* Power electronics is the study of electronic circuit to control and convert the flow of electrical power.

* Control of electrical power means output of ele voltage can be controlled.

* Conversion of electric power, mean converting electrical power from one form to another form.

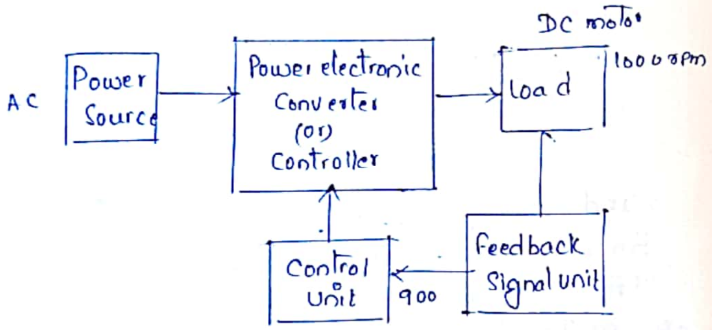


fig: Block diagram of power electronic system

Types of power electronic converters:

1. AC - AC converters.
2. AC - DC converters
3. DC - AC converters
4. DC - DC converters.

* AC - DC converters:

* Uncontrolled rectifiers converts fixed AC i/p voltage to fixed DC output voltage
Ex: Diodes.

* Controlled rectifiers converts fixed AC input voltage to variable dc output voltage.
Ex: SCR's.

* AC - AC converters:

* AC voltage controllers converts fixed AC input voltage to variable AC output voltages

* Cyclo converter converts input power at one frequency to output power at another frequency. It is also known as frequency changer.

* DC - DC converters:

* Chopper converts fixed dc input voltage to variable dc output voltage.

* Inverter converts fixed dc input voltage to variable AC output voltage (dc - AC)

* In order to control and convert the flow of electrical power in the electronic circuit, each power electronic converter is composed with power semi conducting devices such as diodes, power BJT, IGBT, SCR's etc.

Advantages of power electronic system:

* High efficiency due to low losses in the power semi conducting devices.
* Small size, less weight, so installation cost is low.
* Reliable and flexible in operation.

* Due to absence of rotating parts power electronics system has less maintanance and have long life.

Disadvantages:

* Thyristor control rectifiers (converters) have low over load capacity.
* Power Semiconducting devices has tendency to generate harmonics in the supply side as well as load side.

Applications:

1. Commerical applications:
   Personal Computers, Smart mobiles etc.
2. Domestic applications -
   Refrigerators, air conditioners, cooking equipments entertaining equipments etc.
3. Industrial applications
   Blowers, welding equipments, fans etc.
4. Telecommunication applications
   mobile Battery charges, UPS (uninterruptable power supply) etc.
5. Transportation applications
   Battery charges for electric vehicles, electric locomotives, trolley buses, street cars.
6. Utility system applications
   Alternative energy sources (Solar, wind)
   HVDC transmission system.

Unit-1 : Power Semi Conducting devices

Power Semi conductor devices

- Power diodes
- Power transistors
  - → Power BJ's
  - → Power MOSFET's
  - → Power IGBT's
- Thyristors
  - → SCR
  - → SCS
  - → SUS
  - → PUT
  - → TRIAC
  - → DIAC
  - → GTO
  - → RCT
  - → LASCR

* Each power Semiconducting device acts as a Switch, by turning on and off the Switch we can control and convert the flow of electrical power in electronic circuits.
* Power diode is uncontrolled device because they turn on and off are not under the control.
* Power Transistors are controlled devices because it is turned on when current signal is present at base terminal, and will remains into on state as long as current signal is present at base terminal. It will turned off when current signal at base terminal is absent.
* Thyristor is a controlled device because it is turned on by applying low voltage short duration pulse to the gate terminal. Once thyristor is on gate looses it's control and thyristor will

will remains into on state. Thyristor is turned off only when current flowing through the thyristor is reduced to zero forcefully by using some external circuits (or) commutation circuits.

* The name thyristor is derived by combining the capital letters of THYRotran and trans ISTOR

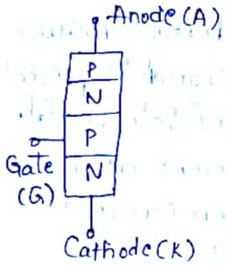
THYRotran trans ISTOR

THYRISTOR

* Thyristor is the name given to the power semi conducting devices having common PNPN structure.

* Semiconductor devices such as signal diodes and transistors are specially designed to operate at low power rating where as power semi conductor devices such as power diodes and transistors are specially designed to operate at high power ratings.

Silicon Controlled rectifier (or) thyristor:



(ii) Schematic diagram of scr

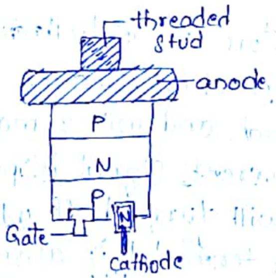


fig (i) Construction of scr

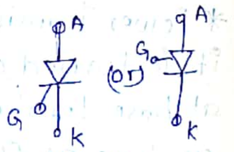


fig (iii) Symbols.

* SCR is a silicon controlled rectifier having four layers, 3 junctions power semiconductor (or) switching device. It has three terminals. Anode, cathode and gate.

* The function of threaded stud is tightening the SCR to the frame of heat sink with the help of nuts.

* Like diode SCR blocks current flow from cathode to anode. Unlike diode SCR also blocks current flow from anode to cathode until a sufficient gate pulse is applied between gate and cathode.

Operation and static V-I characteristics of SCR:

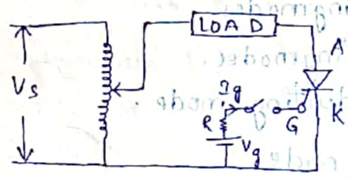


fig: Circuit to obtain VI characteristics of SCR.

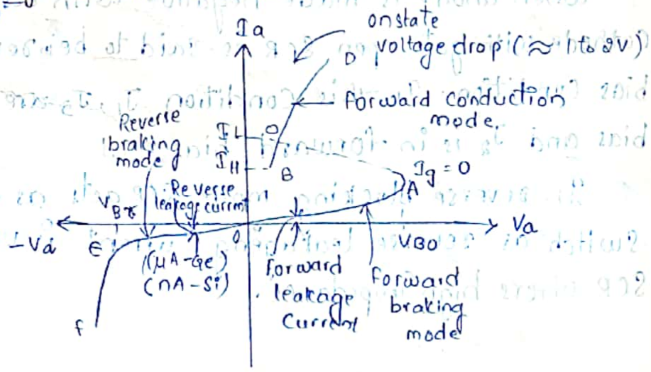


fig: Static V-I characteristics of SCR.

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where
I_L - latching current.
I_H - Holding current.
V_{BO} = Forward breake over voltage.
V_{Br} - Reverse brake down voltage

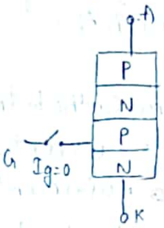


fig. Schematic diagram of SCR.

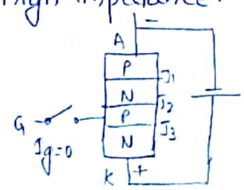
SCR can be operated in 3modes

1. Reverse blocking modes.
2. forward blocking modes.
3. forward conducting mode.

Reverse blocking node:

When anode is made negative with respect to Cathode with gate open SCR is said to be in reverse bias condition. In this Condition J_1, J_3 are reverse bias and J_2 is in forward bias.

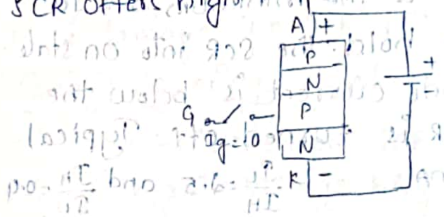
In reverse blocking mode SCR acts as a open switch as reverse leakageng current is very small. SCR offers high impedance.



Forward blocking mode:

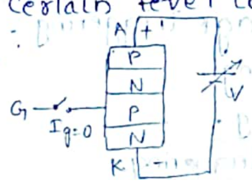
When anode is made positive with respect to Cathode with gate open then SCR is said to be in forward bias Condition. In this condition J_1, J_3 are forward bias and J_2 is reverse bias.

In forward blocking mode SCR acts as a open switch as forward leakage current is small. SCR offers high impedance.



Forward conduction mode

As forward voltage increases at a particular voltage called forward break over voltage the reverse biasing junction undergoes breakdown. Once brake down occurs in at reverse biasing junction J_2, its looses its reverse blocking capabilities that means generated charge carriers will move freely across the three junctions. As a result current flows through the SCR and the SCR get turn on. Once SCR is turned on it will remains into on-state, it is turned-off only when current flowing through the SCR reached below certain level current level called holding current.



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Latching current : It is the minimum anode current required to switch the SCR from off state to on state. If anode current is below the latching current the SCR will be not be turn on.

Typical value of SCR is 25mA

Latching current is associated with turn on process. Latching current is always grater than holding current.

Holding current: It is the minimum anode current required to hold the SCR into on state. (Below the) If the anode current is below the holding current SCR is turned off. Typical value of this is 10mA $\frac{I_L}{I_H} = 2.5$ and $\frac{I_H}{I_L} = 0.4$

Forward break over voltage (V_{BO}):

The voltage at which SCR switches from off state to on state without applying a gate pulse is called forward break over voltage.

Reverse break down voltage (V_{BR}):

The voltage at which a large reverse current will flows through the SCR in reverse bias condition is called reverse brake down voltage.

Turn-on methods of SCR :

When anode is made positive with respect to cathode, the SCR can be triggered in 5 ways.

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

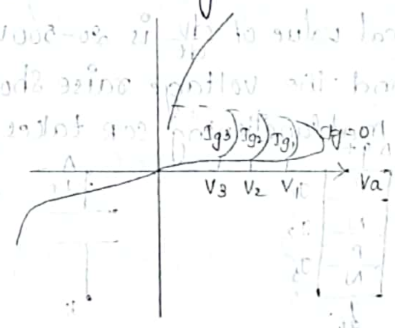
Forward voltage triggering method:

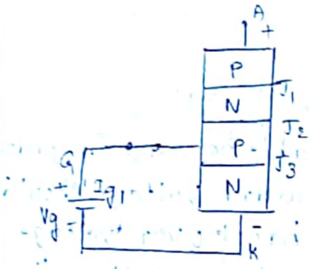
This method is undesirable because in order to turn on the SCR the forward voltage should be increased upto forward break over voltage (V_{BO}). But practially forward break over voltage is very large and may gives rise to looses and may damage the SCR permanantly.

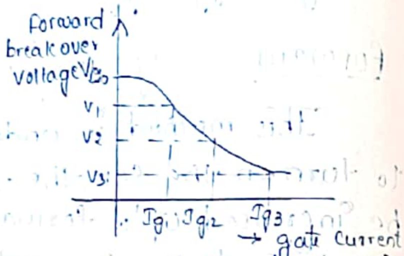
Gate triggering method:

In this method SCR is turned on by applying gate voltage (V_g) between gate and cathode. This gate voltage establishes gate current I_{G1} and flows through the gate terminal. Now the electrons in the cathode N-layer are injected into gate P-layer, as a result the width of the depletion layer at reverse biased junction J_2 decreases and undergoes brakedown at a voltage (V_1) which is lower than forward break over voltage (V_{BO}).

If the magnitude of gate current increases forward break over voltage increases.





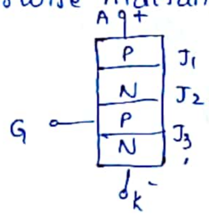


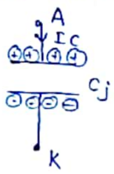
$\frac{dv}{dt}$ triggering method:

In this method the reverse bias junction J_2 acts like a capacitor due to charges existing across the reverse biased junction J_2. Charging current through the junction capacitance C_J is given by $I_c = C_j \frac{dv}{dt}$. If the rate of raise of forward voltage $\frac{dv}{dt}$ is more the charging current will also more and this charging current plays the role of gate i.e SCR is turned on even though the gate signal is not applied due to charging current (I_c).

This method is undesirable because malfunctioning of SCR takes place due to charging current I_c.

Typical value of $\frac{dv}{dt}$ is 20-500 V/μs. i.e per micro second the voltage raise should be 20-500V. Otherwise malfunctioning SCR takes place.





$$I_c = C_j \frac{dv}{dt}$$

Temperature triggering:

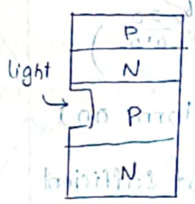
This method is undesirable because in this method SCR is triggered at high temperature. This high temperature gives rise to losses and may damage the SCR permanently.

Light triggering:

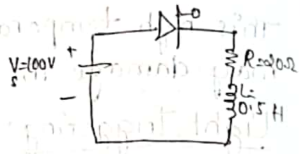
In this method a special terminal called is which is placed inside the P-layer instead of gate terminal. When light is allowed to strike on this terminals free charges carriers are generated. When the intensity of light is grater than rated value, the generated charge carriers will move freely across the three junctions. As a result current flows through the SCR and SCR gets turned ~~off~~ ON.

This method is mainly used in HVDC transmission system.

It is also called as light accurated silicon control rectifier.



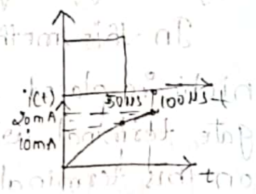
* The SCR shown in figure as the latching current of 20 milli amps and it is fired by pulse of width 50 μ sec. Determine whether the SCR is triggered (or) not.



Sol: Given that,

$I_L = 20\ mA$

width of pulse = 50 μ sec



$i(t) = \frac{V}{R}(1-e^{-t\frac{R}{L}})$ → RL

$i(t) = \frac{V}{R}e^{-t/RC}$ → RC

$i(t) \geq I_L$ ⇒ Condition to turn on SCR

At t=0

$i(t) = \frac{V}{R}(1-e^{-0\frac{R}{L}}) = 0 < I_L$ (SCR doesn't turn on)

$i(t) = \frac{100}{20}(1-e^{-50\times10^{-6}\frac{20}{0.5}})$

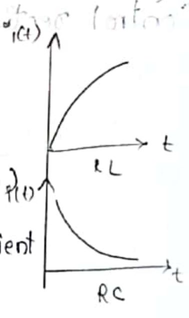
$= 5(1-e^{-50\times10^{-6}\frac{20}{0.5}}) =$

$i(t) = 9.99\ mA < I_L$ (SCR doesn't turn on)

At t = 100 μs

$i(t) = \frac{100}{20}(1-e^{-100\times10^{-6}\times\frac{20}{0.5}})$

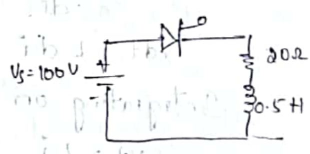
$i(t) = 20\ mA = I_L$ (SCR turns on)



50 μsec pulse width is not sufficient to turn on the SCR. It requires 100μsec width of the pulse to trigger

* SCR is connected in series with 0.5H inductor and 20Ω resistor. A 100 V dc voltage applied to the circuit, if the latching current of the SCR is 4 milli amps. Find the minimum width of the gate pulse required to turn on the SCR.

Sol: Given that;



$I_L = 4\ mA$

width of the pulse t = ?

$i(t) = \frac{V}{R}(1-e^{-t\times\frac{R}{L}})$

$i(t) \geq I_L$ ⇒ Condition to turn on SCR

w.k.t $i(t) = I_L = 4$ milli amps

$4\times10^{-3} = \frac{100}{20}(1-e^{-t\frac{20}{0.5}})$

$\Rightarrow 4\times10^{-3}\times\frac{20}{100} = 1-e^{-40t}$

$0.8\times10^{-3} = 1-e^{-40t}$

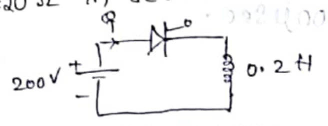
$e^{-40t} = 1-0.8\times10^{-3}$

$-40t = \ln(0.999)$

$t = 20\ \mu s$

* Latching current for the SCR is inserted between dc voltage source of 200 V and the load is 100 milli amps. Compute the minimum width of the gate pulse required to turn on the SCR in case load consist of (1) L=0.2H (2) R=20Ω in series with L=0.2 H.

Sol: (i)



$I_L = 100mA$

$i \geq I_L$

$i = I_L = 100 \, mA$

W.K.T $V = L\frac{di}{dt}$

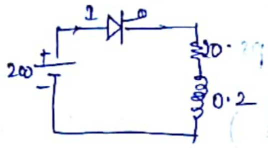
$Vdt = L\,di$

Integrating on both sides.

$Vt = Li$

$t = \frac{Li}{V} = \frac{0.2 \times 100 \times 10^{-3}}{200} = 100\mu s$

(ii)



$I_L = 100mA$

$t = ?$

$i(t) = \frac{V}{R}\left(1 - e^{-t\frac{R}{L}}\right)$

$100 \times 10^{-3} = \frac{200}{20}\left(1 - e^{-t\frac{20}{0.2}}\right)$

$10 \times 10^{-3} = 1 - e^{-t\frac{20}{0.2}}$

$e^{-t\frac{20}{0.2}} = 1 - 10 \times 10^{-3}$

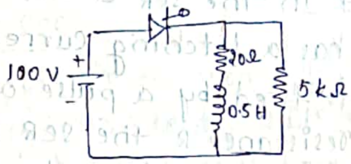
$-100t = \ln(0.99)$

$100t = 0.01$

$t = \frac{0.01}{100}$

$t = 100\mu sec.$

* An SCR having the turn on time 5μ sec, latching current of 50 milli ampere and holding current of 40 m amperes each triggered by a short duration pulse shown in the circuit below. Calculate the minimum width of the pulse required to turn on the SCR.



Sol: Given that

$T_{ON} = 5\mu s$

$I_L = 50mA$

$I_H = 40mA$

$i \geq I_L$

w.k.T $i = I_L = 50mA$

Apply KCL at node A.

$i = i_1 + i_2 \rightarrow (1)$

$i_2 = \frac{100}{5 \times 10^3}$

$i_1 = \frac{V}{R}\left(1 - e^{-t\frac{R}{L}}\right)$

$i_1 = \frac{100}{20}\left(1 - e^{-t\frac{20}{0.5}}\right)$

$= 5\left(1 - e^{-40t}\right)$

Now.

eq (1) $\Rightarrow i = i_1 + i_2$

$50 \times 10^{-3} = 5\left(1 - e^{-40t}\right) + \frac{100}{5 \times 10^3}$

$\frac{50 \times 10^{-3} - 0.02}{5} = 1 - e^{-40t}$

$6 \times 10^{-3} = 1 - e^{-40t}$

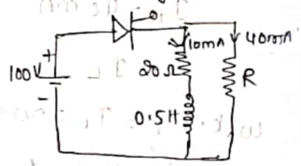
$e^{-40t} = 1 - 6 \times 10^{-3}$

$e^{-40t} = 0.994$

$-40t = \ln(0.994)$

$t = 150\,\mu sec.$

* In the SCR circuit shown in fig, the SCR has a latching current of 50 milli amps and it is fired by a pulse of $50\mu sec$. Show that without resistance 'R' the SCR will fails to remains on. When the firing edge and also find the maximum value of resistance 'R' to ensure firing.



Sol: Given that;

$I_L = 50\,mA$

$t = 50\,\mu s$

1. without 'R'

$i \geq I_L$

$i = \frac{V}{R}(1 - e^{-t\frac{R}{L}})$

$= \frac{100}{20}(1 - e^{-50\times10^{-6}\frac{20}{0.5}})$

$i = 10\,mA < I_L$ (SCR does not turn on).

2. To turn on SCR.

$i = I_L = 50\,mA$.

$V = I_2 R$

$R = \frac{V}{I_2} = \frac{100}{40\times10^{-3}} = 2.5\,k\Omega$.

Turn off methods of SCR:

Turn off methods of SCR:

SCR is triggered by applying a low voltage short duration pulse between gate and cathode. Once SCR is turn on it will remains into on state.

Conditions to turn off the SCR:

* Current flowing through the SCR (or) anode current should be less than holding current i.e $I_A < I_H$
* Reverse voltage is applied for sufficient time across the SCR to recover its blocking mode.

Commutation:

The process of bringing the SCR from forward conduction mode to forward blocking mode is called commutation i.e the process of turn off of SCR is called commutation.

There are two types of commutation.

1. Forced commutation
2. Natural commutation (or) line commutation

Forced Commutation	Natural Commutation
* The process of turn off SCR by using external circuits (or) commutation circuit is called forced commutation.	* The process of turn off SCR without using any external circuit is called natural commutation.
* Forced commutation is possible only when the supply is DC.	* Natural commutation is possible when the supply is AC.
* In case of dc circuits the current flowing through	* In case of ac circuits the current passes through

the SCR is reduced to zero (or) reduced below a holding current by using commutation circuits.	zero naturally for every half cycle. As current passes becomes zero for every half cycle, simultaneously a reverse voltage will appear across the SCR and the SCR get turned off.
* It requires commutation circuit to turn off the SCR. The commutation circuit consist of commutating elements such as inductor, capacitor, one (or) more diodes, thyristors, etc. The commutation circuit stores energy during the on period of SCR. This stored energy can be utilised to turn off the SCR.	* It does not requires any commutation circuit.
* Choppers and inverters required forced commutation to turn off the SCR and also step up cyclo-converters	* phase control rectifiers, AC voltage controllers and step down cyclo-converter requires natural commutation to turn-off the SCR

Principle of Natural Commutation:

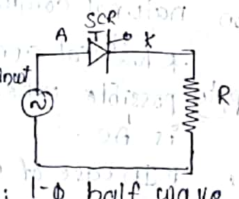
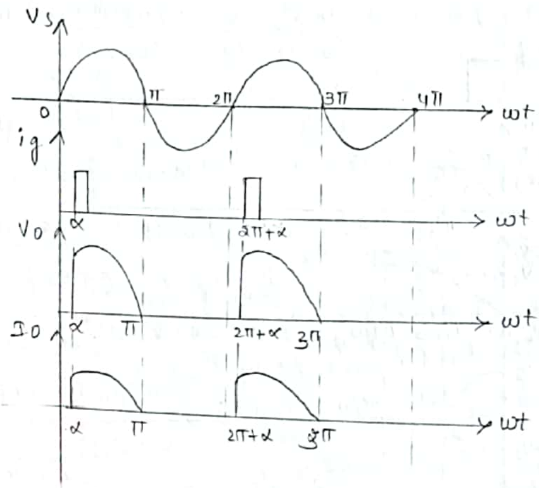


Fig 1: 1-φ half wave rectifier with R - load.



During +HC (0 - π, 2π - 3π, ...)

At $\omega t = \alpha$, SCR = ON, $V_0 = V_i$; $I_0 = \frac{V_0}{R}$

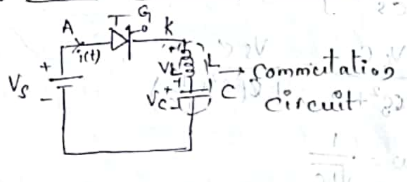
At $\omega t = \pi$, $V_g = 0$, $V_0 = 0$, $I_0 = 0$.

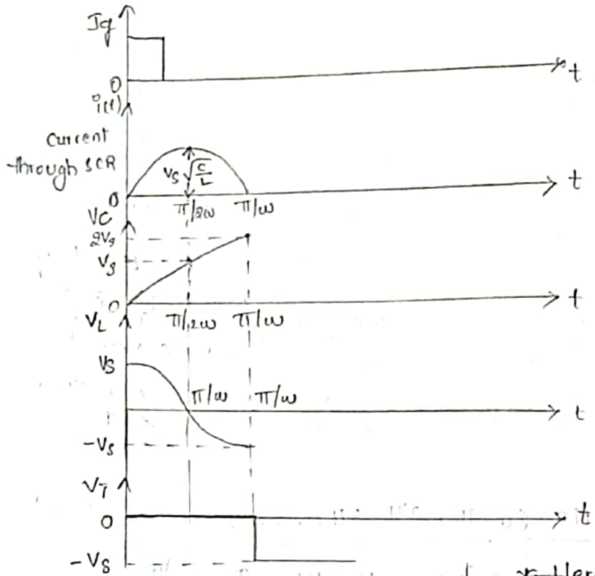
During -HC (π - 2π, 3π - 4π, ...)

SCR - off, $V_0 = 0$, $I_0 = 0$.

Here to turn off the SCR it doesn't requires any external circuit, but it uses main voltage (or) supply voltage to turn on the SCR. So it is also called as line natural commutation commutation.

Principle of forced Commutation:





Assume SCR is fired at $t=0$.

<u>Current through SCR</u>:

Apply KVL

$$V_s = L\frac{di(t)}{dt} + \frac{1}{C}\int i(t)\,dt$$

Apply L.T on Both Sides.

$$\frac{V_s}{s} = L s I(s) + \frac{1}{C}\frac{I(s)}{s}$$

$$\frac{V_s}{s} = I(s)\left[Ls + \frac{1}{Cs}\right]$$

$$\frac{V_s}{s} = \left[\frac{Ls^2C+1}{Cs}\right] I(s)$$

$$I(s) = \frac{V_s C}{LCs^2+1} = \frac{V_s C}{LC(s^2+\frac{1}{LC})}$$

let $\omega = \frac{1}{\sqrt{LC}}$

* Here to turn off the SCR forcefully it uses Commutation Circuit. Commutation circuit consists of commutating element such as inductor and capacitor. The natural characteristic of inductor & capacitor reduces the current flowing through the SCR to zero.

$$I(s) = \frac{V_s}{L(s^2+\omega^2)} = \frac{V_s}{L\omega}\cdot\frac{\omega}{(s^2+\omega^2)}$$

Apply I.L.T.

$$i(t) = \frac{V_s}{L\omega}\sin\omega t$$

$$= \frac{V_s}{L\cdot\frac{1}{\sqrt{LC}}}\sin\omega t$$

$$i(t) = V_s\sqrt{\frac{C}{L}}\sin\omega t \rightarrow (1)$$

$$i(t) = I_m \sin\omega t$$

At $t=0$, $i(t)=0$

$t=\frac{\pi}{2\omega}$, $i(t) = I_m = V_s\sqrt{\frac{C}{L}}$

$t=\frac{\pi}{\omega}$, $i(t)=0$.

from eq (1) it is observed that current flowing through the SCR goes to zero at instant $t=\pi/\omega$. This shows that at $t=\pi/\omega$ current flowing through the SCR becomes zero and SCR gets turned off.

<u>Voltage across Capacitor</u>:

$$V_c = \frac{1}{C}\int_0^t i(t)\,dt$$

$$V_c = \frac{1}{C}\int_0^t V_s\sqrt{\frac{C}{L}}\sin\omega t$$

$$V_c = \frac{1}{C}V_s\sqrt{\frac{C}{L}}\left(\frac{-\cos\omega t}{\omega}\right)_0^t$$

$$= \frac{V_s}{\sqrt{LC}\,\omega}(-\cos\omega t+1)$$

$$V_c = \frac{V_s}{\sqrt{LC}\,\frac{1}{\sqrt{LC}}}(1-\cos\omega t)$$

$$V_c = V_s(1-\cos\omega t)$$

At $t=0$, $V_C = 0$.

$t = \pi/2\omega$, $V_C = V_s$

$t = \pi/\omega$, $V_C = 2V_s$

Voltage across 'L'

$$V_L = L\frac{di(t)}{dt} = L\frac{d}{dt} V_s\sqrt{\frac{C}{L}}\sin\omega t$$

$$= L V_s\sqrt{\frac{C}{L}}\cos\omega t\,(\omega)$$

$$= V_s\sqrt{LC}\;\omega\cos\omega t$$

$$= V_s\sqrt{LC}\frac{1}{\sqrt{LC}}\cos\omega t$$

$$V_L = V_s\cos\omega t$$

At $t=0$, $V_L = V_s$

$t=\pi/2\omega$, $V_L = 0$

$t=\pi/\omega$, $V_L = -V_s$

Voltage across thyristor

During on period of SCR

$V_T = 0$

Apply KVL

$$-V_s + V_T + V_C + V_L = 0$$

$$V_T = V_s - V_C - V_L$$

$$V_T = V_s - 2V_s - 0$$

$$V_T = -V_s$$

During conduction period of SCR, voltage across thyristor is zero. During off period of SCR voltage across thyristor is $V_T = -V_s$ i.e during off period SCR is subjected to reverse voltage to recover its blocking capabilities.

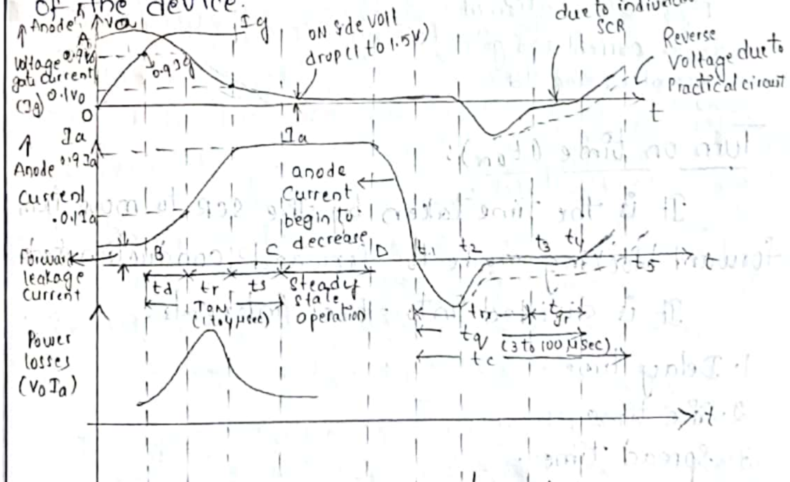
Dynamic characteristics of SCR:

IMP During on and off period of SCR, SCR is subjected to different voltage across input and different currents through it. The time variations of voltages across the SCR and current through the SCR during on & off period gives dynamic characteristics.

Dynamic characteristics also tells about switching losses and device velocity in changing from forward conduction state to forward blocking state and vice versa.

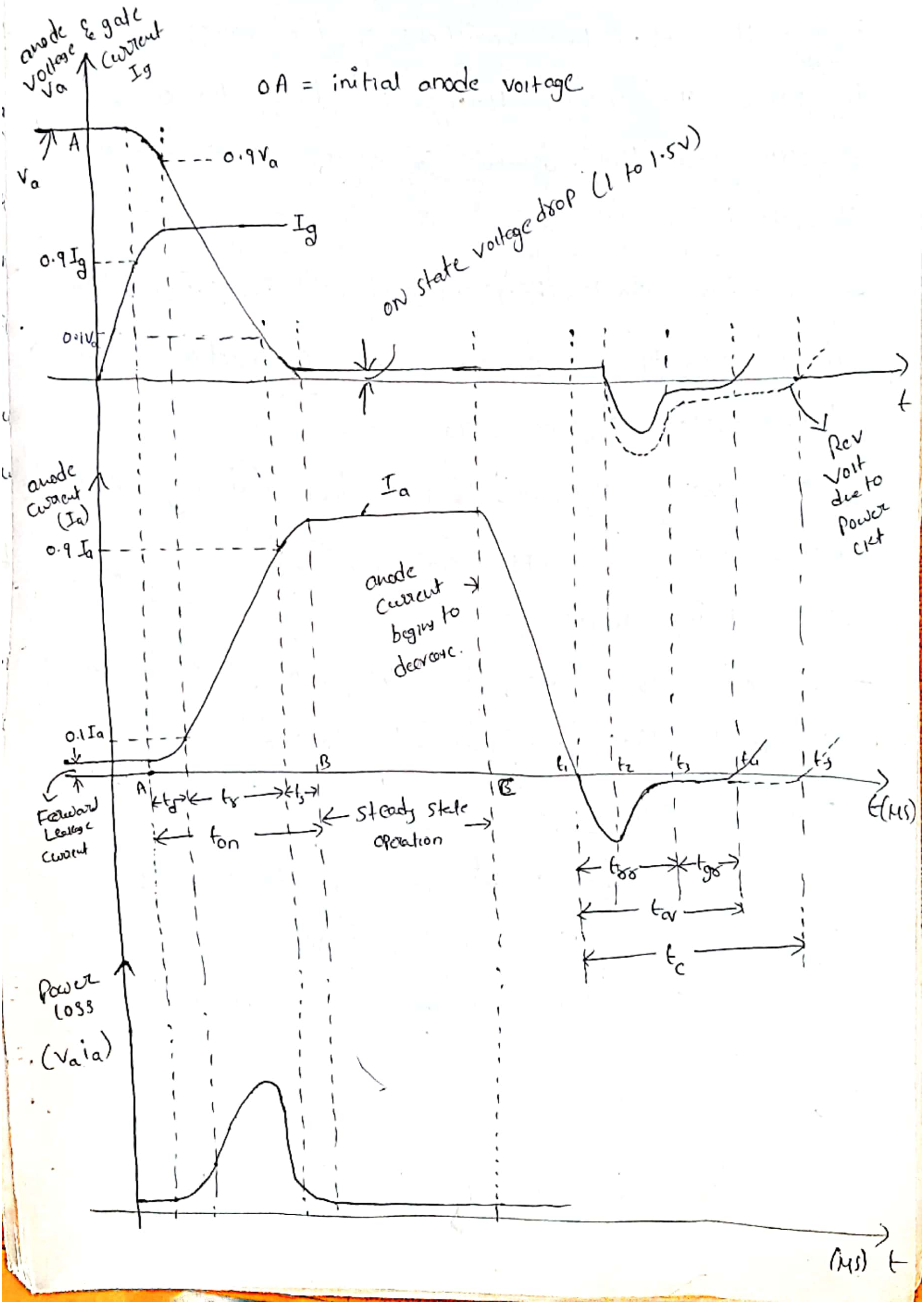
The losses that occur across the SCR during changing from forward conduction state to forward blocking state and vice versa.

Static characteristics tells about the operation of the device.



Dynamic characteristics of SCR:

Dynamic (or) Switching characteristics of SCR :-



where

OA = V_a = Initial anode voltage.

I_a = anode current.

I_g = gate current.

t_d = delay time

t_r = rise time.

t_s = Spread time

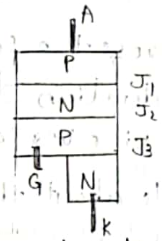
t_{rr} = reverse recovery time.

t_{gr} = Gate recovery time.

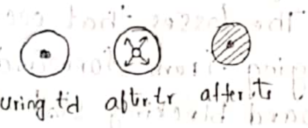
t_q = device turn off time.

t_c = circuit turn off time

T_{ON} = turn on time.



Fig(2): Distribution of anode current and gate current during td



Fig(3): Conducting area of SCR

Turn on time (t_{on}):

It is the time taken by the SCR to move from forward blocking mode to forward conduction mode.

It is divided into three intervals.

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

Delay time: It is time during which anode voltage falls from V_a to $0.9\,V_a$ (or)

It is the time during which anode current rises from forward leakage current I_a to $0.9\,I_a$.

Rise time:

It is the time during which anode voltage falls from $0.1\,V_a$ to $0.9\,V_a$.

(or)

It is time during which anode current rises from $0.1\,I_a$ to $0.9\,I_a$

The power loss (or) switching losses is more during rise time because simultaneously large anode voltage and anode current appear across the device during rise time.

Spread time:

It is the time during which the anode voltage falls from $0.9\,V_a$ to its lower value i.e. on state voltage drop (1 to 1.5V).

(or)

It is the time during which the anode current rises from $0.9\,I_a$ to its steady state value (I_a).

The sum of delay time, rise time and spread time gives turn on time.

$$T_{ON} = t_d + t_r + t_s$$

⇒ Typical value of turn on time is 1 to 4 μsec

⇒ Turn on time depends upon magnitude of gate current and load circuit parameters.

* If gate current increases voltage required to turn on SCR decreases ; As a result turn on time decreases.

* If load circuit consist of series RL, $\frac{di}{dt}$ is slow then turn on time increases.

* If load circuit consist of series RC, $\frac{di}{dt}$ is fast then turn on time decreases.

Turn off time (t_{off}):

It is the time taken by the SCR to move from forward conduction state to forward blocking state.

It is divided into two intervals.

1. Reverse recovery time.
2. Gate recovery time.

Reverse recovery time :

It is the time during which excessive charge carriers are removed from top and bottom layers of SCR.

Gate recovery time :

It is the time during which excessive charge carriers are removed from two inner layers ~~of SCR (or) across junction J_2~~ across junction J_2.

Device turn off time :

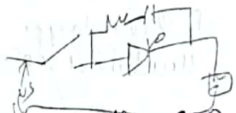
It is the time between the instant at which anode current falls to zero (t_1) and the instant at which reverse voltage due to individual SCR reaches to zero (t_4).

(or)

The turn off time provided to individual SCR is called device turn off time.

Circuit turn off time :

It is time between the instant at which anode current falls to zero (t_1) and the instant at which reverse voltage due to practical circuit (t_5) reaches to zero.



(or)

~~It is~~ The turn off time provided to the SCR by practical circuit is called circuit turn off time.

The typical value of turn off time is 3 to 100 μsec.

For reliable operation of SCR circuit turn off time be always grater than device turn off time.

Converter grade SCR	Inverter grade SCR.
* Converter grade SCR's have slow turn off time (50 to 100 μs)	* Inverter grade SCR's have fast turn off time (3 to 50 μs)
* They are cheaper	* They are costlier.
* Converter grade SCR's are used where slow turn off time is possible such as phase control rectifiers and AC voltage controller.	* Inverter grade SCR's are used where fast turn off time is possible such as choppers and inverters.

Series and parallel operation of SCR's:

Nowadays the available voltage and current ratings of SCR are 10 KV and 3 KA. But sometimes we face more demand than these ratings. In order to meet high voltage (or) current demand, two (or) more SCR should be connected in series (or) parallel.

Series connection of SCR needs high voltage demand where as parallel connection of SCR needs high current demand.

String efficiency:

It is a measure of utilisation of SCR rating. It is given by

$$\eta = \frac{\text{Actual voltage/current rating of whole string}}{\text{Individual V/I rating of SCR} \times n}$$

where n = no. of series (or) parallel connected in SCR in a string.

Ideally string efficiency is 1 (100%) i.e all the SCR's in a string utilises their rating fully (or) completly.

But practically string efficiency is always less than 1 (less than 100%) because SCR's connected in a string doesn't share equal voltage due to having difference in their V-I characteristics even though SCR's have same rating.

Derating factor (D):

It is a measure of reliability of the string. It is given by

$$D = 1 - \eta$$

If number of SCR's in a string increases, the voltage (or) current shared by SCR decreases (burdon on each SCR decreases). This will increases the reliability of the string but reduces the utilisation of SCR rating. So string efficiency decreases i.e if reliability of the string increases string efficiency get decreases and vice versa.

Series connection of SCR's:

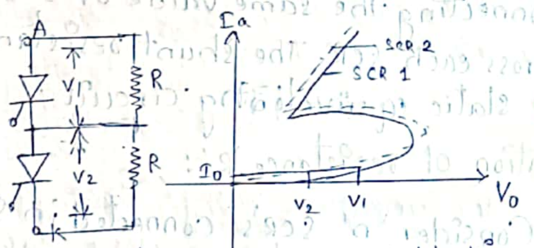


fig ①: Series connection of SCR's   fig ②: forward blocking characteristics

When system voltage is grater than voltage rating of single SCR. In such a case two (or) more SCR's should be connected in series in order to meet high voltage demand.

Consider two SCR's connected in series. shown in fig ①. Let the voltage rating of each SCR is V_1.

From fig ② It is observed that due to having difference in their forward blocking characteristics, for the same leakaging currents, SCR 1 blocks more voltage V_1 and SCR 2 blocks voltage V_2 $(V_2 < V_1)$ that is unequal voltage sharing takes place in the series connected SCR. Thus string efficiency is less than 1.

$$\therefore \eta = \frac{V_1 + V_2}{2V_1} = \frac{1}{2}\left[1 + \frac{V_2}{V_1}\right] < 1$$

The internal region for sharing unequal voltage in the series connected SCR's is due to having differences in their internal resistance.

The unequal voltage sharing can be avoided by connecting the same value of shunt resistance 'R' across each SCR. The shunt resistance is called static equivalizing circuit.

Derivation of resistance 'R':

Consider 'n' SCR's connected in series shown in fig 3. Let SCR 1 has minimum leakaging current and remaining n-1 SCR's has maximum leakaging current. As SCR 1 has minimum leakaging current, it blocks maximum voltage (V_{bm}) which is grater than voltage blocked by remaining n-1 SCR's.

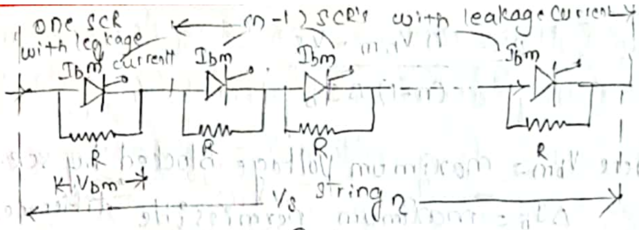


fig ③

Voltage across SCR-1 $V_{bm} = I_1 R$

Voltage across (n-1) SCR-2 $= (n-1) I_2 R$

From fig: $I = I_{bmin} + I_1 \rightarrow ①$

$I = I_{bmax} + I_2 \rightarrow ②$

Now take string voltage.

$$V_s = I_1 R + (n-1) I_2 R$$

$$= I_1 R + (n-1)(I - I_{bmax}) R$$

$$V_s = I_1 R + (n-1)(I_{bmin} + I_1 - I_{bmax}) R$$

$$= I_1 R + (n-1)(I_1 - (I_{bmax} - I_{bmin})) R$$

$$V_s = I_1 R + (n-1)[I_1 - \Delta I_b] R$$

where $\Delta I_b = I_{bmax} - I_{bmin}$

$$V_s = I_1 R + (n-1) I_1 R - (n-1) \Delta I_b R$$

$$= (1 + n - 1) I_1 R - (n-1) \Delta I_b R$$

$$V_s = n I_1 R - (n-1) \Delta I_b R$$

$$(n-1) \Delta I_b R = n I_1 R - V_s$$

$$R = \frac{n I_1 R - V_s}{(n-1) \Delta I_b}$$

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

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

where V_{bm} = maximum Voltage blocked by SCR.
ΔI_b = maximum permissible difference in the leakage currents.

Once resistance is known the power loss is given by

$V_r - V_m$ = Rms voltage

②

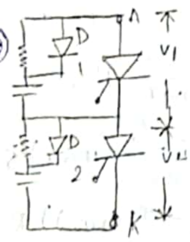


Fig: 1: Series connection of SCR's

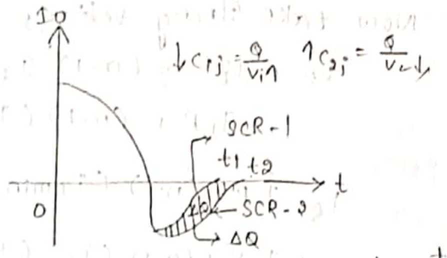


fig 2: Reverse recovery characteristics of SCR's

The unequal voltage sharing due to having difference in the reverse recovery characteristics of series connected SCR's.

From fig ② it is observed that SCR-1 has less reverse recovery time (t_1) and SCR-2 has more reverse recovery time (t_2). As SCR-1 has less reverse recovery time, it blocks maximum voltage and SCR 2 blocks voltage which is less than voltage blocked by SCR 1. i.e unequal voltage sharing takes place in the series connected SCR's due to having difference in the reverse recovery characteristics. Thus string efficiency is less than 1.

$$\eta = \frac{V_1 + V_2}{2V_1} = \frac{1}{2}\left(1 + \frac{V_2}{V_1}\right) < 1.$$

The internal region for sharing unequal voltage in the series connected SCR's is due to having difference in their junction capacitances.

The unequal voltage sharing in the series connected SCR can be avoided by connecting capacitor across each ~~resistor~~ SCR.

During forward blocking mode i.e before the SCR is turned on, capacitor charges to its full voltage. When SCR's is turned on, capacitor discharges through SCR. This discharging current is very high as local resistance path is very low. To limit this high discharging current resistance Rc is connected in series with capacitor.

The Diode 'D' make fast charging of capacitor.

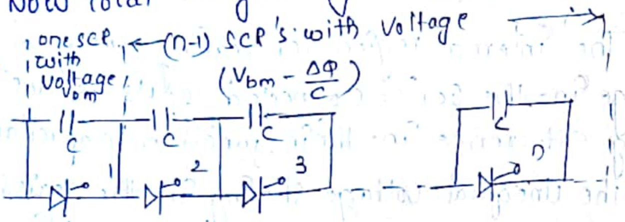
4* Derivation of Capacitance 'c':

Consider 'n' SCR's connected in series shown in fig 3. Let SCR-1 has low junction capacitance, and remaining n-1 SCR's has high junction capacitance. As SCR-1 has low junction capacitance ($\downarrow C_{1j} = \frac{Q_1}{V_1\uparrow}$), it blocks maximum voltage V_{bm} and remaining (n-1) SCR's blocks less voltage ($\uparrow C_{2j} = \frac{Q_2}{V_2\downarrow}$) while i.e $V_{bm} = \frac{\Delta Q}{c}$

i.e voltage across SCR-1 is V_{bm}

Voltage across SCR-2 is $(n-1)\left(V_{bm} - \frac{\Delta Q}{C}\right)$

Now total string voltage is given by.



$$V_s = V_{bm} + (n-1)\left(V_{bm} - \frac{\Delta Q}{C}\right)$$

$$= V_{bm} + (n-1)V_{bm} - (n-1)\frac{\Delta Q}{C}$$

$$= V_{bm}(1+n-1) - (n-1)\frac{\Delta Q}{C}$$

$$V_s = nV_{bm} - (n-1)\frac{\Delta Q}{C}$$

$$(n-1)\frac{\Delta Q}{C} = nV_{bm} - V_s$$

$$C = \frac{(n-1)\Delta Q}{nV_{bm} - V_s}$$

where

ΔQ = maximum permissible difference in the reverse recovery charges of SCR.

* Calculate number of SCRs each with a rating of 400V, 50A in series string with a total voltage of 6kV. Take the derating factor as 15%.

Sol: Given that;

let

V_T = thyristor rating voltage

V_s = Total string voltage

I_T = Thyristor current

I_s = total string current

$V_T = 400V$; $I_T = 50A$

$V_s = 6kV$; $D = 15\%$

we know that,

$$\eta = \frac{V_s}{V_T \times n}$$

and derating factor $D = 1 - \eta$

$$= 1 - \frac{V_s}{V_T \times n}$$

$$0.15 = 1 - \frac{6\times10^3}{400\times n}$$

$$\frac{6\times10^3}{400\times n} = 1 - 0.15$$

$$6\times10^3 = 0.85\times400n$$

$$n_s = \frac{6\times10^3}{0.85\times400}$$

$$n_s = 17.64 \approx 18$$

* SCR's with rating of 1200V and 250A are used in the string to handle 5kV and 2kA. Calculate the number of series and parallel SCRs required in case derating factor (i) 0.2 (ii) 0.4.

Sol: Given that;

$V_T = 1200\,V$ $I_T = 250\,A$

$V_S = 5\,kV$ $I_S = 2\,kA$

(i) when $D = 0.2$:

We know that $\eta = \frac{V_S}{V_T \times n}$

$D = 1 - \eta$

$0.2 = 1 - \frac{5\times10^3}{1200\times n}$

$n = \frac{5\times10^3}{1200\times0.8}$

$n_s = 5.2 \simeq 6 \rightarrow$ Series.

$\eta = \frac{I_S}{I_T \times n} \rightarrow$ Parallel

WKT $D = 1 - \eta$

$= 1 - \frac{I_S}{I_T \times n}$

$0.2 = 1 - \frac{2\times10^3}{250\times n}$

$n_p = 10$.

(ii) when $D = 0.4$

$D = 1 - \eta$

$= 1 - \frac{V_S}{V_T \times n}$

$0.4 = 1 - \frac{5\times10^3}{1200\times n}$

$n = \frac{5\times10^3}{1200\times0.6}$

$n_s = 6.94 \simeq 7$

$\eta_p = \frac{I_S}{I_T \times n}$ WKT $D = 1 - \eta$

$= 1 - \frac{I_S}{I_T \times n}$

$\Rightarrow 0.4 = 1 - \frac{2\times10^3}{250\times n}$

$n_p = \frac{2\times10^3}{250\times0.6} = 13.33 \simeq 14$.

* In a power circuit of 3kV, 4 thyristors each of rating 800V are connected in series. What is the percentage series derating factor.

Sol: Given that;

$V_S = 3\,kV$, $n = 4$, $V_T = 800\,V$

we know that

$D_s = 1 - \eta$

$= 1 - \frac{V_S}{V_T \times n}$

$D = 1 - \frac{3\times10^3}{800\times4} = 0.0625$

$D = 6.25\%$.

* The anode current ~~to a~~ through a conducting SCR is 10A. If its gate current is made by 1/4 then what will be the anode current.

Sol: Given that;

I_a is 10A

Ia is 10A since SCR is turned on by applying gate pulse between gate and cathode. Once SCR is turned on, gate looses its control. Therefore gate has no effect on anode current.

* How many SCR's are connected to its series string to withstand the DC voltage of 3500V in steady state, if SCR's have steady state value rating of 1000V and steady state derating factor of 30%. assuming maximum difference in leakage current of SCR be 100mA. Calculate the value of voltage sharing resistance to be used.

Sol: Given that;

$V_s = 3500\,V$

$V_T = 1000\,V = V_{bm}$

$D = 30\%$

$\Delta I_b = 100\,mA$

w.k.T

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

w.k.T $D = 1 - \eta$

$$D = 1 - \frac{V_s}{V_T \times n}$$

$$0.3 = 1 - \frac{3500}{1000 \times n}$$

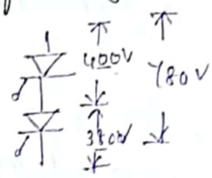
$n_s = 5$

V_{bm} = maximum voltage blocked by SCR = V_T = 1000V

$$R = \frac{(5)(1000) - 3500}{(5-1)\,100 \times 10^{-3}}$$

$R = 3.95\,k\Omega$.

* Two SCR's have a difference of 2mA in current are connected in a series in a circuit. Voltage across the devices are 400V and 380V. Calculate the required equilizing resistance and also design a suitable circuit for thyristor if the permissible difference in the blocking voltage is 20V and difference in recovery charge is 33 μ coloumb.



Sol: Given that;

$\Delta I_b = 2\,mA$

$\Delta E = 20\,V$

$\Delta Q = 33\,\mu C$, $n = 2$.

w.k.T

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

$$R = \frac{2 \times 400 - 780}{(2-1)\,2 \times 10^{-3}} = 10\,k\Omega$$

w.k.T

$$C = \frac{(n-1)\,\Delta Q}{nV_{bm} - V_s} = \frac{(2-1)(33 \times 10^{-6})}{2 \times 400 - 780} = 1.65\,\mu F.$$

* A 3-ϕ converter is used for HVDC Transmission System and it is operated from 3-ϕ 25 kV supply. The thyristor each of 1600 V, 16A are available. The leakage current difference of device is 35mA. A

String efficiency is assumed as 80% and $\Delta Q = 25\mu C$. Determine no. of devices connected in series.
(ii) Equilizing components.

Sol: Given that;

$V_{rms} = 25KV$, $V_T = 1600V$, $I_T = 16A$; $\Delta I_b = 35mA$

$V_s = V_m = \sqrt{2} \times V_{rms} = \sqrt{2} \times 25 = 35.35 \text{ KV}$.

(i) w.k.T

$$\text{String } \eta = \frac{V_s}{V_T \times n}$$

$$n = \frac{V_s}{V_T \times \eta} = \frac{35.35}{1600 \times 0.80}$$

$$n = 27.6 \approx$$

$$n \simeq 28.$$

(ii) $$R = \frac{nV_{bm} - V_s}{(n-1)\Delta I_b} = \frac{28 \times 1600 - 35.35 \times 10^3}{(28-1)(35 \times 10^{-3})}$$

$$R = 10 \text{ K}\Omega.$$

$$C = \frac{(n-1)\Delta Q}{nV_{bm} - V_s} = \frac{(28-1)25 \times 10^{-6}}{28 \times 1600 - 35.35 \times 10^3}$$

$$C = 71.42 \text{ nF}.$$

* No. of thyristors each with a rating of 500V, 75A required in each branch of series parallel combination for a circuit with total voltage and total current ratings of 7.5 KV and 1KA. If the device derating factor is 14%. Then what is the number of thyristors in series and parallel branch respectively. $n_s = 18$ $n_p = 16$

Sol: Given that;

$V_T = 500V$ $V_s = 7.5KV$

$I_T = 75A$ $I_s = 1KA$.

$D = 14\%$.

$$\eta = \frac{V_s}{V_T \times n}$$

$$D = 1 - \eta$$

$$0.14 = 1 - \frac{V_s}{V_T \times n}$$

$$0.14 = 1 - \frac{7.5 \times 10^3}{500 \times n}$$

$$\frac{75 \times 10^3}{500 \times n} = 0.86$$

$$n = \frac{75 \times 10^3}{500 \times 0.86}$$

$$n_s = 174.4 \simeq 175$$

$$D = 1 - \eta$$

$$0.14 = 1 - \frac{I_s}{I_T \times n}$$

$$0.14 = 1 - \frac{1 \times 10^3}{75 \times n_p}$$

$$\frac{1 \times 10^3}{75 \times n_p} = 1 - 0.14$$

$$n_p = 16.$$

Problems arising in series connection of SCR (2M):

* Unequal voltage sharing in series connected SCR's due to having difference in the forward blocking characteristics.
* Unequal voltage sharing in series connected SCR's due to having difference in the reverse recovery characteristics.

Parallel connection of SCR's:

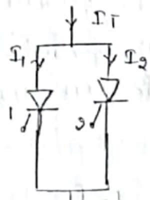


Fig 1: parallel SCR's

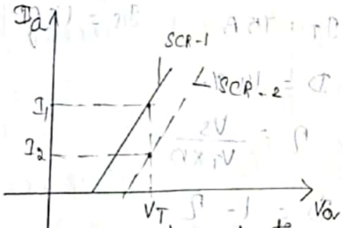


Fig 2: Forward conduction chart

When current required by the load is greater than the current rating of single SCR. In such a case two (or) more SCR's connected in parallel in order to meet high current gain.

(2M) Problems arising in parallel connection of SCR's:

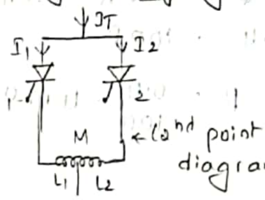
* Unequal current sharing in the parallel connected SCR's due to having difference in their forward conduction characteristics.
* From fig 2. it is observed that due to having difference in the forward conduction characteristics for the same voltage drops V_T SCR1 shares the current I_1 and SCR 2 shares the current I_2 which is less than I_1 that is unequal current sharing takes place in the parallel connected SCR's. Thus string efficiency is less than 1. $\eta = \frac{I_1+I_2}{2I_1}$ & $\eta = \frac{1}{2}(1+\frac{I_2}{I_1}) < 1$.
* The internal region for sharing unequal current in the parallel connected SCR is due to having difference in their junction temperature.
* To avoid unequal current sharing in the parallel connected SCR, all the SCR's in a string should operate at same junction temperature. This can be achieved by using following three methods.

Methods to ensure proper current sharing in the SCR's:

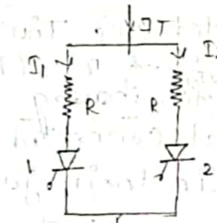
* The unequal current sharing can be avoided by mounting all SCR's on a common heat sink symmetrically.

Fig: unsymmetrical configuration

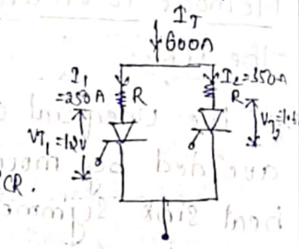
Fig: symmetrical configuration.



* The unequal current sharing can be avoided by connecting reactance.
* The unequal current sharing can be avoided by connecting resistor in series with SCR. Here the resistor 'R' tries to share equal currents in the parallel connected SCR.



* It is required to operate 250 A SCR in parallel with 350 A SCR with their respective on stage voltages SCR's are 1.6 & 1.2 V. Calculate the value of resistance to be inserted to be in series with each SCR. If the two SCR's shared the total current of 600A in proportion to their current rating.



Sol: Given that:

Let R = resistance connected in series with each SCR.

$$V_{T_1} + I_1 R = V_{T_2} + I_2 R.$$

$$1.6 + (250) R = 1.2 + (350) R.$$

$$1.6 - 1.2 = 350 R - 250 R.$$

$$0.4 = 100 R$$

$$R = \frac{0.4}{100} = 4\, m\Omega.$$

Firing circuits:

Firing circuits generates gating signals (or) gate pulses to the SCR. There are three firing circuits to generate gate pulses to the SCR.

1. R - firing circuit.
2. RC firing circuit.
3. UJT firing circuit.

R - firing circuit:

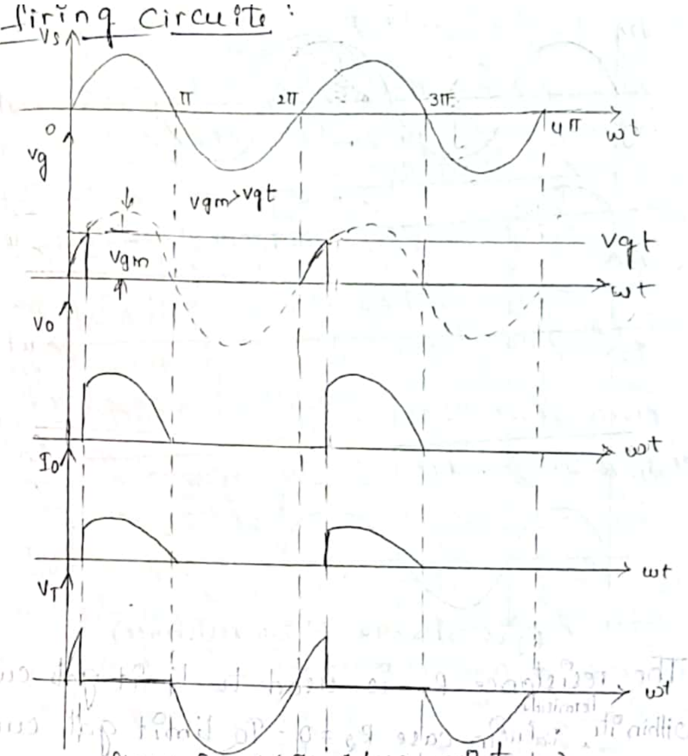


fig1: For α < 90° (low resistance)

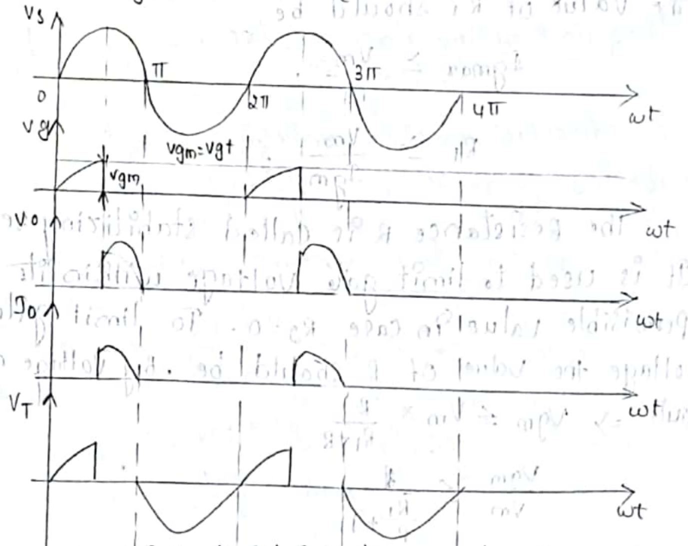


fig 2: For α = 90° (medium resistance)

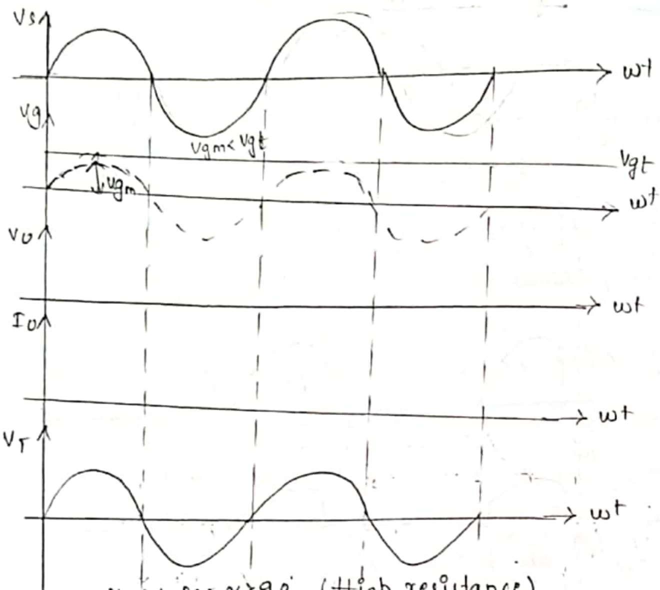


Fig 3: For $\alpha > 90°$ (High resistance)

The resistance R_1 is used to limit gate current within its permissible value in case $R_2 = 0$. To limit gate current the value of R_1 should be

$$I_{gmax} \geq \frac{V_m}{R_1}$$

$$R_1 \geq \frac{V_m}{I_{gm}}$$

The Resistance R is called stabilizing resistance. It is used to limit gate voltage within its permissible value in case $R_2 = 0$. To limit gate voltage the value of R should be. By voltage division rule $\Rightarrow V_{gm} \leq V_m \times \frac{R}{R_1+R}$

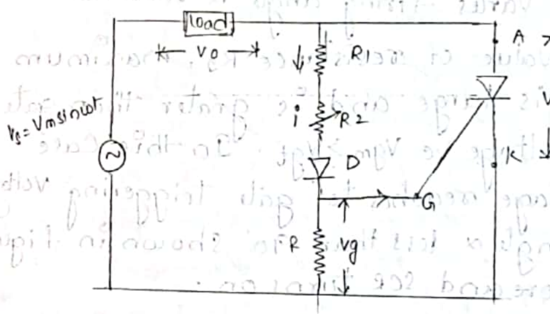
$$\frac{V_{gm}}{V_m} \leq \frac{1}{\frac{R_1}{R}+1}$$

$$\frac{R_1}{R}+1 \leq \frac{V_m}{V_{gm}}$$

$$\frac{R_1}{R} \leq \frac{V_m}{V_{gm}} - 1 = \frac{V_m - V_{gm}}{V_{gm}}$$

$$R \leq \frac{V_{gm} R_1}{V_m - V_{gm}}$$

The diode 'D' blocks gate current during negative half cycle and allows the current during positive half cycle.



let V_{gm} = maximum gate voltage (or) peak gate voltage.

V_{gt} = Triggering Voltage (or) turn on Voltage (or) fingering Voltage.

V_{gm} and V_{gt} can be expressed as

$$V_g = V_{gt}$$

$$V_{gm} \sin \omega t = V_{gt}$$

$$V_{gt} = V_{gm} \sin \alpha$$

$$\frac{V_{gt}}{V_{gm}} = \sin \alpha$$

$$\alpha = \sin^{-1}\left(\frac{V_{gt}}{V_{gm}}\right)$$

$$V_{gm} = V_m \times \frac{R}{R_1 + R_2 + R}$$

Now
$$\alpha = \sin^{-1}\left(\frac{V_{gt}(R_1 + R_2 + R)}{V_m R}\right)$$

At R_1, R_2, V_{gt}, V_m are constant.

$$\alpha = \sin^{-1} R_2$$
$$\alpha \propto R_2$$

From above equation it is observed that if resistance R_2 varies firing angle α also varies.

For low value of resistance R_2, maximum gate voltage is large and is grater than gate triggering voltage i.e $V_{gm} > V_{gt}$. In this case the gate voltage reaches to gate triggering voltage at firing angle α less than 90° shown in figure 2.1. ~~therefore~~ and SCR turns on.

$\therefore V_0 = V_s$; $I_0 = \frac{V_0}{R}$; $V_T = 0$

As resistance R_2 increases, maximum gate voltage decreases and becomes equals to gate triggering voltage i.e

$$V_{gm} = V_{gt}$$

In this case gate voltage ~~equa~~ reaches to gate triggering voltage at firing angle $\alpha = 90°$ shown in figure 2-2 and SCR turns on.

$\therefore V_0 = V_s$, $I_0 = \frac{V_0}{R}$, $V_T = 0$

As resistance R_2 further increased to a large value, maximum gate voltage further decreases and becomes less than gate triggering voltages. i.e $V_{gm} < V_{gt}$.

In this case gate voltage never reaches to gate triggering voltage. Shown in figure 2-3. and SCR doesn't turns on

$\therefore V_0 = 0$, $I_0 = 0$, $V_T = V_s$.

(2m)

Limitations of R-firing circuit:

In R-firing circuit the range of firing angle is $0 < \alpha < 90°$ i.e firing angle never becomes more than 90° because for $\alpha > 90°$, maximum gate voltage is less than the gate triggering voltage ($V_{gm} < V_{gt}$). In this case gate voltage never reaches to gate triggering voltage and SCR doesn't turns on.

RC firing Ciricuit:

1. RC half wave firing circuit:

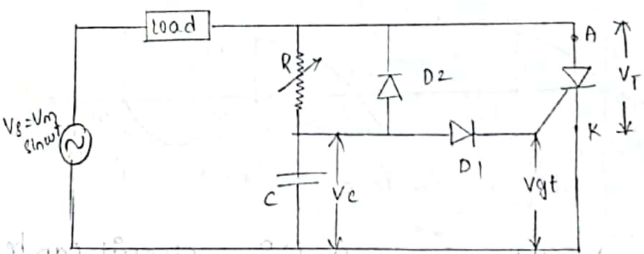


Fig: RC half wave firing circuit

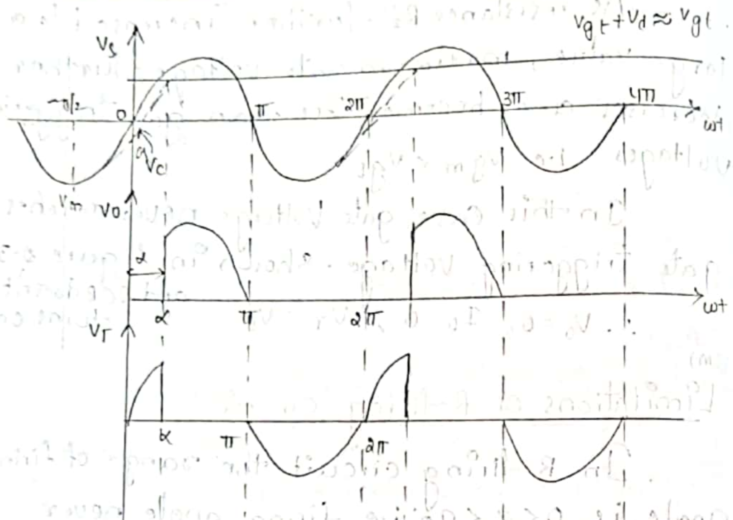


Fig: 2(i) For low resistance

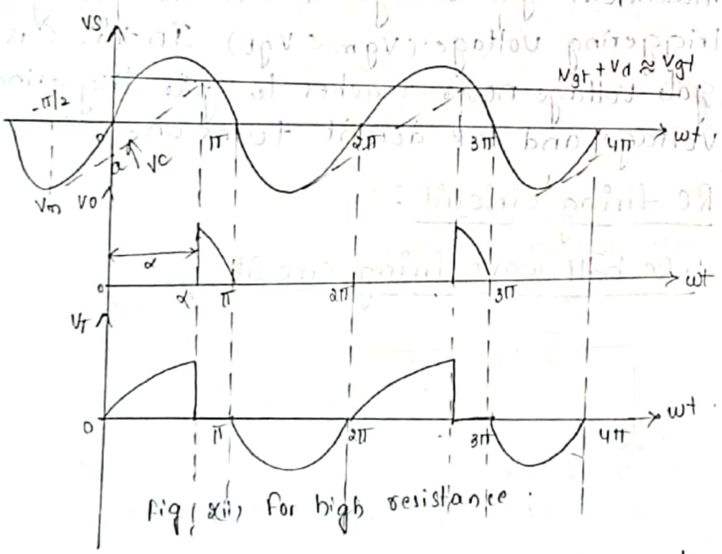


Fig: 2(ii) For high resistance

The limited range of R-firing circuit can be can overcomed by using RC-firing circuit. RC firing circuit uses RC network in order to increase the range of firing angle.

In RC firing circuit firing angle can be controlled from 0-180° by varying the resistance Rg.

For low resistance R current drawn from the supply is high. As current drawn from the supply is high, capacitor charges very quickly and reaches to gate triggering voltage shown in figure 2-(i). As a result α is low and average output voltage is high.

For high resistance R current drawn from the supply is low. As current drawn from the supply is low, capacitor charges takes more time to reach the gate triggering voltage as shown in figure 2(ii). As a result α is high and average output voltage is low.

SCR is triggered when $V_c = V_{gt}$ i.e at $V_c = V_{gt}$ condition, minimum gate current required to turn on the SCR is flowing through the SCR gate terminal.

Let I_{gt} = minimum current flowing through gate terminal of SCR. and this current is supplied from source through load, resistance R, diode D, and gate to cathode.

Therefore the maximum value of R should be

$$V_s \geq I_{gt} R + V_c$$

$$V_s \geq I_{gt} R + V_{gt} + V_d$$

$$\frac{V_s - V_{gt} - V_d}{I_{gt}} \geq R$$

$$R \leq \frac{V_s - V_{gt} - V_d}{I_{gt}}.$$

In RC firing circuit, firing angle never becomes zero and never becomes 180°. Because in RC firing circuit α_1 is the minimum firing angle and α_2 is the maximum firing angle required to turn on the SCR. Before α_1 and after α_2 capacitor voltage never reaches to gate triggering voltage since $V_c < V_{gt}$.

For zero average output voltage the empherical formula is for the value RC is given by

$$RC = \frac{1.3T}{2} \approx \frac{4}{\omega}$$

RC full wave firing circuit:

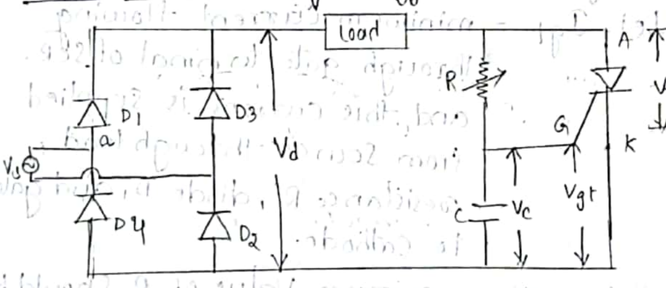


Fig (i) RC full wave firing circuit

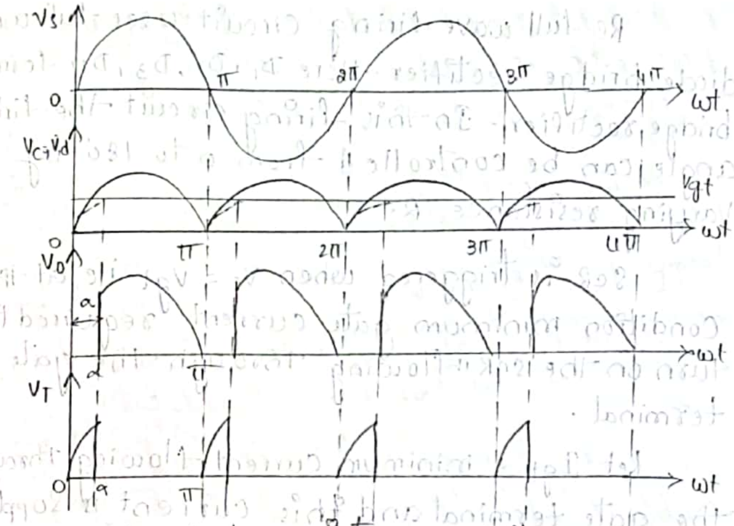


Fig: 2(i) low resistance (α=90°)

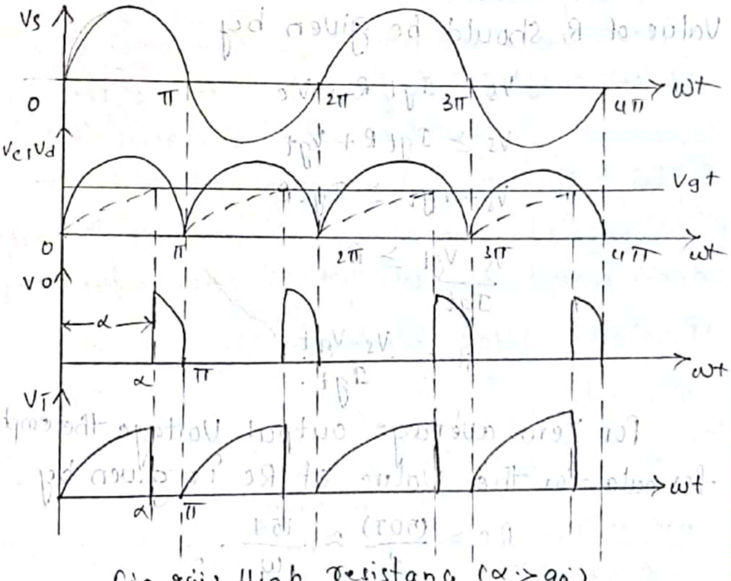


Fig 2(ii) High resistance (α>90°)

Rc full wave firing circuit uses full wave diode bridge rectifier. Here D_1, D_2, D_3, D_4 forms bridge rectifier. In this firing circuit the firing angle can be controlled from 0 to 180 by varying resistance R.

SCR is triggered when $V_c = V_{gt}$ i.e at this condition minimum gate current required to turn on the SCR is flowing through the gate terminal.

Let I_{gt} = minimum current flowing through the gate terminal and this current is supplied from source through load, resistance R and gate to cathode circuit. To turn on the SCR maximum value of R should be given by

$$V_s \geq I_{gt} R + V_c$$

$$V_s \geq I_{gt} R + V_{gt}$$

$$V_s - V_{gt} \geq I_{gt} R$$

$$\frac{V_s - V_{gt}}{I_{gt}} \geq R$$

$$R = \frac{V_s - V_{gt}}{I_{gt}}$$

For zero average output voltage the emperical formula for the value of Rc is given by

$$R_C = \frac{(50T)}{2} \approx \frac{157}{\omega}$$

UJT triggering:

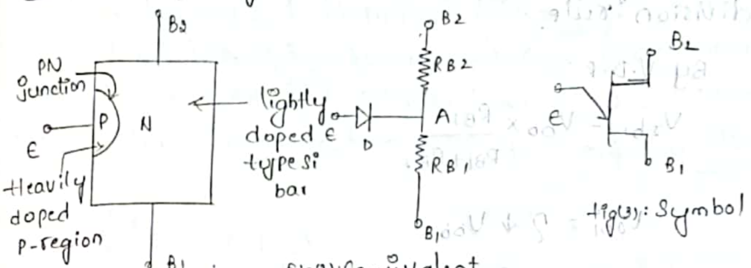
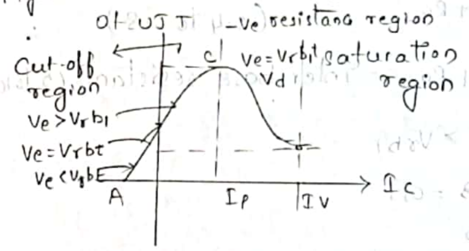


Fig (1): Basic structure of UJT

Fig (2): Equivalent circuit of UJT

Fig (3): Symbol



UJT is a two layer 3 terminal power semiconductor switching device. It is also called as double base diode.

The diode in the equivalent circuit of UJT represents PN junction is formed between heavily doped p region and lightly doped N-type silicon bar.

Point A represents at this point P region is formed.

Operation of UJT:

UJT can be operated when base B_2 is +ve with respect to B_1 by voltage source V_{BB} and emitter terminal is made positive w.r.to B_1 by voltage source V_e.

Initially imagine emitter voltage V_e is zero and

The voltage across resistor R_{B1} is given by Voltage division rule.

By V.D.R

$$V_{rb1} = V_{bb} \times \frac{R_{B1}}{R_{B1}+R_{B2}}$$

$$V_{rb1} = \eta \downarrow V_{bb}$$

where $\eta = \frac{R_{B1}}{R_{B1}+R_{B2}}$ = Intrinsic stand off ratio (0.4 to 0.8)

$R_{BB} = R_{B1} + R_{B2}$ = inter base resistance (5 to 10kΩ)

Case (i): when $V_e > V_{rb1}$

D = R.B = off

$I_e = 0$

UJT = doesn't on.

But due to minority charge carriers a reverse current flows through emitter circuit shown in fig (iv)

Case (ii):

As V_e increases at one instant, $V_e = V_{rb1}$

when $V_e = V_{rb1}$

$I_e = 0$

D = R.B = off

UJT = doesn't turn on.

Case (iii):

As V_e further increased, V_e becomes grater than V_{rb1}

when $V_e > V_{rb1}$

D = F.B = ON

Emitter current I_e flows through emitter circuit but this emitter current is not sufficient to turn on UJT due to having voltage drop across diode V_d. a sufficient emitter current can flow through the emitter circuit when V_e exceeds V_{rb1} by voltage V_d.

i.e $V_e = V_{rb1} + V_d$

and UJT gets turned on.

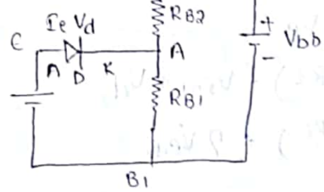
At point c, UJT turns ON and emitter terminal injects holes in to the N-layer from P layer. The injected holes are repelled by base B_2 and attracted by base B_1. As a result the region between emitter and B_1 is filled up with additional charge carriers and conductivity of the reason increases i.e

$$I_e \uparrow \rightarrow R_{B1} \downarrow \rightarrow \eta \downarrow \rightarrow V_{rb} \downarrow \rightarrow V_e \downarrow$$

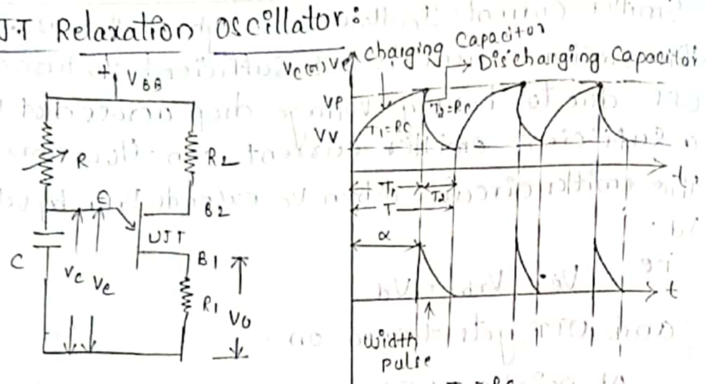
and falls to valley point D beyond the valley point no more increase in conductivity is possible and UJT has saturated PN-junction.

As emitter voltage I_e increases emitter voltage V_e decreases. This shows that UJT has -ve resistance characteristics.

Due to having -ve resistance characteristics UJT is popularly used in relaxation oscillators.



UJT Relaxation oscillator:



$T_1 = RC$

$T_2 = R_1C$

Relaxation oscillator is a non electronic circuit that produces non sinusoidal output signals, the output signals may be saw tooth, square (or) rectangle.

The resistance R_1 and R_2 are the current limiting resistors which are small compared to internal resistance of UJT.

The variable resistor R and capacitor 'c' determines the frequency of oscillations.

The capacitor 'c' charging and discharging between peak point voltage (V_p) and valley point V_v continously as long as supply voltage is present.

From fig:

$T = T_1 + T_2$

$T_2 << T_1 \quad T = T_1$

At $t = T = T_1$

$V_c = V_p$

$V_{BB}(1 - e^{-T/RC}) = V_{rb1} + V_d$

$V_{BB}(1 - e^{-T/RC}) = \eta V_{BB}$

$1 - e^{-T/RC} = \eta$

$-e^{-T/RC} = \eta - 1$

$e^{-T/RC} = 1 - \eta$

$e^{T/RC} = \frac{1}{1-\eta}$

$\frac{T}{RC} = \ln\left(\frac{1}{1-\eta}\right)$

$T = RC \ln\left(\frac{1}{1-\eta}\right)$

$f = \frac{1}{RC \ln\left(\frac{1}{1-\eta}\right)}$

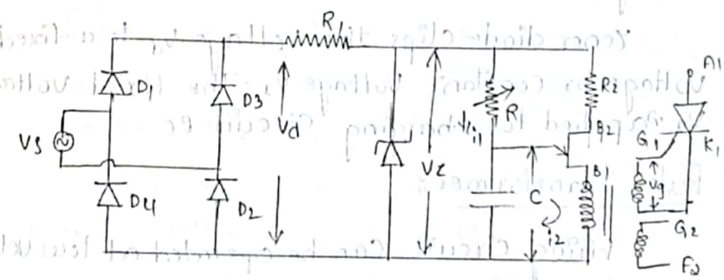
↓

Frequency of oscillations.

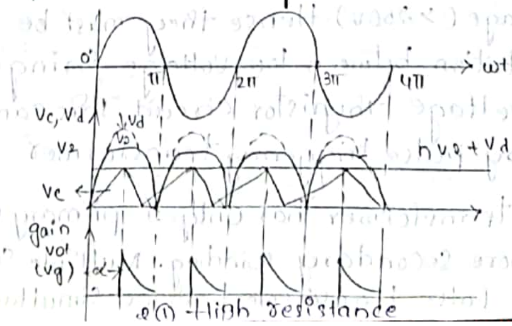
If $R \to R_{min}$, $f \to f_{max}$

$R \to R_{max}$, $f \to f_{min}$

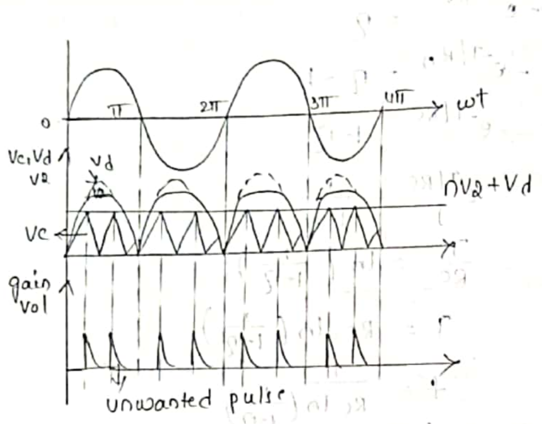
Synchronized UJT triggering:



(i) UJT firing circuit



e (ii) High resistance



& (ii) low resistance.

UJT firing circuit uses diode bridge rectifier which converts fixed Ac into pulse setting dc(V_4)

The resistance R_1 lowers the voltage V_4 to a voltage which is suitable for zener diode.

Zener diode clips the voltage V_d to a fixed voltage or constant voltage V_2. The fixed voltage V_2 applied to charging circuit RC.

Pulse transformer:

Firing circuit can be operated at low voltage (5 to 20V) and thyristor circuit can be operated at high voltage (>250V). Hence they must be electrical isolation between low voltage firing circuit and high voltage thyristor circuit. This can be provided by pulse ~~triggering~~ transformer.

Pulse transformer has only 1 primary winding and 2 (or) more secondary winding. Multiple secondary winding of pulse transformer allows simultaneously application of gate pulse through two (or) more devices.

Advantages of pulse transformer:

It provides electrical isolation between low voltage firing circuit and high voltage thyristor circuit.

From the same firing circuit it is possible to turn on two (or) more devices.

* Silicon UJT have 20V between the base if the intrinsic stand of ratio is 0.6. Find the value of stand of voltage and peak point voltage.

Sol: $V_{bb} = 20V$

$\eta = 0.6$

$V_p = V_{rb1} + V_d$

$V_{rb1} = \eta V_{bb}$

$V_{rb1} = 0.6 \times 20$

$= 12$

$V_p = 12 + V_d$

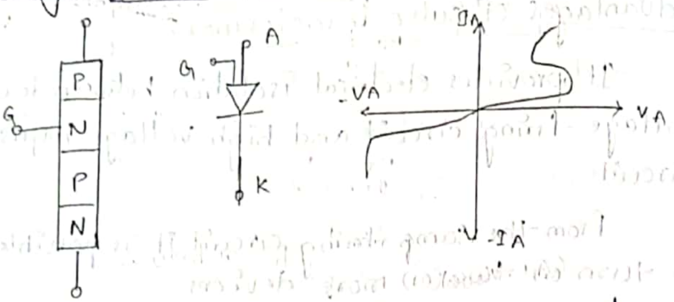
Neglect V_d

then

$V_p = 12$.

Thyristor family devices:

1. Programmable Unijunction transistor (PUT):

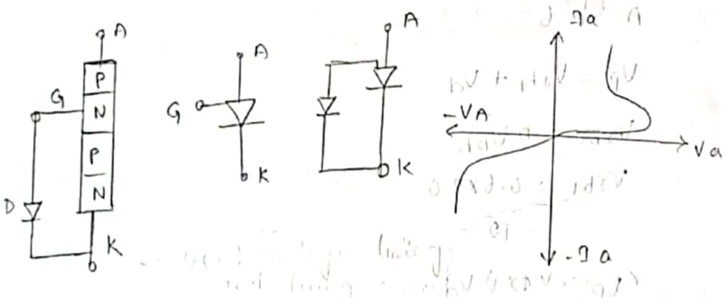


PUT - Programmable Unijunction transistor

Used in logic timing and firing circuit

It has 200 V, 1A.

2. Silicon unilateral switch (SUS):



SUS - Silicon unilateral switch

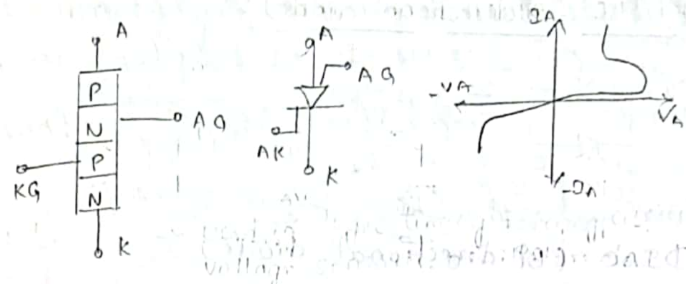
Used in logic timing and firing circuit.

It has 20 V, 0.5 A

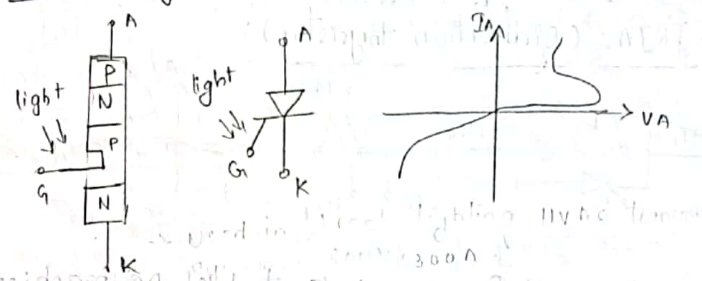
3. Silicon controlled switches (SCS):

Used in logic timing and firing circuit, voltage sensors, oscillators etc.

It has 100V, 200mA.

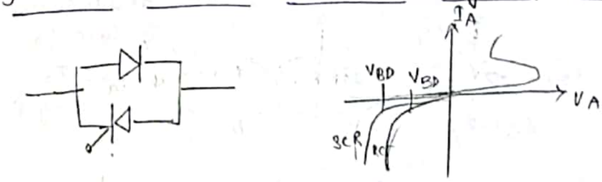


4. LASCR (light activated Si controlled rectifier):



It is used in street lighting, HVDC transmission system. It has 600V, 300A.

5. RCT/ASCR (Power conducting thyristor):

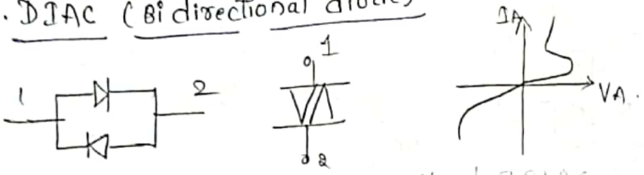


RCT (Reverse conducting thyristor) ASCR (Asymmetric SCR)

It is used in VSI

It has 2500V, 400A.

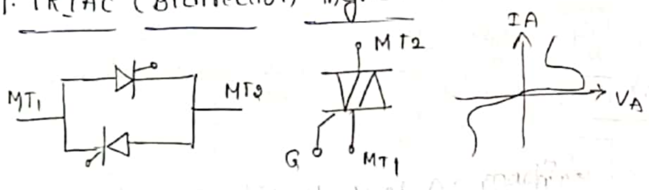
6. DIAC (Bidirectional diode):



DIAC (Bi directional diode)

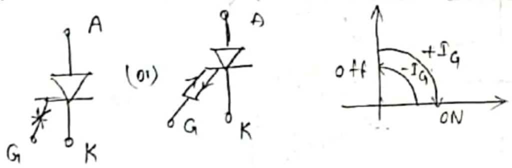
It is used in firing circuit of TRIAC.

7. TRIAC (Bidirection thyristor):



It is used in speed control of AC machiner.

8. GTO (Gate turn off thyristor): (20-30% of anode current to turn off)



$\downarrow C_G = \frac{I_a}{I_g} \uparrow$

→ Used in choppers, UPS, converters etc.

→ 500V, 300mA

GTO is turned on by applying positive gate current and turned off by applying -ve gate current so it is called as self commutating device (It does not requires any commutation circuit).

The negative gate current require to turn off the GTO is 20-30% of anode current. The positive gate current required to turn on the GTO is high compared to SCR.

The current gain of GTO is low as it requires large gate current to turn off the GTO.

$$\text{Current gain} = \frac{I_a}{I_g}.$$

Latching and holding currents of GTO are high compared to SCR.

Power diodes:

symbol

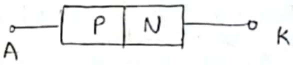
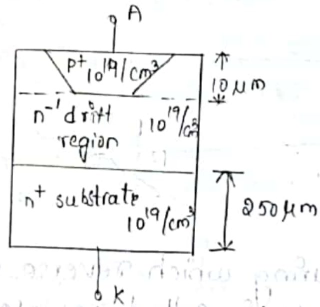


Fig: structure of signal diode.



structure of power diode

* Signal diodes are used to design to operate at low power rating where as power diodes are designed to operate at high power ratings.
* Constriction characteristics point of view both signal and power diodes are same but there is

a little difference in their construction.

* n^- drift region is present in power diodes, which is not present in signal diodes. The thickness of n^- drift region depends on break down voltage of the diode.

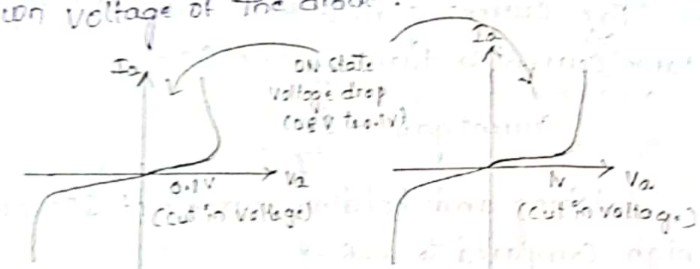


Fig 1: V-I characteristics of signal diode

Fig 2: V-I characteristics of power diode.

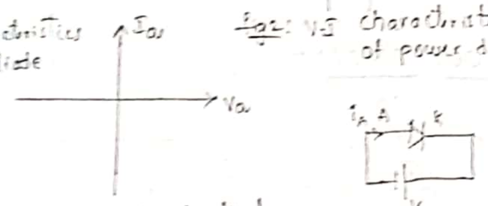
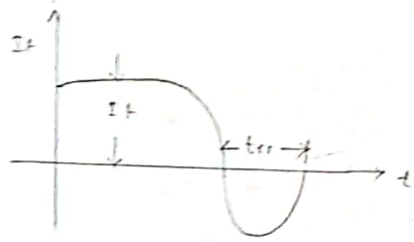


Fig 3: Ideal chat of diode.



The time during which reverse current flows through the diode is called reverse recovery time. The time between the instant at which diode forward current reaches to zero and the instant at which the reverse current reaches to zero is called reverse recovery time.

Based on reverse recovery time diodes are classified into three types.

1. General purpose diode – 25 μs.
2. Fast recovery diode – 5 μs (or) less.
3. Schottkey diode

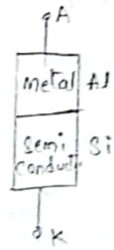
General purpose diodes has reverse recovery time of about 25 μs. General purpose diodes are used in battery charges, electric traction, weldings, UPS etc.

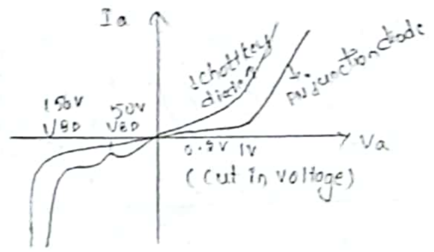
Fast recovery diodes has reverse recovery time of about 5 μs (or) less. Fast recovery diodes are used in commutation circuits, choppers, inverters, UPS etc.

Schottkey diode uses metal to semiconductor junction instead of P-N junction. Metal is made with aluminium and semiconductor is made with silicon. So schottkey diode has aluminium silicon junction.

Due to absence of P-N junction, its storage time is less and then turn off time is low. Hence schottkey diodes have low turn off time and high operating frequency.

Due to absence of n^- drift region of on state voltage is less than PN junction diode.





Type	V/I rating	Maximum operating frequency	On state Voltage drop.
GPD	50V - 5kV / 1A - 5kA	2 kHz	1-2 V
FRD	50V - 3kV / 1A - 1kA	12 kHz	1-1.5 V
Schottkey diode	100V / 1A-300A	20 kHz	0.5-1V

Power BJT:

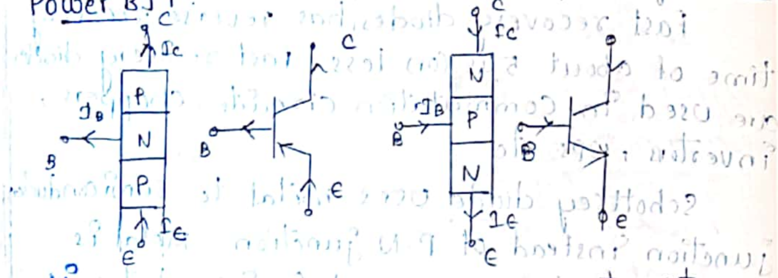
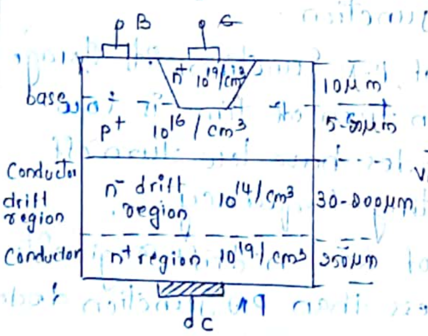
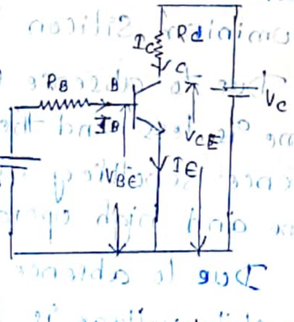
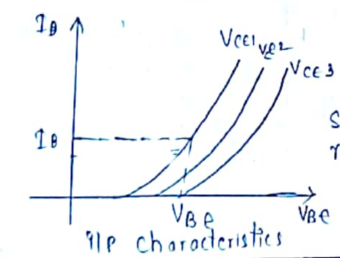


fig (i) PNP transistor   fig (ii) NPN transistor

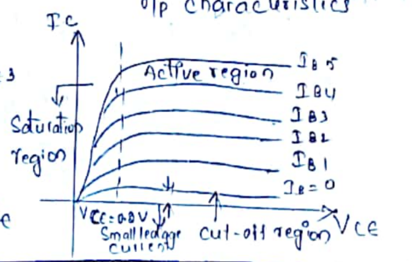




o/p characteristics



i/p characteristics



BJT is a three terminal, three layer power semiconductor switching device. It may be PNP (or) NPN transistors.

In the two transistors NPN is commonly used in high voltage and current applications because it is easy to manufacture and low cost.

The term bipolar indicates the current flow in the device is due to both majority and minority charge carriers.

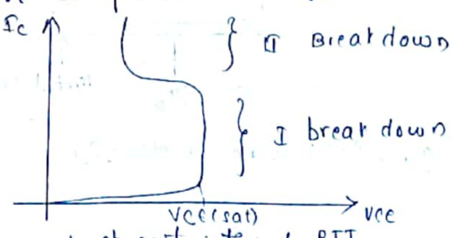
BJT is a current control device because its output current I_C is controlled by controlling input current I_B.

Advantages:

* It has small turn on and turn off time. Hence there switching frequency is are high.
* BJT has low on state conduction loss.
* It does n't requires any commutation circuits
* BJT's are available with low cost.

Disadvantages:

* Drive circuit (control circuit) of BJT is complex
* Parllell Pallering of BJT is not possible because of having negative temperature coefficient.



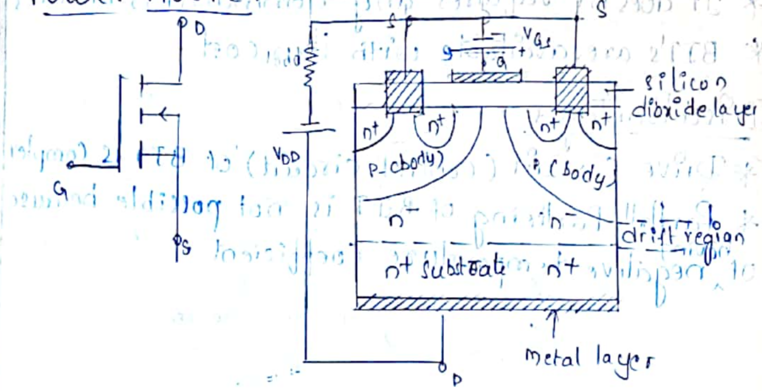
o/p characteristics of BJT

* Due to having negative temperature coefficient, secondary break down is possible in power BJT.

* In BJT primary break down occurs at $V_{CE(Sat)}$ at reverse biased junction. At V_{CE} saturation the collector current increases rapidly and these collector current would rises the increased collector current would rises the temperature at reverse biased junction. This raised temperature would decreases the junction resistance (due to having negative temperature coefficient).

As a result, the voltage V_{CE} decreases and collector current I_C increases rapidly again. This large collector current can create a hotspots in highly concentrated regions. In this regions temperature increases rapidly and BJT get damaged.

Power MOSFET:



Fig(1): Structure of MOSFET

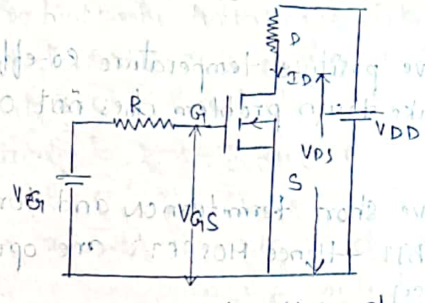


Fig: Circuit to obtain characteristics.

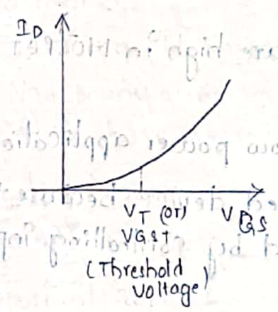
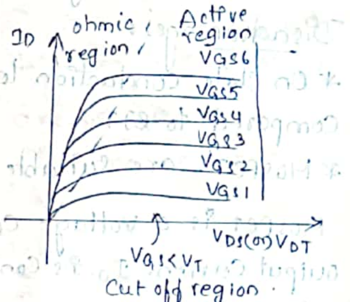


Fig 3(i): Transfer characteristics



$V_{GS6} > V_{GS5} > V_{GS4} > V_{GS3} > V_{GS2} > V_{GS1}$

Fig 3(ii): o/p characteristics

Advantages:

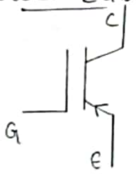
* MOSFETs have positive temperature co-efficient so secondary brake down problem does not occur in MOSFET.
* MOSFET's have short ~~term~~ turn ON and turn off time compared to BJT. Hence MOSFET's are operated at high frequency.
* MOSFET's have high input impedance.

Disadvantages:

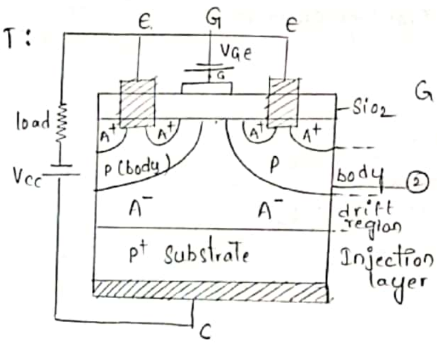
* On state conduction losses are high in MOSFET compared to BJT.
* MOSFET's are suitable for low power applications.

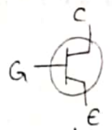
MOSFET is a voltage controlled device because the output current I_D is controlled by controlling input voltage V_{GS}.

Power IGBT:

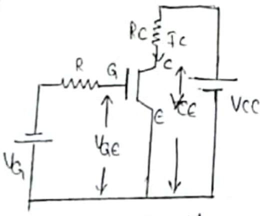


(i) Symbol

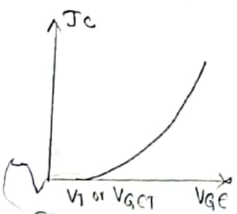




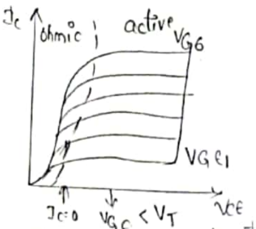
② structure



③ Circuit to obtain characteristics



④ Transfer characteristics



⑤ output characteristics

* IGBT combines the advantages of both BJT and MOSFET i.e., like BJT it has low ON state conduction losses like MOSFET it has high input impedance.
* Gate circuit in MOSFET and emitter collector circuit in BJT combines together to form IGBT.
* IGBT is a voltage controlled device because output current I_C is controlled by controlling input voltage V_{GE}.

Advantages:

* Switching frequency is higher than thyristor.
* No commutation circuits are required.
* IGBT's have approximate flat temperature co-efficient.

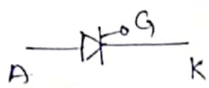
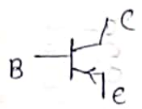
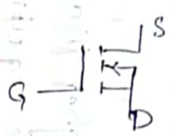
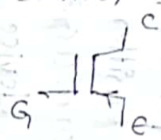
Disadvantages:

* IGBT's are costlier than BJT and MOSFET.

Important topics:

* SCR operation & VI chara's.
* Series and parallel operation of SCR.
* Snubber circuit design.
* 2 transistor model.
* Turn on and turn off methods.

* Comparision between SCR, IGBT, BJT and MOSFET

Parameters	SCR	BJT	MOSFET	IGBT
* Control of gate (or) base	Gate has no control once turned on	Base has full control	Gate has full control	Gate has full control
* Symbol				
* On state voltage drop	<2V	<2V	4.6V	3.3V
* V/I control device	Current control device	CCD	VCD	VCD
* Switching frequency	500 Hz	10 KHz	Upto 100 KHz	20 KHz
* Temperature coefficient	-ve	-ve	+ve	approximately flat but positive at high currents
* Voltage rating	7 KV	1.4 KV	1 KV	1.2 KV
* Current	5 KA	400 A	50 A	500 A
* Type of carriers in device	Bipolar	Bipolar	Unipolar	Unipolar