

current increases rapidly. As a large current associated with V_{BR} and hence more losses to the SCR.

This results in Thyristor damage as junction temperature may exceed its maximum temperature rise.

2. Forward Blocking Mode

When anode is positive with respect to cathode, with gate circuit open, thyristor is said to be forward biased.

Thus junction J_1 and J_3 are forward biased and J_2 is reverse biased. As the forward voltage increases junction J_2 will have an avalanche breakdown at a voltage called forward breakover voltage V_{BO} . When forward voltage is less than V_{BO} thyristor offers high impedance. Thus a thyristor acts as an open switch in forward blocking mode.

3. Forward Conduction Mode

Here thyristor conducts current from anode to cathode with a very small voltage drop across it. So a thyristor can be brought from forward blocking mode to forward conducting mode:

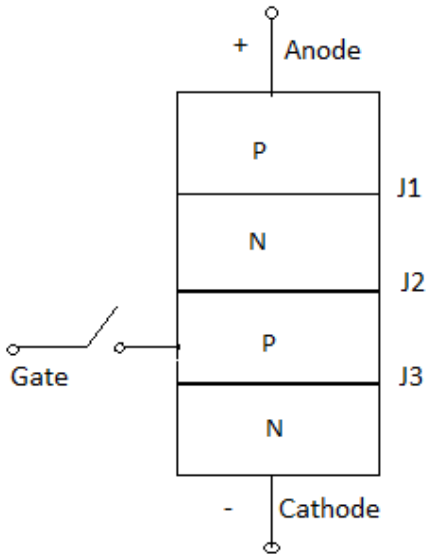
1. By exceeding the forward breakover voltage.
2. By applying a gate pulse between gate and cathode.

During forward conduction mode of operation thyristor is in on state and behaves like a close switch. Voltage drop is of the order of 1 to 2mV. This small voltage drop is due to ohmic drop across the four layers of the device.

Different turn ON methods for SCR

1. Forward voltage triggering
2. Gate triggering
3. $\frac{dv}{dt}$ triggering
4. Light triggering
5. Temperature triggering

1. Forward voltage triggering



A forward voltage is applied between anode and cathode with gate circuit open.

- Junction J_1 and J_3 is forward biased.
- Junction J_2 is reverse biased.
- As the anode to cathode voltage is increased breakdown of the reverse biased junction J_2 occurs. This is known as avalanche breakdown and the voltage at which this phenomena occurs is called forward breakover voltage.
- The conduction of current continues even if the anode cathode voltage reduces below V_{BO} till I_a will not go below I_h . Where I_h is the holding current for the thyristor.

2. Gate triggering

This is the simplest, reliable and efficient method of firing the forward biased SCRs. First SCR is forward biased. Then a positive gate voltage is applied between gate and cathode. In practice the transition from OFF state to ON state by exceeding V_{BO} is never employed as it may destroy the device. The magnitude of V_{BO} , so forward breakover voltage is taken as final voltage rating of the device during the design of SCR application.

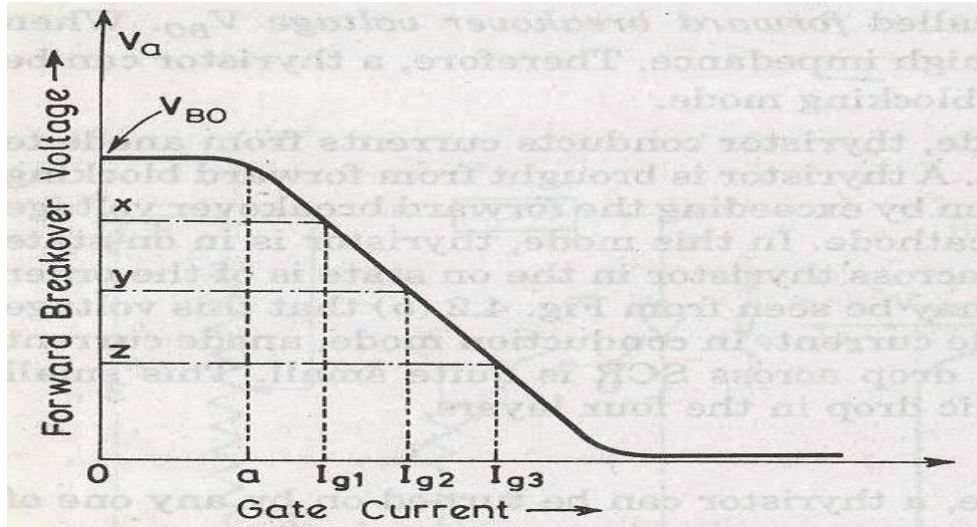
First step is to choose a thyristor with forward breakover voltage (say 800V) higher than the normal working voltage. The benefit is that the thyristor will be in blocking state with normal working voltage applied across the anode and cathode with gate open. When we require the turning ON of a SCR a positive gate voltage between gate and cathode is applied. The point to be noted that cathode n- layer is heavily doped as compared to gate p-layer. So when gate supply is given between gate and cathode gate p-layer is flooded with electron from cathode n-layer. Now the thyristor is forward biased, so some of these electron reach junction J_2 . As a result width of J_2 breaks down or conduction at J_2 occur at a voltage less than V_{BO} . As I_g increases V_{BO} reduces which decreases then turn ON time. Another important point is duration for which the gate current is applied should be more then turn ON time. This means

that if the gate current is reduced to zero before the anode current reaches a minimum value known as holding current, SCR can't turn ON.

In this process power loss is less and also low applied voltage is required for triggering.

3. dv/dt triggering

This is a turning ON method but it may lead to destruction of SCR and so it must be avoided.



When SCR is forward biased, junction J_1 and J_3 are forward biased and junction J_2 is reverse biased so it behaves as if an insulator is placed between two conducting plates. Here J_1 and J_3 act as a conducting plate and J_2 acts as an insulator. J_2 is known as a junction capacitor. So if we increase the rate of change of forward voltage instead of increasing the magnitude of voltage, junction J_2 breaks and starts conducting. A high value of changing current may damage the SCR. So SCR may be protected from high $\frac{dv}{dt}$.

$$q = cv$$

$$I_a = c \frac{dv}{dt}$$

$$I_a \propto \frac{dv}{dt}$$

4. Temperature triggering

During forward bias, J_2 is reverse biased so a leakage forward current is always associated with SCR. Now as we know the leakage current is temperature dependent, so if we increase the temperature the leakage current will also increase and heat dissipation of junction J_2 occurs. When this heat reaches a sufficient value J_2 will break and conduction starts.

Disadvantages

This type of triggering causes local hot spot and may cause thermal run away of the device.

This triggering cannot be controlled easily.

It is very costly as protection is costly.

5. Light triggering

First a new recess niche is made in the inner p-layer. When this recess is irradiated, then free charge carriers (electron and hole) are generated. Now if the intensity is increased above a certain value then it leads to turn ON of SCR. Such SCR are known as Light activated SCR (LASCR).

Some definitions:

Latching current

The latching current may be defined as the minimum value of anode current which at must attain during turn ON process to maintain conduction even if gate signal is removed.

Holding current

It is the minimum value of anode current below which if it falls, the SCR will turn OFF.

Switching characteristics of thyristors

The time variation of voltage across the thyristor and current through it during turn on and turn off process gives the dynamic or switching characteristic of SCR.

Switching characteristic during turn on

Turn on time

It is the time during which it changes from forward blocking state to ON state. Total turn on time is divided into 3 intervals:

1. Delay time
2. Rise time
3. Spread time

Delay time

If I_g and I_a represent the final value of gate current and anode current. Then the delay time can be explained as time during which the gate current attains $0.9 I_g$ to the instant anode current reaches $0.1 I_g$ or the anode current rises from forward leakage current to $0.1 I_a$.

1. Gate current $0.9 I_g$ to $0.1 I_a$.
2. Anode voltage falls from V_a to $0.9V_a$.
3. Anode current rises from forward leakage current to $0.1 I_a$.

Rise time (t_r)

Time during which

1. Anode current rises from $0.1 I_a$ to $0.9 I_a$
2. Forward blocking voltage falls from $0.9V_a$ to $0.1V_a$. V_a is the initial forward blocking voltage.

Spread time (t_p)

1. Time taken by the anode current to rise from $0.9I_a$ to I_a .
2. Time for the forward voltage to fall from $0.1V_o$ to on state voltage drop of 1 to 1.5V. During turn on, SCR is considered to be a charge controlled device. A certain amount of charge is injected in the gate region to begin conduction. So higher the magnitude of gate current it requires less time to inject the charges. Thus turn on time is reduced by using large magnitude of gate current.

How the distribution of charge occurs?

As the gate current begins to flow from gate to cathode with the application of gate signal. Gate current has a non uniform distribution of current density over the cathode surface. Distribution of current density is much higher near the gate. The density decrease as the distance from the gate increases. So anode current flows in a narrow region near gate where gate current densities are highest. From the beginning of rise time the anode current starts spreading itself. The anode current spread at a rate of 0.1mm/sec. The spreading anode current requires some time if the rise time is not sufficient then the anode current cannot spread over the entire region of cathode. Now a large anode current is applied and also a large anode current flowing through the SCR. As a result turn on losses is high. As these losses occur over a small conducting region so local hot spots may form and it may damage the device.

Switching Characteristics During Turn Off

Thyristor turn off means it changed from ON to OFF state. Once thyristor is ON there is no role of gate. As we know thyristor can be made turn OFF by reducing the anode current below the latching current. Here we assume the latching current to be zero ampere. If a forward voltage is applied across the SCR at the moment it reaches zero then SCR will not be able to block this forward voltage. Because the charges trapped in the 4-layer are still favourable for conduction and it may turn on the device. So to avoid such a case, SCR is reverse biased for some time even if the anode current has reached to zero.

So now the turn off time can be different as the instant anode current becomes zero to the instant when SCR regains its forward blocking capability.

$$t_q = t_{rr} + t_{qr}$$

Where,

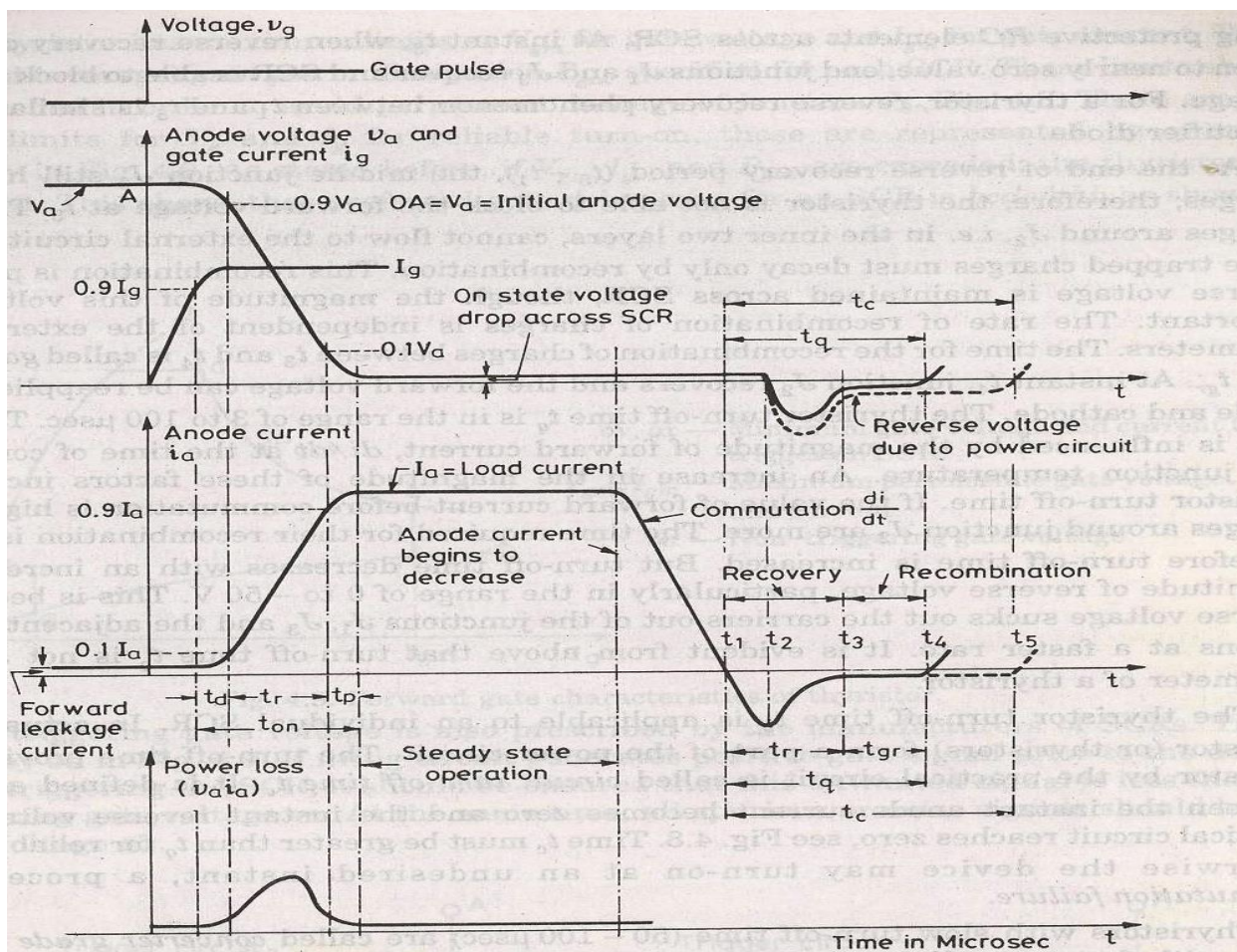
t_q is the turn off time, t_{rr} is the reverse recovery time, t_{gr} is the gate recovery time

At t_1 anode current is zero. Now anode current builds up in reverse direction with same $\frac{dv}{dt}$ slope. This is due to the presence of charge carriers in the four layers. The reverse recovery current removes the excess carriers from J_1 and J_3 between the instants t_1 and t_3 . At instant t_3 the end junction J_1 and J_3 is recovered. But J_2 still has trapped charges which decay due to recombination only so the reverse voltage has to be maintained for some more time. The time taken for the recombination of charges between t_3 and t_4 is called gate recovery time t_{gr} . Junction J_2 recovered and now a forward voltage can be applied across SCR.

The turn off time is affected by:

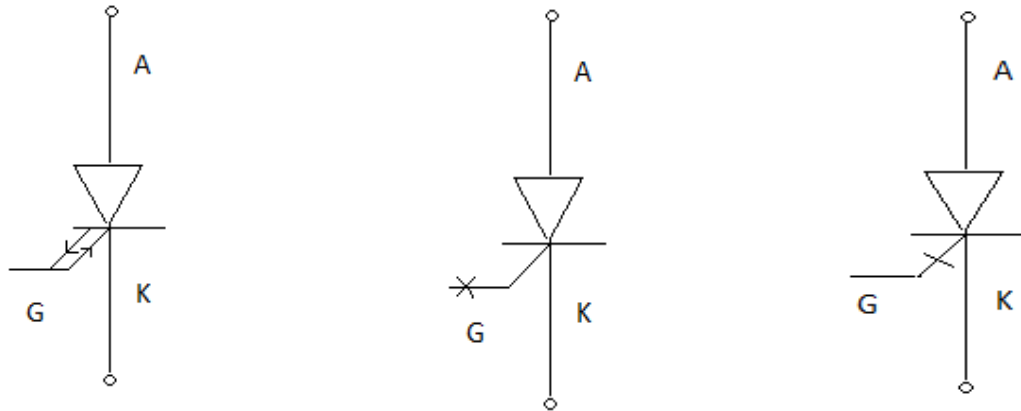
1. Junction temperature
2. Magnitude of forward current $\frac{di}{dt}$ during commutation.

Turn off time decreases with the increase of magnitude of reverse applied voltage.



GTO(Gate turn off thyristor)

A gate turn off thyristor is a pnpn device. In which it can be turned ON like an ordinary SCR by a positive gate current. However it can be easily turned off by a negative gate pulse of appropriate magnitude.



Conventional SCR are turned on by a positive gate signal but once the SCR is turned on gate loses control over it. So to turn it off we require external commutation circuit. These commutation circuits are bulky and costly. So due to these drawbacks GTO comes into existence.

The salient features of GTO are:

1. GTO turned on like conventional SCR and is turned off by a negative gate signal of sufficient magnitude.
2. It is a non latching device.
3. GTO reduces acoustic and electromagnetic noise.

It has high switching frequency and efficiency.

A gate turn off thyristor can turn on like an ordinary thyristor but it is turn off by negative gate pulse of appropriate magnitude.

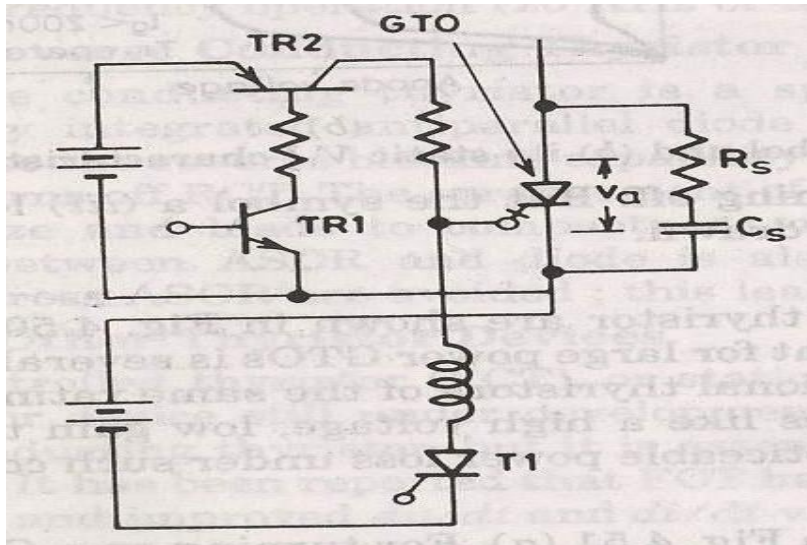
Disadvantage

The negative gate current required to turn off a GTO is quite large that is 20% to 30 % of anode current

Advantage

It is compact and cost less

Switching performance



1. For turning ON a GTO first TR1 is turned on.
2. This in turn switches on TR2 so that a positive gate current pulse is applied to turn on the GTO.
3. Thyristor T_1 is used to apply a high peak negative gate current pulse.

Gate turn-on characteristics

1. The gate turn on characteristics is similar to a thyristor. Total turn on time consists of delay time, rise time, spread time.
2. The turn on time can be reduced by increasing its forward gate current.