B sec

Module-2

Thyristors - Introduction, Principle of Operation of SCR, Static Anode-Cathode Characteristics of SCR, Two transistor model of SCR, Gate Characteristics of SCR, Turn-ON Methods, Turn-OFF Mechanism, Turn-OFF Methods: Natural and Forced Commutation – Class A and Class B types, Gate Trigger Circuit: Resistance Firing Circuit, Resistance capacitance firing circuit, UJT Firing Circuit. (Text 2) L1, L2, L3

Module - 2

Thyristor: principles and characteristics.

→ Thyristors are a family of power semiconductor devices. they are operated as bistable switches, operating from non-conducting state to conducting state.

→ Thyristors have lower-on state conduction losses and higher power handling capability.

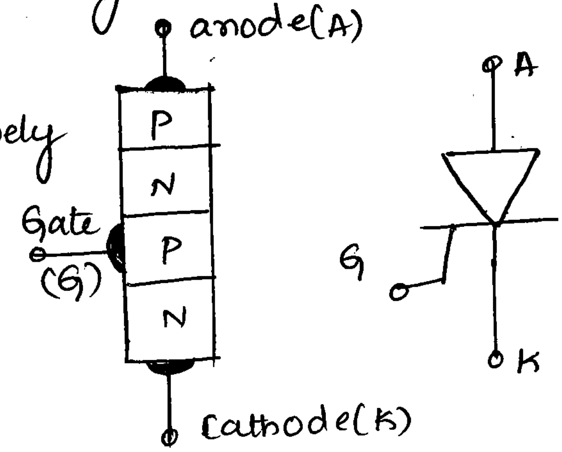
→ Thyristors are being replaced by

Thyristor characteristics principle of operation of SCR

→ SCR is four layered PNPN switching device, having three junctions namely J_1, J_2 and J_3 as shown below

→ It has three external terminals namely, anode(A), cathode(K) and gate(G).

→ The gate terminal carries a low level gate current in the direction gate to cathode.



The device works in 3 states namely

* forward blocking state
* Reverse blocking state
* forward conduction state.

forward blocking state

→ When end P layer is made positive w.r.t to end N layer, the junction J_1 & J_3 are forward biased but the middle junction J_2 becomes reverse biased.

→ Since J_2 is reverse biased, the depletion region doesnot allow to flow any carriers through the device.

Only leakage current negligibly small in magnitude flows through the device due to drift mechanism

→ ~~The SCR under~~ the ~~forward biased conduction~~

Reverse Blocking State :- When the end n-layer is made positive w.r.t end p layer, the middle junction J_2 becomes becomes forward biased, Where as the other ~~th~~ two outer junctions, J_1 & J_3 become reverse biased.

→ The junctions J_1 and J_3 donot allow any current to flow through the device.

→ Only a very small amount of leakage current may flow because of the drift charges This leakage current is insufficient to make the device conduct. this is known as the reverse blocking state or Off-state of the device.

→ The width of depletion layer at the junction J_2 decreases with increase in anode to cathode voltage.

→ When anode to cathode voltage is increased beyond an extent junction J_2 undergoes avalanche breakdown. Since the other junctions J_1 and J_3 are forward biased there will be a free carrier movement across all the junctions resulting in large current through device ∴ Device is said to be conducting state

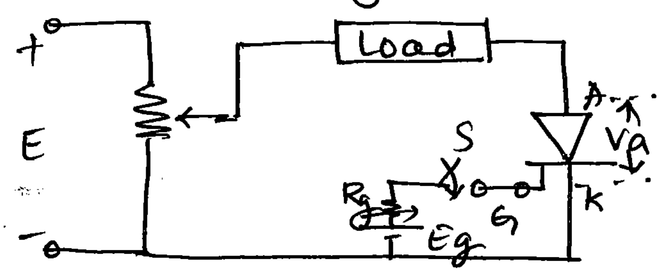
NOTE :-

Latching current (I_L) :- It is min anode current required to maintain the SCR in the ON state immediately after SCR is turned on & gate signal has been removed.

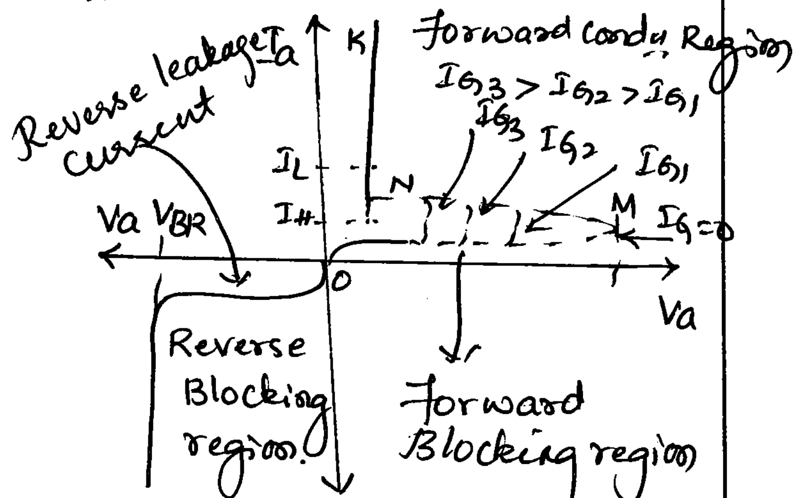
Holding current :- It is the min anode current required to hold the thyristor in on state below which thyristor enters forward blocking state.

Static Anode - Cathode Characteristics of SCR

The circuit diagram is as shown below.



The Static Char of SCR is as shown below, here Va is the anode-Cathode voltage & Ia is the anode current



→ The characteristics is divided into 3 regions namely
→ Reverse Blocking Region
→ Forward — " —
→ forward conduction Region

Reverse Blocking region:-

→ When anode is made -ve w.r.t cathode with switch "S" open the thyristor becomes reverse biased.
→ In this region, the thyristor exhibits a blocking char, similar to diode.
→ Under this bias condition J_1, J_3 are reverse biased & J_2 is forward biased condition ∴ leakage current can flow mean while when reverse voltage increased, then at critical voltage V_{BR} (reverse breakdown voltage), an avalanche will occur at J_1 & J_3 increasingly the current sharply.

NOTE:- If this current is not limited to a safe value, power dissipation will increase to a dangerous level that might destroy the device.
→ The device acts like open switch in this Region

Forward Blocking Region:- In this region anode is +ve w.r.t to Cathode ∴ J_1, J_3 are forward biased while J_2 junction remains reverse biased.
The device doesnot Conduct in this region.

Forward Conduction Region:-

→ When anode to cathode forward Voltage is increased with the gate circuit kept open, avalanche breakdown Occurs at the junction J_2 at a Critical forward break-over Voltage (V_{BO}) & SCR Switches to low impedance condition.

→ The forward breakover Voltage is denoted at point "M", when the device latches on to Conducting state.

→ As soon as device latches on to its ON state, the Voltage across the device drops from several Voltage to 1-2 Volt, Suddenly large amount of current flow through the device.

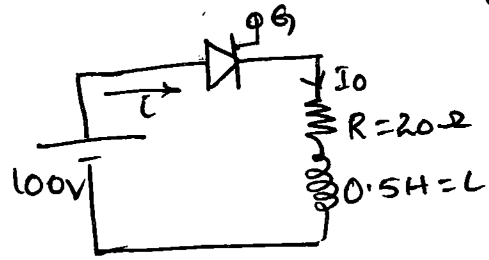
→ The part NK in Char is called forward Conduction State, device acts like a Closed Switch

NOTE:- When a gate-signal is applied, the thyristor turns on before V_{BO} is reached.
The forward Voltage at which device switches to ON State depends on the magnitude of gate current, higher gate current lower the forward breakover Voltage.

* Once SCR is turn ON a forward current that is greater than the min Value Called latching Current, the gate is no longer required to maintain the device in ON State.
* SCR returns to forward blocking state when current falls below a low level called holding current (I_H)

Problems

1. The latching current of a thyristor circuit in fig① is 50mA, the duration of the firing pulse is 50μs, will the thyristor get fired



ans Given $I_L = 50mA$, $t = 50\mu s$

$V = 100V$

→ As the thyristor is triggered, the current will rise exponentially in the inductive circuit

$$i(t) = \frac{V}{R}\left(1 - e^{-t/\tau}\right) \quad \text{where} \quad \tau = \frac{L}{R} = \frac{0.5}{20} = 0.025\,sec$$

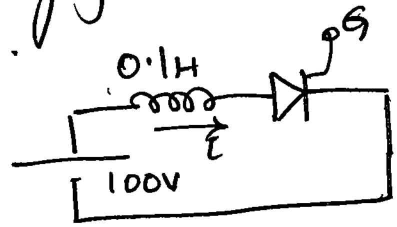
$$i(t) = \frac{100}{20}\left(1 - e^{-(50\mu/0.025)}\right)$$

$$i(50\mu) = 5\left(1 - e^{-50\mu/0.025}\right) = 9.99mA \approx 10mA$$

here one should keenly observe the obtained ckt is 10mA which is less than the latching current $I_L = 50mA$

∴ SCR will not trigger.

2. If the latching current in the circuit shown is 4mA, obtain the min width of gating pulse required to properly turn ON the thyristor.



Given:- $L = 0.1H$, $V = 100V$, $I_L = 4mA$

$$V = L\frac{di}{dt}$$

$$dt = \frac{L}{V}di$$

$$t = \frac{L}{V} \cdot i = \frac{0.1}{100}(4m) = 4\mu sec \quad \boxed{\therefore t_{min} = 4\mu sec}$$

→ The min width of gating pulse required to turn ON thyristor is 4μsec

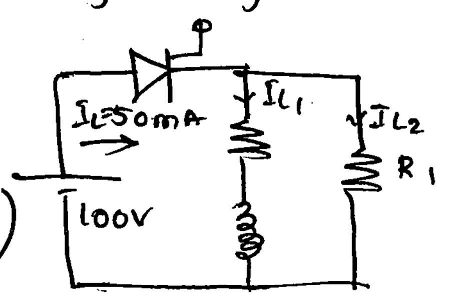
(3) The latching current of an SCR used in phase controlled circuit comprising of an inductive load of $R = 10\Omega, L = 0.1H$ and 1.5mA. The input voltage is $325 \sin 314t$. Obtain the min gate pulse width required for reliable triggering of the SCR. If the gated at $\pi/3$ angle in every positive half cycle.

ans Given $R = 10\Omega$, $L = 0.1H$, $I_L = 15mA$, $t = \pi/3$

$$V_S = 325 \sin 314t$$
$$= 325 \sin 314(\pi/3)$$
$$\boxed{V_S = 281.46V}$$

$$i(t) = \frac{V}{R}\left(1 - e^{-R/L\, t}\right)$$
$$= \frac{V}{R}\left(1 - e^{-t/\tau}\right)$$
$$15m = \frac{281.46}{10}\left(1 - e^{-\frac{10}{0.1}t}\right)$$
$$\Rightarrow \boxed{t = 5.33\,\mu sec}$$

(4) In the thyristor ckt, shown below, the SCR has a latching current of 50mA & is fixed by a pulse width of 50µsec. Show that without resistance the thyristor will fail to remain ON when the firing pulse ends & then find the max value of R_1 to ensure firing.



ans Given $I_L = 50mA$, $t = 50\mu s$, $R = 20\Omega$, $L = 0.5H$

$$I_{L_1} = \frac{V}{R}\left(1 - e^{-R/L\, t}\right) = \frac{100}{20}\left(1 - e^{-\frac{20}{0.5}t}\right)$$

$\boxed{I_{L_1} = 10mA}$ $I_{L_1} < I_L(50mA)$ ∴ without R_1 SCR fails to turn ON.

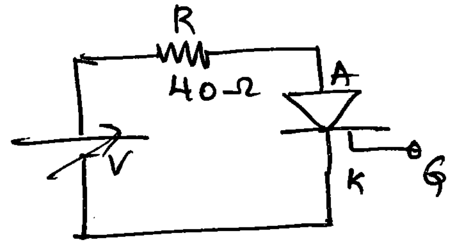
from ckt $I_L = I_{L_1} + I_{L_2}$
$$I_{L_2} = I_L - I_{L_1}$$
$$= (50 - \cancel{10})m$$
$$\boxed{I_{L_2} = 40m}$$

$$\therefore I_{L_2} = \frac{V}{R_1} = \frac{100}{R_1} \Rightarrow R_1 = \frac{100}{40m} = 2.5k\Omega$$

$(R_1 = 2.5k\Omega)$ this value ensures SCR is ON

Proof
$$I_L = I_{L_1} + I_{L_2}$$
$$= i(t) + I_{L_2}$$
$$= 10m + \frac{V}{R} = 10m + \frac{100}{2.5k}$$
$$= 10m + 40m$$
$$50m = 50m$$
hence proved.

Q. ON state Voltage drop across the thyristor in the Ckt shown in figure is 0.8V. The thyristor has a holding Current of 15mA with $I_G = 0$. If the thyristor is turned ON by a momentary pulse of gate current. Determine the value of voltage V below which the thyristor will turn off.



Given $V_{AK} = 0.8V$, $I_H = 15mA$

Applying KVL,

when $I = I_H$ $\quad V = IR + V_{AR}$

$= 15m(40) + 0.8$

$\boxed{V = 1.4V}$

when $I = I_H$, Voltage is 1.4V and to turn-off the thyristor, voltage V must be reduced below 1.4V

Q) A thyristor has a forward breakover Voltage of 175 volts when a gate pulse of 2mA is made to flow. find the Conduction angle if sinusoidal voltage of 350 peak is applied.

ans Given $V_m = 350V$, $V_s = 175V$, $I_g = 2mA$

$V_{BO} = V_s = V_m \sin\omega t$

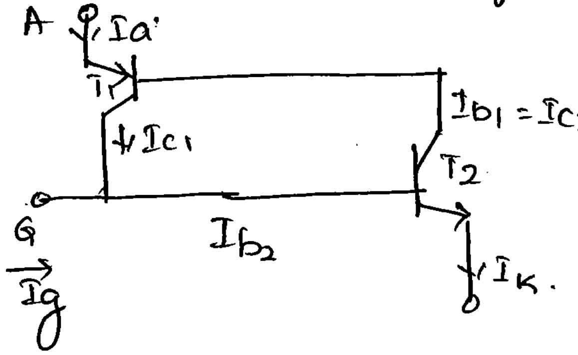
$175 = 350 \sin\omega t$

$\omega t = \sin^{-1}\left(\frac{175}{350}\right)$

$\boxed{\omega t = 30^\circ}$ or $30 \times \frac{\pi}{180} = 0.523$ radians

@ 30°, SCR will turn ON

Two transistor model of SCR (Two transistor analogy)



from the fig,

$$\boxed{I_{C_1} = I_{b_2}} \qquad \boxed{I_{b_1} = I_{C_2}}$$

$$\boxed{I_K = I_a + I_g}$$

W.K.T

$$I_{e_1} = I_{b_1} + I_{C_1}$$

$$I_{b_1} = I_{e_1} - I_{C_1}$$

$$I_{C_1} = \alpha I_{e_1} + I_{CO_1}$$

$$\therefore I_{b_1} = I_{e_1} - (\alpha_1 I_{e_1} + I_{CO_1})$$

$$\therefore \boxed{I_{b_1} = (1-\alpha_1) I_{e_1} - I_{CO_1}}$$

but $I_{e_1} = I_a$

$$\boxed{I_{b_1} = (1-\alpha_1) I_a - I_{CO_1}}$$

for transistor T_2

$$I_{e_2} = I_{b_2} + I_{C_2}$$

$$I_{b_2} = I_{e_2} - I_{C_2}$$

$$\boxed{I_{C_2} = \alpha_2 I_{e_2} + I_{CO_2}}$$

$$I_{b_2} = I_{e_2} - \alpha_2 I_{e_2} - I_{CO_2}$$

$$I_{b_2} = I_{e_2}(1-\alpha_2) - I_{CO_2}$$

$$I_{C_2} = \alpha_2 I_K + I_{CO_2}$$

$$\boxed{I_{C_2} = \alpha_2 (I_a + I_g) + I_{CO_2}}$$

but

$$I_{b_1} = I_{C_2}$$

$$(1-\alpha_1) I_a - I_{CO_1} = \alpha_2 (I_a + I_g) + I_{CO_2}$$

$$(1-\alpha_1) I_a - I_a \alpha_2 = \alpha_2 I_g + I_{CO_1} + I_{CO_2}$$

$$I_a [1 - \alpha_1 - \alpha_2] = \alpha_2 I_g + I_{CO_1} + I_{CO_2}$$

$$\boxed{I_a = \frac{\alpha_2 I_g + I_{CO_1} + I_{CO_2}}{1 - (\alpha_1 + \alpha_2)}}$$

→ The value of anode current becomes infinite when $\alpha_1 + \alpha_2 = 1$ i.e the anode current suddenly attains a very high value, approaching infinite.

→ In other words device latches from non-conducting state to conducting state this is characteristic of the device is known as regenerative action.

→ The gate current I_g is of such a value that $(\alpha_1 + \alpha_2)$ approaches unity value, the device will trigger.

The turn on Condition Condition $\{(\alpha_1 + \alpha_2) \geq 1\}$ of the SCR Can be satisfied in the following ways.

* If the temperature of the device is Very high, the leakage current through it increase, which may then satisfy the required condition to turn it on.
* When the current through the device is extremely small, the alphas will be Very small and the Condition for breakover Can be satisfied Only by large values of hole multiplication factor M_p and electron multiplication factor M_n. Near the breakdown Voltage of junction J_2, the multiplication factors are very high and required condition for breakover Can be obtained by increasing the Voltage across the device V_{BO}, which will close the breakdown voltage of junction J_2.
* The required condition for breakover Can also be realised by increasing α_1 & α_2.

→ The current gain "α_1" varies with the emitter current $\boxed{I_A = I_E}$ and "α_2" varies with $\boxed{I_K = I_A + I_G}$

→ If Gate current I_G is suddenly increased (0 to 100mA) this immediately increase anode current "I_A", which would further increase "α_1 & α_2" (Current gain α_2 depends on $I_A + I_G$)
The increase in the values of α_1 and α_2 further increases I_A ∴ there is a regenerative or +ve feedback effect.

→ If $(\alpha_1 + \alpha_2) \to 1$ I_A attains very large value & the thyristor turns on with a small gate current.

Thyristor Turn-ON methods.

→ A thyristor is turned ON by increasing the anode current this can be accomplished in one of the foll ways.

Thermals.

→ If temp of a thyristor is a high, there is an increase in the no of electron-hole pairs, which increases the leakage currents. this increase in currents causes α_1 & α_2 to increase.
Due to the regenerative action, $(\alpha_1 + \alpha_2)$ may tend to be unity and the thyristor may be turned on.

Note:- This type of turn-on may cause thermal runaway and is normally avoided.

Light:-
If light is allowed to strike the junction of a thyristor, the electron-hole pairs increases; and the thyristor may be turned On.
The light activated thyristors are turned on by allowing the light to strike the silicon wafers.

High voltage

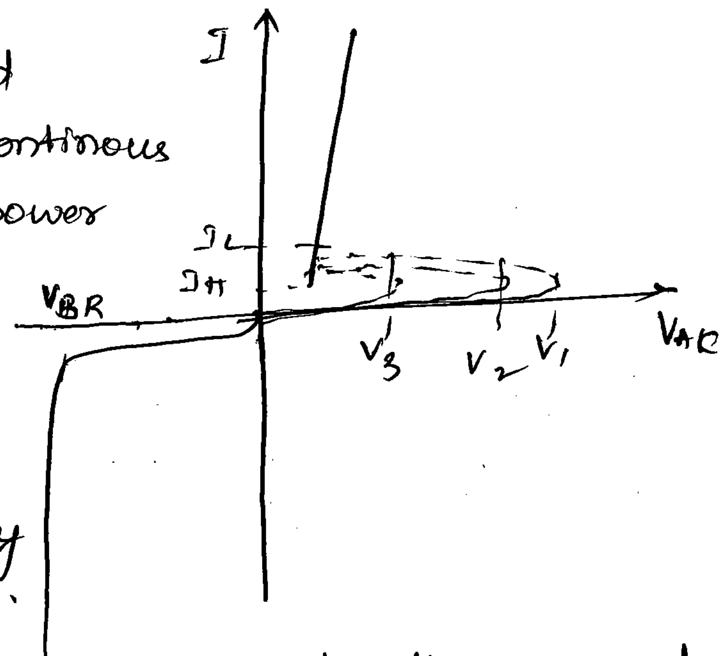
→ If forward voltage > V_{BO} sufficient leakage current initiate regenerative turn-on.

→ This type may be destructive and should be avoided.

Gate current :-

→ If thyristor is forward biased, the injection of gate current by applying positive gate voltage between gate and cathode terminals turns on the thyristor. As gate current is increased, the forward blocking voltage is decreased

→ Gate signal should be removed after the thyristor is on. A continous gating signal would increase the power loss in the gate junction.

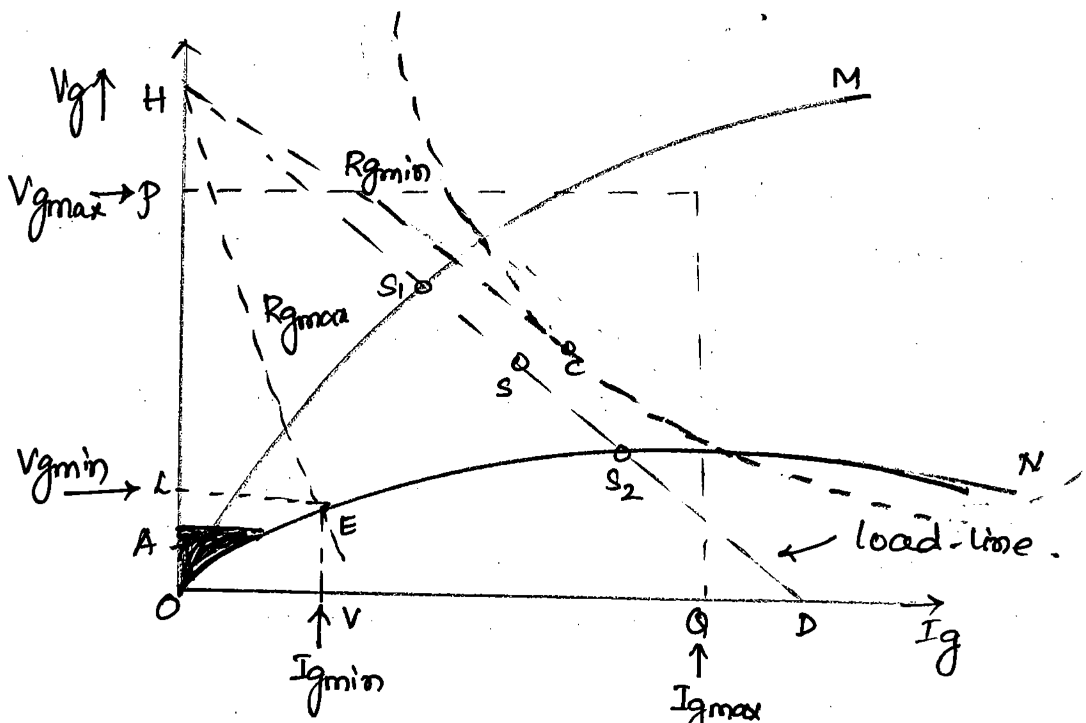


→ Although the thyristor is reversed biased, there should be no gate signal, otherwise, the thyristor may fail due to an leakage current.

→ The width of gate pulse must be longer than the time required for the anode current to rise to the holding current value I_H.

Gate characteristics of SCR

→ In a thyristor, the gate is connected to cathode through a PN junction and resembles a diode.



→ Gate char. is as shown above for particular SCR with gate voltage Vg and gate Ig (Gate to cathode current).

→ The maximum and minimum limits for gate voltage and current to prevent the permanent destruction of junction J_3 and provide reliable triggering.

→ There can be a permissible max gate power dissipation $[P_{gmax} = V_g I_g]$ within this the SCR is operated in safe otherwise there could be chances of permanent damage of junction J_3.

→ The minimum values for gate voltage V_{gmin} and gate current I_{gmin} is also given for reliable turn-on.

→ One should not exceed the max current, voltage & power ratings if so the device will be damaged within these boundaries there are three important regions.

1. First region OA lies near the Origin (shown in hatched) & is defined by maximum gate voltage that will not trigger any device. the gate must be operated in this region whenever forward bias is applied across the thyristor (SCR) & triggering is not necessary

[In other words this region sets a limit on the maximum false signals that can be tolerated in the gate firing circuits]

2. The second region is the ~~max~~ minimum Value of gate Voltage and current required to trigger the SCR

3. The third region is the largest, limits on the gate signals for reliable firing. For applications where fast turn ON is required, a "hard" firing signal in the upper right part of the region may be needed.

→ Curves ON and OM corresponds to the possible spread of the characteristic for SCR of the same ratings.

→ For best results, the operating point "S", which may change from S_1 to S_2, must be as close as possible to the permissible P_g curve & must contained within the maximum and minimum limits of gate voltage and gate current. this provides necessary hard drive for the device.

→ For selecting operating point, usually a load line HD of the gate source voltage $E_s = OH$ is drawn as HD.

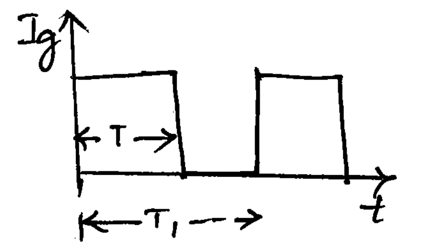
The gradient of the load line HD(= OH/OD) will give required gate source resistance R_g.

→ The max value of this series resistance is given by HE, where E is point of intersection of the lines indicating max Gate voltage & current.

→ The minimum Value of gate source series resistance is obtained by drawing a HC tangential to P_g curve.

→ Higher the magnitude of gate current pulse, lesser is the time needed to turn ON the thyristor ∴ SCR turn-on time can be reduced by using gate current of higher magnitude.

→ Gate pulse width must be equal to or greater than SCR turn-on time (t_{on}) i.e. $\boxed{T \geq t_{on}}$



With pulse firing, if the frequency of firing f is known, the peak instantaneous gate power dissipation P_{gmax} can related

$$P_{gmax} = V_g I_g = \frac{P_{gav}}{f \cdot T}$$

Where $f = \frac{1}{T_1}$., T = pulse width in second.

P_{gmax} is defined as rate of energy flow in every pulse

$$P_{gmax} = \frac{V_g}{T}$$

$|||^{ly}$ $P_{avg} = \frac{V_g}{T_1}$

$$\therefore P_{gmax} T = P_{gavg} T_1$$

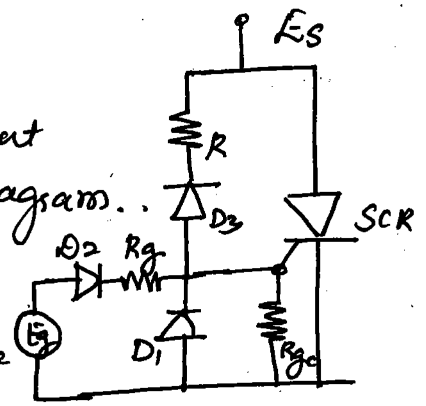
$$P_{gmax} = \frac{P_{gav}}{f \cdot T}$$

→ Duty cycle is defined as the ratio of pulse-On period to the periodic time of pulse.

$$\delta = \frac{T}{T_1} = fT$$

$$\therefore \boxed{\frac{P_{gav}}{\delta} \leq P_{gmax}}$$

Gate circuit parameters



Gate circuit

→ The gate Cathode circuit with different circuit parameters as shown in circuit diagram..

→ A series resistance R_g should be placed in series with the gate-source voltage E_g, to limit the magnitude of Gate voltage and gate current.

→ The shunt resistance R_{gc} is introduced to bypass the thermally generated leakage current across junction J_2 when the device is blocking state, in Order to improve thermal stability of the device. This shunt resistance in turn will increase the required gate current and also the device holding and latching current levels.

→ Diode D_1 applies a -ve voltage between gate and cathode when a reverse voltage is applied across the device. This -ve gate voltage reduces the reverse blocking current & improves turn-off mechanism.

→ This Diode D_1 also serves to limit the reverse voltage applied between cathode & gate, if gate source voltage is alternating.

→ The negative gate current flows through the device while SCR is ON because the diode D_1 will then be reverse biased. this will increase power dissipation of gate power.

→ Diode D_2 will prevent negative source current, Diode D_3 is to prevent forward (to block) the positive gate current coming from the supply when the device is forward biased.

Problem:- An SCR has a V_g-I_g char. given by $\boxed{V_g = 1.5 + 8I_g}$. In Certain application, the gate voltage consists of rectangular pulses of 12V and of duration 50µs with duty cycle 0.2

i) find the the value of R_g series resistor in the gate ckt, to limit the peak power dissipation in the gate to 5W.

ii) Calculate the average power dissipation in the gate.

Soln,

During Conduction

$$V_{gs} = R_g I_g + V_g$$

$$12 = R_g I_g + 1.5 + 8I_g$$

$$12 = (R_g + 8)I_g + 1.5 \quad (1)$$

$$\therefore \; 12 - 1.5 = (R_g + 8)I_g$$

$$12 - 1.5 = (R_g + 8)(0.7)$$

$$\boxed{\therefore R_g = 7\,\Omega}$$

peak power loss $= V_g I_g = 5$

$$5 = (1.5 + 8I_g)I_g$$

$$8I_g^2 + 1.5 - 5 = 0$$

solving we get

$$\boxed{I_g = 0.7\,A}$$

Now to find average, power loss = peak power loss × duty cycle.

$$= 5 \times 0.2$$

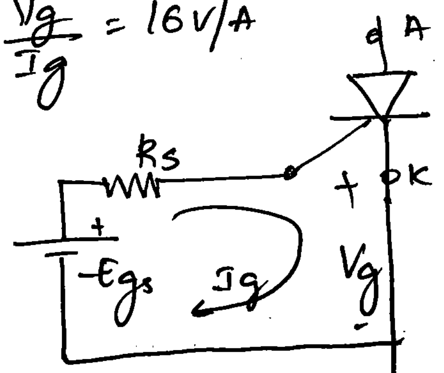
$$\boxed{P_{avg} = 1\,W}$$

2) For an SCR, the gate cathode characteristic is given by a straight line with a gradient of 16 volts per amp passing through the origin, the maximum turn-on time is 4 µs and min gate current required to obtain this quick turn-on is 500mA. If the gate source voltage is 15V,

a) Calculate the resistance to be connected in series with SCR gate.

b) Compute the gate power dissipation, given that the pulse width is equal to the turn-on time and that the average power dissipation is 0.3W, also compute the max triggering frequency that will be possible when pulse firing is used.

Soln. Given $I_{gmin} = 500mA = 0.5A$, $\frac{V_g}{I_g} = 16V/A$



$\therefore V_g = 16 \times 0.5$
$= 8V$

Applying KVL to the loop we get

$E_{gs} - I_g R_s - V_g = 0$

$\therefore R_s = \frac{E_{gs} - V_g}{I_g} = \frac{15-8}{0.5} = 14\Omega$

$\boxed{\therefore R_s = 14\Omega}$

b) power dissipation $P_g = V_g i_g$
$= 8 \times 0.5 = 4W$

$P_{gmax} = \frac{P_{gav}}{f \cdot T_{on}}$

$4 = \frac{0.3}{f \times 4 \times 10^{-6}} \Rightarrow f = \frac{0.3}{16 \times 10^{-6}}$

$\boxed{f = 18.75 \, KHz \approx 19 \, KHz}$

Turn-ON methods of a thyristor

1) Forward Voltage triggering

→ When anode-to-Cathode forward Voltage is increased with gate circuit open, the reverse biased junction J_2 will have an avalanche breakdown at a voltage Called forward breakover Voltage V_{BO}.

→ At this Voltage thyristor changes from off state to ON-state characterised by a low Voltage across it with large Current.

→ The forward Voltage-drop across the SCR during the ON state is of the order 1 to 1.5V and slightly increases with load current.

There are different methods to turn ON device & they are as follows.

2. Thermal triggering (Temperature Triggering)

→ In thyristor when voltage applied between the anode & Cathode is very near to its breakdown voltage, the device can be triggered by increasing its junction temperature.

→ By increasing the temp to a Certain value, a situation comes when the reverse biased junction Collapses making the device conduct this is known as thermal triggering.

3. Radiation Triggering (Light Triggering)

→ In this Method thyristor is bombarded by energy particles such as neutrons or photons. this external energy, helps to generate "electron hole pair" in the device. thus increasing the charge carriers

→ Usually Light activated thyristors are turned on by this Method.

1. Dc Gate Triggering:- The device is triggered by applying
→ A Dc voltage of a proper magnitude and polarity between Gate and Cathode of the device in such way ~~gate~~ is +ve ~~Cathode is~~ w.r.t Cathode.
→ When applied voltage is sufficient to produce the required gate current, the device starts conducting.

Disadv:-
→ One drawback of this scheme is that power and control circuits are dc and there is no isolation between two.
→ ~~A~~ Continuous Dc signal needed to apply which causes more gate power loss.

2. Ac Gate triggering:-
→ This method used for ac applications and this method provides proper isolation between power & control circuits.
→ This method is accomplished by applying a Ac source.
→ The firing angle control is obtained very conveniently by changing the phase angle of the control signal.
→ Gate drive is maintained for one half cycle after device is turned ON, and a reverse voltage is applied between the Gate & the cathode during negative half cycle.
→ The drawback of this method a separate transformer is required to step-down the ac supply which adds to the cost.

3. Pulse Gate triggering:- In this method, the gate drive consists ~~of~~ a single pulse appearing periodically or a sequence of high frequency pulses this is known as Carrier frequency gating.

Advantage:- There is no need of applying continous signals & hence gate losses are very much ~~less~~ Reduced

$\frac{dv}{dt}$ Triggering:-

W.K.T during forward conduction J_1, J_3 are forward biased J_2 is reverse biased and this junction breaks to help in conduction but the forward voltage helps in biasing of these junction, the junction especially has special feature or characteristic of a capacitor due to existing charges across the junction.

→ If the forward voltage is suddenly applied, a charging current will flow tending to turn on device.

→ If the voltage impressed across the device is denoted by V, the charge by Q and the capacitance by C_j then

$$i_c = \frac{dQ}{dt} = \frac{d}{dt}(C_j V) = C_j \frac{dv}{dt} + \underbrace{V\frac{dC_j}{dt}}_{\text{negligible}}$$

$$\boxed{\therefore i_c = C_j \frac{dv}{dt}}$$

∴ if the rate of change of voltage across device is large, the device may turn-on even though the voltage appearing across the device is small.

Gate Triggering:-

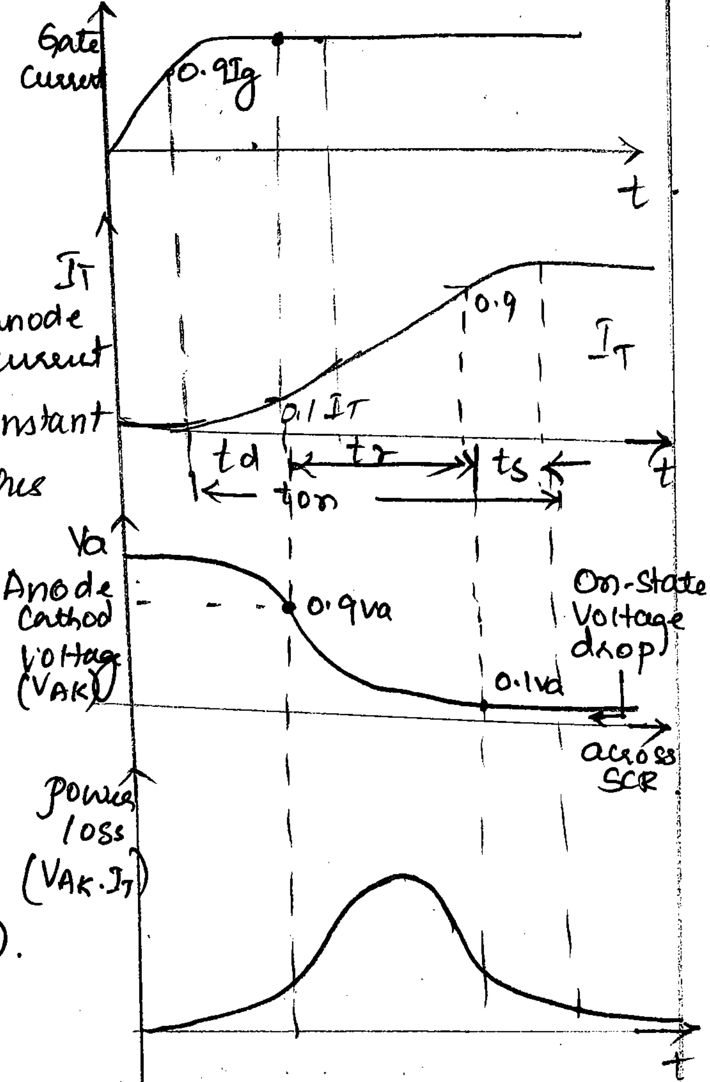
→ Most widely used method for triggering SCRs, by applying positive signal at the gate terminal of the device, it can triggered much before the specified breakover voltage.

→ The conduction period of the SCR can be controlled by varying the gate signal within the specified values of the max & min gate currents.

There are 3 types of gate triggering namely

1. DC Gate triggering
2. A.C Gate triggering
3. Pulse Gate triggering.

Dynamic Turn-ON Switching Characteristics.



The turn-on time is subdivided into three distinct periods, called delay time, rise time and spread time.

i) Delay time (td):-

→ This is the time between the instant at which the gate current reaches 90% of its final value and the instant at which the anode current reaches 10% of its final value.

→ It can also defined as time during which anode voltage falls from Va to 0.9Va (where Va is initial value of the anode voltage).

ii) Rise time (tr):-

This is the time required for the anode current to rise from 10 to 90% of its final value.

→ During rise time, turn-on losses are the highest due to high anode voltage Va and large anode current IA occuring together in the thyristor hence large dissipation takes place in the thyristor $\boxed{P = V_a I_a}$.

NOTE:- The t_r can be reduced or minimized if high and steep current pulses are applied to the gate.

iii) Spread time (t_s):-

→ The spread time is the time required for the forward blocking voltage to fall from 0.1 to its Value to the ~~on-state~~ on state Voltage drop

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

iv) Turn-on Time (t_{on}):-

→ This is the sum of the delay time, rise-time and spread time

$$\boxed{t_{on} = t_d + t_r + t_s} \quad \ldots \text{ of the order } 1 \text{ to } 4\,\mu\text{sec}$$

* This depends on foll,

The width of firing pulses must be more than 10 µsec in the range of 20 to 100 µs.

* The amplitude of the gate pulse should be 3 to 5 times of min gate current required to trigger the SCR.

Turn-Off Mechanism (Turn-off characteristics)

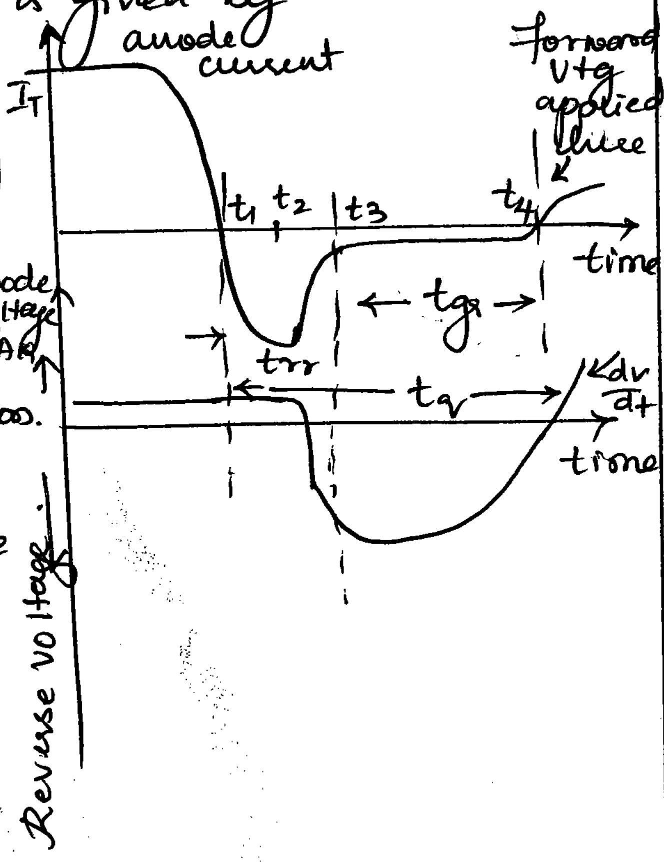
→ When SCR is conducting, the gate has no control over the device, & the device can be brought back to blocking state only by reducing the forward current holding current.

→ ~~The~~ However, if a forward ~~c~~ Voltage is applied immediately after reducing the anode current to zero, device will not block forward voltage instead device tries to conduct even though its not being triggered.
∴ device has to kept for some duration in reverse biased state before a forward anode voltage is applied.

→ The turn-off time of the thyristor is defined as the minimum time interval between the instant at which the anode current becomes zero, and the instant at which the device is capable of blocking forward voltage.

→ The total turn-off time is given by

$$\boxed{t_{off} = t_{rr} + t_{gr}}$$



@ instant t_1, anode forward current becomes zero. During the reverse recovery time t_1 to t_3, the anode current flows in the reverse direction.

→ @ t_2 a reverse anode voltage is developed & reverse recovery current continue to decrease.

→ @ t_3, J_1 & J_3 are able to block reverse voltage

However, thyristor is not yet able to block a trapped forward voltage because carriers, called trapped carriers are still present at the junction J_2.

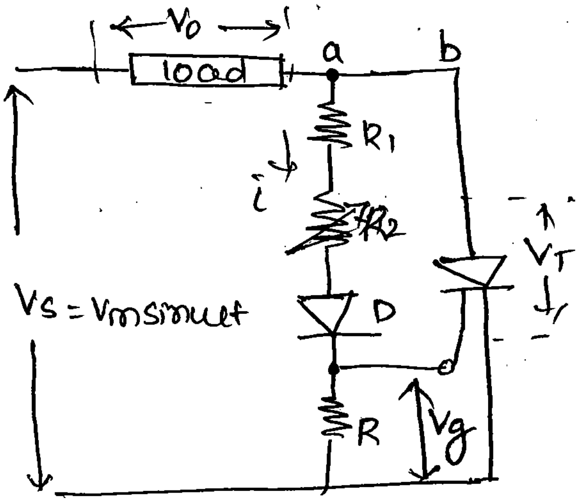
→ During interval t_3 to t_4 these carriers recombine.

@ t_4 recombination is complete ∴ forward voltage can be applied.

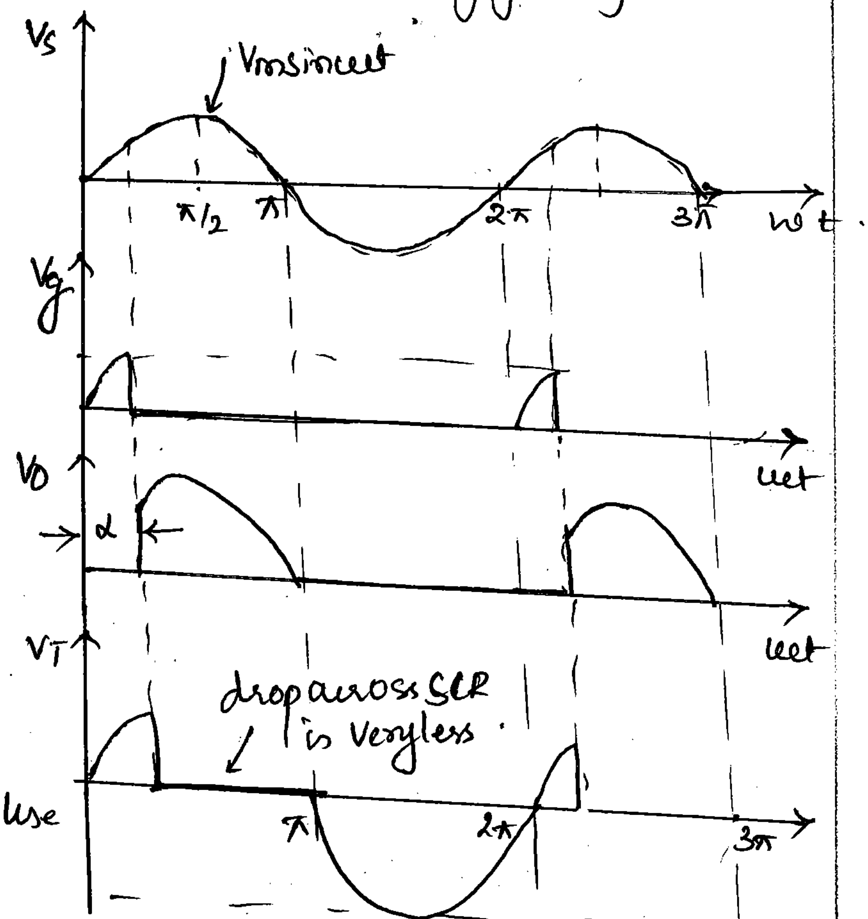
→ The total turn-off time (t_q) for a device is sum of the duration for which the reverse recovery current flows after the application of reverse voltage, & the time required for the recombination of all excess carriers in the inner two layers of the device.

Resistance firing circuits :-

Ckt shows the most basic resistance triggering circuit.



circuit diagram.



→ In the circuit R_2 is Variable, R is stabilizing resistance.

→ The drop across "R" is use to trigger the SCR.

→ The current i which may flow from source, through load, R_1, D and gate to Cathode known as gate current which is responsible for SCR triggering.

→ This current should not exceed max permissible gate current I_{gm} ∴ $I_1 < I_{gm}$

$$\frac{V_m}{R_1} \le I_{gm} \quad \text{Or} \quad \boxed{R_1 \geq \frac{V_m}{I_{gm}}}$$

→ Thus R is used limit gate current to safe value as R_2 is Varied.

The resistance R should have such a value that max voltage drop across it does not exceed max possible gate voltage V_{gm} which can happen only when R_2 is zero.

$$\frac{V_m}{R_1 + R} R \le V_{gm}$$

$$\boxed{R \le \frac{V_{gm} R_1}{V_m - V_{gm}}}$$

NOTE:- Firing angle can be increased by making R_2 minimal but meanwhile R_2 is more α can be increased not beyond 90°.

⇒ as R_1, R_2 are large, gate trigger circuit draws a small current.

⇒ Diode D allows the flow of current during positive half cycle only i.e. V_g (gate voltage) is half-wave dc pulse, the amplitude of this dc pulse can be controlled by R_2.

⇒ R_2 is adjusted such that $\boxed{V_{gp} = V_{gt}}$ i.e. R_2 is ~~small~~ large current i_2 is small ∴ drop across R i.e. $\boxed{V_g = iR}$ is small.
∴ SCR might not be triggered when $(V_{gp} < V_{gt})$

⇒ When $\boxed{V_{gp} = V_{gt}}$ SCR is ON, gate loses its control over SCR and V_g is reduced to almost zero (1V).

⇒ Firing angle can ~~be~~ never be zero. however large V_{gp} may lead to $2^\circ - 4^\circ$ of firing angle.

The relationship between firing angle, V_{gp}, V_{gt} is given by

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

$$\alpha = \sin^{-1}(V_{gt}/V_{gp})$$

Since $V_{gp} = \frac{V_m R}{R_1 + R_2 + R}$

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

RC - firing circuits:-

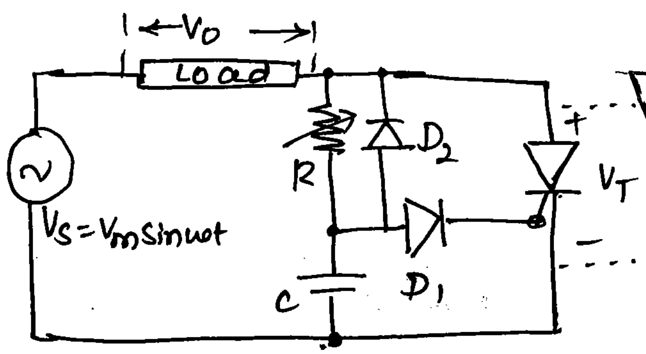
→ The limited range of firing angle control by resistance firing circuit can be overcome by RC firing circuit.

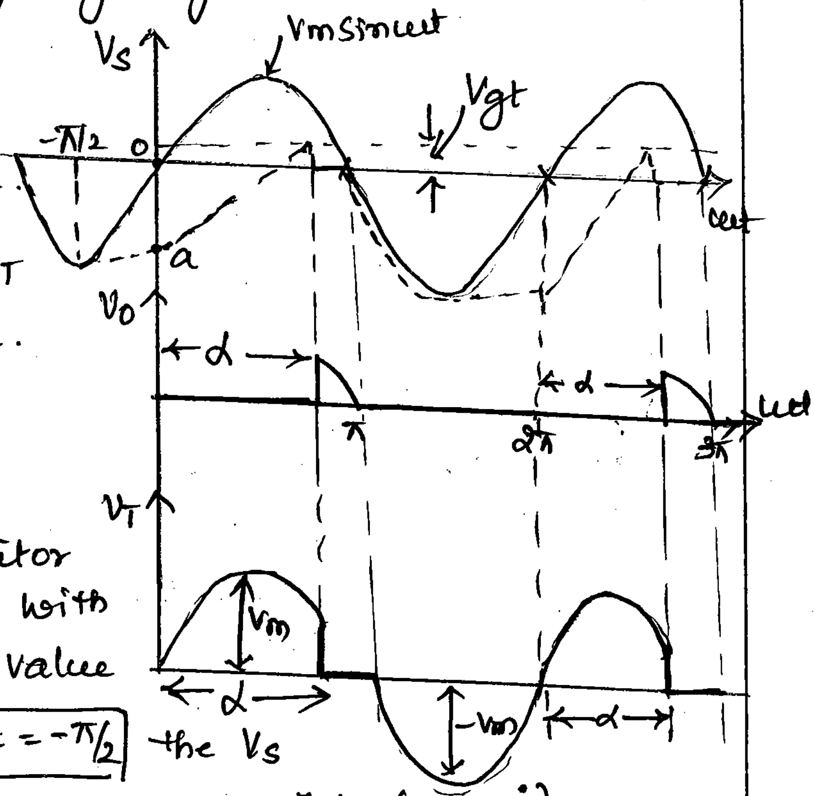
→ There are several range of RC firing ckts but only two are presented here

i) RC half-wave trigger circuit ii) RC- full wave trigger circuit

RC half-wave trigger circuit:-

→ The below figure illustrates RC half wave trigger circuit, by varying the value of R, firing angle can be controlled from 0° to 180°.





Working:-

→ During -ve half cycle, capacitor C charges through Diode D2 with lower plate positive to peak value $\boxed{V_m \text{ at } \omega t = -90^\circ}$, after $\boxed{\omega t = -\pi/2}$ the V_s voltage decreases from $-V_m$ at $\omega t = -\pi/2$ to zero ($\omega t = 0^\circ$).

→ During this period ($-\pi/2$ to 0) the capacitor voltage falls from $-V_m$ to some lower value $-oa$ at $\omega t = 0^\circ$ as shown in w/f

→ Now as SCR anode voltage passes through zero & becomes positive, C begins to charge through variable resistance R from initial voltage $-oa$.

→ When capacitor charges to positive voltage equal to gate voltage trigger voltage V_{gt}, SCR is fired & after this, capacitor holds to small positive voltage.

→ The diode D_1 is used to prevent the breakdown of cathode to gate junction through D_2 during the negative half cycle.

→ The RC value can be shown using empirical formula

$$\boxed{RC \geq \frac{1.3T}{2} \approx \frac{4}{\omega}} \qquad T = \frac{1}{f} = \text{period of ac line frequency}$$

→ The SCR will trigger when $\boxed{V_c = V_{gt} + V_d}$ where V_d is the voltage drop across the diode D_1.

→ At the instant of triggering, if V_c is assumed to be const., the current I_{gt} must be supplied by voltage source through R, D_1 and gate to cathode circuit.

The max. value of R is given by

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

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

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

Where V_s → source voltage at which thyristor turns on

NOTE: ① The SCR is ON, voltage drops across it to 1 to 1.5V this, in turn, lowers the voltage across R and C to this low value of 1 to 1.5V. Low voltage across SCR during conduction period keeps C discharged in positive half cycle until negative voltage cycle across C appears. This charges to C to $-V_m$.

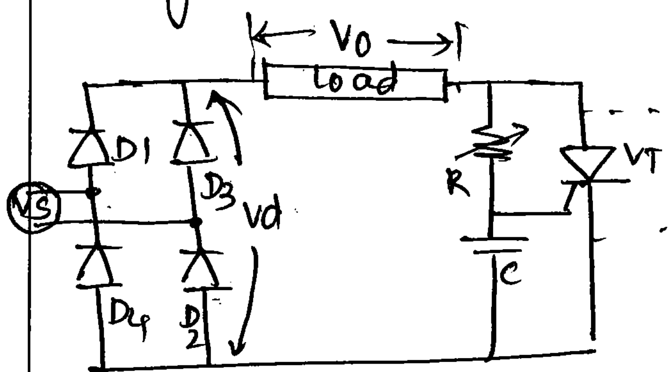
② When R is more, the time taken to charge C from $-V_a$ to $(V_{gt} + V_d) \approx V_{gt}$ is more, firing angle is more

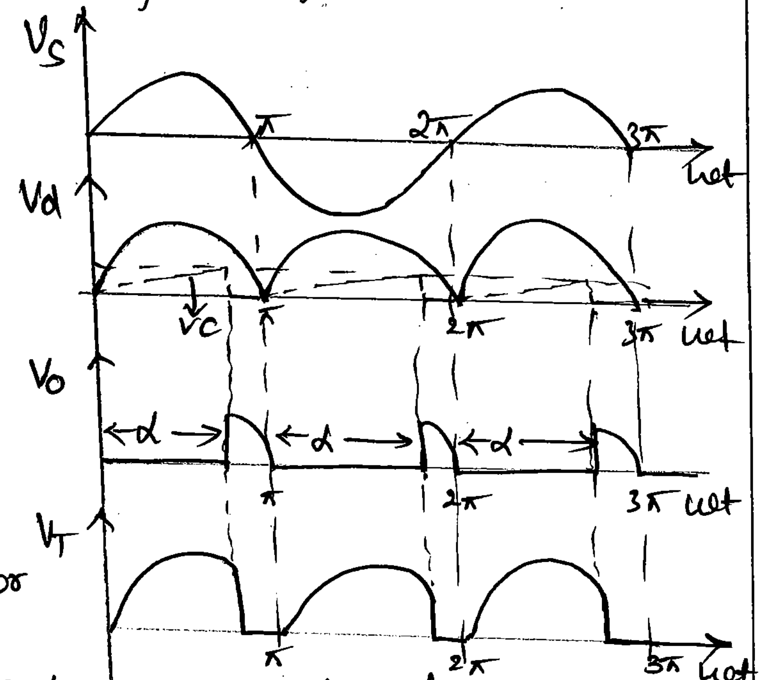
∴ average output voltage is low

③ When R is less, firing angle is low ∴ average o/p voltage is more.

RC Fullwave trigger circuit:-

The circuit diagram is as shown below, which gives fullwave output voltage. Diodes D1 - D4 form a full wave diode bridge.





→ In this circuit, the initial Voltage from which capacitor 'C' charges is almost zero.

→ The capacitor C is set to this low voltage by clamping action of SCR gate.

→ When C charges to Voltage equal to V_{gt}, SCR triggers & rectified voltage V_d appears across the load as V_o.

→ The value of RC is calculated

$$RC \geq 50\frac{T}{2} \approx \frac{157}{\omega}$$

The R value can be given by

$$\boxed{R << \frac{V_s - V_{gt}}{I_{gt}}}$$

where V_{gt} → trigger voltage
V_s → Source Voltage.

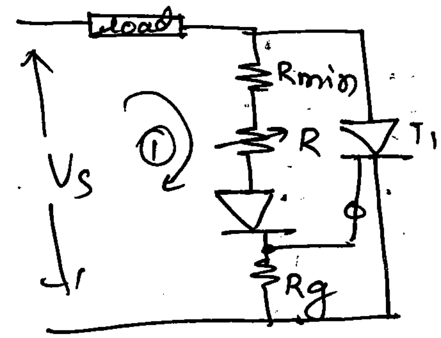
Problems

1) For the thyristor in the circuit, the gate voltage required to trigger is $\boxed{V_{GT} = 0.6\,V}$, and the corresponding gate current is $\boxed{I_{GT} = 250\,\mu A}$, a silicon diode is used and the input to circuit is $\boxed{V = 100 \sin\omega t}$. Find the firing angle α at which the thyristor will turn ON if $R_{min} = 10\,k\Omega$ & $\boxed{R = 220\,k\Omega}$

Given:- $R_{min} = 10\,k\Omega$, $R = 220\,k\Omega$

$I_{GT} = 250\,\mu A$, $V_{GT} = 0.6\,V$

$V_s = 100 \sin\omega t$



Applying KVL to loop 1 we get

$$V_s - I_{GT} R_{min} - I_{GT} R - V_D - I_{GT} R_g = 0$$

$$V_s = I_{GT}(R_{min} + R) + V_D + V_{GT}$$

$$= 250\mu(10k + 220k) + 0.7 + 0.6$$

$$\boxed{V_s = 58.8\,V}$$

W.K.T $V_s = V_m \sin\alpha$

$$\sin\alpha = \frac{V_s}{V_m} \Rightarrow \alpha = \sin^{-1}\left(\frac{V_s}{V_m}\right) = \sin^{-1}\left(\frac{58.8}{100}\right)$$

$$\boxed{\therefore \alpha = 36.01^\circ}$$

(2) Repeat the problem for $I_{gmin} = 0.1\,mA$, $V_{gmin} = 0.5\,V$, peak amplitude $V_m = 34\,V$, find α for $R = 100\,k\Omega$ and $R_{min} = 10\,k\Omega$.

$$V_s = I_{gmin}(R_{min} + R) + V_D + V_{gmin}$$

$$= 0.1m(110k) + 0.6 + 0.5$$

$$\boxed{V_s = 12.1\,V}$$

NOTE:-
For R firing ckt
$(\alpha < 90^\circ)$

$$\alpha = \sin^{-1}\left(\frac{V_s}{V_m}\right) = \sin^{-1}\left(\frac{12.1}{34}\right)$$

$$= 20.2^\circ$$

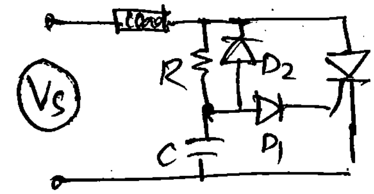
(3) Design a suitable Rc half wave triggering circuit for a thyristorised network operation on a 220V, 50Hz supply. The specifications of SCR are $V_{gtmin} = 5V$, $I_{gmin} = 30mA$

an: Given $\boxed{V_{gt(min)} = 5V}$, $\boxed{I_{gmin} = 30mA}$ $\boxed{f = 50Hz}$ $\boxed{V_s = 220V}$

assume $\boxed{V_D = 0.7V}$

$$T = \frac{1}{f} = \frac{1}{50} = 20ms$$

$$R = \frac{V_s - V_{gtmin} - V_D}{I_{gt}} = \frac{220 - 5 - 0.7}{30m}$$



ckt diag

$$\boxed{R = 7.1433 K\Omega}$$

To find Capacitor 'C' use Empherical relation

$$RC \geq \frac{1.3T}{2}$$

$$C \geq \frac{1.3T}{2R} = \frac{1.3 * 20 \times 10^{-3}}{2(7.14 * 10^{3})} = 1.819 \mu F$$

$$\boxed{C \geq 1.819 \mu F}$$

(4) A thyristor in ckt (R-firing ckt) with $I_{gmin} = 0.1mA$ and $V_{gmin} = 0.5V$. The diode is silicon and the peak amplitude of the input is 24 volts, Determine the trigger angle α for $R_V = 100K\Omega$

$R_{min} = 10K\Omega$ $\boxed{V_{gmin} = V_{gt}}$ $\boxed{I_{gt} = I_{gmin}}$

an: Given:- $V_{gmin} = 0.5$, $I_{gmin} = 0.1m$ $R = 100K$, $R_{min} = 10K$

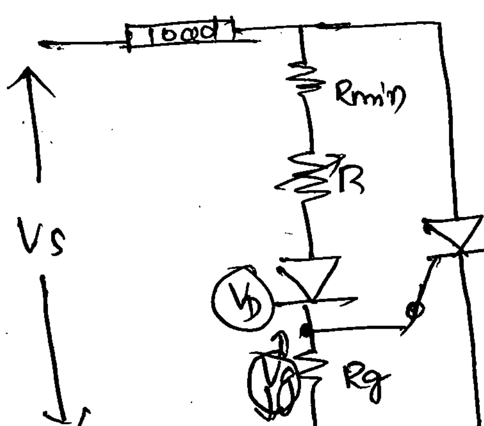
Apply KVL we get

$$V_S = I_g(R_{min} + R) + V_D + V_g$$

at trigger point,

$$V_s = 0.1m(110K) + 0.7 + 0.5$$

$$\boxed{V_s = 12.2V}$$



W.K.T $V_s = V_m \sin\alpha$

$$\alpha = \sin^{-1}\left(\frac{V_s}{V_m}\right) = \sin^{-1}\left(\frac{12.2}{24}\right)$$

$$\boxed{\alpha = 30.6^{\circ}}$$

(5) A thyristor is supplied from 230V, 50Hz mains, if conduction angle is 120°, determine the voltage at which the SCR is triggered

Given $V_S = 230$, $f = 50\,Hz$ $\beta = 120°$

$$V_m = \sqrt{2}\,V_S = \sqrt{2}(230) = 325.26V$$

firing angle $\alpha = 180° - \beta$ $\boxed{\because \alpha + \beta = 180°}$

$= 180 - 120$

$$\boxed{\alpha = 60°}$$

Voltage which turns on the SCR is $V_{BO} = V_m \sin\alpha = 325.26 \sin 60°$

$$\boxed{\therefore V_{BO} = 281.68V}$$

(6) The R-firing ckt has $I_{gmin} = 0.1m$ $V_{gmin} = 0.5V$, $R = 10k$ which uses silicon diode find R_{min} needed to cause triggering when V_s reaches 3.2V.

$$V_S = I_g(R_{min} + R) + V_D + V_g$$

$$V_S = I_g R_{min} + I_g R + V_D + V_g$$

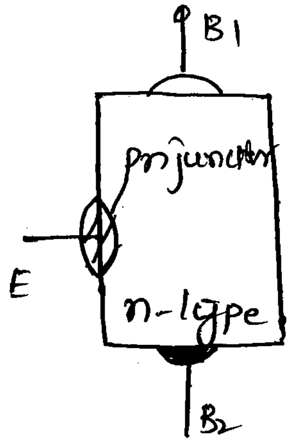
$$V_S - V_D - V_g - I_g R = I_g R_{min}$$

$$R_{min} = \frac{3.2 - 0.6 - 0.5 - (0.1m)(10k)}{0.1m} = \underline{\underline{11K}}$$

Unijunction Transistor:-(UJT)

→ a three terminal, single junction device, it has Emitter, B1, B2 terminals.

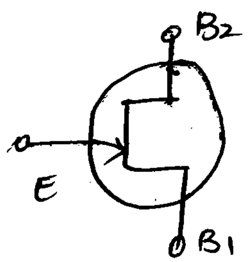
Basic Structure :-



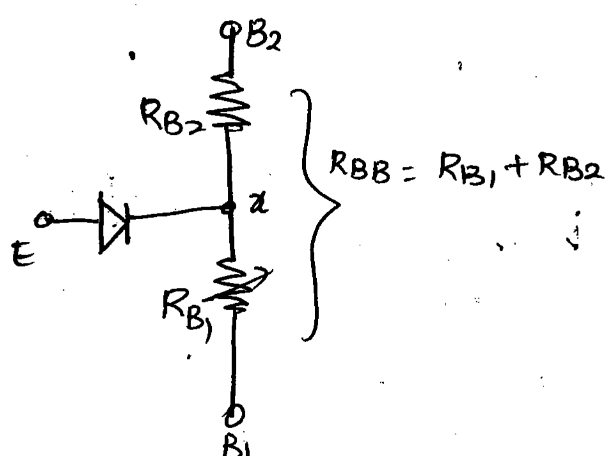
→ It has lightly doped n-type Si bar provided with ohmic contacts at each end. These two connections are known as base-1(B_1) base 2 (B_2).

→ A small heavily doped P-region is alloyed into to one side of the bar closer to B_2 this is UJT Emitter E.

→ An inter base resistance R_{BB} Exists between B1 & B2. this can be broken into two resistances R_{B1} & R_{B2}. Since Emitter is closer to B_2 $R_{B1} > R_{B2}$.



Symbol



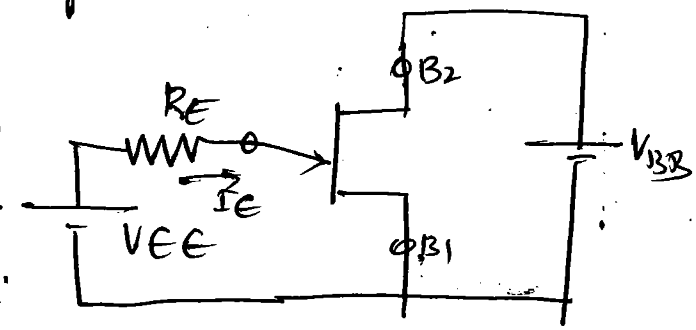
Equivalent circuit

→ In the above equivalent circuit Diode represents the pn-junction between Emitter and point x.

Working:-

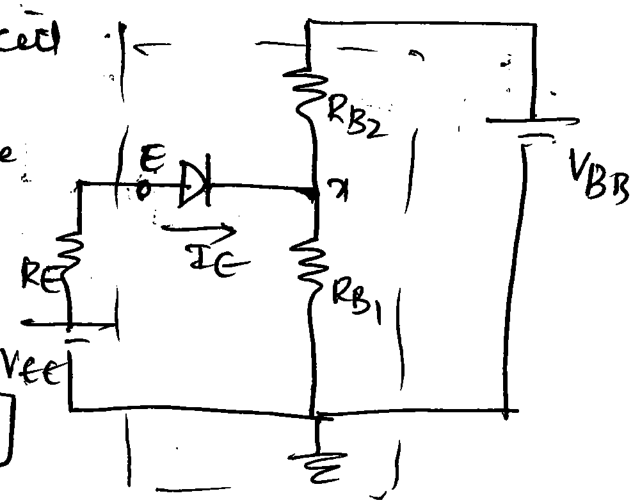
- When Emitter diode is reverse biased, only a very small current flows. under this condition RB1 is high ∴ UJT is off.
- When Diodes is ON RB1 drops to very low resistance. allowing emitter current to flow.

device
Circuit Operation can be dealt with circuit shown with two power supplies. VBB (fixed), VEE (variable).



→ $V_x = \left(\frac{R_{B1}}{R_1 + R_{B2}}\right) V_{BB} = \eta V_{BB}$ where η intrinsic stand off ratio. (0.5 to 0.8)

When voltage @ x point can be written as shown with reference to Equivalent circuit :-



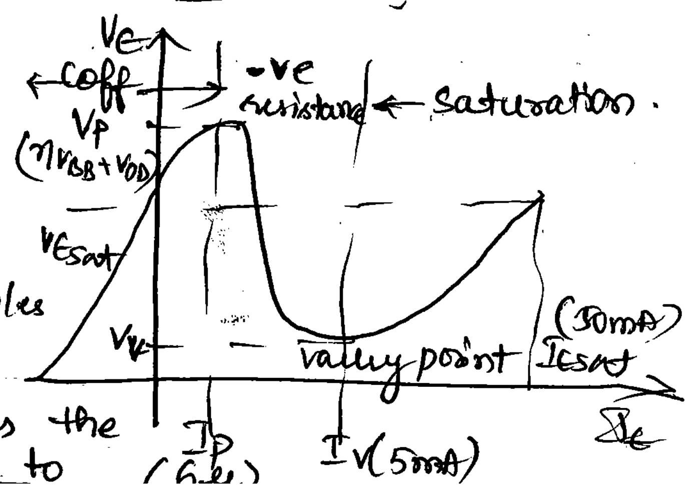
→ When the voltage @ anode of diode D1 is more than $\boxed{V_D + V_x}$ the UJT is said to be turned on.

→ As VE approaches $\boxed{V_P = V_D + V_x}$ diode is ON the current is peak current I_P.

→ at this point holes are injected from p region to n-bar into B1 region.

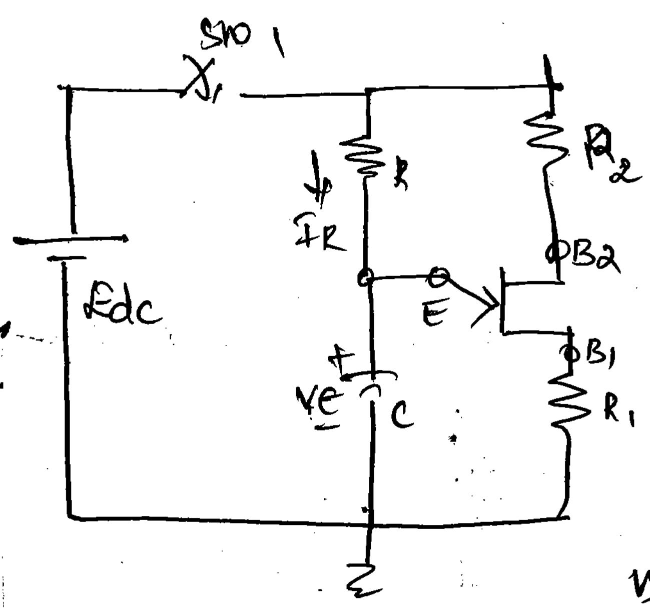
→ As n-bar is lightly doped, holes recombine very ~~high~~ likely.

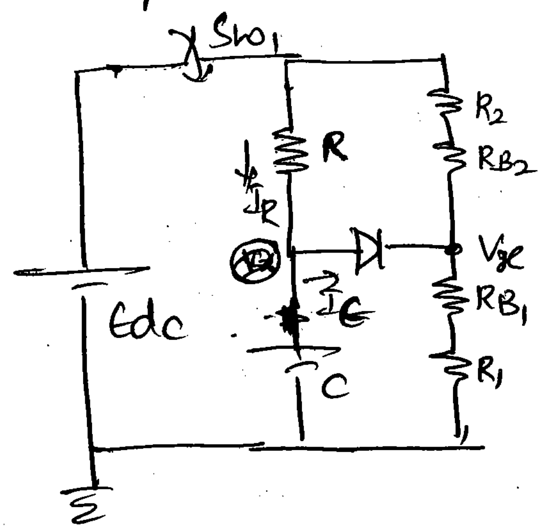
When half of Bar has more holes the RB1 reduces which cause Vx to



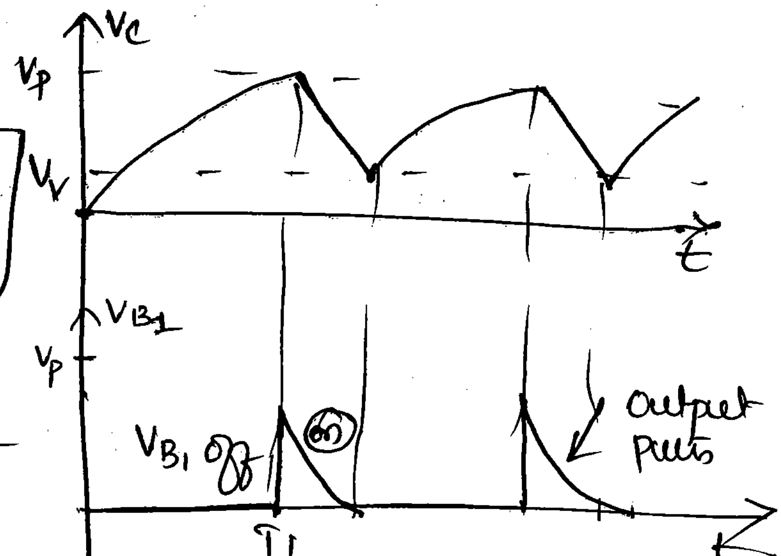
→ The UJT operation has switched to the low-voltage, high current region of its $V_E - I_E$ curve.
In this region the Emitter voltage is small & I_E increases.
Once UJT is on increasing V_{EE} will serve to increase I_E while V_E remains around 2V.

UJT Relaxation Oscillator





$$\boxed{V_x = \frac{(R_1 + R_{B1})\, E_{dc}}{R_1 + R_{B1} + R_2 + R_{B2}}}$$



$$V_{B1\,off} = \left(\frac{R_1}{R_1 + R_{BB} + R_2}\right) E_{dc}$$

$$\boxed{R_2 = \frac{10^4}{\eta V_{BB}}} \quad (1)$$

the emitter diode forward char vary with temp. In order to provide compensation against this thermal effect the value of R_2 can be Eq (1)

Working

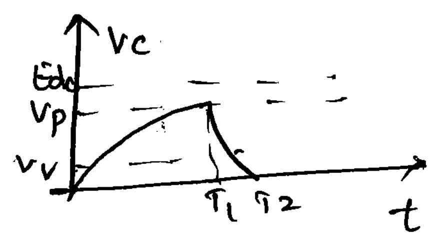
→ Initially the Capacitor Voltage is Zero ∴ Device is off.
i.e, $V_x < \eta V_D$ ∴ $I_E = 0$ & Capacitor Charge through R towards Edc.

→ When voltage at Emitter reaches to peak value V_{P1}
the Emitter diode is ON with R_{B1} dropping, since diode is forward biased the Capacitor discharge through the low resistance path containing the diode R_{B1} & R_1

→ The discharge time is very short when compared to its charging time constant.

→ When the voltage approaches valley voltage (V_v), the Emitter Current drops below Valley current (I_v) ∴ UJT is off. this occurs at time T_2 when voltage across Capacitor has dropped to valley voltage again diode reverse biased $I_E = 0$

→ The process is repeated which results in generation of waveform.



Pulse Outputs:-
The UJT relaxation Oscillator circuit can also supply pulse waveforms. if the o/p is taken at B_1, the train of pulses occurring during the discharge of the capacitor through the UJT Emitter.

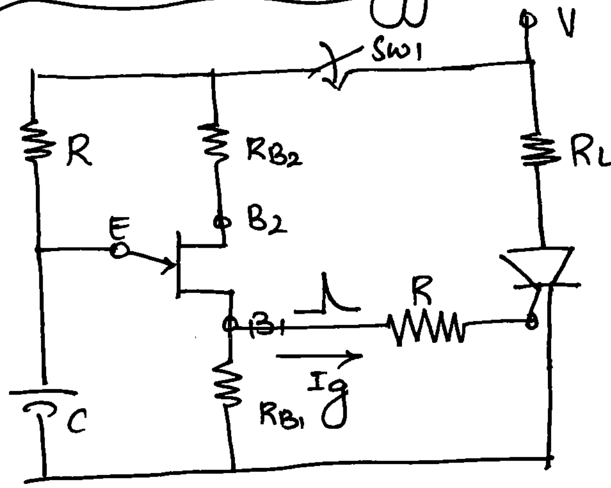
→ The waveform is as shown in previous page and Corresponding Equ. for amplitude is also written.

Varying the frequency:- The frequency of oscillations is normally controlled by varying the charging time constant RC. however the limits are

$$\boxed{R_{min} = \frac{E_{dc} - V_v}{I_v}} ; \boxed{R_{max} = \frac{E_{dc} - V_P}{I_P}}$$

NOTE:-
R should be within safe range
$\boxed{R_{min} < R < R_{max}}$

UJT as an SCR Trigger:-



→ The basic circuit is as shown below

→ The B1 pulse is used to trigger SCR a predetermined interval of time after the SW1 is closed

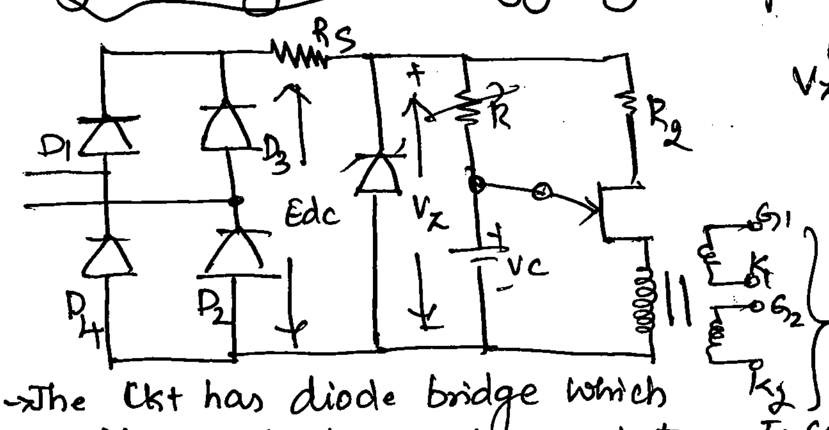
→ The first pulse at B1 triggers the SCR, after SCR is triggered ON Subsequent pulses at its gate has no effect.

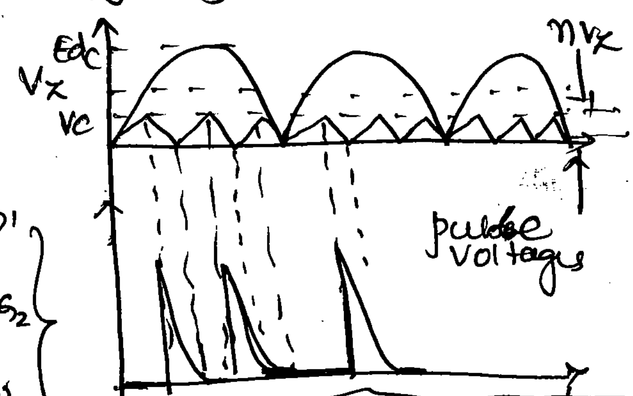
NOTE:-

An important design consideration in this type of circuit concerns premature triggering of SCR. The voltage at B1 (When (UJT is off) must be smaller than the voltage needed to trigger the SCR, otherwise the SCR will be triggered immediately upon switch closure.

$$\boxed{\therefore V_{B_1\,off} < (I_g R + V_g)}$$

Synchronized UJT-Triggering (Ramp Triggering):-





→ The Ckt has diode bridge which rectifies ac to dc, Rs lower Edc to suitable value for Zener diode.

→ Zener is used to get constant (V_z) which is used to charge C.

NOTE:- as V_z goes to zero at the end of each half cycle the synchronization of trigger ckt with supply voltage across SCR is achieved.

→ Capacitor charges untill peak voltage (V_p) when device is ON C discharges through Emitter & primary of pulse transformer.

→ The secondary voltage (pulses) are fed to SCR to turn ON

(1) Derive the expression for periodic time $\left[T = Rc \log_e \frac{1}{1-\eta}\right]$ of the UJT Relaxation Oscillator.

The voltage across the Capacitor is given by

$$V_P = V_{BB}\left(1 - e^{-t/Rc}\right) \quad \ldots (1)$$

When $V_P = \eta V_{BB} + V_D$, the Capacitor will discharge through R_1

$$\therefore \eta V_{BB} + V_D = V_{BB}\left(1 - e^{-t/Rc}\right)$$

Neglecting the diode drop V_D we can write

$$\eta \cancel{V_{BB}} = \cancel{V_{BB}}\left(1 - e^{-t/Rc}\right)$$

$$\eta = \left(1 - e^{-t/Rc}\right)$$

$$e^{-t/Rc} = 1 - \eta \quad \therefore e^{t/Rc} = \frac{1}{1-\eta} \quad \ldots (2)$$

taking $\log_e$ on both sides we get

$$\frac{t}{Rc} = \log_e\left(\frac{1}{1-\eta}\right)$$

$$t = Rc \log_e\left(\frac{1}{1-\eta}\right) \quad \text{Here } t = T$$

$$\therefore T = Rc \log_e\left(\frac{1}{1-\eta}\right)$$

$\therefore$ frequency of oscillations

$$\boxed{f = \frac{1}{Rc \log_e\left(\frac{1}{1-\eta}\right)}}$$

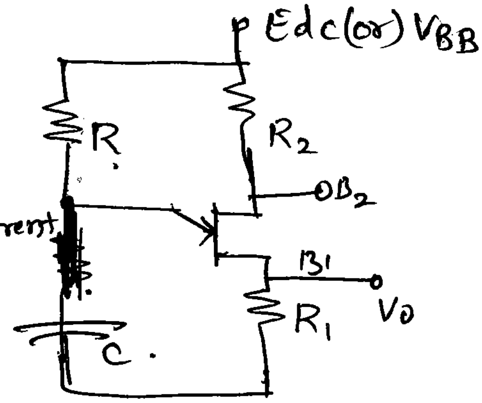
UJT oscillator List of formulae's

$R_2 = \frac{10^4}{\eta V_{BB}}$; $R_1 = \frac{V_{BB}}{I_{EO}} - R_2 - R_{BB}$.

Where

$I_{EO} \rightarrow$ leakage current

diode is off.



$R_{max} = \frac{V_{BB} - V_P}{I_P} = \frac{V_{BB} - (\eta V_{BB} + V_D)}{I_P}$

$R_{min} = \frac{V_{BB} - V_V}{I_V}$

$$\boxed{f = \frac{1}{RC \log_e \frac{1}{1-\eta}}}$$

1) A relaxation Oscillator using a UJT as shown in fig is to be designed for SCR triggering. The UJT has foll. data $\eta = 0.72$, $I_P = 0.6mA$ $V_P = 18V$ $V_V = 1V$ $I_V = 2.5mA$ $R_{BB} = 5K\Omega$ Normal leakage current with Emitter open $\boxed{I_C = 4.2mA \text{ leakage}}$

The firing frequency of 2KHz, for $C = 0.04\mu F$ find R, R_1 & R_2

ans Given $\boxed{\eta = 0.72}$ $\boxed{I_P = 0.6mA}$, $V_P = 18V$ $V_V = 1V$ $I_V = 2.5mA$

$R_{BB} = 5K\Omega$ $f = 2KHz$

W.K.T $f = \frac{1}{RC \log_e \frac{1}{1-\eta}}$ $\Rightarrow R = \frac{1}{fc \ln \frac{1}{1-\eta}} = \frac{10^6}{2\times10^3\times0.04 \ln \frac{1}{0.28}}$

$\boxed{R = 9.82K\Omega}$

as V_D is not given

$V_P = \eta V_{BB}$

$V_{BB} = \frac{V_P}{\eta} = \frac{18}{0.72} = 25V$

To find R_2

$R_2 = \frac{10^4}{\eta V_{BB}} = \frac{10^4}{0.72\times25}$

$= 555.5\Omega$

To find R_1

With emitter open, $V_{BB} = \text{leakage current}\,(R_1 + R_2 + R_{BB})$

$$R_1 = \frac{V_{BB}}{\text{leakage current}} - R_2 - R_{BB}$$

$$= \frac{25}{4.2 \times 10^{-3}} - 5 \times 10^{3} - 0.55K$$

$$\boxed{R_1 = 396.83\ \Omega}$$

(2) If the firing frequency in previous problem is changed by varying resistor R, obtain the max & min values of R and corresponding frequencies.

$$R_{max} = \frac{V_{BB} - V_P}{I_P} = \frac{25 - 18}{0.6 \times 10^{-3}} = 11.67K$$

$$R_{min} = \frac{V_{BB} - V_V}{I_V} = \frac{25 - 1}{2.5 \times 10^{-3}} = 9.6K\Omega$$

$$\therefore f_{min} = \frac{1}{R_{max} C \ln \frac{1}{1-\eta}} = \frac{10^3}{11.67 \times 0.04 \times \ln \frac{1}{0.28}} = 1.68\,KHz$$

$$f_{max} = \frac{1}{R_{min} C \ln \frac{1}{1-\eta}} = \frac{10^3}{9.6 \times 0.04 \times \ln \frac{1}{0.28}} = 2.05\,KHz$$

$\therefore$ Frequency can be in the range

$$\boxed{1.68K < f < 2.05\,KHz}$$

(3) Design a UJT relaxation oscillator for triggering SCR with foll. Specifications $\eta = 0.7$, $I_P = 50\mu A$, $V_V = 2V$, $I_V = 6mA$, $V_{BB} = 20V$

$R_{BB} = 7K\Omega$ $I_{EO} = 2mA$ assume $C = 0.1\mu F$

~~$V_P = 14V$~~ as $V_P = \eta V_{BB} + V_D \simeq \eta V_{BB} = 0.7 \times 20 = 14V$

The value of R_2 can be found by $R_2 = \frac{10^4}{\eta V_{BB}} = \frac{10^4}{0.7 \times 20}$

$$\boxed{R_2 = 714.29\Omega}$$

To find R_1

$V_{BB} = \text{leakagcurrent}\ (R_1 + R_2 + R_{BB})$

$$R_1 = \frac{V_{BB}}{I_{EO}} - R_2 - R_{BB}$$

$$= \frac{\cancel{20}\,10}{\cancel{2} \times 10^{-3}} - 714.29 - 7K\Omega$$

$$= 10K - 7.71K$$

$$\boxed{R_1 = 2.28K\Omega}$$

To find R_{max} & R_{min}

$$R_{max} = \frac{V_{BB} - V_P}{I_P} = \frac{20 - 14}{50 \times 10^{-6}}$$

$$\boxed{R_{max} = 120K\Omega}$$

$$R_{min} = \frac{V_{BB} - V_V}{I_V} = \frac{20 - 2}{6 \times 10^{-3}} = 3K\Omega.$$

$$f_{max} = \frac{1}{R_{min} \times C\ \ln \frac{1}{1-\eta}} = \frac{10^6}{3 \times 10^3 \times 0.1 \times \ln\left(\frac{1}{1-0.7}\right)}$$

$$= 2.78KHz$$

$$f_{min} = \frac{1}{R_{max} \times C\ \ln \frac{1}{1-\eta}} = \frac{10^6}{120 \times 10^3 \times 0.1 \times \ln \frac{1}{1-0.7}}$$

$$\boxed{f_{min} = 70.72Hz}$$

Design a UJT triggering ckt in fig the parameters for UJT are $V_{BB} = 30V$, $\eta = 0.51$, $I_p = 10\mu A$, $V_v = 3.5V$, $I_v = 10mA$ frequency of oscillations is $f = 60Hz$ & width of the triggering pulse is $t_g = 50\mu$

Given $I_p =$

NOTE:- R_1 can be found

$\tau_2 = R_1 C$

↓

triggering pulse width

$$T = \frac{1}{f} = \frac{1}{60} = 16.67 ms$$

W.K.T $V_P = \eta V_{BB} + \cancel{V_D} = \eta V_{BB} = 0.51 \times 30 = 15.8V$

To find R_1 & R_2

$$R_2 = \frac{10^4}{\eta V_{BB}} = \frac{10^4}{15.8} = 654\Omega$$

$$\boxed{R_1 = \frac{t_g}{C} = \frac{50\mu}{0.5\mu} = 100\Omega}$$

To find R_{max} & R_{min}

$$R_{max} = \frac{V_{BB} - V_P}{I_P} = \frac{30 - 15.8}{10\mu} = 1.42 M\Omega$$

$$R_{min} = \frac{V_S - V_V}{I_V} = \frac{30 - 3.5}{10m} = 2.65 K\Omega$$

To find R

$$f = \frac{1}{RC \ln \frac{1}{1-\eta}}$$

assume $C = 0.5\mu F$

$$R = \frac{T}{C \ln \frac{1}{1-\eta}} = \frac{16.67m}{0.5\mu \times \ln \frac{1}{1-0.51}}$$

$$\boxed{R = 46.7 K\Omega}$$

Commutation or turn-off methods

→ The term Commutation means the transfer of current from One path to another.

→ Communtation is one of the fundamental principles the use of thyristors for Control purposes.

→ The thyristor Can operate in two modes Either in ON state, off state. By itself it Cannot Control the level of current or voltage.

→ Control Can only be achieved by variation in the time thyristors when switched ON and off & Commutation is Central to this process (switching process).

The two methods by which a thyristor Can be Commutated are as follows.

1. Natural Commutation:-

→ The simplest and most widely used method of commutation makes use of the alternating, reverse nature of ac voltages to effect the current transfer.

→ N.K.T in ac circuits, the current always passes through zero every half cycle. as the current passes through natural zero, a reverse voltage simultaneously appear across the device. this immediately turn-off the device & this process is known as natural Commutation.

NOTE:- Since no additional circuits are required this is called natural Commutation.

Uses:- ① Line Commutated Converters

② Line Commutated Inverters.

Forced Commutation:-

→ Once thyristors are operating in the ON State, Carrying forward current, they Can only be turned off by reducing the current flowing through them to zero for sufficient time to allow the removal of charged carriers.

→ In Case of dc circuits, for switching off the thyristors, the forward current should be forced to be zero by means of External Circuits the process is Called forced commutation & the external circuit required for its known as Commutation Circuits.

→ A reverse Voltage is developed across the device by means of a commutating circuit that immediately brings the forward current in the device to zero, thus turning off device.

→ The classification of the methods of forced commutation is based on the arrangement of the commutating components & the manner in which zero current is obtained in SCR.

There are 6 - basic methods of Commutation by which thyristors may be turned off.

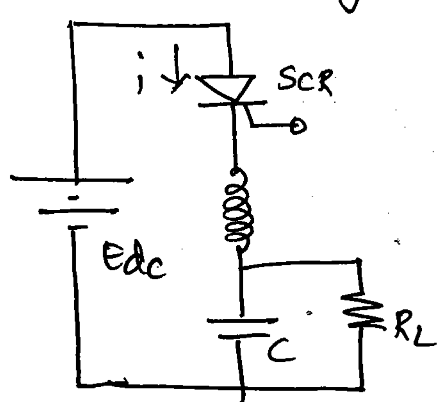
1. Class A - Self Commutation by resonating the load.
2. Class-B Self Commutation by an LC CKt
3. Class-C - Complementary commutation.
4. Class-D - Auxilary Commutation
5. ClassE - External pulse Commutation
6. ClassF - a.c Line Commutation

1. Class A - Self commutation by Resonating the load:-

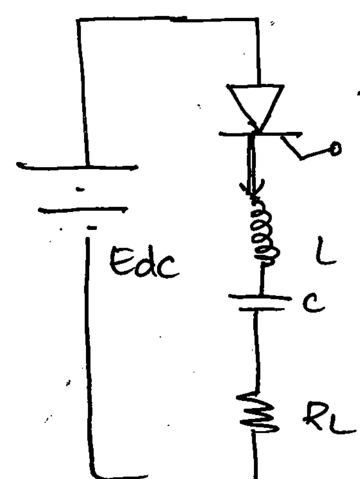
→ This is also called as resonant commutation.
There are two variation in circuit namely i) load in parallel ii) Load in series with capacitor.

In this method of commutation, the forward current passing through the device is reduced to less than the level of holding current of the device, hence, this method is also known as current commutation method.

The circuit diagram is as shown below.



"load in parallel"



"load in series with C"

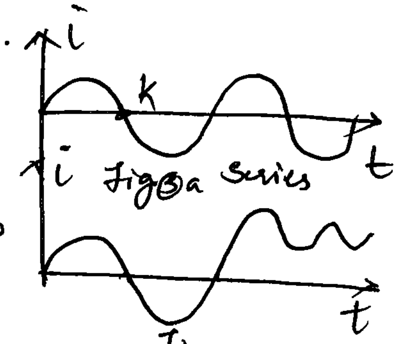
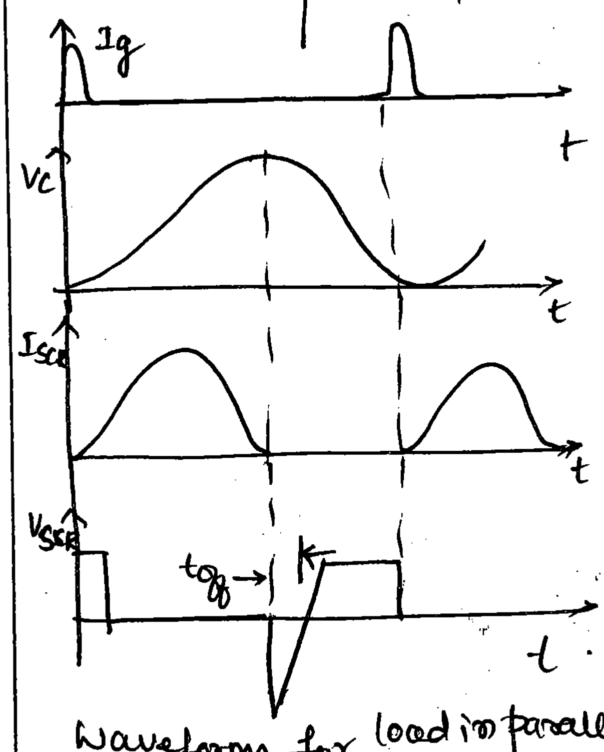


Fig 3b (Parallel load)

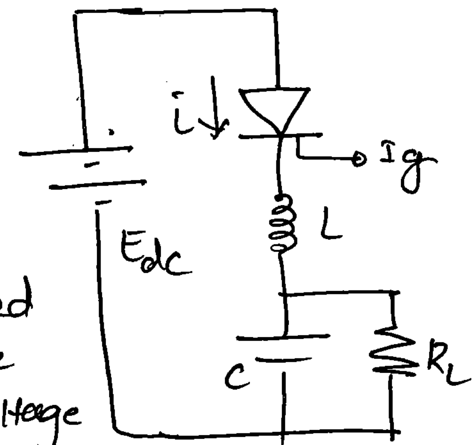


Waveforms for load in parallel.

* In process of commutation, the forward passing through device is reduced to less than holding current
* The load Resistance R_L & the commutating components are so selected that their combo forms an underdamped resonant ckt.
* when such ckt is excited with DC, a current of nature fig③ will be obtained.
* @ K current is zero beyond which current is reverse direction.
* When T_1 is ON only charging current flows which will decay soon to holding

Design considerations:-

(a) load in parallel with capacitor C.



The voltage in the circuit

$$E_{dc} = L\frac{di}{dt} + V \quad \cdots (1)$$

Where,
$E_{dc} \rightarrow$ applied dc voltage
$V \Rightarrow$ load voltage
i = load current.

$$\& \quad i = \frac{Cdv}{dt} + \frac{V}{R} \quad \cdots (2)$$

Taking laplace transforms to equ. (1) & (2) we get.

$$E_{dc}(s) = sLI(s) + V(s) \quad \cdots (3)$$

$$\& \quad I(s) = \frac{V(s)}{R} + sCV(s) \quad \cdots (4)$$

NOTE:- Class A is suitable for high frequency operation above 1000Hz.

from (3) $\quad V(s) = E_{dc}(s) - sLI(s)$ but $E_{dc}(s) = \frac{E_{dc}}{s}$ ∴

$$\therefore V(s) = \frac{E_{dc}}{s} - sLI(s) \quad \cdots (5)$$

Substitute

$$I(s) = \frac{E_{dc}}{sR} - s\frac{L}{R}I(s) + sC\frac{E_{dc}}{s} - s^2LC\,I(s)$$

$$I(s) + \frac{sL}{R}I(s) + s^2LC\,I(s) = \frac{E_{dc}}{sR} + sC\frac{E_{dc}}{s}$$

$$I(s)\left[1 + s\frac{L}{R} + s^2LC\right] = \frac{E_{dc}}{s}\left[\frac{1}{R} + sC\right]$$

$$I(s) = \frac{\frac{E_{dc}}{s}\left[\frac{1+sCR}{\cancel{R}}\right]}{\frac{R + sL + s^2LRC}{\cancel{R}}} = \frac{E_{dc}}{s}\left[\frac{1+RCs}{s^2LRC + sL + R}\right]$$

NOTE:- The time for switching off the device is determined by the resonant frequency which in turn depends on the values of commutation components.

$$\therefore I(s) = \frac{E_{dc}}{L}\left[\frac{2\epsilon}{s\omega_n} + \frac{(-2\epsilon/\omega_n)s + (1-4\epsilon^2)}{s^2 + 2\epsilon\omega_n s + \omega_n^2}\right]$$

$$= \frac{E_{dc}}{L}\left[\frac{2\epsilon}{s\omega_n} - \frac{2\epsilon}{\omega_n}\left[\frac{s+\epsilon\omega_n - \epsilon\omega_n}{(s+\epsilon\omega_n)^2 + \omega_d^2}\right] + \frac{1-4\epsilon^2}{(s+\epsilon\omega_n)^2 + \omega_d^2}\right]$$

$$= \frac{E_{dc}}{L}\left[\frac{2\epsilon}{s\omega_n} - \frac{2\epsilon}{\omega_n}\frac{(s+\epsilon\omega_n)}{(s+\epsilon\omega_n)^2 + \omega_d^2} + \frac{2\epsilon^2 \cancel{\omega_n}}{\cancel{\omega_n}}\left[\frac{1}{(s+\epsilon\omega_n)^2 + \omega_d^2}\right] + \frac{(1-4\epsilon^2)}{(s+\epsilon\omega_n)^2 + \omega_d^2}\right]$$

$$= \frac{E_{dc}}{L}\left\{\left[\left(\frac{2\epsilon}{s\omega_n}\right) - \frac{2\epsilon}{\omega_n}\left[\frac{s+\epsilon\omega_n}{(s+\epsilon\omega_n)^2 + \omega_d^2}\right] + \frac{1-4\epsilon^2 + 2\epsilon^2}{(s+\epsilon\omega_n)^2 + \omega_d^2}\right\}$$

$$I(s) = \frac{E_{dc}}{L}\left\{\left(\frac{2\epsilon}{s\omega_n}\right) - \frac{2\epsilon}{\omega_n}\left[\frac{s+\epsilon\omega_n}{(s+\epsilon\omega_n)^2 + \omega_d^2}\right] + \left[\frac{1-2\epsilon^2}{(s+\epsilon\omega_n)^2 + \omega_d^2}\right]\right\}$$

Taking inverse laplace transform we get.

$$i(t) = \frac{E_{dc}}{L}\left[\left(\frac{2\epsilon}{\omega_n}\right) - \frac{2\epsilon}{\omega_n}e^{-\epsilon\omega_n t}\cos\omega_d t + \frac{1-2\epsilon^2}{\omega_d}e^{-\epsilon\omega_n t}\sin\omega_d t\right\} \quad ; t > 0$$

$$i(t) = \frac{E_{dc}}{L}\left[\left(\frac{2\epsilon}{\omega_n}\right) + e^{-\epsilon\omega_n t}\left(\left(\underbrace{\frac{1-2\epsilon^2}{\omega_d}}_{a}\right)\sin\omega_d t - \underbrace{\frac{2\epsilon}{\omega_n}}_{b}\cos\omega_d t\right)\right]$$

NOTE:- $a\sin\theta_1 - b\cos\theta_1$

$$\sqrt{a^2+b^2}\left[\frac{a}{\sqrt{a^2+b^2}}\sin\theta_1 - \frac{b}{\sqrt{a^2+b^2}}\cos\theta_1\right]$$

$$\sqrt{a^2+b^2}\left[\cos\theta_2\sin\theta_1 - \sin\theta_2\cos\theta_1\right]$$

$$\sqrt{a^2+b^2}\left(\sin(\theta_1 - \theta_2)\right] \quad \& \quad \phi = \tan^{-1}(b/a)$$

$$I(s) = \frac{E_{dc}}{sRLC}\left[\frac{1+RCs}{s^2+\frac{s}{RC}+\frac{1}{LC}}\right] \quad \cdots (6)$$ (2)

$$I(s) = \frac{E_{dc}}{s\cancel{R}L\cancel{C}} \frac{\cancel{R}\cancel{C}\left[s+\frac{1}{RC}\right]}{\left[s^2+\frac{1}{RC}s+\frac{1}{LC}\right]} = \frac{E_{dc}}{sL}\left[\frac{s+\frac{1}{RC}}{s^2+\frac{1}{RC}s+\frac{1}{LC}}\right]$$

let $\frac{1}{RC} = 2\xi\omega_n$, $\frac{1}{LC} = \omega_n^2$

$$\therefore I(s) = \frac{E_{dc}}{Ls}\left[\frac{s+2\xi\omega_n}{s^2+2\epsilon\omega_n s+\omega_n^2}\right]$$

Using partial fraction Expansion.

$$= \frac{E_{dc}}{L}\left[\frac{A}{s} + \frac{Bs+D}{s^2+2\epsilon\omega_n s+\omega_n^2}\right]$$

$$s+2\epsilon\omega_n = A\left[s^2+2\epsilon\omega_n s+\omega_n^2\right] + (Bs+D)s$$

$$= As^2 + 2A\epsilon\omega_n s + \omega_n^2 A + Bs^2 + sD$$

$$s+2\xi\omega_n = (A+B)s^2 + (2A\epsilon\omega_n + D)s + \omega_n^2 A$$

Comparing the Coefficients we can write

$A+B=0$ $\quad$ $2A\epsilon\omega_n + D = 1$ $\quad$ Note:- $\boxed{\omega_d = \omega_n\sqrt{1-\xi^2}}$

$\omega_n^{\cancel{2}} A = 2\epsilon\cancel{\omega_n}$

$\boxed{A = \frac{2\epsilon}{\omega_n}}$ & $\boxed{B = \frac{-2\epsilon}{\omega_n}}$, $D = 1 - 2A\epsilon\omega_n$

$= 1 - 2\epsilon\cancel{\omega_n}\cdot\frac{2\epsilon}{\cancel{\omega_n}}$

$\boxed{D = 1 - 4\epsilon^2}$

Consider,

$$\therefore a^2+b^2 = \frac{(1-2\epsilon^2)^2}{\omega_d^2} + \frac{4\epsilon^2}{\omega_n^2} = \left[\frac{(1+4\epsilon^4-4\epsilon^2)\omega_n^2 + 4\epsilon^2\omega_d^2}{\omega_d^2\,\omega_n^2}\right] \quad (3)$$

$$= \frac{(1+4\epsilon^4-4\epsilon^2)\cancel{\omega_n^2} + 4\epsilon^2\cancel{\omega_n^2}(1-\epsilon^2)}{\cancel{\omega_n^2}\,\omega_d^2}$$

NOTE:-
$\omega_d = \omega_n\sqrt{1-\epsilon^2}$
$\omega_d^2 = \omega_n^2(1-\epsilon^2)$

$$= \frac{1+4\epsilon^4-4\epsilon^2+4\epsilon^2-4\epsilon^4}{\omega_d^2} = \frac{1}{\omega_d^2}$$

$$\therefore \sqrt{a^2+b^2} = \frac{1}{\omega_d}$$

$$\therefore i(t) = \frac{E_{dc}}{L}\left[\frac{2\epsilon}{\omega_n} + e^{-\epsilon\omega_n t}\frac{1}{\omega_d}(\cos\phi\sin\omega_d t - \sin\phi\cos\omega_d t)\right]$$

$$i(t) = \frac{E_{dc}}{L}\left[\frac{2\epsilon}{\omega_n} + \frac{e^{-\epsilon\omega_n t}}{\omega_d}\sin(\omega_d t-\phi)\right]$$

$$= \frac{E_{dc}}{L}\frac{2\epsilon}{\omega_n} + \frac{E_{dc}}{L}\frac{e^{-\epsilon\omega_n t}}{\omega_d}\cdot\sin(\omega_d t-\phi)\left(\frac{2\epsilon}{\omega_n}\right)\left(\frac{\omega_n}{2\epsilon}\right)$$

$$= \frac{E_{dc}}{R} + \frac{E_{dc}}{R}\frac{\omega_n}{2\epsilon\omega_d}e^{-\epsilon\omega_n t}\sin(\omega_d t-\phi)$$

$$= \frac{E_{dc}}{R} + \frac{E_{dc}}{R}\frac{\cancel{\omega_n}}{2\epsilon\cancel{\omega_n}\sqrt{1-\epsilon^2}}e^{-\epsilon\omega_n t}\sin(\omega_d t-\phi)$$

$$\boxed{i(t) = \frac{E_{dc}}{R}\left[1 + \frac{1}{2\epsilon\sqrt{1-\epsilon^2}}e^{-\epsilon\omega_n t}\sin(\omega_d t-\phi)\right]}$$

where $\phi = \tan^{-1}\frac{2\epsilon/\omega_n}{1-2\epsilon^2/\omega_d} = \tan^{-1}\frac{2\epsilon\,\omega_d}{\omega_n(1-2\epsilon^2)}$

$$\therefore \phi = \tan^{-1}\frac{2\epsilon\sqrt{1-\epsilon^2}}{1-2\epsilon^2} \quad \& \ \epsilon\omega_n = \frac{1}{RC}$$

Now the load voltage is given by equ ⑤

$$V(s) = \frac{E_{dc}}{s} - sLI(s)$$

substituting for $I(s)$ from ④

$$V(s) = \frac{E_{dc}}{s} - sL\left[\frac{V(s)}{R} + sCV(s)\right]$$

$$= \frac{E_{dc}}{s} - \frac{sLV(s)}{R} - s^2LCV(s)$$

$$V(s)\left[1 + \frac{sL}{R} + s^2LC\right] = \frac{E_{dc}}{s}$$

$$\therefore V(s) = \frac{E_{dc}}{s\left(s^2LC + s\frac{L}{R} + 1\right)} \quad \cdots ⑧$$

$$= \frac{E_{dc}/LC}{s\left(s^2 + s\underbrace{\frac{1}{RC}}_{2\epsilon\omega_n} + \underbrace{\frac{1}{LC}}_{\omega_n^2}\right)} = \frac{E_{dc}\,\omega_n^2}{s\left(s^2 + s2\epsilon\omega_n + \omega_n^2\right)}$$

$$V(s) = E_{dc}\left[\frac{A}{s} + \frac{Bs + D}{s^2 + 2\epsilon\omega_n s + \omega_n^2}\right]$$

$$\Rightarrow \omega_n^2 = A\left(s^2 + 2\epsilon\omega_n s + \omega_n^2\right) + (Bs + D)s$$

$$\omega_n^2 = As^2 + A2\epsilon\omega_n s + A\omega_n^2 + Bs^2 + Ds$$

$$\omega_n^2 = (A + B)s^2 + (A2\epsilon\omega_n + D)s + A\omega_n^2$$

Comparing the coeff of s^2, s and const we get

$A + B = 0$, $\quad A2\epsilon\omega_n + D = 0 \quad$ $A\omega_n^2 = \omega_n^2$

$\boxed{B = -1}$ $\quad \boxed{D = -2\epsilon\omega_n}$ $\quad \boxed{A = 1}$

$$\therefore V(s) = E_{dc}\left[\frac{1}{s} + \frac{(-s) + (-2\epsilon\omega_n)}{s^2 + 2\epsilon\omega_n s + \omega_n^2}\right]$$

$$V(s) = E_{dc}\left[\frac{1}{s} - \frac{s + 2\epsilon\omega_n}{(s+\epsilon\omega_n)^2 + \omega_d^2}\right]$$

$$= E_{dc}\left[\frac{1}{s} - \frac{s+\epsilon\omega_n}{(s+\epsilon\omega_n)^2+\omega_d^2} - \frac{\epsilon\omega_n}{(s+\epsilon\omega_n)^2+\omega_d^2}\right]$$

taking inverse laplace transform we get.

$$= E_{dc}\left[1 - \frac{e^{-\epsilon\omega_n t}}{\cancel{\sqrt{1-\epsilon^2}}}\cos\omega_d t - \frac{\epsilon\omega_n}{\omega_d} e^{-\omega_n\epsilon t}\sin\omega_d t\right]$$

$$= E_{dc}\left[1 - e^{-\epsilon\omega_n t}\left(\cos\omega_d t + \frac{\epsilon \cancel{\omega_n}}{\cancel{\omega_n}\sqrt{1-\epsilon^2}}\sin\omega_d t\right)\right]$$

$$= E_{dc}\left[1 - \frac{e^{-\epsilon\omega_n t}}{\sqrt{1-\epsilon^2}}\left(\underbrace{\sqrt{1-\epsilon^2}}_{b}\cos\omega_d t + \underbrace{\epsilon}_{a}\sin\omega_d t\right)\right]$$

$$a^2 + b^2 = 1 - \epsilon^2 + \epsilon^2 = 1$$

$$\therefore E_{dc}\left[1 - \frac{e^{-\epsilon\omega_n t}}{\sqrt{1-\epsilon^2}}(\sin\phi\cos\omega_d t + \cos\phi\sin\omega_d t)\right]$$

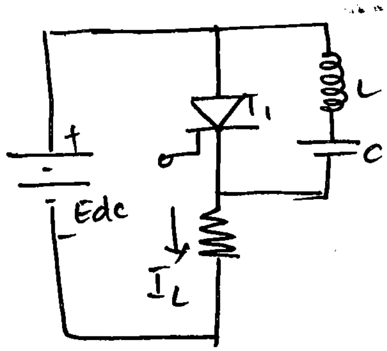
$$= E_{dc}\left[1 - \frac{e^{-\epsilon\omega_n t}}{\sqrt{1-\epsilon^2}}\sin(\omega_d t + \phi)\right]$$

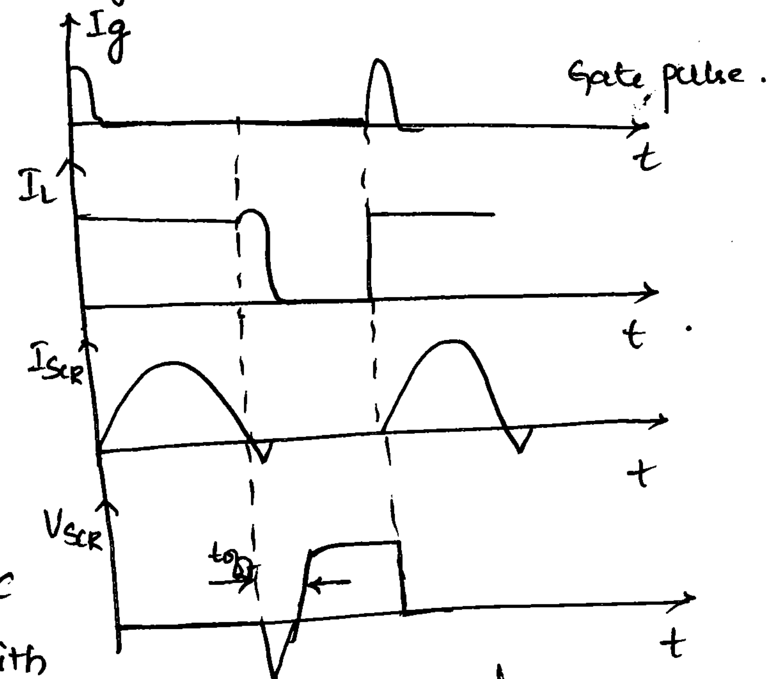
$$v(t) = E_{dc} - \frac{E_{dc}}{\sqrt{1-\epsilon^2}} e^{-\epsilon\omega_n t}\sin(\omega_d t + \phi)$$

where $\phi = \tan^{-1}\frac{\sqrt{1-\epsilon^2}}{\epsilon}$

2. Class B – Self Commutation by a LC Circuit:-

→ The circuit diagram with LC across Thyristor T_1 is as shown below. and corresponding waveforms also shown below.





Working:-

→ Initially as soon as Edc is applied, the Capacitor C starts getting charged with upper plate positive and lower plate -ve, and it charges to Edc.

* When thyristor T_1 is triggered the circuit current flows in two directions:
① The load current I_L flows through the path $Edc_+ - T - RL - Edc_-$,
② Commutating current I_c.
* The moment thyristor T_1 is turned ON, Capacitor C starts discharging through the path $C_+ - L - T - C$.
* When the Capacitor C becomes completely discharged, it starts getting charged with reverse polarity.
* Due to the reverse voltage, a commutating current I_c starts flowing which opposes the load current I_L.

When $I_c > I_L$ T_1 is off, & C charges again to Edc through L and load thus when C is fully charged, thyristor is ON again.

∴ Thyristor gets ON, automatically turns off & after sometime its again ON & again off process continues.

NOTE:- Desired frequency of ON and OFF state can be obtained by designing the commutating components as per the requirement.

Application:- used in DC chopper circuits.

Design considerations.

The circuit equations of the LC circuits are

$$L\frac{di}{dt} + \frac{1}{C}\int i\,dt = 0$$

$$\therefore L\frac{d^2 i}{dt^2} + \frac{1}{C}\, i(t) = 0$$

Taking laplace transform of the above equation, $\left(s^2 L + \frac{1}{C}\right) I(s) = 0$

$\therefore i(t) = E_{dc}\sqrt{\frac{C}{L}}\,\sin\omega_0 t$ where $\omega_0 = \sqrt{\frac{1}{LC}}$.

$\therefore$ peak commutation current is

$$I_{c(peak)} = E_{dc}\sqrt{C/L}$$

For this Class B commutation method, the peak discharge current of the capacitor is assumed to be twice the load-current I_L, & the time for which the SCR is reverse biased is approximately equal to one-quarter period of the resonant ckt

$$\therefore I_{cpeak} = 2I_L = E_{dc}\sqrt{C/L}.$$

and $\boxed{t_{off} = \frac{\pi}{2}\sqrt{LC}}$