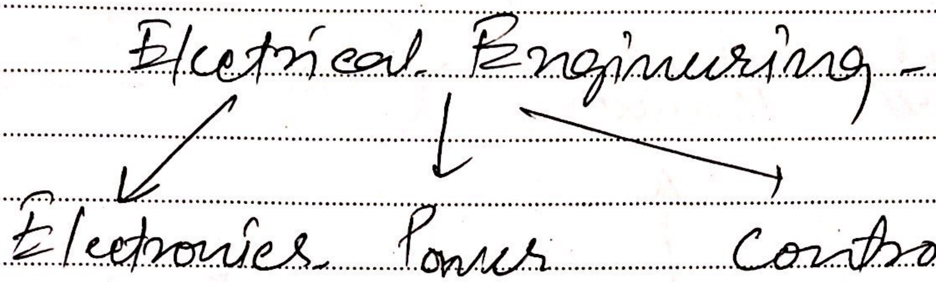
Power Electronics :-



* Electronics essentially deals with the study of semiconductors devices and circuits for the processing of information at lower power levels.

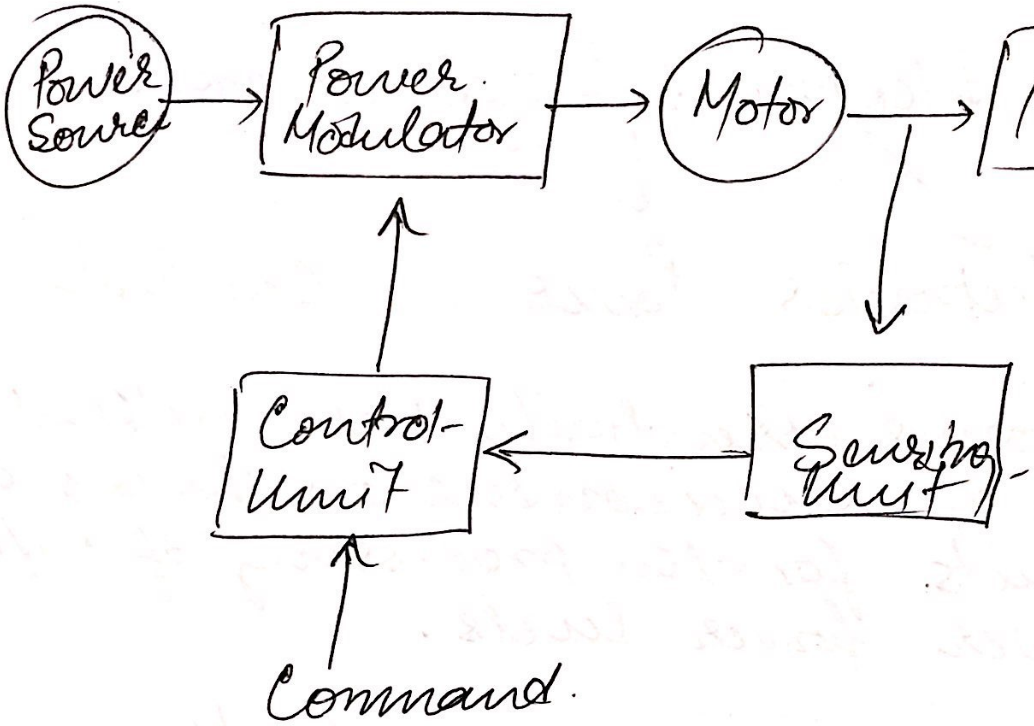
* Power electronics deals with the use of electronics for the control and conversation of large amount of electrical power.

The design of power electronics equipment involves interactions between the source and the loads, and utilises small signal electronic control circuits as well as power semiconductors devices.

Therefore power electronics draws as well as depends upon all other areas of electrical engineering.

* Control-engineering ~~dela~~ deals with the principles of control theory to design a system which gives the desired behavior in a controlled manner.

Power Electronic System :-



Power Electronics Converters -

A converter uses a matrix of power semiconductor switches to convert electrical power at high efficiency.

→ The converter system is consist of switches, inductive components L, C and transformers.

→ Switches include two terminal devices such as diodes and three terminal devices such as transistor or thyristors.

These converters are generally classified into the following five broad catagories -

⇒ ① Phase Controlled Rectifiers
(AC to DC converters)

→ These controllers convert fixed AC voltage to a variable DC o/p voltage.

→ These converters takes power from one or more AC voltages or current sources and delivers to a load.

→ The o/p variable is a low-ripple DC voltage or DC current.

→ These controller circuits use line voltage for their commutation, hence they are also called as line commutated AC to DC converter.

Applications:- ① High voltage DC transmission system.
② DC Motor drives.
③ Regulated DC power supply
④ Battery charger ckt.

⇒ ② Choppers (DC to DC Converters):-

→ A chopper converts fixed DC i/p voltage to a variable DC o/p voltage.

→ The DC o/p voltage may be different in amplitude than the i/p source voltage.

→ choppers are designed using semiconductor devices such as power transistors, IGBTs (Insulated Gate Bipolar Transistors) GTOs (Gate Turn-off thyristor) Power MOSFETs and thyristors.

Applications :- ① DC drives.
② Battery driven vehicles.
③ Subway cars.
④ Switch mode power supplies.

⇒ ③. Inverters (DC to AC converters) :-

→ An inverter converts a fixed DC voltage to an AC voltage of variable frequency and of fixed or variable magnitude.

→ Inverters are design using semiconductor devices such as power transistors, MOSFETS, IGBT, GTO and thyristors.

Applications :- ①. High voltage DC transmission.
② Aircraft and space power supplies.
③ Induction Motor and Synchronous motor drives.

⇒ ④. Cycloconverters :- (AC to AC)

→ These converters convert i/p power at one frequency to o/p power at a different frequency through one stage conversion.

→ These are designed using thyristors.

Application :- AC drives for Motors.

⇒ ⑤. AC voltage converters:- (AC regulators)

→ These converts convert fixed AC voltage directly to a variable AC voltage at the same frequency using line commutation.

→ These converters uses thyristor.

Applications:- ① speed control of fans and pumps.

Thyristor :-

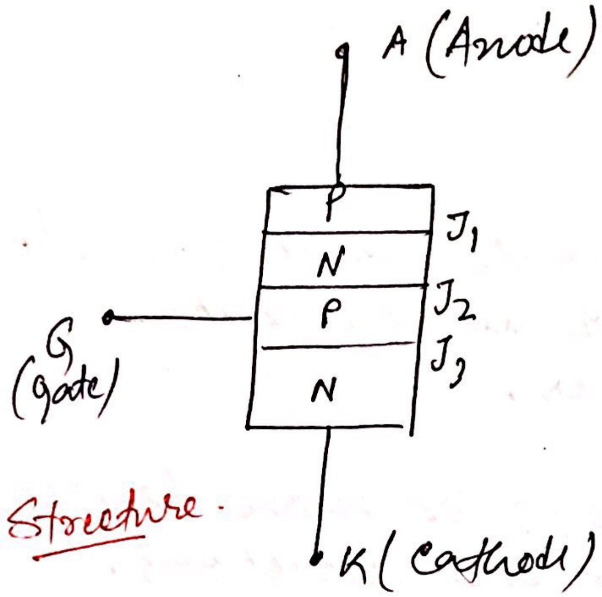
① Thyristor is a general name given to a family of power semiconductor switching devices.

② The thyristor has four or more layers and three or more junctions.

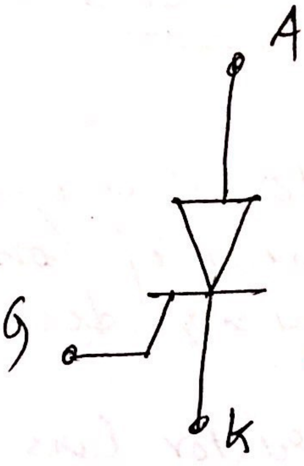
③ The SCR (Silicon Controlled Rectifier) is the mostly widely used and important member of the thyristor family.

④. The name thyristor is derived by a combination of capital latters from thyratron and transistor.

SCR



Structure.



Symbol.

→ The structure and symbol of the thyristor (SCR) are shown in the above figure.

→ It is a four layer PNPN device, having three junctions J_1, J_2 and J_3. ~~It has~~

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

→ The anode and cathode are connected to the main power ckt and the gate terminal carries a low level gate current in the direction gate to cathode.

→ The gate terminal is provided at the P layer near the cathode, and is known as cathode gate.

① Forward Blocking State (OFF State) :-

→ When the end P layer is made positive with respect to the end N layer, the two outer junction J_1 and J_3 are forward bias but the middle junction J_2 becomes reverse bias.

→ Thus the junction J_2 because of the presence of depletion layer does not allow any current to flow through the device.

→ Only leakage current of negligibly small magnitude will flow through the device.

→ This current is insufficient to make the device ON. In other words the SCR under the forward biased condition does not conduct.
This is called the Forward blocking state or OFF state of the device.

②. Reverse Blocking State (or) OFF State :-

→ When the N layer is made positive with respect to end P layer the middle junction J_2 becomes forward bias whereas the two outer layer junctions J_1 and J_3 becomes reverse bias.

→ The junction J_1 and J_3 do not allow any current to flow through the device.

→ Only a very small amount of leakage current may flow because of the [illegible] of [illegible] minority charges.

→ The leakage current again insufficient to make the device conduct. This is known as reverse blocking state or OFF state of the device.

③ Conducting State (or) ON State :-

→ When the voltage between the anode (A) and cathode (K) is kept on increasing, a stage will come when the deplation layer at J_2 will break down.

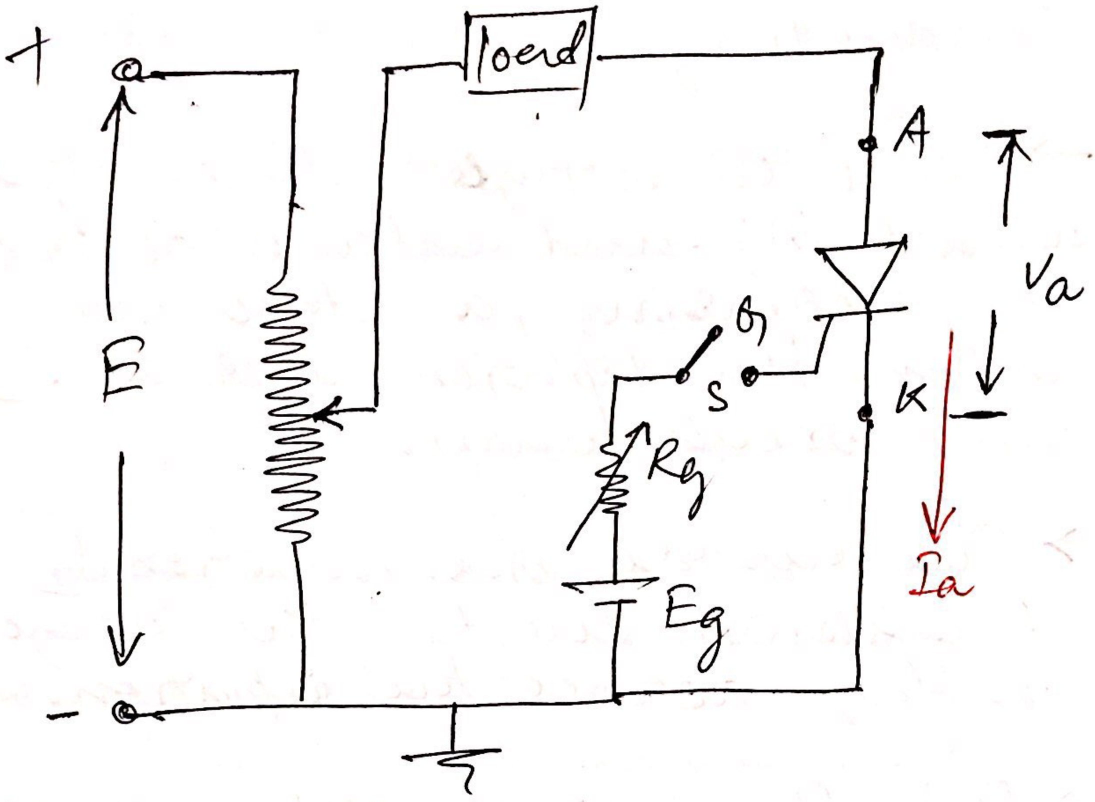
→ The reverse bias junction J_2 will breakdown due to the large voltage across the deplation layer.

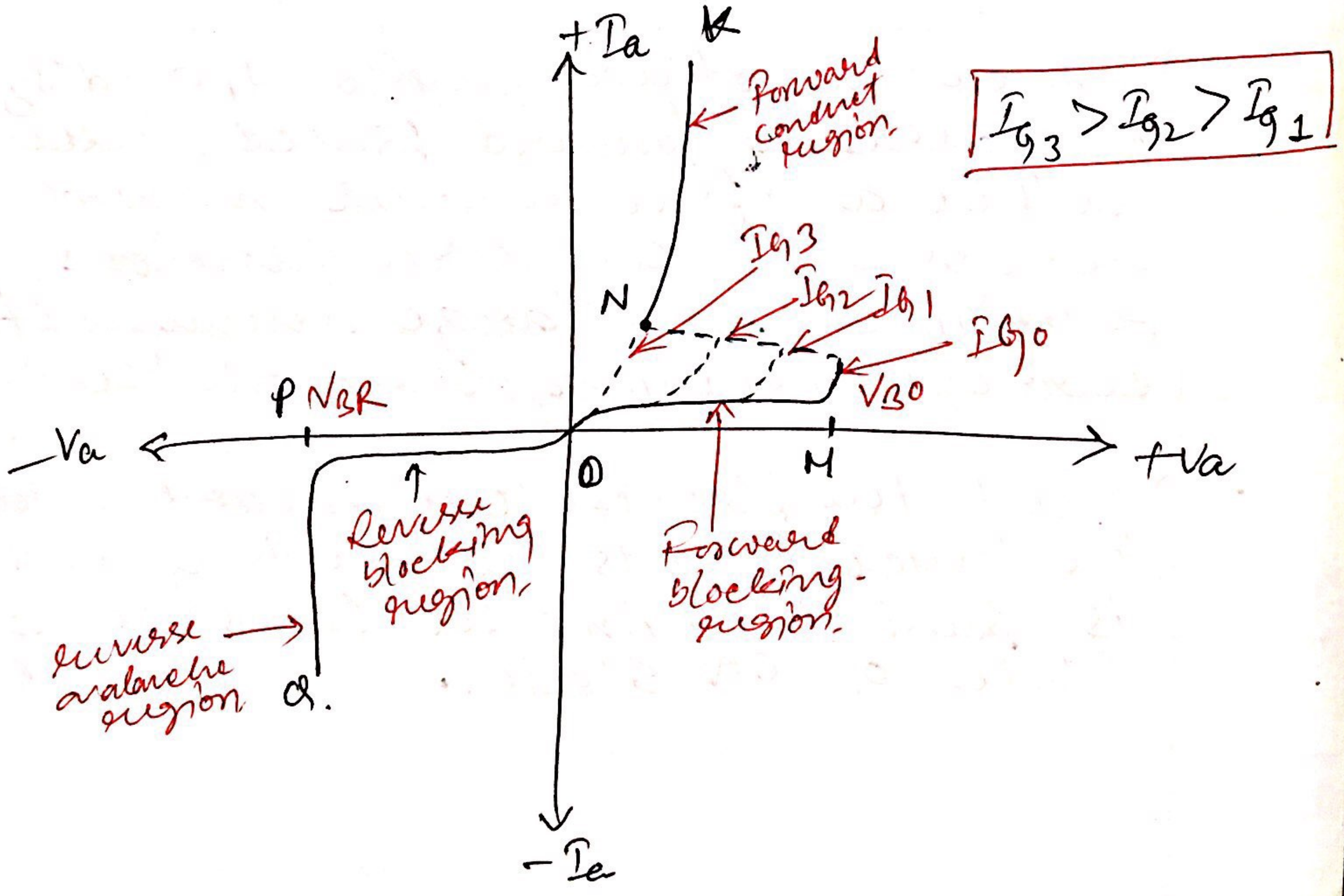
→ This phenomenon is known as the Avelanche Break down.

→ Since the other junction J_1 and J_3 are already forward biased, there will be a free carrier movement across all the three junctions resulting in a large amount of current flowing through the devic

→ Due to the flow of this forward curren the device starts conducting and it is said to be in the Conducting State or ON State.

=: STATIC characteristics of SCR :-=





① Reverse Blocking Region :-

→ When the cathode is made positive with respect to anode with the switch (S) open, the SCR becomes Reverse bias.

→ In the figure OP is the reverse blocking region.

→ In this condition junction J_1 and J_3 are reverse bias and the middle junction J_2 is forward bias.

→ Therefore, only a small leakage current (mA) flows.

→ If the reverse voltage is increased, then at a critical breakdown level called reverse breakdown voltage (V_{BR}) an avalanche will occur at J_1 and J_3 increasing the current sharply.

→ If this current is not limited to a safe value, power dissipation will increase to a dangerous level that may destroy the device.

→ The region PQ is the reverse avalanche region.

②. Forward Blocking-Region :-

→ In this region junction, J_1 and J_3 are FB and J_2 remains R.B.

→ Hence anode current is very small leakage current.

→ The region OM in the VI characteristics is known as forward blocking region.

③. Forward Conduction Region :-

→ When the forward voltage is increased with gate terminal open, avalanche breakdown will occur at the junction J_2, at a critical forward break over voltage (V_{BO}). and the SCR switches to ON state.

→ The region MN in the characteristics shows that, as soon as the device is switch ON, the voltage across the device will drops to a low voltage depending upon the SCR rating and a very large current flows through the device.

→ The part NK of the characteristics is called forward conduction state.

→ In this situation the SCR acts as closed switch.

* (Gate signal is applied) :=

→ When a gate signal is applied, the SCR turns ON before (V_{BO}) is reached.

→ The forward voltage at which the device switch ON depends upon the magnitude of Gate current.

(higher the gate current lower is the forward breakover voltage)

→ Once the SCR is conducting, the gate signal is no longer required to maintain the device in its ON state.

Latching Current :-

It is defined as the minimum anode current requires to keep the SCR in ON state after removing gate signal.

The latching current is associated with turn-ON process

Holding Current:-

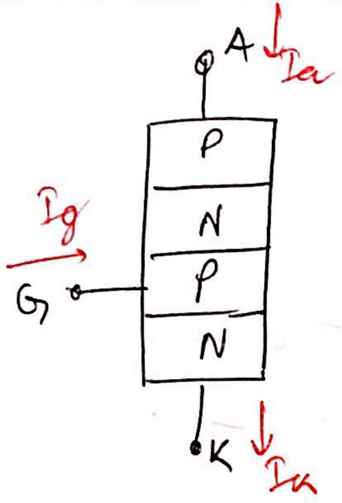
It is the minimum anode current to maintain the SCR in the ON state after the removal of the gate signal. (If the forward current is reduced bellow holding current, a depletion layer will develop across the junction J_2 and the device will go to OFF state)

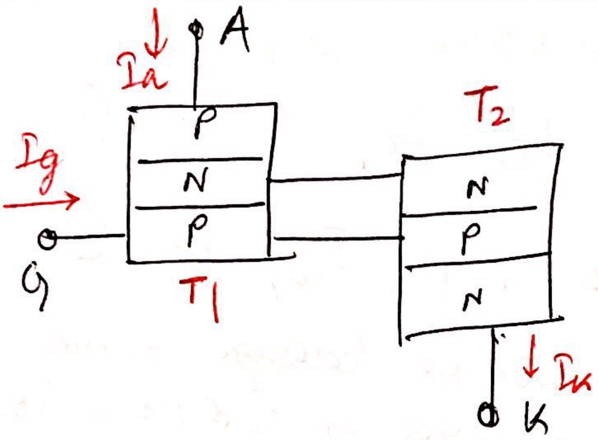
→ The holding current is related to turning OFF process

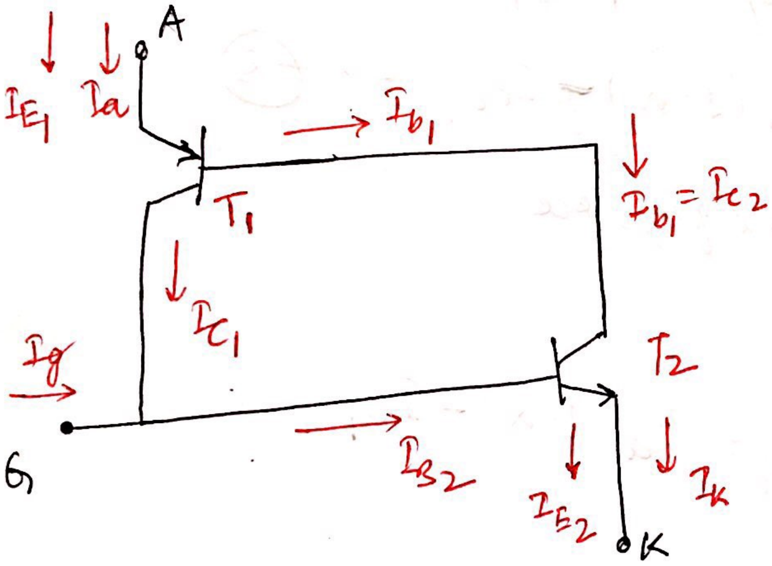
NOTE :=

The holding current is normally lower than latching current, and both the values are very close to eachother.

"Two Transistor Model of SCR"







I_a = anode current
I_K = cathode current
I_g = gate current
I_{E_1} = emitter current (T_1)
I_{b_1} = base current (T_1)
I_{c_1} = collector current (T_1)
I_{E_2} = emitter current (T_2)
I_{b_2} = base current (T_2)
I_{c_2} = collector current (T_2)
α_1 = current gain (T_1)
α_2 = current gain (T_2)

$$I_{C_1} = I_{b_2}$$

$$I_{b_1} = I_{c_2}$$

and $I_K = I_a + I_g$

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From transistor analysis -

$$I_{b_1} = I_{E_1} - I_{c_1} \quad \text{——} ①$$

and $$I_{c_1} = \alpha_1 I_{E_1} + I_{co_1} \quad \text{——} ②$$

I_{co_1} = reverse leakage current of the reverse biased junction. J_2.

$$① \Rightarrow I_{b_1} = I_{E_1} - \alpha_1 I_{E_1} + I_{co_1}$$

$$\Rightarrow I_{b_1} = I_{E_1}(1-\alpha) + I_{co_1} \quad \text{——} ③$$

From the above figure

$$I_a = I_{E_1}$$

$$\therefore ③ \Rightarrow I_{b_1} = I_a(1-\alpha) - I_{co_1}$$

Also for 'T_2'

$$I_{c_2} = \alpha_2 I_{E_2} + I_{co_2} \quad \text{——} ④$$

I_{co_2} = reverse leakage current

Again from the above diagram -

$$I_K = I_{E_2}$$

$$④ \Rightarrow I_{c_2} = \alpha_2 I_K + I_{co_2}$$

$$I_{b_1} = I_{c_2}$$

$$\Rightarrow (1-\alpha_1) I_a - I_{co_1} = \alpha_2 I_k + I_{co_2}$$

$$\Rightarrow (1-\alpha_1) I_a - I_{co_1} = \alpha_2 (I_a + I_g) + I_{co_2}$$

$$\Rightarrow I_a [1-(\alpha_1+\alpha_2)] = I_{co_1} + I_{co_2} + \alpha_2 I_g$$

$$\Rightarrow I_a = \frac{\alpha_2 I_g + I_{co_1} + I_{co_2}}{1-(\alpha_1+\alpha_2)}$$

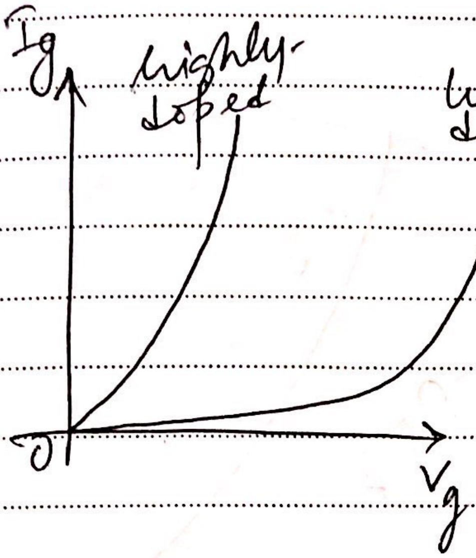
Neglecting the leakage current.

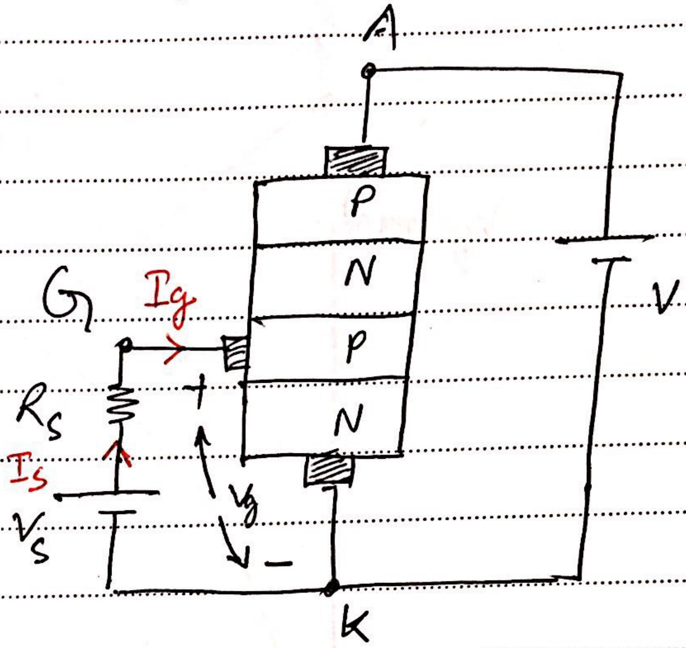
$$\boxed{I_a = \frac{\alpha_2 I_g}{1-(\alpha_1+\alpha_2)}}$$

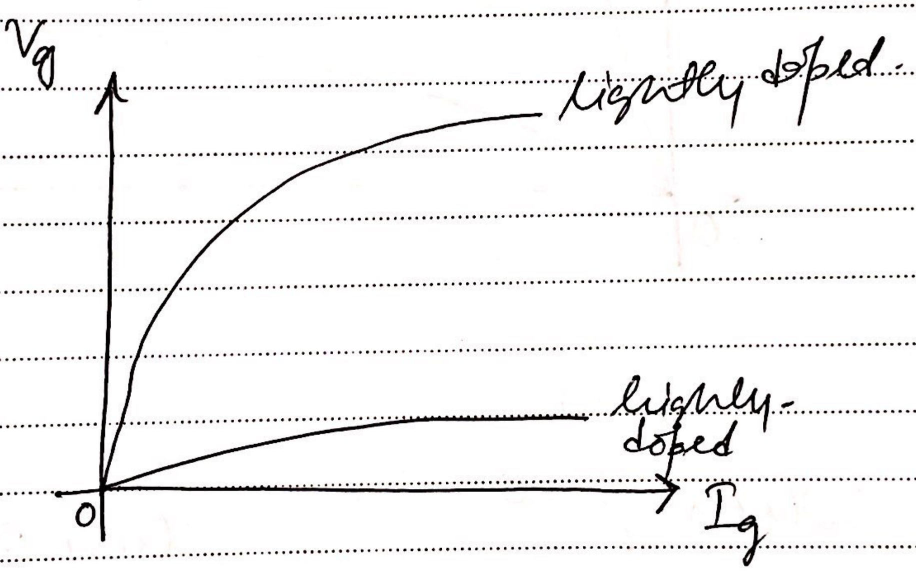
NOTE:- if $\alpha_1+\alpha_2 = 1$

The value of anode current becomes '∞', i.e. anode current suddenly attains a very high value. In other words we can say that the device suddenly jumps to 'on' state from OFF state.

(Gate Characteristics of SCR)





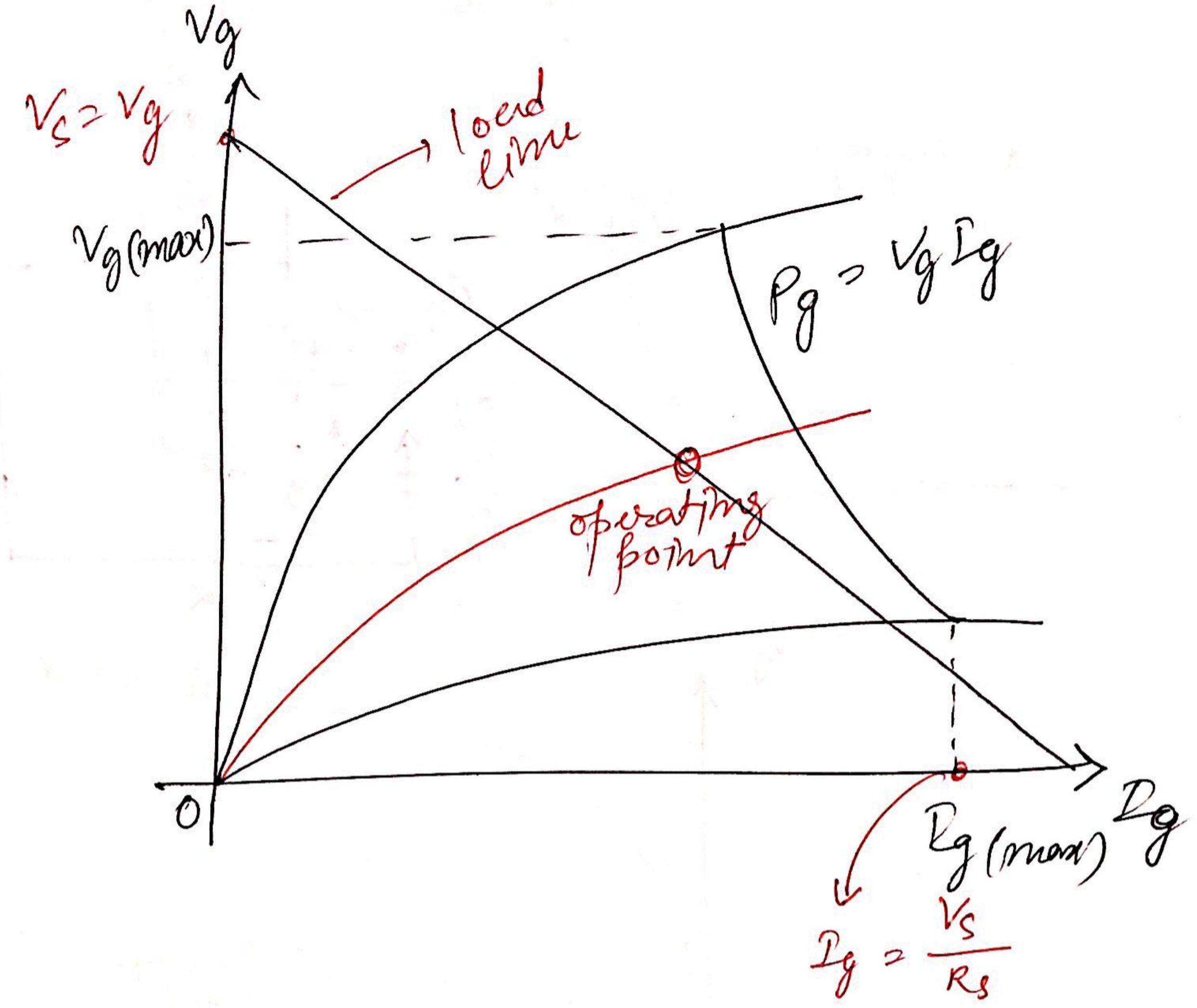


$I_s = I_g$ —— ①

$V_s = I_s R_s + V_g$ —— ②

$\boxed{V_s = I_g R_s + V_g}$ —— ③

$x \qquad y$



when y = 0

$$I_g = \frac{V_s}{R_s}.$$

when x = 0

$$V_s = V_g$$

$$V_s = I_g R_s + V_g$$

$$y = mx + c$$

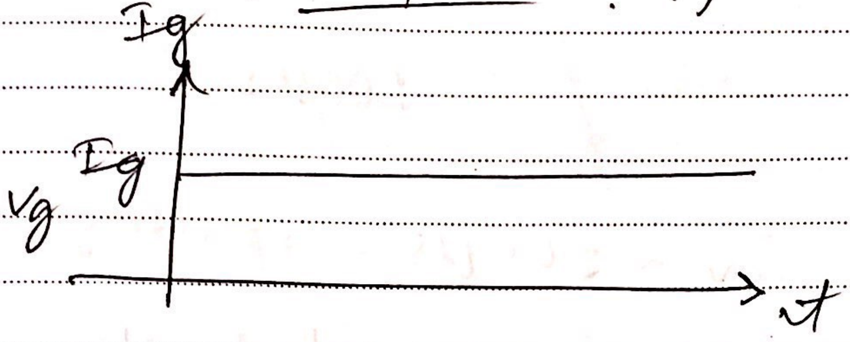
$$V_g = -I_g R_s + V_s$$

$$\boxed{m = -R_s}$$

Slope of load line.

(Gate signal is not removed)

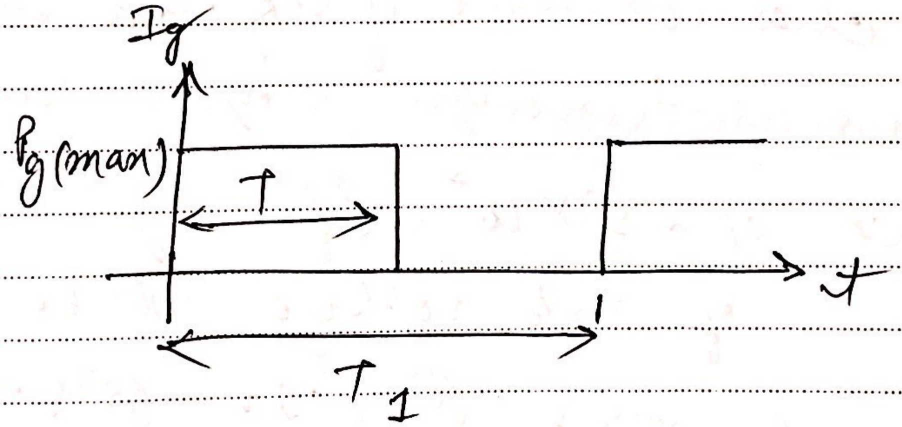
① Continuous pulse triggering -



$P_g = I_g V_g$

$P_{g(avg)} = P_{g(max)}$

② Pulse Gate Triggering :-



$P_{g(max)} = V_g I_g$

$P_{g(avg)} = P_{g(max)} (\text{dutycycle})$

$= P_{g(max)} \frac{T}{T_1}$

NOTE :-

Practically, SCR triggering is approximately (10kHz).

$T = \frac{1}{f} = 100\mu s.$

if. $T_{ON} < 100\mu s$ → pulse gate triggering

$P_{g(avg)} < P_{g(max)}$

$T_{ON} > 100\mu s$ → Continuous pulse triggering

$P_{g(avg)} = P_{g(max)} = V_g I_g$

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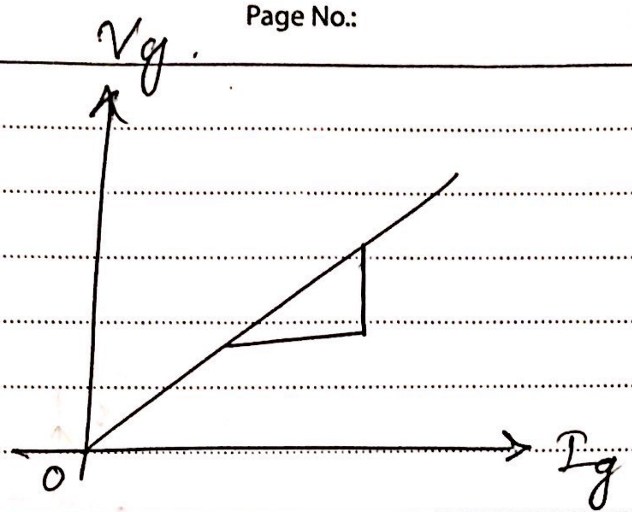
Q. $I_g - V_g$ characteristics of SCR is a straight line passing through origin, with a gradient of 2.5×10^3. If $P_g = 0.015W$, the value of gate voltage will be

ⓐ 5V, ⓑ 7.5V, ⓒ 6.1V ⓓ 8.5V.



$$\frac{V_g}{I_g} = 2.5\times10^3$$

$$P_g = V_g I_g = 0.015$$

$$I_g = \frac{V_g}{2.5\times10^3}$$

$$V_g \times \frac{V_g}{2.5\times10^3} = 0.015$$

$$\Rightarrow V_g^2 = 37.5$$

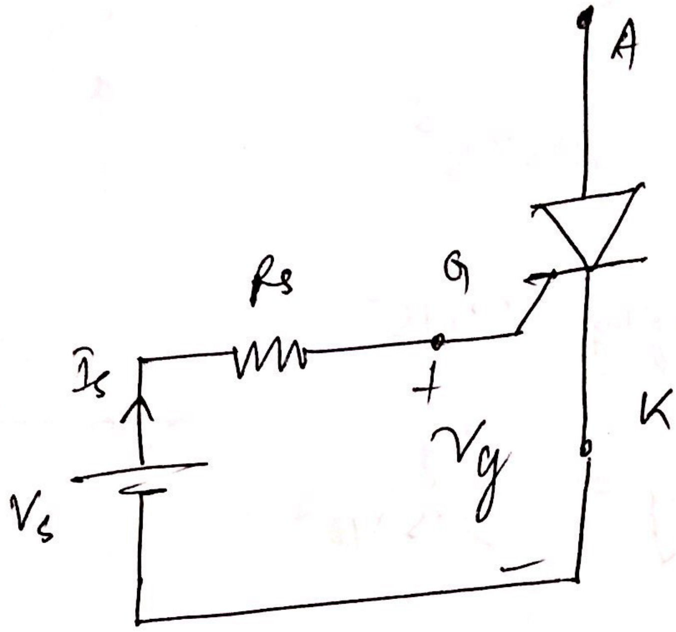
$$\Rightarrow V_g = 6.123 \text{ V.}$$

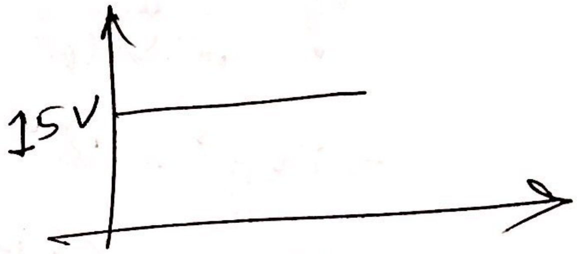
= x =

Q. For a SCR the gate cathode characteristics is.

$$V_g = 10 I_g + 1.$$

The gate source voltage is pulse of 15V with 20μs for an average power of 0.3W and peak power 5W. The value of Rs to be connected in series with SCR gate terminal. Find the D.C. and freq of the triggering signal.





$P_{g(avg)} = 0.3W$

$P_{g(max)} = 5W$

$P_{g(max)} = I_g V_g$ —— ①

$\Rightarrow 5 = I_g V_g$

$V_g = 10 I_g + 1$ —— ②

$I_g = \frac{5}{V_g}$, $V_g = \frac{5}{I_g}$

$\Rightarrow 5 = 10 I_g^2 + I_g$

$\Rightarrow 10 I_g^2 + I_g - 5 = 0$

$\Rightarrow I_g = 0.659\,A$

$= -0.759\,A$

$V_g = \frac{5}{0.659}\,V$

$= 7.587V$

$$V_s = I_g R_s + V_g$$

$$\Rightarrow R_s = \frac{V_s - V_g}{I_g}$$

$$= \frac{15 - 7.587}{0.659}\,\Omega$$

$$\boxed{R_s = 11.25\,\Omega}$$

<u>Duty cycle</u>:-

$$P_g(avg) = P_g(max)\,DC.$$

$$\Rightarrow DC = \frac{P_g(avg)}{P_g(max)} = \frac{0.3}{5} = 6\%$$

<u>Frequency</u>:-

$$DC = \frac{T_{ON}}{T}$$

$$DC = T_{ON} f.$$

$$f = \frac{DC}{T_{ON}}$$

$$= \frac{0.06}{20\mu}$$

$$= 3\,kHz$$

Q. An SCR has a V_g - I_g characteristics as $V_g = 1.5 + 8I_g$. In a certain application, the gate voltage consists of rectangular pulses of 12V and of duration 50μs, with duty cycle 0.2

①. Find the value of R_g series resistor in gate circuit to limit the peak power dissipation in the gate of 5W.

②. Calculate average power dissipation in the gate.

Solution:

① $P_{peak} = 5W$.

$= V_g I_g$ —— ①

The eqn for finding R_g is —— ③

$V_s = I_g R_g + V_g$

given chi eqn is - $V_g = 1.5 + 8I_g$ —— ②

from eqn ① $I_g = \frac{5}{V_g}$

from eq ② $V_g = 1.5 + \frac{40}{V_g}$

$\Rightarrow V_g^2 - 1.5V_g - 40 = 0$

$\boxed{\therefore V_g = 7.11V.}$ $V_g = -5.61V.$

from eqⁿ ①.

$$I_g = \frac{5}{V_g}$$

$$= 0.70A$$

From eqⁿ Ⓑ.

$$V_3 = I_g R_g + V_g$$

$$\Rightarrow 12 = 0.70 \times R_g + 7.11$$

$$\Rightarrow R_g = \frac{12 - 7.11}{0.70}\ \Omega$$

$$= 6.99\ \Omega$$

$$\simeq 7\ \Omega$$

②. $P_{avg} = V_g I_g$ (DC)

$$= 5W \times 0.2$$

$$= 1W.$$

=x=

Q. If the $V_g - I_g$ characteristics of an SCR is assumed to be a straight line passing throug the origin with a gradient of 3×10^3, calculate the gate to source resistance. Given- $E_{gs} = 10V$. and $P_g = 0{\cdot}012W$.

Solution:-

Eqn. for finding R_g is-

$$V_s = I_g R_g + V_g$$

given- $V_s = E_{gs} = 10V$. $P_g = I_g V_g = 0{\cdot}012W$

gradient $\frac{V_g}{I_g} = 3\times10^3$

$$\Rightarrow I_g = \frac{V_g}{3\times10^3}$$

$$\therefore V_g^2 = 0{\cdot}012\times3\times10^3$$

$$= 36 \text{ v}$$

$$\text{i.e. } V_g = 6V$$

$$\therefore I_g = \frac{6}{3\times10^3} = 2mA$$

i.e. $10 = 2\times10^{-3} R_g + 6$

$\Rightarrow R_g = \frac{4}{2\times10^{-3}}\ \Omega$

$= 2\,k\Omega$

—x—

Q. For an SCR, the gate cathode characteristics is given by a straight line with a gradient of 16V per amp, passing through the origin, the maximum turn on time is 4 μs and minimum gate current needed to obtain this quick turn on is 500 mA. If the gate to source voltage is 15V, calculate the resistance to be connected in series with the SCR gate.

Solution:–

$\frac{V_g}{R_g} = 16$, $I_g = 500mA$.

i.e. $V_g = 16\times500\times10^{-3}\ V$

$= 8V$

$V_s = I_g R_g + V_g$

$\Rightarrow R_g = \frac{15-8}{.5}\ \Omega$

$= 14\Omega$.

Turn-ON Methods of A Thyristor (SCR)

①. Forward. Voltage Triggering -

②. Thermal - Triggering (Temperature).

③. Radiation - Triggering - (Light Triggering)

④. $\frac{dV}{dt}$ Triggering -

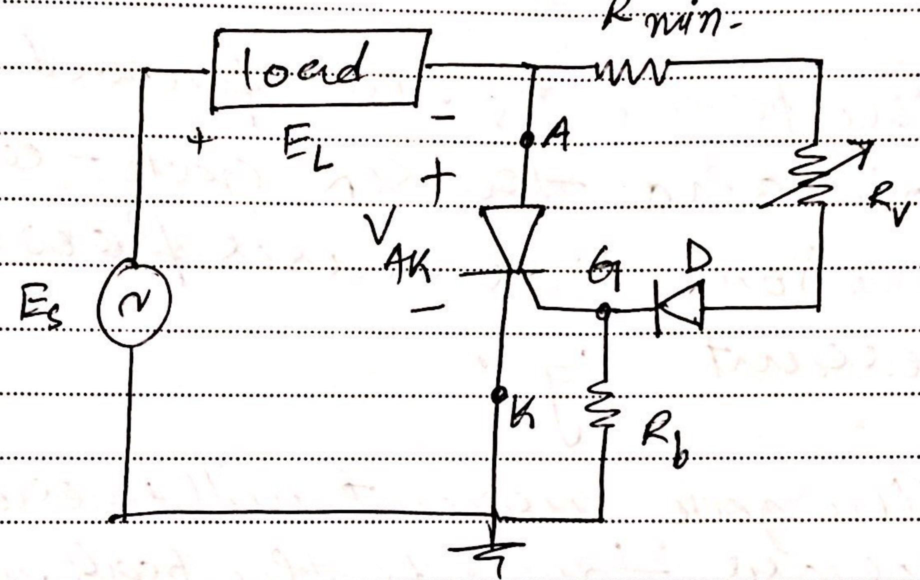
⑤. Gate. Triggering -

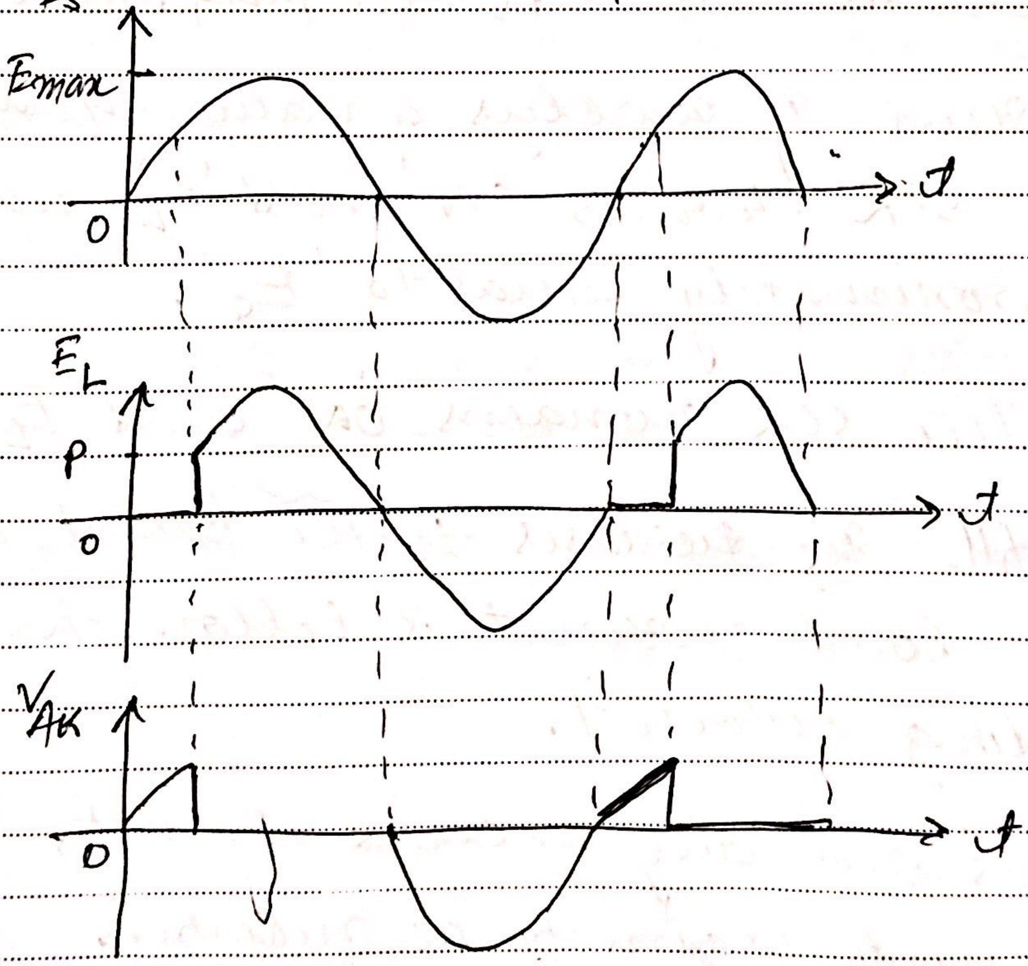
- ⓐ. DC.
- ⓑ AC
  - Resistance firing ckt
  - RC. firing ckt
- ⓒ Pulse.

(Gate Trigger ckt) :-

→ Resistance firing ckt
→ Resistance capacitance firing ckt

Resistance firing ckt :-





① As E_s goes positive, the SCR becomes forward bias from anode to cathode, however it will not conduct until the gate current exceeds $I_{g(min)}$. (latching current)

②. The positive E_s also forward bias the diode and the SCR gate-cathode junction, this causes flow of a gate current I_g.

③ The gate current will increase as E_s increases towards the peak value.

④ When I_g reaches a value equal to $I_{g(min)}$, the SCR turns 'ON' and 'E_L' will approximately equal to 'E_s'.

⑤. The SCR remains 'ON' and "$E_L \simeq E_s$" until E_s decreases to the point where the load current is bellow the SCR holding current.

⑥ This normally occurs when E_s reaches '0' and begins to go negative.

⑦ The SCR now turns OFF and remains turn-OFF while E_s goes '-Ve' since its anode to cathode is reverse bias.

⑧ Since the SCR is now OFF, the load voltage is '0' during this period.

⑨ The same sequence will repeat when E_s will goes positive again.

⑩ The load waveform can be controlled by varying 'R_V', which varies the resistance in the gate ckt. If 'R_V' increased, the gate current will reach its trigger value $I_g(min)$ at a greater value of E_s, making the SCR to trigger at a latter point in the E_s positive half cycle.

⑪ Thus the trigger angle 'α' can increase or decrease depending upon 'R_V'.

⑫ If R_V is made very high, SCR gate current will never reach $I_g(min)$ and SCR will remain OFF.

⑬ The limiting resistor $R(min)$ is placed between anode and gate so that the peak gate current of thyristor I_{gm} shouldnot exceed.

$$\boxed{R_{min} \geq \frac{E(max)}{I_{gm}}}$$

⑭. The diode is used to prevent the gate-cathode reverse bias from exceeding peak reverse gate voltage during the -ve half cycle of 'Es'. The diode must have peak reverse voltage rating greater than the i/p voltage E max.

⑮ The stabilising resistor R_b should have such a value that maximum voltage drop across it does not exceed maximum possible gate voltage $V_g(max)$.

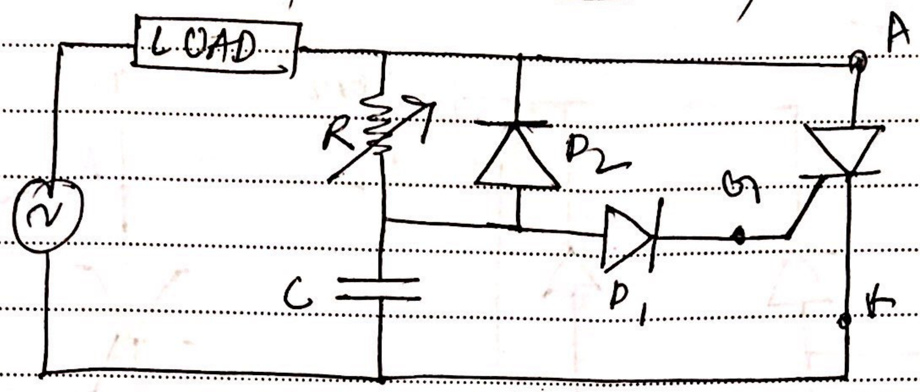
Disadvantages:-

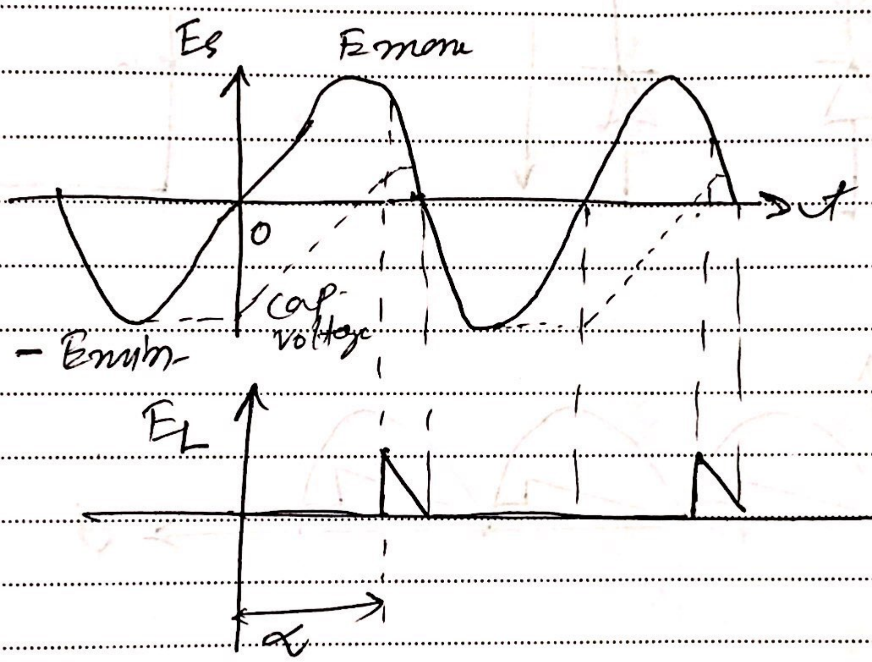
α can be varied from '0°' to 90°.

The gate current has to reach $I_g(min)$ somewhere between (0°-90°).

Experiment No. :- Resistance Capacitance Firing Ckt :- Page No.:

Half Wave :-



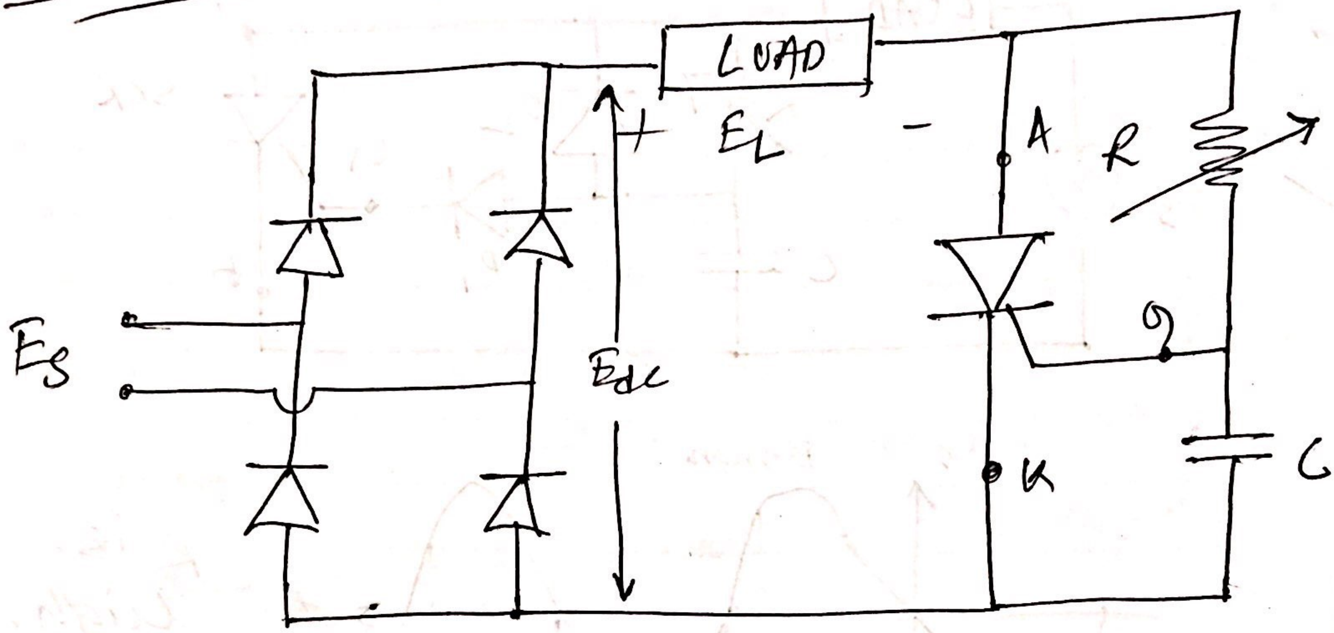


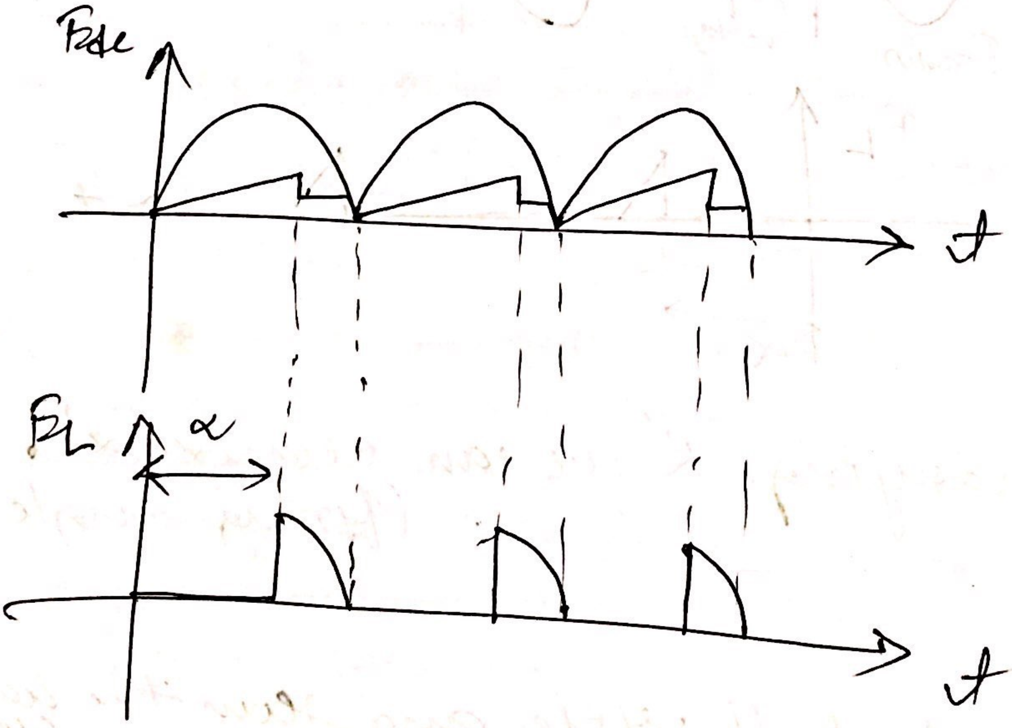
R is high.

By varying R we can change 'α'. (firing angle)

first -Ve half cycle and then +Ve half cycle

Full Wave:-





By varying 'R' we can vary 'α'.

Turn-OFF Mechanism.

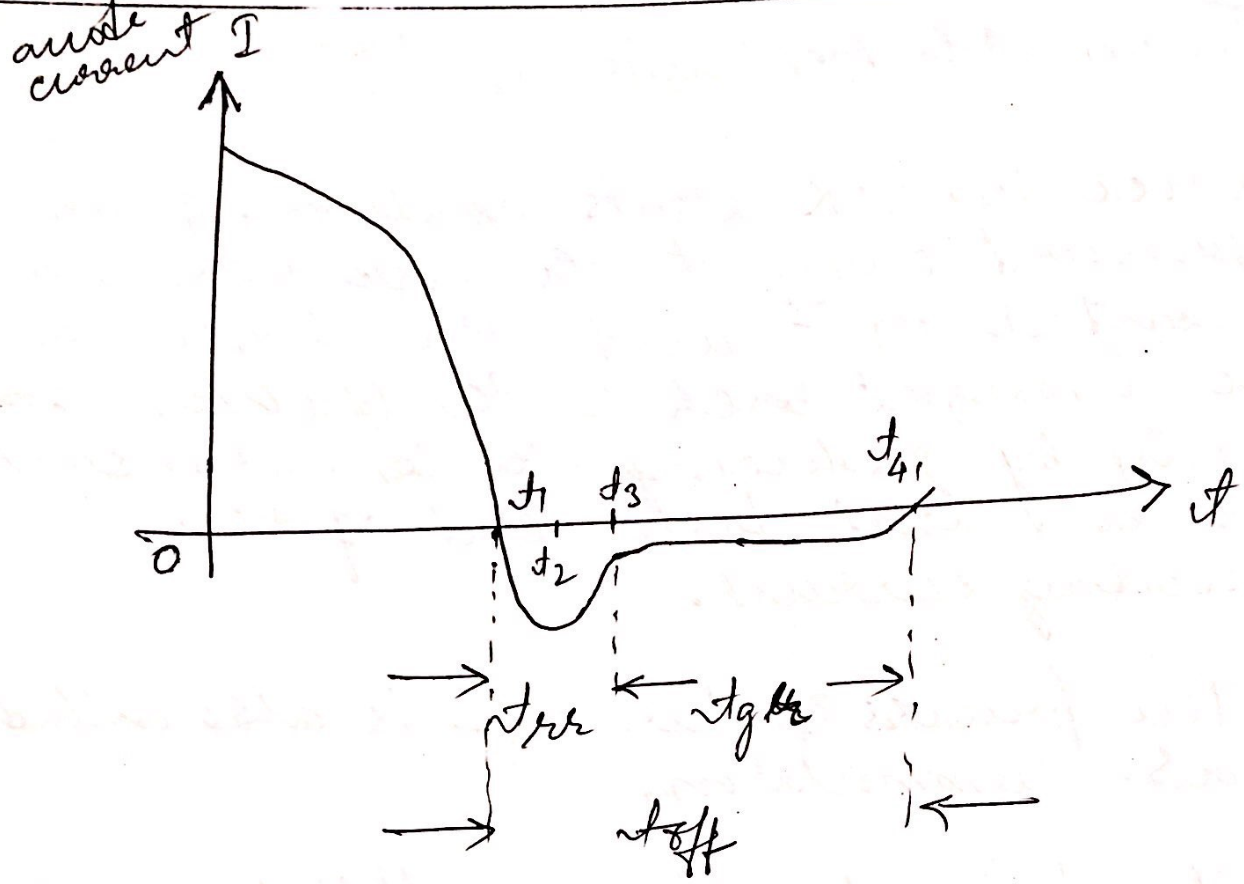
→ Once the SCR starts conducting an forward current, the gate has no control on it and the device can be brought back to the blocking state only by reducing the forward current to a level below that of the holding current.

* → The process of turn-off is also called as Commutation.

→ If a forward voltage is applied immediately after reducing the anode current to zero, it will not block the forward voltage and will start conducting again, although it is not triggered by a gate pulse.

→ Therefore it is necessary to keep the device in reverse bias for a finite period before a forward anode voltage can be reapplied.

* 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 the forward voltage.



The total turn-off time (t_{off}) is divided into two time interval. the reverse recovery time (t_{rr}) and the gate recovery time (t_{gr}).

→ At the instant t_1, the anode forward current becomes zero.

→ During the reverse recovery time (t_{rr}) (t_1 to t_3) the anode current flows in the reverse direction.

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→ At the instant t_2 a reverse anode voltage is developed and the reverse recovery current continues to decrease.

→ At time 't_3' junction J_1 and J_3 are able to block reverse voltage.

→ During the interval t_3 to t_4 carrier recombines and at time t_4 the recombination is complete and therefore a forward voltage can be reapplied.

→ The SCR turn off time is the interval between t_1 and t_4.

→ Thus the total turn-off time required for the device is the sum of the duration for which the reverse recovery current flows after application of reverse voltage and the time required for the recombination of all carriers in the inner two layer of the device.

→ Turn off time is (10–100) μs.

Turn OFF Methods :-

→ The term commutation means the transfer of current from one path to another

→ In case of a SCR it is not possible for a SCR to turn itself OFF, the circuit in which ~~it~~ is connected must reduce the SCR current to zero to enable it to turn off.

→ Commutation is the term to describe the methods of achieving this.

→ Two methods by which SCR (Thyristor) can be commuted are as follows.

① Natural Commutation :-

→ This is the simplest and most widely used method of commutation.

→ This method uses AC voltage to reverse the current direction through SCR.

→ In AC circuits the current always passes through zero in every half cycle.

→ As the current passes through zero, a reverse voltage will appear across the device. This immediately turns off the device.

→ This process is called as natural commutation since no external ckt. is required.

② Forced Commutation :-

→ In case of DC circuits, for switching off the thyristor, the forward current should be forced to zero by means of some external circuits.

→ This process is called forced commutation and the external ckt required for it are known as commutation ckt.

→ The components which constitute the commutating ckt are called as commutating components.

→ A reverse voltage is developed across the device by means of commutating ckt that immediately brings the forward current to zero.

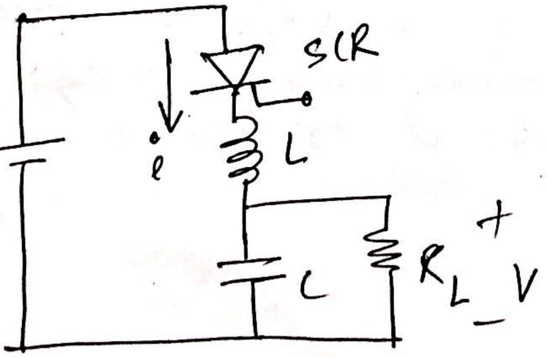
The classification of the methods of forced commutation is based on the arrangement of commutating components and the manner in which zero current is obtained in SCR.

=X=

① Class A - self commutation by Resonating the load :-

- → This is also known as resonant commutation.
- → In this process of commutation, the forward current passing through the device is reduced to less than the level of holding current to make the device off.
- → So this method is also known as current commutation method.

ⓐ Load in parallel with capacitor C :-



E_{dc} = applied DC voltage.

V = load voltage.

i = load current

$$\rightarrow E_{dc} = L\frac{di}{dt} + V$$

$$\rightarrow i = C\frac{dV}{dt} + \frac{V}{R}$$

By using Laplace Transform :-

$$\Rightarrow E_{dc}(S) = S\,L\,I(S) + V(S) \quad \text{——} ①$$

$$\Rightarrow I(S) = S.C.V(S) + \frac{V(S)}{R} \quad \text{——} ②$$

$$① \Rightarrow V(S) = E_{dc}(S) - S\,L\,I(S) \quad \left\{E_{dc}(S) = \frac{E_{dc}}{S}\right\}$$

$$\Rightarrow V(S) = \frac{E_{dc}}{S} - S\,L\,I(S)$$

$$② \Rightarrow I(S) = \frac{E_{dc}}{R.S} - \frac{S L I(S)}{R} + SC\left[\frac{E_{dc}}{S} - S L I(S)\right]$$

$$\Rightarrow I(S) + \frac{S L I(S)}{R} + S^2L(I(S)) = \frac{E_{dc}}{RS} + \frac{E_{dc}SC}{S}$$

$$\Rightarrow I(S)\left[1 + \frac{SL}{R} + S^2LC\right] = \frac{E_{dc}}{S}\left[\frac{1}{R} + SC\right]$$

$$\Rightarrow I(S)\left[\frac{R + LS + RLS^2C}{R}\right] = \frac{E_{dc}}{S}\left[\frac{1+RSC}{R}\right]$$

$$\Rightarrow I(s) = \frac{E_{dc}}{s}\left[\frac{1 + RsC}{R + Ls + s^2 RLC}\right]$$

$$\boxed{\left\{\Rightarrow I(s) = \frac{E_{dc}}{RLCs}\left[\frac{1 + RsC}{s^2 + s\frac{1}{RC} + \frac{1}{LC}}\right]\right\}}$$

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The characteristics eq^n is:

$\left(s^2 + s\frac{1}{RC} + \frac{1}{LC}\right)$ $s^2 + 2\xi\omega_n s + \omega_n^2$

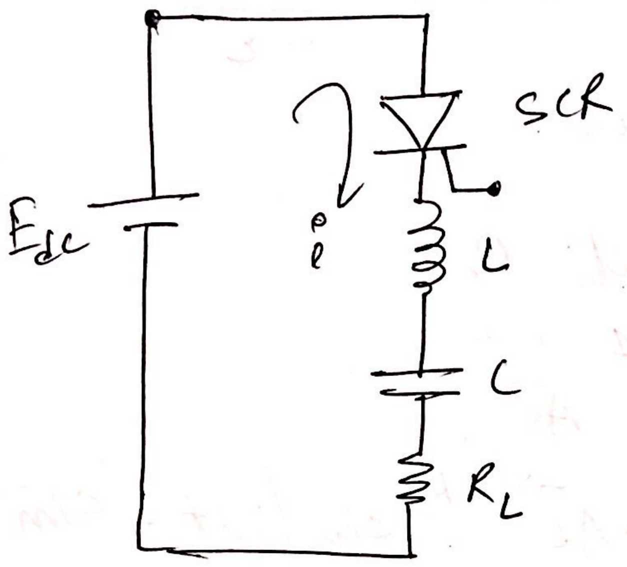
ξ = damping ratio

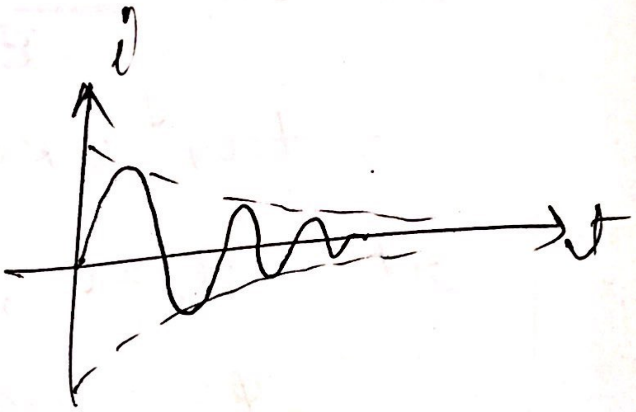
$\therefore 2\xi\omega_n = \frac{1}{RC}$ $\omega_n = \frac{1}{\sqrt{LC}}$ ω_n = natural freq^n.

$\Rightarrow \xi = \frac{1}{2RC\omega_n}$. For Underdamp System, $\xi < 1$

$= \frac{1}{2R}\sqrt{\frac{L}{C}}$ $\frac{\sqrt{L}}{2R\sqrt{C}} < 1$ $R > \sqrt{\frac{L}{4C}}$

ⓑ Load in series with capacitor C :-





$$E_{dc} = iR + L\frac{di}{dt} + \frac{1}{C}\int i\,dt$$

Differentiating and dividing by L,

$$\frac{d^2i}{dt^2} + \frac{R}{L}\frac{di}{dt} + \frac{i}{LC} = \frac{1}{L}\frac{dE_{dc}}{dt}$$

$$\Rightarrow \frac{d^2i}{dt^2} + \frac{R}{L}\frac{di}{dt} + \frac{i}{LC} = 0 \qquad E_{dc} = \text{constant}$$

Solution of 2nd order eqn is

$$i = e^{-\varepsilon t}\left[A_1 \cos\omega t + A_2 \sin\omega t\right]$$

Where $\varepsilon = \frac{R}{2L}$, $\omega_0 = \frac{1}{\sqrt{LC}}$

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

$$i(s) = \frac{sE(s)/L}{s^2 + s\frac{R}{L} + \frac{1}{LC}}$$

Characteristics eq^n. $s^2 + 2\xi\omega_n s + \omega_n^2$

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

ξ = damping ratio

ω_n = natural freq^n.

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

, Underdamp System

$0 < \xi < 1$

$\xi < 1$

$\Rightarrow R < 2\omega_n L$, $\omega_n = \sqrt{\frac{1}{LC}}$

$$\Rightarrow R < \sqrt{\frac{4L}{C}}$$

Class 'A' Commutation.

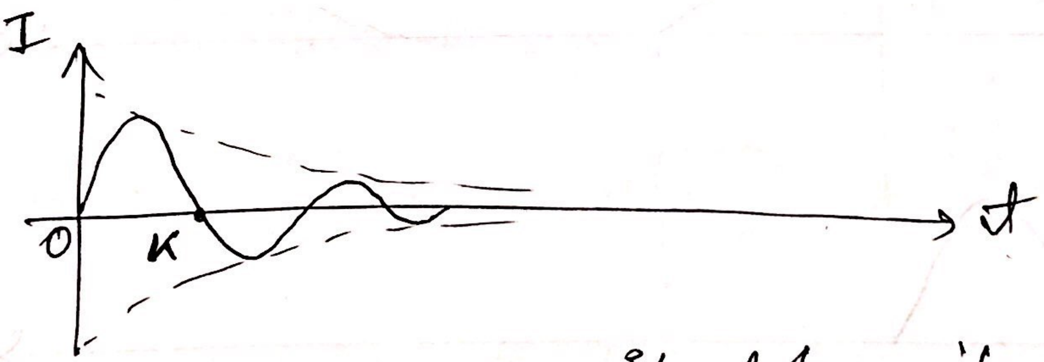
①. This is also known as resonant commutation.

②. In this process of commutation, the forward current passing through the device is reduced to less than the level of holding current of the device.

③ Hence, this method is also known as the current commutation method.

④. The load resistance and the commutating components are so selected that their combination forms an underdamped system.

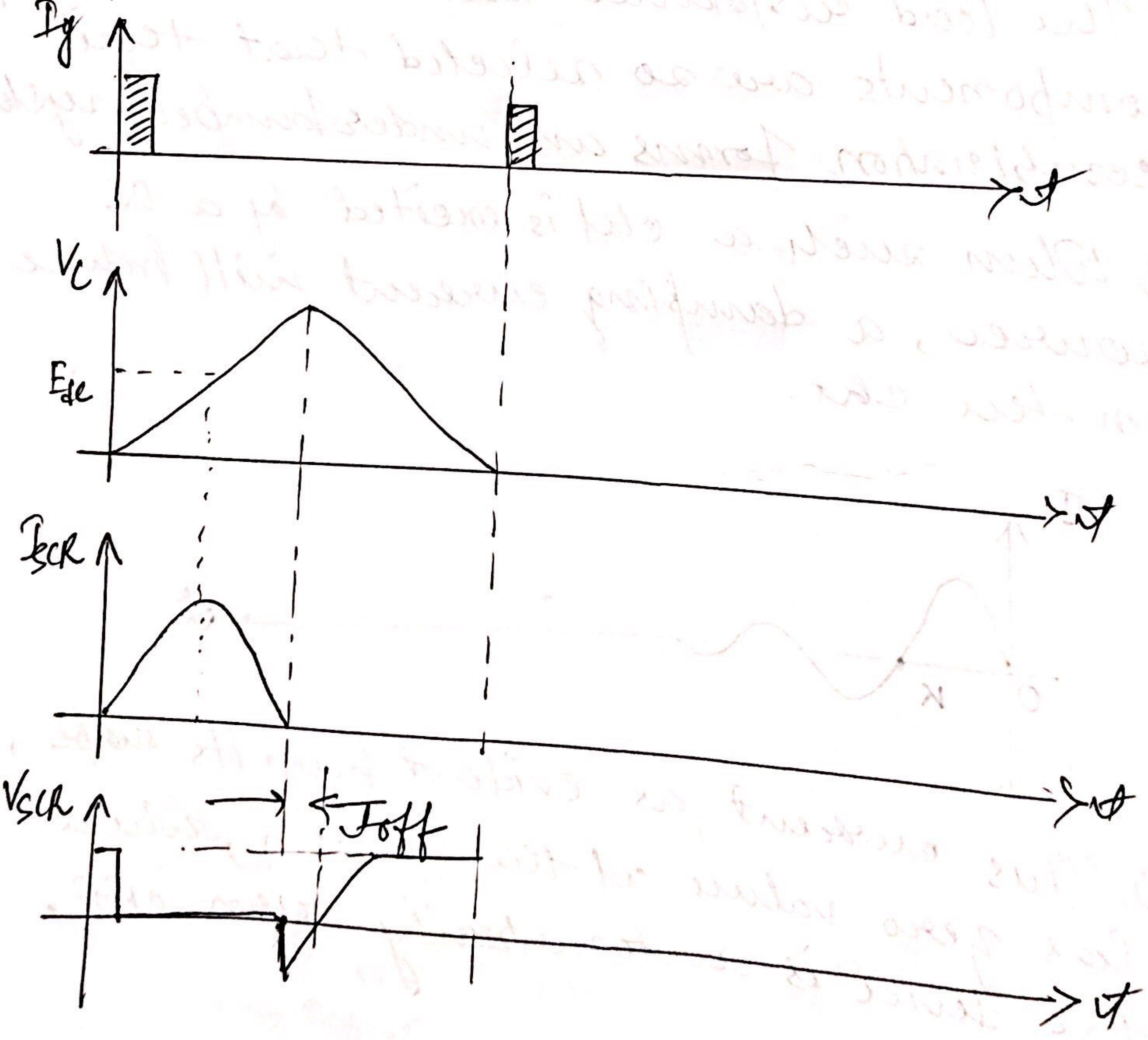
⑤. When such a ckt is excited by a DC source, a damping current will produce in the ckt.



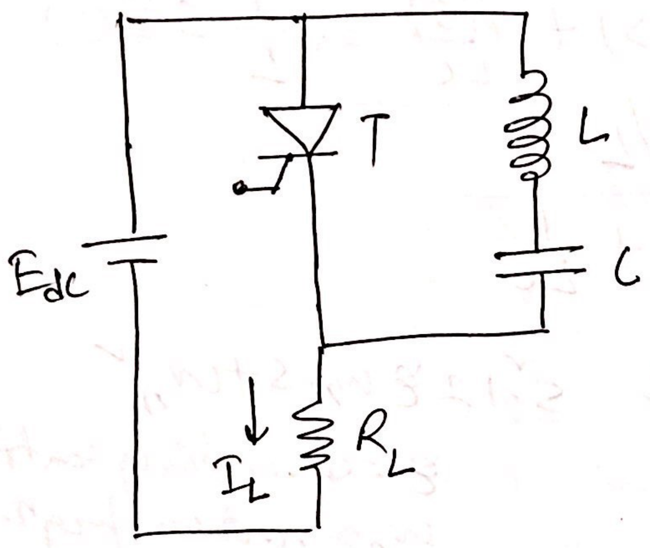
⑥. This current, as evident from its shape, has zero value at the point 'K', where the device is automatically turn OFF.

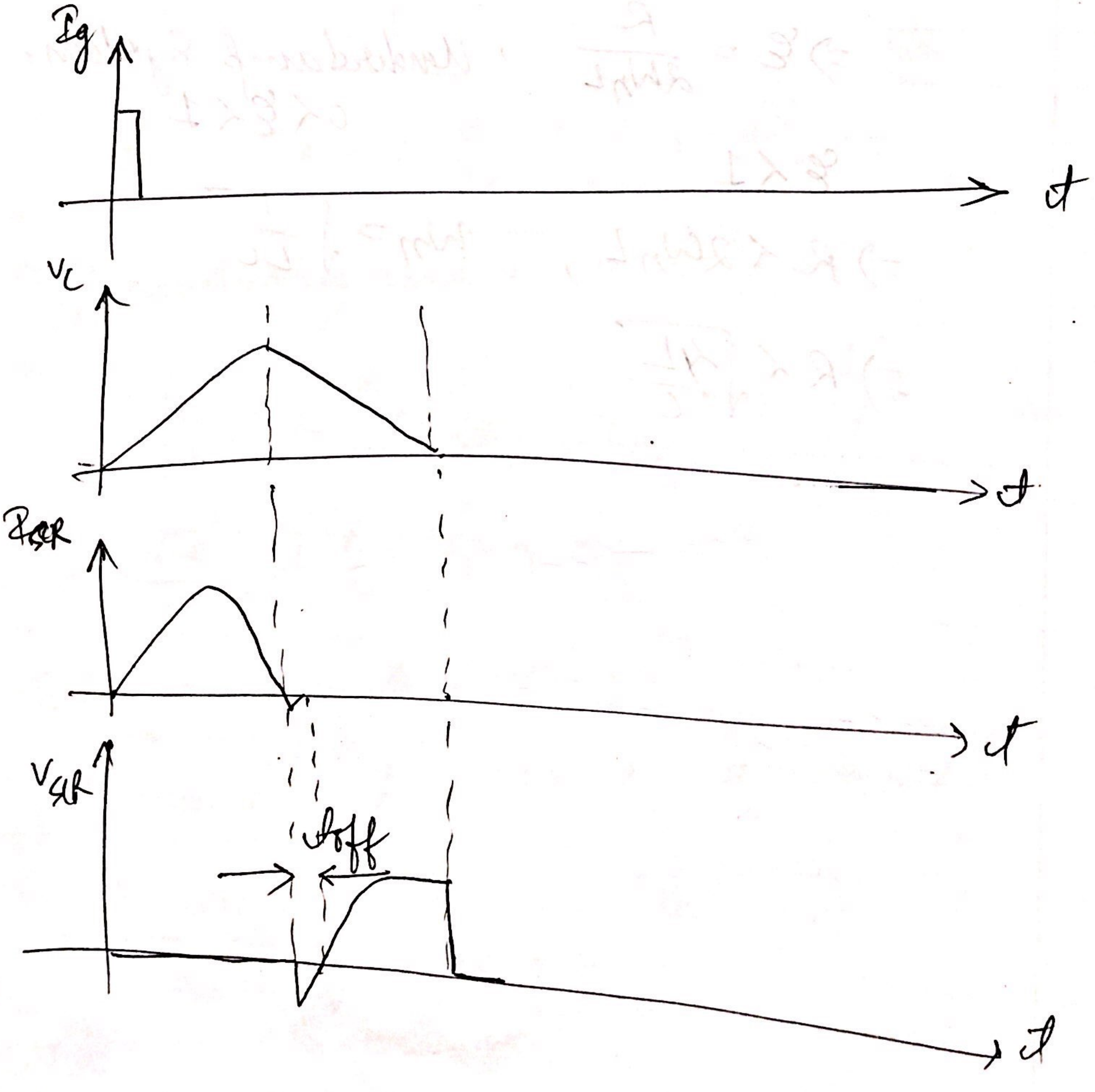
⑦ Beyond point 'K', the current is reversed in nature which assures definite commutation of the device.

⑧. When the thyristor (SCR) is ON it only carries charging current of capacitor 'C', which will soon decay to a value lesser than the holding current of the device, when capacitor 'C' is charged up to E_{dc}.



② Class B Self commutation by an LC circuit:-





① Initially, as soon as the supply voltage E_{dc} is applied, the capacitor starts charging with its upper plate +ve and lower plate -ve, and it charges upto E_{dc}.

② When the SCR is triggered, the current flows through the E_{dc}, SCR, R_L and completes the loop.

③ But again the stored energy in the inductor is also starts getting deliver towards the capacitor.

④ Thereby the voltage across the capacitor starts getting increase and also a commutating current starts flowing.

⑤ When this commutating current is become greater than the load current, the SCR becomes turn OFF.

⑥ When the SCR turn off, the capacitor C again starts getting charged to its original polarity through 'L' and the load (R_L).

⑦ Thus when it fully charged the SCR will again turn ON.

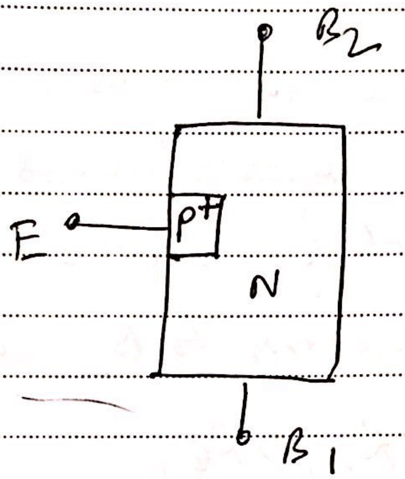
⑧. Hence from the above discussion, it becomes clear that the ~~thy~~ SCR after getting ON for sometime automatically gets OFF and after remaining OFF for some time, it again gets turn ON.

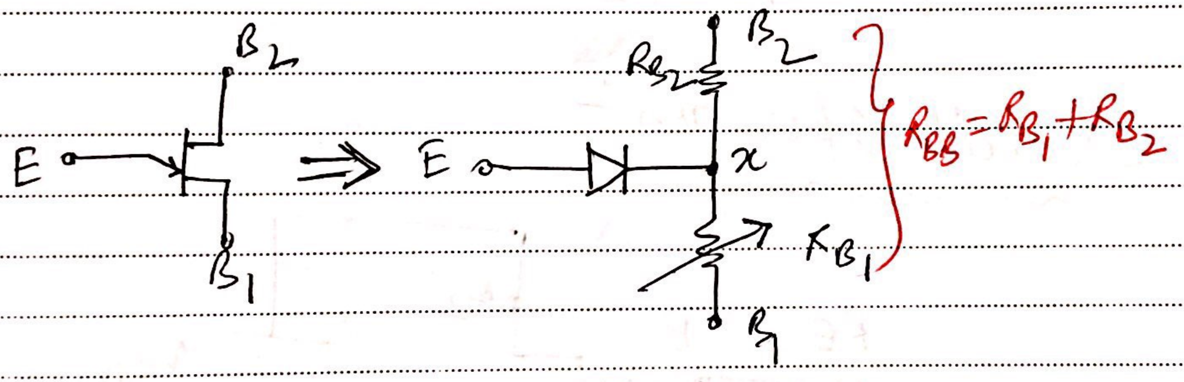
⑨ This process of switching ON and OFF is a continuous-process.

⑩. The desired frequency of ON and OFF states can be obtained by designing the commutating components as per requirement.

Unijunction Transistor = (UJT)

① It is a three terminal, single junction device.





② A UJT is consist of a lightly doped 'N' region provided with ohmic contact at each end.

③ The two end connections are called base-1 (B_1) and base-2 (B_2).

④ A small heavily doped P region is alloyed into one side of the bar closer to B_2.

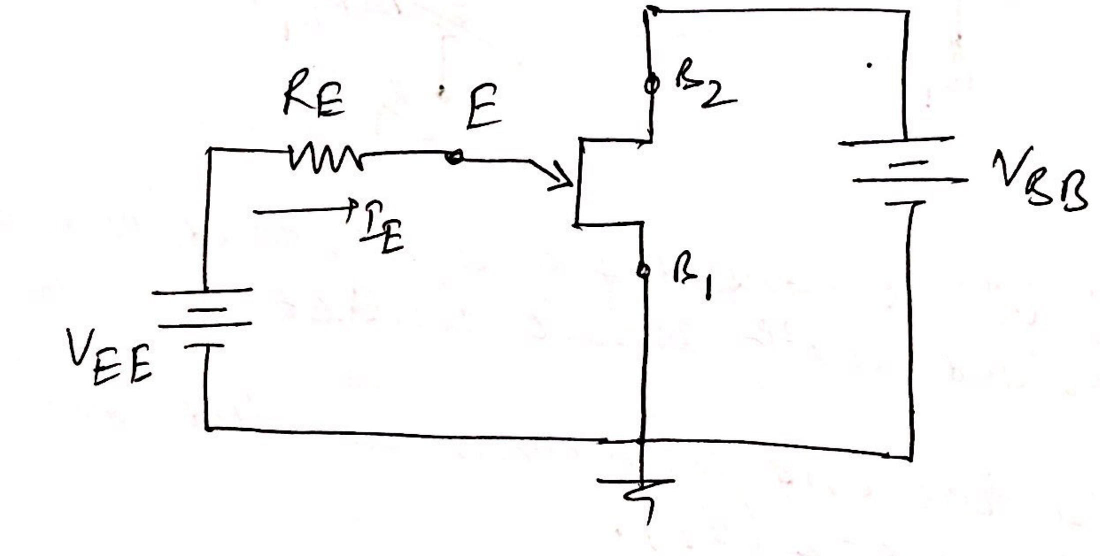
⑤ This 'P' region is UJT emitter (E) and forms a P-N junction with the bar.

⑥. An interbase resistance R_{BB} exists between B_1 and B_2, which is normally the resistance of the N-type bar.

⑦. This internal resistance can be broken up into two resistances, the resistance from B_1 to emitter called R_{B_1} and resistance from emitter to B_2 called R_{B_2}.

⑧ Normally $R_{B_1} > R_{B_2}$

Circuit Operation:-

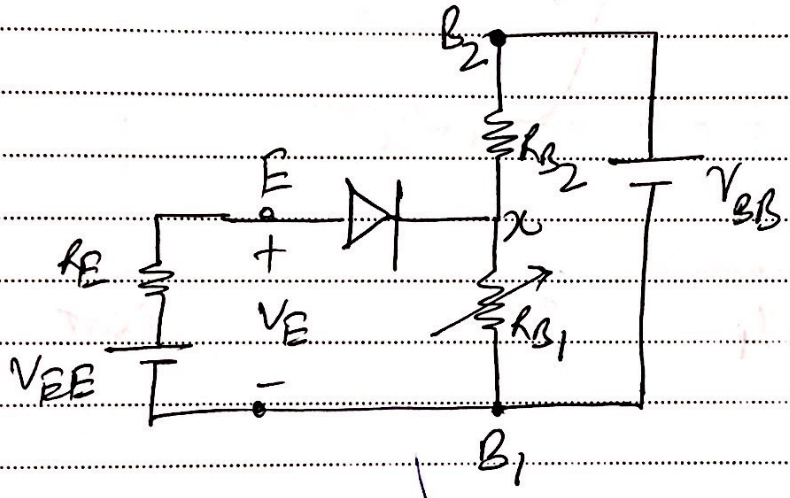


→ The UJT is normally operated with both B_2 and E biased positive relative to B_1.

→ B_1 is always the UJT reference terminal.

→ V_{BB} source is normally fixed and provides a constant voltage from B_2 to B_1.

→ V_{EE} source is normally a variable voltage and is considered the i/p to the circuit.



OFF State:-

$$V_x = V_{BB}\frac{R_{B_1}}{R_{B_1}+R_{B_2}}$$

$$= V_{BB}\,\eta$$

where $\eta = \frac{R_{B_1}}{R_{B_1}+R_{B_2}}$ (intrinsic stand off ratio)

η (0.5 to 0.8)

→ As long as V_{EE} less than V_x, emitter diode is reverse biased. This is the OFF state of UJT.

→ In OFF state UJT has a very high resistance between E and B_1 and I_E is a negligible reverse leakage current.

→ The off state extends upto the emitter voltage $V_E = V_P$, called the peak voltage

$$V_P = V_x + V_D = \eta V_{BB} + V_D$$

→ V_P varies as V_{BB} varies for the UJT.

ON State :-

→ As V_E approaches V_P, P-N junction becomes forward bias.

→ I_E becomes +ve near the peak point (P), where V_P is the peak voltage and I_P is peak current.

→ At this point holes from heavily doped emitter are injected into N layer. (more towards B_1)

→ The N layer which is lightly doped, offers very little chance for these holes to recombine.

→ So the lower half of UJT will have more holes and its resistance drastically reduced.

→ The decrease in R_{B_1} causes voltage drop.

→ This will causes diode to be more forward bias thereby I_E increases further.

→ This process will enter into a regenerative action.

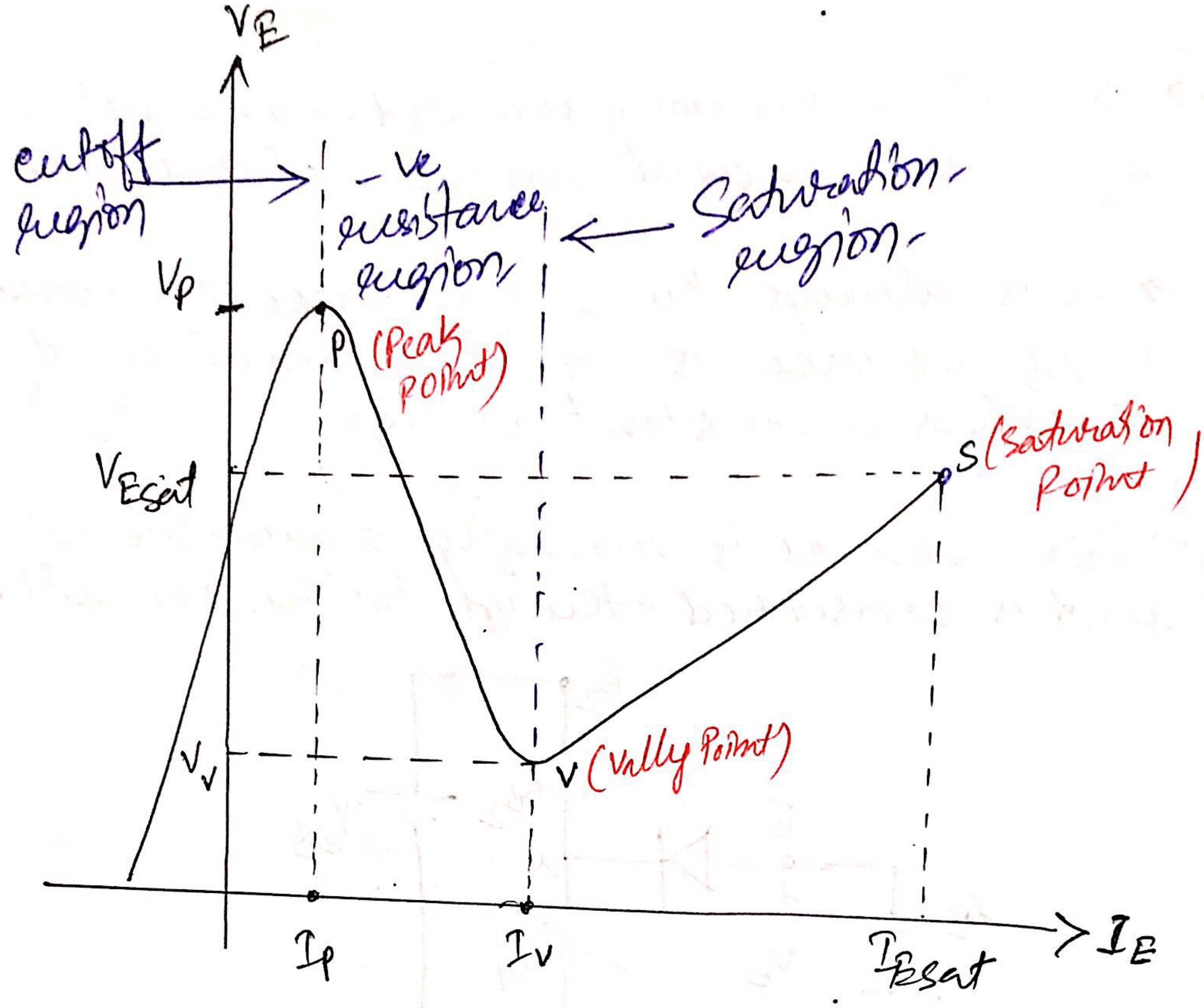
→ This drop in resistance is seen as a -ve resistance region in the V-I characteristics.

Turning OFF the UJT :-

→ Once UJT is ON, I_E mainly depends upon V_{EE} and R_E

→ As V_{EE} decreases I_E also decreases. When I_E decreases to point 'V' (the valley point), the emitter current is I_V (vally current), which is essentially the holding current needed to keep the UJT ON.

→ When I_E decreases bellow I_V, the UJT turns off.


VE
cutoff region
-ve resistance region
Saturation region
Vp
P (Peak Point)
VEsat
S (Saturation Point)
Vv
V (Vally Point)
Ip
Iv
IEsat
IE

UJT. triggering Ckt :-