

Semiconductor devices: discrete devices and integrated circuits —

Part 1: Discrete devices —

Section 1.6 Recommendations for thyristors

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Committees responsible for this British Standard

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- British Broadcasting Corporation
- British Telecommunications
- Electronic Components Industry Federation
- Electronic Engineering Association
- Ministry of Defence
- National Supervising Inspectorate
- Telecommunication Engineering and Manufacturing Association (TEMA)

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- Electricity Supply Industry in England and Wales
- Engineering Equipment and Materials Users' Association
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National foreword

This British Standard has been prepared under the direction of the Electronic Components Standards Policy Committee. It is identical with IEC Publication 747-6:1983 “*Semiconductor devices. Discrete devices and integrated circuits — Part 6: Thyristors*”, as amended by Amendment 1:1991 and Amendment 2:1994, published by the International Electrotechnical Commission (IEC).

Terminology and conventions. The text of the International Standard has been approved as suitable for publication as a British Standard without deviation. Some terminology and certain conventions are not identical with those used in British Standards.

Cross-reference

International Standard	Corresponding British Standard
IEC 747-1:1983	BS 6493 <i>Semiconductor devices: discrete devices and integral circuits</i> Section 1.1:1984 <i>General</i> (Identical)

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to vi, pages 1 to 110 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.

Chapter I. General

1 Introductory note

As a rule, it will be necessary to use Publication 747-1 together with the present publication. In 747-1, the user will find all basic information on:

- terminology;
- letter symbols;
- essential ratings and characteristics;
- measuring methods;
- acceptance and reliability.

2 Scope

The present publication gives standards for the following category or sub-category of devices:

- reverse blocking triode thyristors;
- bidirectional triode thyristors (triacs);
- ambient-rated bidirectional diode thyristors (diacs);
- reverse conducting triode thyristors.

The sequence of the different chapters is in accordance with Publication 747-1, Chapter III, Sub-clause 2.1.

3 Marking of thyristors

Each thyristor shall be clearly and indelibly marked with the following information:

- manufacturer's name or identification;
- manufacturer's or supplier's type;
- marking to permit the distinction between anode, cathode and gate terminals.

Chapter II. Terminology and letter symbols

NOTE The terms followed by an asterisk (*) do not apply to bi-directional thyristors.

1 Types of thyristors

(See Figure 1 and Figure 2, page 4.)

Number of terminals	Behaviour in the third quadrant		
	Blocking	Conducting	Switching
2 (diode)	Reverse blocking diode thyristor	Reverse conducting diode thyristor	Bi-directional diode thyristor
2 (triode)	Reverse blocking triode thyristor	Reverse conducting triode thyristor	Bi-directional triode thyristor

1.1 Reverse blocking diode thyristor*

A two-terminal thyristor which for negative anode voltage does not switch, but exhibits a reverse blocking state.

1.2 Reverse blocking triode thyristor*

A three-terminal thyristor which for negative anode voltage does not switch, but exhibits a reverse blocking state.

1.2.1 Asymmetrical thyristor

A reverse blocking triode thyristor whose rated reverse voltage is significantly lower than its rated off-state voltage.

1.3 Reverse conducting diode thyristor*

A two-terminal thyristor which for negative anode voltage does not switch and conducts large currents at voltages comparable in magnitude to the forward on-state voltage.

1.4 Reverse conducting triode thyristor*

A three-terminal thyristor which for negative anode voltage does not switch and conducts large currents at voltages comparable in magnitude to the forward on-state voltage.

1.5 Bi-directional diode thyristor (diac)

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

1.6 Bi-directional trigger diode thyristor

A bi-directional diode thyristor with only three layers.

1.7 Bi-directional triode thyristor (triac)

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

1.8 Turn-off thyristor

A 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.

1.9 P-gate thyristor*

A thyristor in which the gate terminal is connected to the P-region nearest the cathode and which is normally switched to the on-state by applying a positive signal to the gate terminal with respect to the cathode terminal.

1.10 N-gate thyristor*

A thyristor in which the gate terminal is connected to the N-region nearest the anode and which is normally switched to the on-state by applying a negative signal to the gate terminal with respect to the anode terminal.

2 General terms

2.1 Main terminals

The two terminals through which the principal current flows.

2.2 Anode terminal*

The terminal to which forward current flows from the external circuit.

2.3 Cathode terminal*

The terminal from which forward current flows to the external circuit.

2.4 Main terminal 1 (of a bi-directional thyristor)

The main terminal which is named “1” by the manufacturer.

2.5 Main terminal 2 (of a bi-directional thyristor)

The main terminal which is named “2” by the manufacturer.

2.6 Gate terminal

A terminal to or from which only control current flows.

NOTE This control current is usually called the gate current.

2.7 Principal voltage

The voltage (potential difference) between the main terminals.

NOTE In the case of reverse blocking and reverse conducting thyristors, the principal voltage is called positive when the anode potential is higher than the cathode potential, and called negative when the anode potential is lower than the cathode potential. In the case of bi-directional thyristors, the polarity of the principal voltage (with regard to the main terminals) must be specified.

2.8 Principal current

The current which flows through the main terminals.

2.9 Anode-cathode voltage (abbreviation: anode voltage)*

The voltage (potential difference) between anode terminal and cathode terminal.

NOTE It is called positive when the anode potential is higher than the cathode potential, and called negative when the anode potential is lower than the cathode potential.

2.10 Principal (voltage-current) characteristic

A function, usually represented graphically, relating the principal voltage to the principal current, with the gate current, where applicable, as a parameter (see Figure 2, page 4, for bi-directional thyristors).

2.11 Anode-cathode (voltage-current) characteristic*

A function usually represented graphically relating the anode voltage to the principal current, with the gate current, where applicable, as a parameter (see Figure 1, page 4).

NOTE Where no confusion is likely to occur, the term can be abbreviated to “anode characteristic” or “characteristic”.

2.12 On-state

The condition of a thyristor corresponding to the low-resistance low-voltage portion of the principal characteristic.

NOTE In the case of reverse conducting devices, this definition is applicable only for positive anode voltages.

2.13 Off-state

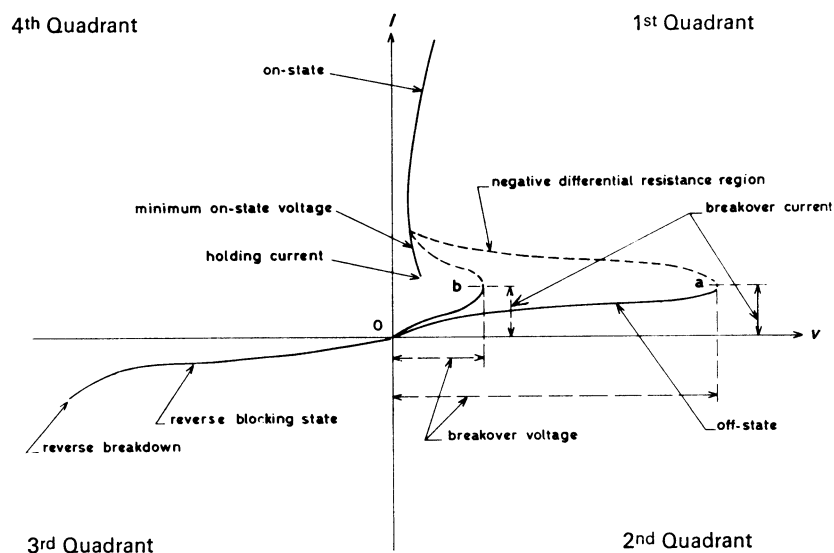
The condition of a thyristor corresponding to the portion of the principal characteristic between the origin and the breakover point or points.

2.14 Reverse blocking state*

The condition of a reverse blocking thyristor corresponding to the portion of the anode characteristic for reverse currents of lower magnitude than the current at the reverse breakdown voltage.

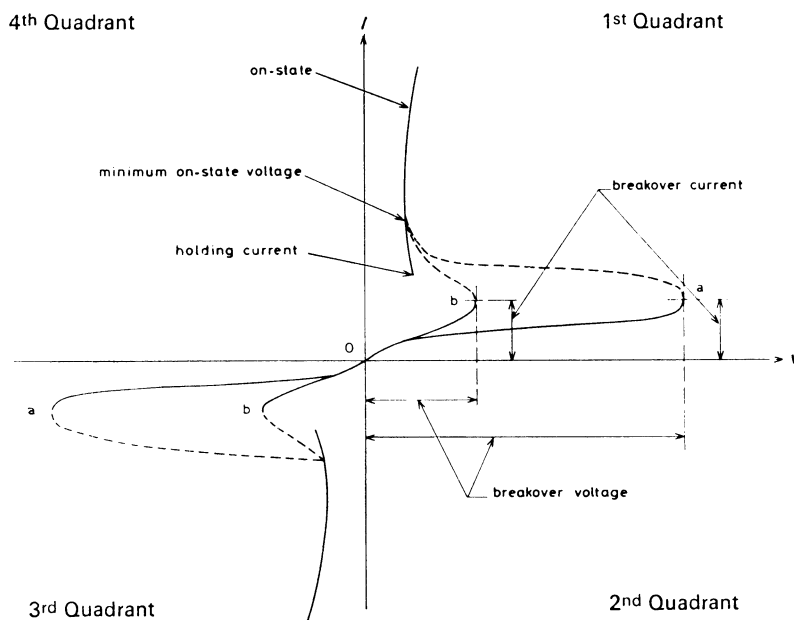
2.15 Negative differential resistance region

Any portion of the principal characteristic within which the differential resistance is negative.



NOTE Curve a corresponds to zero gate current or to a diode thyristor.
Curve b is with gate current present.

Figure 1 — Anode-cathode voltage-current characteristic for reverse blocking diode and triode thyristors



NOTE Curve a corresponds to zero gate current or to a diode thyristor.
Curve b is with the gate current present.

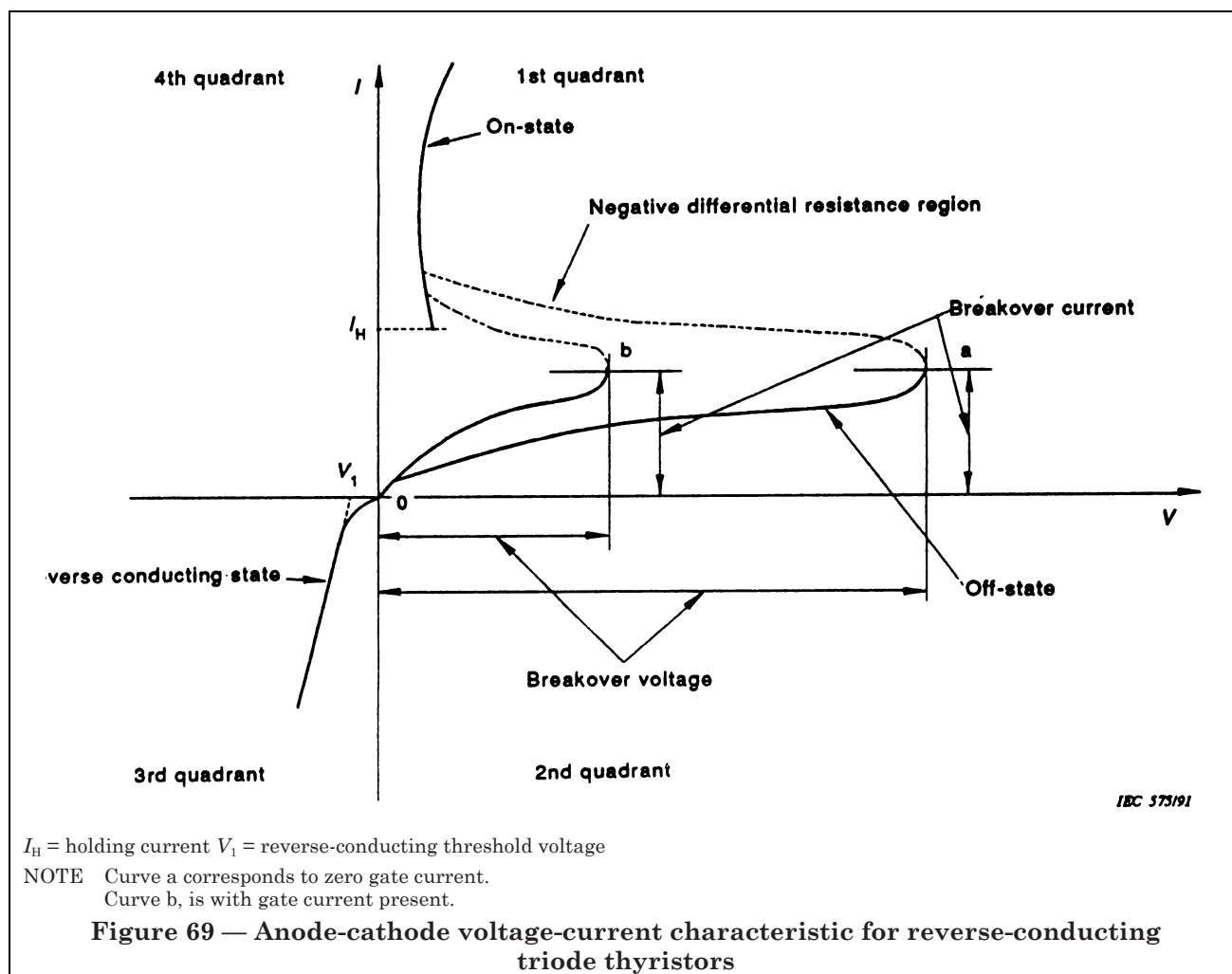
Figure 2 — Voltage-current characteristic for bi-directional diode and triode thyristors

2.16 Breakover point

Any point on the principal characteristic for which the differential resistance is zero and where the principal voltage reaches a maximum value.

2.17 Reverse-conducting triode thyristors

2.17.1



2.17.2 Reverse-conducting state

The condition of a reverse-conducting triode thyristor corresponding to the third quadrant portion of the anode-cathode characteristic.

2.18 Reverse-conducting current

The current that flows through a reverse-conducting thyristor when negative anode-to-cathode voltage is applied.

2.19 Mean reverse-conducting current

The mean value of the reverse-conducting current averaged over a full cycle.

2.20 Overload reverse-conducting current

The reverse-conducting current, whose continuous application would cause the maximum-rated virtual junction temperature to be exceeded, but that is limited in time such that this temperature is not exceeded.

NOTE Device may be subjected to overload reverse-conducting currents as frequently as called for by the application, while being subjected to normal operating voltages.

2.21 Surge reverse-conducting current

The reverse-conducting current, whose continuous application would cause the maximum-rated virtual junction temperature to be exceeded, but that is assumed to occur rarely and with a limited number of such occurrences during the service life of the device and to be a consequence of unusual circuit conditions (for example, a fault).

2.22 Reverse-conducting threshold voltage

The value of the reverse voltage obtained at the intersection of the straight line approximation of the reverse-conducting characteristic with the voltage axis.

2.23 Reverse-conducting slope resistance

The value of the resistance calculated from the slope of the straight line approximation of the reverse-conducting characteristic.

2.24 Reverse-conducting power dissipation

The power dissipation resulting from the flow of the reverse-conducting current.

2.25 Thermal resistance for on-state current (for a reverse conducting triode thyristor)

The temperature difference between two specified points or regions divided by the power dissipation caused by on-state current, under conditions of thermal equilibrium (see note of subclause 2.26).

2.26 Thermal resistance for reverse-conducting current

The temperature difference between two specified points or regions divided by the power dissipation caused by reverse-conducting current, under conditions of thermal equilibrium (see note).

NOTE In the case of the reverse-conducting thyristor, junction temperature varies within the silicon chip, because power dissipation due to on-state current (P_T) and that due to reverse-conducting current (P_{RC}) occurs in different places. (See Appendix B.)

3 Terms relating to ratings and characteristics

NOTE When several distinctive forms of a letter symbol exist, the most commonly used form is given (see Clause 4).

3.1 Principal voltages, anode-cathode voltages

3.1.1 *Forward voltage**

A positive anode voltage.

3.1.2 *Breakover voltage*

The principal voltage at the breakover point.

3.1.3 *Reverse voltage**

A negative anode voltage.

3.1.4 *Continuous (direct) reverse voltage** (V_R)

The value of the constant voltage applied to the thyristor when it is in the reverse blocking state.

3.1.5 *Reverse breakdown voltage (of a reverse blocking thyristor)** (V_{BR})

The reverse voltage at which the reverse current becomes greater than a specified value.

3.1.6 *Crest (peak) working reverse voltage (of a reverse blocking thyristor)** (V_{RWM})

The highest instantaneous value of the reverse voltage which occurs across the thyristor, excluding all repetitive and non-repetitive transient voltages (Note 1).

3.1.7 *Repetitive peak reverse voltage (maximum recurrent reverse voltage) (of a reverse blocking thyristor)** (V_{RRM})

The highest instantaneous value of the reverse voltage which occurs across the thyristor, including all repetitive transient voltages, but excluding all non-repetitive transient voltages (Note 1).

NOTE Preference should be given to the term “repetitive peak reverse voltage”.

3.1.8 Non-repetitive peak reverse voltage (peak transient reverse voltage) (of a reverse blocking thyristor)* (V_{RSM})

The highest instantaneous value of any non-repetitive transient reverse voltage which occurs across the thyristor (see note to Sub-clause 3.1.15).

NOTE Preference should be given to the term “non-repetitive peak reverse voltage”.

3.1.9 On-state voltage

The principal voltage when the thyristor is in the on-state.

3.1.10 Threshold voltage ($V_{T(To)}$)

The value of the on-state voltage obtained at the intersection of the straight line approximation of the on-state characteristic with the voltage axis.

3.1.11 Off-state voltage

The principal voltage when the thyristor is in the off-state.

3.1.12 Continuous (direct) off-state voltage (V_D)

The value of the constant voltage applied to the thyristor when it is in the off-state.

3.1.13 Crest (peak) working off-state voltage (V_{DWM})

The highest instantaneous value of the off-state voltage which occurs across the thyristor, excluding all repetitive and non-repetitive transient voltages (Note 1).

3.1.14 Repetitive peak off-state voltage (V_{DRM})

The highest instantaneous value of the off-state voltage which occurs across the thyristor including all repetitive transient voltages, but excluding all non-repetitive transient voltages (Note 1).

3.1.15 Non-repetitive peak off-state voltage (V_{DSM})

The highest instantaneous value of any non-repetitive transient off-state voltage which occurs across the thyristor (Note 1).

NOTE 1 A repetitive voltage is usually a function of the circuit and increases the power dissipation of the device. A non-repetitive transient voltage is usually due to an external cause and it is assumed that its effect has completely disappeared before the next transient arrives.

3.2 Principal currents, anode currents, cathode currents

3.2.1 Breakover current

The principal current at the breakover point.

3.2.2 Reverse current*

The principal current for negative anode voltage.

3.2.3 Reverse blocking current (of a reverse blocking thyristor)*

The reverse current when a reverse blocking thyristor is in the reverse blocking state.

3.2.4 Resistive reverse current

That part of the steady-state reverse current exclusive of the recovery current, if any.

3.2.5 Reverse recovery current (i_{RR})

That part of the reverse current which occurs during the reverse recovery time.

3.2.6 On-state current

The principal current when the thyristor is in the on-state.

3.2.7 Continuous (direct) on-state current (I_T)

The value of the constant on-state current.

3.2.8 Mean on-state current (of a reverse blocking thyristor)*

The mean value of the on-state current averaged over a full cycle.

3.2.9 R.M.S. on-state current (of a bi-directional thyristor)

The r.m.s. value of the on-state current for full cycle.

3.2.10 Repetitive peak on-state current (I_{TRM})

The peak value of the on-state current including all repetitive transient currents.

3.2.11 Overload on-state current (I_{ov})

A current, the continuous application of which would cause the maximum rated virtual temperature to be exceeded, but which is limited in time such that this temperature is not exceeded.

NOTE Devices may be subjected to overload currents as frequently as called for by the application, whilst being subjected to normal operating voltages.

3.2.12 Surge on-state current (I_{TSM})

A current the application of which causes the maximum rated virtual temperature to be exceeded, but which is assumed to occur rarely and with a limited number of such occurrences during the service life of the device and to be a consequence of unusual circuit conditions (e.g. fault conditions).

3.2.13 Latching current (I_L)

The minimum principal current required to maintain the thyristor in the on-state, immediately after switching from the off-state to the on-state, after the triggering signal has been removed.

NOTE The value of latching current is dependent on operating conditions.

3.2.14 Holding current

The minimum principal current required to maintain the thyristor in the on-state.

3.2.15 Off-state current

The principal current when the thyristor is in the off-state.

3.2.16 Peak case non-rupture current

The peak value of current that should not be exceeded in order to avoid bursting of the case or the emission of a plasma beam, under specified conditions of current, wave-shape and time.

NOTE This definition implies that a fine crack in the case might be found in a device subjected to the peak case non-rupture current, provided that no plasma beam was emitted. Parts of the case should not break away, nor should the device melt externally or burst into flames.

3.2.17 Case non-rupture I^2t

The value of I^2t that should not be exceeded in order to avoid bursting of the case or the emission of a plasma beam, under specified conditions of current, wave-shape and time, given as follows:

$$I^2t = \int_0^{t_w} I^2 dt$$

where t_w is the current pulse duration.

NOTE This definition implies that a fine crack in the case might be found in a device subjected to the case non-rupture I^2t , provided no plasma was emitted. Parts of the case should not break away, nor should the device melt externally or burst into flames.

3.3 Gate characteristics**3.3.1 Gate voltage**

The voltage between a gate terminal and a specified main terminal.

3.3.2 Forward gate voltage*

The negative gate-anode voltage for N-gate thyristors. The positive gate-cathode voltage for P-gate thyristors.

3.3.3 Peak forward gate voltage* (V_{FGM})

The highest instantaneous value of forward gate voltage including all transient voltages.

3.3.4 Reverse gate voltage*

The positive gate-anode voltage for N-gate thyristors. The negative gate-cathode voltage for P-gate thyristors.

3.3.5 Peak reverse gate voltage* (V_{RGM})

The highest instantaneous value of reverse gate voltage including all transient voltages.

3.3.6 Gate trigger voltage

The gate voltage required to produce the gate trigger current.

3.3.7 Gate non-trigger voltage

The highest gate voltage which will not cause the thyristor to switch from the off-state to the on-state.

3.3.8 Gate turn-off voltage

The gate voltage required to produce the gate turn-off current.

NOTE Not all thyristors can be turned off by the gate.

3.3.9 Forward gate current*

The gate current corresponding to the forward gate voltage.

3.3.10 Peak forward gate current* (I_{FGM})

The highest instantaneous value of forward gate current including all transient currents.

3.3.11 Reverse gate current*

The gate current corresponding to the reverse gate voltage.

3.3.12 Gate trigger current

The lowest gate current required to switch a thyristor from the off-state to the on-state.

3.3.13 Gate non-trigger current

The gate current corresponding to the gate non-trigger voltage.

3.3.14 Gate turn-off current

The lowest gate current required to switch a thyristor from the on-state to the off-state.

NOTE Not all thyristors can be turned off by the gate.

3.4 Power dissipation**3.4.1 Reverse power dissipation (of a reverse conducting triode thyristor) (P_{R})**

The power dissipation resulting from the flow of the reverse current.

3.4.2 On-state power dissipation (P_{T})

The power dissipation resulting from the flow of on-state current.

3.4.3 Mean on-state power dissipation

The mean value of the product of the instantaneous on-state voltage and the instantaneous on-state current averaged over a full cycle.

3.4.4 Turn-on dissipation

The power dissipated within the thyristor during the change between off-state and on-state, when the thyristor is switched from an off-state voltage to an on-state current.

3.4.5 Turn-off dissipation

The power dissipated within the thyristor during the change between on-state and off-state or reverse blocking state, when the thyristor is switched from an on-state current to an off-state voltage or to a reverse blocking voltage.

3.5 Other characteristics**3.5.1 Straight line approximation of the on-state characteristic**

An approximation of the voltage versus current on-state characteristic by means of a straight line which crosses this characteristic at two specified points.

3.5.2 On-state slope resistance (r_{T})

The value of the resistance calculated from the slope of the straight line approximation of the on-state characteristic.

3.5.3 Thermal resistance (R_{th})

Under consideration.

3.5.4 Transient thermal impedance ($Z_{(th)t}$)

Under consideration.

3.5.5 Virtual junction temperature (T_{vj})

Under consideration.

3.5.6 Reverse recovery time (of a reverse blocking thyristor) (t_{rr})

The time interval between the instant when the current passes through zero, when changing from the on-state to the reverse blocking state, and the instant when the reverse current is reduced from its peak value I_{RM} to a specified low value (as shown in Figure 3), or when the extrapolated reverse current reaches zero (as shown in Figure 4).

NOTE The extrapolation is carried out with respect to specified points A and B, as shown in generalized form in Figure 4.

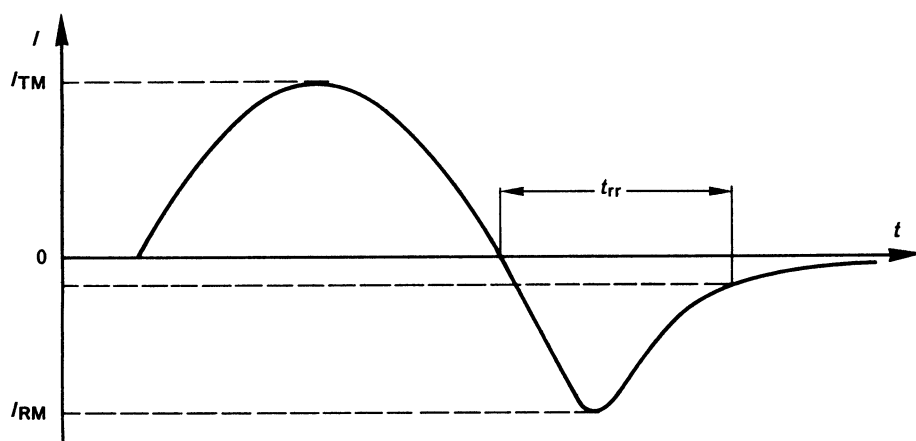


Figure 3

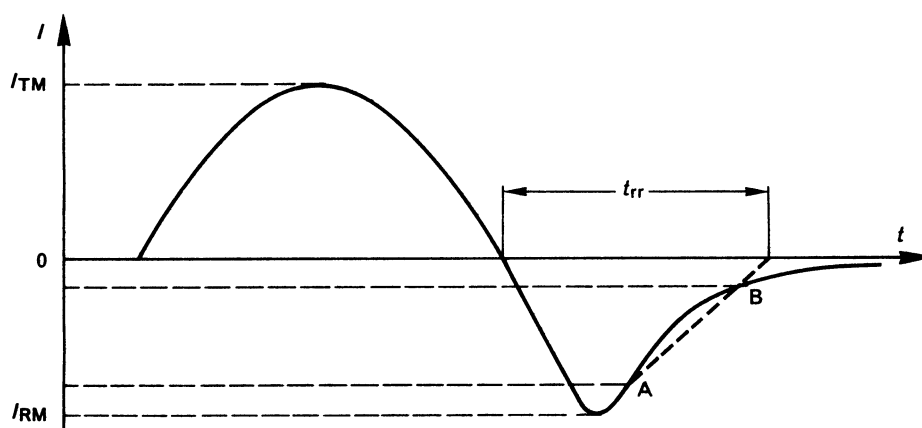
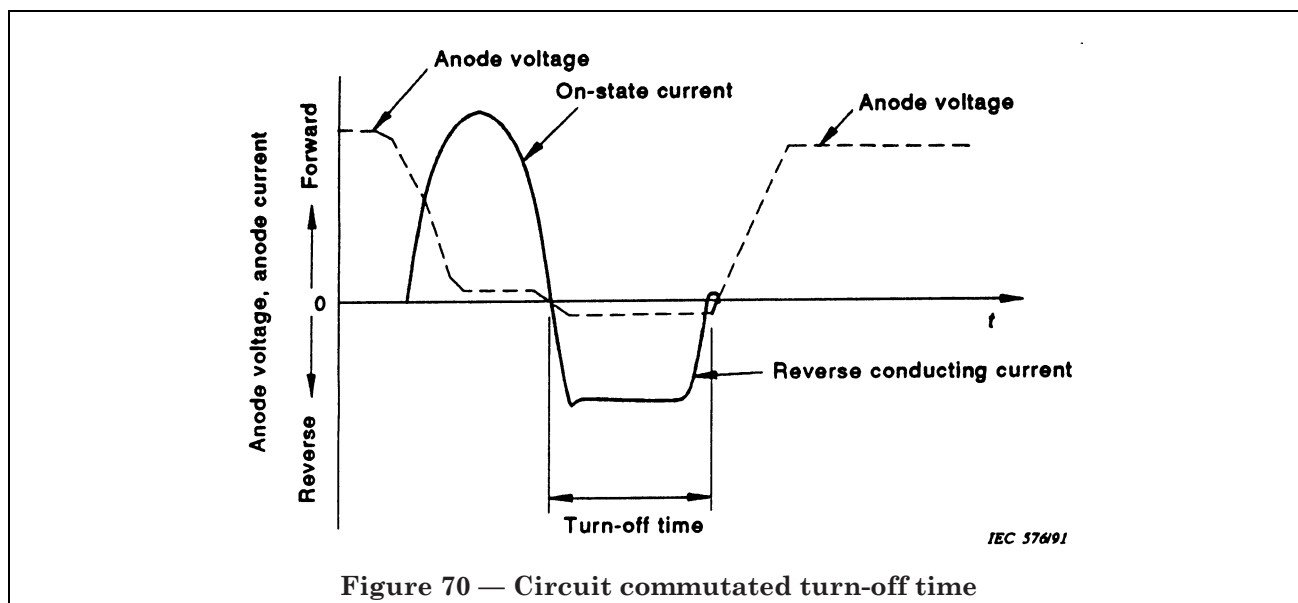


Figure 4

3.5.7 Circuit commutated turn-off time (t_q)

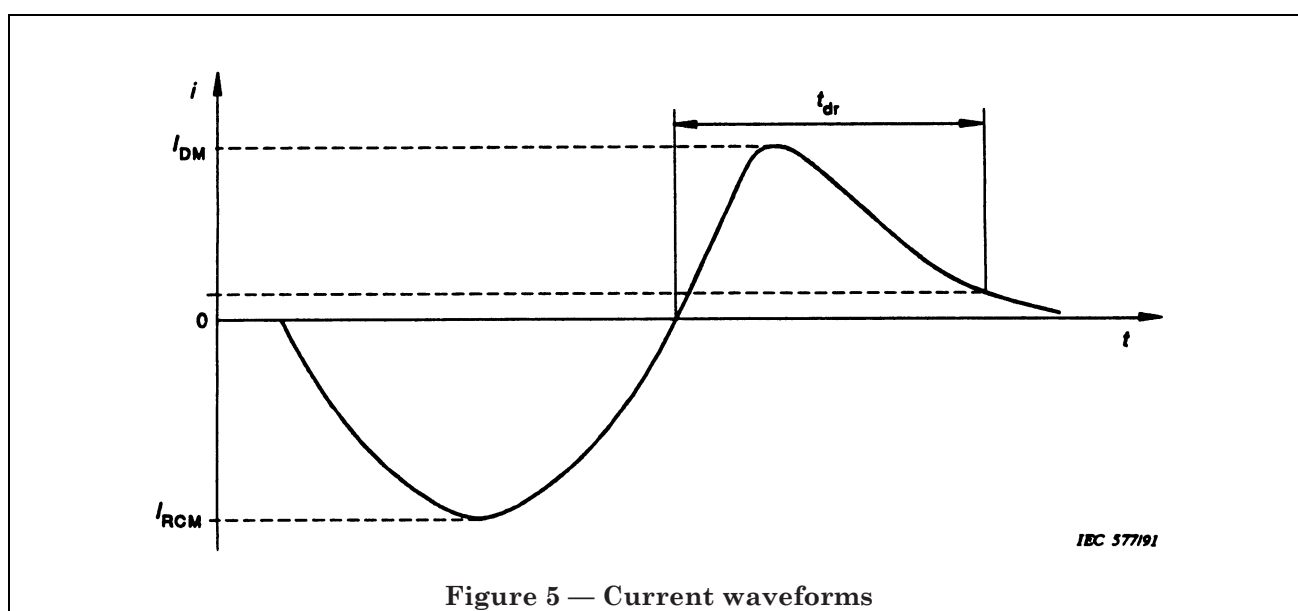
The minimum time interval between the instant when the on-state current has decreased to zero after external switching of the anode voltage circuit, and the earliest instant when the specified anode voltage, which the thyristor is capable of supporting without turning on, passes through zero (as shown in Figure 70).



3.5.8 Off-state recovery time (of a reverse-conducting thyristor)

The time interval between the instant when the current passes through zero, when changing from the reverse-conducting state to the off-state condition, and the instant when the off-state current is reduced from its peak value I_{DM} to a specified low value (as shown in Figure 5) or when the extrapolated off-state current reaches zero (as shown in Figure 6).

NOTE The extrapolation is carried out with respect to specified points A and B as shown in generalized form in Figure 6.



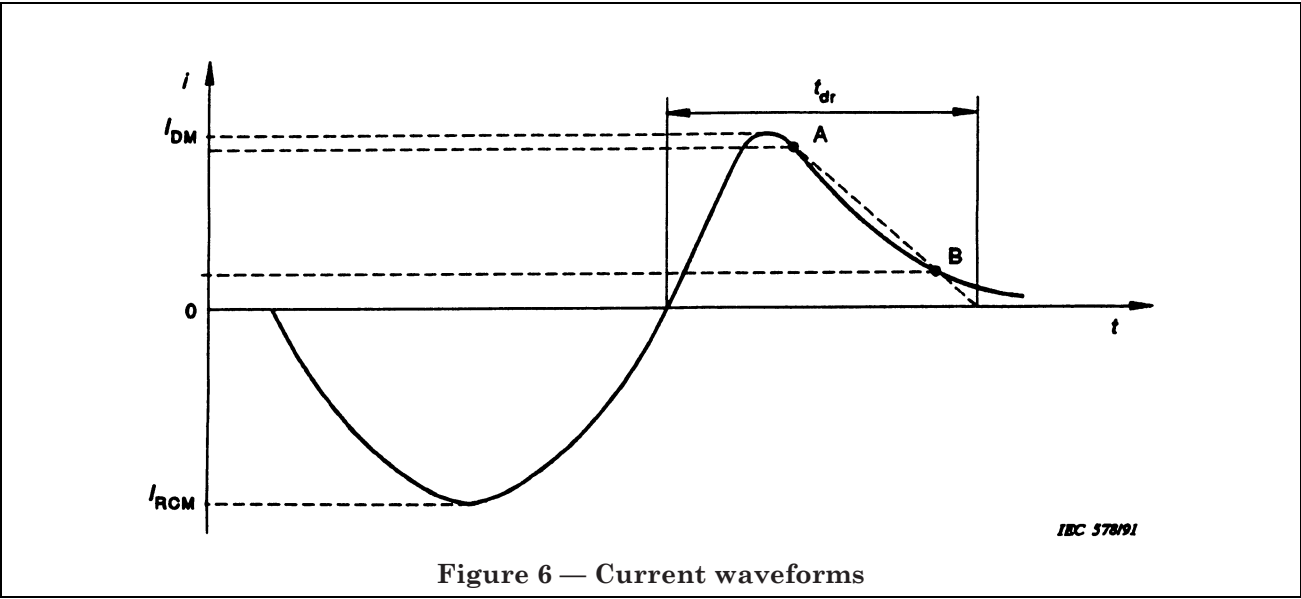


Figure 6 — Current waveforms

3.5.9 Hold-off interval (t_H)

The interval between the instant when the principal current of the semiconductor devices of a convertor valve has decreased to zero and the instant when the same semiconductor devices are subjected to off-state voltage.

NOTE The hold-off interval should exceed the circuit commutated turn-off time of the semiconductor devices. Both of them depend on the service conditions of the convertor.

3.5.10 Gate controlled turn-on time (t_{gt})

The time interval during which the thyristor is switching from the off-state to the on-state as a result of the application of a gate trigger pulse.

NOTE The interval is usually measured from a specified point at the beginning of the gate pulse to the instant at which the principal voltage has dropped from its initial value to a specified value. The turn-on time is the sum of the delay time and the rise time.

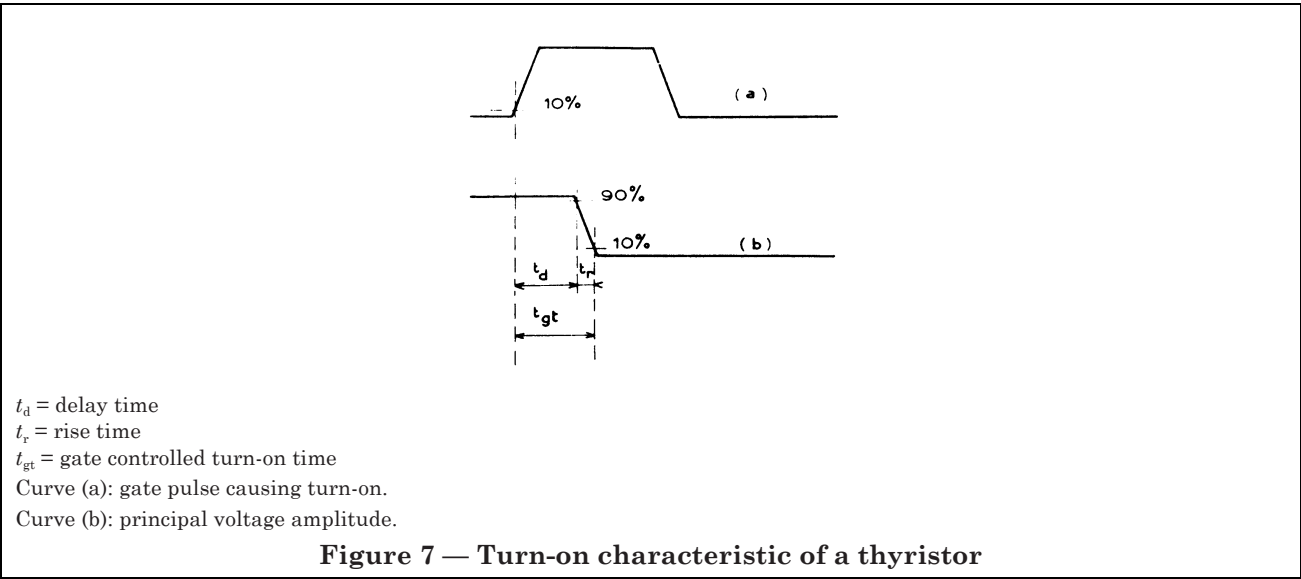


Figure 7 — Turn-on characteristic of a thyristor

3.5.11 Gate controlled delay time (t_{gd}), (t_d)

The time interval between a specified point at the beginning of the gate pulse and the instant at which the principal voltage has dropped to a specified value, near its initial value, during the switching of a thyristor from the off-state to the on-state by a gate pulse.

NOTE Where no confusion is likely to occur, the term can be abbreviated to “delay time”.

3.5.12 Gate controlled rise time (t_{gr}), (t_r)

The time interval between the instant when the principal voltage has dropped from a specified value, near its initial value, and the instant when it reaches a specified low value, during the switching of a thyristor from the off-state to the on-state by a gate pulse.

NOTE Where no confusion is likely to occur, the term can be abbreviated to “rise time”.

3.5.13 Gate controlled turn-off time (t_{go}), (t_{gt})

The time interval between the application at the gate terminal of a pulse of a specified waveform, which pulse switches the thyristor from its on-state to its off-state, and the instant when the principal current has decreased to a specified value, the circuit conditions being specified.

NOTE Not all thyristors can be turned off by the gate.

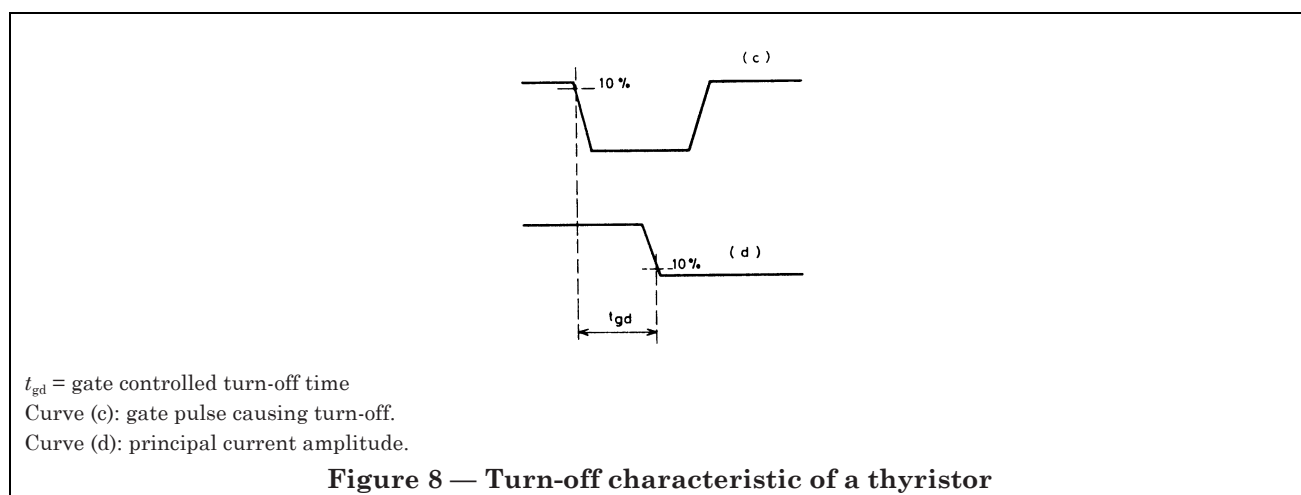


Figure 8 — Turn-off characteristic of a thyristor

3.5.14 Critical rate of rise of on-state current

The highest value of the rate of rise of on-state current which a thyristor can withstand without deleterious effect.

3.5.15 Critical rate of rise of off-state voltage

The highest value of the rate of rise of voltage that will not cause switching from the off-state to the on-state under specified conditions.

3.5.16 Critical rate of rise of commutating voltage (of a reverse-conducting thyristor)

The highest value of the rate of rise of principal voltage, immediately following reverse-conducting current conduction, that will not cause switching from the off-state to the on-state.

3.5.17 Critical rate of rise of commutating voltage (of a triac) or: Critical rate of rise of the reapplied off-state voltage (of a triac)

The highest value of the rate of rise of principal voltage, immediately following on-state current conduction in the opposite direction, that will not cause switching from the off-state to the on-state.

3.5.18 Recovered charge (Q_r)

The total charge recovered from the thyristor during a specified integration time after switching from a specified on-state current condition to a specified reverse condition:

$$Q_r = \int_{t_0}^{t_0 + t_1} i_R \cdot dt$$

where:

t_0 is the instant when the current passes through zero, and

t_1 is the specified integration time (see Figure 71).

NOTE This charge includes components due to both carrier storage and depletion layer capacitance.

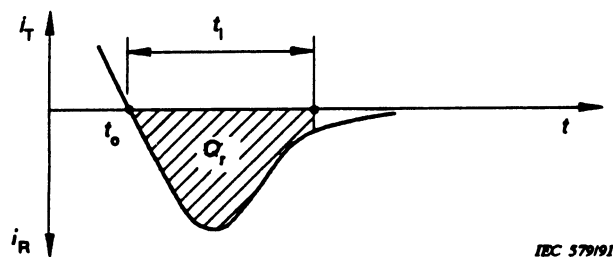


Figure 71 — Recovered charge

3.5.19 Off-state recovered charge (of a reverse conducting thyristor)

The total charge recovered from the thyristor after switching from a specified reverse-conducting current condition to a specified off-state condition.

4 Letter symbols

4.1 General

The general rules of Publication 747-1, Chapter V, are applicable in part.

4.2 Additional general subscripts

In addition to the list of recommended general subscripts given in Publication 747-1, Chapter V, the following special subscripts are recommended for the field of thyristors:

4.2.1 For currents, voltages and powers

(See also Sub-clause 2.2.1 of Publication 747-1, Chapter V)

A, a = anode

K, k = cathode

G, g = gate

D, d = off-state, non-trigger

T, t = on-state, trigger

H, h = holding

(BO) = breakover

Q, q = turn-off

(TO) = threshold.

RC = reverse conducting state (for reverse-conducting triode thyristors)

4.2.2 For electrical parameters

(See also Sub-clause 2.2.2 of Publication 747-1, Chapter V)

t = turn-on

q = turn-off

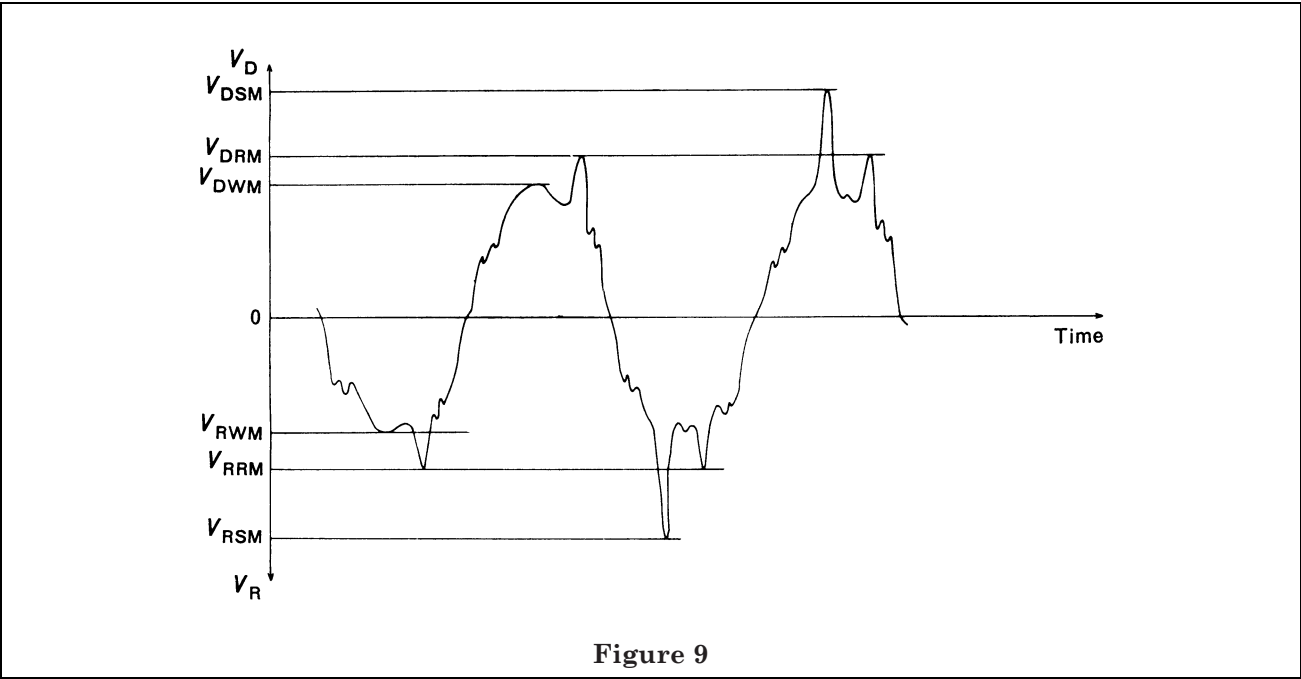
T = slope.

4.3 List of letter symbols

The symbols contained in the following lists are recommended for use in the field of thyristors; they have been compiled in accordance with the general rules.

4.3.1 Principal voltages, anode-cathode voltages

Name and designation	Letter symbol	Remarks
Continuous (direct) off-state voltage	V_D	
Peak off-state voltage	V_{DM}	
Crest (peak) working off-state voltage	V_{DWM}	
Repetitive peak off-state voltage	V_{DRM}	
Non-repetitive peak off-state voltage	V_{DSM}	
Breakover continuous (direct) voltage	$V_{(BO)}$	
Continuous (direct) on-state voltage	V_T	
Minimum on-state voltage	V_{TMIN}	
On-state threshold voltage	$V_{T(TO)}$	
Continuous (direct) reverse voltage	V_R	
Crest (peak) working reverse voltage	V_{RWM}	
Repetitive peak reverse voltage	V_{RRM}	
Non-repetitive peak reverse voltage	V_{RSM}	
Reverse breakdown voltage	$V_{(BR)}$	
Reverse conducting threshold voltage	$V_{RC(TO)}$	



4.3.2 Principal currents, anode currents, cathode currents

Name and designation	Letter symbol	Remarks
Continuous (direct) off-state current	I_D	
Continuous (direct) breakover current	$I_{(BO)}$	
Continuous (direct) holding current	I_H	
Continuous (direct) on-state current	I_T	
Overload on-state current	$I_{(OV)}$	
Repetitive peak on-state current	I_{TRM}	
Surge (non-repetitive) on-state current	I_{TSM}	
Continuous (direct) reverse blocking current	I_R	
Repetitive peak reverse current	I_{RRM}	
Reverse recovery current	i_{RR}	
Latching current	I_L	
Continuous reverse-conducting current	I_{RC}	
Mean reverse-conducting current	$I_{RO(AV)}$	
Peak reverse-conducting current	I_{RCM}	
Overload reverse-conducting current	$I_{RC(OV)}$	
Surge reverse-conducting current	I_{RCSM}	

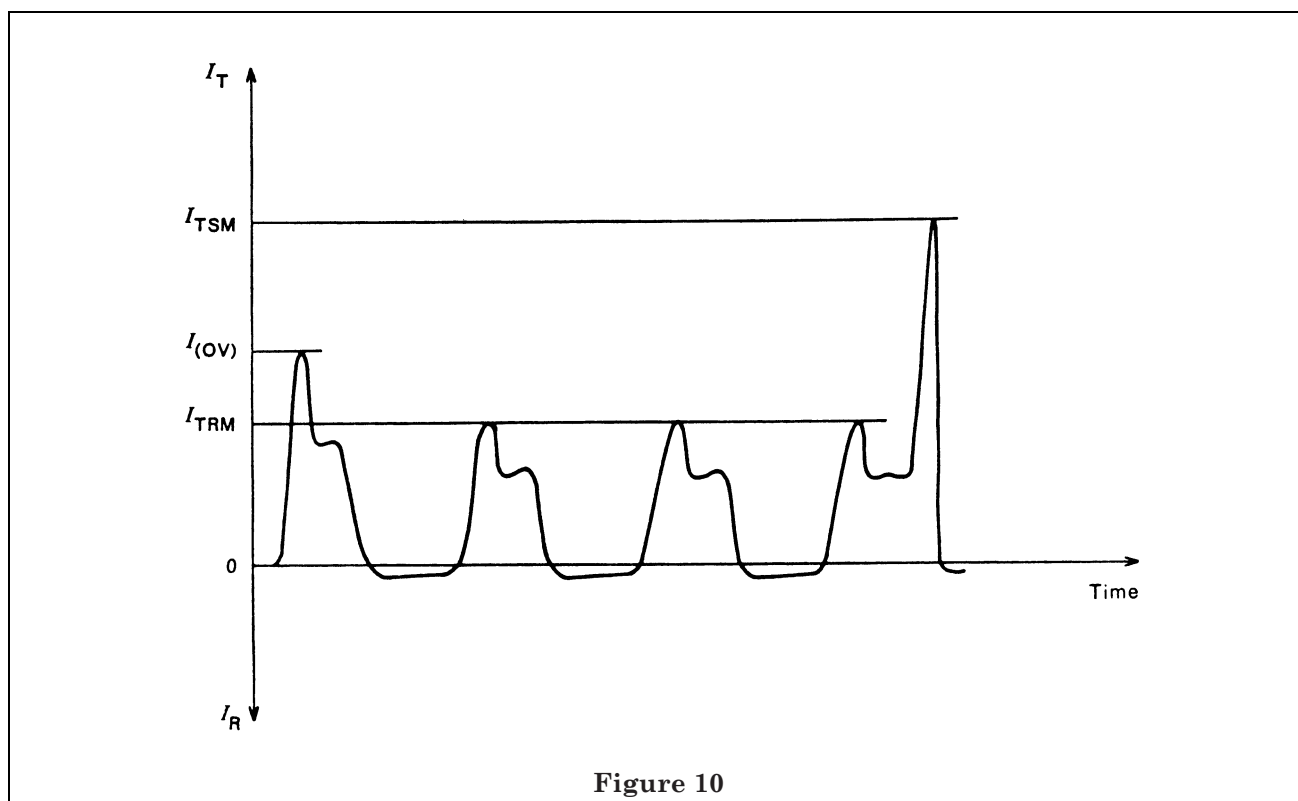


Figure 10

4.3.3 Gate voltages

Name and designation	Letter symbol	Remarks
Forward gate continuous (direct) voltage	V_{FG}	
Peak forward gate voltage	V_{FGM}	
Reverse gate continuous (direct) voltage	V_{RG}	
Peak reverse gate voltage	V_{RGM}	
Gate trigger continuous (direct) voltage	V_{GT}	
Minimum gate trigger voltage	V_{GTMIN}	
Gate non-trigger continuous (direct) voltage	V_{GD}	
Gate turn-off continuous (direct) voltage	V_{GQ}	

4.3.4 Gate currents

Name and designation	Letter symbol	Remarks
Forward gate continuous (direct) current	I_{FG}	
Peak forward gate current	I_{FGM}	
Reverse gate continuous (direct) current	I_{RG}	
Gate trigger continuous (direct) current	I_{GT}	
Gate non-trigger continuous (direct) current	I_{GD}	
Gate turn-off continuous (direct) current	I_{GQ}	

4.3.5 Time quantities

Name and designation	Letter symbol	Remarks
Gate controlled turn-on time	t_{gt}	
Gate controlled turn-off time	t_{gq}	
Circuit commutated recovery time (circuit commutated turn-off time)	t_q	
Gate-controlled delay time	$t_{gd}, (t_d)$	t_d and t_r are to be used only when misinterpretation will not result
Gate-controlled rise time	$t_{gr}, (t_r)$	t_d and t_r are to be used only when misinterpretation will not result
Off-state recovery time	t_{dr}	For reverse conducting triode thyristors
Hold-off interval	t_H	

4.3.6 Sundry quantities

Name and designation	Letter symbol	Remarks
On-state slope resistance	r_T	
Critical rate of rise of commutating voltage	$dv/dt (c), [dv/dt (com)]$	For reverse conducting triode thyristors, $dv/dt (c)$ is the preferred symbol
Off-state recovered charge	Q_{dr}	For reverse conducting triode thyristors
Total energy of on-state current pulse	E_P W_P	
Reverse-conducting slope resistance	r_{RC}	
Thermal resistance for on-state current	$R_{th(T)}$	
Thermal resistance for reverse-conducting current	$R_{th(RC)}$	

4.3.7 Power dissipation

Name and designation	Letter symbol	Remarks
On-state power dissipation	P_T	
Reverse power dissipation	P_R	For reverse blocking and conducting triode thyristors
Off-state power dissipation	P_D	
Turn-on dissipation: — average turn-on dissipation — total instantaneous turn-on dissipation — peak turn-on dissipation	$P_{TT(AV)}$ P_{TT} P_{TTM}	
Turn-off dissipation: — average turn-off dissipation — total instantaneous turn-off dissipation — peak turn-off dissipation	$P_{RQ(AV)}$ or $P_{DQ(AV)}$ p_{RQ} or p_{DQ} P_{RQM} or P_{DQM}	
Reverse-conducting power dissipation	P_{RC}	

Chapter III. Essential ratings and characteristics

Section 1. Reverse-blocking triode thyristors

1 General

1.1 Range of application

This section gives standards for reverse-blocking triode thyristors, which may be either of the P-gate or the N-gate types.

Turn-off thyristors are not specifically covered by these standards. The term “reverse-blocking triode thyristor” has been abbreviated in the text to a “thyristor”.

1.2 Rating methods

Thyristors shall be specified as ambient-rated devices or as case-rated devices.

At higher frequencies, the current ratings of *fast-switching thyristors* depend on the on-state, turn-on, turn-off and gate-power dissipation in a rather complicated way. Therefore, ratings dependent on frequency are necessary.

Besides the current ratings given for a specified case temperature, the average power dissipation must be known to calculate the cooling conditions necessary. For this calculation, the average power dissipation or the total energy dissipation for one pulse shall be given. If the energy dissipation per pulse is given, the average power dissipation is obtained by multiplying it by the repetition frequency.

1.3 Recommended temperatures

Many of the ratings and characteristics are required to be quoted at a temperature of 25 °C and at one other specified temperature. Unless otherwise stated, the one other specified temperature shall be chosen by the manufacturer from the list in IEC 747-1; in addition, temperatures of – 40 °C and + 35 °C may be used.

2 Rating conditions

The ratings given in clause 3 shall be stated under one or more of the following thermal conditions.

2.1 Ambient-rated thyristors

2.1.1 Natural convection

At 25 °C and at one higher temperature (see 1.3). The cooling fluid and pressure (in the case of a gas) shall be specified.

Air pressure shall be at least 90 kPa (900 mbar), corresponding to a maximum level of 1 000 m above sea-level.

2.1.2 Forced circulation

At a temperature taken from the list of recommended temperatures (see 1.3). The type, pressure and flow of the cooling fluid shall be specified.

2.2 Case-rated thyristors

At a case temperature taken from the list of recommended temperatures (see 1.3).

NOTE For small thyristors, the temperature on one of the terminals may be specified.

3 Voltage and current ratings (limiting values)

The following ratings must be valid for the whole range of operating conditions as stated for the particular device.

3.1 Anode-cathode voltages

3.1.1 Non-repetitive peak reverse voltage (V_{RSM})

Maximum rated value. If this value has to be derated at higher operating frequencies, the derating factor or curve shall be given.

3.1.2 Repetitive peak reverse voltage (V_{RRM})

Maximum rated value. If this value has to be derated at higher operating frequencies, the derating factor or curve shall be given.

3.1.3 Crest (peak) working reverse voltage (V_{RWM}) (where appropriate)

Maximum rated value of a repetitive reverse voltage having a half-wave sinusoidal wave-form at mains frequency, usually 50 Hz or 60 Hz (duration: 10 ms or 8,3 ms).

3.1.4 Continuous (direct) reverse voltage (where appropriate)

Maximum rated value.

3.1.5 Non-repetitive peak off-state voltage (V_{DSM})

Maximum rated value. If this value has to be derated at higher operating frequencies, the derating factor or curve shall be given.

3.1.6 Repetitive peak off-state voltage (V_{DRM})

Maximum rated value. If this value has to be derated at higher operating frequencies, the derating factor or curve shall be given.

3.1.7 Crest (peak) working off-state voltage (V_{DWM}) (where appropriate)

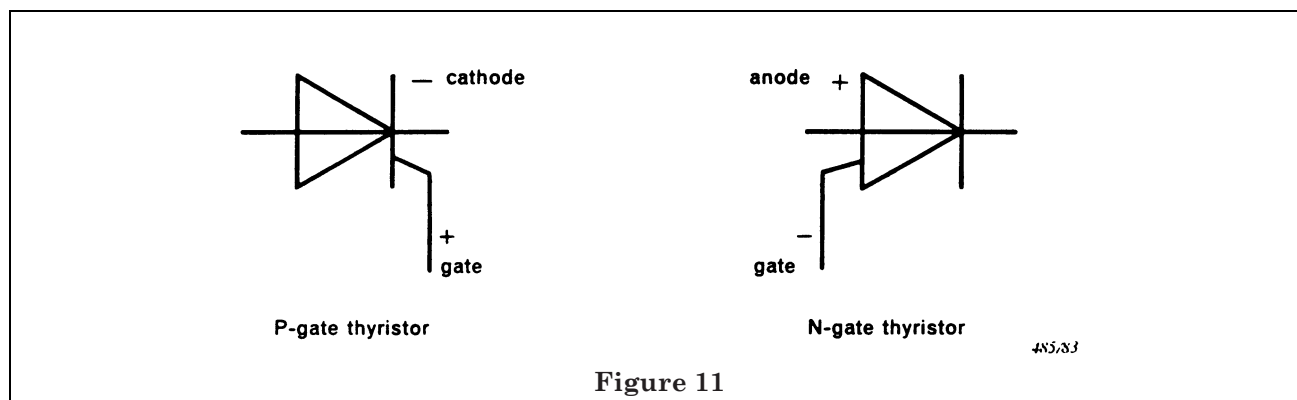
Maximum rated value of a repetitive off-state voltage having a half-wave sinusoidal waveform at mains frequency, usually 50 Hz or 60 Hz (duration: 10 ms or 8,3 ms).

3.1.8 Continuous (direct) off-state voltage (where appropriate)

Maximum rated value under specified conditions of control signal and gate-circuit impedance.

3.2 Gate voltages

Gate voltages are applied between gate and cathode terminals of a P-gate thyristor (gate positive for a forward-gate voltage), and between anode and gate terminals of an N-gate thyristor (anode positive for a forward-gate voltage).

**3.2.1 Peak forward-gate voltage (anode positive with respect to cathode)**

Maximum rated value.

3.2.2 Peak forward-gate voltage (anode negative with respect to cathode)

Maximum rated value.

3.2.3 Peak reverse-gate voltage (where appropriate)

Maximum rated value.

3.3 On-state current**3.3.1 Mean on-state current**

The maximum rated values shall be specified in a diagram showing the mean on-state current for continuous operation with half-sine waves of 180° conduction angle and with rectangular pulses of various conduction angles, at least 180° and 120°, at 50 Hz or 60 Hz, versus ambient or case temperature.

As a reference value for certain characteristics (clause 7), the maximum rated value for half-sine waves of 180° conduction angle at 45 °C ambient or 85 °C case temperature should be given as a figure.

NOTE The maximum rated value of the mean on-state current is given on the assumption that no overload occurs.

3.3.2 Repetitive peak on-state current (where appropriate)

Maximum rated value for continuous operation. This rating should be expressed with relation to the on-state current conduction angle, cooling conditions and operating frequency.

3.3.3 R.M.S. on-state current (where appropriate)

Maximum rated value for continuous operation.

3.3.4 Overload on-state current

Where this rating is appropriate, it shall be given by stating the maximum virtual junction temperature and the maximum transient thermal impedance. In addition, overload current ratings may be given by means of diagrams.

3.3.5 Surge on-state current

This rating shall be given at initial conditions corresponding to maximum rated virtual junction temperature. In addition, figures corresponding to lower initial virtual junction temperatures may be given.

Surge current ratings shall be given for the following time periods.

- a) For times smaller than one half-cycle (at 50 Hz or 60 Hz), but greater than approximately 1 ms, in terms of maximum rated value of

$$\int i^2 dt$$

These ratings may be given by means of a curve or by specified values. No immediate subsequent application of reverse voltage or off-state voltage is assumed.

NOTE For fast turn-on thyristors or fast plasma-spreading thyristors such as those with distributed gate or interdigitated gate structures, values for times below 1 ms may be needed.

- b) For times equal to, or greater than, one half-cycle and smaller than 15 cycles (at 50 Hz or 60 Hz), in the form of a curve showing the maximum rated surge current versus time. Temporary loss of gate control must be assumed to occur.

These ratings should preferably be given for a reverse voltage of 80 % of the maximum repetitive peak reverse voltage. Additional ratings may be given for reverse voltages of 50 % or 100 % of the maximum repetitive peak reverse voltage.

- c) For a time equal to one cycle, with no reverse voltage applied.

3.3.6 Continuous (direct) on-state current (where appropriate)

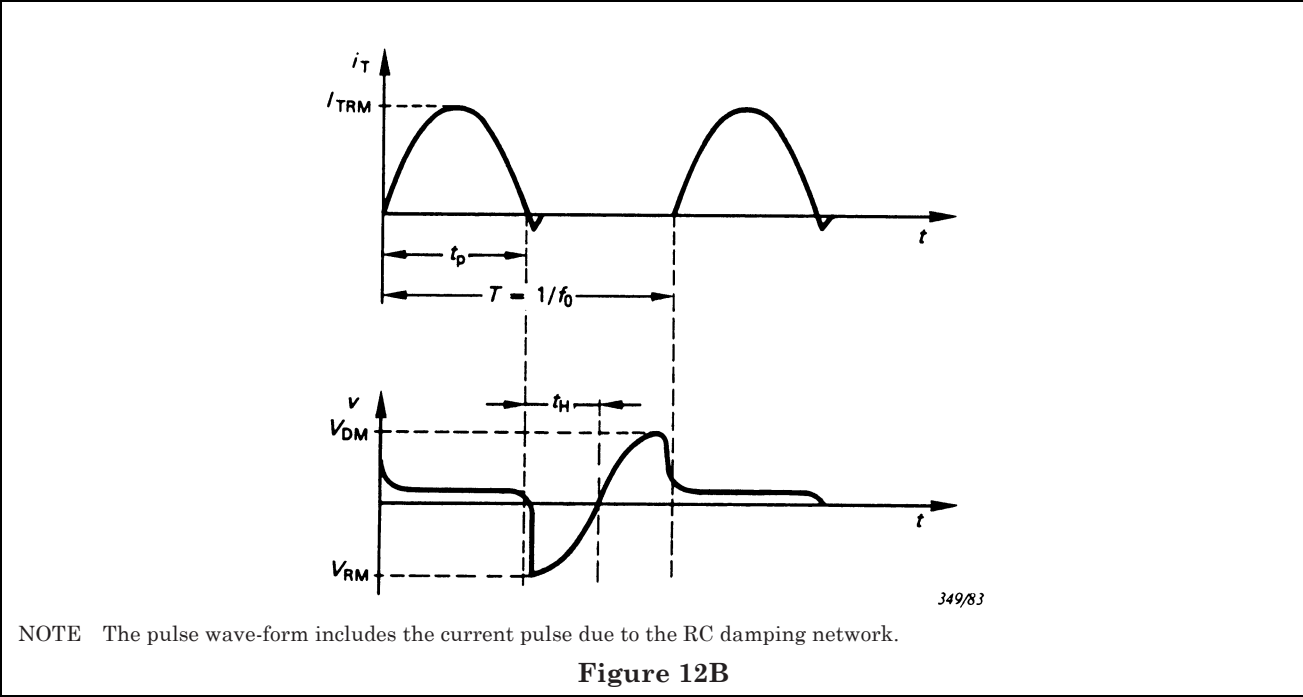
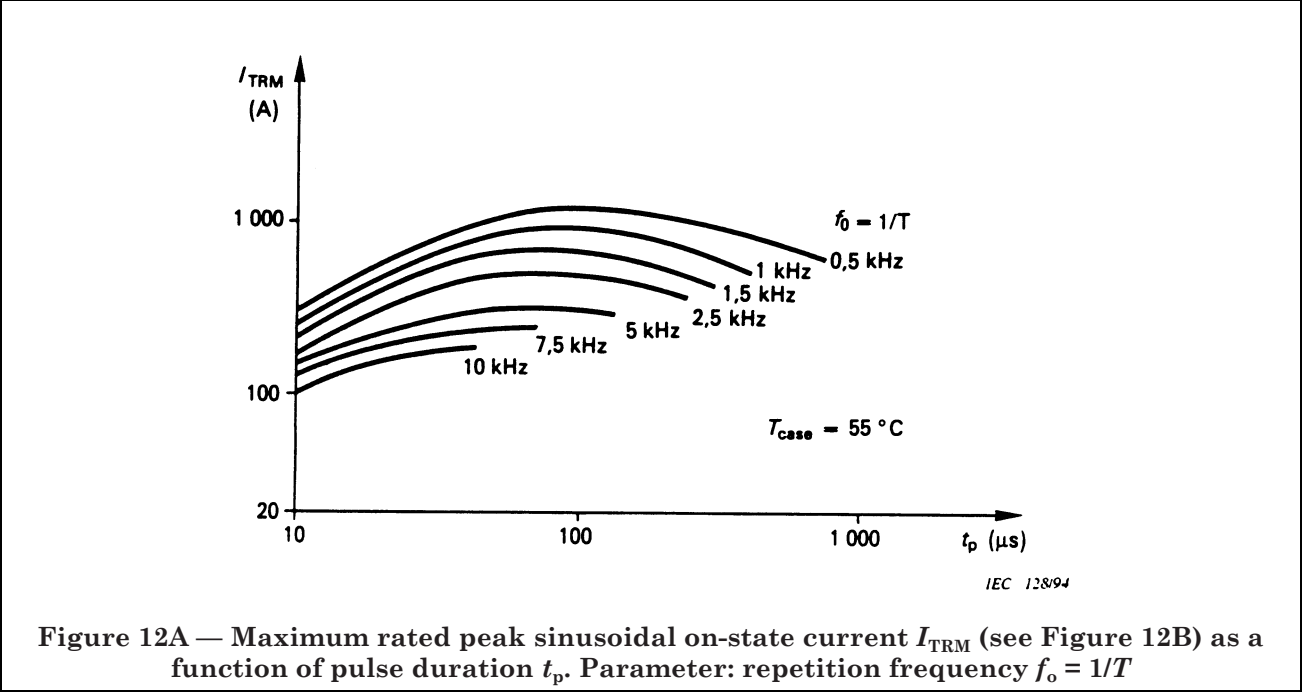
Maximum rated value.

3.3.7 Peak value of sinusoidal on-state current at higher frequencies (where appropriate)

Curves showing the maximum rated peak on-state current values as functions of the half-sine wave current pulse duration, with the repetition frequency as a parameter, under the following conditions:

- a) specified case temperature;
- b) specified off-state voltage before turn-on;
- c) specified reverse voltage;
- d) specified gate conditions during turn-on and turn-off;
- e) specified RC damping network (snubber).

Figure 12A is given as an example. Figure 12B is given for explanatory purposes only.



3.3.8 Peak value of a trapezoidal on-state current at higher frequencies (where appropriate)

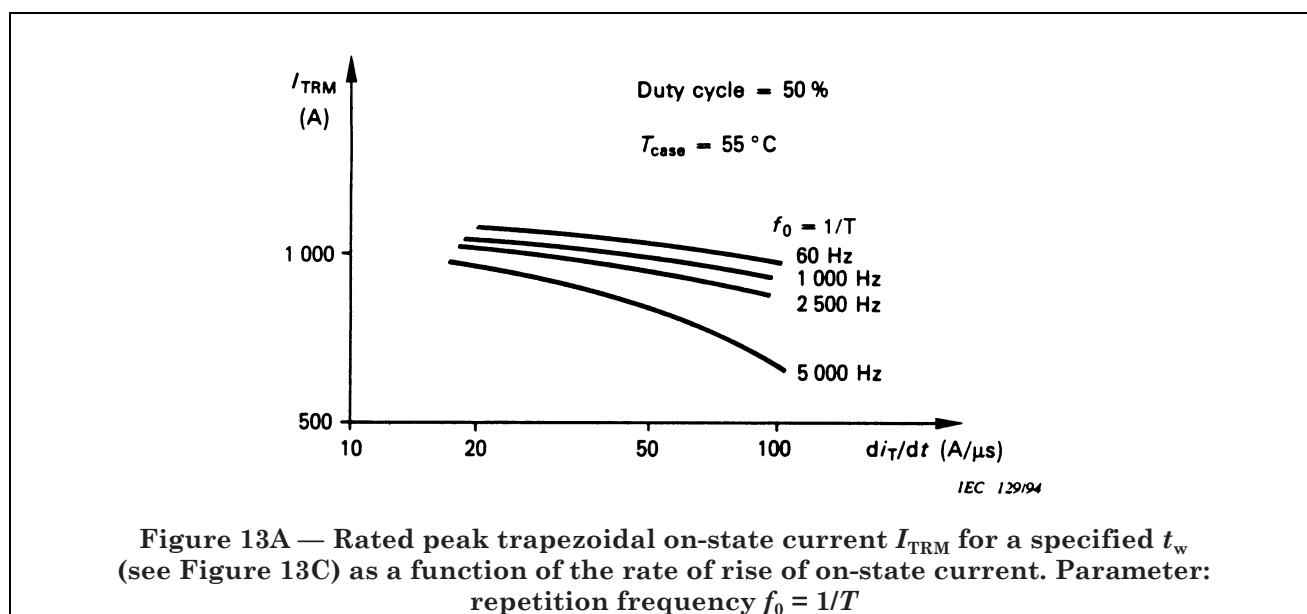
Curves showing the maximum rated on-state current values related to the rate of rise of on-state current, the repetition frequency and either the duty cycle or pulse duration under the following conditions:

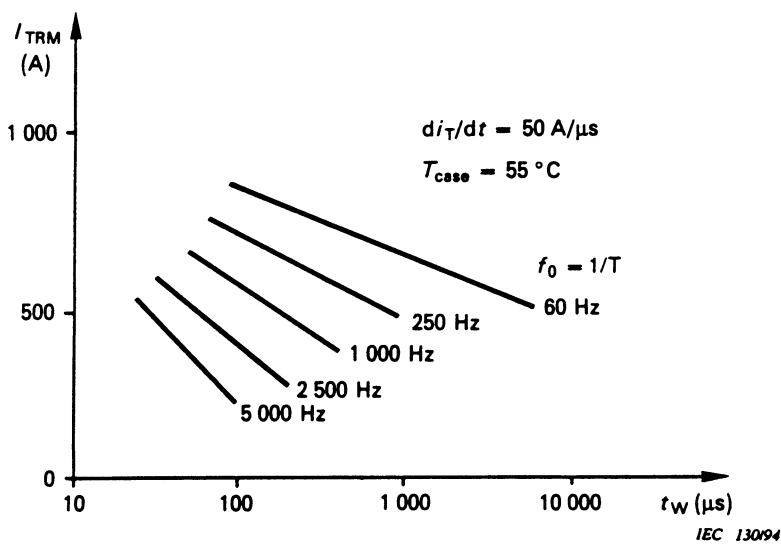
- a) specified case temperature;
- b) specified off-state voltage before turn-on;
- c) specified reverse voltage;

NOTE As there is a significant dependence on the applied reverse voltage, it is recommended that two or more families of curves be given.

- d) specified gate conditions during turn-on and turn-off;
- e) specified RC damping network (snubber);
- f) specified duty cycle or pulse duration.

Figure 13A and Figure 13B are given as examples. Figure 13C is given for explanatory purposes only.





NOTE Different sets of curves are required for different values of di_T/dt .

Figure 13B — Maximum rated peak trapezoidal on-state current I_{TRM} having a specified di_T/dt (see Figure 13C) as a function of t_w . Parameter: repetition frequency $f_0 = 1/T$

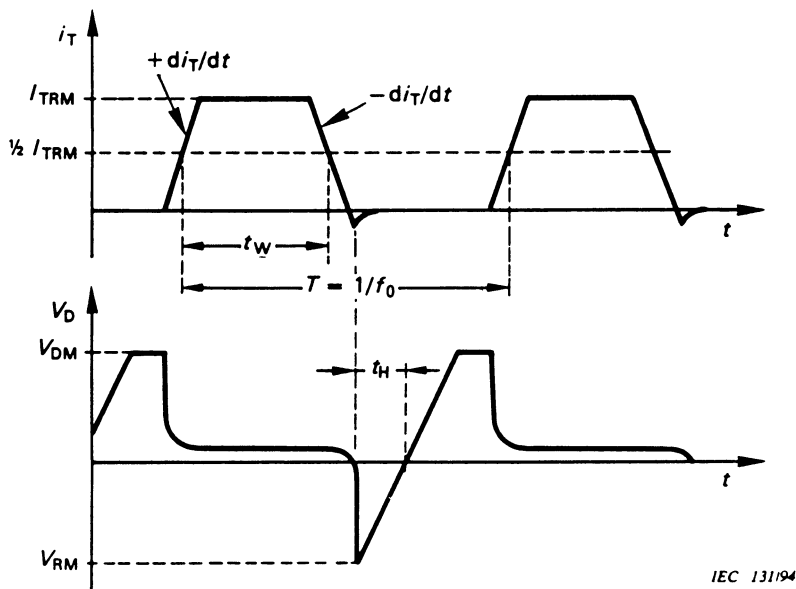


Figure 13C

3.3.9 Critical rate of rise of on-state current

Maximum rated value under the following specified conditions:

- a) off-state voltage (prior to turn-on), preferably equal to two-thirds of the repetitive peak off-state voltage of 3.1.6;
- b) peak value of on-state current;
- c) repetition rate, preferably 50 Hz or 60 Hz;
- d) ambient or case temperature, equal to the highest temperature at which the peak value of on-state current is permitted;
- e) gate-trigger conditions;
- f) test duration (the duration should be longer than the thermal time constant of the device, for example, 5 s).

NOTE 1 di/dt ratings are not applicable to low-current thyristors.

NOTE 2 The rated value of di/dt should be given for the case of no RC network connected in parallel with the thyristor. If an additional di/dt rating is given for the case where an RC network is present, the permissible amplitude and duration of the surges from this network or the parameters of this network must be stated.

3.3.10 Peak case non-rupture current

The limiting value “peak case non-rupture current” should be specified, where appropriate, as the maximum value of a triangular current rising at a specified rate, preferably 25 A/ μ s, and having a specified pulse duration for a starting case temperature to be specified, preferably 25 °C.

NOTE The “peak case non-rupture current” is needed for high-current rectifier diodes and thyristors (mean current ratings of about 1 000 A and higher) that are used in large convertor installations (as a rule, several devices are connected in parallel), where a device failing to block reverse voltage causes a high, steeply rising, short-circuit current that can fracture the case and cause damage to the equipment before a fuse operates.

Therefore, the determination or verification of this limiting value of current needs a high-power testing facility, and the costs of the testing itself and of the samples which are destroyed in the test are considerable and are justified only in cases where the above danger really exists.

The value of the peak case non-rupture current depends considerably on the location of the initial breakdown on the silicon chip and is usually lowest if the breakdown occurs near the edge.

3.4 Gate current

3.4.1 Peak forward-gate current

Maximum rated value, with anode-cathode voltage polarity specified.

NOTE Any qualifications (for example, of time, energy, etc.) applicable to this rating shall be stated.

4 Frequency ratings (limiting values)

Where applicable, the maximum and/or minimum frequencies for which the voltage and current ratings in clause 3 apply.

5 Power dissipation ratings (limiting values)

5.1 Gate power dissipation

5.1.1 Peak gate power dissipation

Maximum rated value for specified pulse duration.

6 Temperature ratings (limiting values)

6.1 Ambient-rated and case-rated thyristors

Minimum and maximum rated cooling fluid or case temperatures.

6.2 Storage temperatures

Minimum and maximum rated values.

6.3 Virtual junction temperature (where appropriate)

Maximum rated value.

7 Electrical characteristics

(At ambient or case temperature of 25 °C, unless otherwise stated.)

7.1 On-state characteristics (where appropriate)

Curves showing instantaneous value of on-state voltage versus on-state current up to the maximum value of the peak repetitive on-state current (3.3.2), at an ambient or case temperature of 25 °C and at one other higher temperature, preferably equal to the maximum rated virtual junction temperature.

7.2 On-state voltage

Maximum value at a current of π times the rated mean on-state current (3.3.1), at the maximum rated virtual junction temperature or at a case or ambient temperature of 25 °C.

NOTE 1 π may be taken as equal to 3.

NOTE 2 The reference value for calculating the on-state power dissipation under operating conditions is the on-state voltage at maximum virtual junction temperature. If, however, a well-established correlation exists between this value and the value at 25 °C, the latter may be given for convenience of testing.

7.3 Holding current

Maximum value and, where appropriate, minimum value under the following specified conditions:

- a) source voltage in the principal circuit, preferably equal to 12 V;
- b) gate-bias conditions;
- c) peak initial on-state current.

NOTE The maximum value of the holding current is the smallest current that will maintain all thyristors of a given type in the on-state.

The minimum value of the holding current is the highest current below which all thyristors of a given type will return to the off-state.

7.4 Latching current

Maximum value under the following specified conditions:

- a) source voltage in the principal circuit, preferably equal to 12 V;
- b) triggering pulse: rise time, fall time, duration, amplitude, and resistance of the trigger pulse generator.

NOTE The maximum value of the latching current is the smallest current that will maintain all thyristors of a given type in the on-state.

7.5 Repetitive peak off-state current

Maximum value at the rated repetitive peak off-state voltage at 25 °C and, where appropriate, at the maximum rated virtual junction temperature.

7.6 Repetitive peak reverse current

Maximum value at the rated repetitive peak reverse voltage at 25 °C; in addition, where appropriate, maximum value at the maximum rated virtual junction temperature.

7.7 Gate-trigger current and gate-trigger voltage

Values of gate current and gate voltage required to turn on all thyristors of a given type.

The following conditions shall be specified:

- a) off-state voltage, preferably equal to 12 V;
- b) gate-circuit conditions;
- c) ambient or case temperature.

7.8 Gate non-trigger current and gate non-trigger voltage

Values of the gate current and gate voltage which will not turn on any thyristor of a given type.

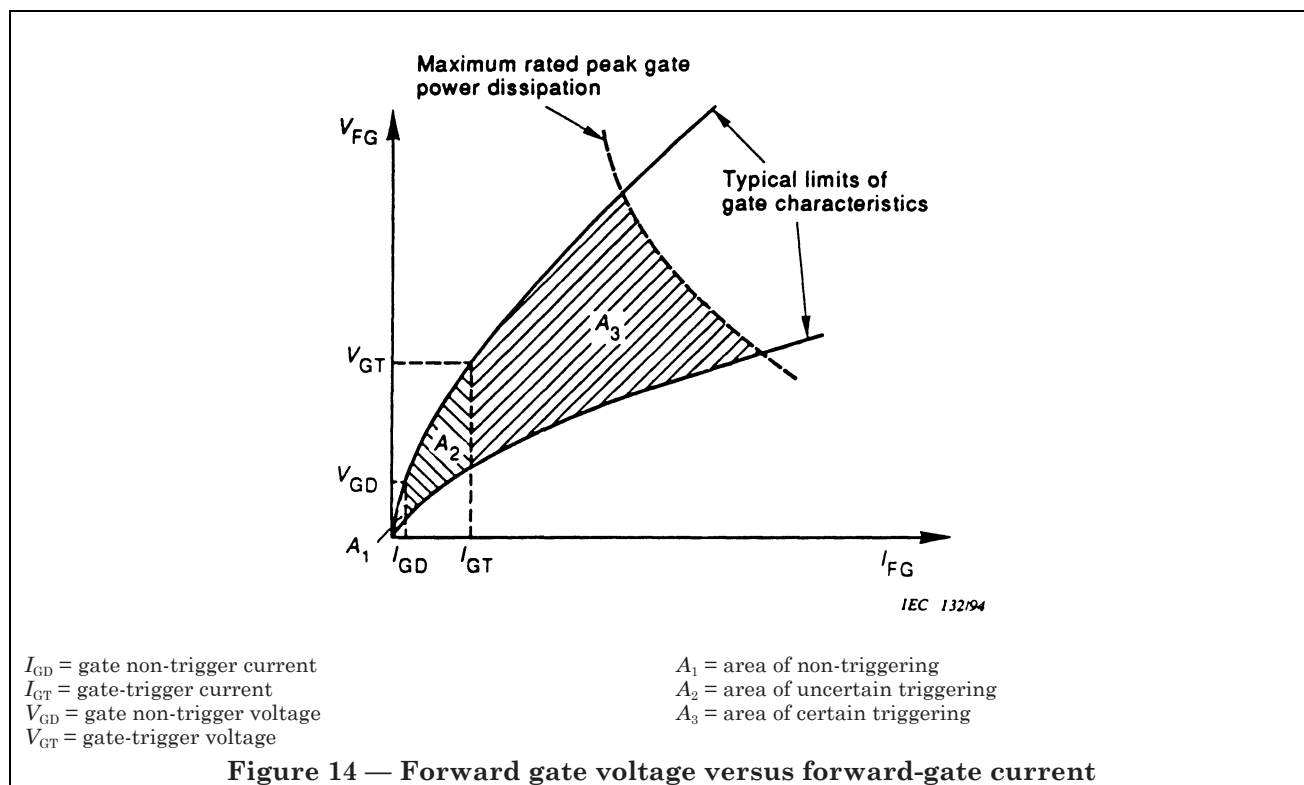
The following conditions shall be specified:

- a) off-state voltage, preferably equal to two-thirds of the repetitive peak off-state voltage (V_{DRM}) of 3.1.6;
- b) ambient or case temperature, preferably equal to the maximum rated virtual junction temperature;
- c) gate-circuit conditions.

Presentation of limiting values and characteristics for the gate

Limiting values and characteristics for the gate are preferably given with reference to a diagram as shown in Figure 14. The area indicating certain triggering has a lower limit given by the gate-trigger current.

NOTE The values of gate non-trigger voltage and current shall be given at maximum rated virtual junction temperature. The values of gate-trigger voltage and current should be given at 25 °C and at minimum operating temperature.



7.9 Gate-controlled delay time

Typical and, where appropriate, maximum and/or minimum value(s), under the following specified conditions:

- gate-current amplitude and gate-circuit impedance;
- rise time of the gate pulse, preferably 0,5 μ s;
- minimum duration of the gate pulse, preferably two times the specified delay time;
- off-state voltage (prior to turn-on), preferably equal to 0,5 times the repetitive peak off-state voltage of 3.1.6.

7.10 Circuit commutated turn-off time

Maximum value under the following specified conditions:

- wave-shape of the preceding on-state current;
 NOTE The wave-shape shall preferably be rectangular and the duration must be sufficient to achieve charge carrier equilibrium. The amplitude shall be preferably three times the rated mean on-state current.
- ambient or case temperature equal to the highest temperature at which the peak value of the on-state current is permitted;
- wave-shape of the reverse-blocking voltage;
- reverse voltage at the time of initiation of off-state voltage (time instant t_1 in Figure 15);
- peak value and rate of rise of off-state voltage;
 NOTE The peak value of the off-state voltage shall be at least two-thirds of the rated repetitive peak off-state voltage.
- gate bias while the thyristor is in the off-state:
 - gate-source voltage,
 - gate-source impedance;

g) rate of fall on on-state current ($-di/dt$)

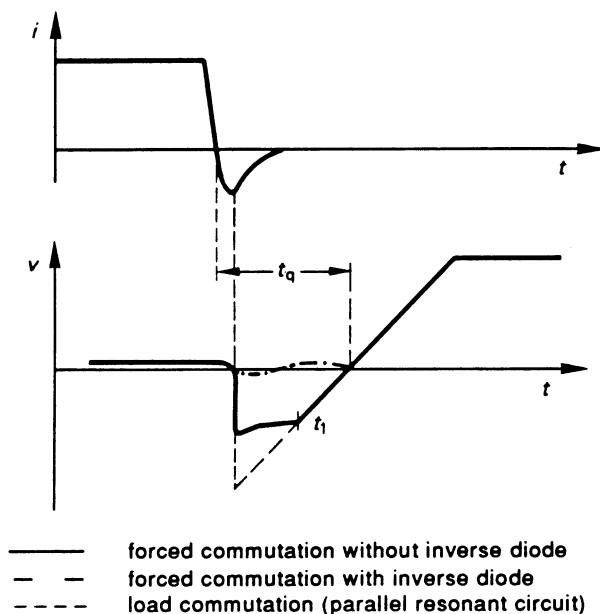


Figure 15 — Examples of current and voltage wave-shapes during turn-off of a thyristor under various circuit conditions

7.11 Critical rate of rise of off-state voltage

Maximum value of the rate of rise of an applied voltage rising in an approximately linear manner.

The following conditions shall be specified:

- ambient or case temperature, preferably equal to the maximum rated virtual junction temperature;
- peak off-state voltage, preferably equal to two-thirds the repetitive peak off-state voltage (V_{DRM}) of 3.1.6;
- gate-bias conditions;
- switching repetition frequency.

7.12 Total power dissipation

For case-rated thyristors only, curves showing the maximum total power dissipation at maximum virtual junction temperature as a function of mean on-state current and conduction angle, at the maximum value of the repetitive peak reverse voltage and at the maximum value of the repetitive peak off-state voltage. A curve shall be given for each operating condition specified in 3.3.1.

7.12.1 Total energy dissipated during one half-sine wave on-state current pulse (where appropriate)

Curves showing the maximum total dissipated energy comprising turn-on plus on-state plus reverse recovery energy related to the peak on-state current and pulse duration under the following conditions.

NOTE Curves for maximum total energy dissipation are given under conditions that cause the maximum operating junction temperature to be reached.

- Specified off-state voltage before turn-on.
- Specified reverse voltage.

NOTE As there is a significant dependence on the reverse recovery dissipation, it is recommended that two or more families of curves be given based on different reverse voltages, in order to make it possible to calculate the reverse recovery dissipation.

- Specified gate conditions during turn-on and turn-off.
- Specified RC damping network (snubber).

Figure 16A is given as an example.