LECTURE NOTES ON

POWER ELECTRONIC &PLC

5TH SEMESTER E&TC

Prepared by: B.SUBHALAXMI PANI

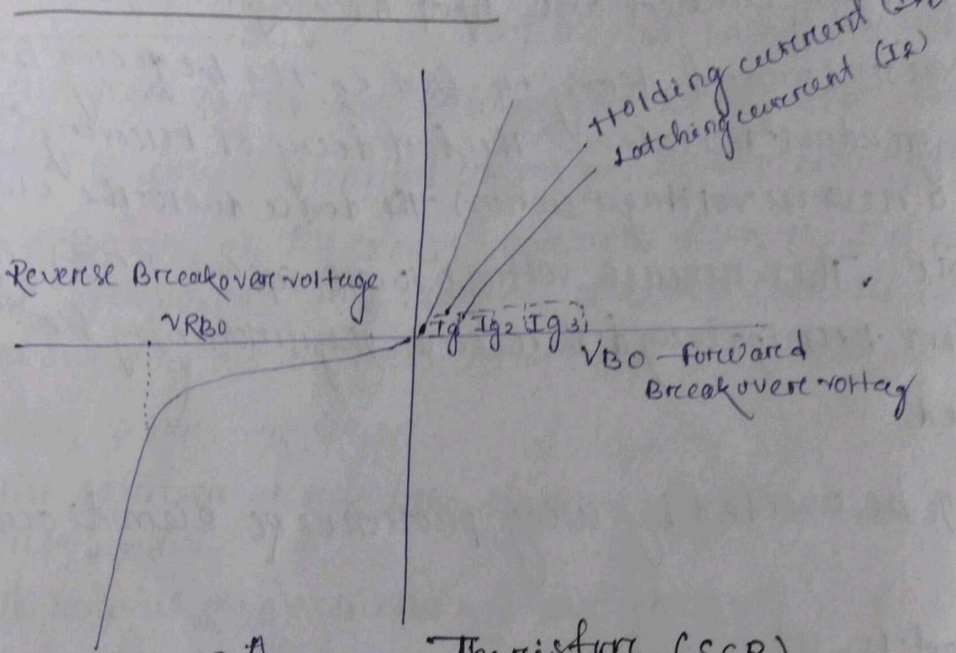
GOVERNMENT POLYTECHNIC, DHENKANAL

DEPARTMENT OF ELCTRONICS AND TELECOMMUNICATION ENGINEERING

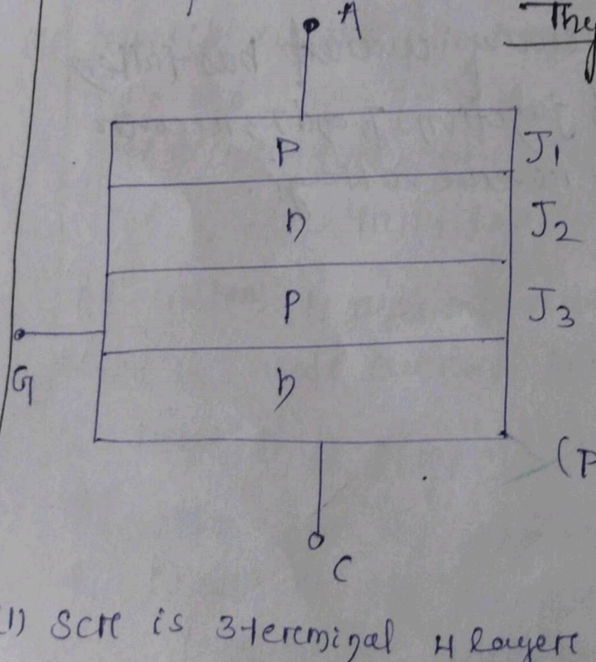
Thyristor

→ Two-transistor theory.

VI Characteristics of SCR

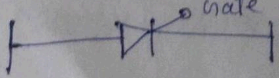


Thyristor (SCR)



(pnp, npn)-transistor

(1) SCR is 3-terminal 4 layer 3 junction pnpn semiconductor device



Important terminals

→ Ig - gate current

→ This is the current by which increse or decrese voltge level of the SCR.

→ When gate current is increse the voltage value increse inside the reverse Pn junction. J2 .

→ The maximum value of voltage on which junction J2 breakdown is known as forward Breakover voltage.

→ Ih - Holding current → The minimum current below which SCR gets atterned off.

→ IL - Latching current → The minimum current after above which current continious to flow inside the SCR.

VRBO (Reverse Breakover voltage)

It is the maximum reverse voltage at which Scr stops to operate or damage.

Thyristor Basic mode

→ Reverse blocking mode → When cathode is make positive with respect to anode then SCR is reverse baised, so junction J1 and J3 are reverse baised where as J2 is forward bias.

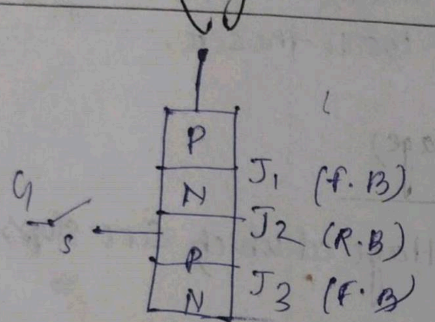
→ ~~A small leakage current, order of μ~~ Now the SCR behaves as if two diodes are connected in series with reverse voltge applied accross them so a small lekage current with this is reverse bocking mode of SCR.

→ If reversed voltage is increased then at a critical breakdown point called Reverse brake down voltage (VBR). And avalanched occurs at J1 and J3 so the reverse current increases rapidly.

→ This large current increses the temprature of the junction which may increased by its permesible temprature due to which the SCR may damage.

→ When reversed voltage is less than VBR, the device offers the high impedance in the reverse direction to the SCR behaves like an open switch. The VI characteristics after avalanch break down during reverse blocking mode is applicable only when load resistor is zero. When the load resistance is zero. When the load resistance is present the large anode current is associated with avalanch break down at VBR which cause a voltage drop across the load. So the VI characteristics in 3rd quadrant will bend to the right of vertical line drawn at VBR.

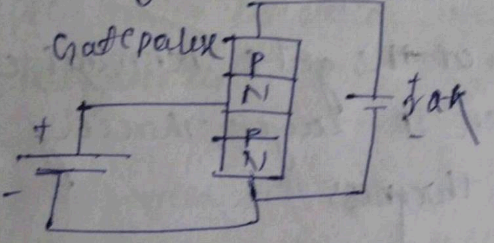
Forward blocking mode :-



(1) When anode is made +ve with respect to cathode with gate ckt open, the SCR is said to be forward bias. Now junction J_1 and J_3 are forward baised and junction J_2 is reverse biased.
A small leakage current will flow across SCR.
Now if the forward voltage is increase the junction J_2 will have an avalanch break down at a voltage called forward break over voltage (V_{BO})
When forward voltage is less than VBO SCR offers high impedance so the thyristor can be treated as an open switch even in the forward blocking mode.

forwarcd conduction mode :-

A thyristor is brought from forward blocking mode of forward condiction mode by turcing of on by exceeding the break over voltage or by applying a gate pulse between gate and cathod. In this mode a thyristor is in on state and behavet like a closeed switch.
The voltage drop across the thayristor in the on state is of the order of 1 to 2 volt depending upon the Thyristion rating.



Scr terminal methods

With anode positive with respect to cathod a SCR can be turned on by any one of following triggerings.

(1) forward voltage triggering
(2) gate triggering.
(3) $\frac{dv}{DT}$ Triggering
(4) tempreture triggering
(5) Light triggering.

forward triggering voltage

When forward voltage is appled with anode and cathode - with gate circuit open J2 is reversed baised.
~~As a region depletion layer~~
When the anode terminal is positive with respect to cathode (Vak), Junction J1 and J3 is forward biased and junction J2 is reverse biased.

- No current flows due to depletion region in J_2 is reverse biased (except leakage current).
- As V_{AK} is further increased, at a voltage V_{BO} (forward break over voltage) the junction J_2 undergoes avalanche breakdown and so a current flows and the device tends to turn ON (even when gate is open).

Gate Triggering :-

- This is most widely used SCR triggering method.
- Applying a positive voltage between gate and cathode can Turn ON a forward biased thyristor.
- When a positive voltage is applied at the gate terminal, charge carriers are injected in the inner p-layer, thereby reducing the depletion layer thickness.
- As the applied voltage increases, the carrier injection increases therefore the voltage at which forward break-over occur decreases.

(d) dv/dt Triggering

- When the device is forward biased, J_1 and J_3 are forward biased, J_2 is reverse biased.
- Junction J_2 behaves as a capacitor, due to the charges existing across the junction.
- If voltage across the device is v, the charge by q and capacitance by C then,

$$i_c = dq/dt$$
$$q = CV$$
$$i_c = d(CV)/dt$$
$$C \cdot dv/dt + v \cdot dC/dt$$
$$\text{as } dC/dt = 0$$

ie = $C \cdot dV/dt$

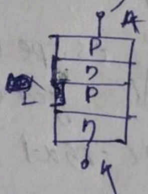
Therefore when the rate of change of voltage across the device becomes large, the device may turn ON, even if the voltage across the device is small.

Temprature Triggering

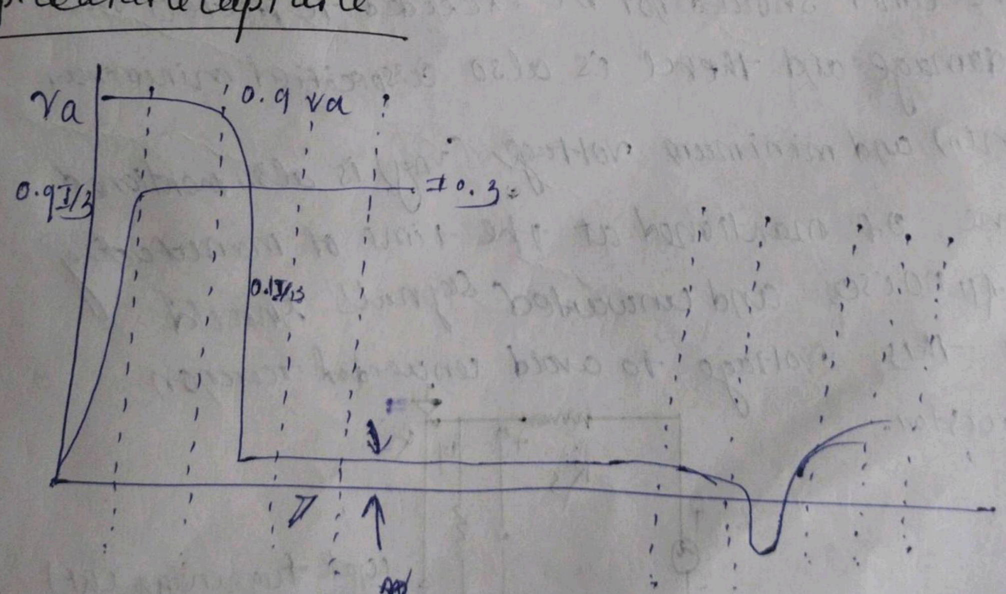
- The width of depletion layer of SCR decreases with increase in junction temprature.
- Therefore in SCR when V_{AR} is very near its break down voltage, the device is triggered by increasing the junction temprature.
- By increasing the junction temprature the reverse biased junction collapses thus the device starts to conduct.

Light Triggering

- For light triggered SCRs a special terminal niche is made inside the inner p layer instead of gate terminal.
- When light is allowed to strike this terminal, free charge carriers are generated.
- When intensity of light becomes more than a normal value, the thyristor start conducting.
- This type of SCRs are called as LASCR



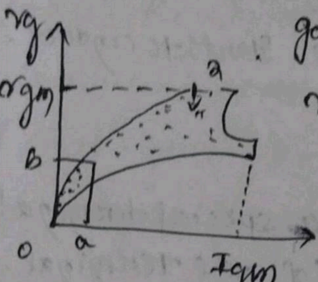
Temprature capture



It is also called thermal trigger.

During forward blocking mode most of the applied voltage appears across junction (J_2) as the junction J_2 is associated with leakage current it would raise the temperature of junction. with increase in temperature. The junction depletion layer decrease gradually. This lead to more leakage with its probes and some high temperature. The depletion of reverse biased junction (J_2) vanishes and the device get turned on.

Gate characteristics of an SCR

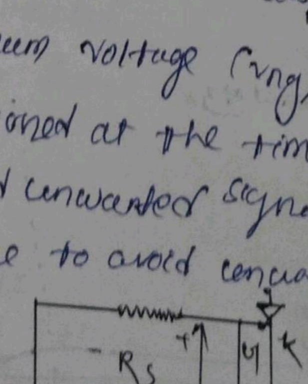


gate driver curve

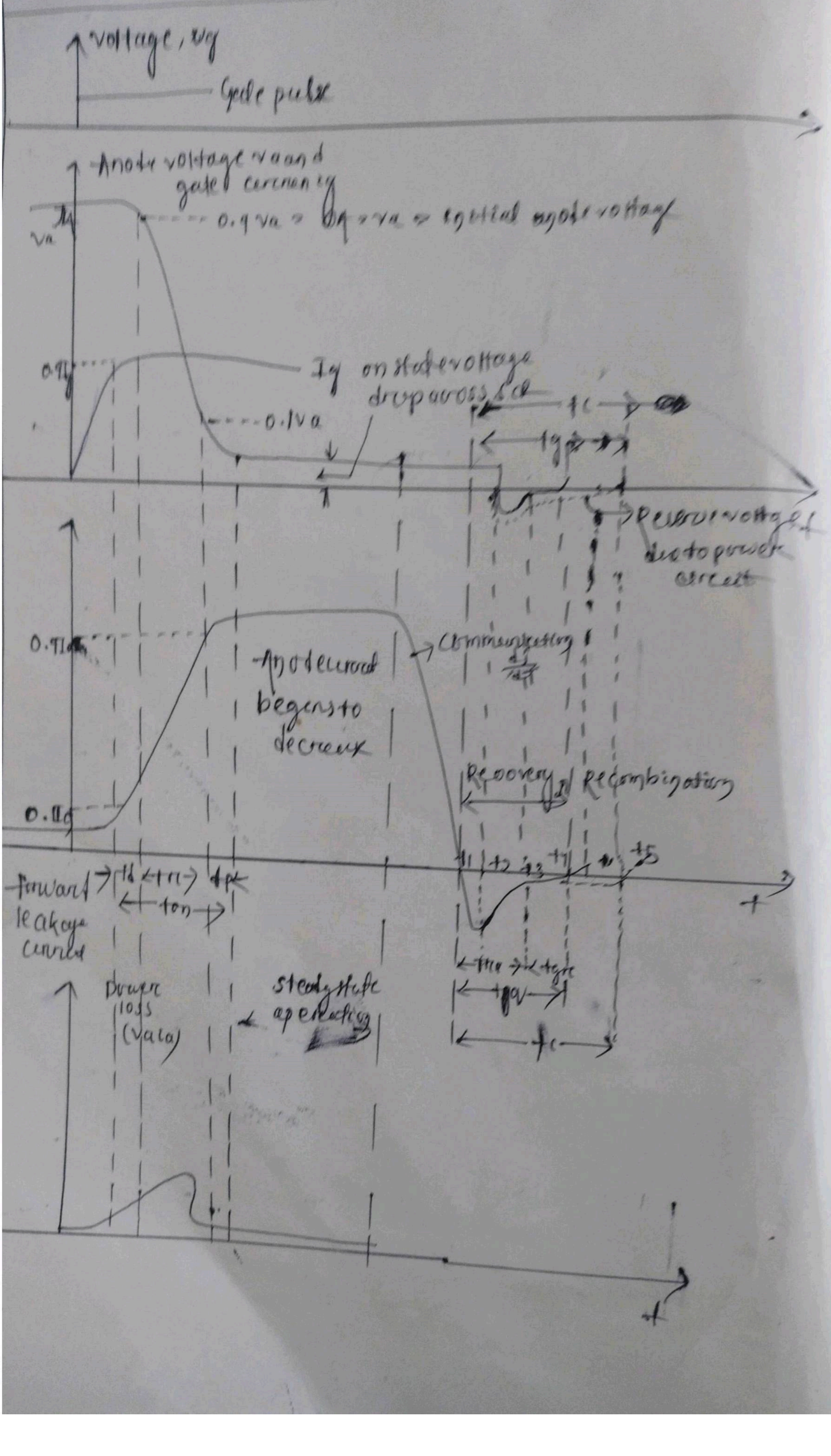
Vgm = max^m allowable gate voltage.

Igm = max^m allowable gate current

This characteristics of SCR gives a very brief idea to operate it with in a safe region of applied gate voltage and current. so this is a very important characteristics of SCR. At the time of manufacturing SCR is specified with maximum gate voltage limit (Vg max) and gate current limit (Ig max) and maximum power average that is gate power dissipation limit (Pgav). These limit should not be exceeded to protect the SCR from damage and there is also a specified minimum voltage (Vg-min) and minimum voltage (Vng) is also mentioned at the time. of maintained at the time of manufacturing of the device. All noises and unwanted signals should lie under this voltage to avoid unwanted turn on of the thyristor.



(Gate triggering ckt)



voltage, vg
Gate pulse
Anode voltage va and gate current ig
va
0.9 va
0.1 va
Ig on state voltage drop across SCR
tc
tq
0.9 Ia
Anode current begins to decrease
Commutating
Recovery
Recombination
0.1 Ig
t1 t2 t3 t4 t5
Forward leakage current
td
tr
ton
tp
trr
tgr
tc
Power loss (vaia)
Steady state operation
t

monsing

SWITCHING CHARACTERISTICS OF THYRISTOR

→ During turn-on & turn-off process, a thyristor is subjected to different voltage across it and different current through it.

→ The time variations of the voltage across a thyristor and the current through it during turn-on & turn-off processes 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 between gate and cathode.

→ There is transition time from forward off state to forward on state. This transition time is called thyristor turn-on time & is defined as, the time during which it changes from forward blocking mode to final on-state.

→ Total turn-on time can be divided into three intervals; (i) Delay time (td) (ii) Rise time (tr) & (iii) Spread time (tp).

(i) Delay time (td) - The delay time td is measured from the instant at which gate current reaches 0.9Ig to the instant at which anode current reaches 0.1Ia.

→ Here Ig and Ia are respectively the final values of gate and anode currents.

→ The delay time may also be defined as, the time during which anode voltage falls from Va to 0.9Va where, Va = initial values of anode voltage.

→ In another way, delay time is the time, during which anode current rises from forward leakage current to 0.1Ia, where Ia = final value of anode current.

→ With the thyristor initially in the forward blocking state anode voltage is Va and anode current is small leakage current.

→ The ~~turn~~ turn on process is indicated by a rise in anode current from small forward leakage current and a fall in anode-cathode voltage from forward blocking voltage Va.

→ A gate current begins to flow from gate to cathode with the application of gate signal, the gate current has non-uniform distribution of current density over the cathode surface due to the p-layer.

→ The delay time can be decreased by applying high gate current and more forward voltage between anode and cathode.

(ii) Rise-time (t_r):-

→ The rise-time t_r is the time taken by the anode current to rise from $0.1 I_a$ to $0.9 I_a$. The rise time is also defined as; the time required for the forward blocking off-state voltage to fall from 0.9 to 0.1 of its final value V_a.

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

→ Thus, t_r can be reduced, if high and steep current pulse are applied to the gate.

→ From the beginning spreading from the narrow conducting region near the gate.

→ The anode current spreads at a rate of about 0.1 mm/ms.
As the rise is small, the anode current is not able to spread over, the entire cross-section of cathode.

→ During rise time t_r, 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 these losses occur over a small conducting region local hotspots may be formed and the device maybe damaged.

(iii) Spread time (t_P):-

-> The spread time is the time taken by the anode current to rise from 0.9I_a to I_a. It is also defined as, the time for the forward blocking voltage to fall from 0.1 of its initial values to the on-state voltage drop (1 to 1.5V)

-> 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 the 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 the order of 1 to 1.5V.

Total turn on time of an SCR is equal to the sum of delay time, rise time, and spread time.

(B) Switching characteristics during turn-off:-

-> Thyristor turn-off means that, it has changed from on to off state and is capable of blocking the forward voltage. This dynamic process of the 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 turned 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 (hole and electrons) in the four layer are still favourable for conduction.

Therefore, the device will go into conduction immidiatly, even though gate signal is not applied, in order to avoid such as occurrence. it is essential that the thyristor is ~~resp~~ reverse biased for a finite period after the anode current has reached zero.

→ Turn-off time (t_q):- The turn-off time, t_q of a thyristor is defined as the time between the instant, anode current becomes zero & the instant SCR regains forward blocking capability.

→ During t_q, all the excess carriers from the SCR must be removed. This removal of excess carriers consists of sweeping out of holes from outer p-layer and electron from outer n-layer.

→ The carriers around the junction J_2, can be removed only by recombination.

→ The turn-off time is devided into two intervall.

(i) reverse recovery time t_{rr}, and (ii) gate recovery time, t_{gr}. and

(ii) gate recovery time, t_{gr}.

i.e, $t_q = t_{rr} + t_{gr}$

→ At instant t_1 anode current becomes zero.

→ After t_1, anode current builds up in the reverse direction with the same di/dt slope as before t_1.

→ The reason for the reversal of anode current after t_1 is due to the presence of carrier stored in the four layer. The reverse recovery current removes exess carriers from the end junctions J_1 and J_3 between the instants t_1 and t_3

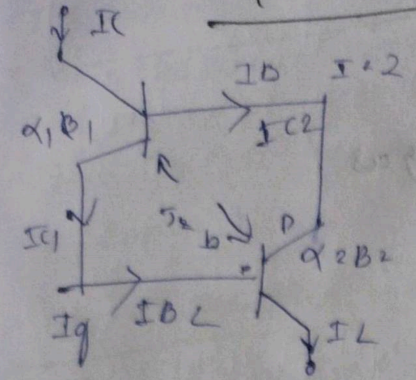
-> In other words, reverse recovery current, flow due to the sweeping out of holes from top p-layer and electrons from bottom n-layer. At instant t2, when about 60% of the stored charges are removed from the outer two-layers, carrier density across J1 & J3 begins to decrease and with this, reverse recovery current also start decaying.

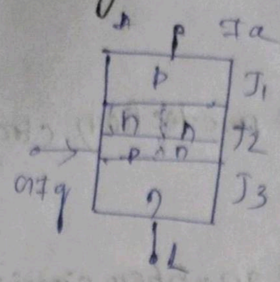
-> The reverse current decay is fast in the beginning but becomes gradual thereafter. The fast decay of recovery current causes a reverse voltage across the device due to the circuit inductance. This reverse voltage surge appear across the thyristor terminals and therefore thyristor may be damaged.

-> This can be avoided by using protective RC elements across SCR.

-> At instant t3, when reverse recovery current has fallen to nearly zero value, end junctions J_1 and J_3 recover and SCR is able to block the reverse voltage.

2 transistor of thyristor





The principle of thyristor operation can explained with the use of the two transistor mode or two transistor analog. from the scheming diagram of thyristor we can see that two thyristor mode is offend by cuting the two middle layer along the ~~dotted~~ the dotted line in two separate halves.

In this figure J1 and J2 and J2, J3 be consider to constructed pnp and npn transistor separately. the circuit representation of the two transistor model is shown in the fig.

In the off state of a transistor.

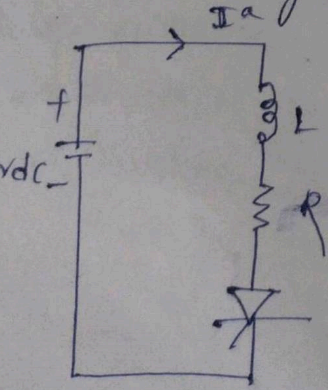
$IC = \alpha IE + ICBO$

protection of SCR

Different types of protection circuit such as
(i) $\frac{di}{dt}$ protection.
(ii) $\frac{dv}{dt}$ protection (snubber circuit)
(iii) metal oxide thyristor
(iv) Semiconductor fuses.

di/dt protection

- di/dt - the rate of change of current in a device.
- When SCR is forward biased and is turned ON by the gate signal, the anode current flows.
- The anode current requires some time to spread inside the device. (Spreading of charge carriers).
- But if the rate of rise of anode current (di/dt) is greater than the spread velocity of charge carriers then local hot spots is created near to gate due to increased current density. This localised heating may damage the device.
- Local spot heating is avoided by ensuring that the conduction spreads to the whole area very rapidly. (OR) the di/dt value must be maintained below a threshold (limiting) value.
- This is done by means of connecting an inductor in series with the thyristor.

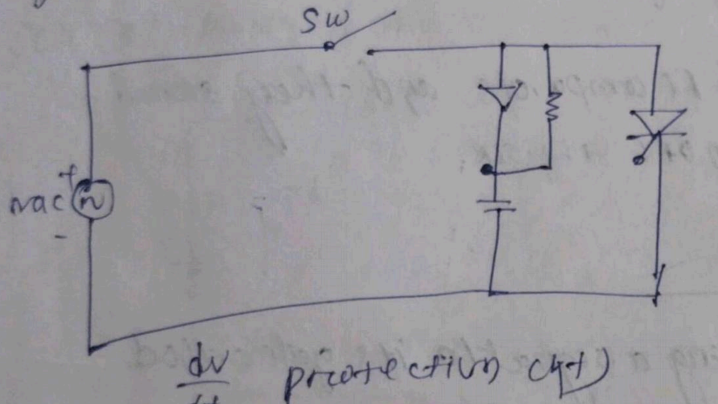


($\frac{di}{dt}$ protection ckt)

- The inductance L opposes the high di/dt variation.
- When the current variation is high, the inductor smooths it and protects the SCR from damage. (Though di/dt variation is high, the inductor 'L' smooths it because it takes some time to change). $L \geq [Vs / (di/dt)]$

dv/dt protection

- dv/dt is the rate of change of voltage in SCR.
- We know that $i_c = C \cdot dv/dt$, i.e. when dv/dt is high, i_c is high.
- This high current i_c may turn ON SCR even when gate current is zero. This is called as dv/dt turn on or false turn ON of SCR.
- To protect the thyristor against false turn on or against high dv/dt a "Snubber circuit" is used.



$\frac{dv}{dt}$ protection ckt

Commutation techniques of thyristor.

(i) Line commutation / Natural commutation.
(ii) Force commutation.

Depending upon the source voltage to the thyristor circuit the commutation technic is classified into two types.

(i) Line commutation / Natural combination
(ii) Force commutation.

mmutation → Line commutation.

→ Forced commutation → voltage commutation
→ Current commutation

Voltage commutation

Voltage commutation is the commutation technique of SCR in which the anode cathode voltage will be reversed till SCR can achive forward blocking mode.

Current commutation

It is the commutation technique of SCR the anode current kept below holding current.

When an external circuit is required turn off the SCR the process of turning off SCR is called ~~com~~ current commutation.

The commutation circuit used LC components and they stored energy and used it to turn off the SCR.

Necessary of commutation

A SCR is turn on by applying a signal to its gate cathod circuit. turnoff a SCR is not possible very easily and is required some special circuit: conditions to the satisfied fort successful combination.

→ The anode to cathode current value of SCR must be reduced below holding current value.

→ The anode cathode voltage must be reversed.

→ The rate of change of anode cathode voltage must be less than $\frac{dv}{dt}$ rating of SCR to avoid retriggering.

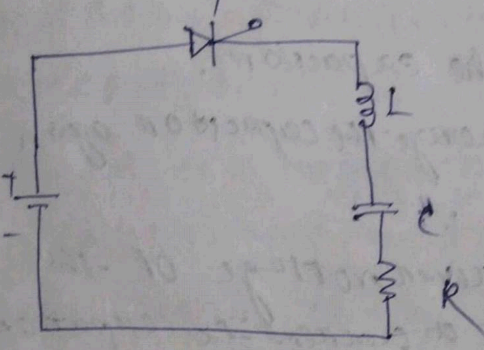
Type of force commutation

(1) class A commutation
(2) Class B commutation
(3) Class C commutation
(4) Class D commutation
(5) class E commutation
(6) class F commutation

A. Class A commutation

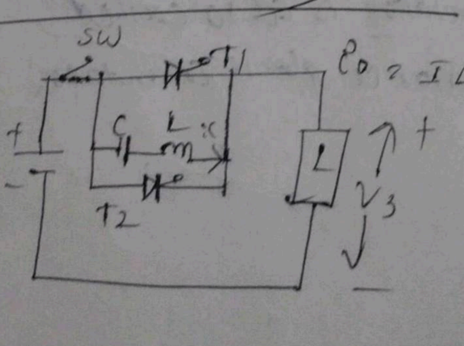
when DC voltage is applied the current (I) first raised to it's maximum value and then begins to fall.

→ when current lekage to zero and takes to reverse thyristor SCR (T) turned off on the source.



→ Due to negative current it assionce the definite commutation of the device.

B. Class B commutation



In this circuit we used a secondary thyristor called as auxiliary thyristor to turn off the main thyristor.

In this circuit the commutation component L and C are connected across the thyristor.

when the supply voltage is switched on the capacitor charges to the voltage V_{dc}

The main SCR (T1) as well as the auxiliary SCR (T2) are in off condition.

when T1 is turned on and (T1 2 0).

A constant load current I0 when flow through the load when T2 is switched on a current begins to flow from capacitor (C) through (T2) then to load and back to C.

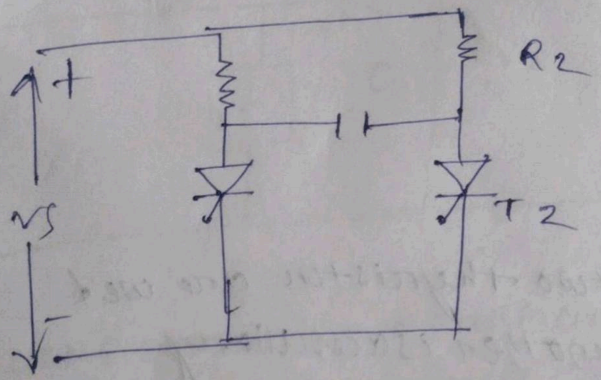
→ at the end of discharge of the capacitor.

→ the inductance energy will charge the capacitor again in reverse direction.

Since SCR (T1) conducting the reverse voltage of the capacitor. it will produce a current Ic capacitor. it will produce a current Ic which opposes the load current IL.

As soon as the Ic becomes equal to Ia the SCR (T1) is turned off This type of commutation is also called as current commutation. or resonance pulse commutation.

Class C commutation (complimentary)



-> In this type of communication a SCR time load current is commutated by transferring the load current to another incoming thyristor.

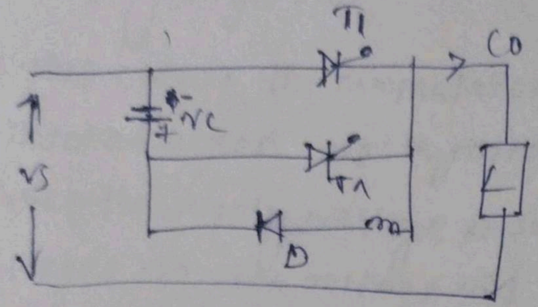
-> In this figure to firing turn on of SCR T1 commutates/turn off (T2) and subsequently firing of SCR T2 would turn off T1.

-> When the SCR T1 is turned on the load current flows to R1 and T1 at the same time capacitance C charged ~~that~~ to the supply voltage Vs through resistor R2.

-> Now the capacitor will be charged in the opposite direction through register R1 and SCR T2

-> The circuit is now ready to commute SCR T2 when SCR T1 is turned on.

Class D commutation



→ In case of class D commutation two thyristor are used hence is main thyristor-1, another is auxillary thyristor (TA). In this method auxillary thyristor (TA) is required for commutating the main thyristor (T1).

→ Initially the auxillary thyristor TA / turns on so that the capacitor is charged up to Vs.

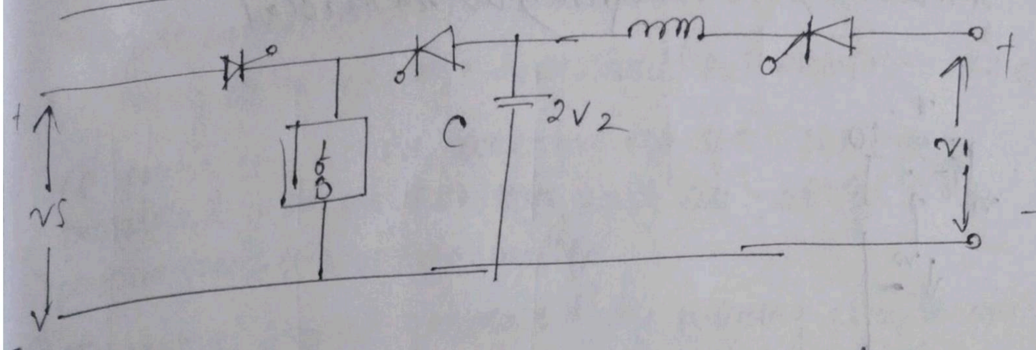
→ The SCR TA turns off when capacitor is fully charged because the current through TA falls below the holding current.

→ When SCR T1 is turned on the load current (IL) flows to SCR T1 and load and the same time the capacitance (C) discharge through thyristor (T1) and (L) and d (D).

→ At the end of discharge. The capacitor will be charged towards to the supply voltage with reverse polarity.

→ When thyristor (TA) is turned on,

Class E commutation or External pulse commutation



→ In class E commutation a pulse current is obtained from a separate voltage source to turn off the conducting SCR. The peak value off this current pulse must be more than the load current. In this circuit VS is the voltage of the main source and V1 is the auxiliary supply.

→ Thyristor T1 is conducting and load is connected to the source that is VS

→ When the thyristor T3 is turned at small t = 0 (time) then V1, T3, L and C forms as ossilative circuit.

→ Therefore capacitor change to a voltage V1 with upper plate positive (+) and osslatory current pulse too.

→ Now Thyristor T3 gets commutator.

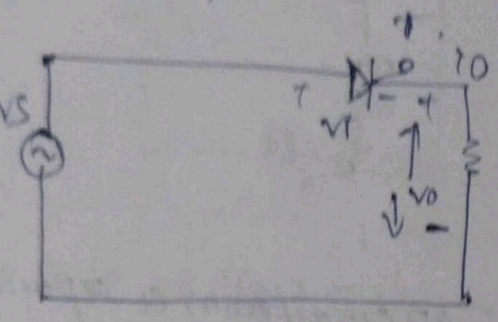
→ Now for the ~~turning~~ turning off ~~which~~ main thyristor T1 thyristor T2 is turned on.

→ With T2 on the T1 is subjected to reverse voltage equal to (VS - 2V1) and therefore thyristor T1 gets turned off.

→ After T1 turned off the capacitor (C) discharges through load.

Class 1 commutation or Natural

This type of commutation is also known as natural commutation.



This type of commutation is also is known natural commutation this can occurs the only occurs AC when an SCR is energized for AC source. the current has to pass through its natural at the end of every positive half cycle.

then the AC source apply reverse biased across we turn of thyristor. As a result SCR gets turned off.

this is called as natural commutation. because no external circuit is applied to turn off the thyristor.

application

this methods of commutation is applied to face controlled converters, line commutator converts AC voltage controllers and step down cycle converter.

Firing Circuit of thyristor

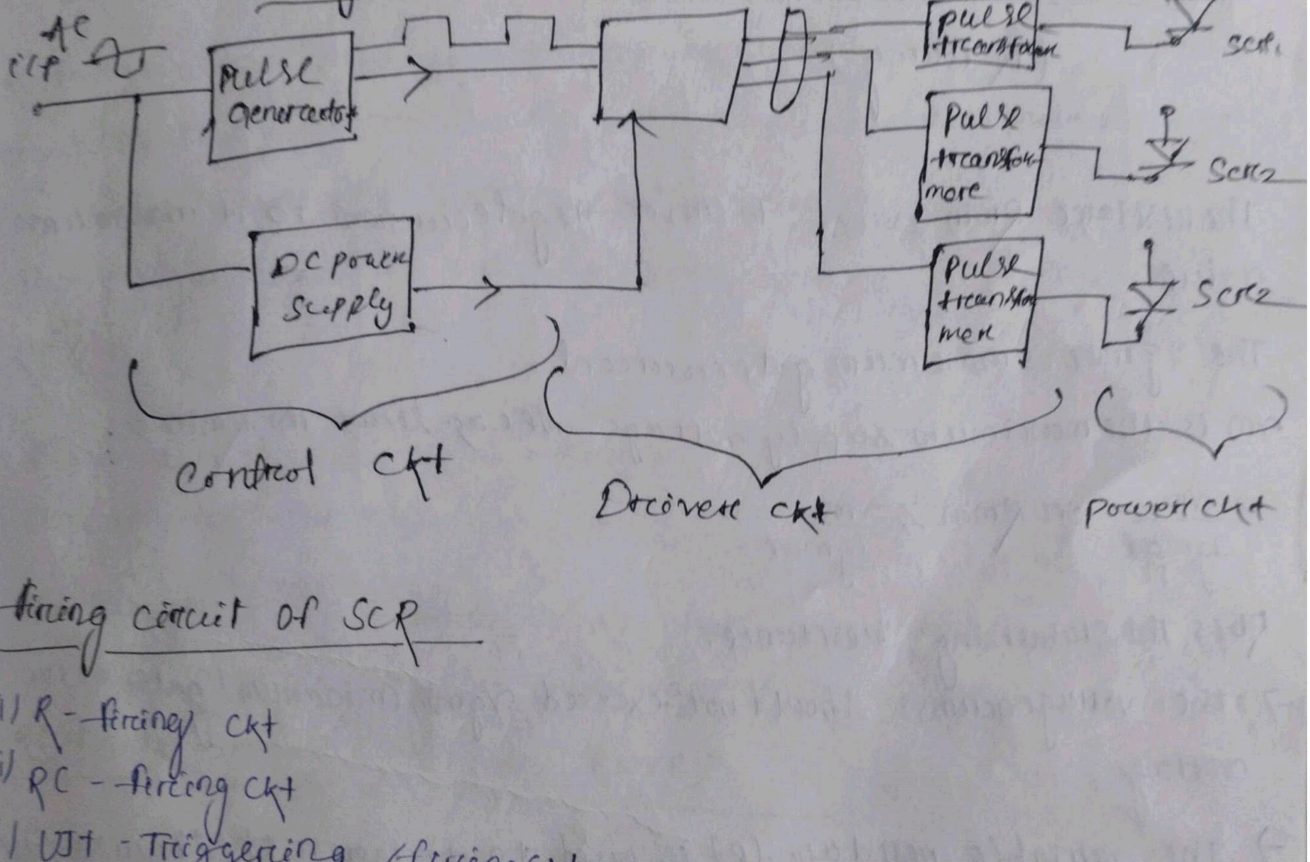
The gate control circuit is also called as firing or triggering circuit. The firing or triggering circuit should fulfill following function.

① If power circuit 1st more than one SCR. The firing circuit should produce gate pulses for each SCR at the desire instant for the proper operation of the circuit.

② The control signal generated by a firing circuit may not be able to turned on an SCR. It is therefore common the feed the voltage pulses to driver circuit and then to gate cathode circuit.

→ A driver circuit consist a pulse amplifier and a pulse transformer.

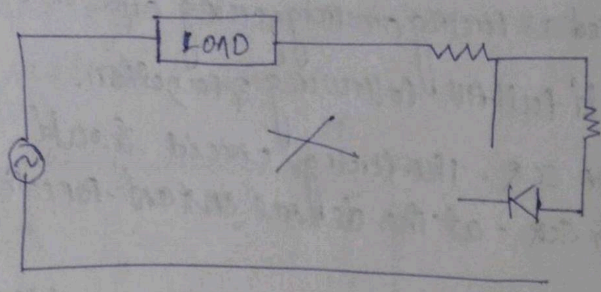
Layout design of firing circuit

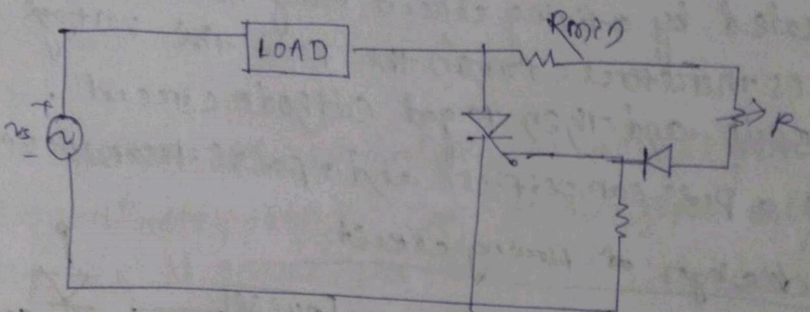


Firing circuit of SCR

(i) R - firing ckt
(ii) RC - firing ckt
(iii) UJT - Triggering / firing Ckt
(iv) Ram Ckt

R-firing circuit





(R-firing)

The resistance Rmin is used to limit the gate current to its maximum value.

The Igmax is maximum gate current.

Vm is the maximum supply voltage. We can limit the Rmin as

$\frac{Vm}{Igmax}$ or $Rmin \geq \frac{Vm}{igmax}$

Rb is the Stabilizing resistance.

-> The voltage across Rb should not exceed Vgmin (minimum gate voltage.

-> The variable resistance (R) is used to trigger the thyristor. When R is 0 then the firing angle is minimum

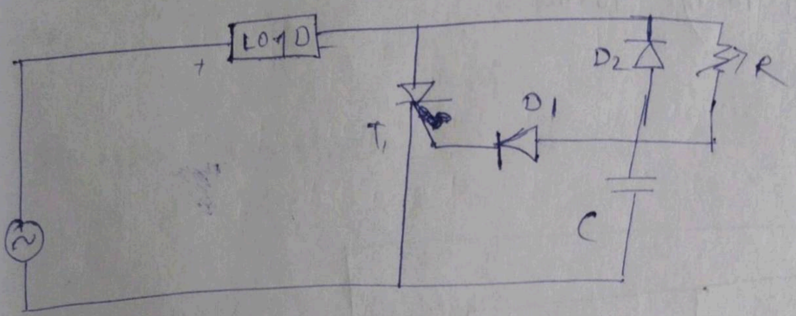
-> firing angle (α) -> firing angle of SCR can be defined as the angle in the AC cycle at which thyristor start on of ...

conducting when opositive voltage is applied across its gate terminal.

-> The anode cathode voltage and gate current are in phase

-> Triggering angle firing angle range should in between 0 to 90°.

RC firing circuit (half wave rectifier)



-> RC firing circuit -> The capacitor charges through diode d2 in the negative cycle of the supply voltage. the capacitor charges upto -Vm. that is negative pick of the supply voltage.

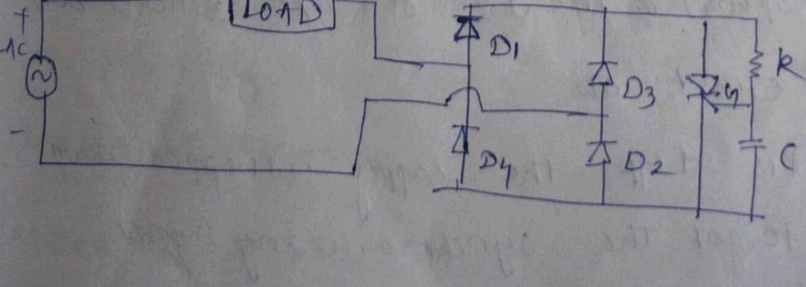
-> The firing angle in this case will range upto 0 to 180°.

-> $RC \geq \frac{1.3}{2F}$

-> f = frequency of the supply voltage
(Condition for minimum firing angle)

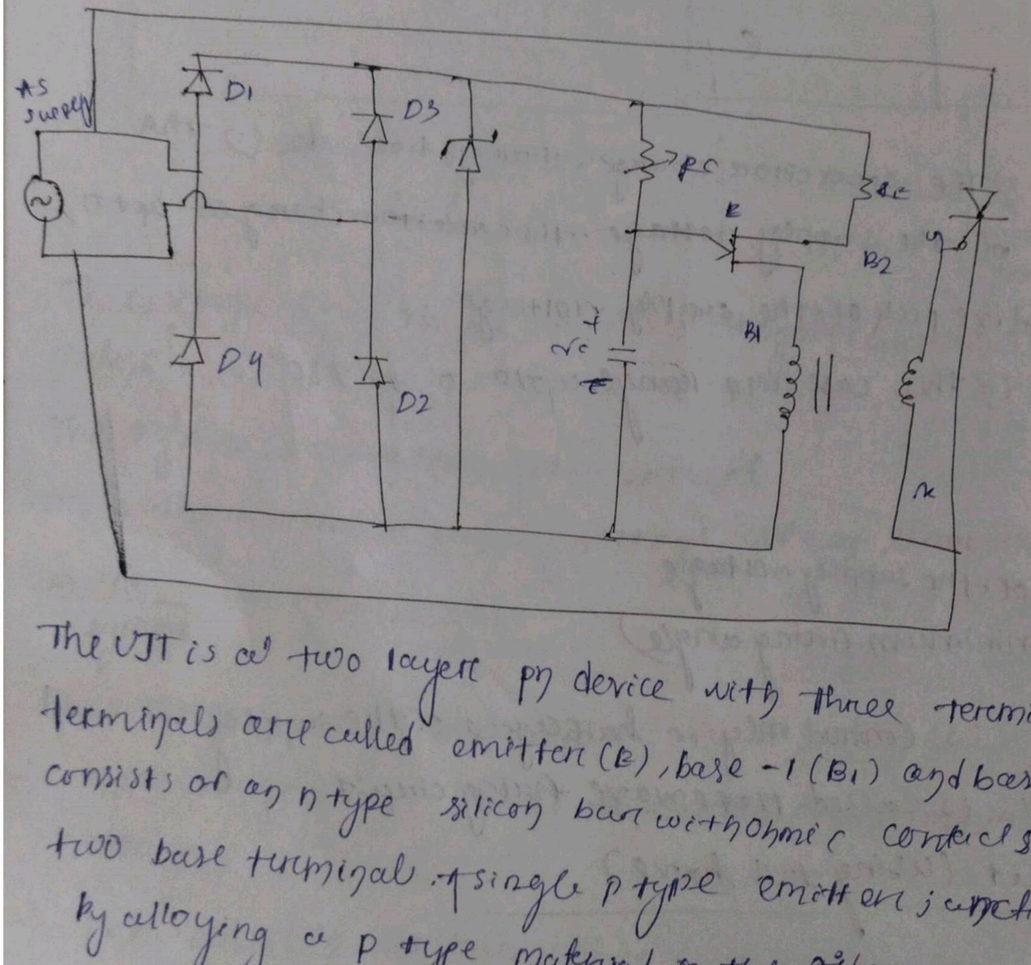
=> The triggering is control only in half cycle of the supply voltage so this is called Half wave firing circuit.

RC firing circuit (using full wave)



Power can be delivered to the load in half wave during the positive half-cycle of es because the SCR conducts only when it is forward biased. This limitation can be overcome in several ways, one of which is shown in fig. Here, the ac line voltage is converted to pulsating dc by the fullwave diode bridge. This allows the SCR to be triggered "on" for both half-cycle of the line voltage, which doubles the available power to the load.

UJT Triggering of SCR



The UJT is a two layer pn device with three terminals, the terminals are called emitter (E), base-1 (B1) and base-2 (B2). It consists of an n type silicon bar with ohmic contacts for the two base terminal. A single p type emitter junction is formed by alloying a p type material on the side of the silicon bar. Its structure, equivalent circuit.

The UJT triggering circuit is set up. The supply is stepped down to a suitable value to get the synchronizing signal, which is fed to the triggering circuit. The waveforms