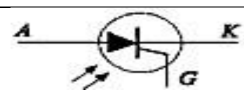
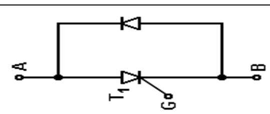
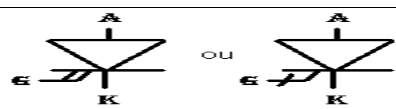
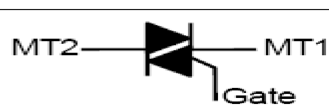
Prabhat...

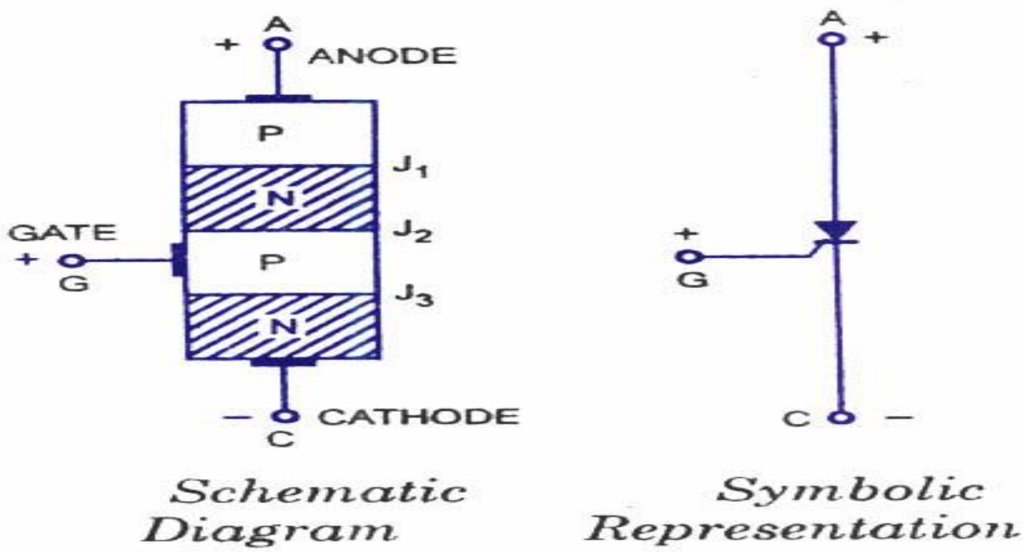
Thyristor (control device→ ON-OFF control)

- Thyristor is a power switch made of semiconductor material having 4 layers and 3 terminals.
- It is a static switch latching from ON→OFF & OFF→ON.
- It is semi-controlled switch, because ON state can be controlled by gate signal but after thyristor is turn ON, it remain latched in ON state due to internal regenerative action and gate losses control.
- Thyristors are very much in use. In some cases transistors are replaced by power transistors because it is very fast operating device so some extra harmonics are introduced. power transistors has lesser switching speed but almost same control.
- Thyristors may be used in power-switching circuits, relay-replacement circuits, inverter circuits, oscillator circuits, level-detector circuits, chopper circuits, light-dimming circuits, low-cost timer circuits, logic circuits, speed-control circuits, phase-control circuits, etc.

Thyristor family

Thyritsor	Circuit symbol	Voltage/current rating	Upper frequency range
SCR		7000V/5000A	1.0 kHz
LASCR		6000V/3000A	1.0 kHz
ASCR/RCT		2500V/400A	2.0 kHz
GTO		5000V/3000A	2.0 kHz
SITH		2500V/500A	100 kHz
MCT		1200V/40A	20 kHz
Triac		1200V/1000A	0.50 kHz

Basic Construction of Thyristor – SCR



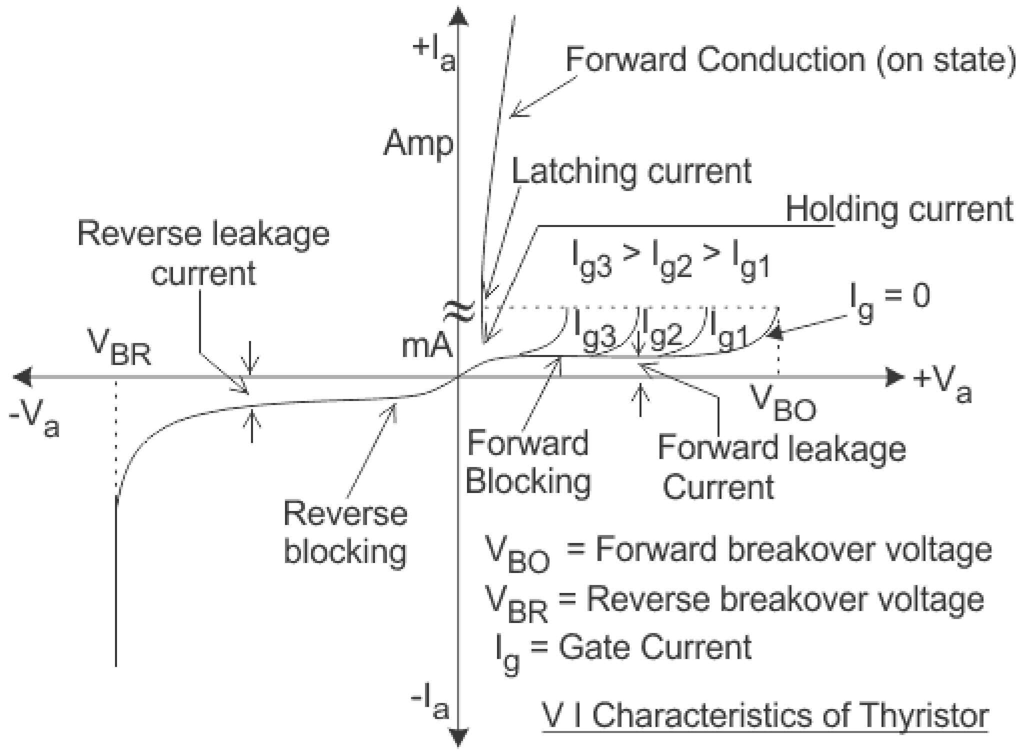
Silicon Controlled Rectifier

A high- resistive, n-base region, presents in every thyristor. As it is seen in the figure, this n-base region is associated with junction, J_2. This must support the large applied forward voltages that occur when the switch is in its off- or forward-blocking state (non-conducting). This n-base region is typically doped with impurity phosphorous atoms at a concentration of 10^{13} to 10^{14} per cube centimeter. This region is typically made 10 to 100 micrometer thick to support large voltages. High-voltage thyristors are generally made by diffusing aluminum or gallium into both surfaces to create p-doped regions forming deep junctions with the n-base. The doping profile of the p-regions ranges from about 10^{15} to 10^{17} per cube centimeter. These p-regions can be up to tens of micrometer thick. The cathode region (typically only a few micrometer thick) is formed by using phosphorous atoms at a doping density of 10^{17} to 10^{18} cube centimeter. For higher forward-blocking voltage rating of thyristor, the n-base region is made thicker. But thicker n – based high-resistive region slows down on off operation of the device. This is because of more stored charge during conduction. A device rated for forward blocking voltage of 1 kV will operate much more slowly than the thyristor rated for 100 V. Thicker high-resistive region also causes larger forward voltage drop during conduction. Impurity atoms, such as platinum or gold, or electron irradiation are used to create charge-carrier recombination sites in the thyristor. The large number of recombination sites reduces the mean carrier lifetime (average time that an electron or hole moves through the Si before recombining with its opposite charge-carrier type). A reduced carrier lifetime shortens the switching times (in particular the turn-off or recovery time) at the expense of increasing the forward-conduction drop. There are other effects associated with the relative thickness and layout of the various regions that make up modern thyristors, but the major trade off between forward-blocking voltage rating and switching times and between forward-blocking voltage rating and forward-voltage drop during conduction should be kept in mind.

V-I Characteristics of a Thyristor

Thyristor has 3 basic modes of operation.

1) Forward blocking mode (OFF state).
2) Forward conduction mode (ON state).
3) Reverse blocking mode.



Forward Blocking Mode

Considering the anode is positive w.r.t cathode, with gate kept in open condition. The thyristor is now said to be forward biased. the junctions J_1 and J_3 are now forward biased but junction J_2 goes into reverse biased condition. In this particular mode, a small current, called forward leakage current is allowed to flow initially as shown in the diagram for characteristics of thyristor. Now, if we keep on increasing the forward biased anode to cathode voltage.In this particular mode, the thyristor conducts currents from anode to cathode with a very small voltage drop across it. A thyristor is brought from forward blocking mode to forward conduction mode by turning it on by exceeding the forward break over voltage (V_{BO}) or by applying a gate pulse between gate and cathode. In this mode, thyristor is in on-state and behaves like a closed switch. Voltage drop across thyristor in the on state is of the order of 1 to 2 V depending beyond a certain point, then the reverse biased junction J_2 will have an avalanche breakdown at a voltage called forward break over voltage V_{B0} of the thyristor.

Forward Conduction Mode

When the anode to cathode forward voltage is increased, with gate circuit open, the reverse junction J_2 will have an avalanche breakdown at forward break over voltage V_{BO} leading to thyristor turn on.In this mode of operation, the thyristor conducts maximum current with minimum voltage drop, this is known as the forward conduction forward conduction or the turn on mode of the thyristor.

Reverse Blocking Mode of Thyristor

The anode is negative w.r.t cathode, with gate kept in open condition. Here Junctions J_1 and J_3 are reverse biased whereas the junction J_2 is forward biased. The behavior of the thyristor here is similar to that of two diodes are connected in series with reverse voltage applied across them. As a result only a small leakage current of the order of a few μAmps flows. This is the reverse blocking mode or the off-state, of the thyristor. If the reverse voltage is now increased, then at a particular voltage, known as the critical breakdown voltage V_{BR}, an avalanche occurs at J_1 and J_3 and the reverse current increases rapidly. A large current associated with V_{BR} gives rise to more losses in the SCR, which results in heating. This may lead to thyristor damage as the junction temperature may exceed its permissible temperature rise. It should, therefore, be ensured that maximum working reverse voltage across a thyristor does not exceed V_{BR}. When reverse voltageapplied across a thyristor is less than V_{BR}, the device offers very high impedance in the reverse direction. The SCR in the reverse blocking mode may therefore be treated as open circuit.

- Once the thyristor is turned on by a gate signal and its anode current is greater than the holding current, the device continues to conduct due to positive feedback even if the gate signal is removed. This is because the thyristor is a latching device and it has been latched to the on-state.

Latching current – it can be defined as the minimum value of anode current which thyristor must attain during turn-on to maintain the conduction when gate signal is removed.

Holding current – it can be defined as the minimum value of anode current below which it must fall for turning - off the thyristor.

Latching current is more than holding current. it is usual to take latching current 2 to 3 times greater than holding current.

Thyristor Triggering methods

The various SCR triggering methods are

- Forward Voltage Triggering
- Thermal or Temperature Triggering
- Radiation or Light triggering
- dv/dt Triggering
- Gate Triggering

Forward Voltage Triggering

- In this mode, an additional forward voltage is applied between anode and cathode.
- When the anode terminal is positive with respect to cathode (V_{AK}) , Junction J1 and J3 is forward biased and junction J2 is reverse biased.
- No current flows due to depletion region in J2 is reverse biased (except leakage current).
- As V_{AK} is further increased, at a voltage V_{BO} (Forward Break Over Voltage) the junction J2 undergoes avalanche breakdown and so a current flows and the device tends to turn ON(even when gate is open)
- This method is not preferred because during turn on of thyristor, it is associated with large voltage and large current which results in huge power loss and device may be damaged.

Thermal or Temperature Triggering

- The width of depletion layer of SCR decreases with increase in junction temperature due to the generation of electron-hole pair.
- Therefore in SCR when V_{AR} is very near its breakdown voltage, the device is triggered by increasing the junction temperature.
- By increasing the junction temperature the reverse biased junction collapses thus the device starts to conduct.
- This method is not preferred because temperature changes the characteristics of SCR.

Radiation or Light triggering

- For light triggered SCRs a special terminal niche is made inside the inner P layer instead of gate terminal.
- When light is allowed to strike this terminal, free charge carriers are generated.
- When intensity of light becomes more than a normal value, the thyristor starts conducting.
- This type of SCRs are called as LASCR

dv/dt Triggering

- When the device is forward biased, J1 and J3 are forward biased, J2 is reverse biased.
- Junction J2 behaves as a capacitor, due to the charges existing across the junction.
- If voltage across the device is V, the charge by Q and capacitance by C then,

$i_c = dQ/dt$

$Q = CV$

$i_c = d(CV)/dt$

$= C.dV/d + V.dC/dt$ .... as $dC/dt = 0$

$i_c = C.dV/dt$

- Therefore when the rate of change of voltage across the device becomes large, the device may turn ON, even if the voltage across the device is small.

Gate Triggering

- This is most widely used SCR triggering method.
- Applying a positive voltage between gate and cathode can Turn ON a forward biased thyristor.

- When a positive voltage is applied at the gate terminal, charge carriers are injected in the inner P-layer, thereby reducing the depletion layer thickness.
- As the applied voltage increases, the carrier injection increases, therefore the voltage at which forward break-over occurs decreases.

- Three types of signals are used for gate triggering.

1. DC gate triggering:-

A DC voltage of proper polarity is applied between gate and cathode (Gate terminal is positive with respect to Cathode).

When applied voltage is sufficient to produce the required gate Current, the device starts conducting.

One drawback of this scheme is that both power and control circuits are DC and there is no isolation between the two.

Another disadvantages is that a continuous DC signal has to be applied. So gate power loss is high.

2. AC Gate Triggering:-

Here AC source is used for gate signals.

This scheme provides proper isolation between power and control circuit.

Drawback of this scheme is that a separate transformer is required to step down ac supply.

There are two methods of AC voltage triggering namely (i) R Triggering (ii) RC triggering.

(i) Resistance triggering:

- In this method, the variable resistance R is used to control the gate current.
- Depending upon the value of R, when the magnitude of the gate current reaches the sufficient value(latching current of the device) the SCR starts to conduct.
- The diode D is called as blocking diode. It prevents the gate cathode junction from getting damaged in the negative half cycle.
- By considering that the gate circuit is purely resistive, the gate current is in phase with the applied voltage.
- By using this method we can achieve maximum firing angle up to 90

(ii) RC Triggering

- By using this method we can achieve firing angle more than 90°

3. Pulse Gate Triggering:-

- In this method the gate drive consists of a single pulse appearing periodically (or) a sequence of high frequency pulses.
- This is known as carrier frequency gating.

- A pulse transformer is used for isolation.
- The main advantage is that there is no need of applying continuous signals, so the gate losses are reduced.

Advantages of pulse train triggering:

- Low gate dissipation at higher gate current.
- Small gate isolating pulse transformer
- Low dissipation in reverse biased condition is possible.So simple trigger circuits are possible in some cases
- When the first trigger pulse fails to trigger the SCR, the following pulses can succeed in latching SCR. This important while
- Triggering inductive circuits and circuits having back emf's.

Thyristor Switching Characteristics

Switching characteristics during turn-on

Switching characteristics during turn-off

- The switching characteristics are important particularly at high-frequency, to define the device velocity in changing from conduction state to blocking state and vice versa.
- Losses occurring in the device during switching from ON state to OFF state and OFF state to ON state is known as Switching Losses.
- The device's switching characteristics tells us about the switching losses, which is very important parameter to decide the selection of device.
- At high frequency, the switching losses are more.

Turn ON mechanism:-

- When a positive gate signal is applied to a forward biased SCR, the transition of SCR from blocking state to conducting state is called as turn ON mechanism.
- The time taken for SCR to traverse from the blocking state to conducting state is called as turn on time.
- Turn on time is divided into 3 periods.
- $t_{ON} = t_d + t_r + t_p$
- t_d = delay time, t_p or t_s = peak time (or) spread time, t_r – rise time
- when the gate current reaches $0.9I_G$ the anode current I_A starts increasing and reaches $0.1I_A$ (10% of its max value)
- The time taken for anode current to reach $0.1I_A$ is called as **delay time(t_d).**
- In other words, it is the time taken for anode voltage to fall from V_A to $0.9V_A$

- The anode current further increases and reaches $0.9I_A$.
- The time taken by the anode current to increases from $0.1I_A$ to $0.9I_A$ is called as **rise time(t_r).**
- In other words, it is the time taken by the anode voltage to fall from $0.9V_A$ to $0.1V_A$

Spread Time or Peak time (t_s or t_p)

- It is time taken by the anode current to rise from ($0.9I_A$ to maximum value of I_A) 90% to 100% of its full value. (or)
- It is the time taken by V_A to fall from $0.1V_A$ to it's ON state voltage drop (near by zero).
- During this time the conduction spreads over the entire cross-section of cathode and so electrons spread over all the junctions

Turn OFF mechanism:

- Turning OFF an SCR means bringing the SCR from conducting state to blocking state.
- To turn off an SCR two things are to be done

  (1) Reduce the anode current below its holding current level.

  (2) Application of reverse voltage.
- When the anode current is zero, if we apply forward voltage to the SCR, the device will not be able to block this forward voltage due to the fact that excess charge carriers are still at the junctions, so the device will start conducting even when the gate signal is not applied.
- In order to avoid this, reverse biasing of SCR is done to remove the excess charge carriers from all four layers.
- The turn OFF time is defined as the time from the instant the anode current becomes zero to the instant SCR reaches its forward blocking ability.

  Turn off time $t_{OFF} = t_{rr} + t_{gr}$

  t_{rr} = Reverse recovery time

  t_{gr} =Gate recovery time

  Reverse recovery process is the removal of excessive charge carries from the top and bottom layers of SCR.

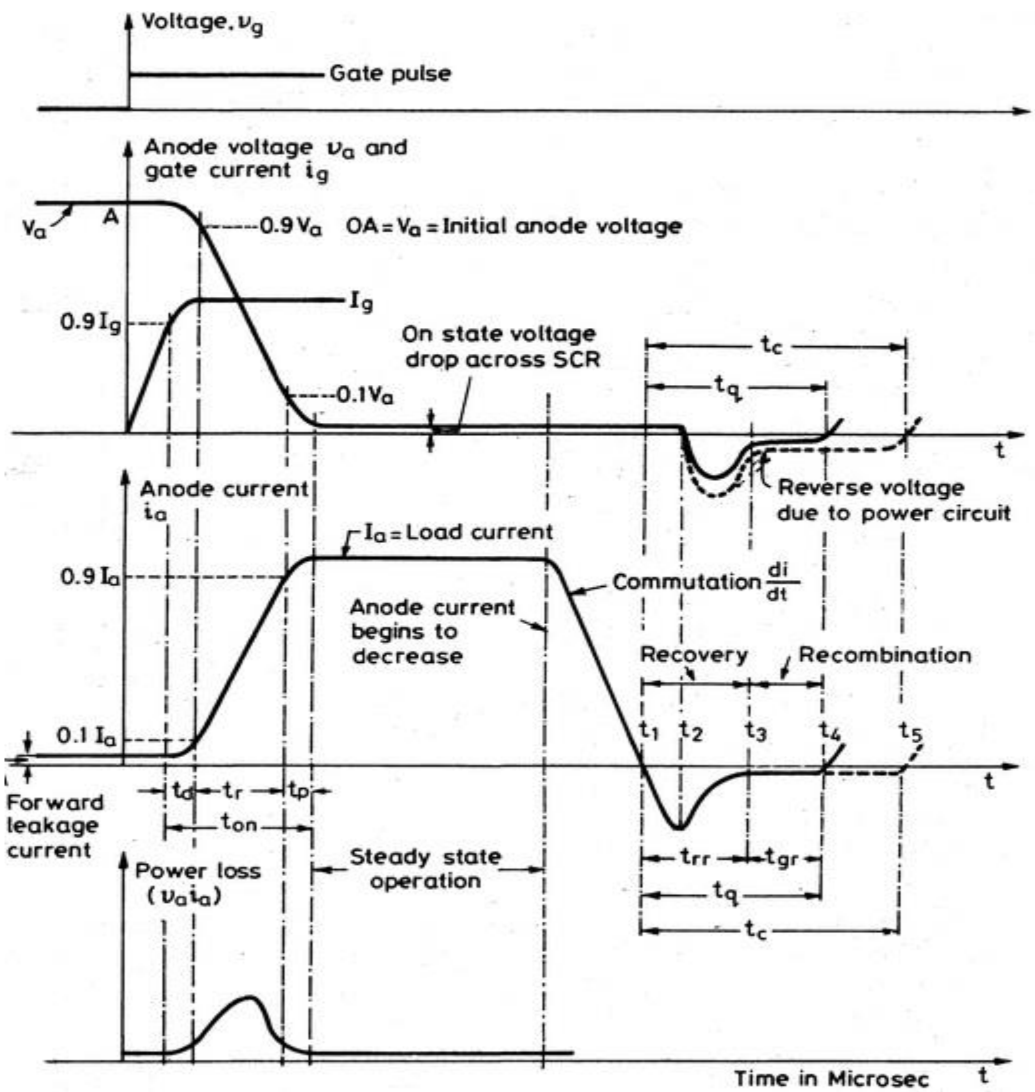
At t_1; current $I_A = 0$

- After t_1; I_A build up in the reverse direction, due to the charge carriers stored in the four layers.
- Reverse recovery current removes the excessive carriers from junctions J_1 and J_3 during the time t_1 to t_3.

  (Reverse recovery current flows due sweeping out of holes from top p-layer and electrons from bottom n layer)

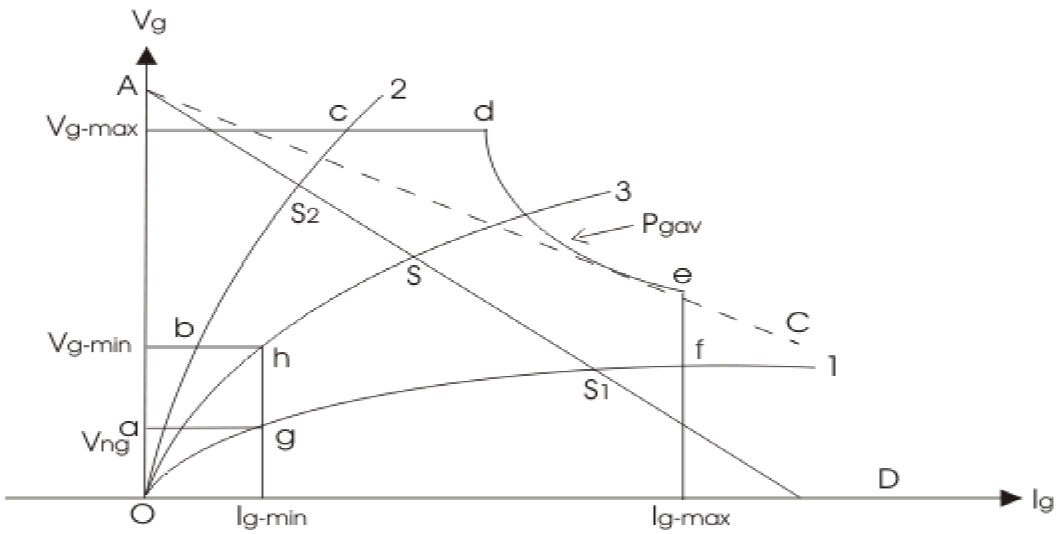
Reverse Recovery Time (t_{rr}):-

- It is the time taken for the removal of excessive carriers from top and bottom layer of SCR.
- At t_2: When nearly 60% of charges are removed from the outer two layers, the reverse recovery current decreases.
- This decaying causes a reverse voltage to be applied across the SCR.
- At t_3 all excessive carriers from J_1 and J_3 is removed.
- The reverse voltage across SCR removes the excessive carriers from junction J_2.
- Gate recovery process is the removal of excessive carriers from J_2 junction by application of reverse voltage.
- Time taken for removal of trapped charges from J_2 is called gate recovery time(t_{gr}).
- At t_4 all the carriers are removed and the device moves to the forward blocking mode.

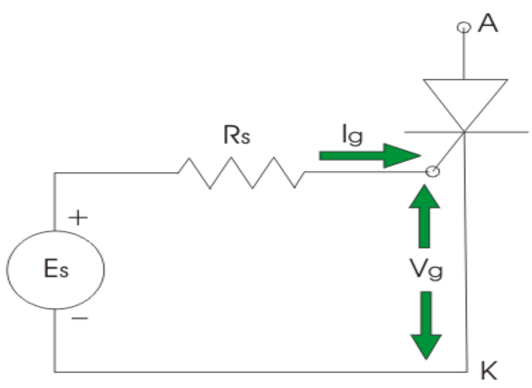


Thyristor gate characteristics

Gate characteristic of thyristor or SCR gives us a brief idea to operate it within a safe region of applied gate voltage and current. So this is a very important characteristic regarding thyristor. At the time of manufacturing each SCR or thyristor is specified with the maximum gate voltage limit (V_{g-max}), gate current limit (I_{g-max}) and maximum average gate power dissipation limit (P_{gav}). These limits should not be exceeded to protect the SCRfrom damage and there is also a specified minimum voltage (V_{g-min}) and minimum current (I_{g-min}) for proper operation of thyristor.



A gate non triggering voltage (V_{ng}) is also mentioned at the time of manufacturing of the device. All noises and unwanted signals should lie under this voltage to avoid unwanted turn on of the thyristor.



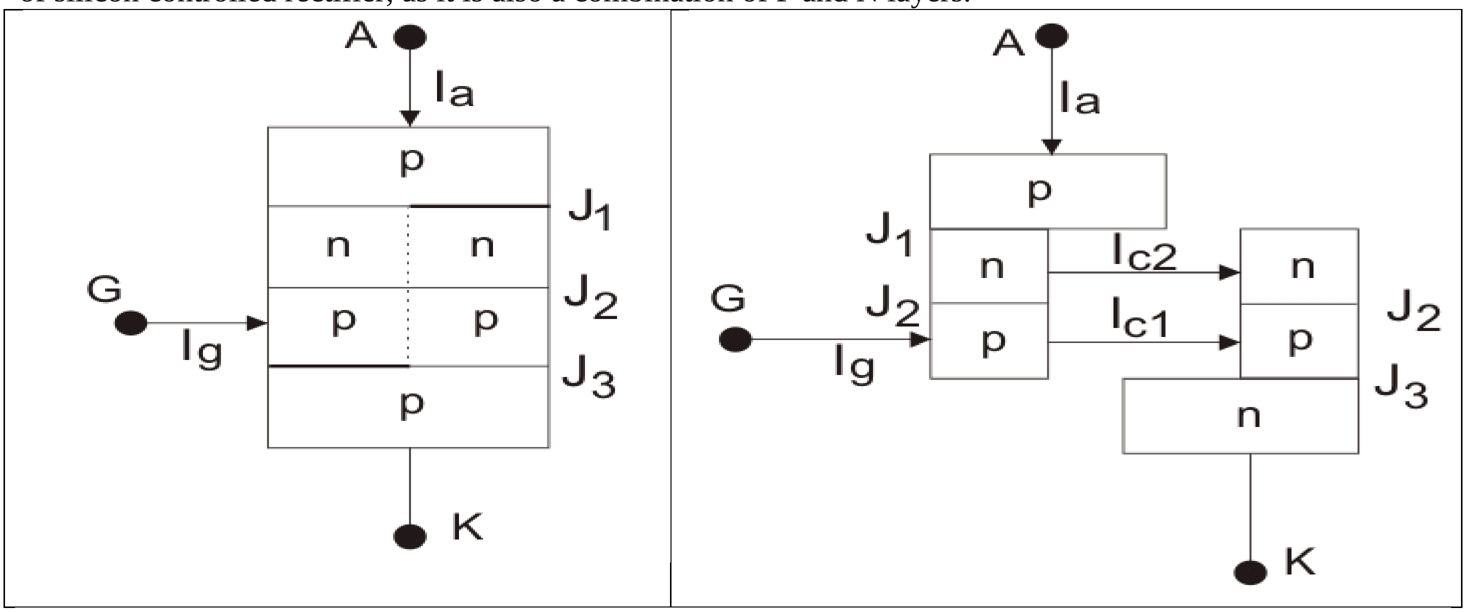
Curve 1 represents the lowest voltage values that must be applied to turn on the SCR and curve 2 represents the highest values of the voltage that can safely applied. So from the figure we can see the safety operated area of SCR is bcdefghb.

$$E_s = V_g + I_g R_s$$

A load line of gate source voltage is drawn as AD where OA = E_s and OD = E_s/R_s which is trigger circuit short circuit current. Now, let a VI characteristic of gate circuit is given by curve 3. The intersection point of load line (AD) and curve 3 is called as operating point S. It is evident that S must lie between S_1 and S_2 on the load line. For decreasing the turn ON time and to avoid unwanted turn ON of the device, operating point should be as close to P_{gav} as possible. Slop of AD = source resistance R_S. Minimum amount of R_s can be determined by drawing a tangent to the P_{gav} carve from the point A.

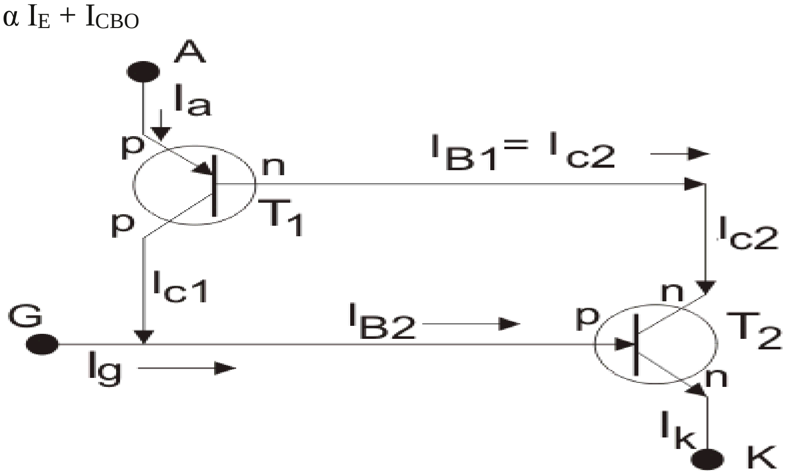
Two Transistor Model of SCR

Basic **operating principle of SCR**, can be easily understood by the **two transistor model of SCR** or analogy of silicon controlled rectifier, as it is also a combination of P and N layers.



When the transistors are in off state, the relation between the collector current and emitter current is

$I_c = \alpha\, I_E + I_{CBO}$



Here, I_C is collector current, I_E is emitter current, I_{CBO} is forward leakage current, α is common base forward current gain and relationship between I_C and I_B is

$$I_C = \beta I_B$$

Let's for transistor T_1 this relation holds

$$I_{C1} = \alpha_1 I_a + I_{CBO1} \cdots\cdots (i)$$

And that for transistor T_2

$$I_{C2} = \alpha_2 I_k + I_{CBO2} \cdots\cdots (ii) \quad again\, I_{C2} = \beta_2 I_{B2}$$

Now, by the analysis of two transistors model we can get anode current,

$$I_a = I_{C1} + I_{C2} \quad [applying\ KCL]$$

From equation (i) and (ii), we get,

$$I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 I_k + I_{CBO2} \cdots\cdots (iii)$$

If applied gate current is I_g then cathode current will be the summation of anode current and gate current i.e.

$$I_k = I_a + I_g$$

By substituting this valyue of I_k in (iii) we get,

$$I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 (I_a + I_g) + I_{CBO2}$$

$$I_a = \frac{\alpha_2 I_g + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}$$

From this relation we can assure that with increasing the value of $(\alpha_1 + \alpha_2)$ towards unity, corresponding anode current will increase. and at $(\alpha_1 + \alpha_2) = 1$ the anode current I_a will become infinite means thyristor is in conduction mode.

At the first stage when we apply a gate current I_g, it acts as base current of $T_{,2}$ transistor i.e. $I_{B2} = I_g$ and emitter current i.e. $I_k = I_g$ of the $T_{,2}$ transistor. Hence establishment of the emitter current gives rise α_2 as

$$\alpha_2 = \frac{I_{CBO1}}{I_g}$$

Presence of base current will generate collector current as

$$I_{C2} = \beta_2 \times I_{B2} = \beta_2 I_g$$

This I_{C2} is nothing but base current I_{B1} of transistor $T_{,1}$, which will cause the flow of collector current,

$$I_{C2} = \beta_1 \times I_{B1} = \beta_1 \beta_2 I_g$$

I_{C1} and I_{B1} lead to increase I_{C1} as $I_a = I_{C1} + I_{B1}$ and hence, α_1 increases. Now, new base current of T_2 is $I_g + I_{C1} = (1 + \beta_1\beta_2)I_g$, which will lead to increase emitter current $I_k = I_g + I_{C1}$and as a result α_2 also increases and this further increases $I_{C2} = \beta_2(1 + \beta_1\beta_2)I_g$.

As $I_{B1} = I_{C2}$, α_1 again increases. This continuous positive feedback effect increases $(\alpha_1 + \alpha_2)$ towards unity and anode current tends to flow at a very large value. The value current then can only be controlled by external resistance of the circuit.

Thyristor ratings

Thyristor ratings or **SCR ratings** are very much required for operating it in a safe zone. A thyristor, or SCR may have several ratings, such as voltage, current, power, dv/dt, di/dt, turn on time, turn off time, etc. Generally these ratings are specified in the data sheet given by manufacturer.

Anode Voltage Rating

This rating gives us a brief idea about withstanding power of a thyristor in forward blocking made in the absence of gate current.

Peak Working Forward Blocking or Forward OFF State Voltage (V_{DWM})

It specifies the maximum forward voltage (positive voltage that applied across anode and cathode) that can be withstand by the SCR at the time of working.

Peak Repetitive Forward Blocking Voltage (V_{DRM})

It specifies the peak forward transient voltage that a SCR can block repeatedly or periodically in forward blocking mode. This rating is specified at a maximum allowable junction temperature with gate circuit open. During commutation process, due to high decreasing rate of reverse anode current a voltage spike Ldi/dt is produced which is the cause of V_{DRM} generation.

Peak Non-Repetitive or Surge Forward Blocking Voltage (V_{DSM})

It is the peak value of the forward transient voltage that does not appear periodically. This type of over voltage generated at the time of switching operation of circuit breaker. Thisvoltage is 130 % of V_{DRM}), although it lies under the forward break over voltage (V_{BD}).

Peak Working Revere Voltage (V_{RWM})

It is the maximum reverse voltage (anode is negative with respect to cathode) which can be withstand by the thyristor repeatedly or periodically. It is nothing but peak negative value of the AC sinusoidal voltage.

Peak Repetitive Revere Voltage (V_{RRM})

It is the value of transient voltage that can be withstand by SCR in reverse bias at maximum allowable temperature. This reason behind the appearance of this voltage is also same as V_{DRM}.

Peak Non Repetitive Revere Voltage (V_{RSM})

It implies the reverse transient voltage that does not appear repetitively. Though thisvoltage value is 130% of V_{RRM}, it lies under reverse break over voltage, V_{BR}.
Forward ON State voltage Drop (V_T)

This is the voltage drop across the anode and cathode when rated current flows through the SCR at rated junction temperature. Generally this value is lie between 1 to 1.5 volts.

Forward dv/dt Rating

When we apply a forward voltage to the thyristor Junction J_1 and J_3 are forward biased whereas junction J_2 is reverse biased and hence it acts a capacitor. So due to Cdv/dt a leakage current flows through the device. This value of current will increase with the value of dv/dt. One thing we have to keep in mind that voltage value is not the reason behind flowing of leakage current, the reason is the rate of voltage increasing. The value ofcapacitance of the junction is constant hence when dv/dt increases to a suitable value that leakage current occurs a avalanche breakdown across junction J_2. This value of dv/dt in called forward dv/dt rating which can turn on the SCR without help of gate current. In practice it is not suitable to apply high dv/dt due to high temperature malfunction of SCR.

Voltage Safety Factor of SCR (V_{SF})

It is described as the ratio of peak repetitive reverse voltage (V_{RRM}) to the maximum value of input voltage.

$$V_{SF} = \frac{Peak\ Repetitive\ Reverse\ Voltage\ (V_{RRM})}{2 \times RMS\ Value\ of\ InputVoltage}$$

Finger Voltage of SCR (V_{FV})

Minimum value of voltage which must be applied between anode and cathode for turning off the device by gate triggering. Generally this voltage value is little mare than normal ON state voltage drop.

Current Rating of SCR

We all know that a thyristor, hence a SCR is made of semiconductor which is very much thermal sensitive. Even due to short time over current, the temperature of the device may rise to such a high value that it may cross its maximum allowable limit. Hence there will be a high chance of permanent destruction of the device. For this reason, **current rating of SCR** is very essential part to protect the SCR.

Maximum RMS Current Rating (I_{RMS})

Generations of heat in the device present where resistive elements are present in the device. Resistive elements such as metallic joints are totally dependent upon rms current as power loss is I_{RMS}^2R, which is converts to heat, hence cause of temperature rise of the device. Hence, I_{RMS} rating of the thyristor must be a suitable value so that maximum heat capability of SCR cannot exceed.

Maximum Average Current Rating (I_{AV})

It is the allowable average current that can be applied safely such that maximum junction temperature and rms current limit cannot be exceeded. Generally manufacturer of SCR, provides a characteristic diagram which shows I_{AV} as a function of the case temperature $I_C$with the current conduction angle φ as a parameter. This characteristic is known as "forward average current de-rating characteristic".

Maximum Surge Current (I_{SM})

If a thyristor operates under its repetitive voltage and current ratings, its maximum allowable temperature is never exceeded. But a SCR may fall into a abnormal operating condition due to fault in the circuit. To overcome this problem, a maximum allowable surge current rating is also specified by manufacturer. This rating specifies maximum non repetitive surge current, that the device can withstand. This rating is specified dependent upon the number of surge cycle. At the time of manufacturing at least three different surge current ratings for different durations are specified. For example,
I_{SM} = 3,000A for 1/2 cycle

I_{SM} = 2,100A for 3 cycles

I_{SM} = 1,800A for 5 cycles

A plot between I_{SM} and cycle numbers are also provided for dealing with the various cycle surge current.

I^2R Rating of SCR

This rating is provided to get an idea about over-voltage tackle power of a thyristor. The rating in term of A^2S is the measure of energy that can be handled by a thyristor to be used to protect it.

di/dt Rating of SCR

While, SCR is getting turn on, conduction stays in a very small area nearer to the gate. This small area of conduction spreads throughout the whole area of the junctions. But if spreading velocity of the charge carriers will be smaller than the di/dt then local hot spot may arise nearer to the gate which may destroy the device. To overcome this problem a maximum rate of rise of current, di/dt is also specified during manufacturing of the devices.

Latching Current of Thyristor

This is the rating of current below which the SCR can't be turned on even the gate signal is applied. That means this much anode current must rise to turn on the device. The gate pulse must be continuous until anode current is greater or equal to latching current ofthyristor other wise the device will fail to be turned on.

Holding Current of Thyristor

This is the rating of current below, which anode current must fall to turn off the device.

Gate Specification of SCR

Gate Triggering Voltage (V_{GT})

This is the value of minimum gate voltage that must be a acquired by the gate circuit. for proper turn on of the SCR. This voltage value is also specified at a particular forward breakdown voltage similar to I_{GT}.

Non Triggering Gate Voltage (V_{NG})

This is the maximum value of gate circuit source voltage below which the device must be in off state. All unwanted noise signals must lie under this voltage to avoid unwanted turn on of the device.

Peak Reverse Gate Voltage (V_{GRM})

This is the value of maximum reverse voltage which can be applied across the cathode and gate.

Average Gate Power Dissipation (P_{GAR})

This is the value of average power dissipation which cannot be exceeded by a gate circuit for a gate current pulse wider than 100 microsecond.

Peak Forwarded Gate Current (I_{GRM})

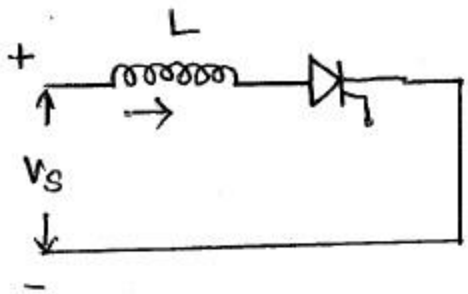
This is the rating of maximum forward gate current that should not be exceeded to reliable and safe operation.

Thyristor Protection or SCR Protection

- For reliable operation of SCR, it should be operated within the specific ratings.
- SCRs are very delicate devices and so they must be protected against abnormal operating conditions. Various protection of SCR are
  1. di/dt Protection
  2. dv/dt Protection
  3. Over voltage Protection
  4. OverCurrentProtection

di/dt Protection:-

- di/dt is the rate of change of current in a device.
- When SCR is forward biased and is turned ON by the gate signal, the anode current flows.
- The anode current requires some time to spread inside the device. (Spreading of charge carriers)
- But if the rate of rise of anode current(di/dt) is greater than the spread velocity of charge carriers then local hot spots is created near the gate due to increased current density. This localised heating may damage the device.
- Local spot heating is avoided by ensuring that the conduction spreads to the whole area very rapidly. (OR) The di/dt value must be maintained below a threshold (limiting) value.
- This is done by means of connecting an inductor in series with the thyristor.

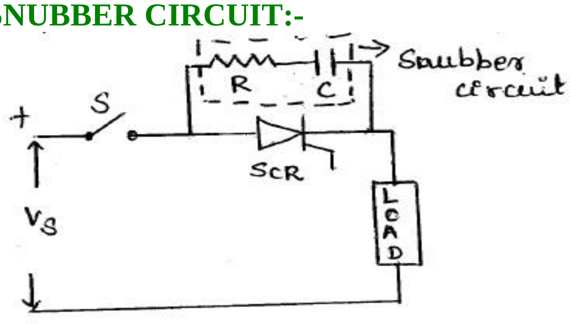


- The inductance L opposes the high di/dt variations.
- When the current variation is high, the inductor smooths it and protects the SCR from damage. (Though di/dt variation is high, the inductor 'L' smooths it because it takes some time to charge). $L \geq [V_s / (di/dt)]$

dv/dt Protection:-

- dv/dt is the rate of charge of voltage in SCR.
- We know that $i_C = C.dv/dt$. ie, when dv/dt is high, i_C is high.
- This high current(i_C) may turn ON SCR even when gate current is zero. This is called as dv/dt turn ON or false turn ON of SCR.
- To protect the thyristor against false turn ON or against high dv/dt a "Snubber Circuit" is used.

SNUBBER CIRCUIT:-



- The snubber Circuit is a series combination of resistor ‘R’ and capacitor ‘C’.
- They are connected across the thyristor to be protected.
- The capacitor ‘C’ is used to limit the dv/dt across the SCR.
- The resistor ‘R’ is used to limit high discharging current through the SCR.
- When switch S is closed, the capacitor ‘C’ behaves as a short-circuit.
- Therefore voltage across SCR is zero.
- As time increases, voltage across ‘C’ increases at a slow rate.
- Therefore dv/dt across ‘C’ and SCR is less than maximum dv/dt rating of the device.
- The capacitor charges to full voltage Vs; after which the gate is triggered, and SCR is turned ON and high current flows through SCR.
- As di/dt is high, it may damage the SCR.To avoid this, the resistor R in series with ‘C’ will limit the magnitude of di/dt.
- The technique of ‘snubbing’ can apply to any switching circuit, not only to thyristor/triac circuits.
- The rate of rise of turn-off voltage is determined by the time constant R_LC. Where R_L is the circuit minimum load resistance, for instance the cold resistance of a heater or lamp, the winding resistance of a motor or the primary resistance of a transformer.

Overvoltage Protection:-

- Overvoltage may result in false turn ON of the device (or) damage the device.
- SCR is subjected to internal and external over voltage.

Internal Overvoltage:

- The reverse recovery current of the SCR decays at a very fast rate. ie, high di/dt.
- So a voltage surge is produced whose magnitude is L(di/dt).

External Overvoltage:

- These are caused by the interruption of current flow in the inductive circuit and also due to lightning strokes on the lines feeding the SCR systems.
- The effect of overvoltage is reduced by using Snubber circuits and Non-Linear Resistors called Voltage Clamping Devices.

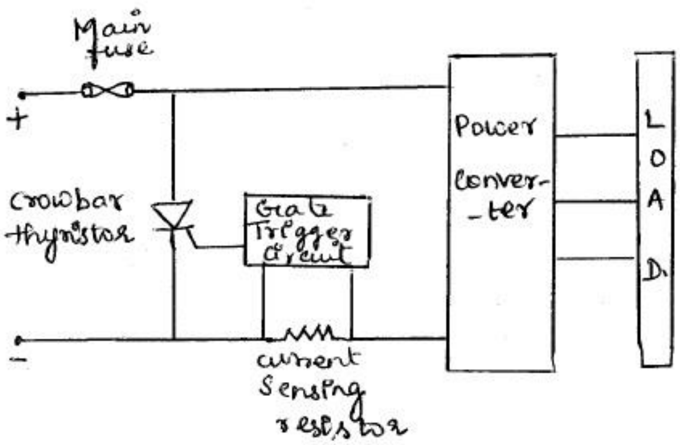
Voltage Clamping Device:

- It is a non-linear resistor called as VARISTOR (VARIable resiSTOR) connected across the SCR.
- The resistance of varistor will decrease with increase in voltage.
- During normal operation, varistor has high Resistance and draws only small leakage current.
- When high voltage appears, it operates in low resistance region and the surge energy is dissipated across the resistance by producing a virtual short-circuit across the SCR.

Over Current Protection:

- In an SCR due to over-current, the junction temperature exceeds the rated value and the device gets damaged.
- Over-current is interrupted by conventional fuses and circuit breakers.
- The fault current must be interrupted before the SCR gets damaged and only the faulty branches of the network should be isolated.
- Circuit breaker has long tripping time. So it is used for protecting SCR against continuous over loads (or) against surge currents of long duration.
- Fast acting current limiting fuse is used to protect SCR against large surge currents of very short duration.

Electronic Crowbar Protection:



- SCR has high surge current ability.
- SCR is used in electronic crowbar circuit for over current protection of power converter.
- In this protection, an additional SCR is connected across the supply which is known as ‘Crowbar SCR’.
- Current sensing resistor detects the value of converter current.
- If it exceeds preset value, then gate trigger circuits turn ON the crowbar SCR.
- So the input terminals are short-circuit by SCR and thus it bypass the converter over current.
- After some time the main fuse interrupts the fault current.

Series Operation of SCRs

Necessity of SCR series connection:

For some industrial applications, the demand for voltage and current ratings is so high that a single SCR cannot meet such requirements. In such cases, SCRs are connected in series in order to meet the high voltage demand and in parallel for meeting the high current demand.

- Series connection of power devices are often required to increase the overall voltage rating.

Problems in SCR series operation:

- When the thyristors are connected in series, they have small differences in their ratings. We know that in the world no two devices are having identical characteristics.
- Consider that two thyristors with same ratings are connected in series.
- The thyristor having highest internal resistance will have minimum leakage current.
- So high voltage will appear across it in off state.
- This creates voltage imbalance in the series connection. Hence equalization is necessary in the series connection.
- **String Efficiency & Derating Factor**

  For SCR series operation, it should be ensured that each SCR rating is fully utilized and the system operation is satisfactory.

  String efficiency is a term that is used for measuring the degree of utilization of SCRs in a string.

The string efficiency of SCRs connected in series/parallel is defined as

String Efficiency = [Actual voltage/current rating of the whole string]/[Individual voltage/current rating of one SCR][Number of SCRs in the string]*

- In practice, this ratio is less than one.
- To get highest possible string efficiency, the SCRs connected in series string must have identical V-I characteristics.
- As a consequence, string efficiency can never be equal to one.
- However, unequal voltage/current sharing by the SCRs in a string can be minimized to a great extend by using external equalizing circuits.
- The measure of the reliability of string is given by a factor called derating factor DRF defined as

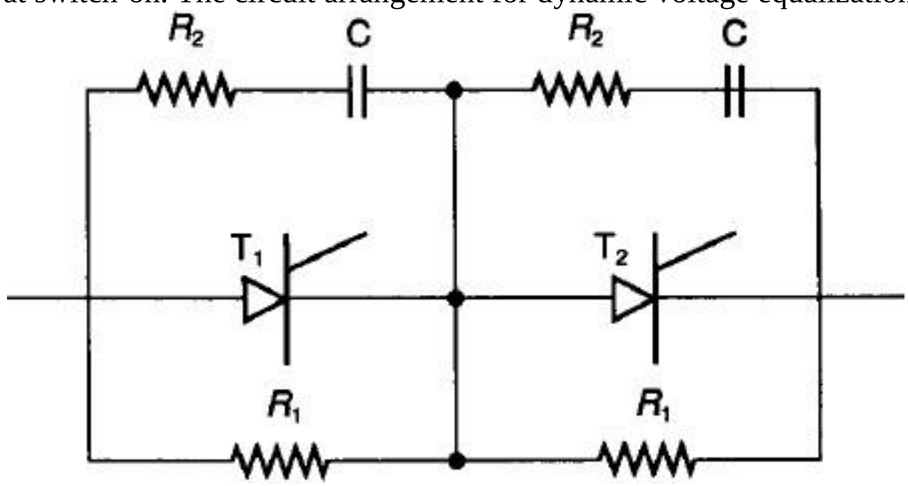
  DRF = 1 – String Efficiency

Static Equalization:

- A uniform voltage distribution in steady state can be achieved by connecting a suitable resistance across each SCR such that each parallel combination has the same resistance.
- This shunt resistance R is called as static equalizing circuit.
- The series connected SCRs suffer from unequal voltage distribution across them during their turn-on and turn-off processes and also during their high frequency operation which means more frequent turning on and turning off of the devices.
- Thus a simple resistor used for static voltage equalization cannot maintain equal voltage distribution under transient condition.

Dynamic equalization

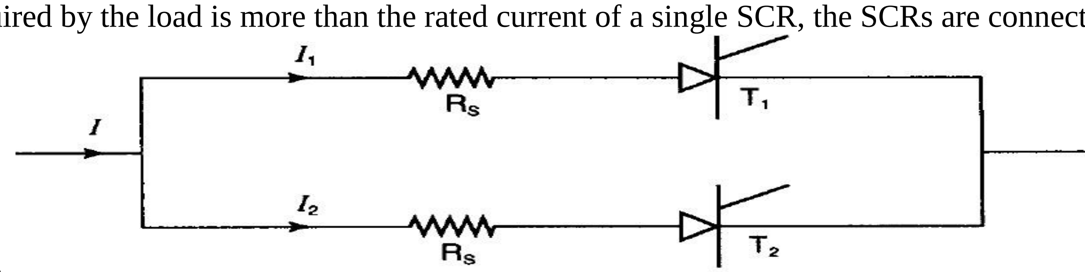
- During the turn-off process, due to the difference in junction capacitance, there is the differences in stored charge for the series connected SCRs.
- It will cause unequal reverse voltage sharing among the thyristors. This problem is solved by connecting capacitor across each thyristor.
- The value of capacitors should be large enough to swap the junction capacitance.
- A small resistance in series with this capacitance will limit the discharge current through the thyristor during turn-on process.
- The R_2-C network will also act as a snubber network to limit the rate of rise of voltage across the thyristor at switch-on. The circuit arrangement for dynamic voltage equalization is shown in Fig



SCR Parallel Operation

The SCRs are connected in a parallel manner to meet the high current demand.

When current required by the load is more than the rated current of a single SCR, the SCRs are connected in parallel in a string.



VI Characteristics of Parallel Connected SCRs:

- The VI characteristics must be identical as far as possible for the SCRs to be connected in parallel.
- For proper operation of these parallel connected SCRs, they should get turned on at the same moment.
- We can understand this with the help of following discussion. Consider n parallel connected SCRs.

- For satisfactory operation of these SCRs, they should get turned on at the same time. Consider that SCR1 has large turn-on time whereas the remaining (n-1) SCRs have low turn-on time.
- Under this assumption, (n-1) SCRs will turn on first but one SCR1 with longer turn-on time is to remain off.
- The voltage drop across (n-1) SCRs falls to a low value and SCR1 is now subjected to this low voltage.
- If the voltage across SCR1 goes below finger voltage, then this SCR will not turn on.
- So the remaining (n-1) SCRs will have to share the entire load current. Consequently these SCRs may be overloaded and damaged because of heating caused by over current.

What is meant by finger voltage?

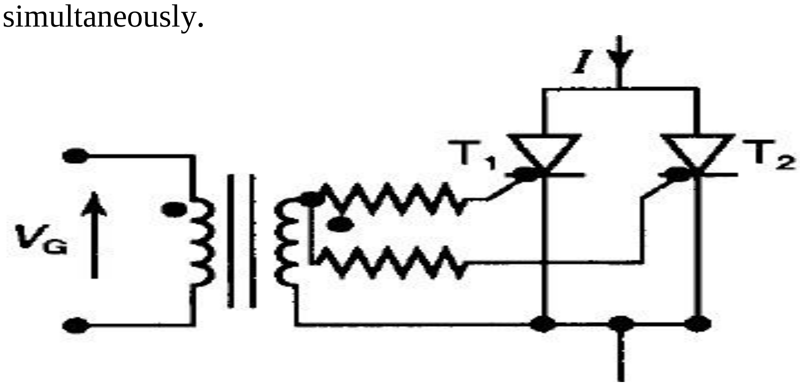
For a given gate drive power, the anode to cathode must have some minimum forward voltage for a thyristor to turn-on. This particular voltage is known as finger voltage.

We should ensure that the parallel connected SCRs should operate at the same temperature.

- This can be achieved by mounting the parallel unit on one common heat sink.
- The unequal current distribution in a parallel unit is also caused by the inductive effect of current carrying conductors.
- When SCRs are arranged unsymmetrical manner, the middle conductor will have more inductance because of more flux linkages from two nearby conductors.
- The result is less current flows through the middle SCR as compared to outer two SCRs.
- The unequal current distribution can be avoided by mounting the SCRs symmetrically on the heat sink.
- In AC circuits current distribution can be made more uniform by the magnetic coupling of the parallel paths.

Switching of Parallel Connected SCRs:

With parallel connected switches, the first to turn on will momentarily carry the full current. At turn-off, the last to turn off will have the full current through it. It is obviously desirable to turn on and turn off all the switches simultaneously.



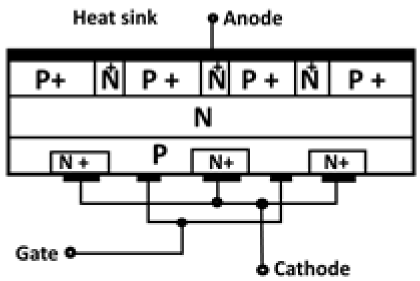
The gate-cathode circuits will not be identical, and to compensate for this a series resistance can be connected in the gate circuit of each switch. This will have the effect of reducing the spread of the gate currents.

Gate Turn Off Thyristor (GTO)

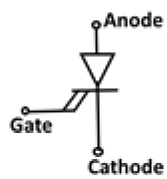
The Gate turn off thyristor (GTO) is a four layer PNPN power semiconductor switching device that can be turned on by a short pulse of gate current and can be turned off by a reverse gate pulse.

- There is no need for an external commutation circuit to turn it off. So inverter circuits built by this device are compact and low-cost.
- The device is turned on by a positive gate current and it is turned off by a negative gate cathode voltage.

Construction

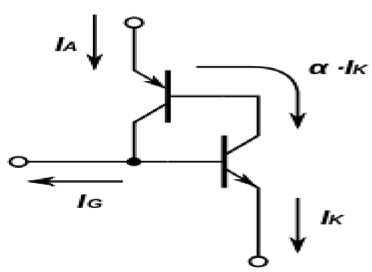


Structure



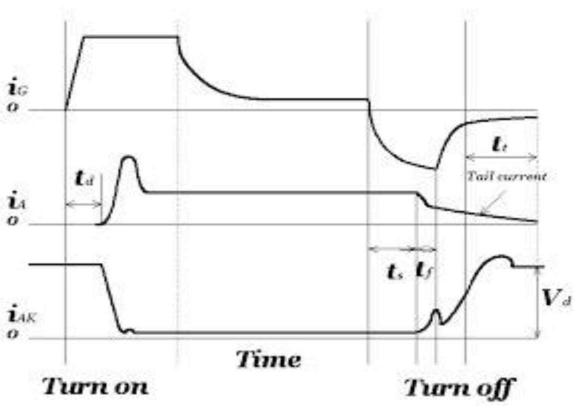
Symbol

The gate turn off thyristor has highly doped N spots in the P-layer at the anode, the plus sign indicating high doping levels. The gate cathode structure is interdigitated that is each electrode is composed of narrow channels closely located.



Eq. circuit of GTO

Switching characteristics



What are the advantages of GTO?

The prime design goal of GTO devices are to achieve fast turn off time and high current turn off capability and to enhance the safe operating area during turn off. The GTO's turn off occurs by removal of excess holes in the cathode base region by reversing the current through the gate terminal. Compare to BJT the GTO has the following advantages:

- High blocking voltage capabilities
- High over current capabilities
- exhibits low gate currents
- fast and efficient turn off
- better static and dynamic dv/dt capabilities

What are the disadvantages of GTO?

Compared to a conventional SCR, the device has the following disadvantages

- Magnitude of latching, holding currents is more. The latching current of the GTO is several times more as compared to conventional thyristors of the same rating.
- On state voltage drop and the associated loss is more.
- Due to multi cathode structure of GTO, triggering gate current is higher than that required for normal SCR.
- Gate drive circuit losses are more. Its reverse voltage blocking capability is less than the forward voltage blocking capability.

Applications

The main applications are in variable speed motor drives, high power inverters and traction. GTOs are increasingly being replaced by integrated gate-commutated thyristors, which are an evolutionary development of the GTO, and insulated gate bipolar transistors, which are members of the transistor family.

Comparison between GTO and thyristor

- Latching and holding current magnitude is higher in GTO
- ON state voltage drop is higher in GTO
- GTO has fast turn on and turn off times. therefore it operates at higher switching frequency.
- The gate signal requirement is higher in GTO.
- The dIa/dt capability during turn on process is higher in GTO because it has interdigitated gate cathode structure.
- GTO unit has higher efficiency and compact in size in comparison to SCR.
- GTO has low reverse blocking capability when compared with forward voltage blocking capability.