BS IEC 60747-6:2016

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Semiconductor devices

Part 6: Discrete devices — Thyristors

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee EPL/47, Semiconductors.

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SEMICONDUCTOR DEVICES –

Part 6: Discrete devices – Thyristors

FOREWORD

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International Standard IEC 60747-6 has been prepared by subcommittee 47E: Discrete semiconductor devices, of IEC technical committee 47: Semiconductor devices.

This third edition cancels and replaces the second edition, published in 2000. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) Clauses 3, 4, 5, 6, and 7 were amended with some deletions of information no longer in use or already included in other parts of the IEC 60747 series, and with some necessary additions;
b) some parts of Clause 8 and Clause 9 were moved and added to Clause 7 of this third edition;
c) Clause 8 and 9 were deleted in this third edition;
d) Annex A was deleted.

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This International Standard is to be used in conjunction with IEC 60747-1:2006 and Amendment 1:2010.

The text of this standard is based on the following documents:

FDIS	Report on voting
47E/532/FDIS	47E/538/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60747 series, published under the general title *Semiconductor devices*, can be found on the IEC website.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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SEMICONDUCTOR DEVICES –

Part 6: Discrete devices – Thyristors

1 Scope

This part of IEC 60747 provides standards for the following types of discrete semiconductor devices:

– reverse-blocking triode thyristors;
– reverse-conducting (triode) thyristors;
– bidirectional triode thyristors (triacs);
– turn-off thyristors.

If no ambiguity is likely to occur, any of the above may be referred to as thyristors.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60747-1:2006, *Semiconductor devices – Part 1: General*
IEC 60747-1:2006/AMD1:*2010*

IEC 60749-23, *Semiconductor devices – Mechanical and climatic test methods– Part 23: High temperature operating life*

IEC 60749-25, *Semiconductor devices – Mechanical and climatic test methods – Part 25: Temperature cycling*

IEC 60749-34:2010, *Semiconductor devices – Mechanical and climatic test methods – Part 34: Power cycling*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1 General

3.1.1
triac
bidirectional triode thyristor
three-terminal thyristor having substantially the same switching behaviour in the first and third quadrants of the current-voltage characteristic

[SOURCE: IEC 60050-521:2002, 521-04-67]

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3.1.2
GTO
gate-turn-off thyristor
turn-off thyristor
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

Note 1 to entry: This note applies to the French languange only.

[SOURCE: IEC 60050-521:2002, 521-04-68]

3.2 Terms and definitions related to ratings and characteristics: currents

3.2.1
overload reverse-conducting current
$I_{RC(OV)}$
reverse-conducting current whose continuous application would cause the maximum rated virtual junction temperature to be exceeded

3.2.2
surge reverse-conducting current
I_{RCSM}
peak non-repetitive reverse current pulse of short duration and specified wave shape

3.2.3
reverse leakage current
I_R
reverse current that occurs when applying reverse voltage to the device

3.2.4
overload on-state current
$I_{T(OV)}$
on-state current whose continuous application would cause the maximum-rated virtual junction temperature to be exceeded

Note 1 to entry: See Figure 1.

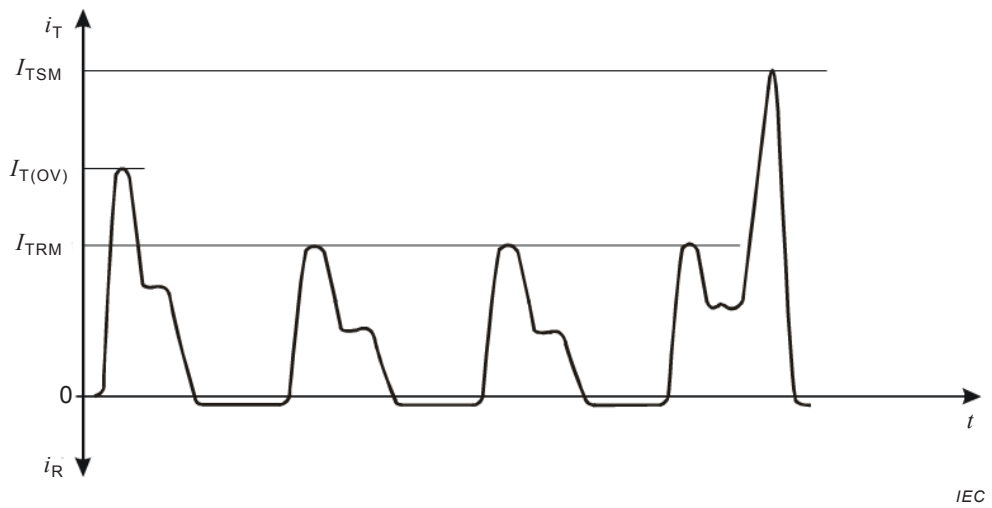

Figure 1 – Peak values of on-state currents

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3.2.5
surge on-state current
I_{TSM}
on-state current pulse of short duration and specified wave shape

Note 1 to entry: Occurrence of I_{TSM} causes or would cause the maximum rated virtual junction 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., a fault) (see Figure 1).

3.2.6
tail current
I_Z
<turn-off thyristor> anode current that flows during the tail time

Note 1 to entry: See Figure 8.

3.2.7
peak tail current
I_{ZM}
<turn-off thyristor> peak value of tail current that occurs shortly after the beginning of the tail time

Note 1 to entry: See Figure 8.

3.2.8
peak case non-rupture current
I_{RSMC}
peak value of current that will not cause bursting of the case or the emission of a plasma beam

3.3 Terms and definitions related to ratings and characteristics: gate voltages and currents

3.3.1
sustaining gate current
I_{FGsus}
<turn-off thyristor> minimum forward gate current required ensuring that, if the anode current drops below the value required to keep all the subdivided cathode areas in conduction, they will all return to conduction when the anode current is increased again

3.3.2
turn-off gate voltage
V_{RGQ}
<turn-off thyristor> reverse gate voltage during the time interval within which the thyristor is turning off

3.3.3
peak turn-off gate voltage
V_{RGQM}
<turn-off thyristor> peak value of the turn-off gate voltage at the end of its rapid rise after the peak value of turn-off gate current (I_{RGQM}) has been reached

3.3.4
turn-off gate bias voltage
V_{RGQB}
<turn-off thyristor> essentially constant value of the turn-off gate voltage that occurs towards the end of the turn-off process, in the case where the gate-control circuit supports this process by maintaining the turn-off gate voltage at a value that is higher than the off-state gate bias voltage

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3.3.5
off-state gate bias voltage
V_{RGB}
<turn-off thyristor> reverse gate voltage which is applied after the thyristor was turned off

3.3.6
on-state gate bias current
I_{FGB}
forward gate current flowing after the thyristor has been turned on

3.3.7
turn-off gate current
I_{RGQ}
<turn-off thyristor> reverse gate current during the time interval within which thyristor is turning off

3.3.8
turn-off gate bias current
I_{RGQB}
<turn-off thyristor> gate current associated with the turn-off gate bias voltage V_{RGQB}

3.3.9
peak turn-off gate current
I_{RGQM}
<turn-off thyristor> peak value of the reverse gate current reached at the end of its rapid rise in the beginning of the turn-off process

Note 1 to entry: Specifications refer to the minimum value of I_{RGQM} that the gate turn-off pulse generator is capable of supplying as a function of the peak on-state current to be switched off under specified conditions.

3.4 Terms and definitions related to ratings and characteristics: power and energy dissipation

3.4.1 General

All definitions are written in terms of triode thyristors. Where appropriate, they apply also to diode thyristors. All definitions for power and power dissipation refer, if not otherwise specified, to the product of anode or principal current and anode or principal voltage. The definitions are general. They do not consider that the beginning and ending of the particular time interval should be identified in order to make specifications for the derived characteristics “mean partial power dissipation” and “partial energy dissipation” meaningful. However, guidance for the specification of these times is given in the relevant notes.

3.4.2 Instantaneous power during a cycle

3.4.2.1
reverse power
P_R
power when the thyristor is in the reverse-blocking state

Note 1 to entry: If not otherwise specified, the term refers to the power in the time interval between the ending of the turn-off time and the change from the reverse blocking state to the off state (either I = 0 or V = 0) (see Figure 2).

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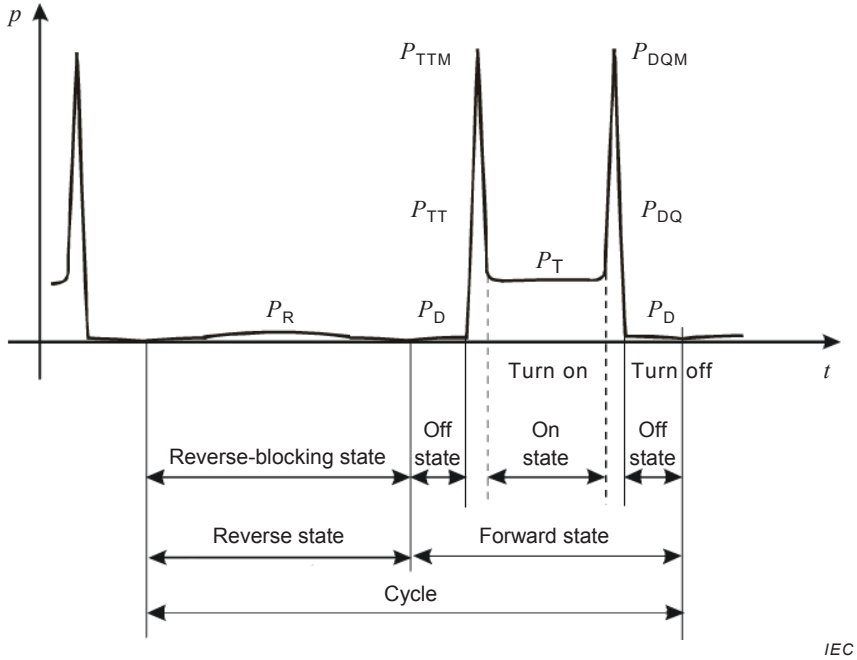

Key

P_R	reverse power	P_T	on-state power
P_D	off-state power	P_{TT}	turn-on power
P_{DQ}	turn-off power		

Figure 2 – Partial power (dissipation) of turn-off thyristors at absolute long on-state period

3.4.2.2
reverse-conducting power
P_{RC}
<reverse-conducting thyristor> power while the thyristor is in the reverse-conducting state

Note 1 to entry: If not otherwise specified, the term refers to the power in the time interval between the ending of the turn-off time and the change from the reverse conducting state to the off state (either I = 0 or V = 0).

3.4.2.3
off-state power
P_D
power while the thyristor is in the off state

Note 1 to entry: If not otherwise specified, the term refers to the power generated during the time interval between the crossing of the origin from the reverse blocking (or conducting) state to the off state (I = 0 or V = 0) and the beginning of the turn-on time; with turn-off thyristors, in addition, during the time interval between the ending of the turn-off time and the crossing of the origin from the off state to the reverse-blocking (or conducting) state.

3.4.2.4
turn-on power
P_{TT}
power in the time interval during which the thyristor is turning on

Note 1 to entry: If not otherwise specified, this time interval corresponds to the turn-on time.

3.4.2.5
turn-off power
P_{RQ}
power in the time interval during which the thyristor is turning off

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Note 1 to entry: If not otherwise specified, this time interval corresponds to the turn-off time.

Note 2 to entry: For turn-off thyristors P_{RQ} is replaced with P_{DQ}.

3.4.3 Mean power dissipation

3.4.3.1
mean partial power dissipation
mean value of the instantaneous power dissipation in a particular time interval of the cycle, averaged over the full cycle

3.4.3.2
mean total power dissipation
$P_{tot(AV)}$
sum of all mean partial power dissipation and the mean gate power dissipation, during a full cycle

$$P_{tot(AV)} = P_{T(AV)} + P_{add(AV)} + P_{G(AV)}$$

3.4.3.3
mean on-state power dissipation
$P_{T(AV)}$
mean partial power dissipation resulting from on-state power

3.4.3.4
mean additional power dissipation
$P_{add(AV)}$
sum of all power dissipation except on-state power dissipation and gate power dissipation

$$P_{add(AV)} = P_{TT(AV)} + P_{RQ(AV)} + P_{D(AV)} + P_{R(AV)}.$$

Note 1 to entry: For turn-off thyristors, $P_{RQ(AV)}$ is replaced with $P_{DQ(AV)}$.

3.4.3.5
mean turn-on power dissipation
$P_{TT(AV)}$
mean partial power dissipation resulting from the turn-on power

3.4.3.6
mean turn-off power dissipation
$P_{RQ(AV)}$
mean partial power dissipation resulting from turn-off power

Note 1 to entry: For turn-off thyristors, $P_{RQ(AV)}$ is replaced with $P_{DQ(AV)}$.

3.4.3.7
mean off-state power dissipation
$P_{D(AV)}$
mean partial power dissipation resulting from off-state power

3.4.3.8
mean reverse power dissipation
$P_{R(AV)}$
mean partial power dissipation resulting from reverse power

3.4.3.9
mean gate power dissipation
$P_{G(AV)}$
gate power dissipation averaged over a full cycle

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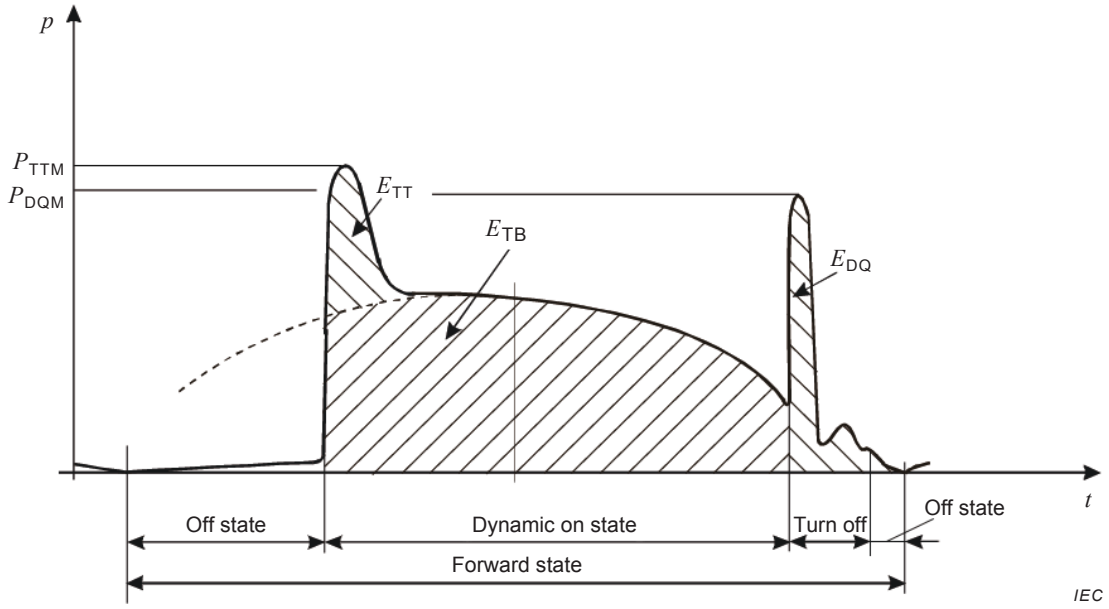
3.4.4 Energy dissipation

3.4.4.1
dynamic on-state energy dissipation
E_T
total energy dissipation from the instant when the rising on-state current reaches a specified low value to the instant that defines the beginning of the turn-off time

3.4.4.2
basic on-state energy dissipation
E_{TB}
energy dissipation resulting from the flow of on-state current when the thyristor is fully turned on during the entire on-state period

Note 1 to entry: This energy dissipation can only be determined by calculations based on the observed waveform of the current. The calculation method is to be specified (see Figure 3).



Key

E_{TB}	basic on-state energy dissipation dissipation	E_{TT}	additional turn-on energy
$E_T = E_{TB} + E_{TT}$	dynamic (total) on-state energy dissipation	E_{DQ}	turn-off energy dissipation

Figure 3 – Components of dynamic on-state energy dissipation of turn-off thyristors at absolute short on-state period

3.4.4.3
additional turn-on energy dissipation
E_{TT}
calculated difference between the dynamic on-state energy dissipation and the basic on-state energy dissipation

$$E_{TT} = E_T - E_{TB}$$

3.4.4.4
turn-off energy dissipation
E_{RQ}
energy dissipation during the turn-off time

Note 1 to entry: For turn-off thyristors, E_{RQ} is replaced with E_{DQ}.

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3.5 Terms and definitions related to ratings and characteristics: recovery times and other characteristics

3.5.1 On-state

3.5.1.1
on-state slope resistance
r_T
value of the resistance calculated from the slope of the straight-line approximation of the on-state characteristic that crosses this characteristic at two specified points

3.5.1.2
on-state threshold voltage
$V_{T(TO)}$
$V_{(TO)}$
value of the on-state voltage obtained at the intersection of its straight-line approximation with the voltage axis

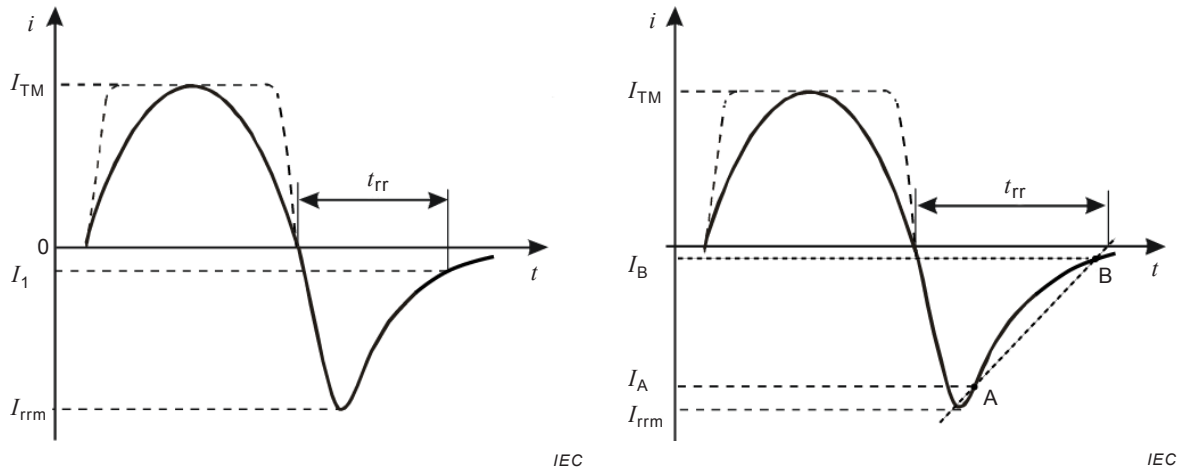
3.5.2 Recovery times

3.5.2.1
reverse recovery time
t_{rr}
<reverse-blocking thyristor> time interval between

– the instant when the current passes through zero while changing from the on-state to the reverse-blocking state, and
– the instant when either the reverse current is reduced from its peak value I_{TM} to a specified low value I_1 (as shown in Figure 4a) and which may be zero), or the extrapolated reverse current reaches zero (as shown in Figure 4b)).

Note 1 to entry: The extrapolation is carried out with respect to specified points A and B, as shown in generalized form in Figure 4b). Point A may be specified at I_{rrm}.

Note 2 to entry: Specified values of t_{rr} refer to a specified waveform of the preceding on-state current pulse, which may be either a half sine wave (solid line) or a trapezoidal wave (dashed line).



a) Determined by specified value b) Determined by extrapolation

Figure 4 – Reverse recovery time

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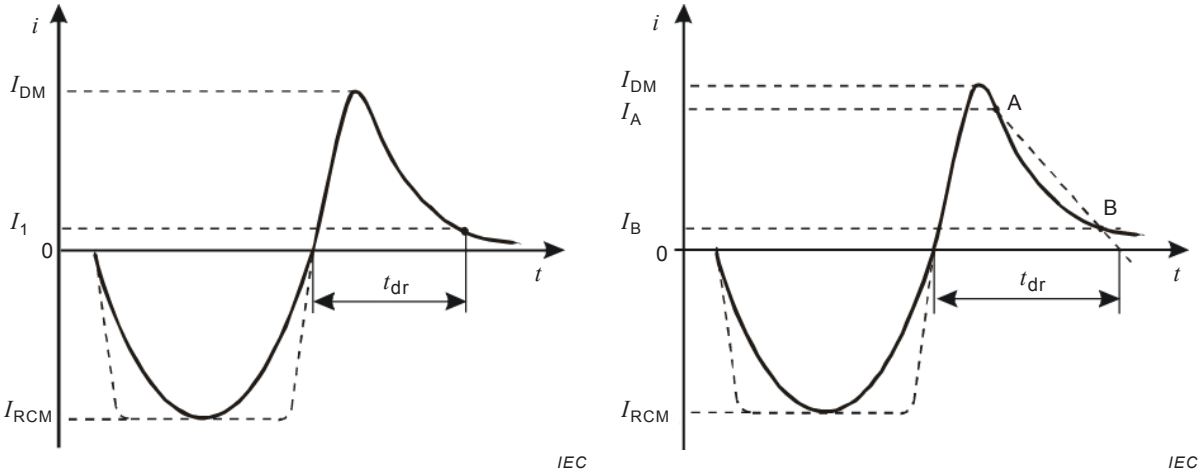
3.5.2.2
off-state recovery time
t_{dr}
<reverse-conducting thyristor> the time interval between

– the instant when the current passes through zero while changing from the reverse-conducting state to the off state and
– the instant when either the off-state current is reduced from its peak value I_{DM} to a specified low value I_1 (as shown in Figure 5a) and which may be zero), or the extrapolated reverse current reaches zero (as shown in Figure 5b)).

Note 1 to entry: The extrapolation is carried out with respect to specified points A and B, as shown in generalized form in Figure 5b). Point A may be specified at I_{DM}.

Note 2 to entry: Specified values of t_{dr} refer to a specified waveform of the preceding reverse-current pulse, which may be either a half sine wave (solid line) or a trapezoidal wave (dashed line).



a) Determined by specified value **b) Determined by extrapolation**

Figure 5 – Off-state recovery time

3.5.2.3
circuit-commutated turn-off time
t_q
time interval between

– the instant when the on-state current has decreased to zero after external switching of the main circuit, and
– the earliest instant when a steeply rising off-state voltage that the thyristor is capable of supporting without breaking over either passes through zero (curve a)) in Figure 6, or begins from a low positive value (curve b)) in Figure 6.

Note 1 to entry: Curve a) refers to a simple reverse-blocking triode thyristor. Curve b) may appear, if the thyristor is bypassed by an external or internal inverse diode (reverse-conducting thyristor), due to the lead inductance of the diode.

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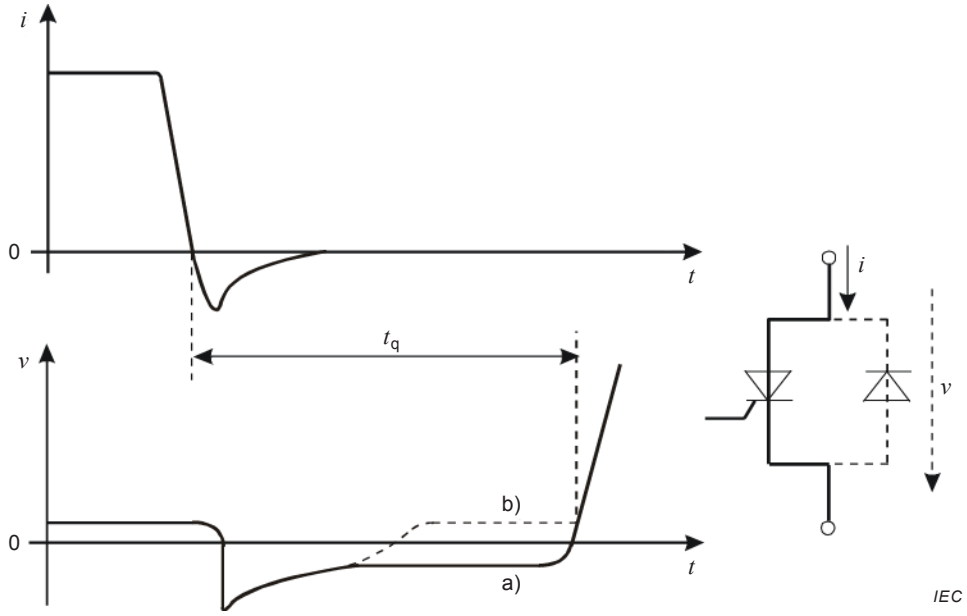

Figure 6 – Circuit-commutated turn-off time

3.5.2.4
hold-off interval
t_H
<in a converter> time interval between

– the instant when the anode current of the thyristor of a converter has decreased to zero and
– the instant when the same thyristor is subjected to off-state voltage.

Note 1 to entry: The hold-off interval is not a characteristic of the thyristor but a service condition of the converter. It will exceed the longest expected individual circuit-commutated turn-off time, which also depends on the service conditions of the converter.

3.5.3 Times and rates of rise characterizing gate-controlled turn-on

The defined terms refer to the switching of a thyristor from the off-state to the on-state by means of a forward gate drive current pulse (see Figure 7).

3.5.3.1
gate controlled turn-on delay time
t_{gd}
time between the instant when the rising gate current reaches 10 % of I_{FGTM} and the instant when the decreasing off-state voltage reaches 90 % of its initial value V_D

3.5.3.2
gate-controlled turn-on rise time
t_{gr}
time interval between 90 % of the decreasing anode voltage V_D and 10 % of V_D

Note 1 to entry: If no ambiguity is likely to occur, the term may be abbreviated to “turn-on rise time”.

3.5.3.3
gate-controlled turn-on time
t_{gt}
sum of gate-controlled turn-on delay time and rise time:

$$t_{gt} = t_{gd} + t_{gr}$$

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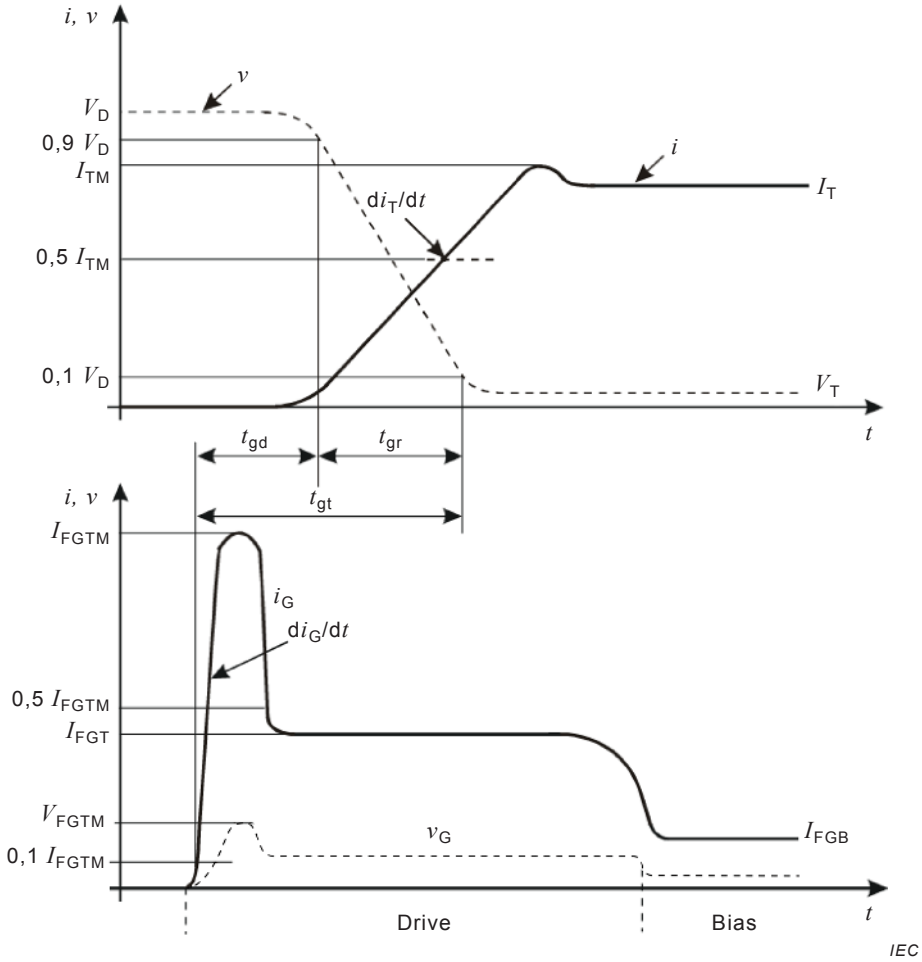
Note 1 to entry: If no ambiguity is likely to occur, the term may be abbreviated to “turn-on time”.



NOTE The reference values of current and voltage are usually specified as follows.

Peak forward gate current I_{FGTM}:

– specified low value: 10 % of I_{FGTM},

– specified level for the measurement of t_{gtw} and di_G/dt: 50 % of I_{FGTM},

Anode voltage V_D:

– upper specified value: 90 % of V_D,

– lower specified value: 10 % of V_D, (where V_D is the off-state voltage prior to turn on),

Anode current I_{TM}:

– specified level for the measurement of di_G/dt: 50 % of I_{TM}.

Figure 7 – Gate-controlled turn-on times

3.5.4 Times and rates of rise characterizing gate-controlled turn-off

The defined terms refer to the switching of a turn-off thyristor from the on-state to the off-state by means of a reverse gate drive current pulse that is supported by an additional reverse gate drive voltage pulse and that is followed by a smaller reverse gate bias current (see Figure 8)

3.5.4.1
gate-controlled turn-off delay time

t_{dq}
time interval between 10 % of rising reverse gate current I_{RGQM} and 90 % of anode current I_T

Note 1 to entry: If no ambiguity is likely to occur, the term may be abbreviated to “turn-off delay time”.

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3.5.4.2
gate-controlled fall time
t_{fq}
time interval between 90 % of anode current I_T and the instant when the anode current I_T reaches, at the end of its steep decrease, the valley point current I_{ZV}

Note 1 to entry: If no ambiguity is likely to occur, the term may be abbreviated to “turn-off fall time”.

3.5.4.3
gate-controlled turn-off time
t_{gq}
sum of gate-controlled turn-off delay time and fall time:

$$t_{gq} = t_{dq} + t_{fq}$$

Note 1 to entry: If no ambiguity is likely to occur, the term may be abbreviated to “turn-off time”.

3.5.4.4
tail time
t_Z
time interval between the instant when the anode current has decreased to the valley point I_{ZV} and the instant when the extrapolated tail current i_Z reaches zero

Note 1 to entry: Unless otherwise specified, the extrapolation is carried out between the peak point of the tail current I_{ZM} and I_{ZL} = 25 % I_{ZM} (see Figure 8).

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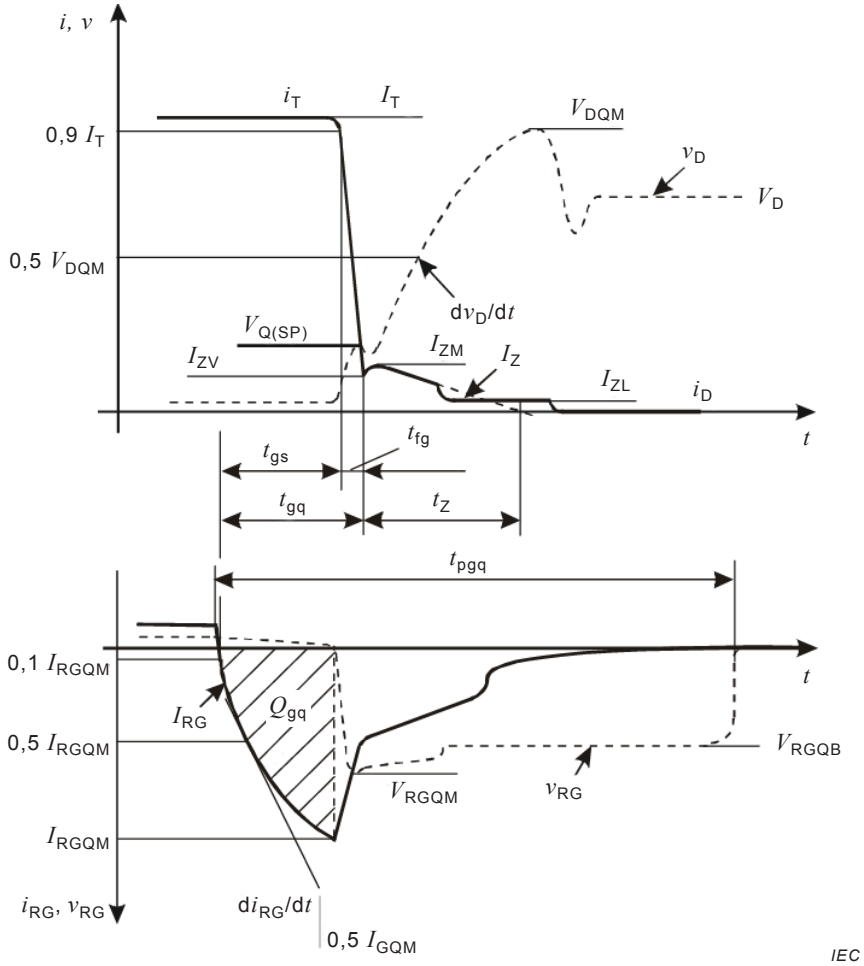

NOTE The reference values of current and voltage referred to in 3.5.4.1 through 3.5.4.4 are usually specified as follows:

gate current:

– specified low value near zero: 10 % of I_{RGQM},

– specified level for the measurement of di_{RG}/dt: 50 % of I_{RGQM},

anode current:

– upper reference value: 90 % of I_T,

anode voltage:

– specified level for the measurement of dv_D/dt: 50 % of V_{DQM}.

Figure 8 – Gate-controlled turn-off times

3.5.4.5
gate turn-off drive-pulse duration

t_{pgq}
duration of the reverse gate-drive voltage pulse measured between two specified levels of reverse gate-drive voltage

3.5.4.6
critical gate turn-off drive-pulse duration

$t_{pgq(cr)}$
lowest value to which the gate turn-off drive-pulse duration can be reduced without the thyristor failing to turn off

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3.5.5 Recovered charges

3.5.5.1
recovered charge
Q_r
<reverse-blocking triode thyristor> 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:

$$Q_r = \int_{t_0}^{t_0+t_i} i_{rr}\,dt$$

where

t_0 is the instant when the current passes through zero;

t_i is the specified integration interval (see Figure 9).

Note 1 to entry: This charge includes components due to both carrier storage and depletion layer capacitance.

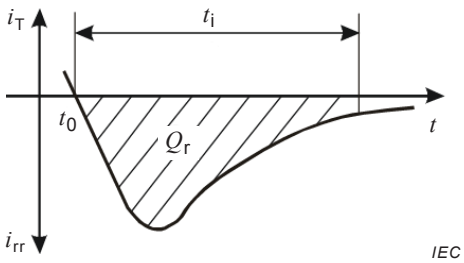

Figure 9 – Recovered charge Q_r

3.5.5.2
off-state recovered charge
Q_{dr}
<reverse-conducting triode thyristor> total charge recovered from the thyristor during a specified integration time after switching from a specified reverse current condition to a specified off-state condition

Note 1 to entry: The formula given in 3.5.5.1 and Figure 9 apply analogously.

3.5.5.3
gate turn-off charge
Q_{gq}
<turn-off thyristor> total charge derived from the integration of the reverse gate current between the instant when the falling forward gate current crosses zero and the instant in which the reverse gate current reaches its peak value I_{RGQM} (see Figure 8)

3.6 Mechanical ratings

3.6.1
mounting torque
M
component of a moment of force M along a given axis passing through the origin point, thus $T = M \cdot e$, where e is the unit vector of the axis

Note 1 to entry: For thyristors having screw connections, the maximum and minimum rated torque values shall be specified.

[SOURCE: IEC 60050-113:2011, 113-03-26, modified — "mounting" has been added to the term, the note has been deleted and Note 1 to entry has been added]

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3.6.2
clamping force
F
additive vector quantity characterizing external interactions on a particle or body

Note 1 to entry: For thyristors designed for mounting by means of clamps the minimum and maximum rated clamping force values and the planarity of mounting surfaces shall be specified.

[SOURCE: IEC 60050-113:2011, 113-03-14, modified — "clamping" has been added to the term, Notes have been deleted and Note 1 to entry has been added]

4 Letter symbols

4.1 General

The general rules of IEC 60747-1:2006, Clause 4, are applicable in part.

4.2 Additional general subscripts

In addition to the lists of recommended general subscripts given in IEC 60747-1:2006, Clause 4, the special subscripts given in Table 1 are recommended for the field of thyristors.

Table 1 – Additional general subscripts

Subscript	Significance	Remarks
A, a	Anode	
(com)	Commutating	See 6.2.12
G,g	Gate	
G	Gate-controlled	
H	Holding	
L	Latching	
Q, q	Turn-off	
RC	Reverse-conducting	
(SP)	Spike	
sus	Sustaining	
T	On state	
T, t	Turn-on, trigger	
V	Valley	Under 3.5.4.2 and 3.5.4.4 only
W	Working	
Z, z	Tail	

4.3 List of letter symbols

The symbols contained in Table 2 to Table 8 are recommended for use in the field of thyristors.

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Table 2 – Principal voltages, anode-cathode voltages

Name and designation	Letter symbol	Remarks
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}	
On-state voltage	V_T	
On-state threshold voltage	$V_{T(TO)}$	
Reverse voltage	V_R	
Crest (peak) working reverse voltage	V_{RWM}	5.1.8.4 and Table 11 only
Repetitive peak reverse voltage	V_{RRM}	
Non-repetitive peak reverse voltage	V_{RSM}	

Table 3 – Principal currents, anode currents, cathode currents

Name and designation	Letter symbol	Remarks
Off-state current	I_D	
Holding current	I_H	
On-state current	I_T	
Overload on-state current	$I_{T(OV)}$	
Repetitive peak on-state current	I_{TRM}	Figure 11
Surge (non-repetitive) on-state current	I_{TSM}	
Reverse blocking current	I_R	
Repetitive peak reverse current	I_{RRM}	
Peak reverse recovery current	I_{rrm}	
Latching current	I_L	
Reverse-conducting current	I_{RC}	
Overload reverse-conducting current	$I_{RC(OV)}$	3.2.1
Direct off-state current	$I_{D(D)}$	6.2.5

Table 4 – Gate voltages

Name and designation	Letter symbol	Remarks
Gate trigger continuous (direct) voltage	V_{GT}	
Gate non-trigger continuous (direct) voltage	V_{GD}	

Table 5 – Gate currents

Name and designation	Letter symbol	Remarks
Forward gate continuous (direct) current	I_{FG}	
Gate trigger continuous (direct) current	I_{GT}	
Gate non-trigger continuous (direct) current	I_{GD}	

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Table 6 – 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 shall be used only when misinterpretation will not result
Gate-controlled rise time	t_{gr}, (t_r)	t_d and t_r shall be used only when misinterpretation will not result
Off-state recovery time	t_{dr}	For reverse conducting triode thyristors in 3.5.3.2
Hold-off interval	t_H	Figures 11b, 47, 53

Table 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	 $P_{TT(AV)}$ P_{TT}	
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_{DQM}	
Reverse-conducting power dissipation	P_{RC}	3.4.2.2
Peak forward gate power	P_{FGM}	5.1.5.4

Table 8 – 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 triacs in 6.2.12, $dv/dt_{(c)}$ is the preferred symbol
Critical rate of rise of on-state current	$di_T/dt_{(cr)}$	5.1.10.4
Off-state recovered charge	Q_{dr}	For reverse conducting triode thyristors in 3.5.6.2
Critical rate of voltage rise	$dv/dt_{(cr)}$	5.2.19.3
Basic on-state energy dissipation	E_{TB}	3.4.4.2
Turn-off energy	E_{RQ}, E_{DQ}	3.4.4.4

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5 Ratings and characteristics for thyristors

5.1 Ratings (limiting values)

5.1.1 Storage temperatures (T_{stg})

Minimum and maximum value is to be specified.

5.1.2 Junction temperature ($T_{vj(min)}$, T_{vjm})

Minimum and maximum value is to be specified.

5.1.3 Operating ambient or case temperature (T_a or T_c)

Minimum and maximum value is to be specified.

5.1.4 Total power dissipation (P_{tot} or P_C)

Where thermal resistance is not given in the characteristics, maximum total power dissipation as a function of temperature over the range of operating temperatures shall also be given.

5.1.5 Gate power dissipation

5.1.5.1 General

If these ratings are dependent on temperature or duty factor, derating information shall be given.

5.1.5.2 Mean gate power

Maximum rated value.

5.1.5.3 Peak gate power dissipation (P_{GM})

Maximum rated value for specified pulse duration.

5.1.5.4 Peak forward gate power (P_{FGM}) for GTO

Maximum rated value for a specified pulse width and repetition rate.

5.1.6 Frequency ratings

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

5.1.7 Special requirements for mounting

5.1.7.1 Mounting torque (M) (where appropriate)

Minimum and maximum values.

5.1.7.2 Clamping force (F) for disc type diodes (where appropriate)

Minimum and maximum values and the planarity of the mounting surface shall be specified.

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5.1.8 Principle anode-cathode voltages

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

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

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

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

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

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

5.1.8.4 Crest (peak) working reverse voltage (V_{RWM})

Maximum value with half wave sinusoidal wave-form at mains frequency, usually 50 Hz or 60 Hz (duration: 10 ms or 8,3 ms).

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

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

5.1.8.6 Repetitive peak reverse voltage (V_{RRM})

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

5.1.8.7 Continuous (direct) reverse voltage (V_R) (where appropriate)

To be specified as a maximum value.

$V_{R(D)}$ may be used for GTO.

5.1.8.8 Continuous (direct) off-state voltage (V_D) (where appropriate)

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

$V_{D(D)}$ may be used for GTO.

5.1.9 Gate voltages

5.1.9.1 General

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). See Figure 10 for reference.

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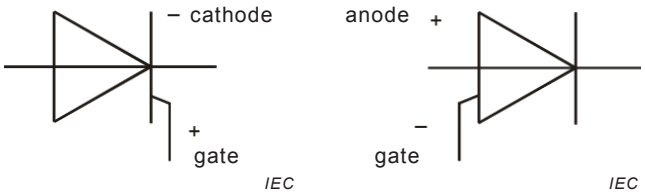

P-gate thyristor N-gate thyristor

Figure 10 – Application of gate voltages for thyristors

5.1.9.2 Peak forward gate voltage (V_{FGM})

Maximum rated value.

5.1.9.3 Peak reverse gate voltage (V_{RGM})

Maximum rated value.

5.1.10 Principal anode cathode currents

5.1.10.1 RMS on-state current ($I_{T(R.M.S.)}$)

A curve showing maximum rated values versus ambient or case temperature or heatsink temperature for full sine waves and under phase control conditions. As a reference value for certain characteristics, the limiting value for full sine waves at 45 °C ambient or 85 °C case temperature or other specified temperature shall be given as an example.

Where no ambiguity arises, $I_{T(RMS)}$ may be used.

NOTE The rated r.m.s. on-state current is given on the assumption that no overload occurs.

5.1.10.2 Repetitive peak on-state current (I_{TRM}) (where appropriate)

This maximum rated value shall be expressed in relation to the conduction angle.

5.1.10.3 Overload on-state current ($I_{T(OV)}$)

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

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

$$\int i^2 \mathrm{d}t$$

These ratings may be given by means of a curve or by specified values. The rating applies for operation with either polarity of principal voltage. No immediate subsequent application of off-state voltage is assumed;

b) for times equal to or greater than one full 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 shall be assumed to occur.

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These ratings are given for full cycles of 50 Hz or 60 Hz sine wave surge current.

5.1.10.4 Critical rate of rise of on-state current ($di_T/dt_{(cr)}$)

Maximum rated value under the following specified conditions:

a) off-state voltage prior to turn-on, preferably equal to a half or two-thirds the maximum rated repetitive peak off-state voltage of 5.1.8.2;

b) peak value of on-state current, preferably equal to $\sqrt{2}$ times the rated r.m.s. on-state current of 5.1.10.1 specified at 85 °C for case or ambient temperature; in case of GTO: preferably equal to the maximum rated repetitive peak controllable on-state current, with current wave shape and pulse width specified;

c) repetition rate, preferably 50 Hz or 60 Hz;

d) ambient or case temperature or junction temperature equal to the highest temperature at which the peak value of the on-state current is permitted;

e) gate-trigger conditions;

f) test duration (should be longer than the thermal time constant of the device, for example 30 s).

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

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

5.1.10.5 Surge non-repetitive reverse current (I_{RCSM}) (for reverse conducting thyristors)

Maximum value under specified pulse conditions.

5.1.10.6 Repetitive peak reverse current (I_{RCRM}) (for reverse conducting thyristors)

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

5.1.10.7 Continuous (direct) reverse current (I_{RC}) (for reverse conducting thyristors)

Maximum value under specified temperature and V_R conditions.

$I_{RC(D)}$ may be used.

5.1.10.8 Mean reverse current ($I_{RC(AV)}$) (for reverse conducting thyristors)

Maximum value 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.

5.1.10.9 On-state currents

5.1.10.9.1 Mean on-state current ($I_{T(AV)}$)

Maximum value 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.

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5.1.10.9.2 Repetitive peak on-state current (I_{TRM}) (where appropriate)

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

5.1.10.10 Short-time and intermittent duty current (for GTO)

Maximum rated on-state current under short-time or intermittent duty.

5.1.10.11 I^2t value (of a surge on-state current) (I^2t)

Maximum value used for the specification of surge on-state current, given in terms of the maximum rated value of

$$I^2t = \int_0^{t_i} i^2 \mathrm{d}t$$

for a specified short integration time t_i.

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

Maximum value with initial conditions corresponding to maximum rated virtual junction temperature.

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

$$\int i^2 \mathrm{d}t$$

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.

For fast turn-on thyristors or fast plasma-spreading thyristors such as those with distributed gate or inter-digitated gate structures (GTO), 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 shall 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.

NOTE Although surge on-state current ratings are given for half sine waves, they are, according to experience, also applicable to approximately triangular current waveforms, which occur when a sinusoidally rising fault current is interrupted by a current-limiting fuse.

5.1.10.13 Direct on-state current (I_T)

Maximum value under specified temperature

$I_{T(D)}$ may be used.

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

Curves 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;

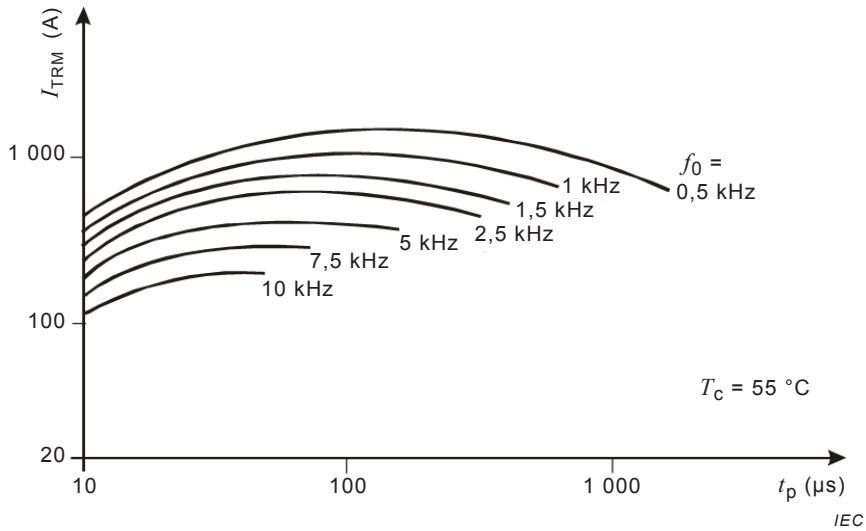
b) specified off-state voltage before turn-on;

c) specified reverse voltage;

d) specified gate conditions during turn-on and turn-off;

e) specified RC damping network (snubber).

Figure 11a) is given as an example. Figure 11b) is given for explanatory purposes only.



a) Maximum rated peak sinusoidal on-state current I_{TRM} (see Figure 11b)) as a function of pulse duration t_p with parameter: repetition frequency $f_0 = 1/T$

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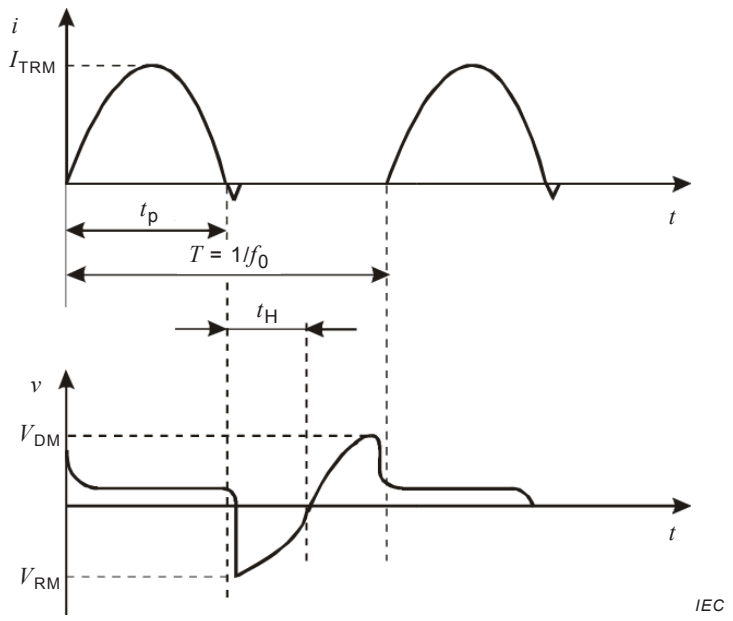

b) Typical current and voltage waveforms for sinusoidal on-state current pulses; t_H is the hold-off interval (see 3.5.2.4)

NOTE The pulse waveform includes the current pulse due to the RC damping network.

Figure 11 – Peak sinusoidal curents and typical waveforms at higher frequencies

5.1.10.15 Maximum peak value of a trapezoidal on-state current at higher frequencies (where appropriate)

Curves 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 (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 12a) and Figure 12b) are given as examples. Figure 12c) is given for explanatory purposes only.

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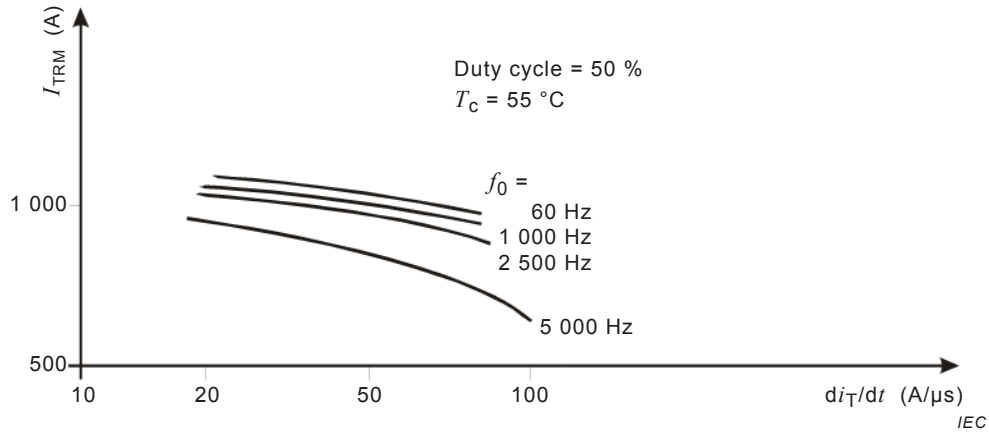
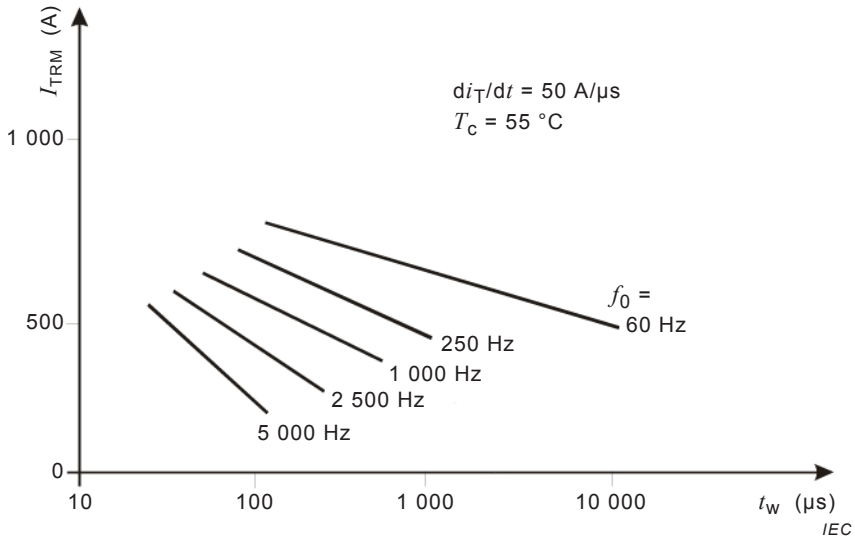


a) Maximum rated peak trapezoidal on-state current I_{TRM} for a specified t_w (see Figure 12c)) as a function of the rate of rise of on-state current with parameter repetition frequency $f_0 = 1/T$



b) Maximum rated peak trapezoidal on-state current I_{TRM} having a specified di_T/dt (see Figure 12c)) as a function of t_w with parameter repetition frequency $f_0 = 1/T$

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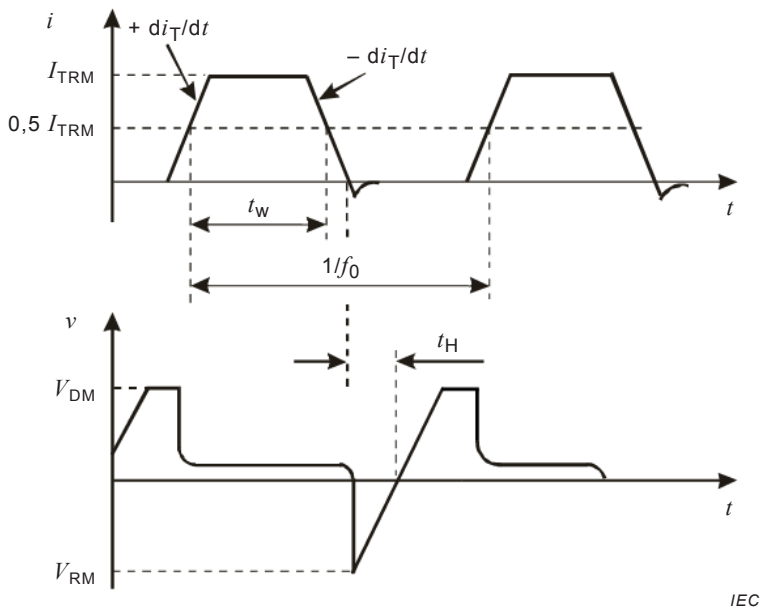

c) Typical current and voltage waveforms for trapezoidal on-state current pulses; t_H is the hold-off interval (see 3.5.2.4)

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

Figure 12 – Peak trapezoidal currents and typical waveforms at higher frequencies

5.1.10.16 Peak case non-rupture current (I_{RSMC})(where appropriate)

Maximum value of a triangular current rising at a specified rate, preferably 25 A/µs, and having a specified pulse duration for a starting case temperature to be specified, preferably 25 °C.

NOTE 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.

5.1.10.17 Non-repetitive peak controllable on-state current (I_{TQSM}) for GTO

Maximum rated value under the following conditions:

a) maximum rated virtual junction temperature;

b) specified reapplied off-state voltage, preferably a half or two-thirds of the maximum rated repetitive peak off-state voltage;

c) specified rate of rise of the reapplied off-state voltage;

d) specified turn-off spike voltage;

e) specified driving voltage in the gate circuit, preferably equal to the maximum rated turn-off gate voltage;

f) specified rate of rise of the turn-off gate current.

5.1.10.18 Repetitive peak controllable on-state current (I_{TQRM}) for GTO

Maximum rated value under the following conditions:

a) maximum rated virtual junction temperature is reached at the end of the turn-off procedure;

b) specified reapplied off-state voltage, preferably a half or two-thirds of the maximum rated repetitive peak off-state voltage;

c) specified rate of rise of the reapplied off-state voltage;

d) specified turn-off spike voltage;

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e) specified driving voltage in the gate circuit, preferably equal to the maximum rated turn-off gate voltage;

f) specified rate of rise of the turn-off gate current.

5.1.11 Peak forward gate current (I_{FGM})

Maximum value with anode-cathode voltage polarity specified and any qualifications (e.g. of time, energy, etc.) applicable to this rating.

5.2 Characteristics

5.2.1 General

In the case of a triac the characteristics recommended here are based upon symmetrical operation of the device, and therefore shall be based upon limiting values for either direction of operation. If a characteristic is sensitive to the gate triggering mode, the mode(s) applicable shall be specified.

5.2.2 Reverse current (I_R)

Maximum value at the maximum continuous (direct) reverse voltage and at a low value of reverse voltage at 25 °C and one higher temperature.

$I_{R(D)}$ may be used.

5.2.3 Reverse conducting voltage (V_{RC}) (for reverse conducting thyristors)

Maximum value at the maximum continuous (direct) reverse current

$V_{RC(D)}$ may be used.

5.2.4 Continuous (direct) off-state current (I_D)

Maximum value at the maximum continuous (direct) blocking voltage and at a low value of blocking voltage at 25 °C and one higher temperature.

$I_{D(D)}$ may be used.

5.2.5 On-state voltage (V_T)

Maximum value under the following conditions:

a) specified on-state current, preferably equal to the maximum rated repetitive peak controllable on-state current;

b) at a case or ambient temperature equal to the maximum rated virtual junction temperature. If a defined relationship exists between the values at this temperature and at 25 °C, the value at the latter temperature may be given;

c) specified value of gate current (required to maintain full on-state conduction).

$V_{T(D)}$ may be used.

5.2.6 On-state characteristics (where appropriate)

Curves showing instantaneous values of on-state voltage versus on-state current up to the maximum rated value of the repetitive peak on-state current, at an ambient or case temperature of 25 °C and at one other higher temperature, preferably equal to the maximum rated virtual junction temperature. These characteristics shall be measured using a pulse method, so that the junction temperature is approximately equal to the case temperature.

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5.2.7 Peak sinusoidal on-state voltage (V_{TM})

Maximum value at a current of π times the rated mean on-state current at the maximum rated virtual junction temperature or at a case or ambient temperature of 25 °C. In case of a triac this is the maximum value at a current of $\sqrt{2}$ times the maximum rated r.m.s. on-state current.

π may be taken as equal to 3.

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.

5.2.8 Threshold voltage ($V_{T(TO)}$ / V_{TO})

Maximum value at maximum rated virtual junction temperature.

5.2.9 On-state slope resistance (r_T)

Maximum value at maximum rated virtual junction temperature.

5.2.10 Holding current (I_H)

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

a) source voltage in the principal circuit (off-state voltage), 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.

5.2.11 Latching current (I_L)

Maximum value under the following specified conditions:

a) source voltage in the principal circuit (off-state voltage), preferably equal to 12 V (24 V in case of a GTO);

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 immediately after the triggering condition has been removed.

5.2.12 Repetitive peak off-state current (I_{DRM})

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

5.2.13 Repetitive peak reverse current (I_{RRM})

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

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5.2.14 Gate-trigger current (I_{GT}) and gate-trigger voltage (V_{GT})

Values of gate current and gate voltage required to turn on all thyristors of a given type. Limiting values and characteristics for the gate are preferably given with reference to a diagram as shown in Figure 13.

The following conditions shall be specified:

a) off-state voltage, preferably equal to 12 V (24 V in case of a GTO);

b) gate-circuit conditions;

c) ambient, case or junction temperature;

d) in case of a GTO specified maximum source resistance that will provide sufficient on-state current to assure conduction of all cathode islands.

The values of gate-trigger voltage and current should be given at 25 °C and at minimum operating temperature.

5.2.15 Gate non-trigger current (I_{GD}) and gate non-trigger voltage (V_{GD})

Values of the gate current and gate voltage which will not turn on any thyristor of a given type (see also Figure 13).

The following conditions shall be specified:

a) off-state voltage, preferably equal to a half or two-thirds of the maximum rated repetitive peak off-state voltage (V_{DRM});

b) ambient or case temperature, preferably equal to the maximum rated virtual junction temperature;

c) gate circuit conditions.

The values of gate non-trigger voltage and current should be given at maximum rated virtual junction temperature. If the characteristics given in Figure 13 are different for different quadrants of a triac, this should be stated.

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