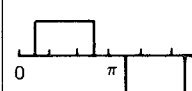
Three-Phase Converter Circuits

(a) Delta-Zigzag (Wye), Three Phase, Single Way (Half Wave), Three Pulse (b) Delta-Wye, Three Phase, Single Way, (Half Wave), Three Pulse (c) Delta-Zigzag (Wye), Three Phase, Single Way (Half Wave), Three Pulse with Bypass Diode (d) Delta-Wye, Three Phase, Single Way (Half Wave), Three Pulse with Bypass Diode (e) Delta-Wye, Three Phase, Double Way (Bridge), Six Pulse (f) Delta-Delta, Three Phase, Double Way (Bridge), Six Pulse (g) Delta-Wye, Three-Phase, Half-Controlled (Semiconverter) Bridge, Double Way, Six-Three Pulse with Bypass Diode (h) Delta-Delta, Three-Phase, Half-Controlled (Semiconverter) Bridge, Double Way, Six-Three Pulse with Bypass Diode

Table 1
Circuit Characteristics — Single Phase

Circuit Number and Name		(65) Single Phase, Single Way, (Half Wave), One Pulse with Bypass Diode	(2) Single Phase, Center Tap, Double Way, Full Wave, Two Pulse	(21) Single-Phase, Double-Way, (Full-Wave) Bridge
Number of Phases		1	1	1
Number of Pulses DC Output		1	2	2
Diagram				
Anode Current	Waveform			
	Average	$I_d/2$	$I_d/2$	$I_d/2$
	RMS	$\frac{I_d}{\sqrt{2}}$	$\frac{I_d}{\sqrt{2}}$	$\frac{I_d}{\sqrt{2}}$
Secondary AC Winding	Waveform	Same as Anode Current	Same as Anode Current	
	Form Factor	$\sqrt{2}$	$\sqrt{2}$	1.0
	RMS	$\frac{I_d}{\sqrt{2}}$	$\frac{I_d}{\sqrt{2}}$	I_d
	kVA Rating	$(1/\sqrt{2})I_d E_s \cdot 10^{-3}$	$(1/\sqrt{2})I_d E_s \cdot 10^{-3}$	$I_d E_s \cdot 10^{-3}$
Primary AC Line	Waveform			
	Form Factor	1.0	1.0	1.0
	RMS	$(1/2)I_d(E_s/E_L)$	$I_d(E_s/E_L)$	$I_d(E_s/E_L)$
	kVA Rating	$(1/\sqrt{2})I_d E_s \cdot 10^{-3}$	$I_d E_s \cdot 10^{-3}$	$I_d E_s \cdot 10^{-3}$
Typical DC Form Factor		1.9	1.4	1.4
at Load L/R (seconds)		0.015	0.015 to 0.02	0.015 to 0.02
DC Voltage E_{do}		$\frac{\sqrt{2}}{\pi} E_s$	$\frac{2\sqrt{2}}{\pi} E_s$	$\frac{2\sqrt{2}}{\pi} E_s$
Peak Inverse Voltage			$2.33 E_s$	$1.41 E_s$

Table 2
Circuit Characteristics — Three Phase

Circuit Number and Name		(3) Delta-Wye Three Phase, Single Way, ($\frac{1}{2}$ Wave), Three Pulse see Fig 2(b)	(5) Delta-Zigzag Three Phase, Single Way, ($\frac{1}{2}$ Wave), Three Pulse see Fig 2(a)	(23) Delta-Wye Three Phase, Double-Way Bridge, Six Pulse see Fig 2(e)	(25) Delta-Delta Three Phase, Double-Way Bridge, Six Pulse see Fig 2(f)
Number of Phases AC Winding		3	3	3	3
Number of Pulses DC Output		3	3	6	6
Phasor Diagram					
Anode Current	Wave Form				
	Average	$I_d/3$	$I_d/3$	$I_d/3$	$I_d/3$
	RMS	$I_d/\sqrt{3}$	$I_d/\sqrt{3}$	$I_d/\sqrt{3}$	$I_d/\sqrt{3}$
DC Winding	Wave Form	Same as Anode Current	Same as Anode Current		
	Form Factor	$\sqrt{3}$	$\sqrt{3}$	1.23	1.06
	RMS	$I_d/\sqrt{3}$	$I_d/\sqrt{3}$	$\sqrt{2} \cdot I_d/\sqrt{3}$	$\sqrt{2} \cdot I_d/3$
	kVA Rating	$2 I_d E_s \cdot 10^{-3}$	$2 I_d E_s \cdot 10^{-3}$	$\sqrt{6} I_d E_s \cdot 10^{-3}$	$\sqrt{6} I_d E_s \cdot 10^{-3}$
AC Winding	Wave Form				Same as DC Winding Current
	Form Factor	1.23	1.23	1.23	1.06
	RMS	$\frac{\sqrt{2}}{3} \cdot I_d \cdot \frac{E_s}{E_L}$	$\frac{\sqrt{2}}{3} \cdot I_d \cdot \frac{E_s}{E_L}$	$\sqrt{\frac{2}{3}} \cdot I_d \cdot \frac{E_s}{E_L}$	$\sqrt{\frac{2}{3}} \cdot I_d \cdot \frac{E_s}{E_L}$
	kVA Rating	$\sqrt{2} I_d E_s \cdot 10^{-3}$	$\sqrt{2} I_d E_s \cdot 10^{-3}$	$\sqrt{6} I_d E_s \cdot 10^{-3}$	$\sqrt{6} I_d E_s \cdot 10^{-3}$
AC Line	Wave Form				
	Form Factor	1.06	1.06	1.06	1.23
	RMS	$\sqrt{\frac{2}{3}} \cdot I_d \cdot \frac{E_s}{E_L}$	$\sqrt{\frac{2}{3}} \cdot I_d \cdot \frac{E_s}{E_L}$	$\sqrt{2} \cdot I_d \cdot \frac{E_s}{E_L}$	$\sqrt{2} \cdot I_d \cdot \frac{E_s}{E_L}$
	kVA Rating	$\sqrt{2} I_d E_s \cdot 10^{-3}$	$\sqrt{2} I_d E_s \cdot 10^{-3}$	$\sqrt{6} I_d E_s \cdot 10^{-3}$	$\sqrt{6} I_d E_s \cdot 10^{-3}$
DC Voltage E_{do}		$\frac{3}{\pi} \sqrt{\frac{3}{2}} E_s = 1.17 E_s$	$\frac{3}{\pi} \sqrt{\frac{3}{2}} E_s = 1.17 E_s$	$\frac{3\sqrt{6}}{\pi} E_s = 2.34 E_s$	$\frac{3\sqrt{6}}{\pi} E_s = 2.34 E_s$
Typical DC Form Factor at Load L/R (seconds)		1.2 0.015 to 0.03	1.2 0.015 to 0.03	1.05 0.015 to 0.05	1.05 0.015 to 0.05
Peak Inverse Voltage		$\sqrt{6} E_s$	$\sqrt{6} E_s$	$\sqrt{6} E_s$	$\sqrt{6} E_s$

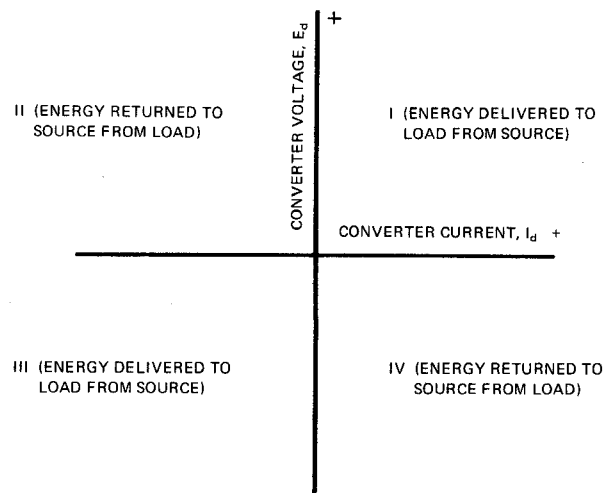


Fig 3
Converter Operating Quadrants

example, by reversal of the motor shunt connection), as well as from ac to dc by operation in Quadrant I.

Direction of motor rotation can be changed by switching to reverse the motor armature or the motor field, without changing the converter operating quadrant.

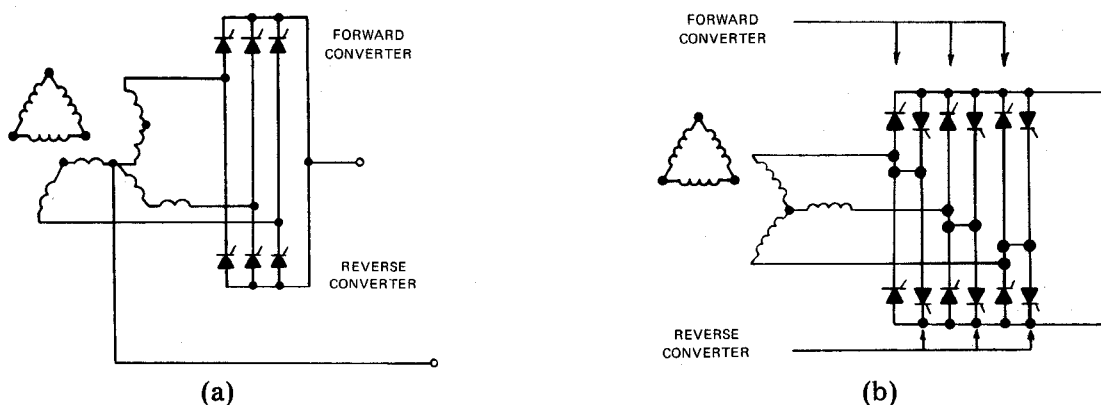
5.4.2 Two and Four Quadrant Reversing Drives. If reversal of motor torque is to be obtained without switching armature connections, a double converter or field reversal is required.

In a double converter the reverse converter section is typically identical to the forward section, except that semiconductor polarities are reversed (see Fig 4 for examples of the 4

quadrant versions of the 3-phase, single-way (half-wave) and double-way (full-wave) circuits). The two sections can share transformer windings. When each section can operate in two quadrants, the double converter can operate in all four quadrants: the forward section in Quadrants I and IV, and the reverse section in Quadrants II and III. (Conversely, a single converter can operate in Quadrants I and IV depending on motor connection.)

The name *regenerative* is applied to reversing drives in which the motor or load energy, or both, can be returned to the ac supply. The ac line, of course, must be capable of absorbing the power returned to it.

Fig 4
Reverse Connected (Dual) Converters for Four Quadrant Operation
(a) Delta-Zigzag (Wye), Three Phase, Single Way (Half Wave), Three Pulse Reversing (For Nonreversing Version see Fig 2(a).) (b) Delta-Wye, Three Phase, Double Way (Bridge), Six Pulse Reversing (For Nonreversing Version see Fig 2(b).)



6. General Requirements

Service conditions are all the external factors (ambient temperature, air humidity, character of ac source, etc) which may have an influence on the performance of a general-purpose power converter.

6.1 Usual Service Conditions. Equipment conforming with this standard shall be capable of operation under the following conditions:

6.1.1 AC Line Voltage Variation

6.1.1.1. The converter shall give rated performance when the steady state ac fundamental line voltage is between 95% and 110% of nominal ac line voltage, measured at the input terminals of the converter equipment or the input transformer, if included.

6.1.1.2. Uninterrupted operation shall result when the ac fundamental line voltage is between 90% and 95% of the rated value but specified performance may not be attained.

6.1.2 AC Source Characteristics. These define the worst conditions under which the drive will continue to function.

NOTE: Line disturbances may come from other controlled converters. See Fig 5 and Appendix B.

6.1.2.1 Repetitive AC Line Voltage Waveform. The drive shall continue to function under the following conditions, separately or simultaneously, when operating with a supply voltage of any value defined in 6.1.1.1.

(1) Repetitive peak deviations of the fundamental line voltage from the instantaneous value of the line voltage may not exceed 25% of the crest working line voltage (Fig 6). E_{LRM} is equal to or less than $1.25 E_{CW}$.

(2) Dips forming excursion of the instantaneous line voltage below 50% of the fundamental line voltage for not more than 100 μ s shall not prevent thyristor gate operation.

(3) The drive converter performance for subcycle voltage dips for longer durations than 100 μ s is dependent upon the particular industrial application and should be jointly reviewed by both purchaser and manufacturer.

6.1.2.2 Nonrepetitive Overvoltages. The drive is not necessarily required to maintain specified performance during the voltage deviations, but damage shall not result to any part of the converter or motor. Nonrepetitive over-

voltage (E_{LSM} in Fig 6) limits are to be defined later.

NOTE: The voltage E_{LSM} may originate from circuit breaker operation, atmospheric disturbances, line capacitor switching, etc. (See Appendix D for details.)

6.1.2.3 AC Source Impedance. Specified converter performance shall result when the source impedance lies within limits recommended by the manufacturer of the converter.

(1) *Minimum Source Impedance.* This impedance can be either series inductance or a transformer impedance. The minimum source impedance is governed by factors covered in Appendix E.

(2) *Maximum Source Impedance.* See Appendix E for discussion.

(3) *Maximum Fault Current.* The manufacturer shall specify the maximum symmetrical short-circuit current available at the system input terminals, in order not to damage any mechanical bracing or exceed the kVA fault rating of any overcurrent protection.

6.1.2.4 AC Line Frequency Variation. The controller shall give specified performance when the frequency of the line voltage is above and below nominal by 2% or less.

6.1.3 Temperature and Cooling Conditions

6.1.3.1 Ambient Temperature. Converter operation shall be within specification when room ambient temperature is between 0 °C (32 °F) and 40 °C (104 °F). The manufacturer may optionally offer modifications or a derated specification for use at temperatures outside this range.

6.1.3.2 Forced Cooling. The installer or user shall ensure that enough coolant at a temperature in the specified range is provided. The manufacturer shall provide information on the amount of coolant required.

6.1.3.3 Transformer Temperature. Transformer temperature rise is limited by the transformer insulation class and cooling type. (See Table 3.)

6.1.4 Altitude. The specifications apply when the altitude does not exceed 1000 m (3300 ft).

6.2 Environmental Recommendations

6.2.1 Unusual Service Conditions. The use of thyristor power converter equipment, associated drive control, and drive equipment under conditions departing from those in 6.1 shall be considered unusual.

Unusual conditions of the kind listed below may require special optional construction or

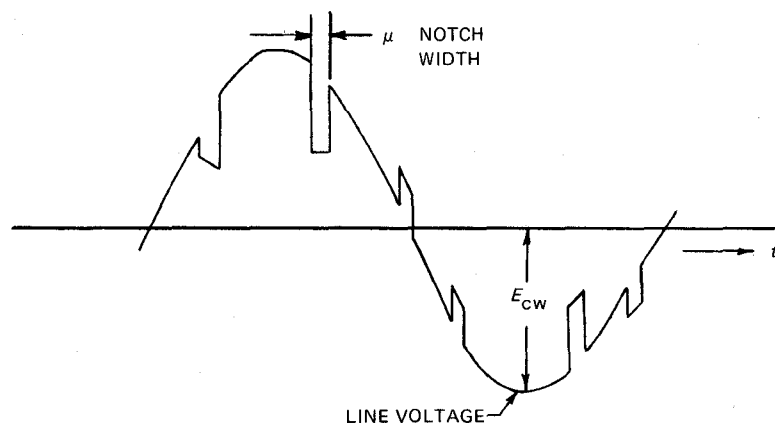


Fig 5
Line Interference

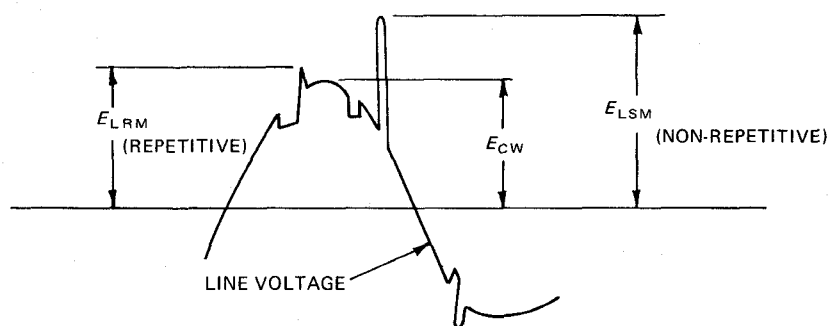


Fig 6
Line Voltage

Table 3
Transformer Characteristic Values

Transformer Duty Class	Long-Time Rating	Maximum RMS Duty Cycle (Per Unit)	Insulation Class			
			Liquid- Filled	105	120	Dry- Type
T ₁	—	1.00	55	65	80	150

NOTES: (1) The temperature ratings are based on a maximum ambient temperature of 40 °C with an average daily ambient temperature not exceeding 30 °C. If either maximum or average temperatures are to be exceeded, as in the case of indoor air cooled units, the temperature rise of the transformer at rated load

shall be reduced by 5 °C for an excess of 5 °C or less, or 10 °C for an excess of 10 °C or less.

(2) Currents in excess of 1.0 per unit may only be applied on a load cycle basis such that the rms loading does not exceed rating class in Section 10 including consideration that one transformer may supply several converters.

(3) Converter transformers shall carry *without injury* the ratings specified for the associated converter class when loaded in accordance with the provisions of item (2). Load cycles exceeding the rms 24 h values specified for the transformer rating class may result in significant reduction of transformer life.

(4) For approximate values of reduction of life at various loads and ambient temperatures, see [2], [5], and [14]. [2] and [5] are Appendixes to the American National Standard C57.12 series on transformers, regulators and reactors.