Power Electronics

by

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power Electronics

Introduction:

This subject mainly deals with studying of power electronic device and power converters.

power electronic devices:

- power diode
- power Transistor
- ~~power~~ thyristor

⇒ power Transistor

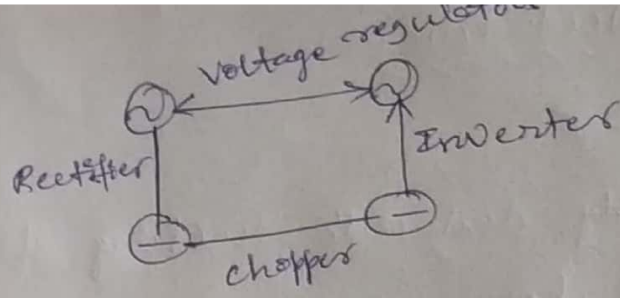
- power BJT
- power MOSFET

⇒ thyristor

- SCR ✓
- TRIAC ✓
- DIAC ✓
- IGBT ✓
- SCS
- MOS
- LASCR
- GTO ✓

power Converters:

1. Rectifiers ⇒ AC ⟶ DC
2. Inverter ⇒ DC ⟶ AC
3. voltage regulators ⇒ AC ⟶ AC
4. choppers ⇒ DC ⟶ DC
5. Cyclo Converter ⇒ fixed frequency to Variable frequency



Application of power Electronics:

* Aerospace
* Commercial
* Industrial
* Residential
* Teli communication
* Transpotation
* utility.

Advantages of power Electronics:

- High efficiency
- High reliability of power Electronic converters
- Long life time and easy maintanance
- Fast dynamic response
- Small size and less weight
- Lower cost of converter equipment.

Dis advantages:

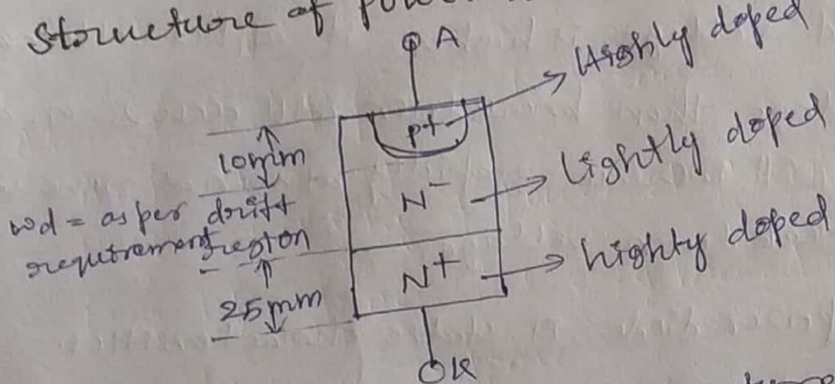
- Generate harmonics
- Low over load capability
- Regeneration of power is difficult in power electronic converter system.

Power Diode:

power diode is same as signal diode but the main difference is power handling capability and constructional difference.

- In order to increase power handling capacity two changes are getting done in structure of diode.
- power diode is are used to perform various operations like Rectification, Free wheeling, Energy feed back in power electronic operations.
- Switching speed of power diode is low compared to signal diode.

Structure of power diode:



The basic vertical oriented structure of a power diode is shown in the figure.

- The vertical oriented structure is preferred in the power devices
- The vertical oriented structure increases voltage handling capacity
- Drift region (N^- layer), it increases and it controls reverse break down voltage of diode
- If we need higher reverse breakdown voltage then, we need higher thickness of drift region.
- Due to light dopping of drift layer resistivity is more, hence power diode has more onstate voltage drop.
- The cross sectional Area of diode gives idea about current handling capacity of power diode.

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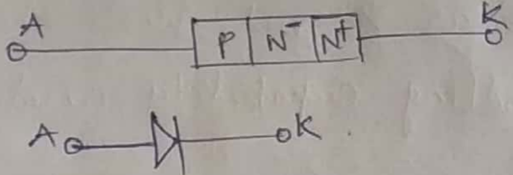
Symbol of power diode:

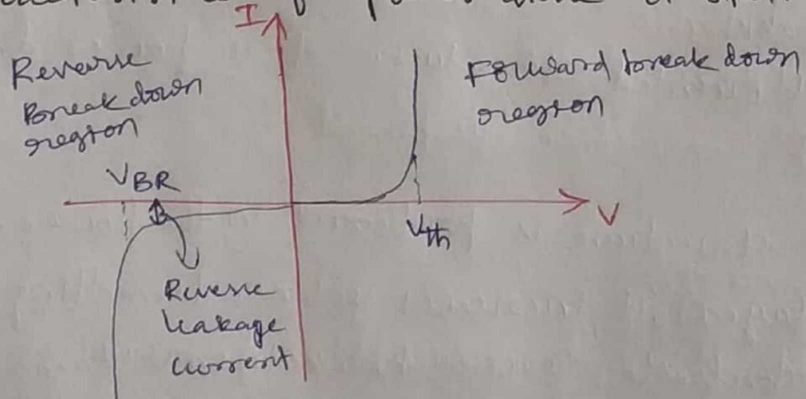


Operation of power diode:

- when the Anode is more +ve w.r.t Cathode, then diode is said to be in forward bias ~~condition~~ and the diode conducts.
- A Conducting diode has a relatively small forward voltage drop.
- when the Cathode is positive w.r.t Anode, then diode is said to be reverse bias ~~region~~ condition. and the diode does n't conducts. only the reverse leakage current flows through it.

= If the reverse applied voltage is higher. if applied voltage ~~excess~~ exceed its rated voltage then breakdown will occur. and reverse current will increase rapidly as soon as reverse voltage exceeds breakdown voltage.

VI - characteristics of power diode or static characteristics.



V_{BR} ⇒ Reverse breakdown Voltage

V_{th} ⇒ Thresh hold Voltage = Cut in voltage or Turn on voltage

VI characteristics of power diode may be (a) forward ~~break down~~ bias region (b) Reverse bias region and (c) Break down region.

(a) Forward bias region:

Above threshold voltage, the current rises suddenly and the diode starts conducting.

(b) Reverse bias region:

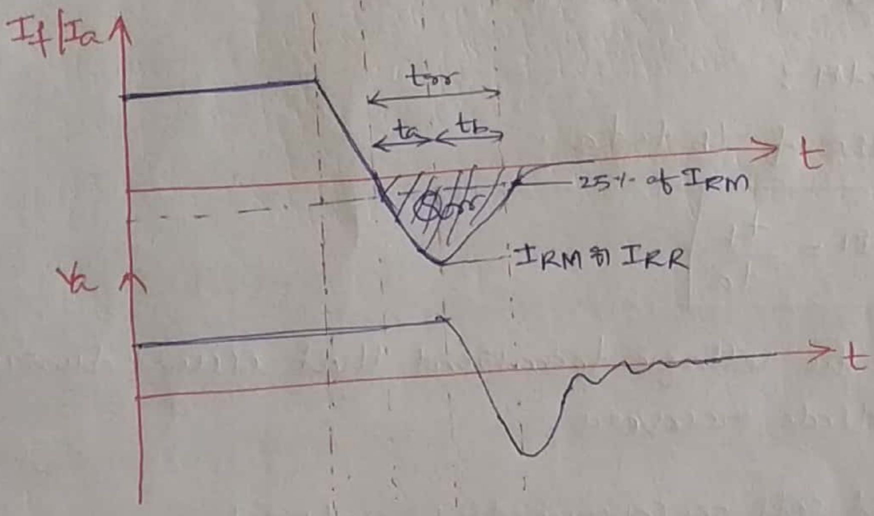
If the voltage is less than zero (cathode is +ve w.r.t Anode) so, the diode is reverse bias region. Only reverse leakage current is with in it.

(c) Break down region:

If the reverse applied voltage exceeds, the rated voltage, the breakdown will occur and reverse current will increase rapidly.

Switching characteristics or Dynamic characteristics:

it is also called reverse recovery characteristics.



where, t_{rr} = reverse recovery time = $t_a + t_b$

I_{RM}/I_{RR} = reverse recovery current

Q_{rr} = the shaded area has some charge with in it.

- The current in the forward bias junction of diode is due to net effect of majority and minority charge carriers. Once, a diode is in forward conduction mode. and then, a forward current is reduced to zero due to any region by applying reverse voltage,
- After forward diode comes to zero, the diode continues to conduct in the opposite direction because of the presence of stored charges in the depletion layer and P or N-layer.
- the diode current flows for a reverse recovery time t_{rr}. It is the time between the instant forward diode current becomes zero and the instant reverse-recovery current decays to 25% of its reverse maximum value

- The reverse recovery time is composed to two segments of time and that is ta and tb

$$t_{rr} = t_a + t_b$$

* Time ta : charges stored in the depletion layers removed
* Time tb : charges from the semiconductor layer is removed.

- Since, ta is the time between zero crossing of forward current and peak reverse current (I_{RM}). during this time, charge stored in the depletion layer is removed
- Time tb is measured from the instant of reverse peak current I_{RM} to the instant, when 25% of I_{RM} is reached.
- the shaded area, Q_{RR} represents stored charges Q_R or reverse recovery charge, which must be removed, during reverse recovery time t_{rr}
- Recovery ~~can~~ be abrupt or smooth.

Softness factor or S-factor :

It is the ratio of tb to ta.

$$S\text{-factor} = \frac{t_b}{t_a}$$

- S-factor: measure of the voltage transient that occurs during the time the diode recovers.

* If S=1, it is called soft recovery diode, $t_b = t_a$.
* If S<1, it is called snappy-recovery diode or fast recovery diode.

Reverse recovery charge (Q_{RR}):

It is the amount of charge carriers that flows through diode in reverse direction due to change over from forward conduction state to reverse blocking state

$$Q_{RR} = \frac{1}{2} \times I_{RM} \times t_{rr} \longrightarrow$$

$$I_{RM} = \frac{2Q_{RR}}{t_{rr}}$$

$$t_{rr} = t_a + t_b$$

$$s = \frac{t_b}{t_a}$$

$$t_b = s t_a$$

when $s = 0$, $t_b = 0$

so $t_{rr} = t_a + t_b$

$t_{rr} = t_a$

$$I_{RM} = t_a \frac{di}{dt} \longrightarrow ②$$

$$\frac{di}{dt} = \frac{I_{RM}}{t_a}$$

putting I_{RM} in ①, we get

$$Q_R = 1/2 \times t_a \frac{di}{dt} \cdot t_a$$

$$= 1/2 \, t_a^2 \frac{di}{dt}$$

$$\boxed{Q_{RR} = 1/2 \frac{di}{dt} t_a^2}$$

Types of power diodes:

Depending on the reverse recovery characteristics, they are 3 types

(a) General purpose diode

(b) Fast recovery or snappy diode

(c) schottkey diode.

(a) General purpose diode:

- These are used for low frequency applications, like; rectification
- At low frequency these diodes are capable of handling current from very low value to high value or from the voltage rating 15V to 5KV
- the diodes have relatively high reverse recovery time about 25ms.
- the current rating varies from one Amper to several thousand amperes.

Applications:

- Rectifier
- Battery charger
- Electric traction
- Electro plating
- UPS

- these diodes are manufactured by diffusion technique.

(b) Fast recovery diode or snappy diode:

- these diodes have low reverse recovery time as compared to the general purpose diode. It is less than 5 ms.

- therefore, they are termed of more quickly and hence can be used in the high frequency applications. such as diode converters.

Applications:

- Inverters
- choppers
- SMPS
- communication circuits
- Induction heating

- these diodes are manufactured by diffusion technique.

(c) Shottkey diode:

- the recovered charge of this diode is much less than that of an equivalent PN-junction diode. as it is due to junction capacitance.
- This diode as relatively low forward voltage drop, high leakage current, the current rating is from 1A to 400A.
- voltage rating vary from 50V to 100V, so this diodes are ideal for high current and low voltage applications.

Applications:

- Rectifier
- free wheeling
- feed back diode
- trapped energy recovery.

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Power BJT:

- The BJT is abbreviated as Bipolar Junction Transistor
- the BJT is a three-layer, two Junction, ~~and~~ three terminal pnp or npn semiconductor device.
- the three terminals are Emitter, Base, Collector.
- It has large current handling and power handling capacity compared to BJT.
- It offers high voltage resistance in OFF state than BJT.
- " " " current handling " ON " " "
- It has vertically oriented structure.
- High gain is maintained by enchancing doping level of emitter several times that of base.
- due to more emitter doping, β current gain will decrease.

Structure of power BJT:

If a layer of P or N is added to PN device, it becomes a BJT.
It has vertically oriented structure.

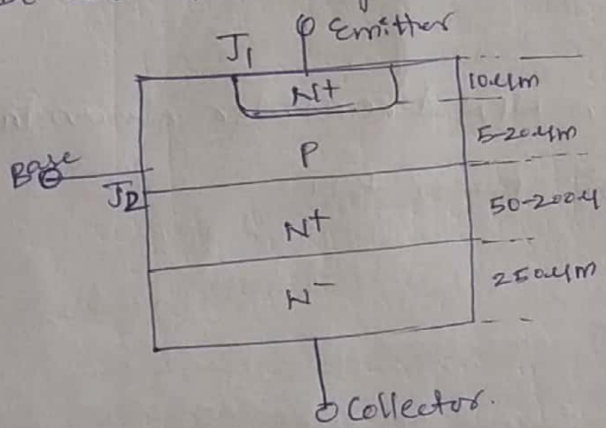
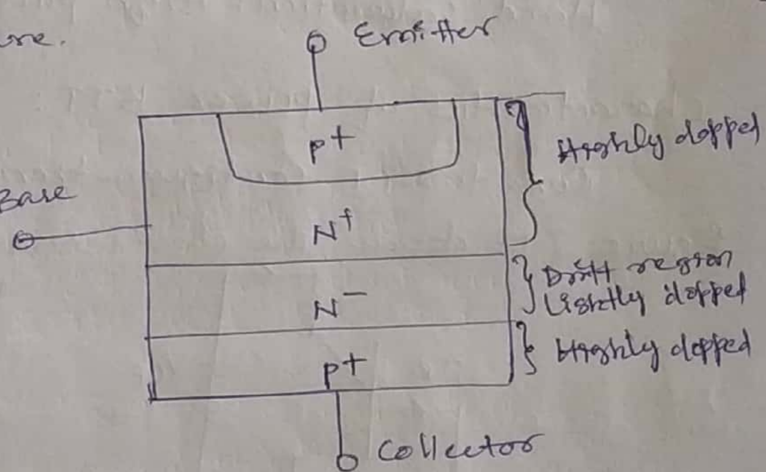


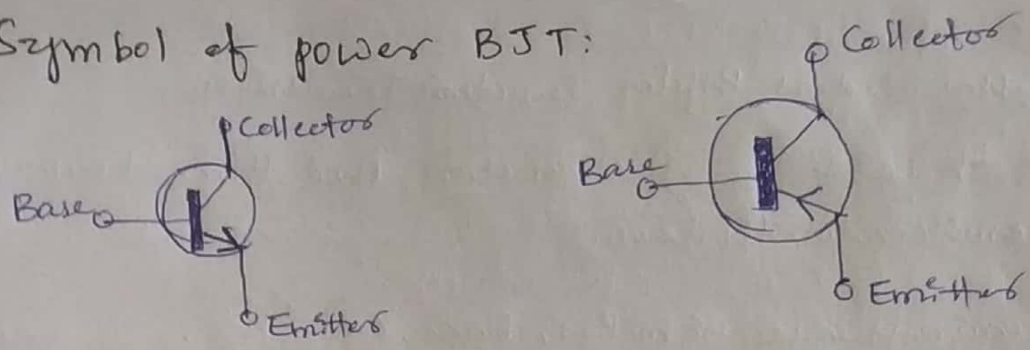
Fig. power BJT PNP structure



power BJT NPN structure.

- It is a three terminal device with high current and power handling capacity and high voltage resistance in OFF state.
- the construction of a power BJT is lightly different ~~from~~ than normal BJT.
- It has an extra lightly dopped N⁻ region called a collector drift region in addition to base contact, emitter contact
- this N⁻ region will increase voltage blocking capacity of power BJT.

Symbol of power BJT:



NPN Transistor

PNP Transistor.

Operation of power BJT:

The power BJT is operated in three modes, (a) Cut off (b) Active and saturation.

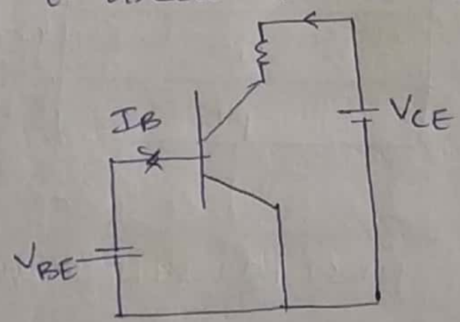
- Cut off Mode: Base Emitter & Collector base junction in Reverse Biase
- Active mode: Base Emitter in forward bias & Collector base reverse bias
- Saturation: (Base Emitter & Collector Base junction in forward bias)

  Quasi saturation: Low power operation working.

  Hard saturation: High power working.

Characteristics of power BJT:

Consider CE configuration of an NPN transistor shown in figure to draw the characteristics of power BJT:



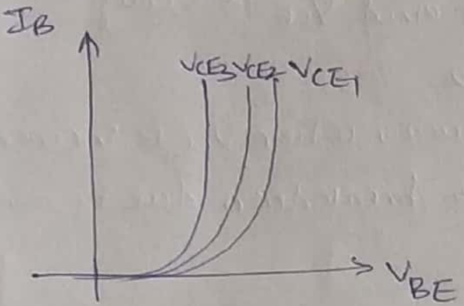
CE Configuration

VI characteristics or steady state characteristics:

It may be input characteristics and output characteristics.

Input characteristics:

It is the graph between I_B versus V_{BE} and different values of V_{CE}

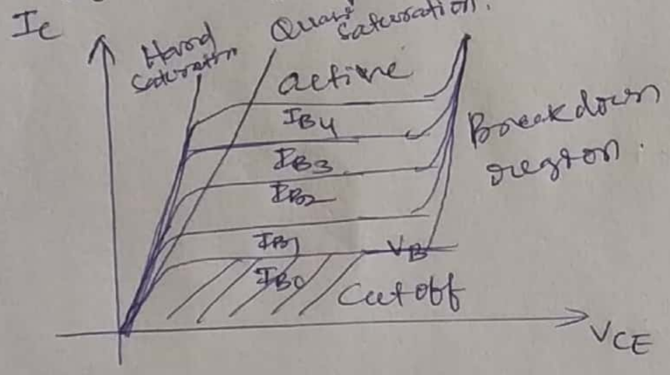


$V_{CE_1} < V_{CE_2} < V_{CE_3}$

- Since, the junction (EB) forms a PN Junction diode the characteristics are similar to PN-diode.

Output characteristics:

It is the graph between V_{CE} and I_c with different values of V_{BE}



- output characteristics of power BJT consists of four regions
  - (a) Cut off region
  - (b) Active region
  - (c) Saturation region
  - (d) Breakdown "
- characteristic curves for power BJT is Just the same except for the little difference in its saturation region. It has additional region of operation known as quasi-saturation as shown in the output characteristic graph.
- In cutoff, I_c is small almost zero. which is not sufficient to turn ON, as J_1 and J_2 are reverse biased.

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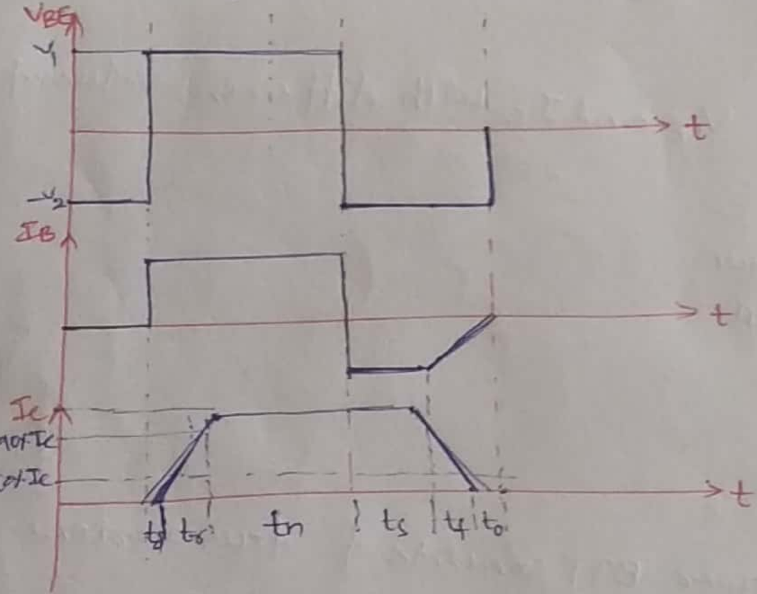
- In Active region, J_1 – F.B & J_2 – R.B here the transistor acts as an amplifier, where the collector current is amplified by a gain.
- In Active region, the current is flat and parallel to X–axis, which shows that I_c is constant for any value of V_{CE}. Hence in this region transistor acts as an amplifier.
- In saturation region, I_c is very high and V_{CE} is very low so, the transistor acts as a closed switch.
- In breakdown region, it is come into picture, when V_{ce} is increased to a very high value. the Junction will get a breakdown due to avalanches break down.

Switching characteristics:

Switching characteristics of power BJT is shown in figure



- As the positive base voltage is applied, base current starts to flow but there is no collector current for some time, this is known as delay time (t_d). required to charge the junction capacitance of the base to emitter to 0.7 V approx.
- For $t > t_d$, collector current starts rising and V_{CE} starts to drop with the magnitude of 9/10 th of its peak value, this time is called rise time (t_r), required to turn on the transistor.
- The transistor remains on so long as the collector current is at least of this value.

- For turning off the BJT, polarity of the base voltage is reversed and thus the base current polarity will also be changed.
- The base current required during the steady-state operation is more than that required to saturate the transistor.
- Thus excess minority carrier charges are stored in the base region which needs to be removed during the turn of process.
- The time required to nullify this charges is the storage time(t). Collector current remains at the same value for this time.
- After this, collector current starts decreasing and base-to-emitter junction changes to the negative polarity. base current also gets reduced.

power MOSFET:

Thyristor:

The term thyristor is the general name given to the family of Semiconductor device having Four layer, three Junction, three terminal devices. ~~and~~

- It is semi controlled device.

Thyristor family:

- PNPN device schottkey diode
- SCR silicon controlled rectifier
- GTO
- SCS
- TRIAC
- DIAC
- LASCR

- SCR is the most dominating member in the ~~thyristor~~ family.

SCR:

SCR is abbrivated as silicon controlled rectifier.
SCR is also called as thyristor.

- It is four Layers (PNPN device), three junction, 3 terminal PNPN device.
- The four layers are PNPN and three terminals are Anode, cathode and Gate.
- It is unidirectional device and it allows current from Anode to cathode.

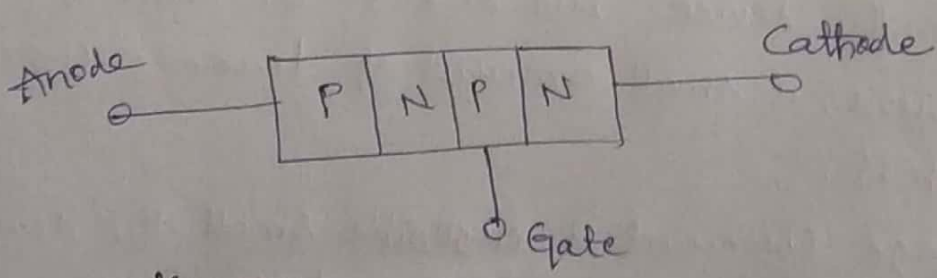


fig:

Structural View of SCR:

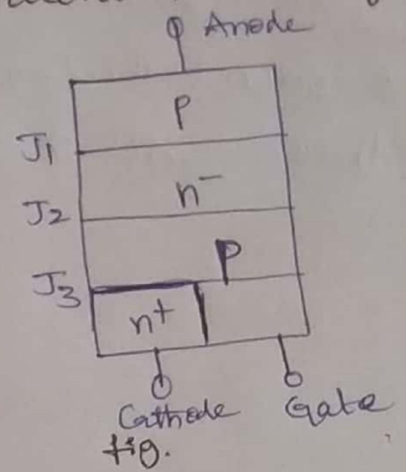
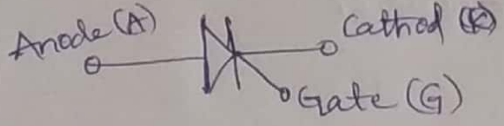


fig.

- SCR is made up of silicon and it acts as rectifier and it has very low resistance in forward direction and high resistance in reverse direction.

SCR Symbol



Operation of SCR:

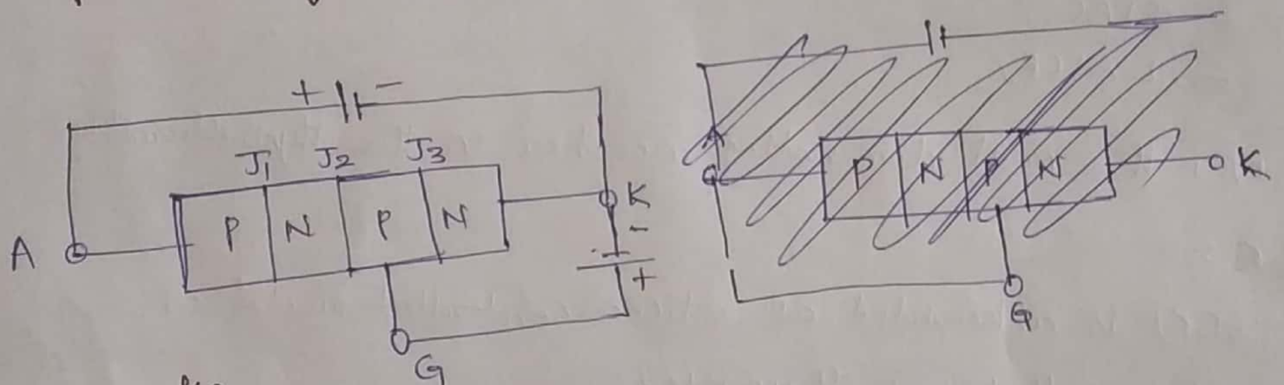


fig.

- The Anode and Cathode terminals are connected to the power supply and the Gate is connected to the control circuit.
- When the Anode is made positive w.r.t cathode, Junctions J_1 and J_3 Jets forward biased, where as the middle junction J_2 is known as junction capacitance as it acts as junction capacitor in this mode.
- Due to the depletion layer formed at the junction, no current flows through the device. but due to the drift of mobile charge carriers, a small amount of leakage current flows through it.
- As the leakage current is negligible small, the device does not conduct. This is known as "Forward Blocking state" or OFF state of the device.

- whenever cathode is more positive when compared to Anode, Junction J_1 and J_3 are reverse biased and J_2 is forward biased.
- As the junction J_1 & J_3 are in reverse biased condition, they don't allow any current to flow through the device. This is called "Reverse Blocking State" or OFF state.
- A very small amount of leakage current flows through it.
= After keeping the device in forward blocking state by increasing the voltage across the anode and cathode, the width of the depletion layer may be reduced across J_1 and J_2.
- At some particular voltage, Junction J_2 disapears and this is due to breakdown of the junction by large voltage gradient. It is also called as Avalanche break down.
- As J_1 & J_3 are in F.B condition there exists a free charge carriers movement from Anode to cathod. As a result the device starts conducting and hence it is said to be Conduction State or ON state.

* By applying gate pulse between Gate and cathode, the width of the depletion layer J_2 is reduced and disapears for some small amount of voltage.

Summary of operations:

(a) Reverse Blocking mode:

J_1, J_3 — R.B & J_2 — FB Acts as open switch

(b) Forward Blocking mode:

J_1, J_3 — F.B & J_2 — R.B Acts as open switch

(c) Forward Conduction mode:

J_1, J_2 & J_3 — F.B acts as ON switch

= By exceeding forward breakdown voltage

= By applying Gate pulse.

VI characteristics or static characteristics of SCR:

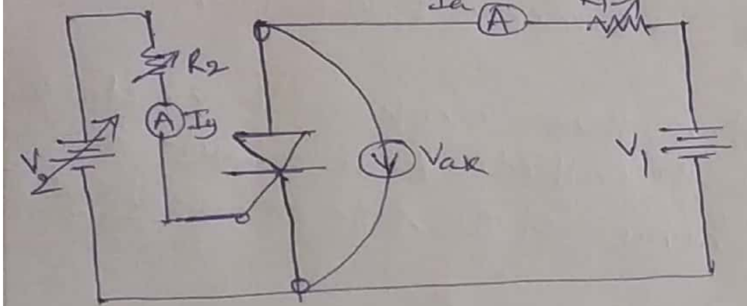
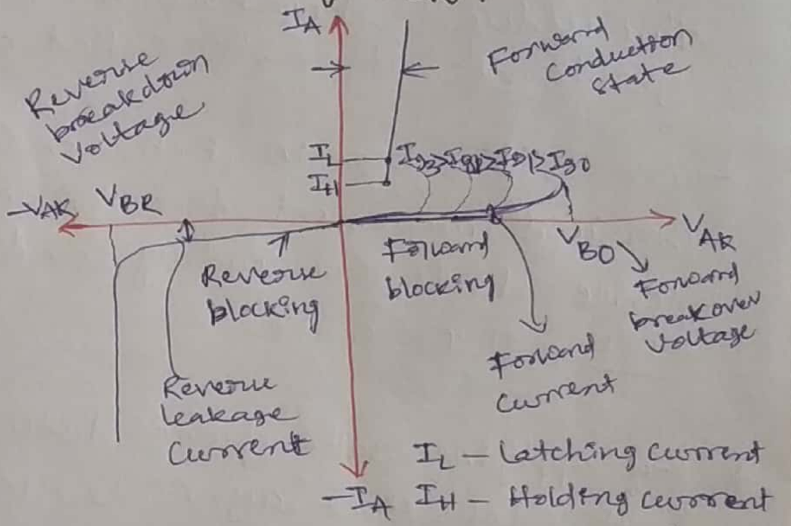


Fig Circuit for obtain SCR VI characteristics



I_L — Latching current

I_H — Holding current

Fig: Static VI characteristics of SCR

The SCR VI characteristics may be, Reverse blocking state, Forward blocking state and Forward Condction state

Latching current (I_L):

the minimum value of anode current, which must attain for thyristor to remain in conduction mode even after removing the gate pulse

Holding current (I_H):

the value of anode current below which it must be fall for SCR to block the junction (J_2). that is to turn off.

$$I_H < I_L$$

* Holding current is smaller than the latching current.

NOTE:

1) Reverse Blocking mode:

When cathode of thyristor is made positive(+ve) w.r.t anode switch is open. Thyristor is reverse bias. Junction J_1 and J_3 are reverse bias where as junction J_2 is forward bias. The device behaves as if 2 diodes are connected in series with reverse voltage applied across them.

The SCR does not conduct any current it is said to be in Reverse blocking mode or off state.

A small Reverse leakage current of the order of few milliamperes (mA) only flows.

* Now if we increase the reverse voltage to the value called as Reverse breakdown voltage than an avalanche will occurs and breaks the junction J_1 and J_3 due to this very huge amount current flows through the device hence the SCR starts conducting, but this method of conducting is not recommandate for the SCR operation. Because may be SCR will damage.

ii) Forward Blocking mode:

When anode is positive with respect to cathode then gate current is open Thyristor is said to be forward blocking mode condition. The junction J_1 and J_3 are FB and junction J_2 Reverse Bias as the forward voltage is increases the junction J_2 have an avalanches breakdown.

* The SCR does not conduct any current except a very few leakage current.

* The SCR can be made to conduct in the forward blocking mode by increasing anode Cathode voltage to a value of forward break over voltage.

* Even though this methode is reccomended as it may also damage SCR.

(iii) Forward Conduction Mode:

In this mode of operation SCR is made to Forward junction mode so it acts as a closed switch.

The only extra thing is we gate signal for a small period of time for which the anode current becomes equal to the latching current.

Once the anode current attains this value the gate losses the control and hence can be removed.

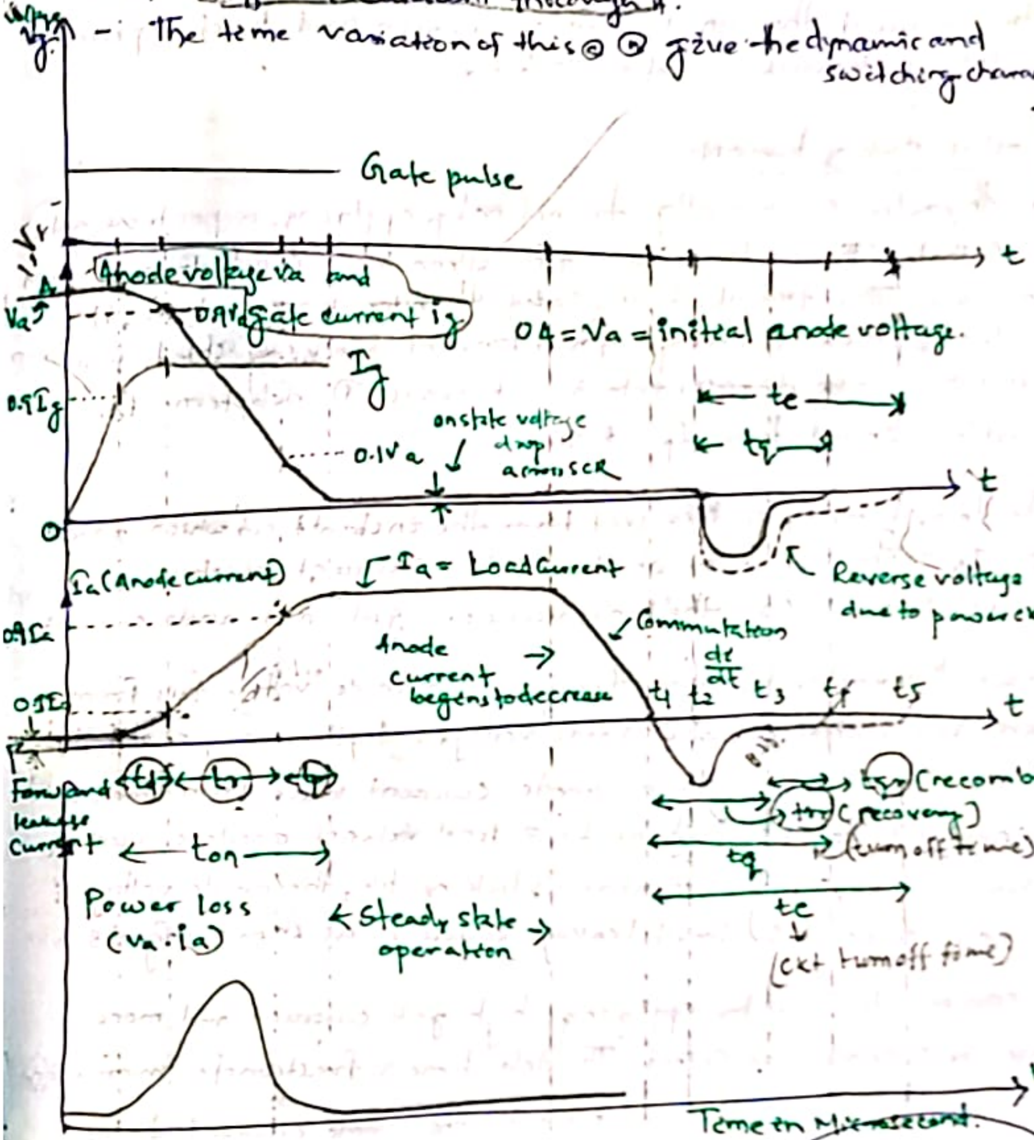
The Removal of Gate Signal will not have any affect of the SCR condunction.

However, if the anode current decreases to a ~~[illegible]~~ value. Called holding current. The SCR will once again to go back to the forward blocking state.

Date: 06/02/2020

Switching or dynamic or Transient Characteristics. (Thyristor)

- Static & switching characteristics are for economical & reliable design of converter equipment.
- During turn on and turn off process, a thyristor is subjected to (a) different voltage across it and (b) different current through it.
- The time variation of this (a) (b) give the dynamic and switching characteristics.



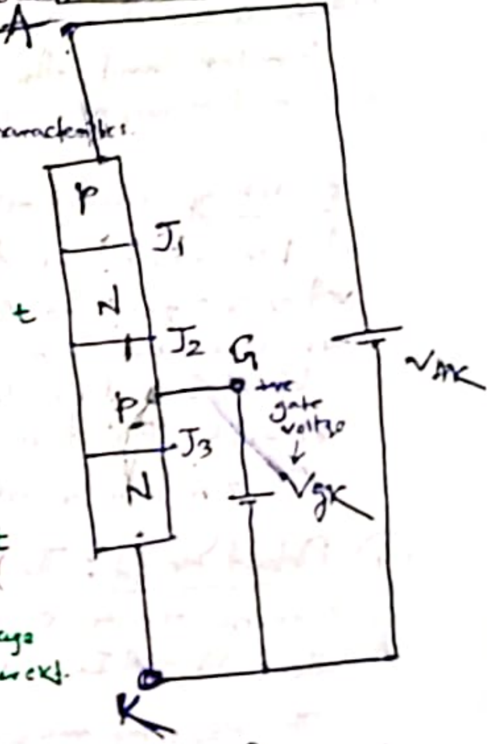


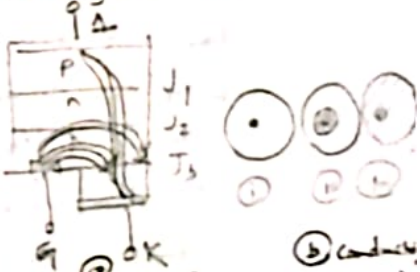
fig. forward Biased Thyristor

fig.: Thyristor voltage and current waveforms during turn on and turn off process.

$I_g \Rightarrow 90\%\ I_g - 100\%\ I_g$

$I_a \Rightarrow 0 - 10\%\ I_a$

V_{AK}



(a) distribution of gate anode current during delay time
(b) conducting area ... during (a) tr (b) tp

Transition Time = forward off state to forward on state

↳ is called = Thyristor turn on time (i.e. forward blocking state to final on state)

① delay time (td) ② rise time (tr) Spread time (tp)

Switching characteristics of Thyristors:

Static and switching characteristics of thyristors are always taken into consideration for economical and reliable design of converter equipment.

During the turn on and turn OFF process, a thyristor is subjected to different voltages across it and different currents through it. The time variation of the voltage across a thyristor and the current through it during turn on and turn off process give the dynamic or switching characteristics of a thyristor.

Switching characteristics during turn ON:

A forward-biased thyristor is usually turned on by applying a positive gate voltage betn gate and cathode. There is however a transition time, called from forward off state to forward on state. This transistor time, called thyristor turn on-time, it is defined as the time during which it changes from forward blocking state to final on-state. Total turn time can be divided into 3 intervals: (1) delay time t_d (ii) rise time t_r and (iii) spread time t_p. fig 4.5.

(i) Delay time t_d: The delay time t_d is measured from the instant at which gate current reaches $0.9I_g$ to the instant at which anode current reaches $0.1I_a$. Here I_g and I_a are respectively the final value of gate and anode current.

The delay time may also be defined as the time during which anode voltage falls from V_a to $0.9V_a$ where V_a = initial value of anode voltage. Another way of defining the delay time is the time during which anode current rises from forward leakage current to $0.1I_a$ where I_a = final value of anode current. With the thyristor initially in the forward blocking state, the anode voltage is OA and the anode current is small leakage current as shown in fig 4.8.

The delay time can be decreased by applying high gate current and more forward voltage betn anode and cathode. The delay time is fraction of a microsecond.

(ii) Rise time t_r: The rise time t_r is the time taken by the anode current to rise from $0.1I_a$ to $0.9I_a$. The rise time is also defined as the time required for forward blocking off state voltage to fall from 0.9 to 0.1 of its initial value OA.

The rise time is inversely proportional to the magnitude of gate current and its build up rates.

The main factor determining t_r is the nature of anode circuit. For Example, for RL circuit, the rate of rise of anode current is slow, therefore, t_r is more. for RC series circuit, di/dt is high, t_r is therefore less.

During the rise time turn on losses in the thyristor are the highest due to high anode voltage (V_a) and large anode current (I_a) occurring together in the thyristor as shown in fig 4.8. As these losses occurring only over a small conducting region, local hotspot may be formed and the device may be damaged.

(iii) Spread time: The spread time is the time taken by the anode current to rise from 0.9Ia to Ia. It is also defined as the time for forward blocking voltage to fall from 0.1 of its initial value to the on-state voltage drop (1 to 1.5 V) during this time, conduction spreads over the entire cross section of the cathode of SCR.

→ The spreading interval depends on the area of cathode and on gate structure of the SCR.

After the spread time, anode current attains steady state value and the voltage drop across SCR is equal to the on-state voltage drop of order of 1 to 1.5V.

The turn on time can be reduced by using higher values of gate currents. The magnitude of gate current is usually 3 to 5 times the minimum gate current required to Trigger an SCR.

Switching characteristics during turn OFF:

Thyristor turn-off means that is has changed from on to off state and is capable of blocking the forward voltage. This dynamic process of SCR from conduction state to forward blocking state is called 'commutation process or turn-off process.

Once the thyristor is on, gate loses control. The SCR can be turn off by reducing the anode current below holding current. If forward voltage is applied to the SCR at the moment its anode current falls to zero. The device will not be able to block this forward voltage as the carriers (holes and electrons) in the four layer are still favourable for conduction. The device will therefore go into conduction immediately even though gate signal is not applied. It is essential that the thyristor is reverse biased for a finite period after the anode current has reached zero.

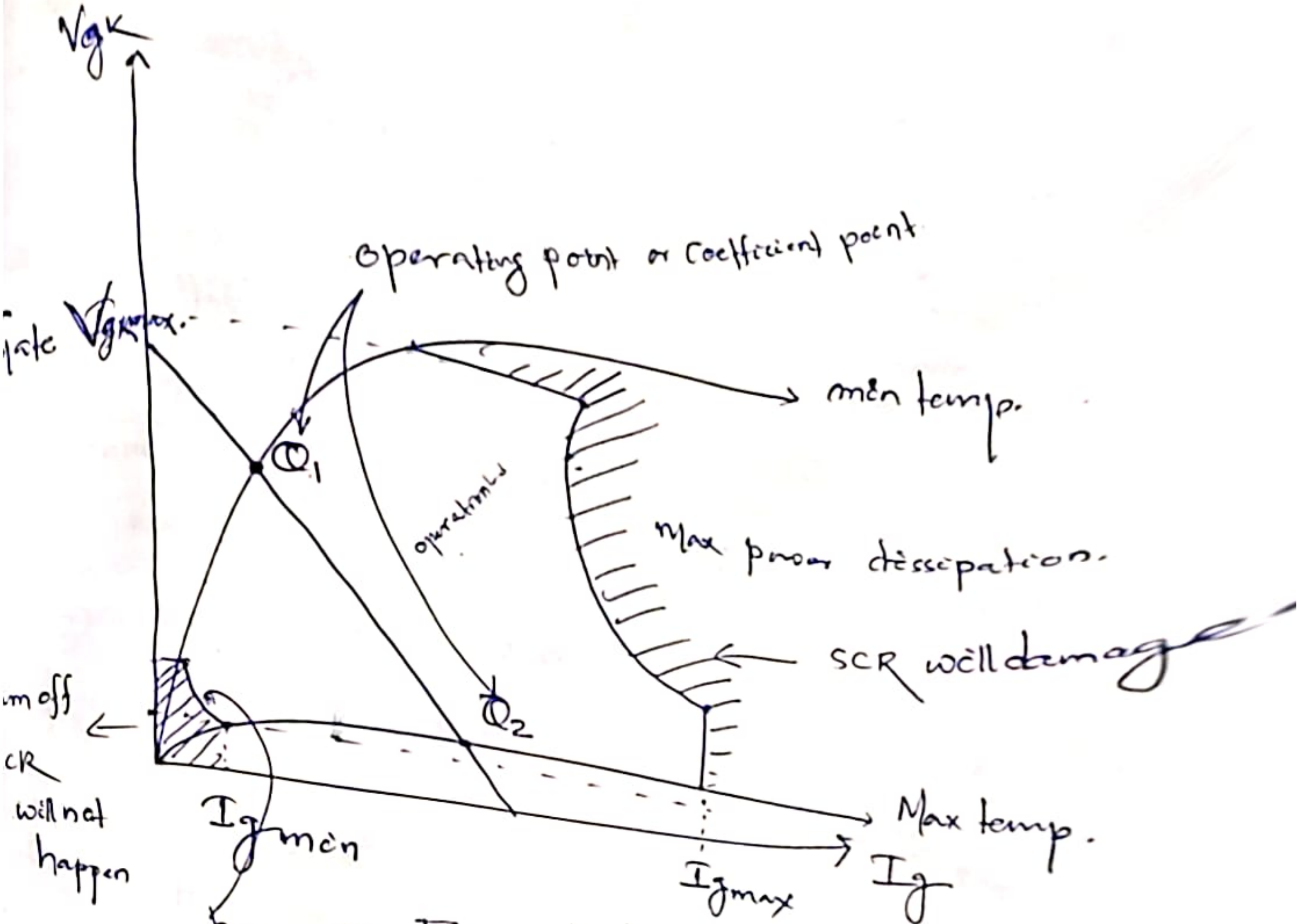


fig. Forward characteristics of thyristor.

Turn ON Methods of thyristor:

Thyristor can be turned ON by the following methods.

(a) Forward voltage triggering

(b) Gate pulse triggering

(c) $\frac{dv}{dt}$ triggering

(d) Thermal triggering

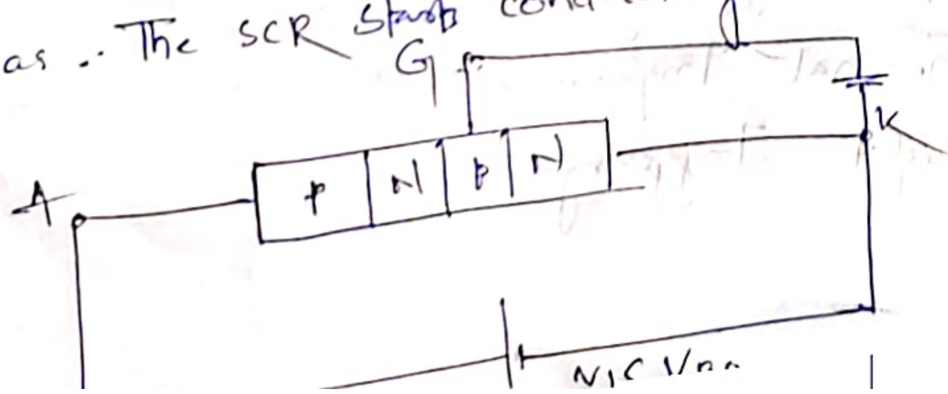
(e) Light triggering.

(1) Forward Voltage Triggering:

With the gate ckt open the thyristor (SCR) will not start conducting with the normal forward voltage (V_{AK}). However, if this voltage increase beyond the forward breakover voltage (V_{BO}). and avalanch will be occurs hence the SCR starts conducting. This method of Triggering is not recommended as it may damage The SCR or whole circuit.

(3) Gate Pulse Triggering:

Gate pulse is the most efficient and most common used method of Triggering. In this method small gate pulse is applied bet to gate and cathode, along with the normal V_{AK}. with this a gate current will be establish which will inject the charge carriers in P-layer (holes) due to which the junction J_2 will be FB. As the other two junction J_1 and J_3 are all ready forward bias. The SCR starts conducting.



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

We know that under forward blocking mode J_1, J_3 are in F B and J is in R.B.

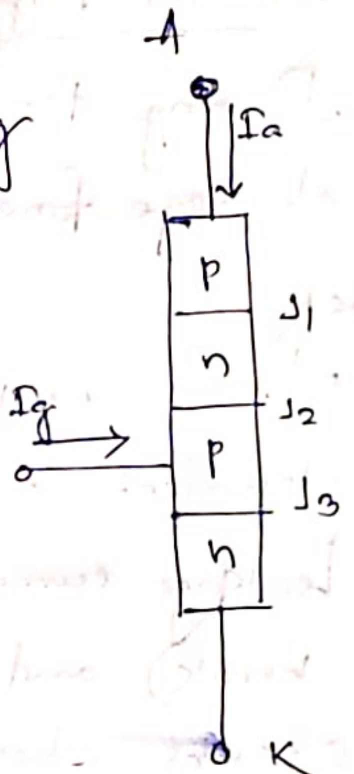


fig. Simple model of thyristor.

Junction J_2 acts as a junction capacitor (So it behaves as if an insulator is placed betn two conducting plates J_1 & J_3 acts as a conduction plate & J_2 acts as insulator).

J_2 is known as junction capacitance because of the opposite polarity carriers presents at the two terminals.

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

Hence the leakage current through the junction is nothing but the capacitor current.

given by $\uparrow I_c = c\frac{dv}{dt}\uparrow$.

If we increase rate of change of forward voltage instead of increasing the magnitude of voltage Junction J_2 breaks and start conducting.

A high value of changing current may damage the SCR.

So, SCR may be protected from high $\frac{dv}{dt}$.

④ Thermal Triggering:

During forward blocking mode J_2 is reverse bias so a leakage forward current always associated with SCR.

Now as we know the leakage current is temprature dependent so if we increase the temprature the leakage current also increase (Junction J_2 will break) and heat dissipation of junction J_2 occurs when this heat reaches a sufficient value J_2 will break and conduction start.

Disadvantages:

This type of triggering causes local hotspot and may causes thermal runway

This triggering can't be control.

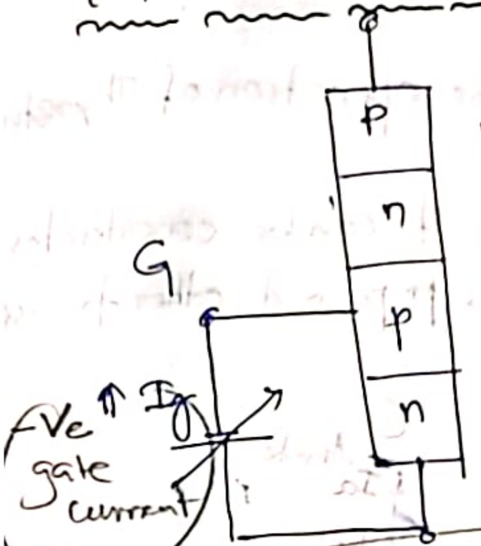
⑤ Light Triggering:

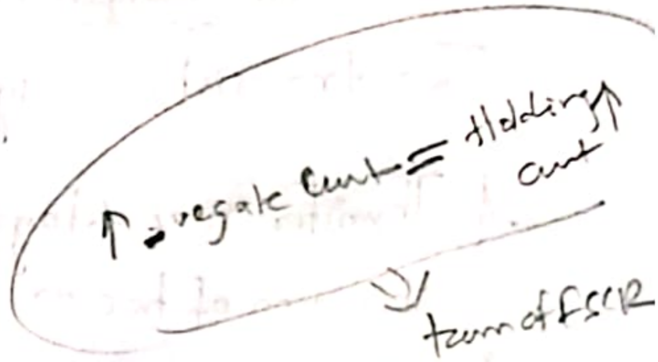
In this method the inner p-layer is radiated with a light ray of an appropriate wavelength and intensity.

With this free charge carriers will be injected in the junction J_2, with this the SCR turns on.

This technique is called as Light activated SCR.

Gate Turn OFF SCR:





By increasing negative gate Current, we can increase holding Current to turn off the SCR.

In some specially designed SCR the characteristics are such that a negative gate current increases the holding current and the current. So that it exceeds the load current and the device turns OFF.

The turn off process of an SCR is called Commutation.

The terms 'Commutation' means the transforma of Current from one path to another path. So the commutation ckt does this job by reducing the Forward (anode) Current to zero.

Based on the manner in which the zero current ho and arrangement of ~~cap~~ commutating components the forced commutation is classified as different type.

1. Class A
2. Class B
3. Class C
4. Class D
5. Class E

Commutation

* Commutation is a process to turn OFF Thyristor (SCR)
- To get desired output for given power electronics circuit, turning of OFF operation of SCR should be preciously timed.
- Turning ON process can be done by Gate pulse but for turning OFF, there is no direct switch.

classification of Commutation

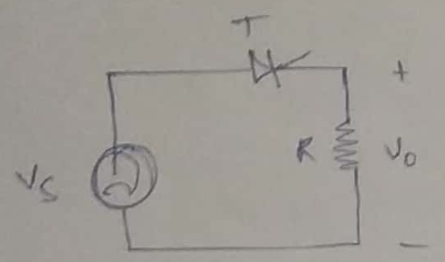
Commutation (depeding on supply)

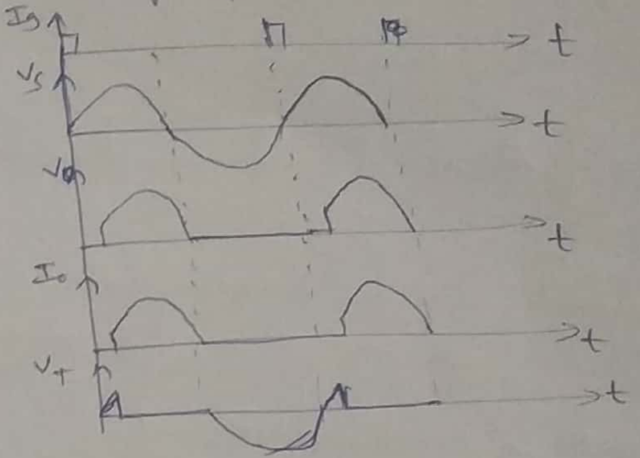
- Natural Commutation or Line Commutation [For AC supply]
  - (class F Commutation)
- Forced Commutation [For DC supply]
  - class A (Load Commutation)
  - class B (Resonant pulse Commutation / Current Commutation)
  - class C (Impulse/ Complimentary Commutation)
  - class D (voltage Commutation)

Natural Commutation or Line Commutation - class F Commutation:

- Generally, if we consider AC supply, the current will flow through the zero crossing line while going from positive peak to negative peak. Thus, a reverse voltage will appear across the device simultaneously which will turn off the thyristor immediately.

- this process is called as natural commutation as thyristor is turned off naturally without using any external components or circuit or supply for commutation purpose.



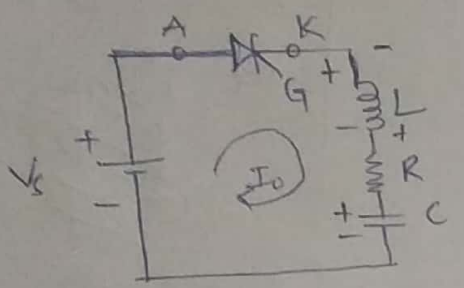


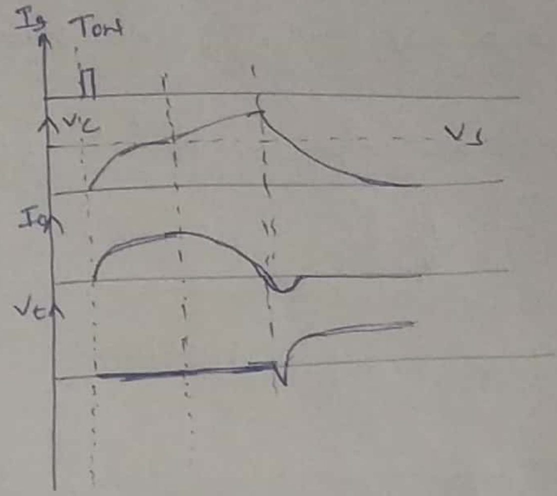
Forced Commutation:

Class A Commutation: or Load Commutation

Class A Commutation is also known as Load Commutation. In this commutation, SCR is OFF by load current.

Class A Commutation Circuit:





where

V_s = Supply Voltage

R = Load Resistance

L & C are commutating elements

Inductor and Capacitor are used to turn OFF the SCR.

Working:

⇒ By applying gate pulse (I_g) to the SCR, SCR will turn ON, then current will flow in the circuit.

$$I_o = \frac{V_s}{Z}$$

Apply Laplace transform on both sides

$$I_o = \frac{V_s/s}{R+Ls+1/Cs}$$

Multiply with s and divided by L on both NUM & DEN

$$I_o = \frac{V_s/s \cdot \frac{s}{L}}{\frac{R}{L}\cdot s + \frac{L}{L}\cdot s\cdot s + \frac{1}{Cs}\cdot\frac{s}{L}}$$

$$I_o = \frac{V_s/L}{s^2+\frac{R}{L}\cdot s+\frac{1}{LC}}$$

So characteristic equation will be

$$s^2 + \frac{R}{L}s + \frac{1}{LC} = 0 \longrightarrow (1)$$

standard characteristic equation is

$$s^2 + 2\xi\omega_n s + \omega_n^2 = 0 \longrightarrow (2)$$

Compare eqn (1) & (2), we have

$$2\xi\omega_n = \frac{R}{L}, \quad \omega_n^2 = \frac{1}{LC}$$

$$\boxed{\xi = \frac{R}{2}\sqrt{\frac{C}{L}}, \quad \omega_n = \sqrt{\frac{1}{LC}}}$$

$$\xi = \frac{R}{2\omega_n L} = \frac{R}{2L}\sqrt{\frac{LC}{1}}$$

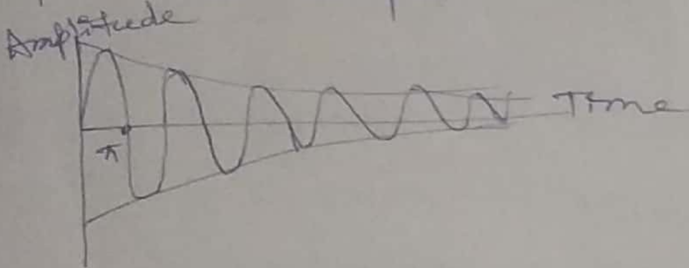
$$2\xi\omega_n = \frac{R}{L}$$

$$2\xi\left(\frac{1}{\sqrt{LC}}\right) = \frac{R}{L}$$

$$\xi = \frac{R}{2L}\sqrt{LC}$$

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

For under damped system



⇒ For under damped system, $\xi < 1$, for stability.

$$\therefore 1 > \frac{R}{2}\sqrt{\frac{C}{L}}$$

$$\therefore R^2 < \frac{4L}{C}$$

Here resonant frequency is

$$\omega_r = \omega_n\sqrt{1-\xi^2}$$

* To turn OFF SCR, $I_A < I_H$
* Here, SCR can stay ON during 0 to π

maximum conduction time of SCR is t, then

$$\therefore t\omega_r = \pi$$

$$\therefore t = \frac{\pi}{\omega_r}$$

$$\therefore t = \frac{\pi}{\omega_n\sqrt{1-\xi^2}}$$

* Turn ON time of SCR for α firing angle will be, $t = \frac{\pi - \alpha}{\omega_n\sqrt{1-\xi^2}}$

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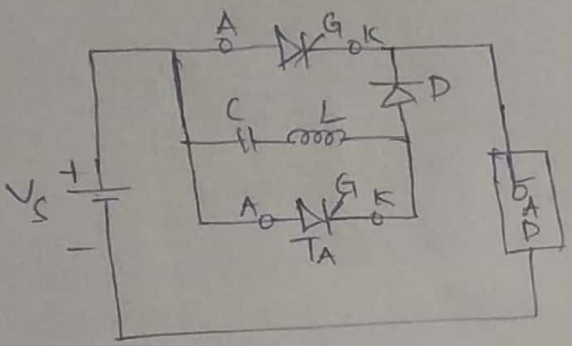
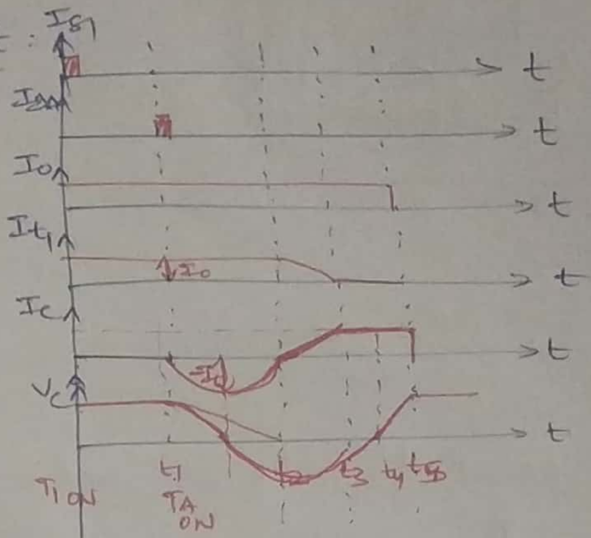
Class B Commutation :

Class B Commutation is also called as current commutation or resonant pulse commutation

Class B Commutation Circuit :

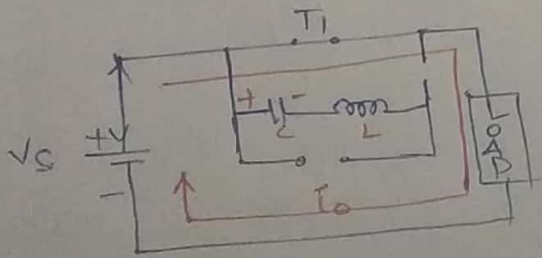




For understanding of class B commutation process, we have to make some assumptions.

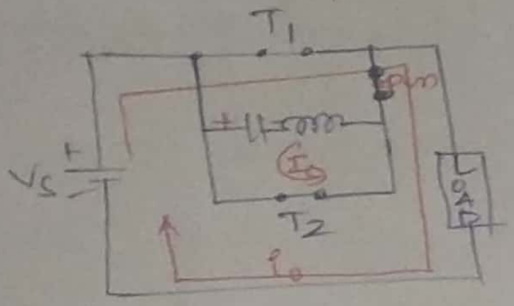
- Load current is constant
- LC circuit is resonating in nature.
- C is initially charged by Vs.

Mode I : When T_1 is "ON"

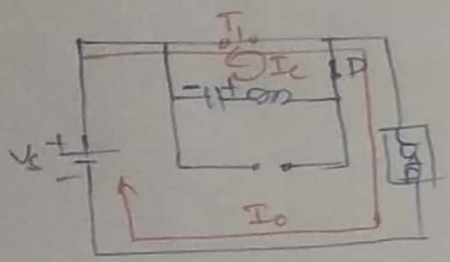


Mode II: At, $t = t_1$

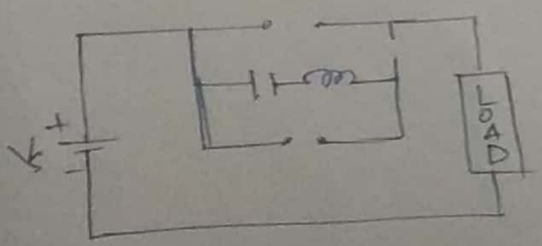
T_A-ON & T_1-ON



Mode III: At $t = t_2$ & T_A-OFF, and D-ON



Mode IV: At $t = t_3$, $i_c = I_0$ (in opposition), T_1-OFF, T_A-OFF



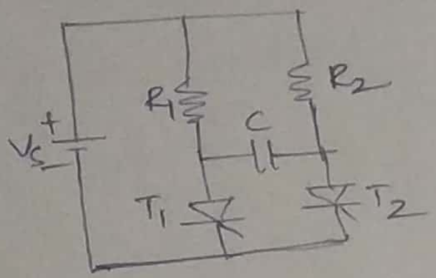
$I_c = -I_p \sin \omega_0 t$

$V_c = V_s \cos \omega_0 t$

Class C Commutation.

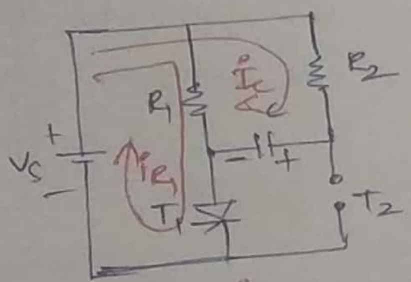
It is also referred as impulse commutation or complimentary commutation.

Class C Commutation Circuit.



In this commutation one SCR is considered as main SCR and the other as auxilary SCR.

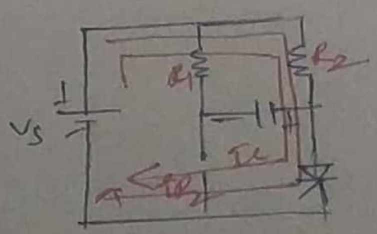
when T_1 - ON at $t = 0$.



$i_{t_1} = i_{r_1} + I_c$

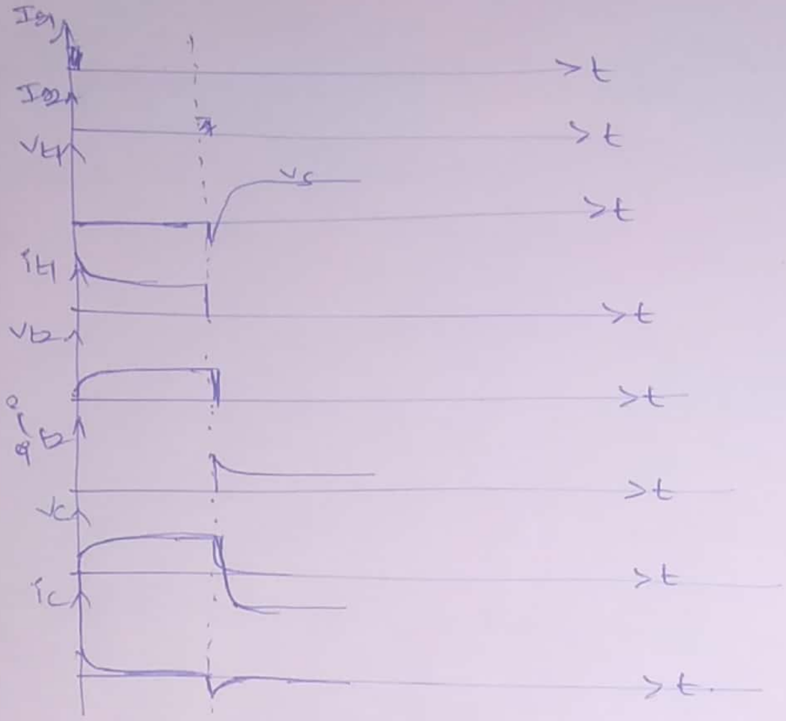
$i_{r_1} = V_s/R_1$, $i_c = V_s/R_2$

When T_2 - ON, at t_2.



$i_{r_1} = \frac{2V_s}{R_1}$, $i_c = V_s/R_2$

$i_{t_2} = \frac{V_s}{R_2} + \frac{2V_s}{R_1}$

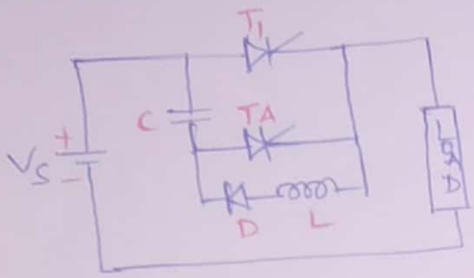


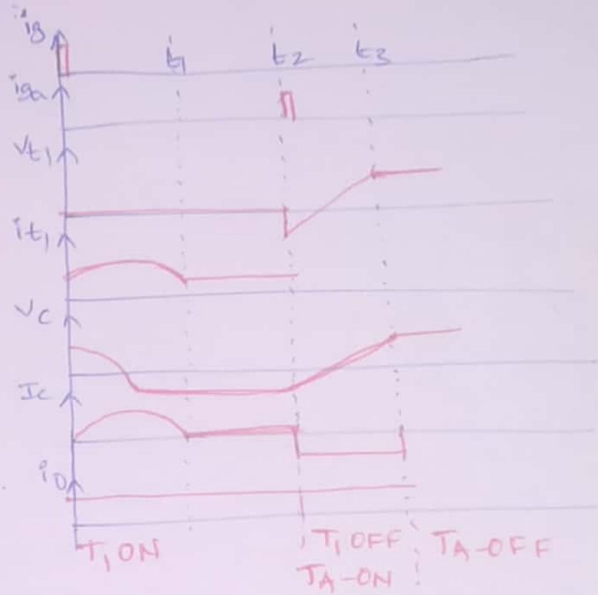
If the SCR T_2 is ON, then the capacitor will be charged up. If the SCR T_1 is ON, then the capacitor will discharge and this discharging current of C will oppose the flow of load current in T_2 as the capacitor is switched across T_2 via T_1.

Class D Commutation:

It is also referred as Voltage Commutation. and it is also called as Auxiliary commutation. It is also referred as parallel capacitor commutation.

Class D Commutation Circuit:

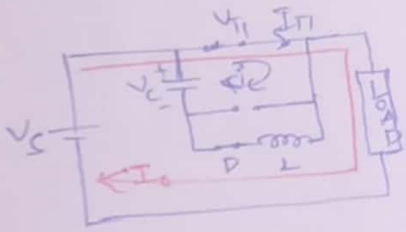




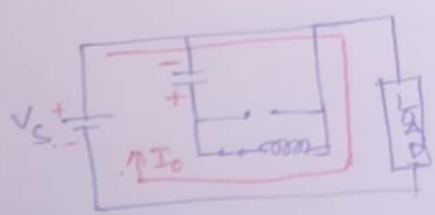
Assumption:

- Load current is Constant
- C is initially charged by Vs.

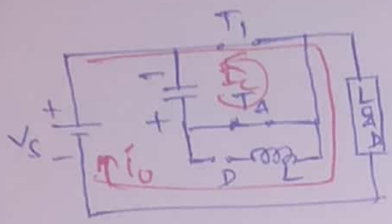
Mode I: At $t=0$, T_1 — ON



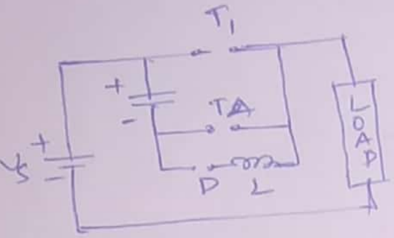
Mode II: At $t=t_1$, T_1 — ON



Mode – III : $t = t_2$, T_1 & T_A – ON,

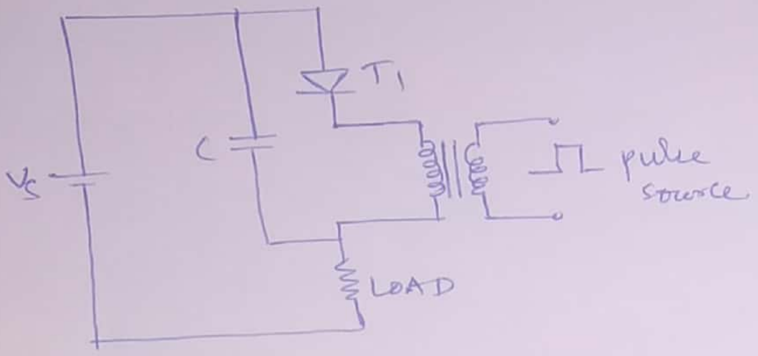


Mode IV :



class E Commutation :

External pulse source for Commutation:



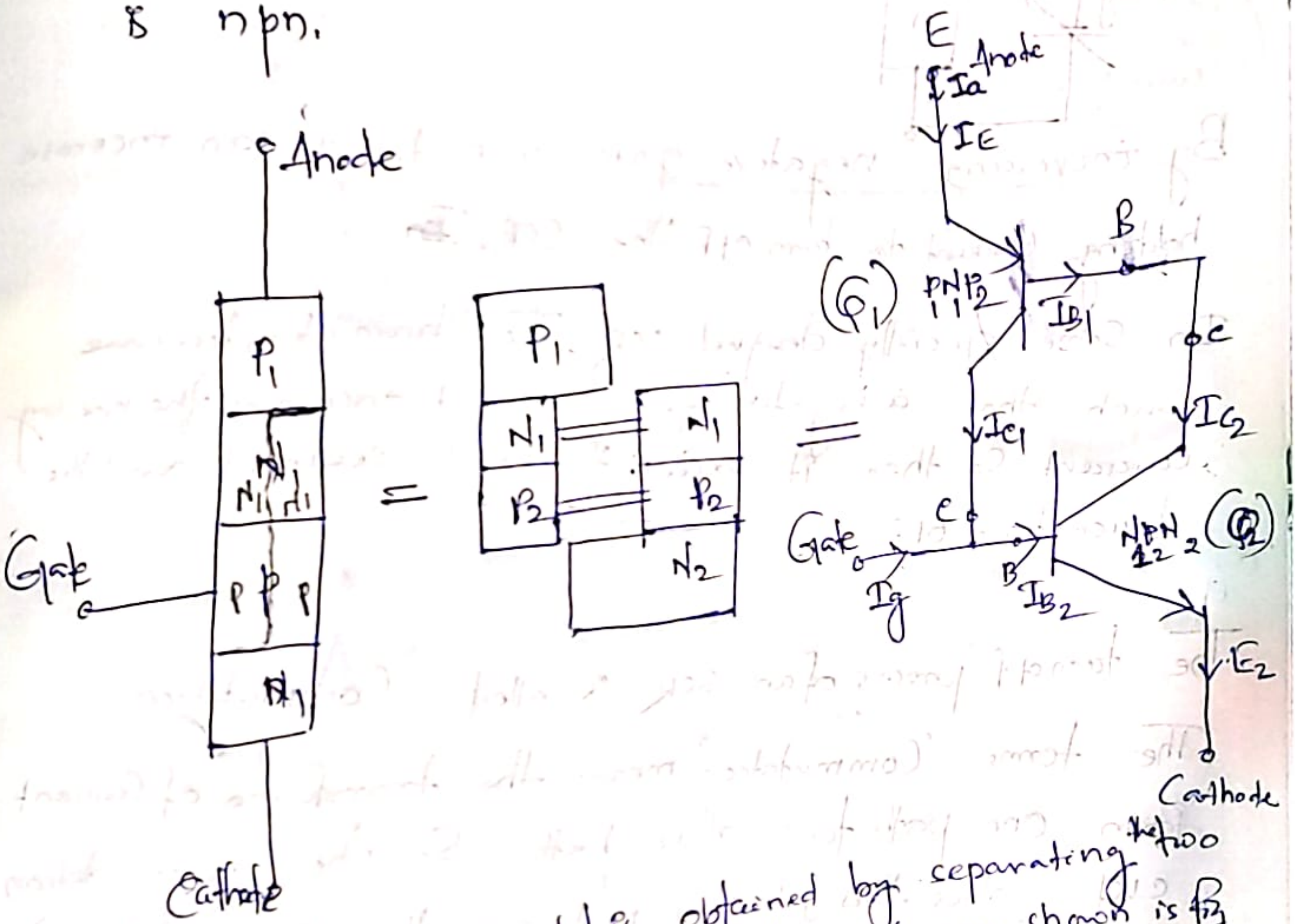
- For the class E commutation techniques, a transformer which can not saturate (as it is having a sufficient iron and air gap) and capable to carry the load current with small voltage drop compared with the supply voltage.
- If the SCR T is triggered, then the current will flow through the load and pulse transformer.
- An external pulse generator is used to generate a positive pulse which is supplied to the cathode of the thyristor through pulse transformer.
- the capacitor C is charged to around V and it is considered to have zero impedance for the turn off pulse duration. The voltage across the thyristor is reversed by the pulse from the electrical transformer which supplies the reverse recovery current, and for the required turn off time it holds the negative voltage.

Date: 11/02/2020

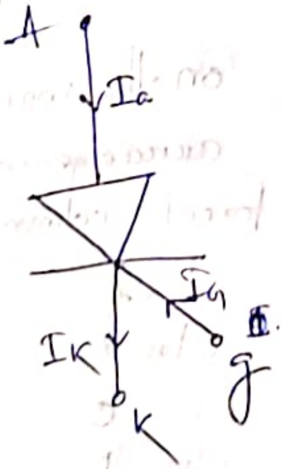
Two Transistor analysis of SCR:

Two transistor analysis explains the operation of Thyristor.

A Thyristor is a 4 layer PNP device it can be considered as combination of two transistor. One is pnp and other transistor is npn.



Two transistor model is obtained by separating the two middle layers of thyristor into two parts as shown is fig.



$I_a = I_{E1}$

$I_{B1} = I_{C2}$

$I_{B2} = I_c + I_g$

$I_C = I_g + I_c$

$I_{E2} = I_K$

If common base current gain of Q_1 & Q_2 is α_1 & α_2, then

$$I_{C_1} = \alpha_1 I_{E_1} + I_{CO1}$$

$$I_{C_2} = \alpha I_{E_2} + I_{CO2}$$

$I_a = ?$

From Q_2 transistor we have, $I_{E_2} = I_{C_2} + I_{B_2}$.

$$I_{E_2} = I_{C_2} + I_{B_2}$$

$$I_{E2} = I_{C_2} + (I_{C_1} + I_g)$$

$$I_K = I_{C_1} + I_{C_2} + I_g$$

$$I_a + \cancel{I_g} = I_{C_1} + I_{C_2} + \cancel{I_g}$$

$$I_a = I_{C_1} + I_{C_2}$$

$$I_a = \alpha_1 I_{E_1} + I_{CO1} + \alpha_2 I_{E_2} + I_{CO2}$$

$$= \alpha_1 I_{E1} + I_{CO1} + \alpha_2 I_K + I_{CO2}$$

$$= \alpha_1 I_a + I_{CO1} + \alpha_2 (I_a + I_g) + I_{CO2}$$

$$= \alpha_1 I_a + I_{CO1} + \alpha_2 I_a + \alpha_2 I_g + I_{CO2}$$

$$I_a - \alpha_1 I_a - \alpha_2 I_a = I_{CO1} + \alpha_2 I_g + I_{CO2}$$

$$I_a (1 - (\alpha_1 + \alpha_2)) = I_{CO1} + \alpha_2 I_g + I_{CO2}$$

$$I_a = \frac{I_{CO1} + \alpha_2 I_g + I_{CO2}}{1 - (\alpha_1 + \alpha_2)} \quad (1)$$

Expression

From the above eqn. If I_{CO1} and I_{CO2} of transistor Q_1 and Q_2 are negligible very small.

$$\uparrow I_a = \frac{\alpha_2 I_g \uparrow}{1-(\alpha_1+\alpha_2)} \quad \text{--- (2)}$$

If $\alpha_1+\alpha_2 = 1$, then anode current becomes $\alpha_2 I_g$ (is ∞)

Hence, Thyristor enters into conducting state to non-conducting state. from the above expression (1) the anode current is depends on.

(a) $\alpha_1 \alpha_2$ (~~Small current Gain~~)

(b) Gate Current (I_g)

(c) leakage Current I_{CO1} & I_{CO2}

(d) α_1 & α_2 Small current gain

⇒ for Silicon transistor ammeter current is very low at low α. with increasing in Emitter Current (I_E) α, α builds ups rapidly.

If α_1, α_2 made unity that is α_1 and α_2 equal to 1

i.e. ($\alpha_1+\alpha_2 = 1$)

The anode current tends to ∞

And the SCR which is in Forward Blocking State changes to Forward conduction state.

(i) Gate Current (I_g):

When the anode is made +ve and the gate current $I_g = 0$, The anode current is equal to. leakage current I_{CO1}, I_{CO2}

When the sufficient gate current (I_g) is injected in transistor Q_2. The base current of transistor Q_2. gets increase.

The Emitter current I_{E2} of transistor Q_2 gets increased. Then SCR is going to turn ON.

(ii) leakage current (I_{CO1}, I_{CO2}):

When anode is made positive junction J_1 and J_3 are F.B. the applied voltage appears across the junction J_2 with this temprature. of the junction is increased and then I_{CO1}, I_{CO2} builds up.

Increasing in the leakage current will increase the ammeter current than $\alpha_1 + \alpha_2 = 1$ when the SCR is going to be turned ON.

Protection of SCR:

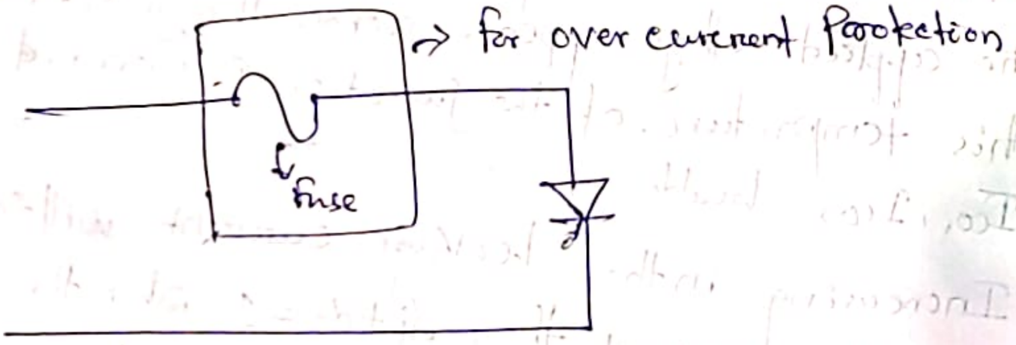
* Protection of device. is an important aspect for its reliable and efficient operation.
  * over current
  * over voltage
  * dv/dt protection
  * di/dt protection
  * Thermal Protection
  * Gate Protection

Thyristor have maximum current and voltage ratings when these ratings are exceeded the junction temprature of thyristor will increases this may cause its damage.

In addition a thyristor has maximum $\frac{di}{dt}$ and $\frac{dv}{dt}$ rating

① Over Current Protection:

When there is sudden changes happen in the ckt. high current passes through the device to avoide this high current we will use first acting fuses or high speed ckt breaker in series with the SCR.



② Over voltages:

There is two types of over voltages

① External over voltage

② Internal over voltage

* Internal Over Voltage:

After commutation of a thyristor reverse recovery current decay's abruptly with a high di/dt which causes a high reverse voltage, (as, $V = L\frac{di}{dt}$)

So, if di/dt is high then V will be large. That can be exceed the rated break over voltage and the device may damage

External Over Voltage:

These are caused due to various reasons in the supply like lightning such a conditions (abnormal voltage spike)

★ The effect of over voltage can be minimize by using Varistor (non linear resistor)

★ di/dt protection:

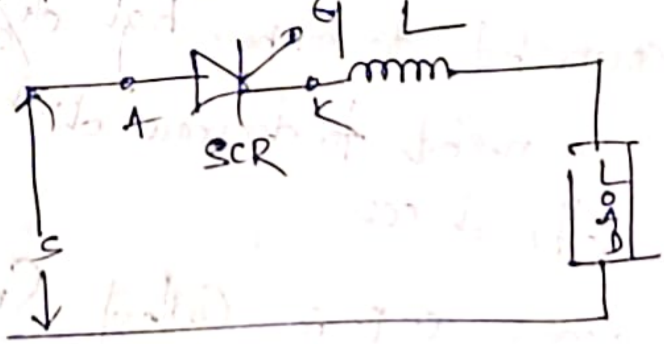
→ $\frac{di}{dt}$ is the rate of change of current in the device (SCR).

→ When SCR is in FB and it is ON by gate signal then there will be flow of anode current.

→ Anode current required a minimum time to spread inside the device.

→ $\frac{di}{dt}$ is greater than the spread velocity of charge then it creates hotspot that may damage SCR.

So, to maintain $\frac{di}{dt}$ through SCR we can connect inductor in series to the SCR.



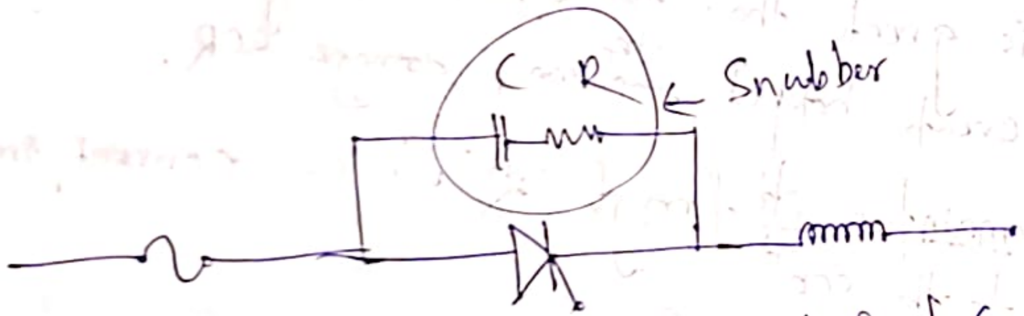
$\frac{dv}{dt}$ Protection:

- $\frac{dv}{dt}$ is the rate of change of voltage w.r.t time in device.
- Higher value of dv/dt may result into falls turn on SCR

With Forward Voltage across the anode & Cathode of a SCR the outer junctions J_1 & J_3 are Forward Bias and the middle junction on J_2 is reverse biased

The junction J_2 behaves like a capacitor due to change existing across the junction J_2

To protection $\frac{dv}{dt}$ P we use snubber ckt.



- Capacitor is connected to by pass high dv/dt through SCR.
- Resistor is Connected to decrease dischange current of Capacitor through SCR
- This RC across SCR is Called Snubber ckt.

Thermal Protection:

With the increase in temprature of the junction insulation may get fail. So, we have to take proper ~~safeguard to~~ measure to limit the temp. rise. we can achieve this by mounting the said thyrister on the heatsink.

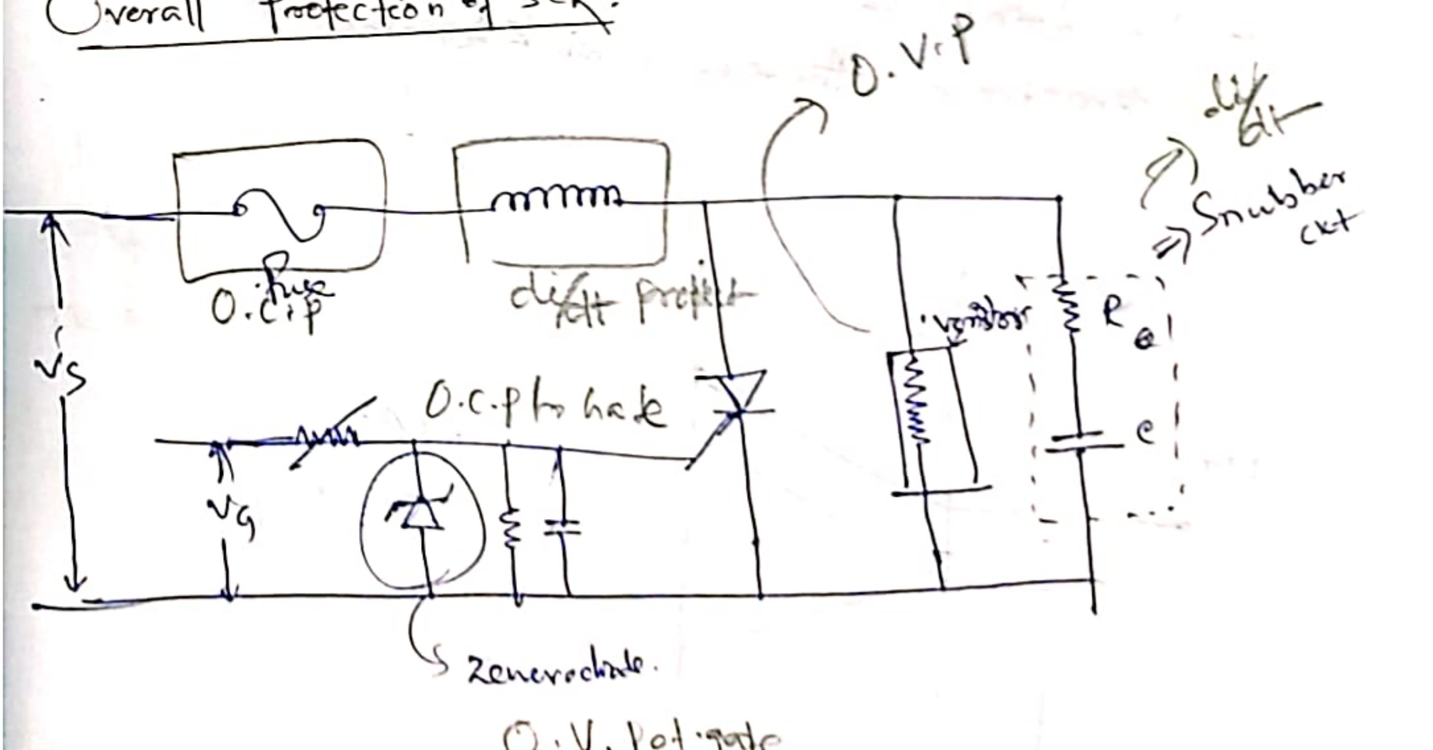
Gate Protection:

→ Over voltage ~~gate protection~~ across the gate can cause false triggering of the SCR.

→ Over current may rises junction temprature beyond specified limit leading to its damage.

→ Power voltage gate protection is achieved by using zenero diode in Reverse bias and a resister can be used to protect the gate circuit from over current.

Overall Protection of SCR:



O.V. pot. gate.

Date: 15/02/2020

1

TRIAC = TRI + AC

(TRIode for Alternating Current)

Triac is a 3 terminal device it is differ from the other Silicon control rectifiers. In the cence that it can conduct both direction.

Thee triode for Alternateng current.

Triode is advance version of diode.

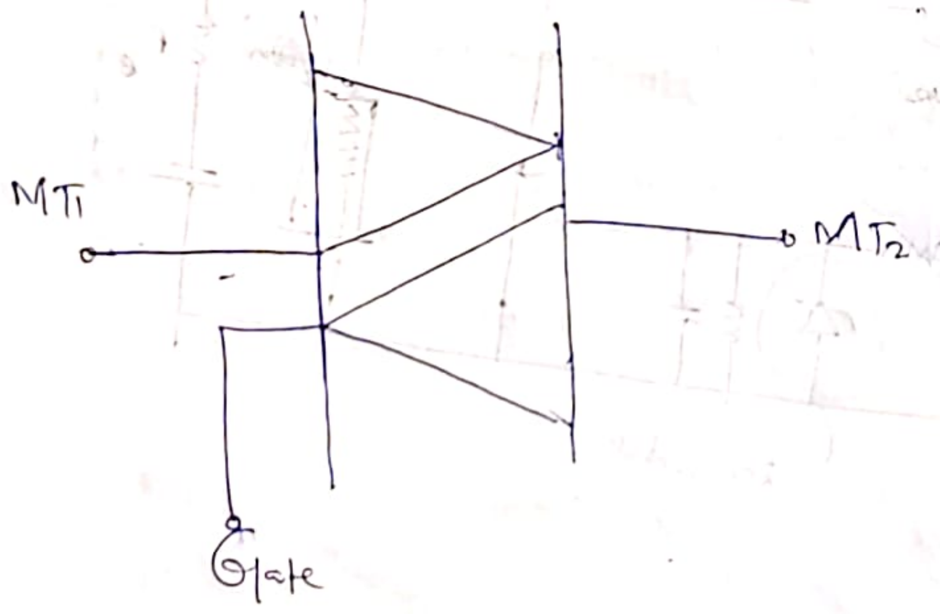
The difference betn triode and Diode is

1. Diode conducts only Forward Bias
2. Triode have controlleng terminal.

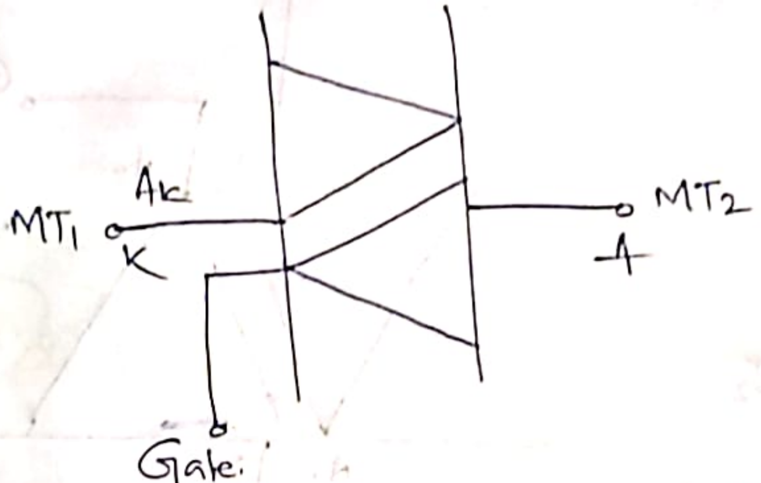
Unlike SCR triac end conducts both the directions. Simpli an SCR is unidirectional device as it can conducts only from anode to Cathode.

But a triac can conduct in both the direction so a triac is bidirectional thyrister with 3 terminal.

Symbole:



The trsac is equivalent to two SCR connected in ante parallel.



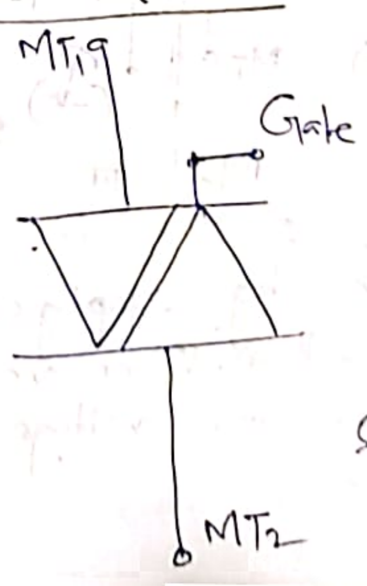
As the triac can conduct the both direction the terms anode and cathode cane applicable two triac.

It has 3 terminal are usually designed as MT1, MT2 (main terminal) and gate terminal. Wheather the gate signal is positive but it can conduct.

This is a 3 terminal 4 layer bidirectional semiconductor device that controls AC power.

Gate terminal is connected to both the 'n' and 'p' region due to which gate signal may be applied which is irrespective of the polarity of the signal.

TRIAC EQV CKT:



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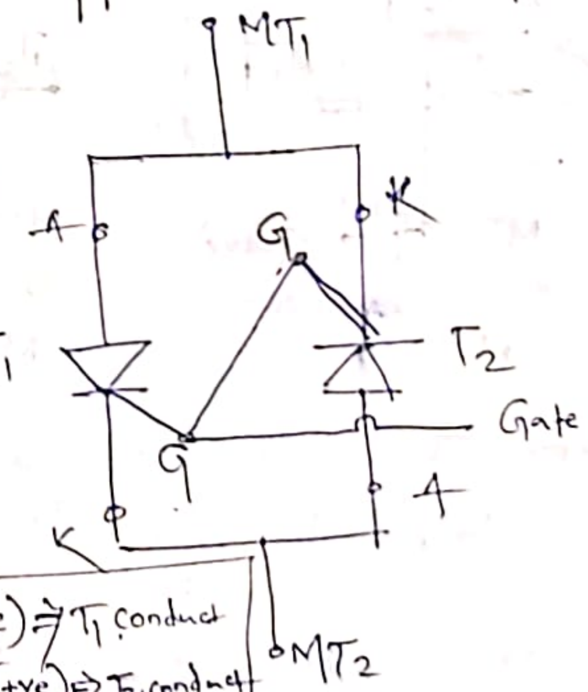
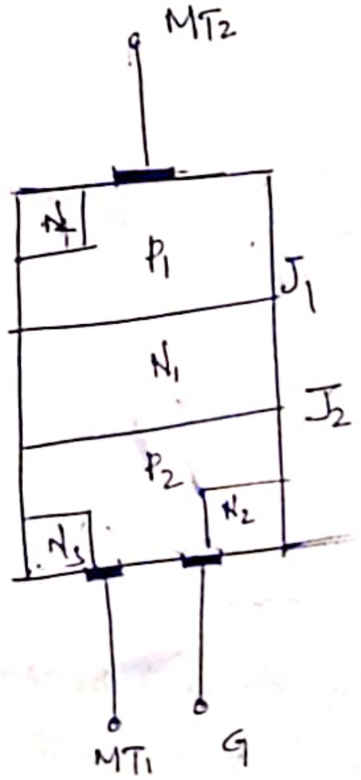
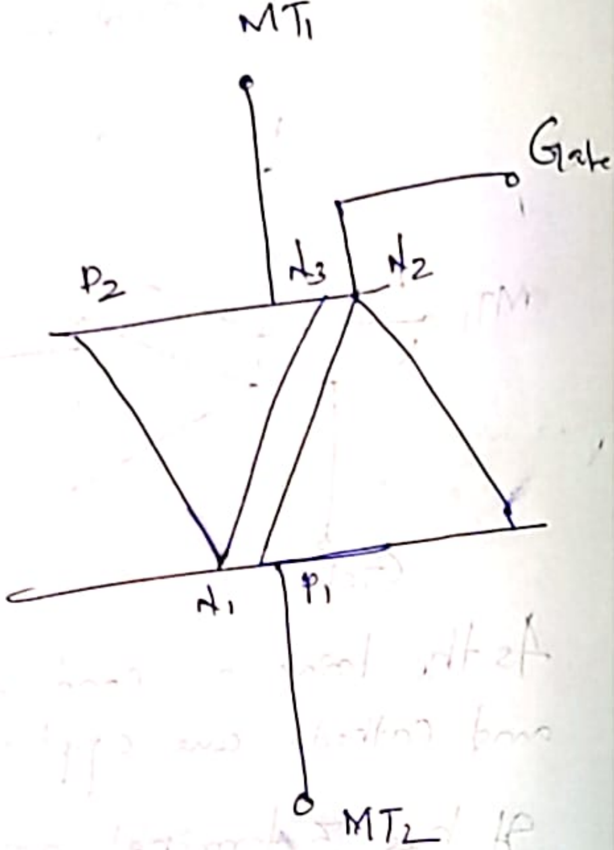


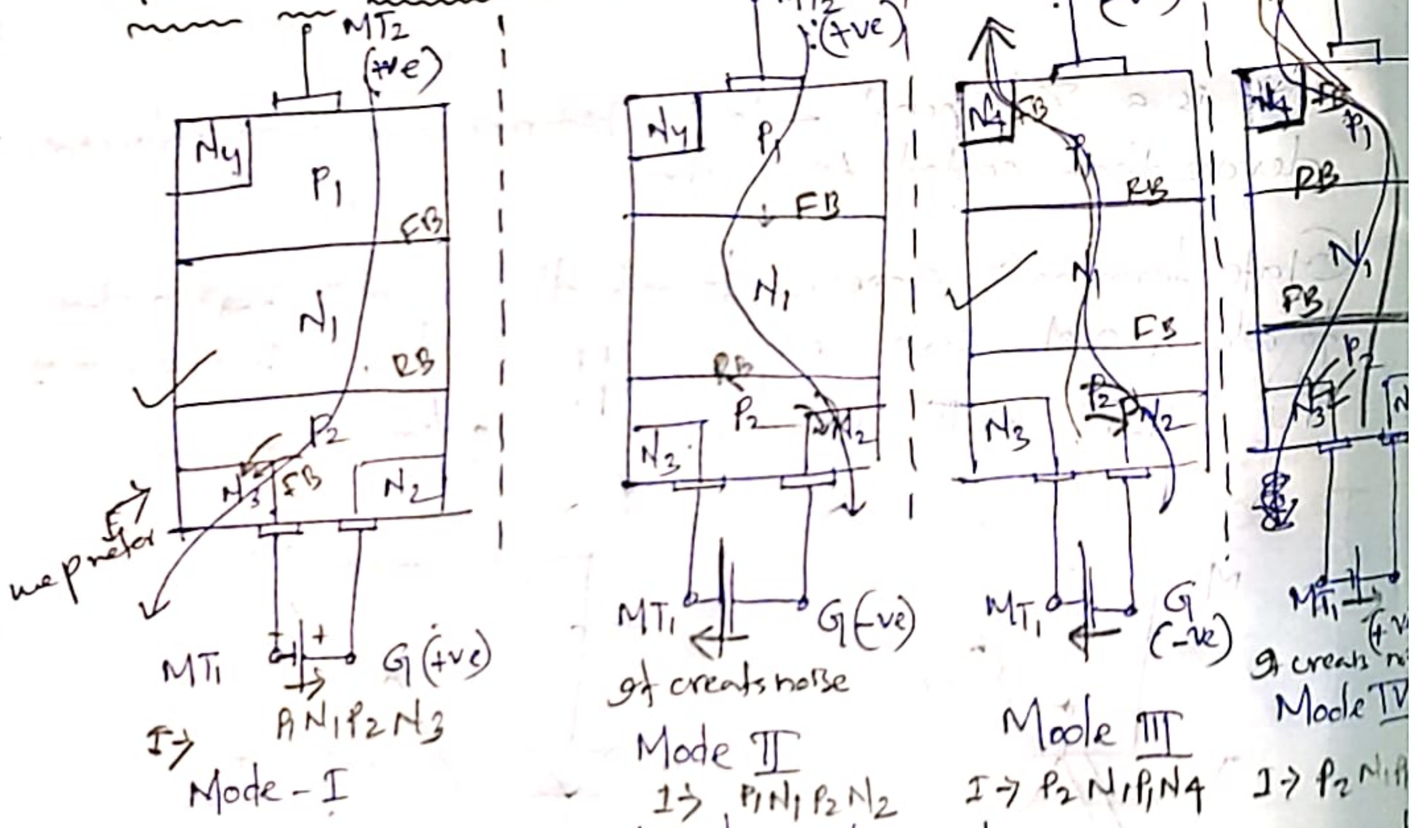
Suppose: MT1 is (+ve) ⇒ T1 conduct
MT2 is (+ve) ⇒ T2 conduct

TRIAC STRUCTURE:





MODES OF OPERATION OF TRIAC:



NOTE: The triac can be turned on by applying gat voltage higher than the breakover voltage. When voltage model applied is less than the breakover voltage we use triggering method to turn it on.

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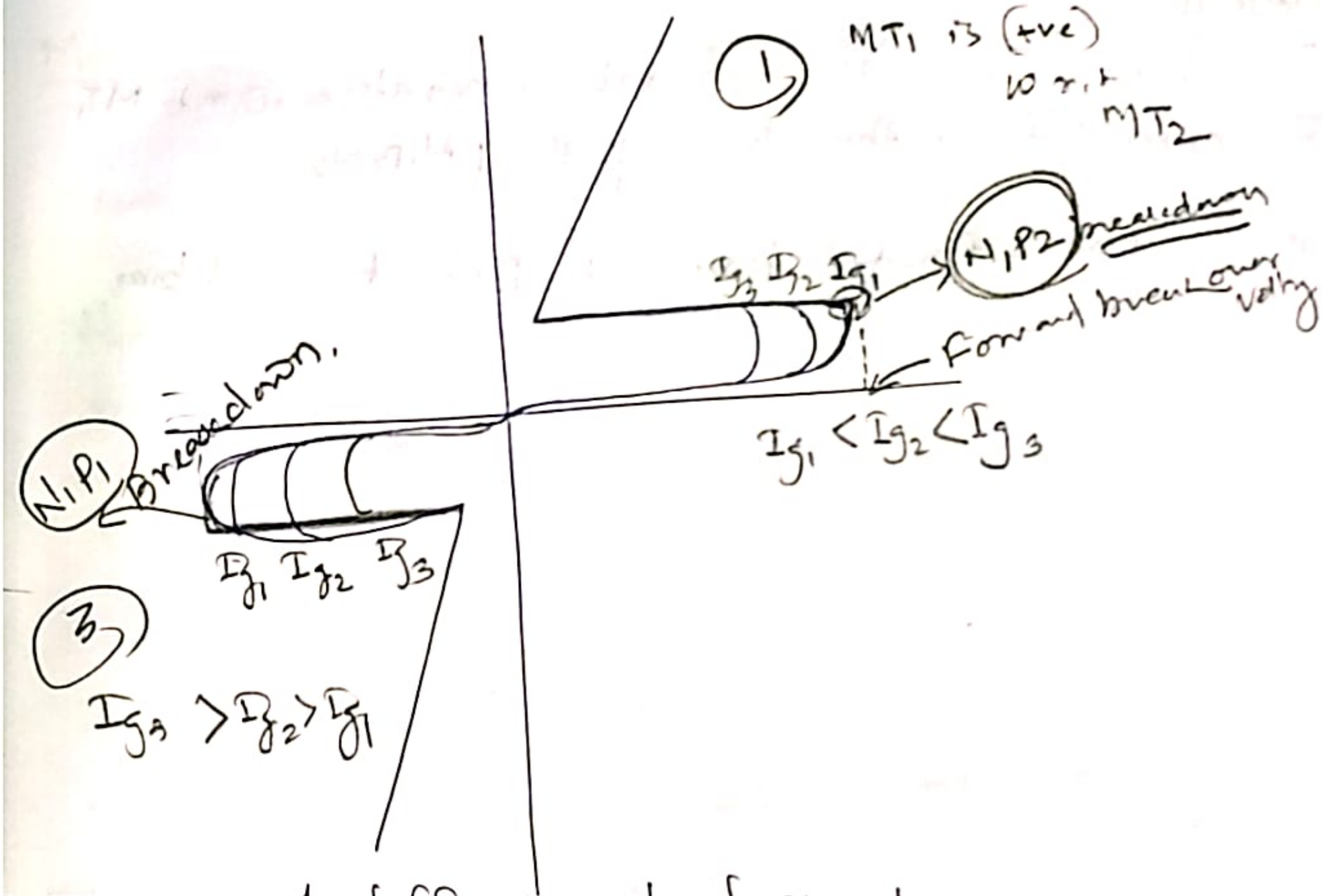


There are 4 defferent mode of operaton.

(i) **Mode I:** When MT_2 and Gate being positive with respect to MT_1 when this happens. Current flows through the path. $P_1N_1P_2N_3$.

Here. P_1N_1 and P_2N_3 are forward bias but N_1P_2 is reverse bias.

The triac is said to be operated in +vely biased region positive gate with respect to MT_1 forward biases P_2 & N_3 and break down occurs.

when gate terminal is +ve w.r.t MT_1, gate current flows through P_2N_2 Junction like an ordinary SCR. When gate current has injected Sufficient charge carries into P_2 layer. Reverse bias in junction N_1P_2 breaks down Just as in a normal SCR. As a result the triac Starts conducting through $P_1N_1P_2N_3$. Current direction is $P_1N_1P_2N_3$

Mode II :

When MT_2 is +ve and gate is negateve w.r.t MT_1
The current flows through the path $P_1N_1P_2N_2$.

Here, P_1N_1, forward bias and P_2N_2 forward bias.

Mode III

when MT_2 is (-ve) and Gate is also (-ve), w.r.t MT_1.
The current flows through the path $N_2P_2N_1P_1N_4$.

Here. P_2N_1 and P_1N_4 are in the forward Bias.

Mode IV

When MT_2 is (-ve) and gate is also (-ve) w.r.t MT_1. The current flows through the path $N_3 P_2 N_1 P_1 N_4$.

Here, Two junction P_2N_1 and P_1N_4 are Forward Bias But N_1P_1 are Reverse bias. The triac is said to be negatively biased region.

Charge carriers are injected so the triac tension. This mode of operation has the disadvantages that it can't be use for high $\frac{di}{dt}$ ckt.

NOTE:

* Sensitivity of triggering in Mode I and Mod III are high and if magnical triggering capability required negative gate pulses should be used.
* triggering is mode 1 is more sensitive than mode 2 & Mode 3.

Characteristics of TRIAC:

Triac characteristics are similar to SCR. But it is applicable to both -ve and +ve triac voltage.

The operation can be summerise as follows:

First Quandrant Operation of triac:

Voltage at terminal MT_2 is (+ve) w.r.t MT_1 and gate voltage is also positive w.r.t MT_1.

2nd Quandrant Operation of triac:

Application of Triac:

1. lamps Control.
2. Speed control of fans
3. Chopper ckt.
4. 1c phase controls

Assignment:

1) Advantages and disadvantages of TRIAC

* Advantages:

- The triac need single pulse of protection.
- It can be triggered with positive or negative polarity of gate pulses.
- A safe breakdown in either direction is possible but for SCR protection should be given with parallel diode.
- It needs only a single heat sink of slightly larger size where as for SCR two heat sinks should be required of smaller size
- When the voltage is reduce to zero the TRIAC turns OFF.

* Disadvantages:

- It can be triggered in any direction so we need to be careful about triggering ckt
- As compared to SCR (Silicon controlled rectifier) it has low ratings.
- The TRIACs are not much reliable as compared to SCR.
- This is not suitable for DC applications.
- The dv/dt rating is very low as compare to SCR.
- It has high switching delay.

Date: 17/02/2020

DI + AC

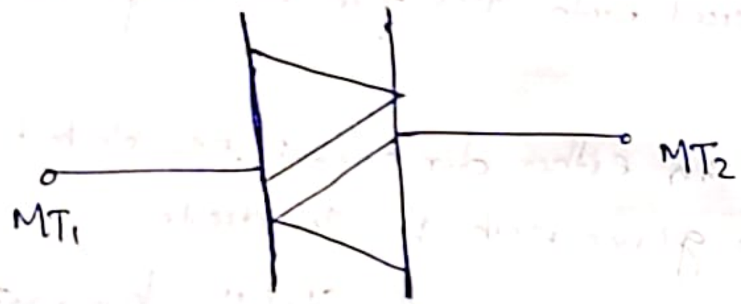
DIAC:

DIAC stands for Diode for alternating current.

A diode is a device which has two electrodes and there is no gate terminal unlike other semiconductor device.

It is used in AC circuit along with triac usually DIAC is used for TRIAC triggering.

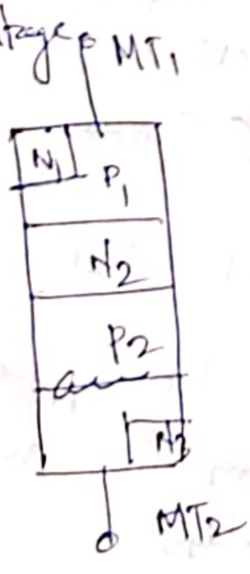
CKT SYMBOL:



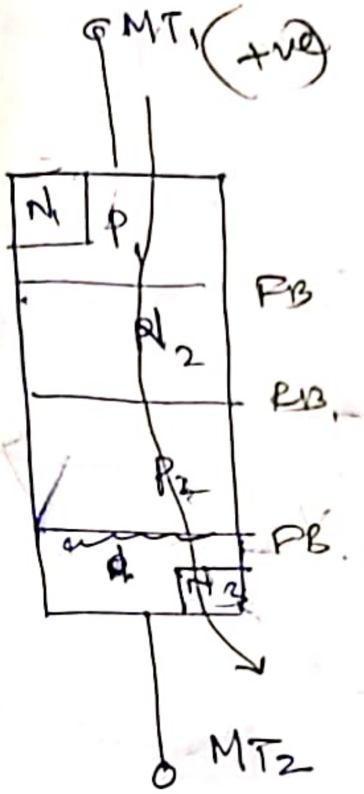
STRUCTURE OF DIOD:

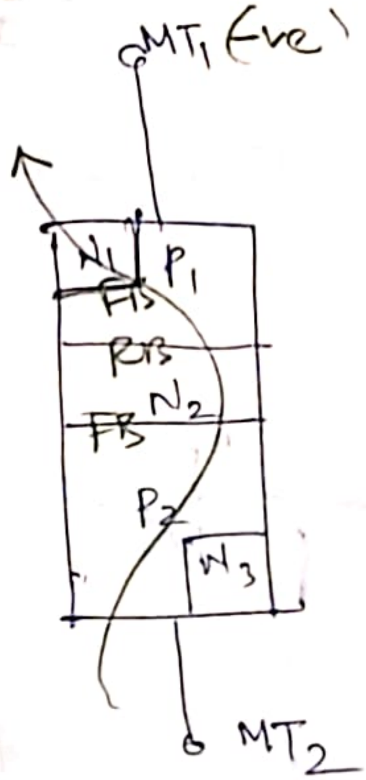
It is a device which consist of 4 layer and two terminals. ~~There is no b.~~ The constructor is almost same as transistor. But there is no base terminal in diode. The 3 regions having same doping level.

It gives symmetrical switching characteristics for either polarity of voltage.



OPERATION:





A diac is a diode that conducts electrical current only after the breakover voltage has been reached.

Case I:

MT1 is more positive with respect to MT2. The P_1N_2 & junction ~~will be~~ are F.B. and N_2P_2 junction reverse Bias ~~The current~~

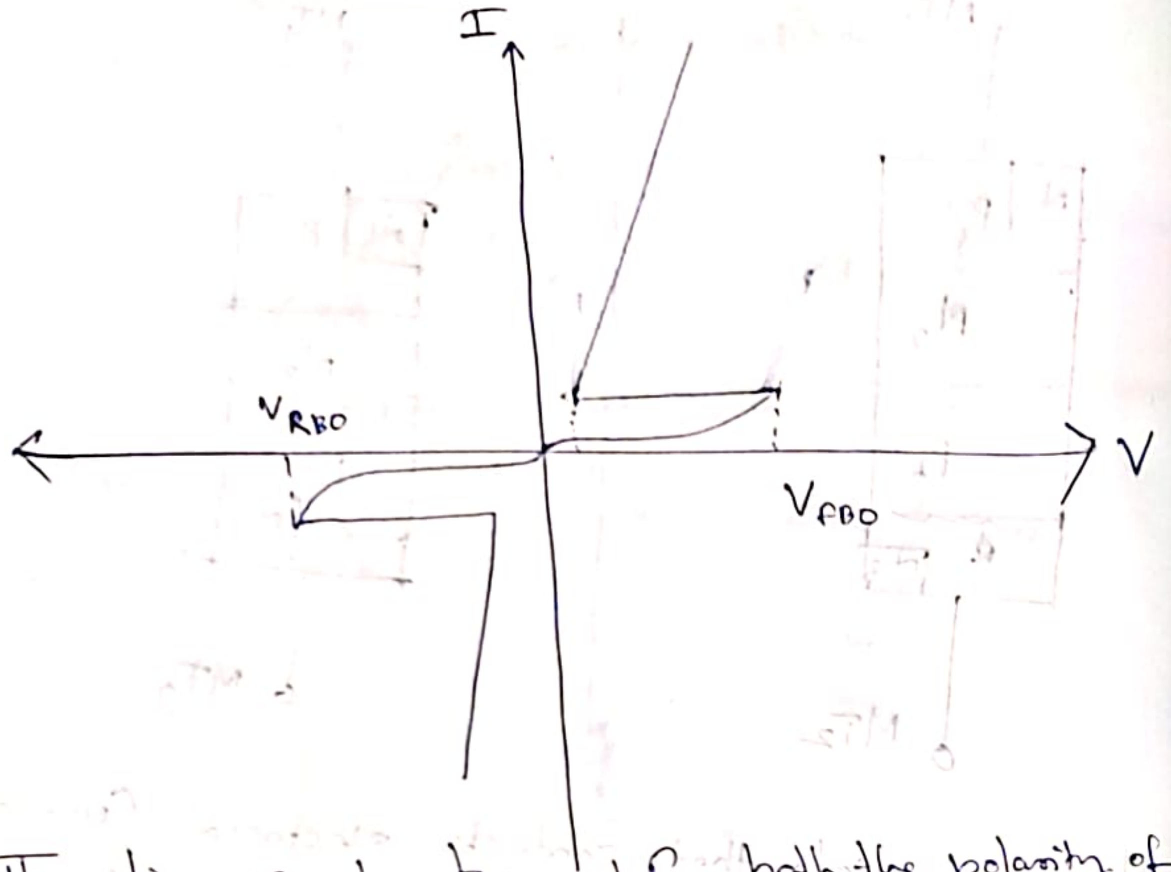
Once we apply breakover voltage betn MT1 and MT2 then the junction N_2P_2 will breaks and conducts. The flow of current which $P_1N_2P_2N_3$

Case II:

MT2 is positive w.r.t MT1. Then P_2N_2 junction will be FB and P_1N_1 junction will be F.B. So, the current direction will be $P_2N_2P_1N_1$.

- Here, N_2P_1 are RB. Once we apply breakover voltage then junction N_2P_1 breaks then the current conducts.

CHARACTERISTICS OF DIAC:



The diac can be turn on for both the polarity of voltage. When MT_1 is more positive to MT_2.

When the applied voltage in higher polarity i.e. +ve or -ve exceeds the break over voltage diac current rises as the device conducts with VI characteristics.

The V~I characteristics looks like a Z

The DIAC acts as an open ckt when the voltage is less then its avalanche ~~voltage~~ breakdown voltage.

When the diac has to be turn off the voltage must be below its avalanch break down voltage.

APPLICATION OF DIAC :

The main application of DIAC is.

1. It uses in triac triggering
2. It can be used in lamp dimmer ckt
3. It can be used in heat control ckt
4. It is used in the Speed control of universal motors.

motor - Operate Either both AC or DC.

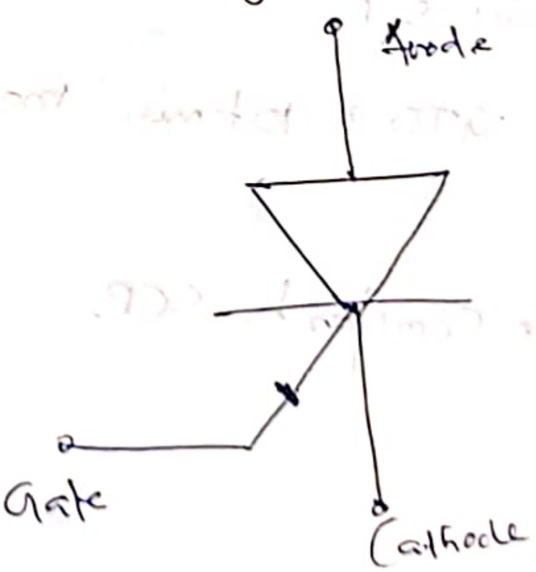
GTO:

GTO Stands for Gate Turn-off Thyristor. A GTO is a high power semiconductor device. GTO's are fully controlled switches which can be turn on and off by gate terminal.

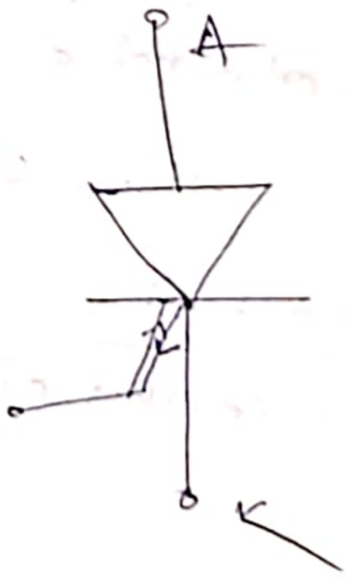
It is invented at GE (General Electric)

GTO SYMBOL:

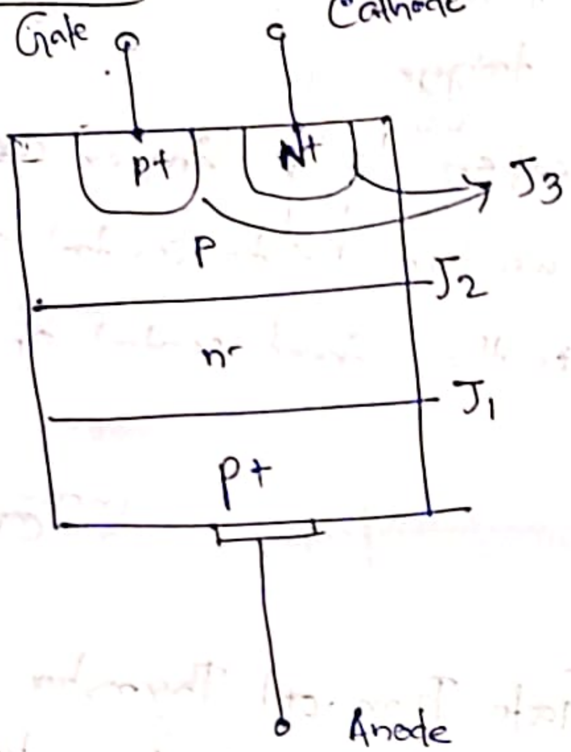
A GTO is 4 layer 3 terminal 3 junction PNPN device.



or.



GTO STRUCTURE:



OPERATION:

A GTO is turn ON by applying a positive gate current (I_g) A GTO is Forward Bias then it starts conduct.

A GTO can turn OFF by ~~+ve~~ -ve gate pulse or -ve gate terminal. ~~Turn ON~~

Turn ON is not as relaible as SCR.

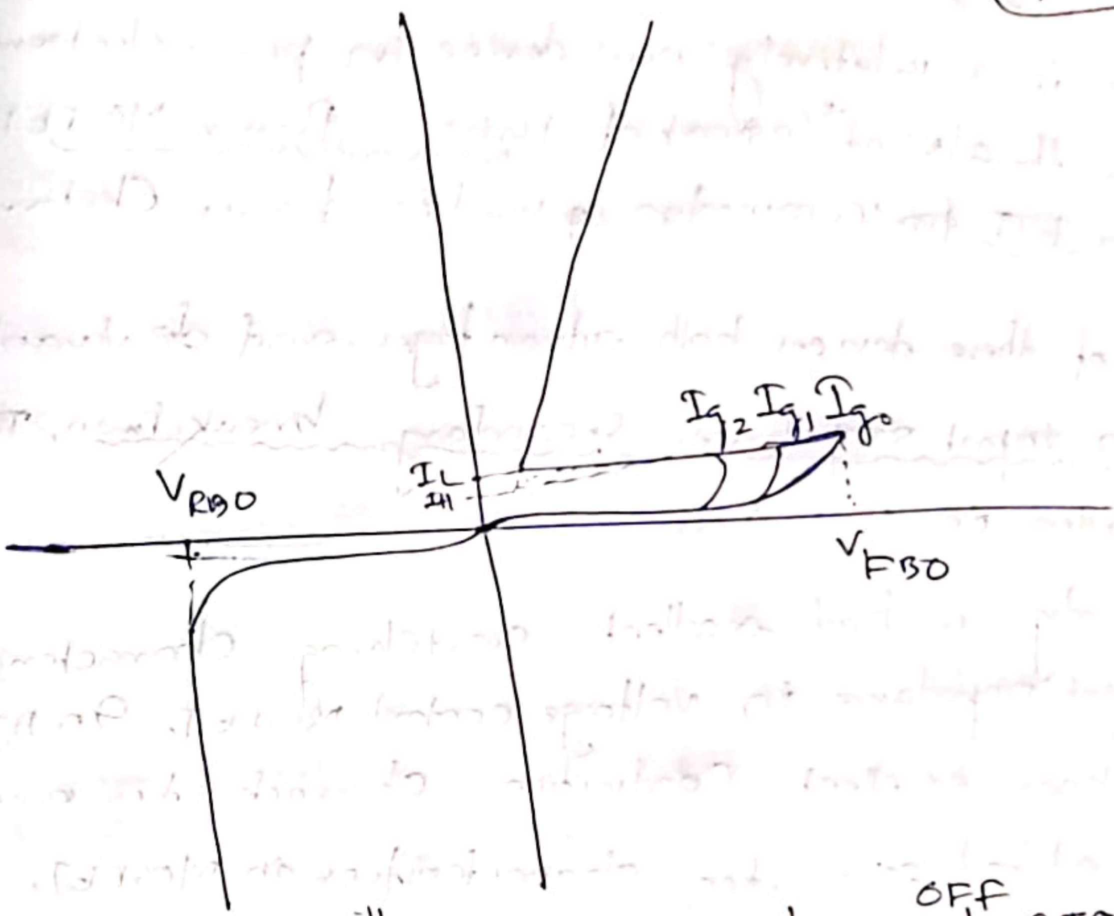
The switching speed of GTO is 10 times more than SCR.

characteristics:

Characteristics of GTO is Similar to SCR.

Static or V-I characteristics :

Exam 23 Feb



-ve gate pulse ~~of GTO will~~ will turn ~~out~~ OFF GTO.

Assignment: (1) Switching char of GTO

(2) Advantages & Disadvantages.

(3) Power MOSFET

IGBT:

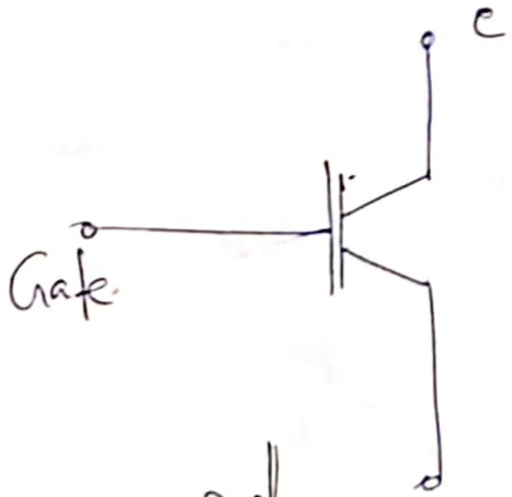
IGBT (Insulated Gate Bipolar transistor)

* IGBT is a relatively new device in power electronics before ~~the advent~~ the advent of IGBT Power MOSFET & Power BJT for commonly used in Power Electronics.

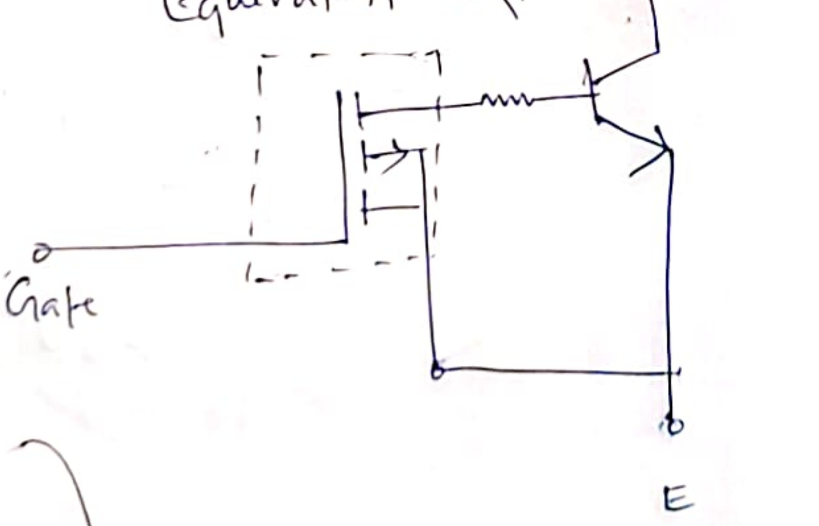
* Both of these devices both advantages and disadvantages bad switch, low input impedance, secondary breakdown, These are 3 problem. in power BJT.

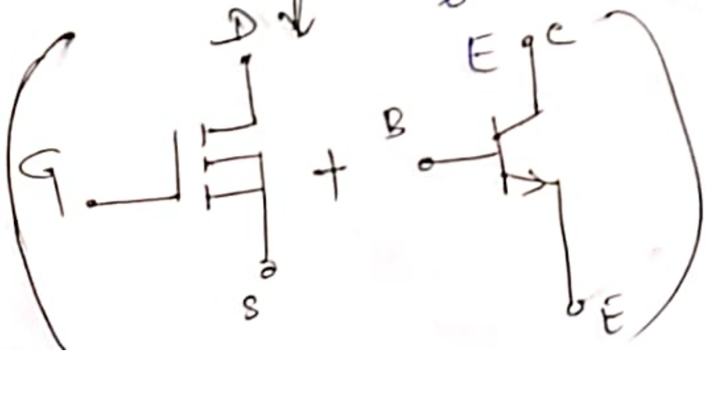
* Similarly we had excellent switching characteristics high input impedance in voltage control MOSFET. In BJT we have excellent conduction characteristics and we had bad conduction characteristics in MOSFET.

** IGBT has i/p characteristics like MOSFET and output characteristics like power BJT.



Equivalent ckt



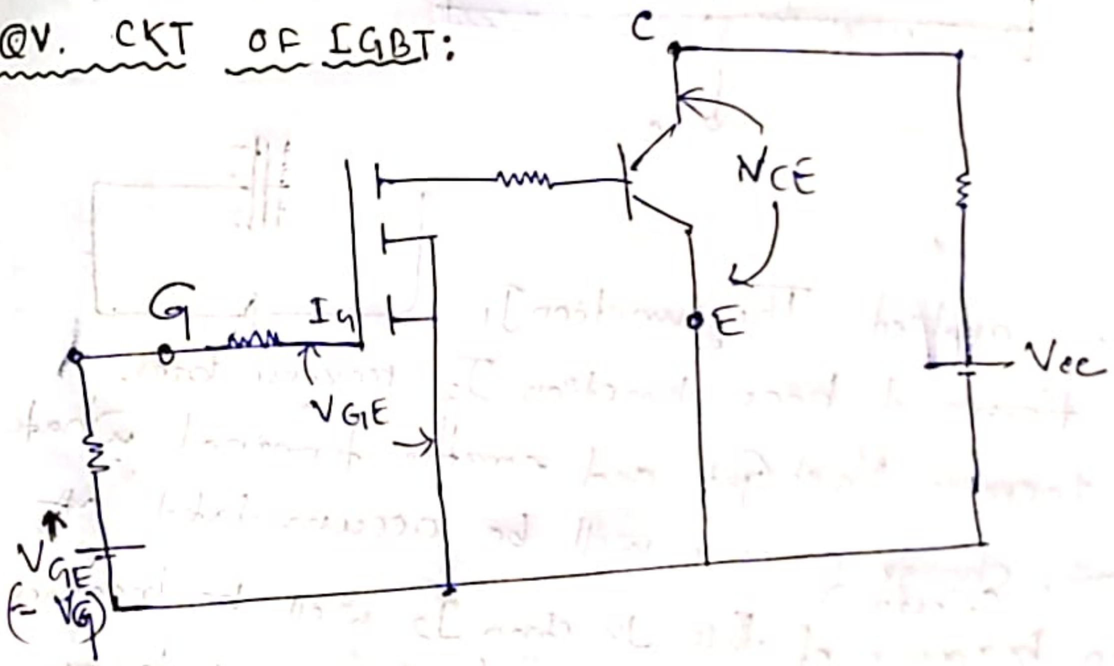


STRUCTURE:

Date: 18/02/2020

Its symbol is also amalgamation of the symbol of two parent devices. The 3 terminals of IGBT are Gate, Collector Emitter. IGBT is also known as various other name like, Metaloxide Insulated Gate transistor (MIG), Gate modulated field Effect transist. (GMFT). Insulated Gate Transistor.

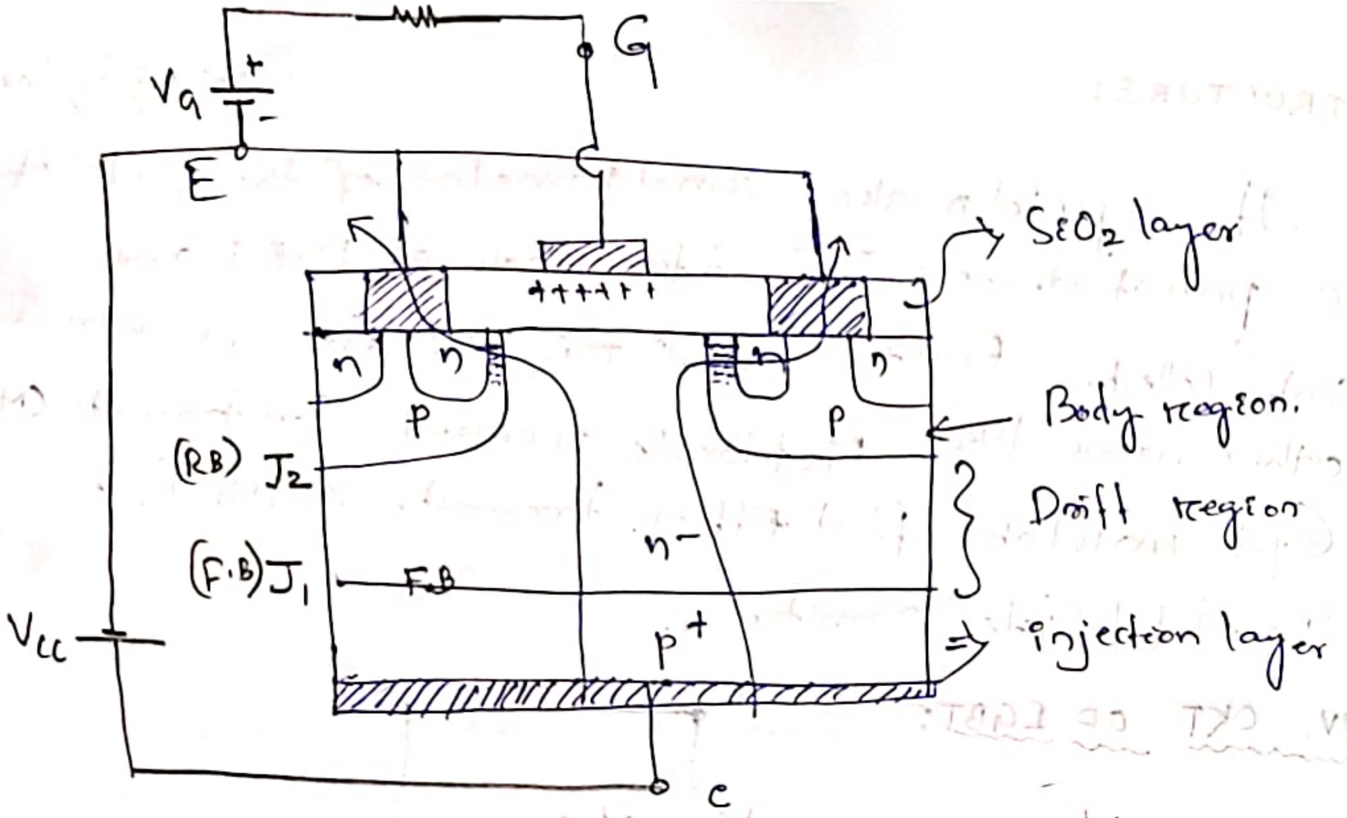
EQV. CKT OF IGBT:

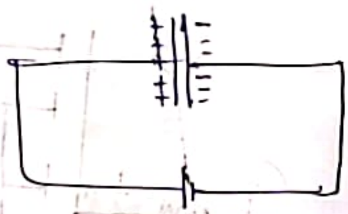


STRUCTURE:

Internal structure of IGBT:

★ The structure of IGBT is very much similar to that of P-MOSFET except one layer known as injection layer which is p+ unlike n+ substrate in PMOSFET.





When V_{CC} applied The junction J_1 becomes forward bias junction J_2 reverse bias.
if we increase V_G at Gate and emitter terminal whatever the minority charge carriers will be accumulated at (electrons)
insulation because of this Junction J_2 will be becomes Forward bias. So current conduction will happen.

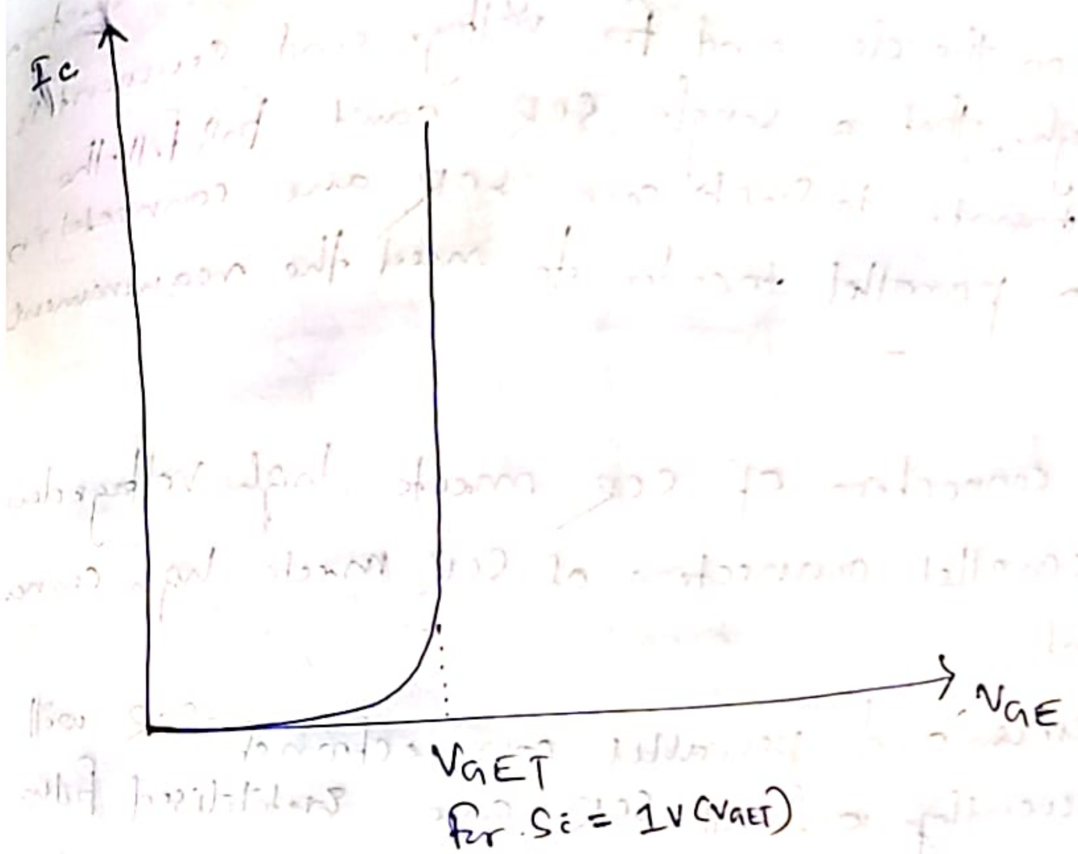
The Current conduction from p^+ n^- p n.
The accumulated minority charge carriers region through Emitter terminal.

$V_G \Uparrow$, $I_C \Uparrow$ & $V_{CE} \Downarrow$

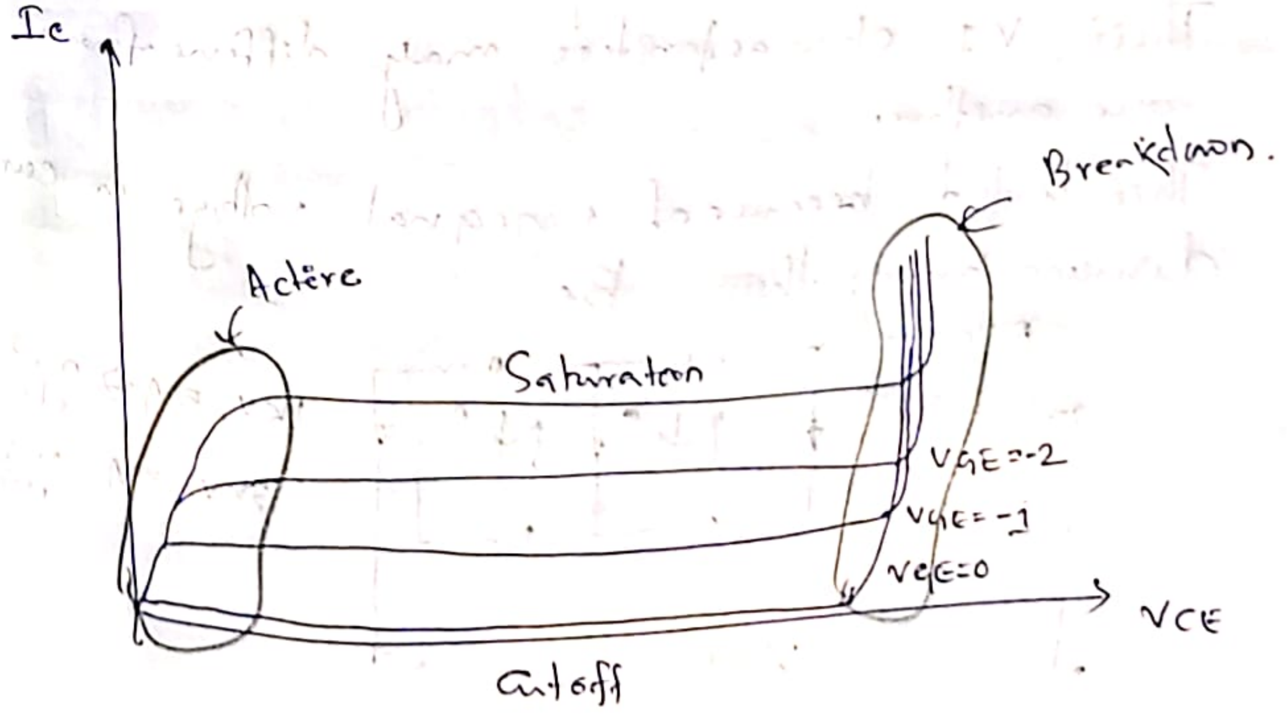
Transfer characteristics:

It is the graph betn Collector Current vs Gate to Emitter voltage

Ic Vs VGE



Output characteristics: Ic Vs VCE at different values of VGE



Series & Parallel connection of SCR:

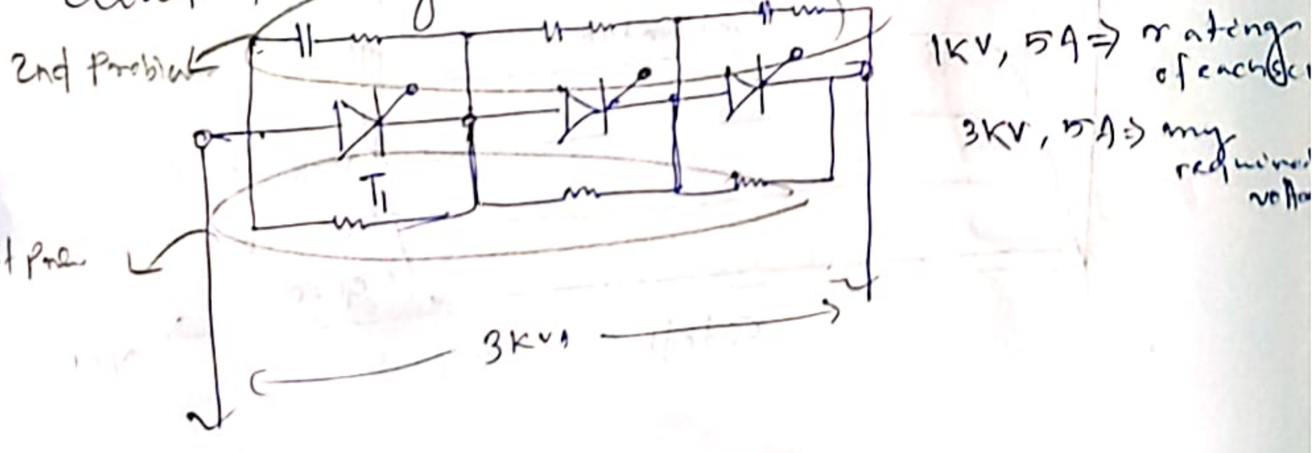
In industry, now adays, SCR are available of ratings upto 10kV and 3 kA But Sometimes we face demand more than this ratings. for Some industrial application the demand for voltage and current is very high. that a single SCR can't full fill the Requirement. in such case SCR are connected in Series or parallel inorder to meet the requirement.

Series connection of SCR meets high voltage demand and parallel connection of SCR meets high current demand.

These series and parallel connection of SCR will go efficiently if all SCR are utilised fully.

Although all SCR in a string are of same rating Their VI characteristics may differ from one another.

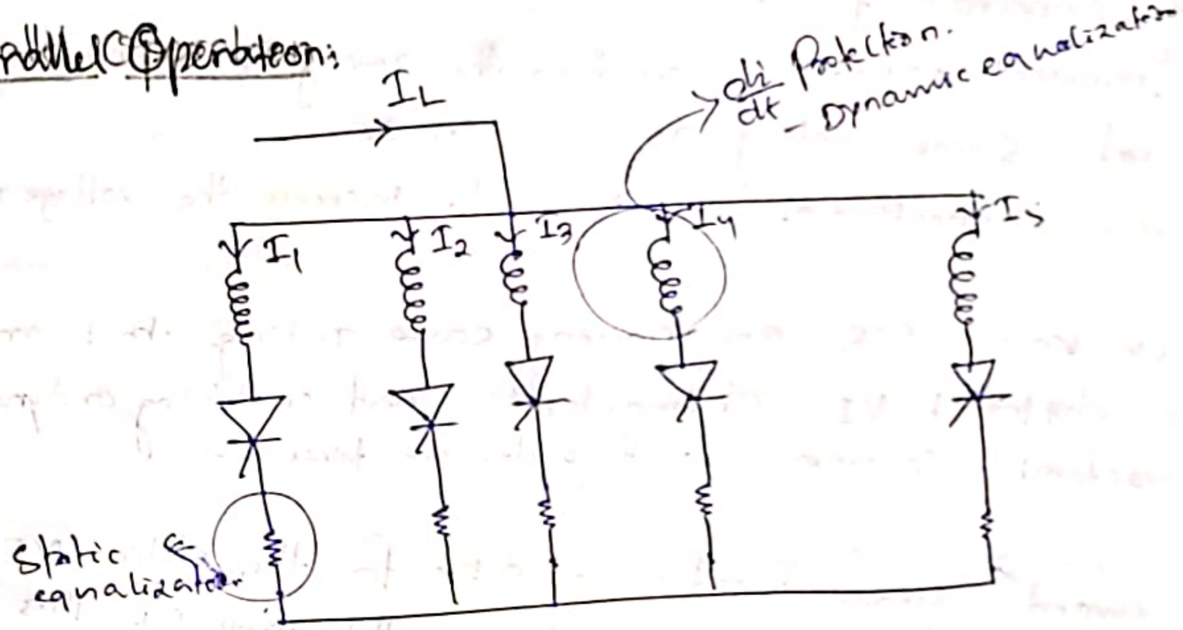
This leads to ~~because of~~ unequal voltage or current division among them. Be



Date: 20/02/2020

⇒ during forward & Reverse block } unequalization will happen.
⇒ Turn on & Turn off

Parallel Operation:



$$\eta_s = \frac{\text{Total voltage/current}}{\text{no. of SCR} \propto \text{one SCR V/I}}$$

Every SCR is not fully utilized so unequalization will occur.

So the efficiency of String is always less than 100% according to the given expression.

String efficiency, is defined as the ratio of maximum voltage or current of hole string to individual voltage or current rating of one SCR.

It is denoted as η_{string}.

$$\eta_{string} = \frac{\text{Actual voltage or Current of whole SCR}}{(\text{Individual voltage/current of one SCR}) \times \text{no. of SCR}}$$

A measure of Reliability of string is given by a factor. Called derating factor (DRF)

$$DRF = 1 - \text{String Efficiency}$$

Series Connection of SCR:

When the required voltage is more than the rating of one SCR. The multiple SCR of same rating are used in series.

* Series connection of SCR is used to increase the voltage rating.

As we know SCR are having same rating but may have different VI characteristics and switching or dynamic characteristics. So unequal voltage division takes place.

To avoid unequalization of SCRs for the static VI characteristics to connect resistor parallel with SCR. This is called Static Equalization.

Due to dynamic characteristics there is a unequal voltage drop takes place. to avoide this we connect combination of capacitor in series with resistor with SCR in parallel.

But in practical, different rating of SCR, is very difficult to use. So, we choose one rating of SCR value to get

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

Where, n = no. of SCR

V_{bm} = voltage blocking by SCR having minimum leakage current.

ΔI_b = Difference betn Max^m and Min^m leakage Current flowing through the SCR.

V_s = Voltage across string.

An additional diode can also be used to improve the performance of dynamic equalization.

String efficiency for Series Connection of SCR:

$$\eta_{string} = \frac{V_s \text{ String Voltage}}{n \times \text{Voltage rating of one SCR}}$$

↳ n = no. of SCR

$$\eta_{string} = \frac{V_s}{n \times V_D}$$

$$C_{min} = \frac{(n-1)\,\Delta Q_{max}}{nV_D - V_s}$$

Here, Q_{max} = Minimum charge required to stored in capacitor

$$\text{Power across SCR} = \frac{V_D^2}{R}$$

Parallel Operation of SCR:

The individual current rating of the SCR. Than we use more than one SCR in parallel. Due to different VI characteristics of SCR of same rating share unequal current in string.

Due to unequal current division when current through SCR increases its temp. also increases which inturn decrease the current, Hence further increasing in current takes place this is a commutative process. This is known as Thermal runway. which can damage the device. To overcome this problem SCR would be ~~maintai~~ maintained at the same temp. This possible by mounting them on heat sink

* To avoid static characteristics problem we will connect Resistor in series with SCR.

* To avoid dynamic VI characteristics problem we connect inductor in series with SCR.

When $I_1 = I_2 = I_3 = I_4 = I_5$ then resultant flux is '0' as 5 coils connected in antiparallel. So the inductance of all the path will be same.

if $I_1 > I_2 > I_3 > I_4 > I_5$, then there will be a resultant flux. This flux induces emf in coil. hence, connected in path one is opposed and in path it is added by the induced emf. Thus reducing the current difference in the path.

Problem:

Q. (a) The voltage and current rating in a particular ckt are 5KV and 100 Amp. SCR with a rating of 1000V and 150 Ampare available minimum derating factor is 20% (=0.2). Calculate the no. of series SCR required to have in give source voltage and current.

(b) If maxm leakage current of SCR is 10mA and Q_{max} = 20μC. Then Calculate the static resistor and dynamic Capacitor for equalization and power across SCR.

Ans: $V_s = 5KV$ & 100 A

$V_D = 1000$ V & 150 A.

(a) DRF = 20% = 0.2

$\eta = 1 - DRF$ = 1 - 0.2 = 0.8 = 80%

$$\eta = \frac{V_S}{n \times V_D}$$

$$\Rightarrow \eta = \frac{V_s}{n \times V_D}$$

or, $$n = \frac{V_s}{\eta \times V_D}$$

$$= \frac{5000}{0.8 \times 1000}$$

$= 6.25 \simeq 7$

∴ We require 7 SCR to meet the requirement of current and voltage.

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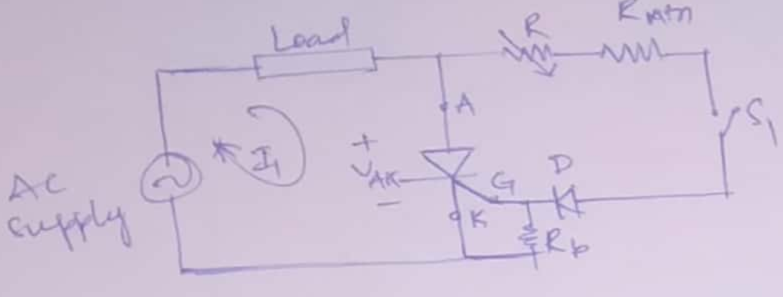
Resistor Trigger Circuit of SCR or R triggering of SCR



During +ve half cycle SCR is in forward bias, and during −ve half cycle SCR is in Reverse bias.

SCR is in forward bias if we give through gate current to the gate terminal then we can turn on SCR.

R_{min} = That will be define minimum gate current.

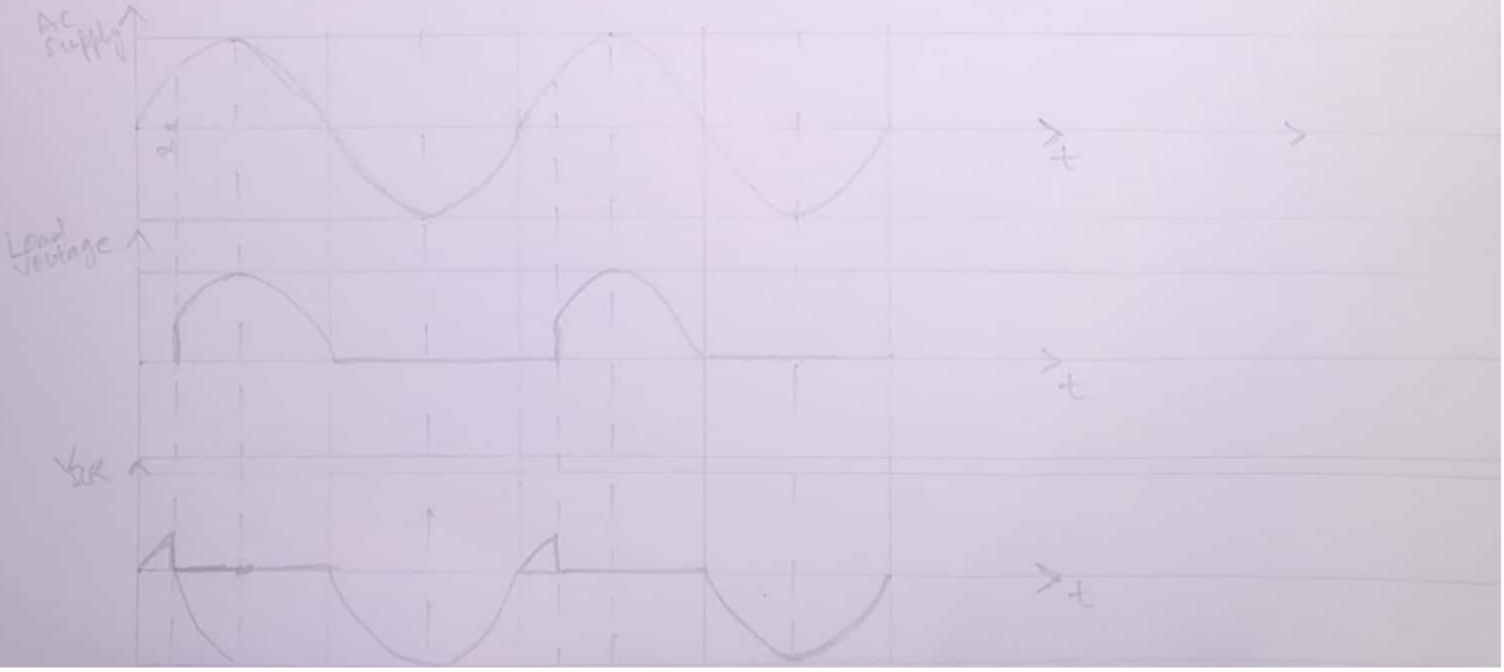
To limit gate current R_{min} is connected.

$$R_{min} \geq \frac{V_m}{I_{gm}}$$

R_b = stabilizing Gate resistance

$$R_b \leq \frac{(R + R_{min}) V_{gm}}{V_m - V_{gm}}$$

R = It will define gate triggering angle.



$\Rightarrow$ If R is more α is less and vice versa.

$\Rightarrow$ the range of α is 0° to 90°.

$\Rightarrow$ Range of α (firing angle) is in between 0° to 90°.

RC Triggering of SCR:

- Half wave RC Triggering of SCR
- Full wave RC Triggering of SCR.

In RC triggering of SCR, we take Resistor and Capacitor elements to trigger SCR. and values of Resistor and Capacitor is very important to define firing angle of SCR.

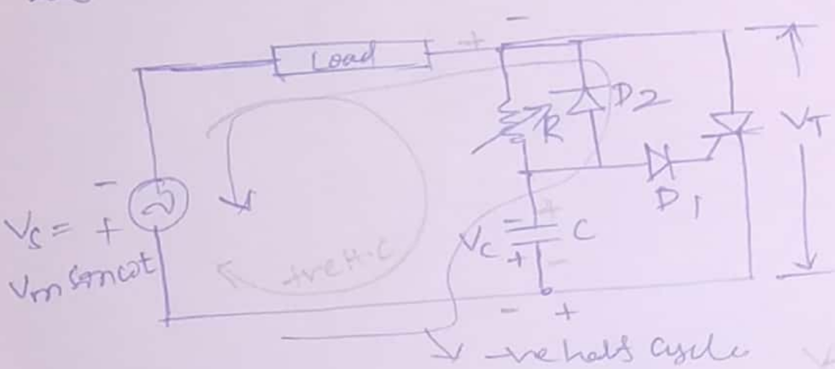
RC time constant defines, firing angle of SCR.

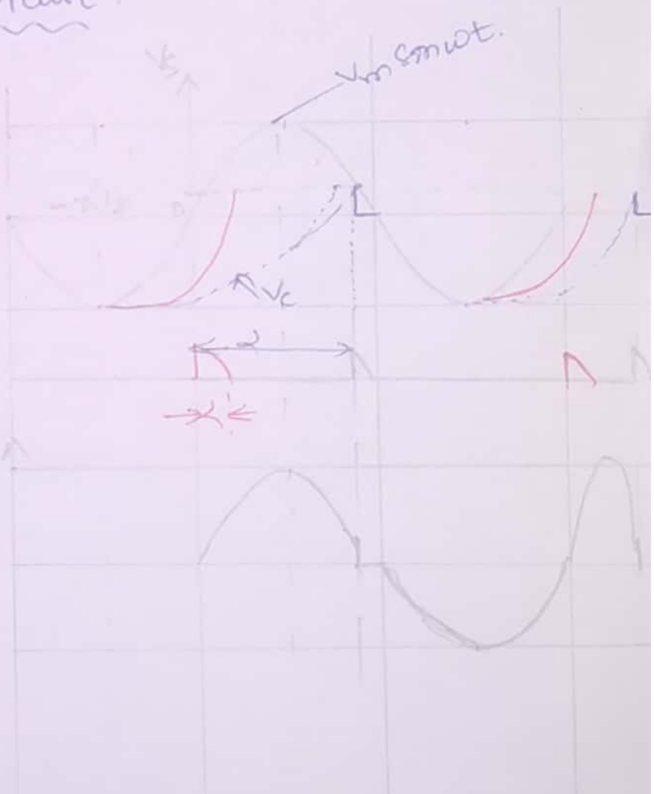
Working of RC Triggering of SCR:

By RC Triggering we can trigger SCR with firing angle ranges from 0° to 180°

We can change firing angle by changing value of Resistor(R)

Half wave RC Triggering of SCR Circuit:

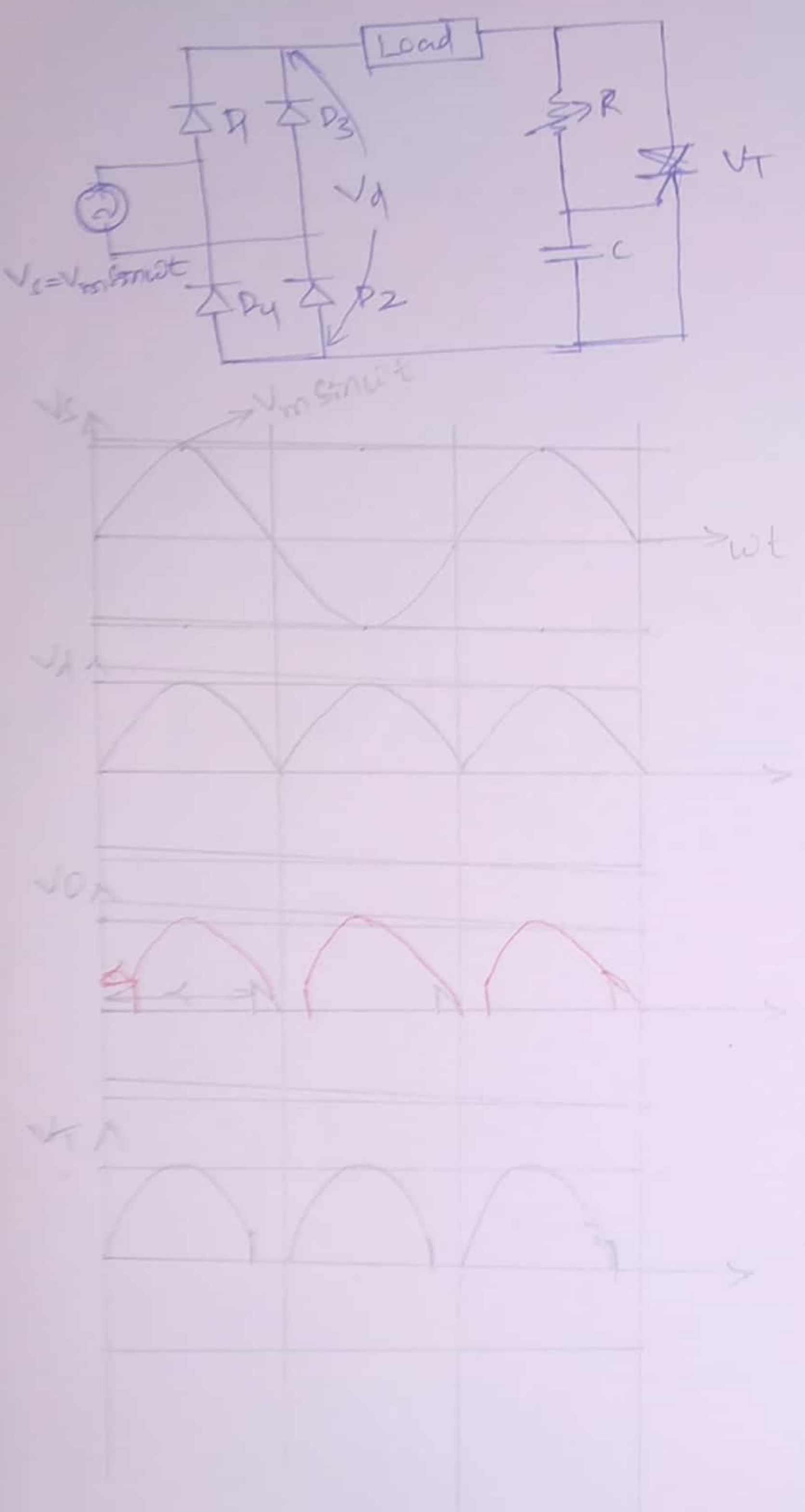




For High value of R ——→

For Low value of R

Full wave RC triggering of SCR :



UJT Triggering circuit of SCR: