Explanation of Maximum Ratings and Characteristics for Thyristors

Introduction

Data sheets for SCRs and Triacs give vital information regarding maximum ratings and characteristics of Thyristors. If the **maximum ratings** of the Thyristors are surpassed, possible irreversible damage may occur. The **characteristics** describe various pertinent device parameters which are guaranteed as either minimums or maximums. Some of these characteristics relate to the ratings but are not ratings in themselves. The characteristic does not define what the circuit must provide or be restricted to, but defines the device characteristic. For example, a minimum value is indicated for the dv/dt because this value depicts the guaranteed worst-case limit for all devices of the specific type. This minimum dv/dt value represents the maximum limit that the circuit should allow.

Maximum Ratings

V_{RRM}: Peak Repetitive Reverse Voltage -- SCR

The peak repetitive reverse voltage rating is the maximum peak reverse voltage that may be continuously applied to the main terminals (anode, cathode) of an SCR. (Figure AN1008.1) An open-gate condition and gate resistance termination is designated for this rating. An increased reverse leakage can result due to a positive gate bias during the reverse voltage exposure time of the SCR. The repetitive peak reverse voltage rating relates to case temperatures up to the maximum rated junction temperature.

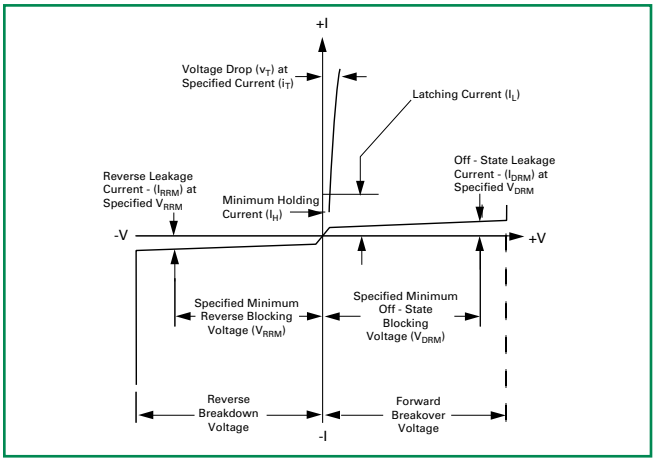

Figure AN1008.1 V-I Characteristics of SCR Device

V_{DRM}: Peak Repetitive Forward (Off-state) Voltage

SCR

The peak repetitive forward (off-state) voltage rating (Figure AN1008.1) refers to the maximum peak forward voltage which may be applied continuously to the main terminals (anode, cathode) of an SCR. This rating represents the maximum voltage the SCR should be required to block in the forward direction. The SCR may or may not go into conduction at voltages above the V_{DRM} rating. This rating is specified for an open-gate condition and gate resistance termination. A positive gate bias should be avoided since it will reduce the forward-voltage blocking capability. The peak repetitive forward (off-state) voltage rating applies for case temperatures up to the maximum rated junction temperature.

Triac

The peak repetitive off-state voltage rating should not be surpassed on a typical, non-transient, working basis. (Figure AN1008.2) V_{DRM} should not be exceeded even instantaneously. This rating applies for either positive or negative bias on main terminal 2 at the rated junction temperature. This voltage is less than the minimum breakover voltage so that breakover will not occur during operation. Leakage current is controlled at this voltage so that the temperature rise due to leakage power does not contribute significantly to the total temperature rise at rated current.

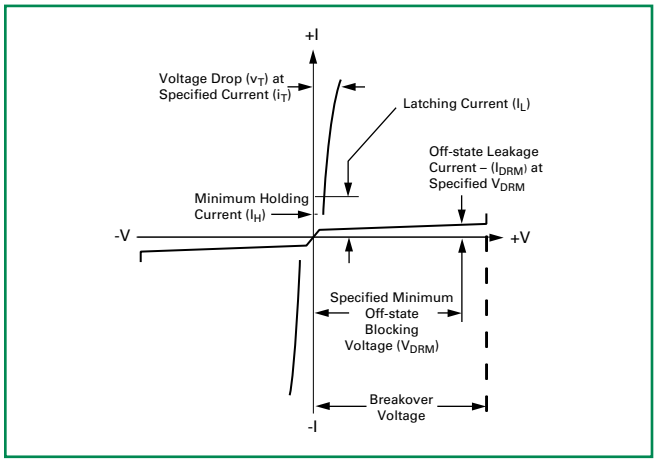

Figure AN1008.2 V-I Characteristics of Triac Device

I_T: Current Rating

SCR

For RMS and average currents, the restricting factor is usually confined so that the power dissipated during the on state and as a result of the junction-to-case thermal resistance will not produce a junction temperature in excess of the maximum junction temperature rating. Power dissipation is changed to RMS and average current ratings for a 60 Hz sine wave with a 180° conduction angle. The average current for conduction angles less than 180° is derated because of the higher RMS current connected with high peak currents. The DC current rating is higher than the average value for 180° conduction since no RMS component is present.

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The dissipation for non-sinusoidal waveshapes can be determined in several ways. Graphically plotting instantaneous dissipation as a function of time is one method. The total maximum allowable power dissipation (P_D) may be determined using the following equation for temperature rise:

$$P_D = \frac{T_{J(MAX)} - T_C}{R_{\theta JC}}$$

where T_J(max) is the maximum rated junction temperature (at zero rated current), T_C is the actual operating case temperature, and $R_{\theta JC}$ is the published junction-to-case thermal resistance. Transient thermal resistance curves are required for short interval pulses.

Triac

The limiting factor for RMS current is determined by multiplying power dissipation by thermal resistance. The resulting current value will ensure an operating junction temperature within maximum value. For convenience, dissipation is converted to RMS current at a 360° conduction angle. The same RMS current can be used at a conduction angle of less than 360°. For information on non-sinusoidal waveshapes and a discussion of dissipation, refer to the preceding description of SCR current rating.

I_{TSM}: Peak Surge (Non-repetitive) On-state Current -- SCR and Triac

The peak surge current is the maximum peak current that may be applied to the device for one full cycle of conduction without device degradation. The maximum peak current is usually specified as sinusoidal at 50 Hz or 60 Hz. This rating applies when the device is conducting rated current before the surge and, thus, with the junction temperature at rated values before the surge. The junction temperature will surpass the rated operating temperature during the surge, and the blocking capacity may be decreased until the device reverts to thermal equilibrium.

The surge-current curve in Figure AN1008.3 illustrates the peak current that may be applied as a function of surge duration. This surge curve is not intended to depict an exponential current decay as a function of applied overload. Instead, the peak current shown for a given number of cycles is the maximum peak surge permitted for that time period. The current must be derated so that the peak junction temperature during the surge overload does not exceed maximum rated junction temperature if blocking is to be retained after a surge.

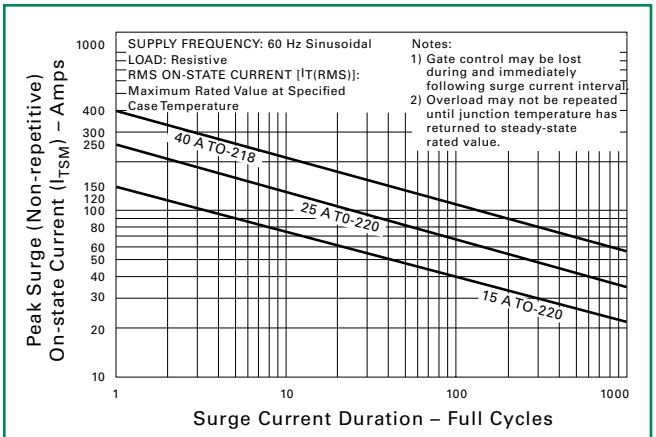

Figure AN1008.3 Peak Surge Current versus Surge Current Duration

I_{TM}: Peak Repetitive On-state Current – SCR and Triac

The I_{TM} rating specifies the maximum peak current that may be applied to the device during brief pulses. When the device operates under these circumstances, blocking capability is maintained. The minimum pulse duration and shape are defined and control the applied di/dt. The operating voltage, the duty factor, the case temperature, and the gate waveform are also defined. This rating must be followed when high repetitive peak currents are employed, such as in pulse modulators, capacitive-discharge circuits, and other applications where snubbers are required.

di/dt: Rate-of-change of On-state Current – SCR and Triac

The di/dt rating specifies the maximum rate-of-rise of current through a Thyristor device during turn-on. The value of principal voltage prior to turn-on and the magnitude and rise time of the gate trigger waveform during turn-on are among the conditions under which the rating applies. If the rate-of-change of current (di/dt) exceeds this maximum value, or if turn-on with high di/dt during minimum gate drive occurs (such as dv/dt or overvoltage events), then localized heating may cause device degradation.

During the first few microseconds of initial turn-on, the effect of di/dt is more pronounced. The di/dt capability of the Thyristor is greatly increased as soon as the total area of the pellet is in full conduction.

The di/dt effects that can occur as a result of voltage or transient turn-on (non-gated) is not related to this rating. The di/dt rating is specified for maximum junction temperature.

As shown in Figure AN1008.4, the di/dt of a surge current can be calculated by means of the following equation.

$$\frac{di}{dt} = \frac{I_{TM}}{2_{t_1}}$$

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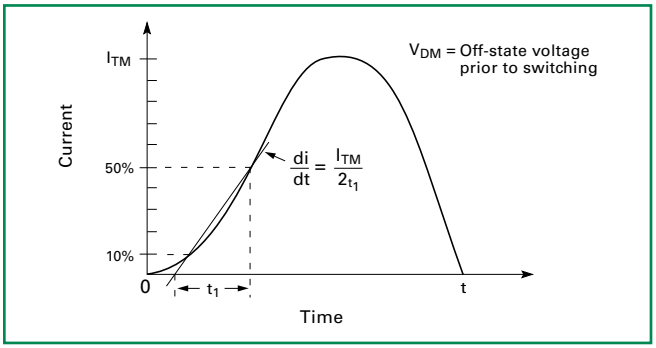

Figure AN1008.4 Relationship of Maximum Current Rating to Time

I^2t Rating -- SCR and Triac

The I^2t rating gives an indication of the energy-absorbing capability of the Thyristor device during surge-overload conditions. The rating is the product of the square of the RMS current $(I_{RMS})^2$ that flows through the device and the time during which the current is present and is expressed in A^2s. This rating is given for fuse selection purposes. It is important that the I^2t rating of the fuse is less than that of the Thyristor device. Without proper fuse or current limit, overload or surge current will permanently damage the device due to excessive junction heating.

P_G: Gate Power Dissipation -- SCR and Triac

Gate power dissipation ratings define both the peak power (P_{GM}) forward or reverse and the average power ($P_{G(AV)}$) that may be applied to the gate. Damage to the gate can occur if these ratings are not observed. The width of the applied gate pulses must be considered in calculating the voltage and current allowed since the peak power allowed is a function of time. The peak power that results from a given signal source relies on the gate characteristics of the specific unit. The average power resulting from high peak powers must not exceed the average-power rating.

T_S, T_J: Temperature Range -- SCR and Triac

The maximum storage temperature (T_S) is greater than the maximum operating temperature (actually maximum junction temperature). Maximum storage temperature is restricted by material limits defined not so much by the silicon but by peripheral materials such as solders used on the chip/die and lead attachments as well as the encapsulating epoxy. The forward and off-state blocking capability of the device determines the maximum junction (T_J) temperature. Maximum blocking voltage and leakage current ratings are established at elevated temperatures near maximum junction temperature; therefore, operation in excess of these limits may result in unreliable operation of the Thyristor.

Characteristics

V_{BO}: Instantaneous Breakover Voltage -- SCR and Triac

Breakover voltage is the voltage at which a device turns on (switches to on state by voltage breakover). (Figure AN1008.1) This value applies for open-gate or gate-resistance termination. Positive gate bias lowers the breakover voltage. Breakover is temperature sensitive and will occur at a higher voltage if the junction temperature is kept below maximum T_J value. If SCRs and Triacs are turned on as a result of an excess of breakover voltage, instantaneous power dissipations may be produced that can damage the chip or die.

I_{DRM}: Peak Repetitive Off-state (Blocking) Current

SCR

I_{DRM} is the maximum leakage current permitted through the SCR when the device is forward biased with rated positive voltage on the anode (DC or instantaneous) at rated junction temperature and with the gate open or gate resistance termination. A 1000 Ω resistor connected between gate and cathode is required on all sensitive SCRs. Leakage current decreases with decreasing junction temperatures. Effects of the off-state leakage currents on the load and other circuitry must be considered for each circuit application. Leakage currents can usually be ignored in applications that control high power.

Triac

The description of peak off-state (blocking/leakage) current for the Triac is the same as for the SCR except that it applies with either positive or negative bias on main terminal 2.(Figure AN1008.2)

I_{RRM}: Peak Repetitive Reverse Current – SCR

This characteristic is essentially the same as the peak forward off-state (blocking/leakage) current except negative voltage is applied to the anode (reverse biased).

V_{TM}: Peak On-State Voltage -- SCR and Triac

The instantaneous on-state voltage (forward drop) is the principal voltage at a specified instantaneous current and case temperature when the Thyristor is in the conducting state. To prevent heating of the junction, this characteristic is measured with a short current pulse. The current pulse should be at least 100 µs duration to ensure the device is in full conduction. The forward-drop characteristic determines the on-state dissipation. See Figure AN1008.5, and refer to "IT: Current Rating" on page AN1008-2.

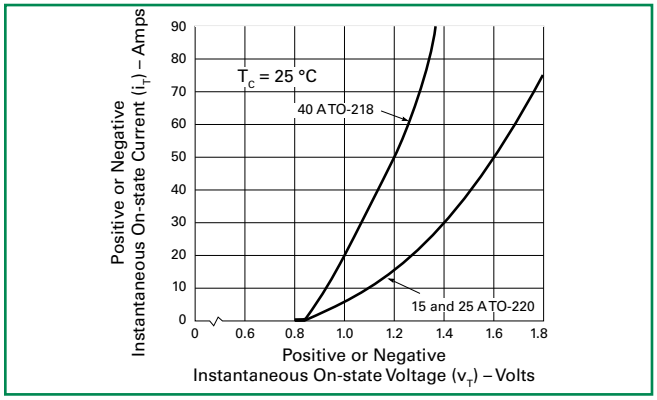

Figure AN1008.5 On-state Current versus On-state Voltage (Typical)

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I_{GT}: DC Gate Trigger Current

SCR

I_{GT} is the minimum DC gate current required to cause the Thyristor to switch from the non-conducting to the conducting state for a specified load voltage and current as well as case temperature. The characteristic curve illustrated in Figure AN1008.6 shows that trigger current is temperature dependent. The Thyristor becomes less sensitive (requires more gate current) with decreasing junction temperatures. The gate current should be increased by a factor of two to five times the minimum threshold DC trigger current for best operation. Where fast turn-on is demanded and high di/dt is present or low temperatures are expected, the gate pulse may be 10 times the minimum IGT, plus it must be fast-rising and of sufficient duration in order to properly turn on the Thyristor.

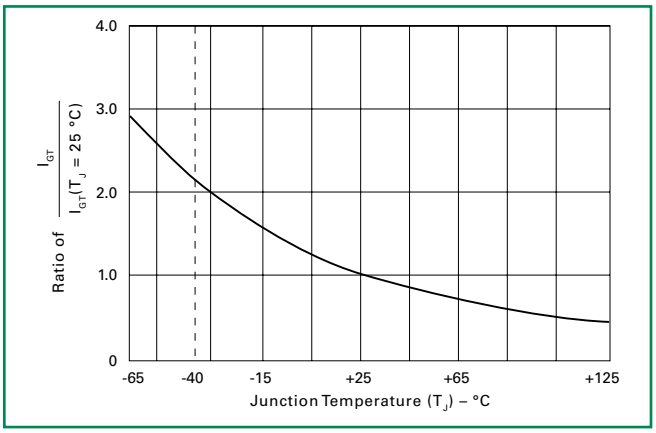

Figure AN1008.6 Normalized DC Gate Trigger Current for All Quadrants versus Case Temperature

Triac

The description for the SCR applies as well to the Triac with the addition that the Triac can be fired in four possible modes (Figure AN1008.7):

Quadrant I (main terminal 2 positive, gate positive)

Quadrant II (main terminal 2 positive, gate negative)

Quadrant III (main terminal 2 negative, gate negative)

Quadrant IV (main terminal 2 negative, gate positive)

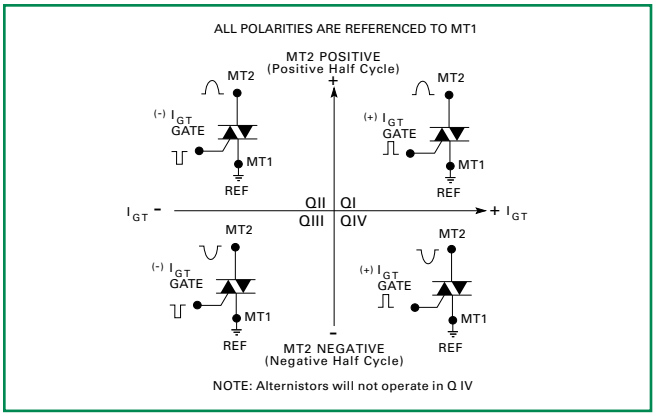

Figure AN1008.7 Definition of Operating Quadrants

V_{GT}: DC Gate Trigger Voltage

SCR

V_{GT} is the DC gate-cathode voltage that is present just prior to triggering when the gate current equals the DC trigger current. As shown in the characteristic curve in Figure AN1008.8, the gate trigger voltage is higher at lower temperatures. The gate-cathode voltage drop can be higher than the DC trigger level if the gate is driven by a current higher than the trigger current.

Triac

The difference in V_{GT} for the SCR and the Triac is that the Triac can be fired in four possible modes. The threshold trigger voltage can be slightly different, depending on which of the four operating modes is actually used.

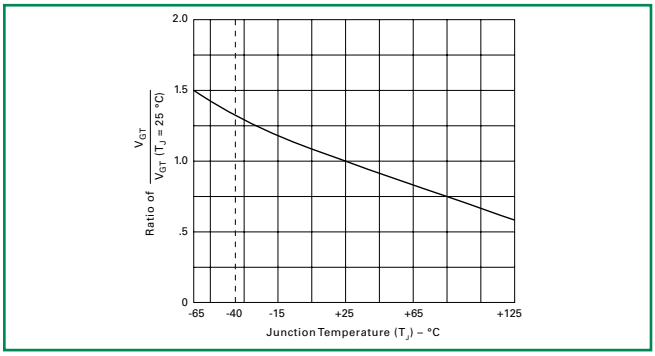

Figure AN1008.8 Normalized DC Gate Trigger Voltage for All Quadrants versus Case Temperature

I_L: Latching Current

SCR

Latching current is the DC anode current above which the gate signal can be withdrawn and the device stays on. It is related to, has the same temperature dependence as, and is somewhat greater than the DC gate trigger current. (Figure AN1008.1 and Figure AN1008.2) Latching current is at least equal to or much greater than the holding current, depending on the Thyristor type.

Latching current is greater for fast-rise-time anode currents since not all of the chip/die is in conduction. It is this dynamic latching current that determines whether a device will stay on when the gate signal is replaced with very short gate pulses. The dynamic latching current varies with the magnitude of the gate drive current and pulse duration. In some circuits, the anode current may oscillate and drop back below the holding level or may even go negative; hence, the unit may turn off and not latch if the gate signal is removed too quickly.

Triac

The description of this characteristic for the Triac is the same as for the SCR, with the addition that the Triac can be latched on in four possible modes (quadrants). Also, the required latching is significantly different depending on which gating quadrants are used. Figure AN1008.9 illustrates typical latching current requirements for the four possible quadrants of operation.

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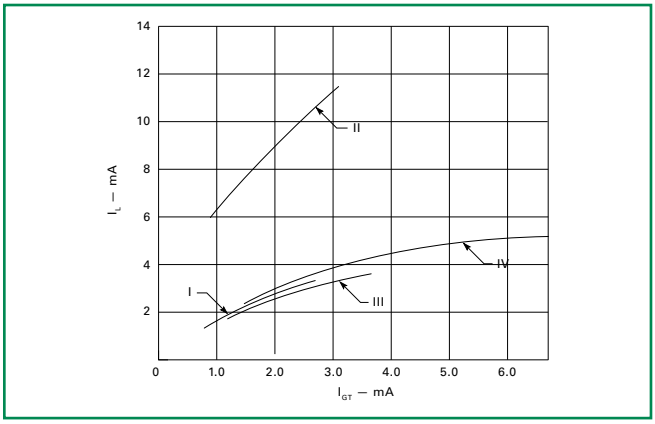

Figure AN1008.9 Typical Triac Latching (I_L) Requirements for Four Quadrants versus Gate Current (I_{GT})

I_H: Holding Current -- SCR and Triac

The holding current is the DC principal on-state current below which the device will not stay in regeneration/on state after latching and gate signal is removed. This current is equal to or lower in value than the latching current (Figure AN1008.1 and Figure AN1008.2) and is related to and has the same temperature dependence as the DC gate trigger current shown in Figure AN1008.10. Both minimum and maximum holding current may be important. If the device is to stay in conduction at low-anode currents, the maximum holding current of a device for a given circuit must be considered. The minimum holding current of a device must be considered if the device is expected to turn off at a low DC anode current. Note that the low DC principal current condition is a DC turn-off mode, and that an initial on-state current (latching current) is required to ensure that the Thyristor has been fully turned on prior to a holding current measurement.

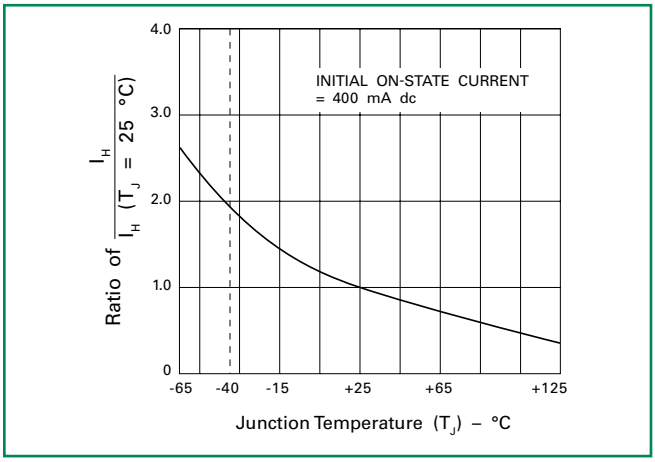

Figure AN1008.10 Normalized DC Holding Current versus Case Temperature

dv/dt, Static: Critical Rate-of-rise of Off-state Voltage — SCR and Triac

Static dv/dt is the minimum rate-of-rise of off-state voltage that a device will hold off, with gate open, without turning on. Figure AN1008.11 illustrates the exponential definition. This value will be reduced by a positive gate signal. This characteristic is temperature-dependent and is lowest at the maximum-rated junction temperature. Therefore, the characteristic is determined at rated junction temperature and at rated forward off-state voltage which is also a worst-case situation. Line or other transients which might be applied to the Thyristor in the off state must be reduced, so that neither the rate-of-rise nor the peak voltage are above specifications if false firing is to be prevented. Turn-on as result of dv/dt is non-destructive as long as the follow current remains within current ratings of the device being used.

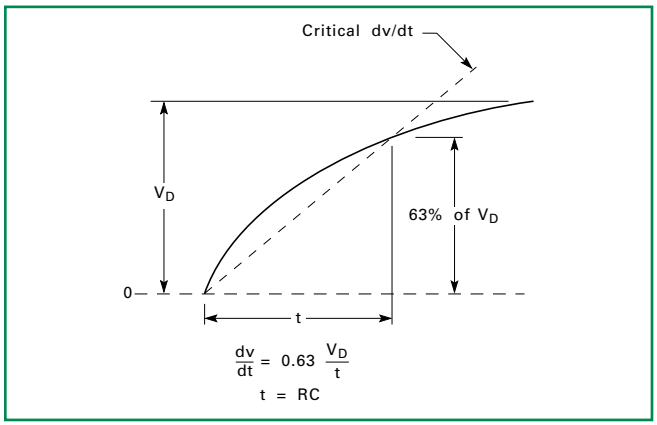

Figure AN1008.11 Exponential Rate-of-rise of Off-state Voltage Defining dv/dt

dv/dt, Commutating: Critical Rate-of-rise of Commutation Voltage -- Triac

Commutating dv/dt is the rate-of-rise of voltage across the main terminals that a Triac can support (block without switching back on) when commutating from the on state in one half cycle to the off state in the opposite half cycle. This parameter is specified at maximum rated case temperature (equal to T_J) since it is temperature-dependent. It is also dependent on current (commutating di/dt) and peak reapplied voltage (line voltage) and is specified at rated current and voltage. All devices are guaranteed to commutate rated current with a resistive load at 50 Hz to 60 Hz. Commutation of rated current is not guaranteed at higher frequencies, and no direct relationship can be made with regard to current/temperature derating for higher-frequency operation. With inductive loading, when the voltage is out of phase with the load current, a voltage stress (dv/dt) occurs across the main terminals of the Triac during the zero-current crossing. (Figure AN1008.12) A snubber (series RC across the Triac) should be used with inductive loads to decrease the applied dv/dt to an amount below the minimum value which the Triac can be guaranteed to commutate off each half cycle.

Commutating dv/dt is specified for a half sinewave current at 60 Hz which fixes the di/dt of the commutating current. The commutating di/dt for 50 Hz is approximately 20% lower while I_{RMS} rating remains the same. (Figure AN1008.4)

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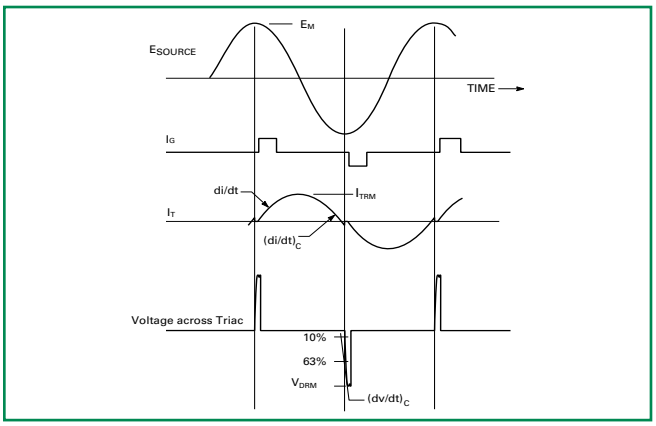

Figure AN1008.12 Waveshapes of Commutating dv/dt and Associated Conditions

t_{gt}: Gate-controlled Turn-on Time -- SCR and Triac

The t_{gt} is the time interval between the application of a gate pulse and the on-state current reaching 90% of its steady-state value. (Figure AN1008.13) As would be expected, turn-on time is a function of gate drive. Shorter turn-on times occur for increased gate drives. This turn-on time is actually only valid for resistive loading. For example, inductive loading would restrict the rate-of-rise of anode current. For this reason, this parameter does not indicate the time that must be allowed for the device to stay on if the gate signal is removed. (Refer to the description of "IL: Latching Current" on page AN1008-4.) However, if the load was resistive and equal to the rated load current value, the device definitely would be operating at a current above the dynamic latching current in the turn-on time interval since current through the device is at 90% of its peak value during this interval.

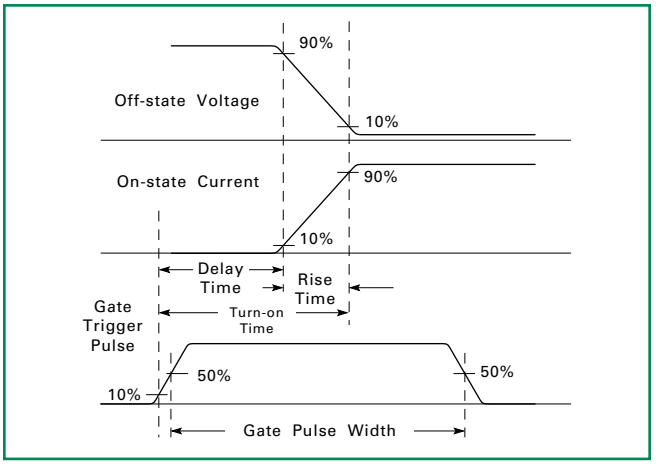

Figure AN1008.13 Waveshapes for Turn-on Time and Associated Conditions

t_q: Circuit-commutated Turn-off Time -- SCR

The circuit-commutated turn-off time of the device is the time during which the circuit provides reverse bias to the device (negative anode) to commutate it off. The turn-off time occurs between the time when the anode current goes negative and when the anode positive voltage may be reapplied. (Figure AN1008.14) Turn-off time is a function of many parameters and very dependent on temperature and gate bias during the turn-off interval. Turn-off time is lengthened for higher temperature so a high junction temperature is specified. The gate is open during the turn-off interval. Positive bias on the gate will lengthen the turn-off time; negative bias on the gate will shorten it.

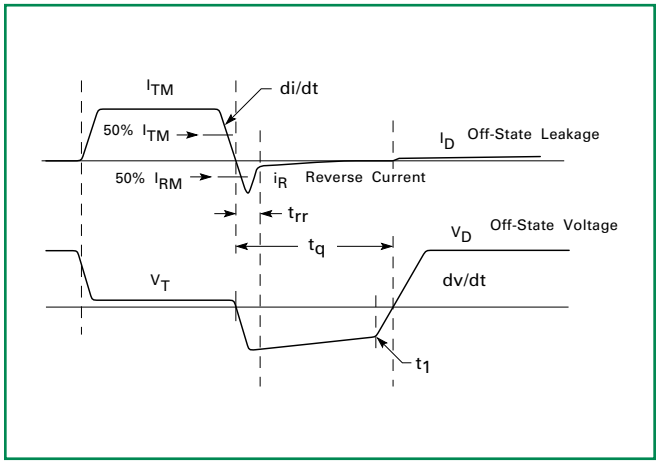

Figure AN1008.14 Waveshapes of t_q Rating Test and Associated Conditions

$R_{\theta JC}$, $R_{\theta JA}$: Thermal Resistance (Junction-to-case, Junction-to-ambient) -- SCR and Triac

The thermal-resistance characteristic defines the steady-state temperature difference between two points at a given rate of heat-energy transfer (dissipation) between the points. The thermal-resistance system is an analog to an electrical circuit where thermal resistance is equivalent to electrical resistance, temperature difference is equivalent to voltage difference, and rate of heat-energy transfer (dissipation) is equivalent to current. Dissipation is represented by a constant current generator since generated heat must flow (steady-state) no matter what the resistance in its path. Junction-to-case thermal resistance establishes the maximum case temperature at maximum rated steady-state current. The case temperature must be held to the maximum at maximum ambient temperature when the device is operating at rated current. Junction-to-ambient thermal resistance is established at a lower steady-state current, where the device is in free air with only the external heat sinking offered by the device package itself. For $R_{\theta JA,}$ power dissipation is limited by what the device package can dissipate in free air without any additional heat sink:

$$R_{\theta JC} = \frac{T_J - T_C}{P_{(AV)}}$$

$$R_{\theta JA} = \frac{T_J - T_A}{P_{(AV)}}$$

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