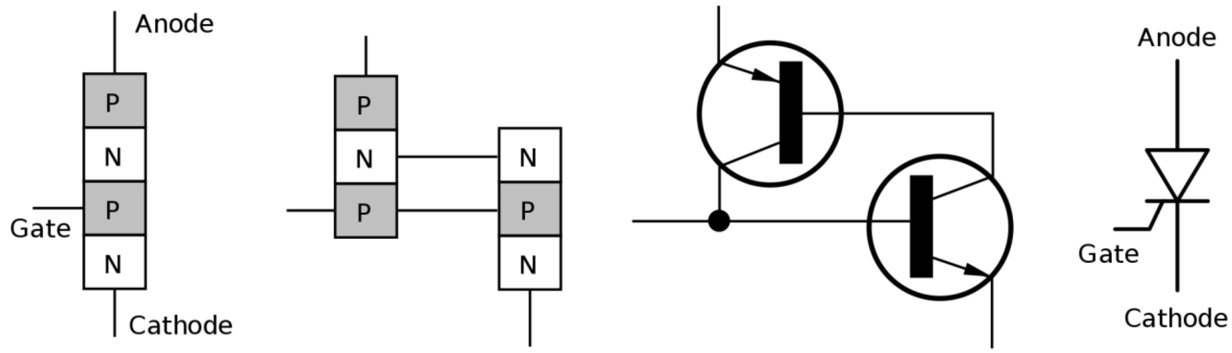
Q. 1. Define Thyristor. (S-03)

The thyristor is a four-layered, three-terminal semiconductor device, with each layer consisting of alternately N-type or P-type material, for example P-N-P-N. The main terminals, labeled anode and cathode, are across all four layers. The control terminal, called the gate, is attached to p-type material near the cathode. (A variant called an SCS—silicon controlled switch—brings all four layers out to terminals.) The operation of a thyristor can be understood in terms of a pair of tightly coupled



Thyristors have three states:

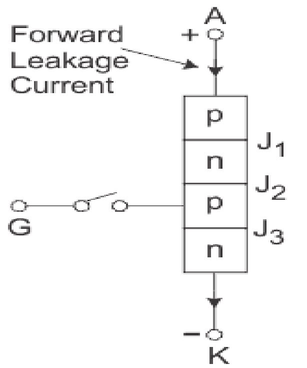
1. Reverse blocking mode – Voltage is applied in the direction that would be blocked by a diode
2. Forward blocking mode – Voltage is applied in the direction that would cause a diode to conduct, but the thyristor has not been triggered into conduction
3. Forward conducting mode – The thyristor has been triggered into conduction and will remain conducting until the forward current drops below a threshold value known as the "holding current"

Q.2. Explain the principal of action of a thyristor (also called SCR). Define the following terms in connection with a thyristor. (S-17)

i. Forward blocking state or " Off" state,
ii. Forward breakover voltage, V_{BO},
iii. Latching current I_L,
iv. Holding current I_H,
v. Reversed blocking state

Forward Blocking Mode

Now considering the anode is positive with respect to the cathode, with gate kept in open condition. The thyristor is now said to be forward biased as shown the figure below.



Forward Biased Condition

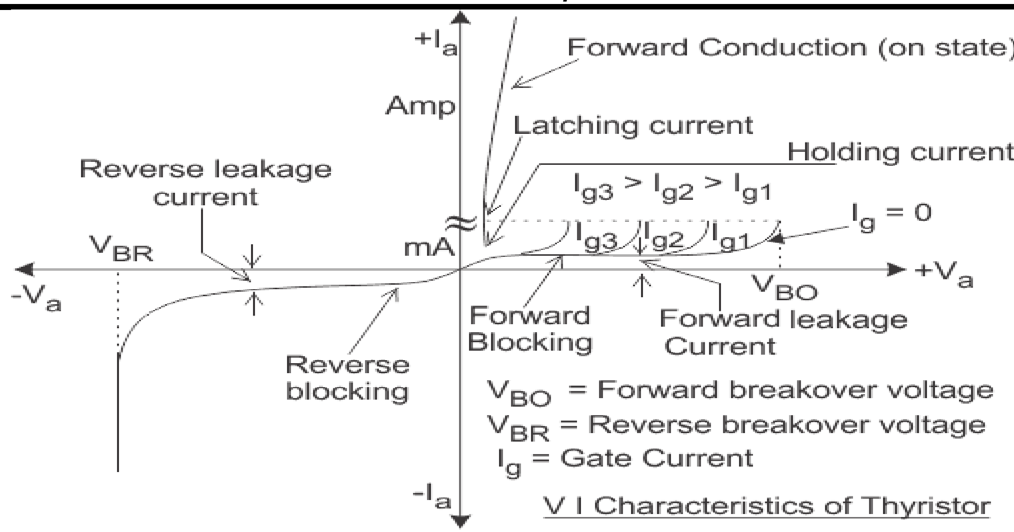
As we can see the junctions J_1 and J_3arenow forward biased but junction J_2 goes into reverse biased condition. In this particular mode, a small current, called forward leakage current is allowed to flow initially as shown in the diagram for characteristics of thyristor. Now, if we keep on increasing the forward biased anode to cathode voltage.

Forward breakover voltage, VBO,

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 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. But, if we keep the forward voltage less than V_{BO}, we can see from the characteristics of thyristor, that the device offers high impedance. Thus even here the thyristor operates as an open switch during the forward blocking mode.

Latching current

- It is defined as the minimum anode current requires keeping turned on SCR after removing gate signal.
- The latching current is associated with turned on process.
- The value of latching current is approximately 2 to 3 times to that of holding current.
- The value of holding current and latching current is constant and it does not depend on gate current magnitude

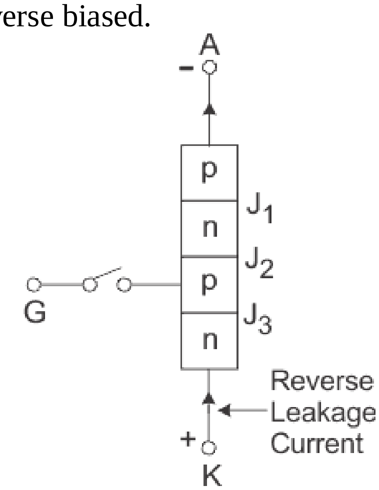


Holding current

- It is defined as the minimum anode current beyond SCR turns off.
- The holding current is associated with turned off process.
- The holding current is always less than the latching current.
- It is given mili – ampere.
- The SCR is turned off if the anode current reduces below 5 milli ampere for the specific rating of holding current milli ampere in the data sheet.

Reverse Blocking Mode of Thyristor

Initially for the **reverse blocking mode of the thyristor**, the cathode is made positive with respect to anode by supplying voltage E and the gate to cathode supply voltage E_s is detached initially by keeping switch S open. For understanding this mode we should look into the fourth quadrant where the thyristor is reverse biased.



Reverse Blocking Mode

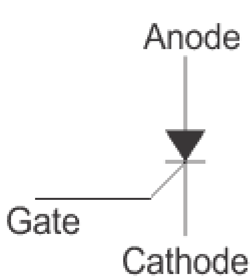
Here Junctions J_1 and J_3 are reverse biased whereas the junction J_2 is forward biased. The behavior of the thyristor here is similar to that of two diodes are connected in series with reverse voltage applied across them. As a result only a small leakage current of the order of a few μAmps flows.

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 VBR, an avalanche occurs at J1 and J3 and the reverse current increases rapidly. A large current associated with VBR 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 VBR. When reverse voltage applied across a thyristor is less than VBR, the device offers very high impedance in the reverse direction. The SCR in the reverse blocking mode may therefore be treated as open circuit.

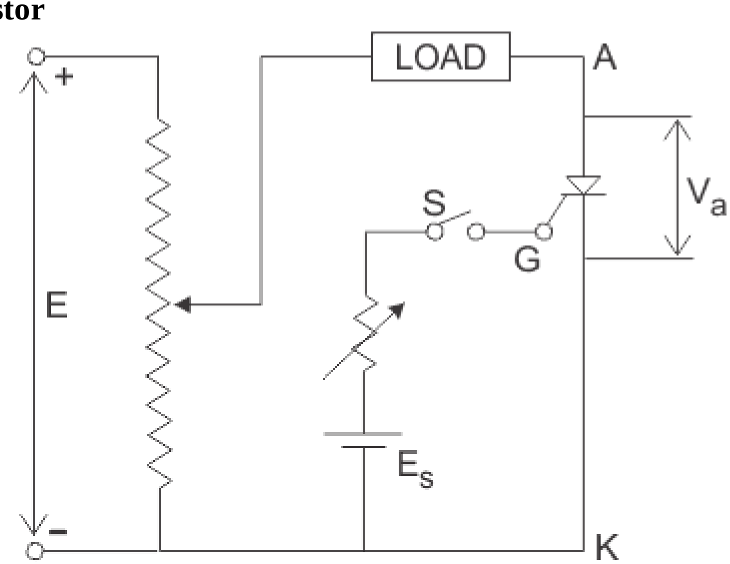
Q.3. Explain in detail V-I characteristics of SCR. OR
Sketch V-I characteristics of SCR at Ia=0 and Ia = rated value. (S-99, W-98)

A thyristor is a four layer 3 junction p-n-p-n semiconductor device consisting of at least three p-n junctions, functioning as an electrical switch for high power operations. It has three basic terminals, namely the anode, cathode and the gate mounted on the semiconductor layers of the device. The symbolic diagram and the basic circuit diagram for determining the characteristics of thyristor is shown in the figure below,

V-I Characteristics of a Thyristor



Thyristol Symbol

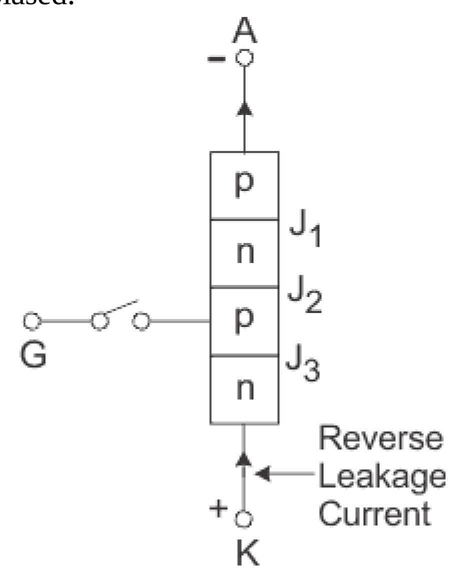


Circuit Diagram of Thyristor

From the circuit diagram above we can see the anode and cathode are connected to the supply voltage through the load. Another secondary supply E_s is applied between the gate and the cathode terminal which supplies for the positive gate current when the switch S is closed. On giving the supply we get the required V-I characteristics of a thyristor show in the figure below for anode to cathode voltage V_a and anode current I_a as we can see from the circuit diagram. A detailed study of the characteristics reveal that the thyristor has three basic modes of operation, namely the reverse blocking mode, forward blocking (off-state) mode and forward conduction (on-state) mode. Which are discussed in great details below, to understand the overall characteristics of a thyristor.

Reverse Blocking Mode of Thyristor

Initially for the reverse blocking mode of the thyristor, the cathode is made positive with respect to anode by supplying voltage E and the gate to cathode supply voltage E_s is detached initially by keeping switch S open. For understanding this mode we should look into the fourth quadrant where the thyristor is reverse biased.



Reverse Blocking Mode

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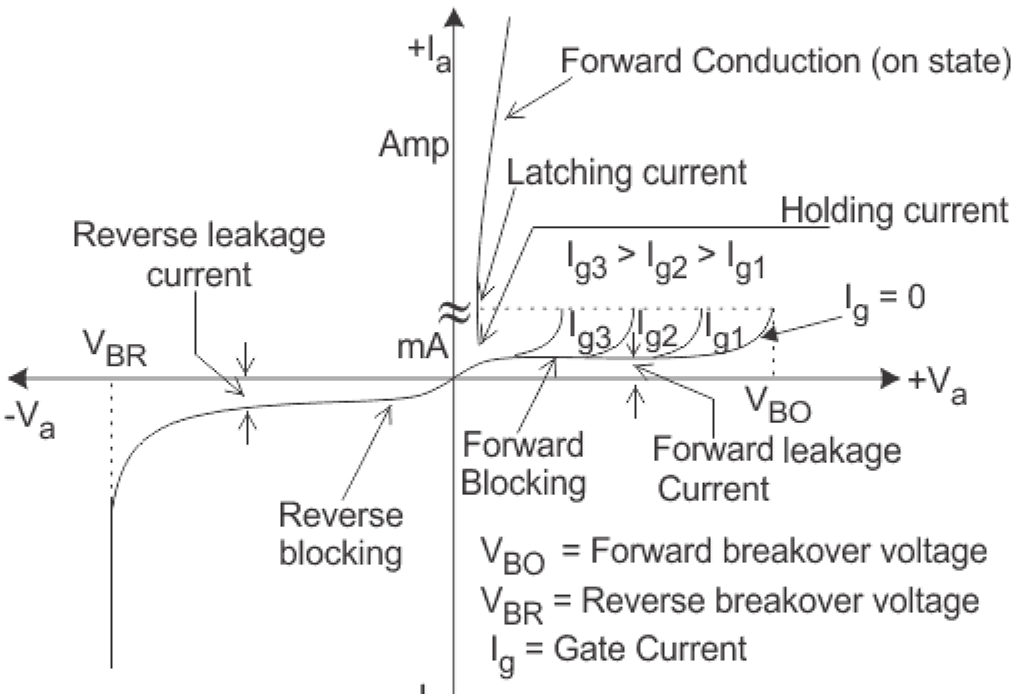

V I Characteristics of Thyristor

Forward Blocking Mode

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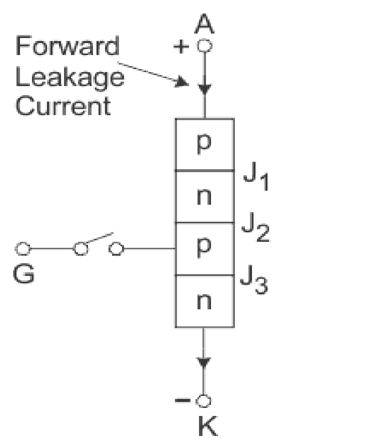

Forward Biased Condition

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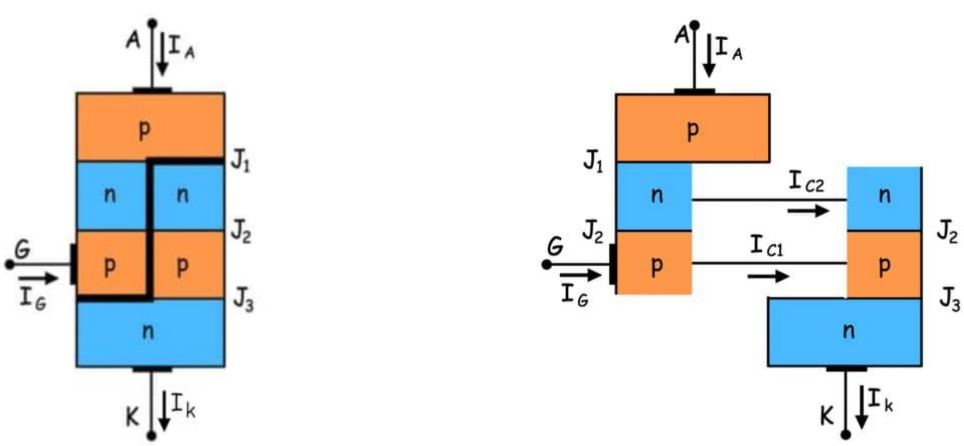
In this particular mode, the thyristor conducts currents from anode to cathode with a very small voltage drop across it. A thyristor is brought from forward blocking mode to forward conduction mode by turning it on by exceeding the forward break over voltage or by applying a gate pulse between gate and 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 J2 will have an avalanche breakdown at a voltage called forward break over voltage VB0 of the thyristor. But, if we keep the forward voltage less than V_{BO}, we can see from the characteristics of thyristor, that the device offers high impedance. Thus even here the thyristor operates as an open switch during the forward blocking mode.

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. Once the thyristor is turned on we can see from the diagram for characteristics of thyristor that the point M at once shifts toward N and then anywhere between N and K. Here NK represents the forward conduction mode of the thyristor. 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.

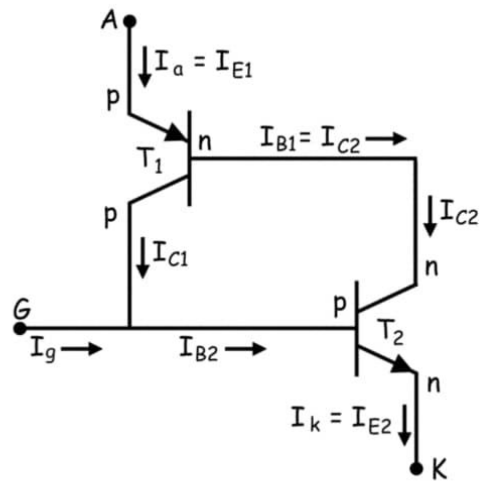
Q.4. Explain with the help of transistor analogy how the SCR turn ON with the gate current. OR Explain two- transistor analogy of SCR. **(W-98, W-99, S-02, S-16, S-17, S-18)**

Basic operating principle of SCR can easily be understood by the two transistor model of SCR, as it is a combination of p and n layers.



This is a pnpn thyristor. If we bisect it through the dotted line then we will get two transistors i.e. one pnp transistor with J_1 and J_2 junctions and another is with J_2 and J_3junctions as shown in figure below.

The relation between the collector current and emitter current is shown below



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

$$I_C = \beta I_B$$

Where, I_B is base current and β is common emitter forward current gain.

Let's for transistor T_1 this relation holds

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

And that for transistor T_2

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

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

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

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

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

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. Now the question is how $(\alpha_1 + \alpha_2)$increasing? Here is the explanation using two transistor model of SCR.

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 of the T_2 transistor $I_{E2} = I_k$. 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 $I_k = I_q + I_{C1}$ 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.

Q.5. Explain in detail, various turn-on methods of a thyristor/SCR.

Triggering means turning ON of a device from its off state. Turning ON of a thyristor refers to **thyristor triggering**. Thyristor is turned on by increasing the anode current flowing through it. The increase in anode current can be achieved by many ways.

1. **Voltage Thyristor Triggering**:- Here the applied forward voltage is gradually increased beyond a pt.known as forward break over voltage VBO and gate is kept 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.
2. **Thermal Thyristor Triggering**:- If the temperature of the thyristor is high, it results in increase in the electron-hole pairs. Which in turn increase the leakage current $\alpha_1$and α_2 to

raise. The regenerative action tends to increase ($\alpha_1 + \alpha_2$) to units and the thyristor may be turned on. This type turn on is not preferred as it may result in thermal turn away and hence it is avoided.

3. Light Thyristor Triggering:- These rays of light are allowed to strike the junctions of the thyristor. This results in increase in number of electron-hole pair and thyristor may be turned on. The light activated SCRs (LASER) are triggered by using this method.
4. **dv/dt Triggering**:- If the rate of rise of anode to cathode voltage is high, the charging current through the capacitive junction is high enough to turn on the thyristor. A high value of charging current may destroy the thyristor hence the device must be protected against high dv/dt.
5. **Gate Triggering**:- This method of thyristor triggering is widely employed because of ease C_8 control over the thyristor gate triggering of thyristor allows us to turn of the thyristor whenever we wish. Here we apply a gate signal to the thyristor. Forward biased thyristor will turn on when gate signal is applied to it. Once the thyristor starts conducting, the gate loses its control over the device and the thyristor continues to conduct. This is because of regenerative action that takes place within the thyristor when gate signal is applied.

Q. 6 Explain dv/dt and di/dt limitation of an SCR and explain how these limitation are improved by using external components OR Explain in brief di/dt capability of an SCR. OR Differentiate between dv/dt and di/dt rating of an SCR. OR What is the significance of di/dt as rated to SCR (S-98, W-98) (W-16)

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 flow 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 of capacitance of the junction is constant hence when dv/dt increases to a suitable value that leakage current occurs an 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.

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.

Q.7. Explain in brief the term 'turn –on time' with respect to SCR. OR Differentiate between delay time and rise time. OR Draw & explain dynamic characteristics of SCR in detail. (S-03, S-98, S-99, W-98, S-18)

Turn ON Time of SCR

A forward biased thyristor can be turned on by applying a positive voltage between gate and cathode terminal. But it takes some transition time to go from forward blocking mode to forward conduction mode. This transition time is called turn on time of SCR and it can be subdivided into three small intervals as delay time (t_d), rise time (t_r), spread time (t_s).

Delay Time of SCR

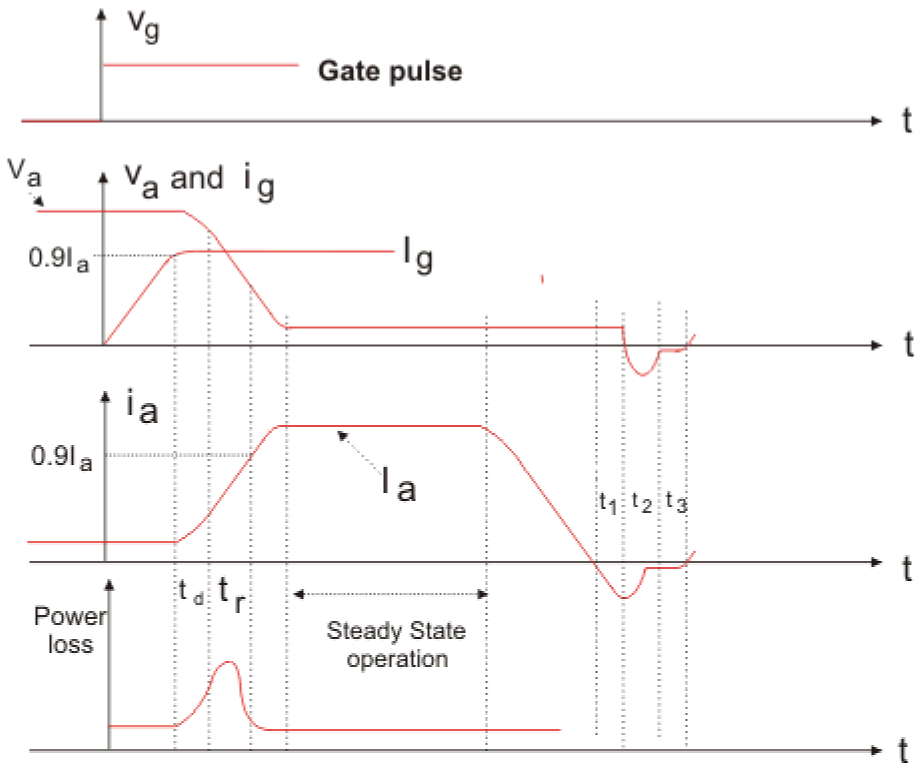
After application of gate current, the thyristor will start conducting over a very tiny region. Delay time of SCR can be defined as the time taken by the gate current to increase from 90% to 100% of its final value I_g. From another point of view, delay time is the interval in which anode current rises from forward leakage current to 10% of its final value and at the same time anode voltage will fall from 100% to 90% of its initial value V_a.

Rise Time of SCR

Rise time of SCR in the time taken by the anode current to rise from 10% to 90% of its final value. At the same time anode voltage will fall from 90% to 10% of its initial value V_a. The phenomenon of decreasing anode voltage and increasing anode current is entirely dependent upon the type of the load. For example if we connect a inductive load, voltage will fall in a faster rate than the current increasing. This is happened because induction does not allow initially high voltage change through it. On the other hand if we connect a capacitive load it does not allow initial high voltage change through it, hence current increasing rate will be faster than the voltage falling rate. High increasing rate of di_a/dt can create local hot spot in the device which is not suitable for proper operation. So, it is advisable to use an inductor in series with the device to tackle high di_a/dt. Usually value of maximum allowable di/dt is in the range of 20 to 200 A per microsecond.

Spread Time of SCR

It is the time taken by the anode current to rise from 90% to 100% of its final value. At the same time the anode voltage decreases from 10% of its initial value to smallest possible value. In this interval of time conduction spreads all over the area of cathode and the SCR will go to fully ON State. Spread time of SCR depends upon the cross-sectional area of cathode.



Q.8. Explain in brief what is meant by turn-off time of an SCR and enumerate different parameters which affects turn-off time. (S-98, W-98)

Turn OFF Time of SCR

Once the thyristor is switched on or in other point of view, the anode current is above latching current, the gate losses control over it. That means gate circuit cannot turn off the device. For turning off the SCR anode current must fall below the holding current. After anode current fall to zero we cannot apply forward voltage across the device due to presence of carrier charges into the four layers. So we must sweep out or recombine these charges to proper turn off of SCR. So turn off time of SCR can be defined as the interval between anode current falls to zero and device regains its forward blocking mode. On the basis of removing carrier charges from the four layers, turn off time of SCR can be divided into two time regions,

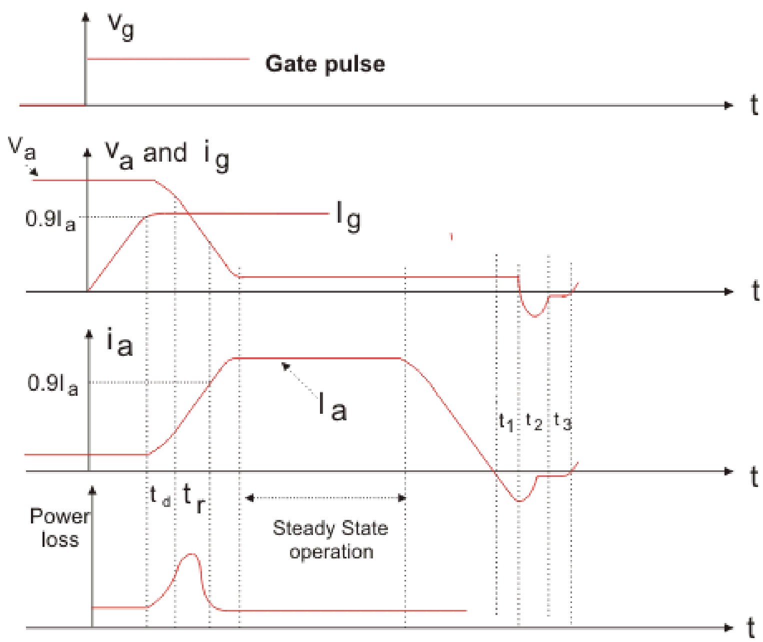
1. Reverse Recovery Time.
2. Gate Recovery Time

Reverse Recovery Time

It is the interval in which change carriers remove from J_1, and J_3 junction. At time t_1, anode current falls to zero and it will continue to increase in reverse direction with same slope (di/dt) of the forward decreasing current. This negative current will help to sweep out the carrier charges from junction J_1 and J_3. At the time t_2 carrier charge density is not sufficient to maintain the reverse current hence after t_2 this negative current will start to decrease. The value of current at t_2 is called reverse recovery current. Due to rapid decreasing of anode current, a reverse spike of voltage may appear across the SCR. Total recovery time $t_3 - t_1$ is called reverse recovery time. After that, device will start to follow the applied reverse voltage and it gains the property to block the forward voltage.

Gate Recovery Time

After sweeping out the carrier charges from junction J_1 and J_3 during reverse recovery time, there still remain trapped charges in J_2 junction which prevent the SCR from blocking the forward voltage. These trapped charges can be removed by recombination only and the interval in which this recombination is done, called gate recovery time.



Q.9 What are the methods of commutation available for thyristors? Discuss the method of forced commutation <u>OR</u> Give broad classification of commutation techniques & explain any one of them. <u>OR</u> Enlist the commutation techniques of SCR. Explain Class-B commutation. **(W-16, W-17, S-17, S-18)**

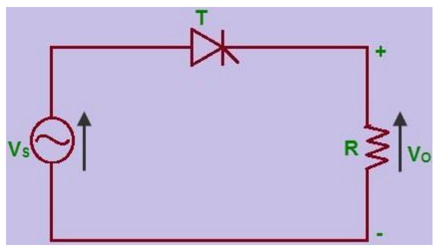
As we have studied above, a thyristor can be turned on by triggering gate terminal with low voltage short duration pulse. But after turning on, it will conduct continuous until the thyristor is reverse biased or the load current falls to zero. This continuous conduction of thyristors causes problems in some applications. The process used for turning off a thyristor is called as commutation. By the commutation process, the thyristor operating mode is changed from forward conducting mode to forward blocking mode. So, the thyristor commutation methods or thyristor commutation techniques are used to turn off.

The commutation techniques of thyristors are classified into two types:

- Natural Commutation
- Forced Commutation

Natural Commutation

Generally, if we consider AC supply, the current will flow through the zero crossing line while going from positive peak to negative peak. Thus, a reverse voltage will appear across the device simultaneously, which will turn off the thyristor immediately. This process is called as natural commutation as thyristor is turned off naturally without using any external components or circuit or supply for commutation purpose.



Natural commutation can be observed in AC voltage controllers, phase controlled rectifiers and cycloconverters.

Forced Commutation

The thyristor can be turned off by reverse biasing the SCR or by using active or passive components. Thyristor current can be reduced to a value below the value of holding current. Since, the thyristor is turned off forcibly it is termed as a forced commutation process. The basic electronics and electrical components such as inductance and capacitance are used as commutating elements for commutation purpose.

Forced commutation can be observed while using DC supply; hence it is also called as DC commutation. The external circuit used for forced commutation process is called as commutation circuit and the elements used in this circuit are called as commutating elements.

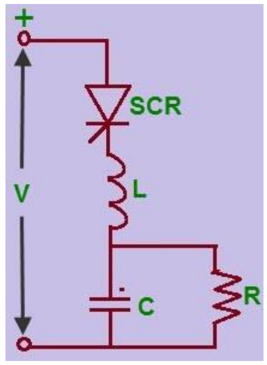
Classification of Forced Commutation Methods

The forced commutation can be classified into different methods as follows:

- Class A: Self commutated by a resonating load
- Class B: Self commutated by an LC circuit
- Class C: C or L-C switched by another load carrying SCR
- Class D: C or L-C switched by an auxiliary SCR
- Class E: An external pulse source for commutation
- Class F: AC line commutation

Class A: Self Commutated by a Resonating Load

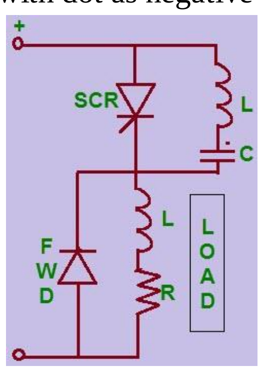
Class A is one of frequently used thyristor commutation techniques. If thyristor is triggered or turned on, then anode current will flow by charging capacitor C with dot as positive. The second order under-damped circuit is formed by the inductor or AC resistor, capacitor and resistor. If the current builds up through SCR and completes the half cycle, then the inductor current will flow through the SCR in the reverse direction which will turn off thyristor.



Class A-Commutation: After the thyristor commutation or turning off the thyristor, the capacitor will start discharging from its peak value through the resistor is an exponential manner. The thyristor will be in reverse bias condition until the capacitor voltage returns to the supply voltage level.

Class B: Self Commutated by an L-C Circuit

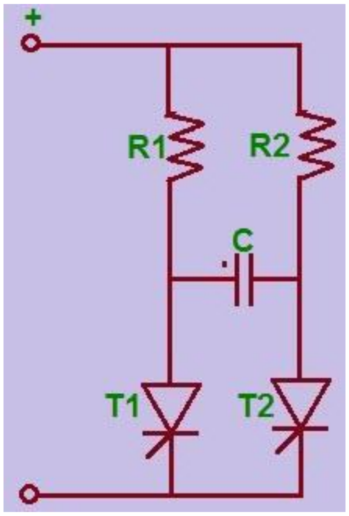
The major difference between the class A and class B thyristor commutation techniques is that the LC is connected in series with thyristor in class A, whereas in parallel with thyristor in class B. Before triggering on the SCR, the capacitor is charged up (dot indicates positive). If the SCR is triggered or given triggering pulse, then the resulting current has two components. The constant load current flowing through the R-L load is ensured by the large reactance connected in series with the load which is clamped with freewheeling diode. If sinusoidal current flows through the resonant L-C circuit, then the capacitor C is charged up with dot as negative at the end of the half cycle.



The total current flowing through the SCR becomes zero with the reverse current flowing through the SCR opposing the load current for a small a small fraction of the negative swing. If the resonant circuit current or reverse current becomes just greater than the load current, then the SCR will be turned OFF.

Class C: C or L-C Switched by another Load Carrying SCR

In the above thyristor commutation techniques we observed only one SCR but in these class C commutation techniques of thyristor there will be two SCRs. One SCR is considered as main thyristor and the other as auxiliary thyristor. In this classification both may act as main SCRs carrying load current and they can be designed with four SCRs with load across the capacitor by using a current source for supplying an integral converter.

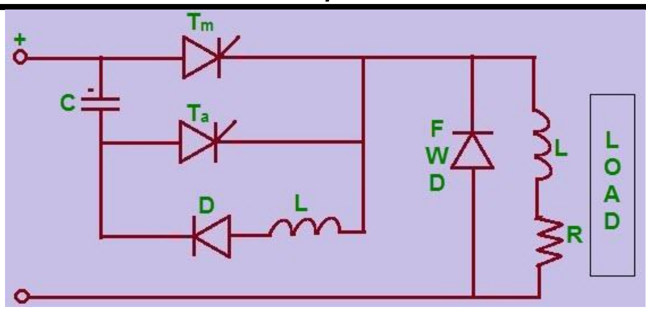


Class C-Commutation

If the thyristor T2 is triggered, then the capacitor will be charged up. If the thyristor T1 is triggered, then the capacitor will discharge and this discharge current of C will oppose the flow of load current in T2 as the capacitor is switched across T2 via T1.

Class D: L-C or C Switched by an Auxiliary SCR

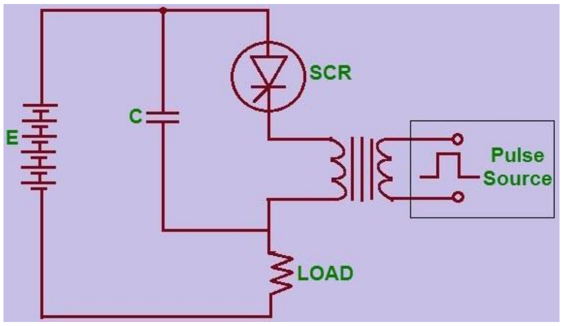
The class C and class D thyristor commutation techniques can be differentiated with the load current in class D: only one of the SCR's will carry the load current while the other acts as an auxiliary thyristor whereas in class C both SCRs will carry load current. The auxiliary thyristor consists of resistor in its anode which is having resistance of approximately ten times the load resistance.



Class D-Commutation: By triggering the Ta (auxiliary thyristor) the capacitor is charged up to supply voltage and then the Ta will turn OFF. The extra voltage if any, due to substantial inductance in the input lines will be discharged through the diode-inductor-load circuit. If the Tm (main thyristor) is triggered, then the current will flow in two paths: commutating current will flow through the C-Tm-L-D path and load current will flow through the load. If the charge on the capacitor is reversed and held at that level using the diode and if Ta is re-triggered, then the voltage across the capacitor will appear across the Tm via Ta. Thus, the main thyristor Tm will be turned off.

Class E: External Pulse Source for Commutation

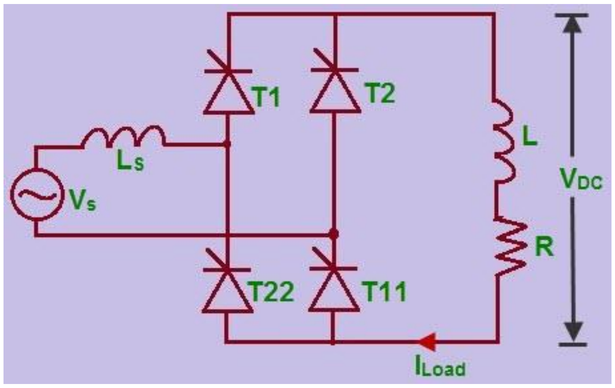
For the class E thyristor commutation techniques, a transformer which can not saturate (as it is having a sufficient iron and air gap) and capable to carry the load current with small voltage drop compared with the supply voltage. If the thyristor T is triggered, then the current will flow through the load and pulse transformer.



Class E-Commutation: An external pulse generator is used to generate a positive pulse which is supplied to the cathode of the thyristor through pulse transformer. The capacitor C is charged to around 1v and it is considered to have zero impedance for the turn off pulse duration. The voltage across the thyristor is reversed by the pulse from the electrical transformer which supplies the reverse recovery current, and for the required turn off time it holds the negative voltage.

Class F: AC Line Commutated

In class F thyristor commutation techniques, an alternating voltage is used for supply and, during the positive half cycle of this supply, load current will flow. If the load is highly inductive, then the current will remain until the energy stored in the inductive load is dissipated. During the negative half cycle as the load current becomes zero, then thyristor will turn off. If voltage exists for a period of rated turn off time of the device, then the negative polarity of the voltage across the outgoing thyristor will turn it off.



Class F-Commutation: Here, the duration of the half cycle must be greater than the turn off time of thyristor. This commutation process is similar to the concept of three phase converter. Let us consider, primarily T1 and T11 are conducting with the triggering angle of the converter, which is equal to 60 degrees, and is operating in continuous conduction mode with highly inductive load.

If the thyristors T2 and T22 are triggered, then instantaneously the current through the incoming devices will not rise to the load current level. If the current through the incoming thyristors reaches the load current level, then the commutation process of outgoing thyristors will be initiated. This reverse biasing voltage of thyristor should be continued until the forward blocking state is reached.

Thyristor can be simply called as a controlled rectifier. There are different types of thyristors, which are used for designing power electronics based innovative electrical projects. The process of turning on thyristor by providing triggering pulses to gate terminal is called as triggering. Similarly, the process of turning off thyristor is called as commutation. Hope this article give brief information about different commutation techniques of the thyristor. Further technical assistance will be provided based on your comments and queries in the comments section below.

Q.11. Explain in brief, voltage, current and power ratings of SCR. (W-99, S-17)

Thyristor ratings or **SCR ratings** are very much required for operating it in a safe zone. The reliable operation can be done when a thyristor does not violate its voltage and current rating during working period. 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. This voltage 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 this voltage 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 of capacitance of the junction is constant hence when dv/dt increases to a suitable value that leakage current occurs an 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, which 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 for a short while. An electrical fuse I^2R rating must be less than that of 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.

Q.12. Explain Series and Parallel connection of SCR. OR What is the necessity of connecting SCR in series? What are the problems associated with series connection? How they are eliminated? (W-16, S-17)

Nowadays, SCRs are available of ratings up to 10 KV and 3 KA. But sometimes we face demand, more than these ratings. In this case combination of more than one SCRs is used. Series connection of SCRs meets high voltage demand and parallel connection of SCRs meets high current demand. These series and parallel connection of SCR or Thyristor will work efficiently if all SCRs are fully utilized. Although all SCRs in a string are of same rating, their V-I characteristics differ from one another. This leads to unequal voltage or current division among them. Hence every SCR is not fully utilized. So the efficiency of string is always less than 100% according to the given expression

$$String\ efficiency = \frac{V_{oi}\ or\ actual\ current\ rating\ of\ the\ whole\ string}{nos\ of\ SCR\ in\ the\ string\ \times V_{oi}\ or\ current\ rating\ of\ individual\ SCR}$$

With increase in the numbers of SCRs in a string voltage or current handled by each SCR is minimized.This phenomenon increases the reliability of the string, but reduces the utilization of each SCR. Thus string efficiency decreases. Reliability of string is measured by derating factor (DRF) which is given by the expression

$$DRF = 1 - string\ efficiency$$

Series Operation of SCR

When the operating voltage is more than the rating of one SCR the multiple SCRs of same ratings are used in series. As we know SCR's having same rating, may have different I-V characteristic, so unequal voltage division is bound to take place. For example if two SCRs in series that is capable of blocking 5 KV individually, then the string should block 10 KV. But practically this does not happen. This can be verified with the help of an example. Let the characteristics of two SCRs are as shown in fig. 1.

So we can see from the diagram, for same leakage current, unequal voltage division takes place. Voltage across SCR_1 is V_1 but that across SCR_2 is V_2. V_2 is much less than V_1. So, SCR_2 is not fully utilized. Hence the string can block $V_1 + V_2 = 8$ KV, rather than 10 KV and the string efficiency is given by = 80%. To improve the efficiency a resistor in parallel with every SCR is used. The value of these resistances are such that the equivalent resistance of each SCR and resistor pair will be same. Hence this will ensure equal voltage division across each SCR. But in practical different rating of resistor is very difficult to use. So we chose one value of resistance to get optimum result which is given by

$$R = \frac{nV_{bm} - V_s}{(n-1)\Delta I_b}$$

Where, n = no. of SCR in the string
V_{bm} = Voltage blocked by the SCR having minimum leakage current.
ΔI_b = Difference between maximum and minimum leakage current flowing through SCR
V_s = Voltage across the string.

This resistance b is called static equalizing circuit. But this resistance is not enough to equalize the voltage division during turn on and turn off. In these transient conditions, to maintain the equal volume across each device a capacitor is used along with resistor in parallel with every SCR. This is nothing but snubber ckt which also known as dynamic equalizing circuit. Additional diodes can also be used to improve the performance of dynamic equalizing circuit.

Parallel Operation of SCR

When the operating current is more than the individual current ratings of SCRs then we use more than one SCRs in parallel. Due to different V-I characteristics SCRs of same rating shares unequal current in a string. Let a string consists of two transistors in parallel as shown in fig. 1 and their current rating by 1 KA. From the V-I characteristics of the devices it can be seen that for operating volume V, current through SCR_1 is 1 KA and that through SCR_2 is 0.8 KA. Hence, SCR_2 is not fully utilized here. Though the string should withstand R KA theoretically it is only capable of handling 1.8 KA. So, the string efficiency is = 90%.

Due to unequal current division when current through SCR increases, its temperature also increases which in turn decreases the resistance. Hence further increase in current takes place and this is a cumulative process. This is known as thermal ‘run away’ which can damage the device. To overcome this problem SCRs would be maintained at the same temperature. This is possible by mounting them on same heat sink. They should be mounted in symmetrical position as flux.

Linkages by the devices will be same. So, the mutual inductance of devices will be same. This will offer same reactance through every device. Thus reducing the difference in current level through the devices. Another way of equalizing the current division in ac circuit can be achieved by using magnetic coupled reactance as shown in Fig – 2.When $I_1 = I_2$ then resultant flux is zero as two coils are connected in anti-parallel. So, the inductance of the both path will be same. If $I_1 > I_2$ then there will be a resultant flux. This flux induces emfs in cols. 1 and 2 as shown in fig. Hence current in path 1 is opposed and in path 2 it is aided by the induced emfs. Thus reducing the current difference in the paths.

Q. 13 Discuss complete protection scheme for SCR to prevent the SCR from over voltage, overcurrent, di/dt and dv/dt. (S-16, W-17)

For satisfactory and reliable operation, the specified ratings of an SCR should not be exceeded due to overload, voltage transients and other abnormal conditions. If the ratings are exceeded, there is a chance of damage permanently to the SCR. Due to the reverse recovery process during the turn OFF the SCR, the voltage overshoots occur in the SCR. Also, during turn ON, switching action produces over voltages in the presence of inductance. In the event of a short circuit, a large current flows through the SCR which is very larger than the rated current. Therefore, to avoid the undesirable effects on the SCR due to these abnormal conditions, SCR must be provided with suitable protection circuits.

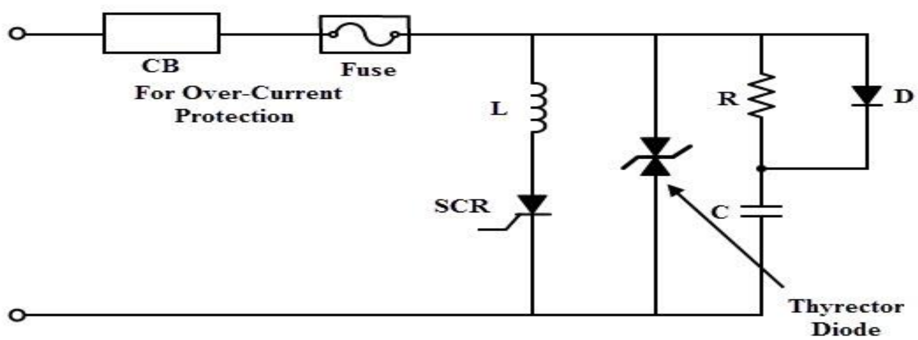
Some of the protection techniques employed for an SCR include over voltage protection, over current protection, dv/dt protection and di/dt protection. Also, to operate the SCR in permissible temperature limits, heat produced at the junctions must be dissipated. This can be accomplished by using heat sinks. Let us discuss in brief on these protection methods.

Protection Against Over voltages

To protect the SCR against the transient over voltages, a parallel R-C snubber network is provided for each SCR in a converter circuit. This snubber network protects the SCR against internal over voltages that are caused during the reverse recovery process. After the SCR is turned OFF or commutated, the reverse recover current is diverted to the snubber circuit which consists of energy storing elements.

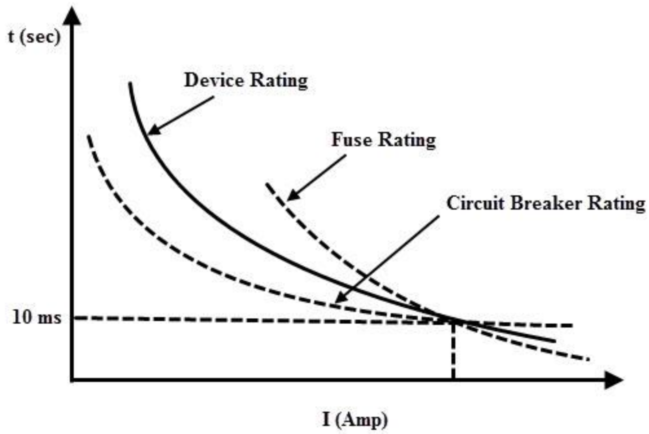
The lightning and switching surges at the input side may damage the converter or the transformer. And the effect of these voltages is minimised by using voltage clamping devices across the SCR. Therefore, voltage clamping devices like metal oxide varistors, selenium thyrector diodes and avalanche diode suppressors are most commonly employed.

These devices have falling resistance characteristics with an increase in voltage. Therefore, these devices provide a low resistance path across the SCR when a surge voltage appears across the device. The figure below shows the protection of SCR against over voltages using thyrector diode and snubber network.



Protection Against Overcurrent

The SCRs can be protected against the over currents using conventional over current protection devices like ordinary fuses (HRC fuse, rewirable fuse, semiconductor fuse, etc,), contractors, relays and circuit breakers. Generally for continuous overloads and surge currents of long duration, a circuit breaker is employed to protect the SCR due to its long tripping time. For an effective tripping of the circuit breaker, tripping time must be properly coordinated with SCR rating. Also, the large surge currents with short duration (are also called as sub-cycle surge currents) are limited by connecting the fast acting fuse in series with an SCR. So the proper coordination of fusing time and the sub-cycle rating must be selected for a reliable protection against over currents. Therefore, the proper coordination of fuse and circuit breaker is essential with the rating of the SCR.



The selection of fuse for protecting the SCR must satisfy the following conditions.

- Fuse must be rated to carry the full load current continuously plus a marginal overload current for a small period.
- I2t rating of the fuse must be less than the I2t rating of the SCR
- During arcing period, fuse voltage must be high in order to force down the current value.
- After interrupting the current, fuse must withstand for any restricted voltage.

di/dt Protection of SCR

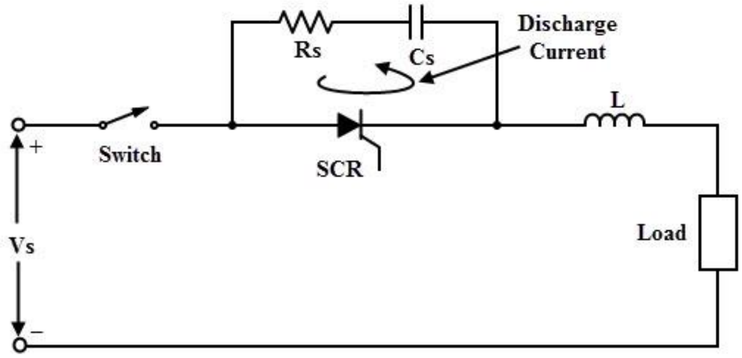
The anode current starts flowing through the SCR when it is turned ON by the application of gate signal. This anode current takes some finite time to spread across the junctions of an SCR. For a good working of SCR, this current must spread uniformly over the surface of the junction. If the rate of rise of anode current (di/dt) is high results a non-uniform spreading of current over the junction. Due to the high current density, this further leads to form local hot spots near the gate-cathode junction. This effect may damage the SCR due to overheating. Hence, during turn ON process of SCR, the di/dt must be kept below the specified limits.To prevent the high rate of change of current, an inductor is connected in series with thyristor. Typical SCR di/dt ratings are in range between 20- 500 ampere per microseconds.

dv/dt Protection of SCR

When the SCR is forward biased, junctions J1 and J3 forward biased and junction J2 is reverse biased. This reverse biased junction J2 exhibits the characteristics of a capacitor. Therefore, if the rate of forward voltage applied is very high across the SCR, charging current flows through the junction J2 is high enough to turn ON the SCR even without any gate signal. This is called as dv/dt triggering of the SCR which is generally not employed as it is false triggering process. Hence, the rate of rise of anode to cathode voltage, dv/dt must be in specified limit to protect the SCR against false triggering. This can be achieved by using RC snubber network across the SCR.

Working of Snubber Circuit

As we discussed above, the protection against high voltage reverse recovery transients and dv/dt is achieved by using an RC snubber circuit. This snubber circuit consists of a series combination of capacitor and resistor which is connected across the SCR. This also consist an inductance in series with the SCR to prevent the high di/dt. The resistance value is of few hundred ohms. The snubber network used for the protection of SCR is shown below.



When the switch closed, a sudden voltage appears across the SCR which is bypassed to the RC network. This is because the capacitor acts as a short circuit which reduces the voltage across the SCR to zero. As the time increases, voltage across the capacitor builds up at slow rate such that dv/dt across the capacitor is too small to turn ON the SCR. Therefore, the dv/dt across the SCR and the capacitor is less than the maximum dv/dt rating of the SCR.

Normally, the capacitor is charged to a voltage equal the maximum supply voltage which is the forward blocking voltage of the SCR. If the SCR is turned ON, the capacitor starts discharging which causes a high current to flow through the SCR. This produces a high di/dt that leads to damage the SCR. And hence, to limit the high di/dt and peak discharge current, a small resistance is placed in series with the capacitor as shown in above. These snubber circuits can also be connected to any switching circuit to limit the high surge or transient voltages.