UNIT – II

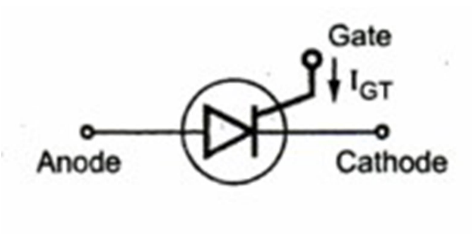
Thyristors

SCR (Silicon Controlled Rectifier)

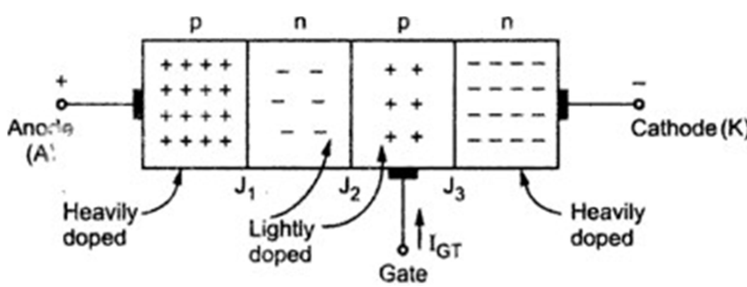
Introduction

Thyristor is a four layer three junction pnpn semiconductor switching device. It has 3 terminals these are anode, cathode and gate. SCR is made up of silicon, it acts as a rectifier. It is a unidirectional device.

Symbol



Structure



Construction

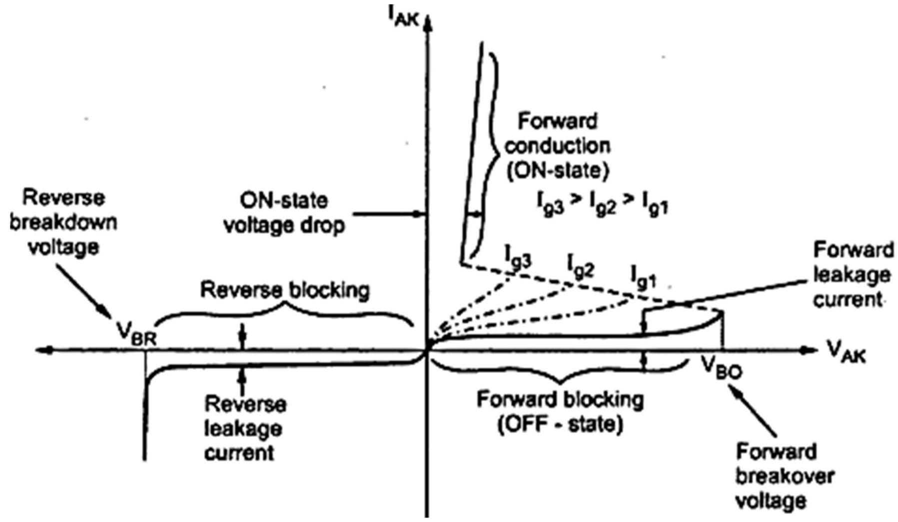
The SCR is a four layer p-n-p-n device where p and n layers are alternately arranged. The outer layers are heavily doped. There are three p-n junctions called J_1,J_2 and J_3. The outer p layer is called anode while outer n layer is called cathode. Middle p layer is called gate.

Anode must be positive with respect to cathode to forward bias the SCR. But this is not sufficient criterion to turn SCR ON. To make it ON, a current is to be passed through the gate terminal denoted as I_{GT}. Thus it is a current operated device.

VI Characteristics

The anode to cathode current I_{AK} is plotted with respect to anode to cathode voltage V_{AK}. The voltage V_{BO} is the forward break-over voltage. V_{BR} is the reverse breakdown voltage and I_{g1}, I_{g2}, I_{g3} are the gate currents applied to the SCR

Graph



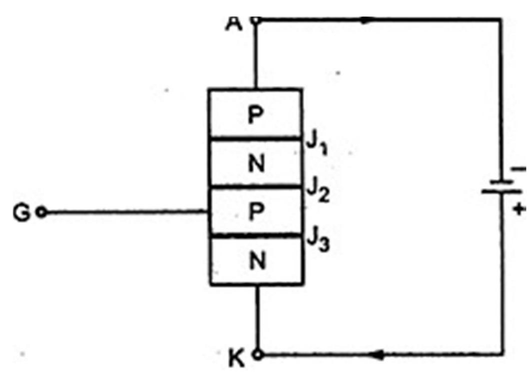
Working

SCR have 3 modes of operation:

1. Reverse blocking mode
2. Forward blocking mode
3. Forward Conduction mode

Reverse Blocking Mode

The SCR is said to be in Reverse biased when anode is made negative with respect to cathode.



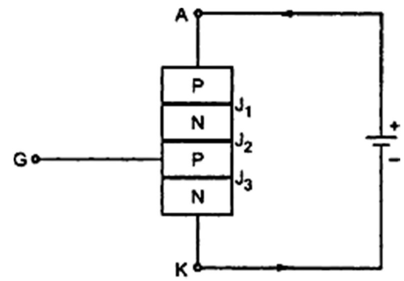
Due to this reverse bias, junction J_1 and J_3 are also reverse biased and SCR does not conduct. A very small current flow from anode and cathode is called as reverse leakage current.

Reverse voltage increases but very small current flows. At reverse break down voltage (V_{BR}), the reverse current increases rapidly. At the time of reverse breakdown, the high voltage is present across the SCR and heavy current flows through it. Hence large power dissipation takes place in the thyristor. Due to this dissipation, the junction temperature exceeds the permissible value and the SCR is damaged. Hence a reverse voltage across the SCR should never exceed V_{BO}.

Forward Blocking Mode

The SCR is said to be forward biased when the anode is made positive with respect to cathode, the junction J_3 becomes forward biased.

A very small current flows from anode and cathode is called as forward leakage current. In the forward blocking mode, the SCR is forward biased but it does not turn on. In the forward blocking mode, a very small forward leakage current flows. In this mode, the voltage (V_{AK}) can be increased till V_{BO}. When the forward voltage reaches V_{BO}, the SCR turns on.



Forward Conduction Mode

SCR changed from forward blocking state to forward conducting state even if gate signal is not applied.

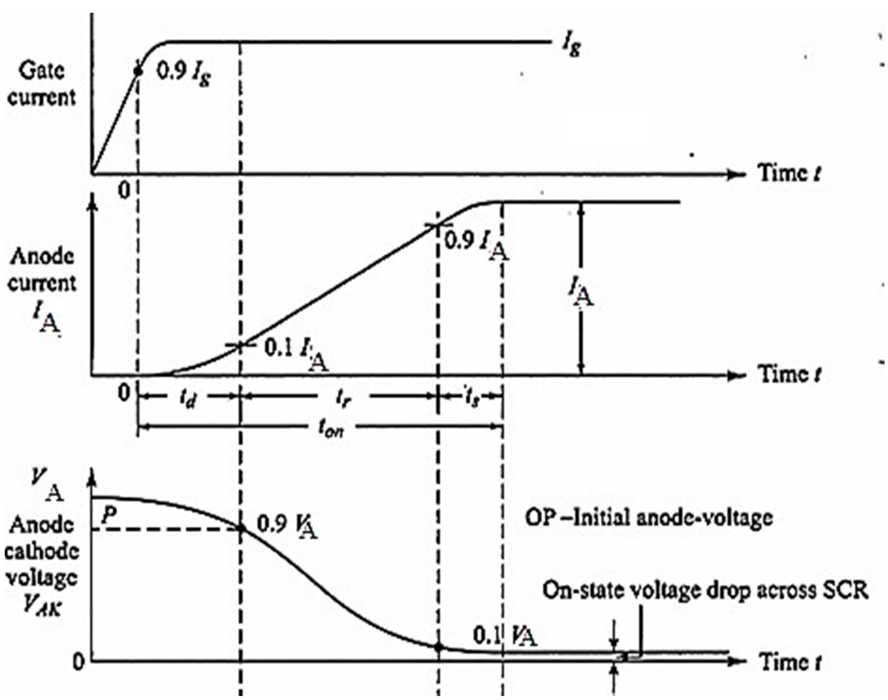
When the voltage increases above V_{BO}, the SCR goes into forward conduction mode (i.e) SCR turns on. Thus SCR is not damaged if voltage $V_{AK} > V_{BO}$, rather it is turned on. The thyristor will only turn off when the forward current drops below holding current.

Turn on and Turn off Characteristics

Turn on characteristics

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.

Turn on Waveforms



Turn on time (ton):-

The time taken for SCR to traverse from the blocking state to conducting state is called as turn on time.

Turn on time (ton) = td+tr+tp

<u>Delay time (td):-</u>

The time taken for anode current to reach $0.1I_A$ and anode voltage to fall from V_A to $0.9V_A$ is called as delay time(t_d).

<u>Rise time (tr):-</u>

Rise time (t_r) is defined as the time during which the anode current to increases from $0.1I_A$ to $0.9I_A$ and anode voltage to fall from $0.9V_A$ to $0.1V_A$.

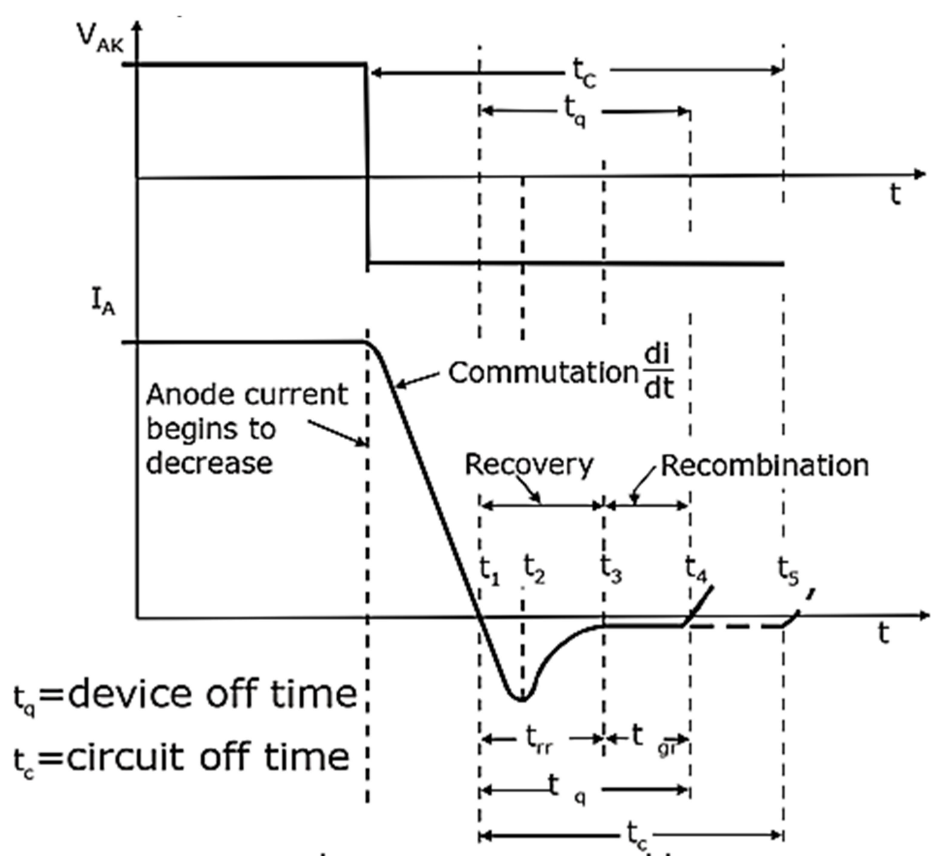
<u>Spread time (ts):-</u>

It is time taken by the anode current to rise from $0.9I_A$ to maximum value of I_A and V_A to fall from $0.1V_A$ to its ON state voltage drop (near by zero).

Turn off characteristics

Turning OFF an SCR means bringing the SCR from conducting state to blocking state.

Turn off Waveforms



Turn off time (toff):-

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 (toff) = trr+tgr

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

Reverse Recovery time (trr):-

It is the time taken for the removal of excessive carriers from top and bottom layer of SCR.

At t_2: 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

Gate Recovery time (tgr):-

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 ratings

Voltage, current, power and temperature limits within which thyristor can be used without damage. If voltage, current and power rating exceeds its specified range, SCR damaged.

Rating of SCR

i. Voltage rating

ii. Current rating

Voltage Rating

The voltage carrying capacity of the device is known as its voltage rating.

1. Peak Repetitive forward blocking voltage (V_{PRM}):

It is the maximum voltage that SCR can withstand repeatedly in its forward blocking state.

2. Peak Repetitive Reverse voltage (V_{RRM}):

It is also called as Peak Inverse Voltage (V_{PIV}). It is the maximum voltage that SCR can withstand repeatedly repetitively in the reverse blocking state. SCR is damaged when the rating of V_{PRM}, V_{RRM} is exceeded.

3. Surge Peak forward blocking voltage (V_{DSM}):

   It is the maximum voltage that the SCR can withstand in the forward blocking state which does not repeat again and again.

4. Non-repetitive Peak Reverse Voltage (V_{RSM}):

   It is the maximum voltage that the SCR can withstand in the reverse blocking state which does not repeat again and again.

   SCR is damaged when V_{DSM}, V_{RSM} is repeated.

5. dv/dt rating:

   The dv/dt rating specifies maximum allowable rate of forward voltage that the device can withstand in forward direction. If forward voltage variation exceeds dv/dt rating, then the device turns on. Such turn on is false triggering and disturbs the operation of controller.

6. Voltage Safety factor (V_f):

   Voltage Safety factor is defined as the ratio of peak inverse voltage (V_{PIV}) to the maximum value of operating voltage.

$$V_f = \frac{\text{Peak Inverse voltage } (V_{PIV})}{\sqrt{2} \times \text{RMS value of operating voltage.}}$$

   If the operating voltage is exceeded. SCR gets damaged.

7. On state voltage:

   The voltage which appears across the device during its on state is known as its on state voltage.

8. Finger voltage:

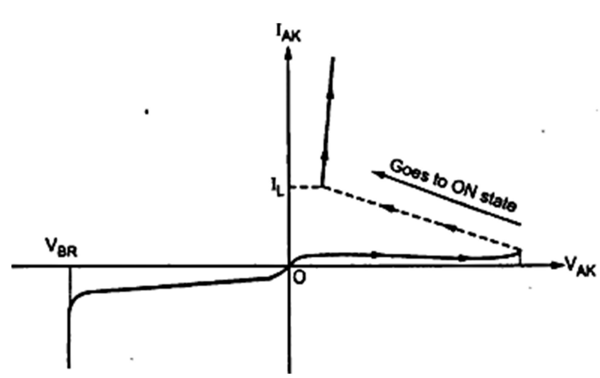
   It is the minimum forward voltage between anode and cathode for turning on SCR by gate triggering.

Current Rating:

The current carrying capacity of the device is known as current rating.

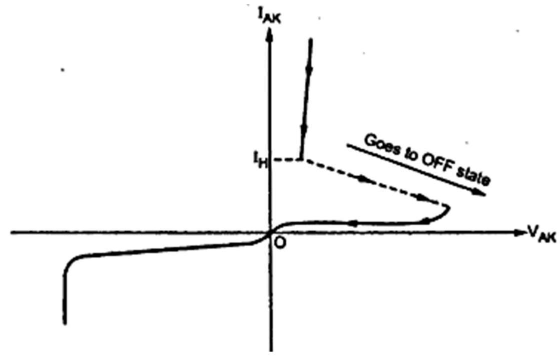
1. Latching current (I_L):

Latching current is the minimum value of current required to trigger the device. It is the minimum value of current which is required to latch the device from its off state to on state.



2. Holding current (I_H):

Holding current is the minimum value of current to hold conduction of SCR. It is the minimum value of current below which the SCR stops conducting and return to its off state.



3. Average current (I_T):

It is the maximum repetitive average current that can flow through SCR. Power loss and switching loss depends on average current rating.

4. RMS current (I_{RMS}):

It is the maximum repetitive RMS current that can flow through SCR.

5. di/dt rating:

The di/dt rating specifies maximum allowable rate of change of current through SCR. If di/dt rating exceeds, junction temperature increases and the SCR may be damaged.

6. I^2t Rating:

The I^2t rating is the measure of thermal energy that SCR can absorb for a short period of time.

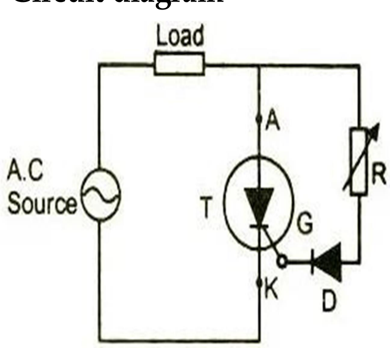
Gate triggering Circuits

Triggering circuits should produce trigger pulses for the thyristor at appropriate instants. Gate triggering circuits are used to apply a positive voltage between gate and cathode can turn ON a forward biased thyristor.

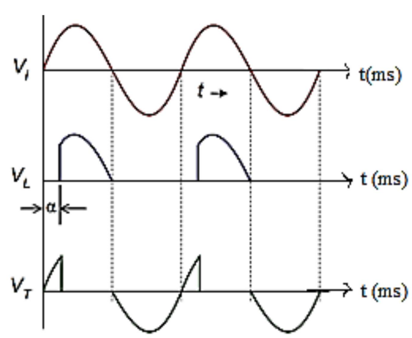
Resistance triggering Circuits

The resistance triggering of SCR is employed to drive the load from the input AC supply. Resistance and diode combination circuit acts as a gate control circuitry to switch the SCR in the desired condition.

Circuit diagram



Waveform



Description

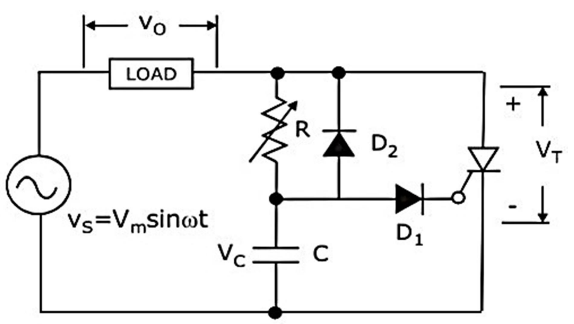
In Resistance triggering method, the variable resistance R is used to control the gate current. Depending upon the value of R, when the magnitude of the gate current reaches the sufficient value, the SCR starts to conduct. The diode D is called as blocking diode. It prevents the gate cathode junction 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. In this, the triggering angle is limited to 90 degrees only.

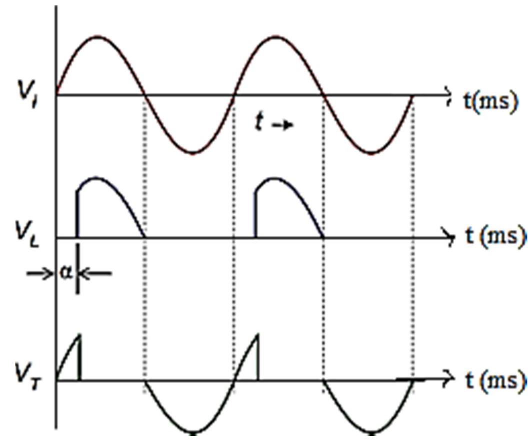
Resistance Capacitance triggering Circuits

The RC triggering circuit consists of two diodes with an RC network connected to turn the SCR.

The limitation of resistance firing circuit can be overcome by the RC triggering circuit which provides the firing angle control from 0 to 180 degrees. By changing the phase and amplitude of the gate current, a large variation of firing angle is obtained using RC triggering circuit.

Circuit diagram **Waveform**





Description

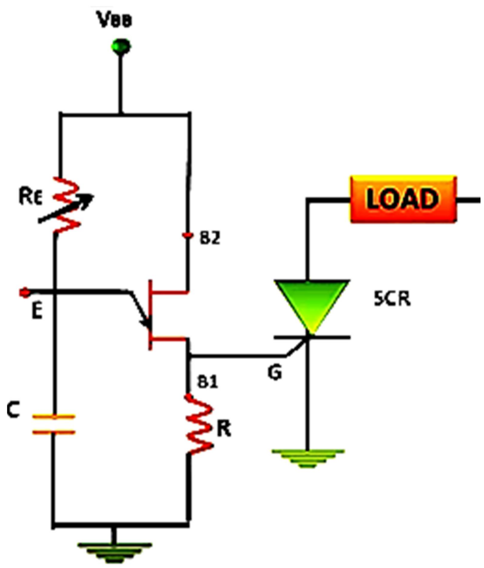
During the positive half cycle, the capacitor is charged through the variable resistance R up to the peak value of the applied voltage. The variable resistor R controls the charging time of the capacitor. Depends upon the voltage across the capacitor, when sufficient amount of gate current will flow in the circuit, the SCR starts to conduct.

During the negative half cycle, the capacitor C is charged up to the negative peak value through the diode D_2. Diode D_1 is used to prevent the reverse break down of the gate cathode junction in the negative half cycle.

UJT triggering Circuits

The Unijunction Transistor (UJT) has a forward breakover voltage which allows for reliable triggering of the silicon controlled rectifier (SCR). In breakdown, it exhibits negative resistance and thus is able to produce a rapidly rising current in a short period of time which is good for triggering SCRs. UJT can be used as Relaxation Oscillator to turn on SCR.

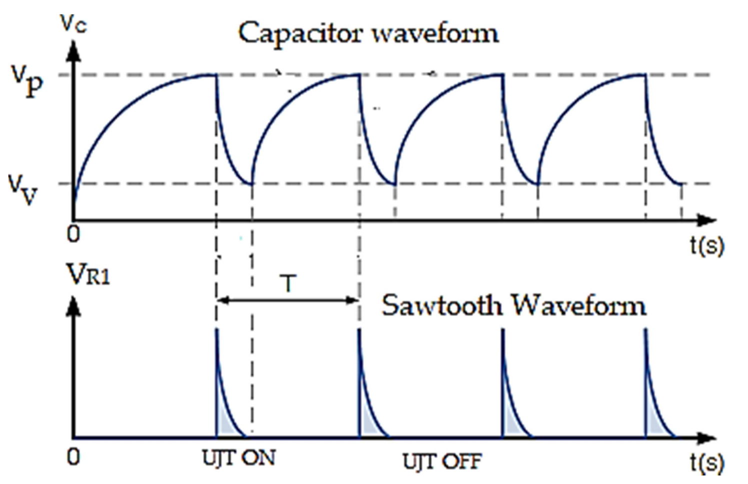
Circuit diagram



Construction

The emitter of UJT is connected with a Resistor R and Capacitor C. The RC determines the frequency of the relaxation oscillator. Both the bases are connected with a resistor each. Resistors R and R_E are current limiting resistors.

Waveform



Analysis

Initially, the voltage across the capacitor is zero.

(i.e) $V_C = 0$. The UJT is in OFF condition.

When the Supply V_{BB} is turned ON, the Capacitor Charges through the Resistance R. During the charging period, the voltage across capacitor (V_C) rises in an exponential manner until it reaches the Peak voltage (V_P). When the capacitor voltage (V_C) becomes equal to Peak voltage (V_P) of UJT, the UJT turns on. Once the UJT is turned on, capacitor starts discharging. When the capacitor discharges to a voltage called Valley voltage (V_V), the UJT turns OFF and again capacitor starts charging. This mode of working of UJT is called Relaxation oscillator.

Protection Circuits

Due to unpredicted changes in the load and supply voltages, fault conditions are arised. Under these conditions, the voltage or current ratings of the power devices are exceeded. Hence there is a possibility of damage to the power device. Such damage can be avoided by using protection circuits.

Protection against dv/dt and overvoltages

Snubber circuits

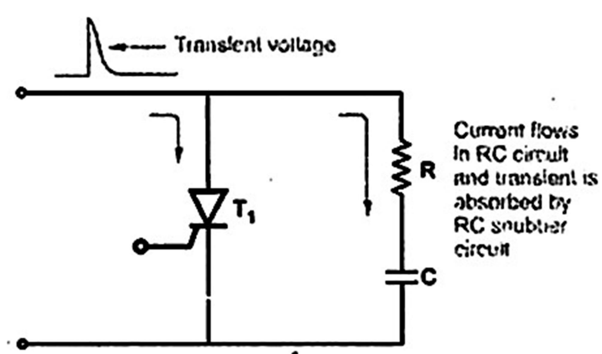
i) High rate of change of voltage across the power device is called dv/dt. It turns-on the thyristor and damages BJTs. The value of dv/dt can be effectively reduced with the help of snubbers (RC circuit).

The transient over voltages can switch on the thyristor. In some cases the thyristor can be damaged due to these transient voltages. These transient voltages are very common when the converter is having inductive loads.

Snubber for transient voltage protection

The thyristors can be protected against transient voltages by a RC network. This RC network is connected in parallel across the thyristor. It is called snubber circuit.

Circuit diagram:



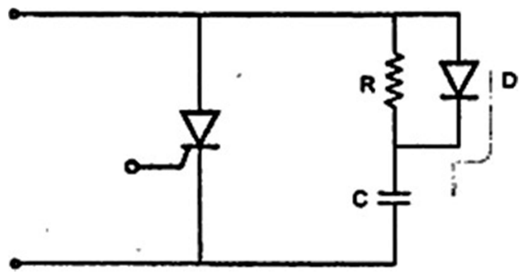
Description

The resistance has the value of few hundred ohms. Whenever there is a large spike or voltage transient across the thyristor, it is absorbed by the RC circuit. The RC circuit (snubber) acts as a low pass filter for this voltage transient. The resistance has normally low value so that the transient is absorbed by the capacitor quickly. Thus the thyristor is protected against voltage transients. The RC snubber circuit is very commonly used for protection of thyristors against transient voltages (high frequency voltage spikes).

Snubber for dv/dt protection

dv/dt also generates large voltage transients. These rapid voltage variations can also be suppressed by snubber circuit.

Circuit diagram :



Description

The capacitor acts as a short for these dv/dt variations. The snubber can be made more effective by connecting a diode across the resistance. In case of voltage transient, the current flows through diode and capacitor. The capacitor acts as a short for the voltage transient. Thus it is suppressed. When thyristor turns-on, the capacitor discharges through resistance R. The R, C and diode snubber is more commonly used because it is very effective for dv/dt and other voltage transients.

Design of snubber

The value of capacitor is given as,

$$C = \frac{1}{2L}\left(\frac{0.564\ V_m}{\frac{dv}{dt}}\right)^2$$

Here V_m is the peak value of supply voltage

$\frac{dv}{dt}$ is the permissible $\frac{dv}{dt}$.

L is the source inductance.

And resistance is given as,

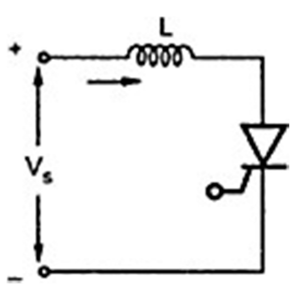
$$R = 2\sigma\sqrt{\frac{L}{C}}$$

Here σ is the damping factor. It's value is normally taken as 0.65.

Protection against di/dt

At the time of turn-on, anode current increases rapidly. This rapid variation of anode current doesn't spread across the junction area of the thyristor. This creates the local hot-spots in the junction and increases the junction temperature. If the junction temperature exceeds permissible value, then the thyristor is damaged. The rapid variations of the thyristor current are also called di/dt.

Circuit diagram :



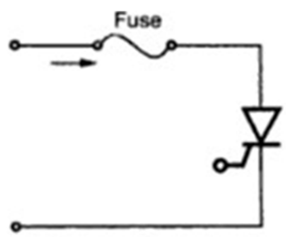
Description

The thyristor can be protected from excessive di/dt by using an inductor in series. The inductance opposes for rapid current variations di/dt. Whenever there is rapid current variation, the inductor smooths it and protects the thyristor from damage.

Overcurrent Protection

The over currents flow in the thyristor circuits due to short circuits. The short circuits can take place because short circuited load, misalignment of firing pulses failure of the thyristors due to over voltages etc. The short circuit currents can be protected automatically because of load or supply transformers appear in the circuit. However the thyristors must be protected against overcurrents by using fast acting fuse.

Circuit diagram :



Fast acting fuse is used to protect thyristor against overcurrent

Description

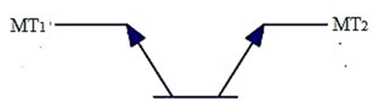
Normally fast acting fuse are used for the protection of thyristor against overcurrents. These fuses melt at comparatively lower currents than current rating of the thyristor. Thus fuse melts and disconnects the circuit and the thyristor is protected. Fuse The fuse should be selected such that it should not melt or disconnect the circuit at normal load currents. Fast acting fuse is used to protect thyristor against overcurrents.

Diac

Introduction

A Diac is a Bidirectional device hence it starts conducting in both the directions. It is also known as bidirectional Thyristor diode. The DIAC stands for the DIode AC switch. It does not have any control terminal.

Symbol

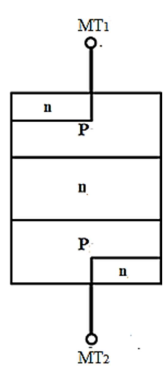
a) 

b) 

MT_1 – Main terminal 1

MT_2 – Main terminal 2

Structure

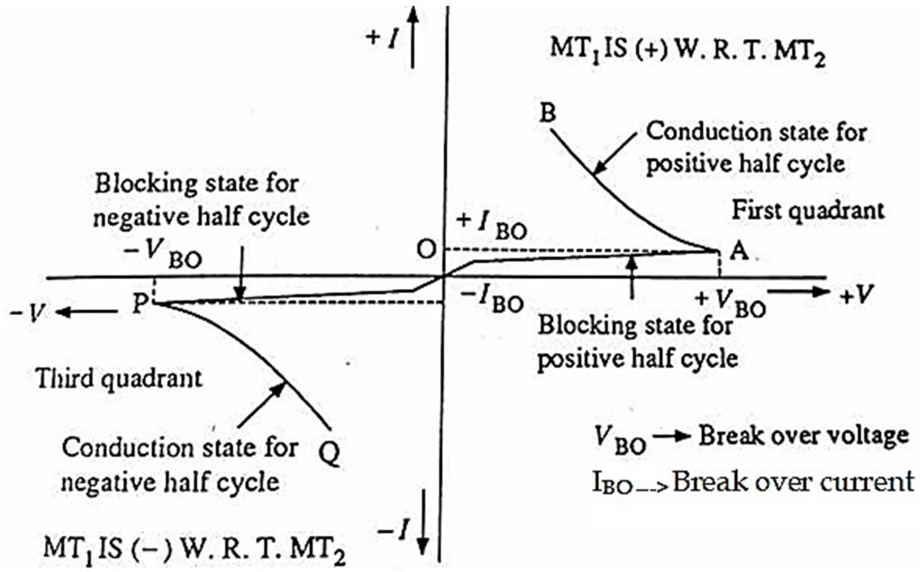


Construction

Diac is a pnpn structured four layer, two terminal semiconductor device. MT_1 and MT_2 are the two main terminal of the device. It has no control terminal.

VI characteristics

Diac can be made to conduct when MT_1 is either positive or negative with respect to MT_2



Description:-

Case i:- MT_1 is Positive

At voltages less than the breakover voltage (V_{BO}) a very small amount of current called leakage current flows through the device. Hence the device remains non-conducting. It is denoted by region OA in the characteristics and is called Blocking State. At the point A, when the voltage level reaches the break over voltage (V_{BO}), the device starts to conduct. During its conduction period the device exhibits negative resistance characteristics. The flow of current in the device starts increasing and voltage across it start decreasing. It is denoted by AB and is called as conduction state.

Case ii:- MT_1 is Negative

At voltages less than the breakover voltage (V_{BO}) a very small amount of current called leakage current flows through the device. Hence the device remains non-conducting. It is denoted by region OP in the characteristics and is called Blocking State. At the point P, when the voltage level reaches the breakover voltage (V_{BO}), the device starts to conduct. During its conduction period the device exhibits negative resistance characteristics. The flow of current in the device starts increasing and voltage across it start decreasing. It is denoted by PQ and is called as conduction state.

Triac

Introduction

A Triac is a Bidirectional device hence it starts conducting in both the directions. The **TRIAC** stands for the **TRI**ode **AC** switch. It has control terminal. It is also called as Bidirectional Triode Thyristor.

Symbol

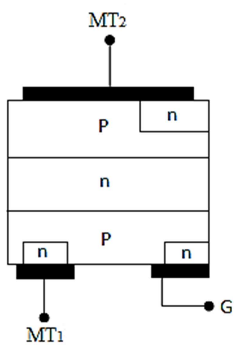
Terminals

G - Gate

MT_1 – Main terminal 1

MT_2 – Main terminal 2

Structure



Construction

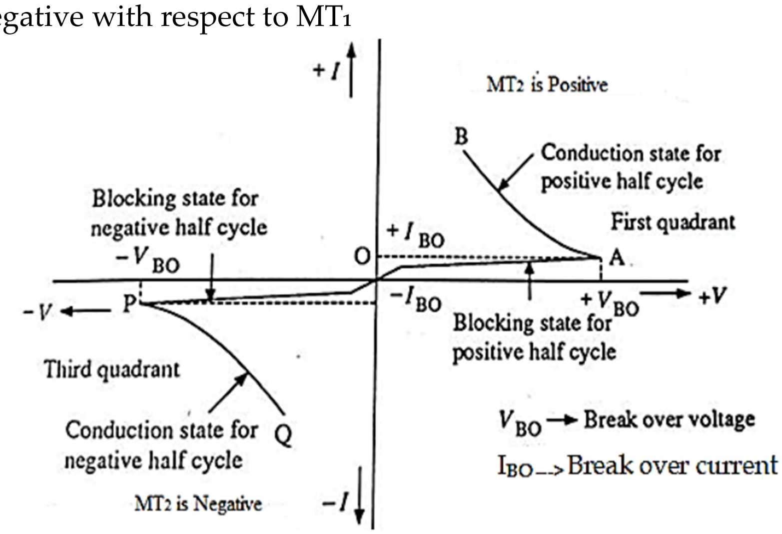
Triac is a three terminal, four layer semiconductor device. Its three terminals are MT_1, MT_2 and gate (G). The gate terminal is a control terminal which is near MT_1.

Gate triggering:-

By applying proper signal at gate, the firing angle of the device changed. The circuits used in gate for triggering the device are called gate triggering circuits.

VI characteristics

With proper gate current, Triac can be made to conduct when MT_2 is either positive or negative with respect to MT_1



Description:-

Case i:- MT_2 is Positive

At voltages less than the break over voltage (V_{BO}) a very small amount of current called leakage current flows through the device. Hence the device remains non-conducting. It is denoted by region OA in the characteristics and is called Blocking State. At the point A, when the voltage level reaches the breakover voltage (V_{BO}), the device starts to conduct. During its conduction period the device exhibits negative resistance characteristics. The flow of current in the device starts increasing and voltage across it start decreasing. It is denoted by AB and is called as conduction state.

Case ii:- MT_2 is Negative

At voltages less than the breakover voltage (V_{BO}) a very small amount of current called leakage current flows through the device. Hence the device remains non-conducting. It is denoted by region OP in the characteristics and is called Blocking State. At the point P, when the voltage level reaches the breakover voltage (V_{BO}), the device starts to conduct. During its conduction period the device exhibits negative resistance characteristics. The flow of current in the device starts increasing and voltage across it start decreasing. It is denoted by PQ and is called as conduction state.

Commutation

Introduction "Commutation" is defined as the process of turning OFF SCR. Commutation can be done by bringing the SCR back into the forward blocking state from the forward conduction state.

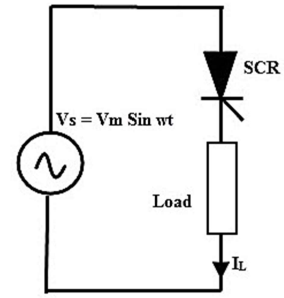
Commutation technique

- ⇔ Natural Commutation
- ⇔ Forced Commutation

Natural Commutation

The process of turning off a SCR without using any external circuits is known as Natural commutation. It is also known as line commutation or source commutation or Class F commutation. Natural Commutation occurs only in AC circuits.

Circuit diagram



Description:-

When a positive cycle reaches to zero and the anode current is zero, immediately a reverse voltage (negative cycle) is applied across the SCR which causes the SCR to turn OFF.

Forced Commutation

The process of turning off a thyristor using external circuits is known as Forced commutation. Forced Commutation is used in DC circuits and it is also called as **DC commutation**. It requires commutating elements like inductance and capacitance to turn off SCR. It is used in Chopper and Inverters circuits.

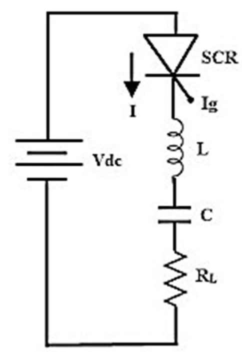
Types

- Class A commutation
- Class B commutation
- Class C commutation
- Class D commutation
- Class E commutation
- Class F commutation.

Class A commutation

Class A commutation is also known as self– commutation or resonant commutation or load commutation.

Circuit diagram



Description:-

The commutating components L and C are connected in series with the load resistance

When the SCR is triggered, the forward currents starts flowing through it and during this the capacitor is charged up V_{dc}. Once the capacitor is fully charged, the SCR becomes reverse biased and turned OFF. The capacitor discharges through the load resistance.