3.4 Switching Characteristics (Dynamic characteristics)

Thyristor Turn-ON Characteristics

When the SCR is turned on with the application of the gate signal, the SCR does not conduct fully at the instant of application of the gate trigger pulse. In the beginning, there is no appreciable increase in the SCR anode current, which is because, only a small portion of the silicon pellet in the immediate vicinity of the gate electrode starts conducting. The duration between 90% of the peak gate trigger pulse and the instant the forward voltage has fallen to 90% of its initial value is called the gate controlled / trigger delay time $t_{gd}$. It is also defined as the duration between 90% of the gate trigger pulse and the instant at which the anode current rises to 10% of its peak value. $t_{gd}$ is usually in the range of 1 sec.

Once $t_{gd}$ has lapsed, the current starts rising towards the peak value. The period during which the anode current rises from 10% to 90% of its peak value is called the rise time. It is also defined as the time for which the anode voltage falls from 90% to 10% of its peak value. The summation of $t_{gd}$ and $t_r$ gives the turn on time $t_{on}$ of the thyristor.
Thyristor Turn OFF Characteristics

When an SCR is turned on by the gate signal, the gate loses control over the device and the device can be brought back to the blocking state only by reducing the forward current to a level below that of the holding current. In AC circuits, however, the current goes through a natural zero value and the device will automatically switch off. But in DC circuits, where no neutral zero value of current exists, the forward current is reduced by applying a reverse voltage across anode and cathode and thus forcing the current through the SCR to zero.

As in the case of diodes, the SCR has a reverse recovery time \( t_r \) which is due to charge storage in the junctions of the SCR. These excess carriers take some time for recombination resulting in the gate recovery time or reverse recombination time \( t_{gr} \). Thus, the turn-off time \( t_q \) is the sum of the durations for which reverse recovery current flows after the application of reverse voltage and the time required for the recombination of all excess carriers present. At the end of the turn off time, a depletion layer develops across \( J_2 \) and the junction can now withstand the forward voltage. The turn off time is dependent on the anode current, the
magnitude of reverse $V_g$ applied ad the magnitude and rate of application of the forward voltage. The turn off time for converte grade SCR’s is 50 to 100 sec and that for inverter grade SCR’s is 10 to 20 sec.

To ensure that SCR has successfully turned off, it is required that the circuit off time $t_c$ be greater than SCR turn off time $t_q$.

**Thyristor Turn ON**

- **Thermal Turn on**: If the temperature of the thyristor is high, there will be an increase in charge carriers which would increase the leakage current. This would cause an increase in $\alpha_1$ and $\alpha_2$ and the thyristor may turn on. This type of turn on many times cause thermal run away and is usually avoided.

- **Light**: If light be allowed to fall on the junctions of a thyristor, charge carrier concentration would increase which may turn on the SCR.

- **LASCR**: Light activated SCRs are turned on by allowing light to strike the silicon wafer.

- **High Voltage Triggering**: This is triggering without application of gate voltage with only application of a large voltage across the anode-cathode such that it is greater than the forward breakdown voltage $V_{BO}$. This type of turn on is destructive and should be avoided.

- **Gate Triggering**: Gate triggering is the method practically employed to turn-on the thyristor. Gate triggering will be discussed in detail later.

**$\frac{dV}{dt}$ Triggering:**

Under transient conditions, the capacitances of the p-n junction will influence the characteristics of a thyristor. If the thyristor is in the blocking state, a rapidly rising voltage applied across the device would cause a high current to flow through the device resulting in turn-on. If $i_{j2}$ is the current through the junction $j_2$ and $C_{j2}$ is the junction capacitance and $V_{j2}$ is the voltage across $j_2$, then

$$i_{j2} = \frac{dq_{j2}}{dt} = \frac{d}{dt} C_{j2} V_{j2} = \frac{C_{j2}}{dt} \frac{dV_{j2}}{dt} + V_{j2} \frac{dC_{j2}}{dt}$$
From the above equation, we see that if $\frac{dv}{dt}$ is large, $I_2$ will be large. A high value of charging current may damage the thyristor and the device must be protected against high $\frac{dv}{dt}$. The manufacturers specify the allowable $\frac{dv}{dt}$.

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**Thyristor Ratings**

<table>
<thead>
<tr>
<th>First Subscript</th>
<th>Second Subscript</th>
<th>Third Subscript</th>
</tr>
</thead>
<tbody>
<tr>
<td>D $\rightarrow$ off state</td>
<td>W $\rightarrow$ working</td>
<td>M $\rightarrow$ Peak Value</td>
</tr>
<tr>
<td>T $\rightarrow$ ON state</td>
<td>R $\rightarrow$ Repetitive</td>
<td></td>
</tr>
<tr>
<td>F $\rightarrow$ Forward</td>
<td>S $\rightarrow$ Surge or non-repetitive</td>
<td></td>
</tr>
<tr>
<td>R $\rightarrow$ Reverse</td>
<td></td>
<td></td>
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</tbody>
</table>

**VOLTAGE RATINGS**

$V_{DWM}$: This specifies the peak off state working forward voltage of the device. This specifies the maximum forward off state voltage which the thyristor can withstand during its working.
$V_{DRM}$: This is the peak repetitive off state forward voltage that the thyristor can block repeatedly in the forward direction (transient).

$V_{DSM}$: This is the peak off state surge / non-repetitive forward voltage that will occur across the thyristor.

$V_{RWM}$: This the peak reverse working voltage that the thyristor can withstand in the reverse direction.

$V_{RRM}$: It is the peak repetitive reverse voltage. It is defined as the maximum permissible instantaneous value of repetitive applied reverse voltage that the thyristor can block in reverse direction.

$V_{RSM}$: Peak surge reverse voltage. This rating occurs for transient conditions for a specified time duration.

$V_T$: On state voltage drop and is dependent on junction temperature.

$V_{TM}$: Peak on state voltage. This is specified for a particular anode current and junction temperature.

$\frac{dv}{dt}$ rating: This is the maximum rate of rise of anode voltage that the SCR has to withstand and which will not trigger the device without gate signal (refer $\frac{dv}{dt}$ triggering).

Current Rating

$I_{T_{average}}$: This is the on state average current which is specified at a particular temperature.
$I_{RMS}$: This is the on-state RMS current.

**Latching current, $I_L$:** After the SCR has switched on, there is a minimum current required to sustain conduction. This current is called the latching current. $I_L$ associated with turn on and is usually greater than holding current.

**Holding current, $I_H$:** After an SCR has been switched to the on state a certain minimum value of anode current is required to maintain the thyristor in this low impedance state. If the anode current is reduced below the critical holding current value, the thyristor cannot maintain the current through it and reverts to its off state usually $I_H$ is associated with turn off the device.

$\frac{di}{dt}$ rating: This is a non repetitive rate of rise of on-state current. This maximum value of rate of rise of current is which the thyristor can withstand without destruction. When thyristor is switched on, conduction starts at a place near the gate. This small area of conduction spreads rapidly and if rate of rise of anode current $\frac{di}{dt}$ is large compared to the spreading velocity of carriers, local hotspots will be formed near the gate due to high current density. This causes the junction temperature to rise above the safe limit and the SCR may be damaged permanently. The $\frac{di}{dt}$ rating is specified in $A/\mu sec$.

**Gate Specifications**

$I_{GT}$: This is the required gate current to trigger the SCR. This is usually specified as a DC value.

$V_{GT}$: This is the specified value of gate voltage to turn on the SCR (dc value).

$V_{GD}$: This is the value of gate voltage, to switch from off state to on state. A value below this will keep the SCR in off state.
\( Q_{br} \) : Amount of charge carriers which have to be recovered during the turn off process.

\( R_{thjc} \) : Thermal resistance between junction and outer case of the device.

**Gate Triggering Methods**

**Types**

The different methods of gate triggering are the following:

- R-triggering.
- RC triggering.
- UJT triggering.