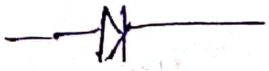
Power Electronics :-

→ It is defined by control and conversion of · high power application · with less switching losses and high efficiency.

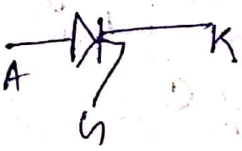
→ The device that we see in power electronics are

① Power diode



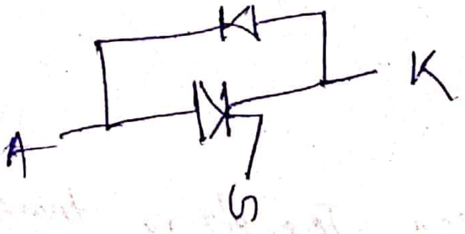
② Thyristor

(a) SCR

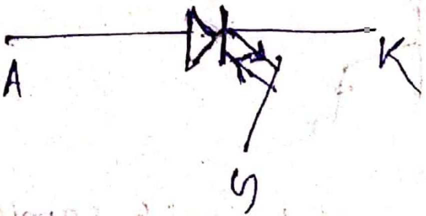


(b) A·SCR / RCT → Reverse control thyrister

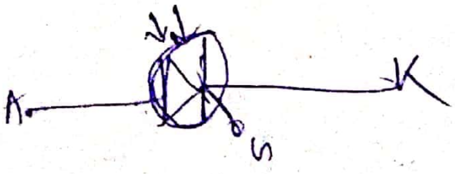
A Asymetric silicon control rectifier.



(c) · GTO → Gate turn off thyristor



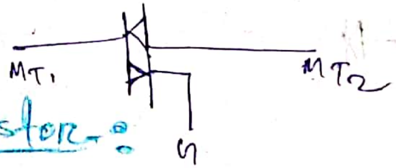
(d) LASCR → Light activated silicon control rectifier.



Pravas Padhiary

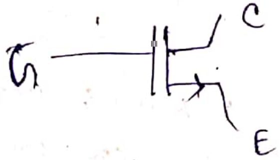
③ DIAC : Diode Alternating Current

④ TRIAC – Triode for alternating current



Transistor :-

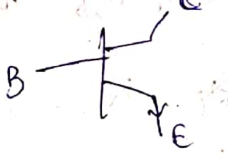
⑤ IGBT – insulated gate Bipolar transistor



IGBT Rating 1.2 KV, 50 KHz

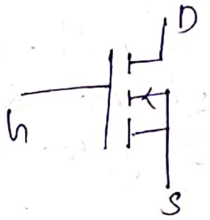
⑥ Transistor :-

BJT – Bipolar Junction transistor



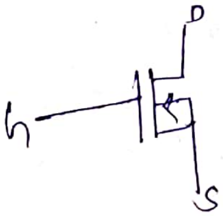
MOSFET – metal oxide semiconductor field effect transistor

enhancement type MOSFET



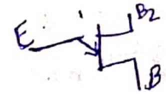
n channel

Depletion type MOSFET



n channel

⑦ UJT unipolar Junction transistor



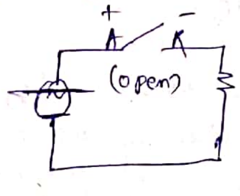
→ Diode rated in P.I.V

→ 0.7 V Silicon

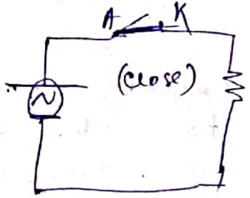
0.3 V Germanium

1 V Power diode

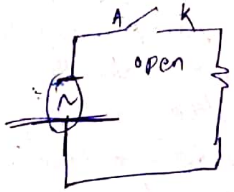
Operating mode of switch :



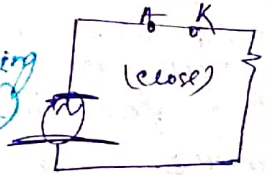
(Forward blocking mode)



(Forward conducting mode)



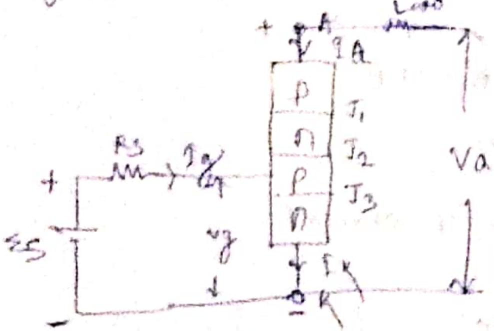
(Reverse blocking mode)



(Reverse conducting mode)

V-I characteristic of a thyristor :- or SCR

→ The anode and cathode are connected to main source through the load. The gate and cathode are fed from a source E_s which provides positive gate current from gate to the cathode.



Here, V_a is the anode voltage across the thyristor terminals A, K and I_a is the anode current.

Thyristor has Three basic modes of operation

→ Reverse blocking mode.

~~→ Reverse conducting mode~~

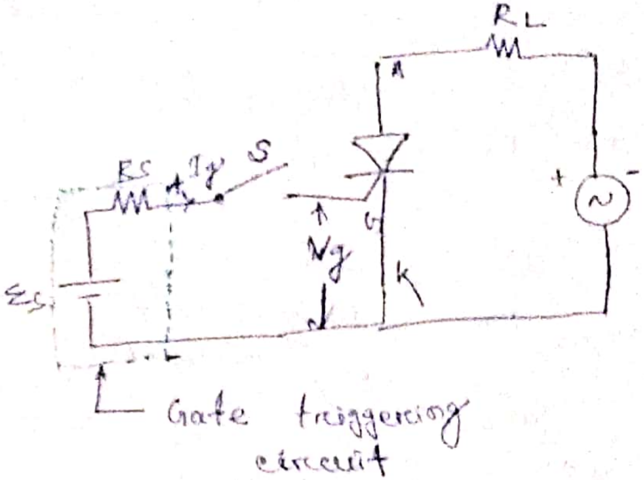
→ Forward conduction mode

→ Forward blocking mode

Reverse blocking mode

When cathode is made positive with respect to anode with switch S open. thyristor is reverse biased. It behaves like the two diodes are connected in series with reverse voltage applied across them. A small leakage current of the order of a few milliamperes flows. This is reverse blocking mode called the off state of the thyristor.

Here J_1 & J_3 R.B. and J_2 F.B.



→ If the reverse voltage is increased, then at a critical breakdown level, called reverse breakdown voltage V_{BR}. an avalanche occurs at J_1 and J_3 and the reverse current increase rapidly. A large current associated with V_{BR} gives rise to more losses in the SCR. This may lead to thyristor damage as the junction temperature may exceed its permissible temperature rise.

→ It should be ensure that maximum working reverse voltage across a thyristor does not exceed V_{BR}.

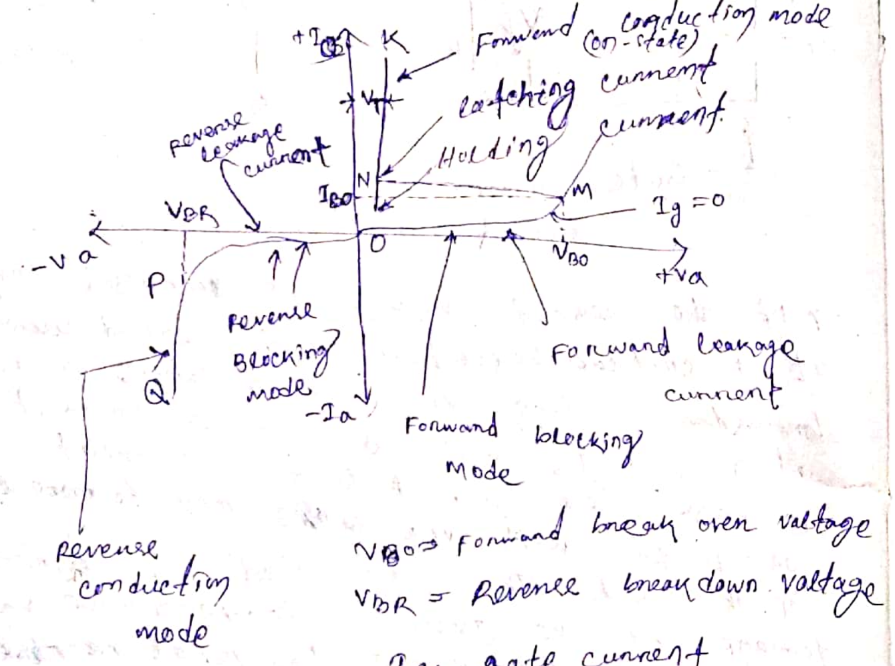
→ When reverse voltage applied across thyristor is less than V_{BR}, the device offers a high impedance in the reverse direction.

→ The SCR in the reverse blocking mode treated as an open switch.

→ in the characteristics

·O P is Reverse blocking mode

PQ is Reverse avalanche region.



VBO = Forward break over voltage

VBR = Reverse breakdown voltage

Ig = gate current

→ Ⓐ VI characteristic after avalanche breakdown during reverse blocking mode is applicable only, when the load resistance is zero.

If the load resistance is present, a large anode current associated with avalanche breakdown at VBR would cause substantial voltage drop across load. as a result, VI characteristic in 3rd quandrant would bend to right of vertical line drawn at VBR.

Forward blocking mode :-

→ when the anode is positive with respect to the cathode, with gate circuit is open. thyristor is said to be forward baised.

→ Here J₁ & J₃ are forward baised and J₂ Reverse baised.

→ In this mode small current, called Forward leakage current flows.

→ "OM" shows forward blocking mode of SCR.

→ As the small leakage current a SCR, due to SCR offers a high impedance.

→ Therefore, a thyristor can treated as an open switch even in the forward blocking mode.

Forward conduction mode :-

→ when anode to cathode forward voltage is increased with gate circuit open, reverse baise Junction J₂ will wave an avalanche breakdown at a voltage called forward breakover voltage VBO.

→ after this breakdown, thyristor gets turned on with point 'M' at once shifting to N and the point any where N and K,

→ NK is represent the forward conduction Mode.

→ A thyristor can be brought from forward blocking mode to forward conduction mode by turning it on by applying...
(i) a positive gate pulse between gate and cathode
or
(ii) a forward breakover voltage across anode and cathode.

→ Here N.K shows the voltage drop across the thyristors is of the order of 1 to 2 V depending upon the SCR.

→ NK across voltage drop increase with increasing slightly with increasing in anode current.

→ Anode current is limited by load impedance alone the voltage across SCR Quite small. (V_T).

→ The small voltage drop V_T across the device is due to ohmic drop in the four layers.

→ In forward conduction mode thyristors treated as <u>closed switch</u>.

Thyristor turn-ON Methods:

(a) Forward voltage triggering
(b) gate triggering
(c) dv/dt triggering
(d) temperature triggering
(e) Light triggering

(a) Forward voltage triggering:

→ when forward voltage is applied between Anode and cathode with gate circuit open, Junction J_2 is reverse baised. As a result dipletion layer formed Junction J_2.

→ The width of this layer decrease with an increase in anode cathode voltage.

→ If forward voltage across anode - cathode is gradually increased, a stage comes the dipeltion layer across J_2 vanishes.

→ At this moment, R.B Junction J_2 said to be avalanche breakdown and the voltage at which it occurs is called forward break over voltage V_{BO}.

→ At this voltage, the thyristor changes from off-state (high voltage with low leakage current) to ON state.

→ But in ON-state Low voltage across SCR and high ~~leakage~~ Forward current.

→ This Forward large current limit by Load impedance.

→ The magnitude of the V_{BO} and V_{BR} are nearly same and temperature dependent. But in practice V_{BR} is slightly more V_{BO}.

→ After avalanche breakdown, J_2 losses its reverse blocking capacity.

→ If the Anode voltage is reduce V_{BO} than continue current condiction SCR.

→ The SCR can now be turned off only by reducing the anode current below a certain value called holding current.

(b) Gate triggering :-

→ Turning on of thyristors by gate triggering is simple, reliable and efficient, it is therefore the most usual method of firing the forward baised SCR.

→ A thyristor with forward break over voltage higher than the normal working voltage is chosen. This means that the thyristor will remaining forward blocking mode with normal working voltage across anode and cathode with gate open. ($I_g = 0$)

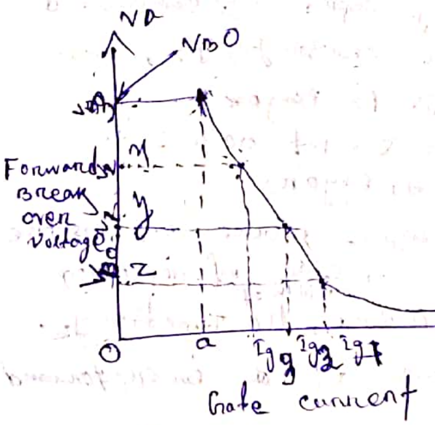
→ However, when turn ON of a thyristor is required, a positive gate voltage between gate and cathode is applied.

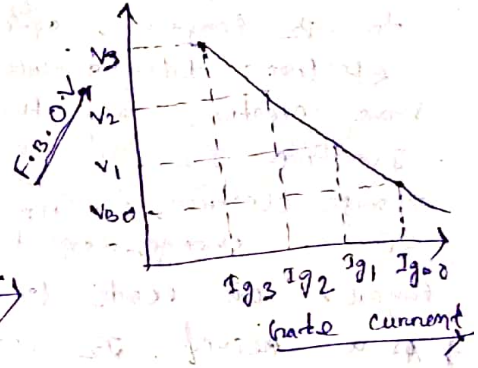
→ With gate current this established, charges are injected into inner p layer and voltage at which forward breakover occurs is reduced.

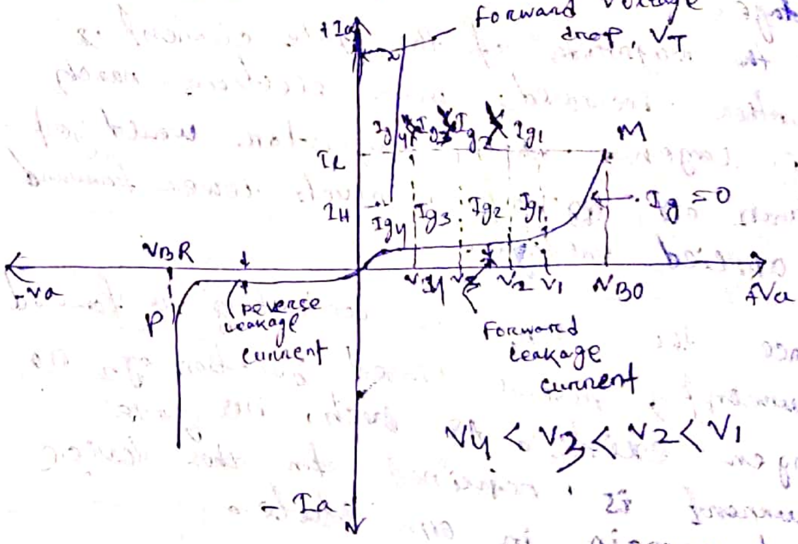
→ Higher gate current, lower is the forward break over voltage.

→ When positive gate current is applied between gate and cathode terminal. In practice the magnitude of gate current is more than the minimum gate current required to turn on the SCR. The magnitudes of gate current are 20 to 200mA.

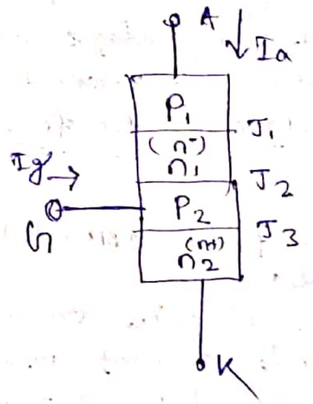
Right







$V_4 < V_3 < V_2 < V_1$



Simple model of thyristor

→ when we applied gate current then the electrons from n2 layer cross Junction J_3.

→ n2 Layer is heavily doped as compared to P2 layer, after crossing J_3, these electrons diffuse through P2 layer.

→ The electrons are then swept across the Junction J_2 into the n1 layer.

→ These electrons in n1 layer reduce the positive space charge on the n1 side of depletion layer. The leads to reduce the width of the Junction J_2.

→ As a result, J_2 occurs at a lower forward voltage.

→ If the magnitude of the gate current is further increased, more electrons reach n1 layer. then thyristor would get turn ON at a much lower forward applied voltage.

→ once the SCR is conducting a forward current, reverse biased Junction J_2 no longer exists. As such, no gate current is required for the device to remain in on state.

If the gate current is removed, the conduction from anode to cathode remains unaffected.

→ However, If the gate current, ~~the thyristor will turn off again.~~ is reduce to zero before the rising anode current attains a value, called latching current. the thyristor will turn-off again.

→ **Latching current:** (I_L)

it is defined as the minimum value of anode current which it must attain during turn ON process to maintain conduction when gate signal is removed.

→ **Holding current:** (I_H)

It is defined as the minimum value of anode current below which it must fall for turning off the thyristor.

$I_L \simeq 3I_H$

→ In industrial applications holding current is almost taken as (typically 10mA) zero.

(c) **$\frac{dv}{dt}$ triggering:** with forward voltage across anode and cathode of a thyristor.

→ The the two Junction J_1, J_3 are F.B and J_2 is R.B.

→ The Reverse baised J_2 has the characteristi of capacitor due to charge exist across the Junction.

→ In other word the space changes exist in the depletion region near Junction J_2. and J_2 Junction behaves like capacitance.

→ If forward ~~to~~ voltage is suddenly applied, a charging current through Junction capacitance C_j may turn on the SCR.

→ The suddenly supplied voltage Va reach across Junction J_2, the charging current I_c. is given by

$$i_c = \frac{dQ}{dt} = \frac{d(C_j \cdot V_a)}{dt}$$

$$= C_j \frac{dV_a}{dt} + V_a \cdot \frac{dC_j}{dt}$$

As the Junction capacitance is almost constant, so $\frac{dC_j}{dt} = 0$

So

$$i_c = C_j \frac{dV_a}{dt}$$

If the rate of increase forward voltage dV_a/dt, also the charging current ~~is~~ increase. This charging current play a rule of gate current. and turns ON the SCR, ~~even~~ through gate signal is zero.

→ If Va is small, it is the rate of change of Va that plays the roles of turning - ON the device.

(d) Temperature triggering :- or (Thermal triggering)

During the forward blocking mode, most of the applied voltage appears accross the Junction J_2.

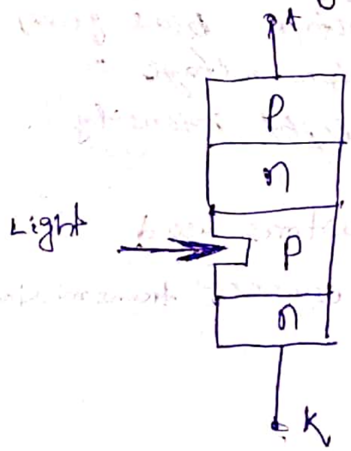
→ This voltage across J_2, associated with leakage current, would rise temperature of this Junction. with increase in temperature decrease its depletion layer.

This further draws more leakage current and more junction temperature.

→ With the commulative Process, at high temperature near the Junction this temperature vanishes the reverse baised Junction J_2 and the device gets turned ON.

Light triggering :-

In light trigger SCR a recess is made in the inner 'p' layers.



→ when this recess is irradiated, free charge carriers are generated just like when gate signal is applied between gate and cathode.

→ The pulse of light of appropriate wavelength is guided by optical fibres for irradiation.

→ If the intensity of this light thrown on the recess exceeds a certain value, forward-biased SCR is turned on. such thyristor is known as Light Activated SCR. (LASCR).

→ LASCR may be triggered with a light source or a gate signal. some times both are used for triggering purpose.

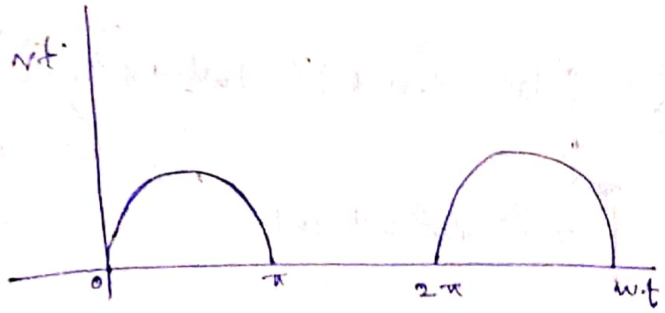
→ The gate is biased with voltage or current slightly less than that required to turn it ON, now a beam of light directed at the inner p-layer junction turns on the SCR.

→ The light intensity required to turn-on the SCR depends upon the voltage bias given to the gate. If the Higher voltage or current bias, Lower light intensity required.

→ Light triggered thyristors used High voltage direct current transmission systems.

→ SCRs are connected in series-parallel combination and light triggering has the advantage of electrical isolation between power and control circuits.

R.M.S value of half wave rectifier:



$T = 2\pi$ (sec)

$f = \frac{1}{2\pi}$ (Hz)

$\omega = 2\pi f$

$= \cancel{2\pi}\frac{1}{\cancel{2\pi}}$

$= 1$ (rad/sec)

$$V_{r.m.s} = \sqrt{\frac{1}{T}\int_0^{\pi} V(t)^2\, dt}$$

$$V(t) = \begin{cases} V_m \sin\omega t ; & (0 < \omega t < \pi) \\ 0 ; & (\pi < \omega t < 2\pi) \end{cases}$$

$$V_{rms} = \frac{1}{T}\int_0^T v(t)^2\,dt$$

$$= \frac{1}{2\pi}\int_0^{2\pi} v(t)^2\,dt$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} v(t)^2\,dt + \int_0^{2\pi} v(t)^2\,dt\right]$$

$$= \frac{1}{2\pi}\int_0^{\pi} (v_m \sin wt)^2\,dwt + \int_0^{2\pi} \cancel{(v_m \sin wt)^2 d} \rightarrow 0$$

$$\boxed{\because \sin 2\pi = 0}$$

$$= \frac{1}{2\pi}\int_0^{\pi} v_m^2 \sin^2 wt\,dwt$$

$$= \frac{v_m^2}{2\pi}\int_0^{\pi} \frac{1-\cos 2(wt)}{2}\,dwt$$

$$= \frac{v_m^2}{2\pi}\left[\frac{1}{2}(wt)_0^{\pi} - \frac{1}{2}\left(\frac{\sin 2(wt)}{2}\right)\right]$$

$$= \frac{v_m^2}{2\pi}\left(\frac{1}{2}(\pi-0) - \frac{1}{2}(0)\right.$$

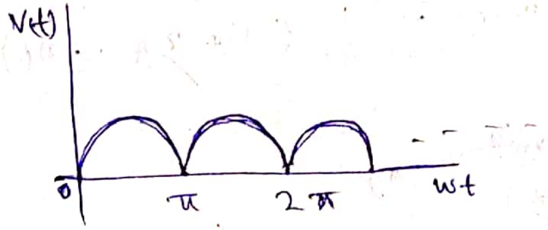
[sin 2π = sin0
y. coordinate of (1, 0)
= 0
(sin 2π = 0)]]

$$= \frac{v_m^2}{2\pi}\left(\frac{\pi}{2}\right)$$

$$V_{rms} = \sqrt{\frac{v_m^2}{4}}$$

$$V_{rms} = \frac{V_M}{2}$$

R.M.S value of full wave rectifier.



$$V_{rms} = \sqrt{\frac{1}{T}\int_0^{\pi} v(t)^2\,dt}$$

$T = \pi$

$f = \frac{1}{\pi}$ cycle/sec

$w = 2\cancel{\pi}\frac{1}{\cancel{\pi}} = 2$

$v(t) = v_M \sin wt$; $0 < wt < \pi$

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^{\pi} v(t)^2\,dt}$$

$$= \sqrt{\frac{1}{T}\int_0^{\pi} v_M(\sin wt)^2\,dwt}$$

$$= \sqrt{\frac{1}{T}\int_0^{\pi} v_m^2 \sin^2 wt\,dwt}$$

$$= \sqrt{\frac{v_m^2}{T}\int_0^{\pi} \sin^2 wt\,dwt}$$

$$= \sqrt{\frac{v_m^2}{T}\int_0^{\pi} \frac{1-\cos 2wt}{2}\,dwt}$$

$$= \sqrt{\frac{v_m^2}{2T}\int_0^{\pi} (1-\cos 2wt)\,dwt}$$

$$= \sqrt{\frac{v_m^2}{2T}\left[(wt)_0^{\pi} - \left(\frac{\sin 2wt}{2}\right)_0^{\pi}\right]}$$

$$= \sqrt{\frac{vm^2}{2T}\left[(\pi-0) - \frac{1}{2}(\sin 2\pi - \sin 0)\right]}$$

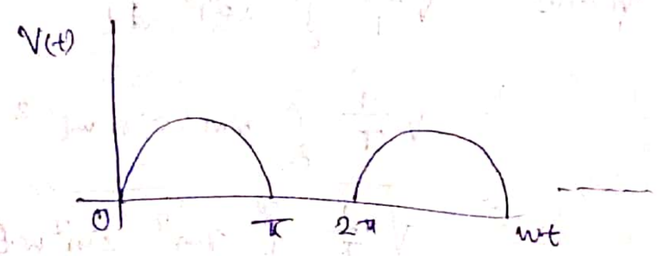
$$= \sqrt{\frac{vm^2}{2T}(\pi)}$$

$$= \sqrt{\frac{vm^2}{2\cancel{\pi}}\cancel{\pi}}$$

$$V_{r.m.s} = \frac{V_M}{\sqrt{2}}$$

Average value for half wave rectifier:

$$V_{Avg} = \frac{1}{T}\int_0^{\pi} v(t) \cdot dt$$



$T = 2\pi$ (sec)

$f = \frac{1}{2\pi}$ Hz

$\omega = \cancel{2\pi} \cdot \frac{1}{\cancel{2\pi}} \cdot 1$ (rad/sec.)

$$v(t) = \begin{cases} Vm \sin(wt) & ; 0 < wt < \pi \\ 0 & ; \pi < wt < 2\pi \end{cases}$$

$$V_{r.m.s} = \frac{1}{T}\int_0^{\pi} v(t)\, dt$$

$$= \frac{1}{T}\int_0^{\pi} Vm \cdot \sin wt\, dwt + \int_0^{2\pi} 0\, dwt$$

$$= \frac{1}{T}\int_0^{\pi} Vm \sin wt\, dwt$$

$$= \frac{1}{T}\int_0^{\pi} vm \sin wt\, dwt$$

$$= \frac{vm}{T}(-\cos wt)_0^{\pi}$$

$$= \frac{Vm}{T}\left[-(\cos\pi - \cos 0)\right]$$

$$= \frac{V.m}{2\pi}(-\cos\pi + \cos 0)$$

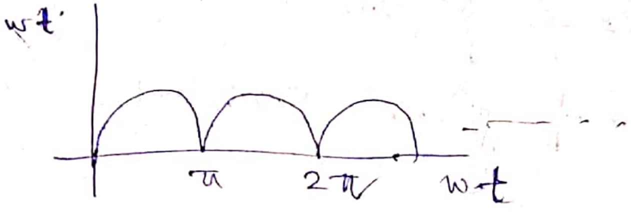
$$= \frac{vm}{2\pi}[-(-1) + 1)$$

$$= \frac{vm}{\cancel{2}\pi}(\cancel{2})$$

$$V_{avg} = \frac{VM}{\pi}$$

Average value of full wave rectifie

$$V_{avg} = \frac{1}{T}\int_0^{\pi} V(t)\, dt$$



$T = \pi$

$f = \frac{1}{\pi}$

$w = 2\cancel{\pi}\frac{1}{\cancel{\pi}} = 2$

$V(t) \Rightarrow V_m \sin(wt)\ ;\ 0 < wt < \pi$

$$V_{avg} = \frac{1}{T}\int_0^{\pi} V_m \sin wt\, dwt$$

$$= \frac{V_m}{T}\int_0^{\pi} \sin wt\, dwt$$

$$= \frac{V_m}{\pi}\int_0^{\pi} \sin wt\, dwt$$

$$= \frac{V_m}{\pi}\left(-\cos wt\right)_0^{\pi}$$

$$= \frac{V_m}{\pi}\left[-\left(\cos\pi - \cos 0\right)\right]$$

$$= \frac{V_m}{\pi}\left(-\cos\pi + \cos 0\right)$$

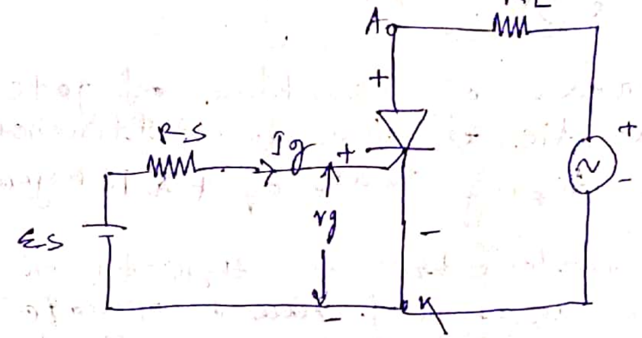
$$= \frac{V_m}{\pi}\left(-(-1) + \cos 0\right)$$

$$= \frac{V_m}{\pi}(1+1)$$

$$= \frac{V_m}{\pi}\, 2$$

$$V_{avg} = \frac{2V_m}{\pi}$$

Gate characteristic of thyristor:



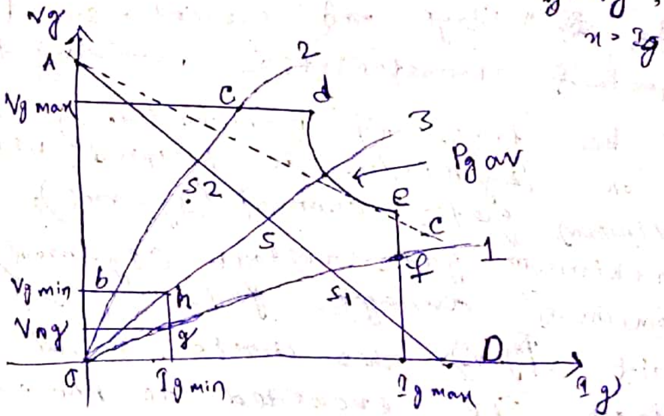
$E_s = V_g + I_g R_s$

$V_g = E_s - I_g R_s$

$y = mx + c$

$y = V_g\ ,\ m = R_s$

$x = I_g\quad c = E_s$



→ Here, positive gate to cathode voltage V_g and positive gate to cathode I_g values as gate cathode represent DC circuit of a thyristors is a PN Junction gate characteristics of the device are similar to that of a diode.

→ For a particular types of SCR the $V_g \cdot I_g$ characteristic is spread between ① & ②.

→ This spread or scatter of gate characteristic is due to difference in the doping levels of P & N layers.

→ Gate characteristic of thyristor or SCR gives us a brief idea to operate it within a safe region of applied gate voltage and current. So it is important characteristics regarding thyristor.

→ At the time of manufacturing each SCR or thyristor is specified with the maximum gate current (I_g - max), maximum gate voltage (I_g - max) and maximum average gate power dissipation limit (P_{gav}). These limits should not ~~Protect~~ be exceeded to protect the SCR from damage and there is also specified minimum voltage (V_g - min) and minimum current (I_g - min) for proper operation of thyristor.

→ A gate non triggering voltage (V_{ng}) is also mentioned at the time of manufacturing of the device. All noises and unwanted signals should lie under this voltage (V_{ng}) to avoid unwanted turn on of the thyristor.

→ Curve 1 represents the lowest voltage values that must be applied to turn on the SCR and curve 2 represents the highest values of voltage that can safely applied. So from the figure we can see the safety operated area of SCR is bcdefghb

→ Now from the triggering ckt, we get

$$E_s = V_g + I_g R_s$$

where,
E_s = gate source voltage
V_g = gate cathode voltage
I_g = gate current
R_s = gate source resistance

→ A load line of gate source voltage is drawn as AD where OA = E_s and OD = E_s/R_s which is trigger circuit short circuit current.

→ Now, let a VI - characteristic of gate circuit is given by curve 3. The intersection point of load line (AD) and curve 3 is called operating point "S".

→ It is must evident that S must lie between S_1 and S_2 on the load line.

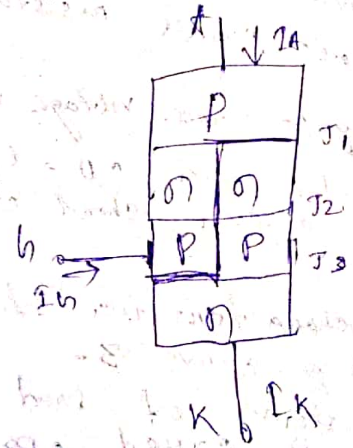
→ ~~for decreasing the turn ON of the device, operating point should be as close to P_{gav} as possible.~~

→ For decreasing the turn ON time and to avoid unwanted signal to turn ON of the device, operating point should be as close to P_{gav} as possible.

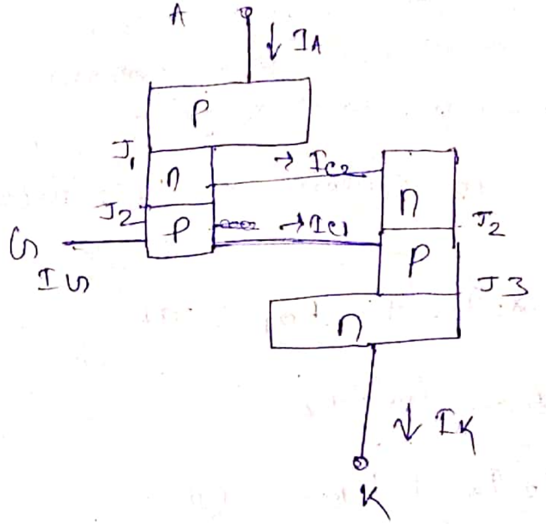
Slop of AD = Source resistance R_s. minimum amount of R_s can be determined by drawing tangent to the P_{gav} curve from the point A.

Two transistor model of SCR or thyristor:

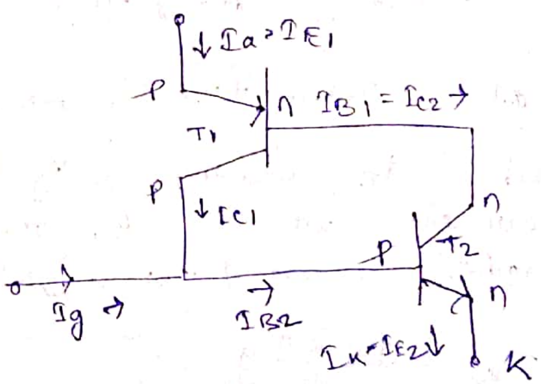
Basic working principle of SCR, can easily be understood by the two transistor model of SCR, as it is a combination of P and n layers.



→ It is a PnPn tyristor. If we bisect two transistor we get one PnP transistor with J_1 and J_2 Junctions and another is npn with J_2 and J_3 Junctions figure belows.



the relation between collector current and Emitter current given below.



Here, I_C is collector current, I_E is emitter current, I_{EBO} is the forward leakage current, α is the common base forward current gain and relationship between I_C and I_B is

$$I_C = \beta I_B$$

where,
I_B = base current and β is common emitter forward current gain.

let's for transistor T_1 this relation holds

$$I_{C1} = \alpha_1 I_a + I_{CBO1} \quad \text{—(i)}$$

And transistor T_2

$$I_{C2} = \alpha_2 I_K + I_{CBO2} \quad \text{(ii)}$$

Now, by the analysis of two transistors model we can get anode current,

$$I_a = I_{C1} + I_{C2} \quad \text{(applying KCL)}$$

$$I_a = \alpha I_a + I_{CBO1} + \alpha_2 I_K + I_{CBO2} \quad \text{—(iii)}$$

If applied gate current is I_g then cathode current will be the summation of anode current and gate current.

$$I_K = I_a + I_g$$

By substituting this value of I_K in (iii)

$$I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 (I_a + I_g) + I_{CBO2}$$

$$I_a = \alpha_1 I_a + I_{CBO1} + \alpha_2 I_a + \alpha_2 I_g + I_{CBO2}$$

$$I_a = (\alpha_1 + \alpha_2) I_a + \alpha_2 I_g + I_{CBO1} + I_{CBO2}$$

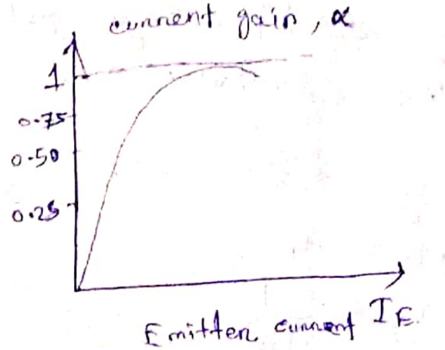
$$[I_a - (\alpha_1 + \alpha_2) I_a] = \alpha_2 I_g + I_{CBO1} + I_{CBO2}$$

$$I_a (1 - (\alpha_1 + \alpha_2))] = \alpha_2 I_g + I_{CBO1} + I_{CBO2}$$

$$I_a = \frac{\alpha_2 I_g + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}$$

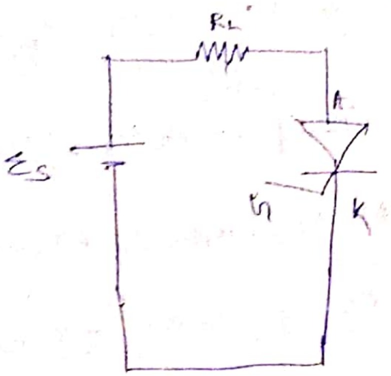
when $I_g = 0$, no gate source apply

$$I_a = \frac{I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}$$



* When we apply gate source in a device then its I_E or I_K increase then its K value is increase then its also increase I_A increase which exceed I_L value then device turn ON.

This I_A can be decrease by using Load ~~impedance~~ resistance.



Q-1 A trigger out of a thyristor as a source voltage of 15V and load line as slope -120 (V/A). The minimum gate current to turn on the SCR is 25mA compute source resistance required in get circuit. The trigger voltage and trigger current of an average gate power dissipation of 0.4W.

Ans :-

$V_g = -I_g R_s + E_s$

$V_g I_g = 0.4$

$V_g = \frac{0.4}{I_g}$

$\frac{0.4}{I_g} = -I_g R_s + E_s$

$0.4 = -I_g^2 120 + 15 I_g$

$1.2 I_g^2 - 15 I_g + 0.4 = 0$

$I_g = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

$a = 120,\ b = -15,\ c = 0.4$

$\Rightarrow \frac{15 \pm \sqrt{(15)^2 - 4 \cdot 120 \cdot 0.4}}{2 \cdot 120}$

$\Rightarrow \frac{15 \pm \sqrt{225 - 192}}{240}$

$\Rightarrow \frac{15 \pm \sqrt{33}}{240}$

$\Rightarrow \frac{15 \pm 5.744}{240}$

$\Rightarrow \frac{15 + 5.744}{240}$ or $\frac{15 - 5.744}{240}$

$\Rightarrow \frac{20.744}{240}$ or $\frac{10.744}{240}$

$\Rightarrow 0.08643$ or 0.04476

$I_g = 86.43\ mA$ or $44.76\ mA$

$\rightarrow V_g \cdot I_g = 0.4$

$V_g = \frac{0.4}{I_g} = \frac{0.4}{0.04476}$

$V_g = 8.93V$

$V_g I_g = 0.4$

$V_g = \frac{0.4}{0.0864}$

$V_g = 4.629\ V$

Q2) ~~A trigger circuit of a thyristor as a source~~ For an SCR the gate cathode characteristic has a straight line slope of 130, for trigger source voltage of 15 V. and Allowable gate Power dissipation of 0.5 W. compute the gate ~~source~~ resistance.

$m = 130$

$E_s = 15V$

$P_g = 0.5W$

$y = mx + c$

$V_g = -I_g R_s + E_s$

$V_g = 130 I_g$

$V_g^2 = 130 \times 0.5$

$V_g = \sqrt{65}$

$V_g = 8.06 V$

$I_g = \frac{0.5}{8.06} =$ $(\because P_g = V_g \cdot I_g)$

$I_g = 0.062$

$= 62 mA$

$V_g = -I_g R_s + E_s$

$8.06 = -R_s * 0.062 + 15$

$R_s = 111.93 \Omega$

Switching Characteristic of SCR :-

→ it is the time variation of voltage across its anode and cathode terminals and the current through during the turn on and turn off Process. There are two types of characteristics

① During turn on Process

② During turn off Process

it is also known as dynamic characteristics of SCR.

① Switching characteristics of SCR during Turn on:

- A forward biase thyristor is usually turn on by applying a +ve gate voltage. There is however a transition time forward off state to forward ON state this transition time is called as turn. ON time.

Turn on time of thyristor is defined as the time during which it changes from forward blocking state to forward ON. state or conduction state.

→ The turn on time of SCR comprises 3 different time intervals :- (i) Delay time
(ii) Rise time
(iii) Spread time

(i) Delay time : (t_d)

→ The delay time is measured from the instant at which gate current reaches to $0.9 I_g$ to the instant at which anode current reaches $0.1 I_a$. Here the I_g and I_a are the final values of gate and anode current respectively.

→ other ways to define delay time is also defined as the time during which anode voltage falls from V_a to $0.9 V_a$. Here V_a is the initial value of anode to cathode voltage when SCR was in forward blocking mode.

→ Another way to define it is the time in which anode current reaches to 0.1 Ia from forward leakage current.

→ The initiation of turn on process basically starts at gate to cathode junction. As soon as we apply gate current, charges are injected into the gate to cathode junction. This change flows in a narrow path due to non-uniform change distribution. Therefore the current density near the gate is more and decreases as the distance from gate junction increases. This means during the delay time the anode current flows in narrow region near gate where gate current density is higher.

(ii) Rise Time :- (tr)

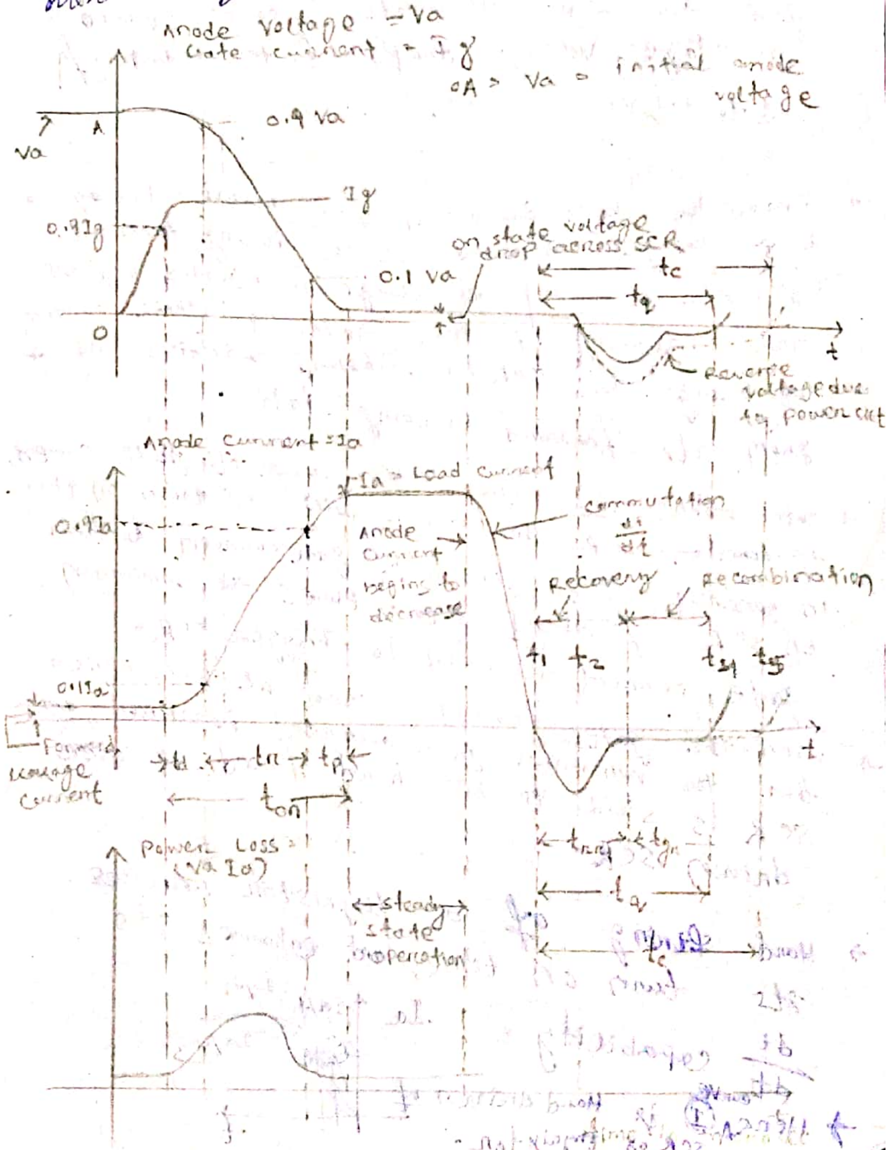
→ it is defined as the time taken by the anode current to rise from 0.1 Ia to 0.9 Ia. During this time, the anode to cathode voltage drops from 0.9 Va to 0.1 Va.

→ Rise time is inversely proportional to the magnitude of gate current and its rate of rise. The more gate current, the lessen will be the rise time.

→ During rise time, the current starts to spread from a narrow ~~cathode~~ conducting region in the gate to cathode junction. But as the rise time is small, ~~the~~ anodes current do not get a change to spread over the entire cross section of cathode.

The rise time also flows in a narrow region. The area of rise time narrow region is more than in case of delay time.

→ Since the voltage and current are more during rise time the turn on losses is more during rise time.



iii) Spread time: (t_p)

→ it is the time taken by anode current to reach $0.9I_a$ to I_a. During this time period, the anode current spread over the entire cross section of cathode.

→ After the spread time, the anode current attains a steady state value and the voltage drop across the SCR terminals becomes equals to on stage voltage drop of the order of 1 to 1.5 V.

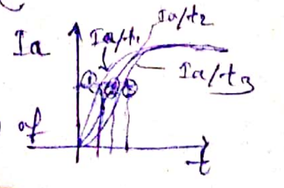
→ From the above discussion, we observe that an SCR is a charge controlled device during turn ON. A certain amount of charge is injected by the gate current in the gate to cathode junction to bring the SCR in forward conduction mode from its forward blocking state.

→ This means the higher the value of gate current, the lesser will be turn on time. ~~to turn on SCR~~ In general, the magnitude of gate current to turn on SCR is about 3 to 5 times the minimum gate current required to trigger SCR.

→ when the gate current is several times higher than the minimum gate current required, an SCR is said to be hard fired or over driven SCR.

→ Hard firing of a thyristor reduces its turn on time and enhances its $\frac{di}{dt}$ capability.

→ Hence curve ① is Hard driven of SCR or thyristor.



⑫ switching characteristics of SCR during Turn off :

* Switching characteristics of SCR during turn off is the transition of SCR from forward conduction state to forward blocking state.

* This transition process involves bringing the anode current below holding current, sweeping out of charges from outer p and n junction and recombination of holes and electrons at the interior junction, Thus it is a dynamic process. this dynamic process of bringing SCR to off state is called commutation or turn off process.

* As we know that, once SCR is turned on this means, the gate has no control over it. in conduction state SCR will continue to be even if gate current is removed. ok but now we want to turn off SCR.

* we need to bring the anode current below holding current. But merely (only) bringing current won't turn off SCR. This is because the charge carrier i.e, electrons and holes are still in favorable condition, and if we apply forward voltage across anode and cathode terminals, SCR will begin to conduct.

* This means we need to apply a reverse voltage for some finite time to give charge carriers time to be swept away ~~and~~ from outer ~~recombined in inner junction~~ junction due to reverse p and n voltage.

* once the charge has been swept away and recombined in inner junction where sweeping is not possible, the SCR will sustain forward voltage... At such time. we will say that SCR is turned off.
This whole process take some time, which is known as turn off time of SCR.

* Turn off time (tq) is defined as the time in between the instant when SCR anode current becomes zero. to the instant when SCR regains forward blocking capability. such time, all the excess carries from outer p and n layers are removed.

* This removal of excess carriers consists of sweeping out of holes from outer p-layer and electrons from outer n-layers. The carriers in the inner junction can only be swept away by recombination.

* Thus there are two different methods for sweeping out the excess carriers. This lead to two different times.

* The time in which excess carriers are removed from two outer p and n layer is called reverse recovery time. "(trr)".

* while the time in which charge carriers in inner layer is removed due to recombination is called the gate recovery time, "tgr".

① Turn off time (tq) = reverse recovery time (trr) + gate recovery time (tgr)

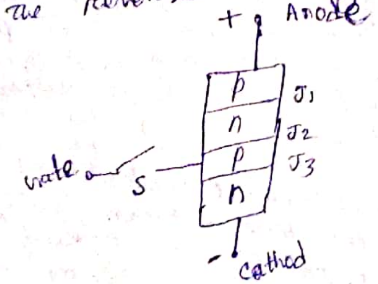
* At instant "t_1", the anode current becomes zero. But carriers are still under favorable condition, the anode current will start flowing in reverse direction with the same slope i.e di/dt.
This is actually good.

* This reverse current will help to sweep out excess holes from outer p and n layer excess electron from outer layer. this reverse current first increases but with the sweeping out of excess carriers, this current starts to decrease.

* At time t_2, when around 60 percent of carriers have been swept away from outer layers, the reverse anode current starts to decrease. The rate of decay of reverse current fast in the beginning but becomes gradual thereafter. This fast decay of reverse current cause a reverse voltage across SCR and may damage. therefore an RC element across SCR terminals helps to protect from such type of happening.

* At time t_3, when reverse current become almost zero, the excess carriers have been completely removed and now SCR can with-stand the reverse voltage.

- The reverse recovery time is $(t_3 - t_1)$.



* After reverse recovery time trr, the excess carriers are still trapped in the inner junction J_2. therefore, the SCR is not able to block the forward voltage. Since, the excess charge around junction J_2 is not able to flow in the external circuit,

therefore these trapped charges must decay due to recombination.

- This recombination is only possible if a reverse voltage is maintained across SCR for some finite time, through the magnitude of this reverse voltage is not important. This is because; the rate of combination only depends on Junction temperature. It is independent of external parameter.

- The time for recombination of charge is called gate recovery time, "tgr". Here the gate recovery time is $(t_4 - t_3)$

- At instant t_4, as there is no excess charge, the SCR can withstand forward voltage. Hence we say that the thyristor turn off. SCR turn off time is in the range of 3 - 100 μs.

- The SCR turn off time depends on the magnitude of anode current prior to starting of commutation process, di/dt and Junction temperature. As increases these factor, increases the thyristor turn off time.

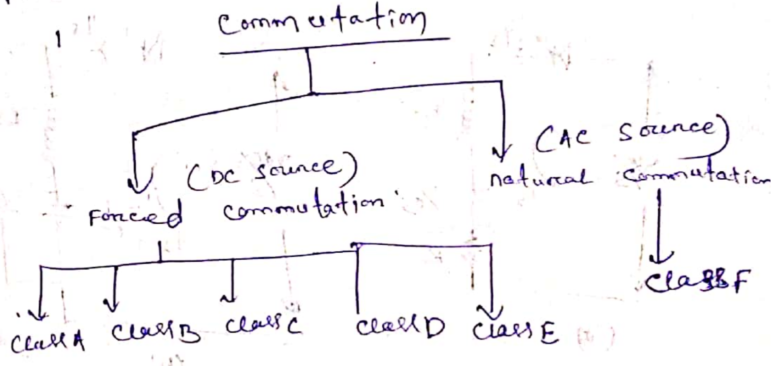
- However turn off time decreases with increases in magnitude of reverse voltage. This is because, high reverse voltage quickly sweeps out holes from p layer and electrons from outer n-layers. Thus turn off time of SCR is not a constant parameter of thyristor, rather it is depends on the external ckt parameter.

- SCR forms a part of external ckt. ckt Turn off time(t_c) is defined as the time between the instant anode current becomes zero to the instant reverse voltage across SCR terminals becomes zero. ckt turn off time t_c must be greater than thyristor turn off time t_q for reliable commutation.

- Thyristor with slow turn off time (50-100 μs) is called converter grade SCR and those with fast turn off time (3-50 μs) is called inverter grade SCR.

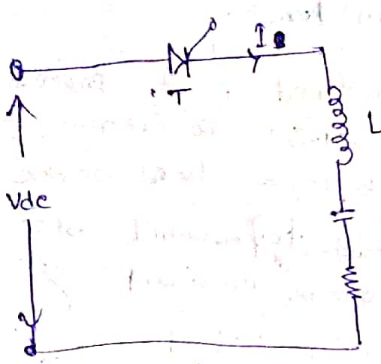
Commutation process of a thyristor:

- Commutation is defined as the process of turning-off a thyristors. To turning off a thyristor means, bringing the device from forward conduction mode to forward blocking mode. Such time anode current is less than the holding current.
- There are two type of commutation process.

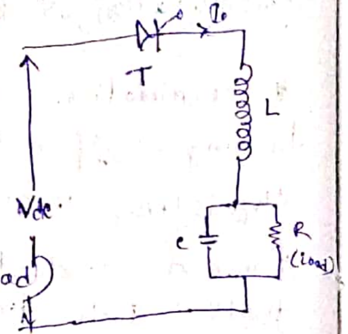


Class A commutation: Load commutation:

- It is also called as load commutation or self commutation.
- It is the process in which R, L, & C component to be arranged in a closed Loop. where L & C are the commutating component. And Here the load resistance for low value of R, L and C are connected in series. For high value of R, load resistance R is connected parallel across the capacitor "C".



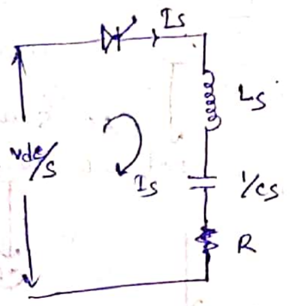
(a)



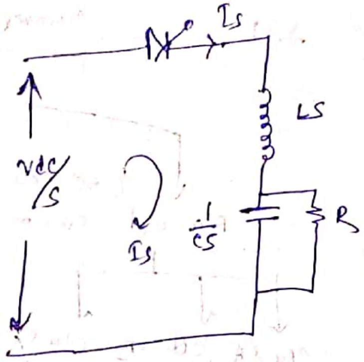
R (Load)

(b)

According to Laplace transform :



(a)



(b)

- Applying KVL on fig-(a)..

$$\frac{Vdc}{s} - I_s Ls - \frac{I_s}{cs} - I_s R = 0$$

$$\frac{Vdc}{s} = I_s \left(Ls + \frac{1}{cs} + R \right)$$

$$\frac{Vdc}{s} = I_s \left(\frac{csLs + 1 + Rcs}{cs} \right)$$

$$I_s = \frac{c\cancel{s}\, Vdc}{\cancel{s}\,(csLs + 1 + Rcs)}$$

$$I_s = \frac{\cancel{c}\, Vdc}{L\cancel{c}\left(s^2 + \frac{1}{Lc} + \frac{Rs}{L}\right)}$$

$$I_s = \frac{Vdc}{L\left(s^2 + \frac{1}{Lc} + \frac{Rs}{L}\right)}$$

~~Current in time domain~~,

$$I(s) = \frac{\frac{Vdc}{L}}{s^2 + \frac{1}{Lc} + \frac{Rs}{L}}$$

current in time domain, imp

$$\boxed{I(t) = \frac{Vdc}{w_r L} e^{-st} \sin(w_r t)}$$

$$\boxed{\because \frac{w_d}{(s+\alpha)^2 + w_d^2} = e^{-\alpha t} \sin w_d t}$$

ringing frequency w_r = damping frequency

To satisfy Load commutation in a R-L-C series ckt. (w_r = resonant frequency)

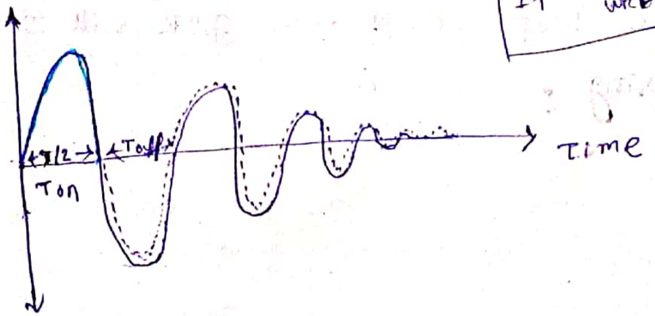
$$w_r = w_n \sqrt{1 - \xi^2}$$

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

for parallel R-L-C ckt,

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

$$\boxed{I_T = \frac{Vs}{w_r L} e^{-\xi w_n t} \sin(w_r t)}$$



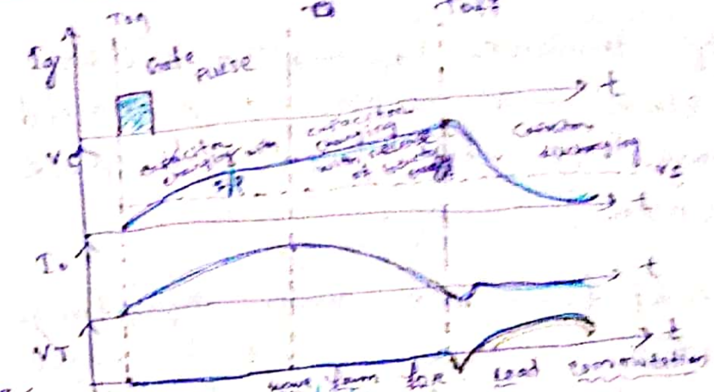
→ In commutation ckt: Class A Commutation when we applied a dc supply to the initially thyristor will turn off $(I_A < I_H)$. when we applied a gate pulse to the thyristor, then the thyristor will be turn on. such time Anode current is greater than the latching current.

→ when thyristor starts to conducting the voltage across the thyristor 'V_T' is zero. and current "I_o" first is rises to maximum value and then begins to fall.

→ In such state of SCR, the capacitor will charge and voltage across the capacitor reaches peak of supply input. Such time the inductor releases its stored energy and opposes the further flow of current.

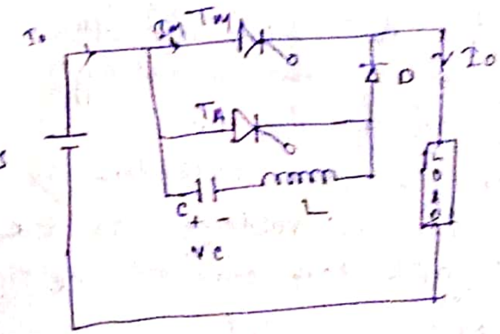
→ A time will reach when the current becomes zero then SCR automatically turn-off.

→ At this instant, now the capacitor starts to discharge, and as the SCR gets turned-off so the drop across the SCR will start increasing.



wave form for load commutation

Class Ⓑ Commutation



→ It's also called resonant-pulse commutation or current commutation.

Assumption:

→ Load current is assumed to remain constant I_o. (i.e load is highly inductive).

→ Capacitor is initially charged with V_S volts as shown in above figure.

→ ~~Before~~ At $t = 0$ sec, Tm is in ON state and $I_M = I_o$

In the above ckt,

Tm = main thyristor

T_A = ~~auxiliary~~ Auxiliary thyristor

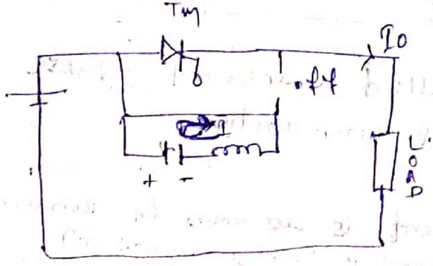
D = Diode

step-1

Initially thyristor Tm and Ta are in off state and capacitor c is charged to voltage Vs with left hand plate positive as shown in fig.

→ Now, at $t=0$ the main thyristor is turned on. Load current is equal to I_0 starts to flowing through the main thyristor TM and Load.

→ Now we want to turn off the thyristor, we fire the auxiliary thyristor 'TA' at $t = t_m$. Till the $t = t_m$, the capacitor is charged with source voltage Vs i.e $V_c = V_s$, ~~[illegible]~~ capacitor current $i_c = 0$



→ Now the capacitor discharges in the manner shown in above fig.

→ The discharge current of capacitor

$$\boxed{I_c = -I_p \sin \omega_0 t}$$

I_c = instantaneous value of discharge current

I_p = peak current

($V_c = V_s$, $i_c > 0$) capacitor discharge then inductor charge. capacitor discharge, then inductor discharge, capacitor charge and polarity change

→ when discharge current decays to zero, the capacitor voltage reverses its polarity.

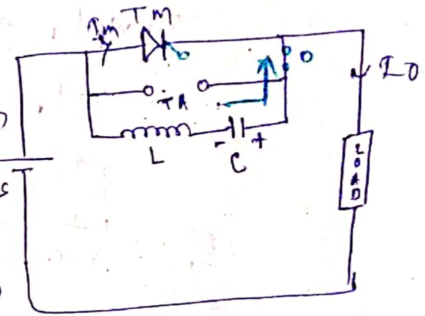
→ capacitor voltage is cosine when I_c is sine function.

$$\boxed{V_c = V_s \cos \omega_0 t}$$

→ At end of step 1, capacitor polarity, reverse and TA turns off.

step-2

In step-2 TA turn off and Diode D turns on.



→ capacitor polarity has reversed. so when TA turns off. capacitor voltage applied a forward bias across the diode, so the diode turns on

→ Now the capacitor current increase from zero to I_0.

Applying KCL

$$\boxed{I_m + I_c = I_0}$$

→ Here the load current I_0 is constant and capacitor current increase slowly.

→ sum of capacitor current and main thyristor current is constant. so as capacitor current increases, I_m decreases.

→ Here the capacitor current is continuously increase by the presence of inductor.

→ when the capacitor current reaches I_0. then I_m becomes zero and main thyristor is turned off.

calculate the total time taken by TM to turn off :

Let time taken by capacitor current to reach I_0 after t_0 time be t_1.

TM is off when $I_c = I_0$

$$I_p \sin \omega_0 t_1 = I_0 \quad \left(\because I_c = I_p \sin \omega_0 t\right)$$

$$\left(I_p = V\sqrt{\frac{C}{L}}\right)$$

$$\left(\omega_0 = \frac{1}{\sqrt{LC}}\right) \to \text{resonant angular frequency}$$

$$\sin \omega_0 t_1 = \frac{I_0}{I_p}$$

$$\omega_0 t_1 = \sin^{-1}\left(\frac{I_0}{I_p}\right)$$

$$\boxed{t_1 = \frac{1}{\omega} \cdot \sin^{-1}\left(\frac{I_0}{I_p}\right)}$$

$$t_1 = \frac{1}{1/\sqrt{LC}} \cdot \sin^{-1}\left(\frac{I_0}{I_p}\right)$$

$$\boxed{t_1 = \sqrt{LC}\, \sin^{-1}\left(\frac{I_0}{I_p}\right)}$$

t_1 is the time taken by Tm to switch-off after t_0 sec.

So, total time taken by Tm turn off from instant TA is turn on at t=0

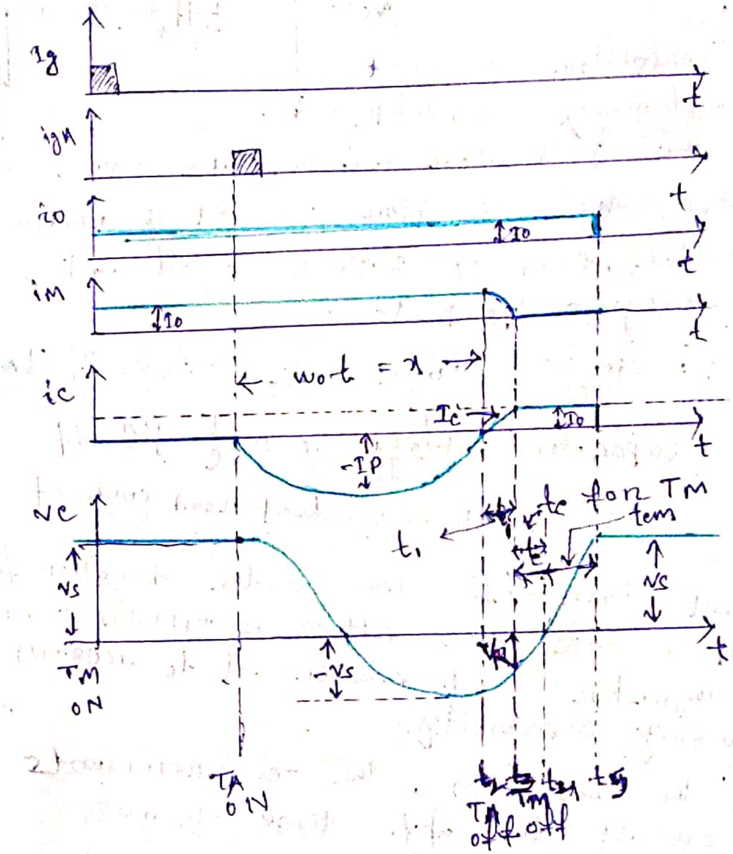
$$= t_0 + t_1 = \pi\sqrt{LC} + \sqrt{LC}\, \sin^{-1}\left(\frac{I_0}{I_p}\right)$$

$$\boxed{\because \text{Total time taken by Tm to turn off} = \pi\sqrt{LC} + \sqrt{LC}\, \sin^{-1}\left(\frac{I_0}{I_p}\right)}$$

Conduction time of auxiliary thyristor

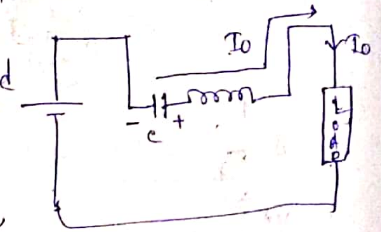
$$\boxed{T_A = t_0 = \pi\sqrt{LC}}$$

$$\frac{\pi}{\omega}$$



step-3

Tm is turned-off but we need to maintain reverse voltage across ~~to~~ it to enable blocking capability. This reverse biase voltage is maintained in step 3.



- when $I_C = I_0$, Tm is turned-off.
- Now capacitor current I_C remains constant, till the capacitor changes to $+V_S$.
- Now the capacitor current is no longer sinusoidal, load is suppressing it and maintaining constant I_0.

To find circuit turn-off time of Tm:

capacitor voltage $V_C = \frac{1}{C}\int I_0 \, dt$

$I_0 \Rightarrow$ constant load current

- circuit turn off time is the duration for which reverse bias voltage is applied across the thyristor, to enable it to regain blocking capability.
- In the waveform, the tcm represents the circuit turn off time of main thyristor Tm.
- In the waveform, the value of reverse voltage which appears across the Tm, when it gets turned-off is V_R.

Now putting the value in the expression for capacitor voltage.

$$V_C = V_R = \frac{1}{C}\int I_0 \, dt$$

$$V_R = \frac{I_0}{C} \cdot t_{cm}$$

$$\boxed{t_{cm} = \frac{V_R \cdot C}{I_0}}$$

→ finding the value of V_{ab}

→ capacitor voltage is a cosine function,

→ V_R is capacitor voltage at time t_1,

$$V_R = V_C$$

$$= V_S \cos \omega_0 t_1$$

$$\boxed{V_R = V_S \cos\left\{\sin^{-1}\left(\frac{I_0}{I_P}\right)\right\}}$$

$$\left[\because \omega_0 t_1 = \sin^{-1}\left(\frac{I_0}{I_P}\right), \quad I_P = V_S\sqrt{\frac{C}{L}}\right]$$

$$\boxed{t_{cm} = V_R \frac{C}{I_0}}$$

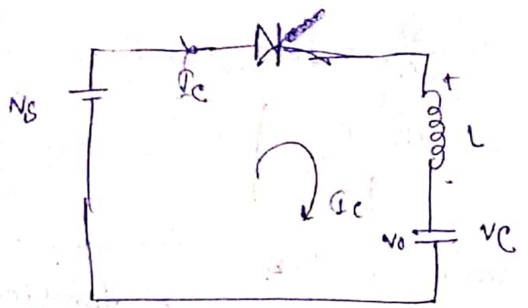
$$\boxed{V_R = V_S \cos\left(\sin^{-1}\frac{I_0}{I_P}\right)}$$

$$\boxed{I_P = V_S\sqrt{\frac{C}{L}}} \qquad \boxed{\omega_0 t_1 = \sin^{-1}\frac{I_0}{I_P}}$$

* another part

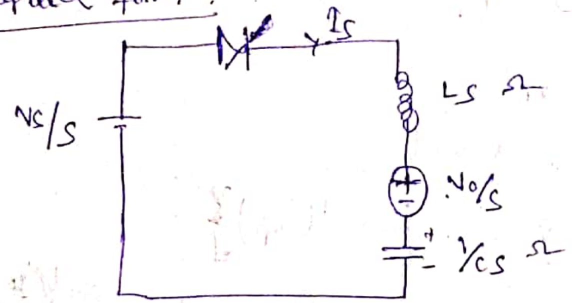
How to find I_c and V_c in RLC with Diode ckt.

①



V_0 - initial voltage of capacitor

Laplace form :-



$$\frac{V_s}{s} - I_s L_s - V_0/s - I_s/C_s = 0$$

$$\int_0^{\infty} x(t) \cdot e^{-st}\, dt$$

$$\frac{V_s}{s} - \frac{V_0}{s} = I_s L_s + I_s \frac{1}{Cs}$$

$$\frac{V_s - V_0}{s} = I_s\left(L_s + \frac{1}{Cs}\right)$$

$$I_s = \frac{V_s - V_0}{\cancel{s}} \times \frac{C\cancel{s}}{Ls \cdot Cs + 1}$$

$$I(s) = \frac{C(V_s - V_0)}{CLs^2 + 1}$$

$$I(s) = \frac{\cancel{C}(V_s - V_0)}{L\cancel{C}\left(s^2 + \frac{1}{LC}\right)}$$

$$\boxed{I(s) = \frac{V_s - V_0}{L\left(s^2 + \frac{1}{LC}\right)}}$$

$$\frac{V_s - V_0}{L} \cdot \left(\frac{1}{s^2 + \frac{1}{LC}}\right) = I_s$$

$$\frac{V_s - V_0}{L}\left(\frac{1}{s^2 + \left(\frac{1}{\sqrt{LC}}\right)^2}\right) = I_s$$

$$\Rightarrow \frac{V_s - V_0}{L}\left[\frac{\frac{1}{\sqrt{LC}}}{\frac{1}{\sqrt{LC}}\left(s^2 + \left(\frac{1}{\sqrt{LC}}\right)^2\right)}\right] = I_s$$

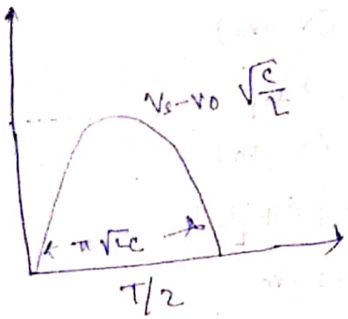
$$\Rightarrow \frac{V_s - V_0}{L}\left(\frac{\sqrt{LC} \times \frac{1}{\sqrt{LC}}}{s^2 + \left(\frac{1}{\sqrt{LC}}\right)^2}\right) = I_s$$

$$\Rightarrow V_s - V_0 \times \sqrt{\frac{C}{L}}\,(\sin w_0 t) = I_s$$

$$\boxed{L(\sin w_0 t) = \frac{w_0}{s^2 + w_0^2}}$$

$$\boxed{w_0 = \frac{1}{\sqrt{LC}}}$$

$$\boxed{I_s = I_c = V_s - V_o \left(\sqrt{\frac{C}{L}} \times \sin w_o t \right)}$$



$$T = \frac{2\pi}{w_o}$$

$$T = 2\pi\sqrt{LC}$$

$$T/2 = \pi\sqrt{LC}$$

$$V_c = \frac{1}{C} \int I(t)\, dt$$

$$= \frac{1}{c} \int \left(I_p \sin\left(\frac{1}{\sqrt{LC}}\right) t \right) dt$$

$$\boxed{I_p = (V_s - V_o)\sqrt{\frac{C}{L}}}$$

$$= \frac{I_p}{c} \left(-\sqrt{LC} \cos \frac{1}{\sqrt{LC}} t \right)$$

$$= \frac{I_p}{C} (-\sqrt{LC}) \cos \frac{1}{\sqrt{LC}} t$$

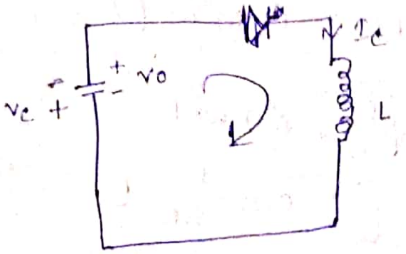
$$= \frac{V_s - V_o}{\cancel{C}} \sqrt{\frac{\cancel{C}}{L}} \left(-\cancel{\sqrt{LC}} \right) \cos \frac{1}{\sqrt{LC}} t$$

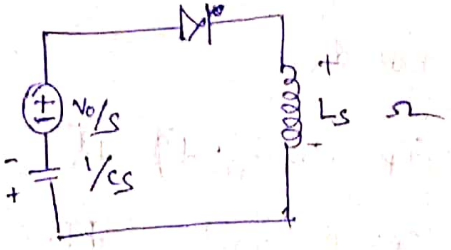
$$= -(V_s - V_o) \cos \frac{1}{\sqrt{LC}}$$

$$= V_s - V_o \left(-\cos \frac{1}{\sqrt{LC}} t \right) + C$$

$$\boxed{\begin{gathered} V_c = -(V_s - V_o) \cos w_o t \\ I_c = V_s - V_o \left(\sqrt{\frac{C}{L}} \times \sin w_o t \right) \end{gathered}}$$

②





$$\frac{V_o}{s} - I_s(Ls) - I_s/Cs = 0$$

$$\frac{V_o}{s} = I_s \left(Ls + \frac{1}{Cs} \right)$$

$$\frac{V_o}{\cancel{s}} \times \frac{C\cancel{s}}{LCs^2 + 1} = I_s$$

$$I_s = \frac{V_o C}{LCs^2 + 1}$$

$$I_s = \frac{V_o \cancel{C}}{L\cancel{C}\left(s^2 + \frac{1}{LC}\right)}$$

$$I_s = \frac{V_o}{L} \left(\frac{1}{s^2 + \frac{1}{LC}} \right)$$

$$= \frac{V_0}{L}\left(\frac{\frac{1}{\sqrt{LC}} \times \sqrt{LC}}{s^2+\left(\frac{1}{\sqrt{LC}}\right)^2}\right)$$

$$= \frac{V_0}{L}\sqrt{LC}\ (\sin w_0 t)$$

$$V_0\sqrt{\frac{C}{L}}\ \sin w_0 t$$

$$I_s = \underbrace{V_0\sqrt{\frac{C}{L}}}_{I_P}\ \sin \frac{1}{\sqrt{LC}}\ t$$

$$V_C = \frac{1}{C}\int I(t)\, dt$$

$$= \frac{1}{C}\int\left[I_P \sin\left(\frac{1}{\sqrt{LC}}\right)t\right] dt$$

$$= \frac{1}{C} I_P \int \sin\frac{1}{\sqrt{LC}}\ t\, dt$$

$$= \frac{I_P}{C} - \sqrt{LC}\cos\frac{1}{\sqrt{LC}}\ t$$

$$= \frac{I_P}{C} - \sqrt{LC}\cos\frac{1}{\sqrt{LC}}\ t$$

$$= -\frac{V_0}{\cancel{C}}\sqrt{\frac{\cancel{C}}{\cancel{L}}} \times \cancel{\sqrt{LC}}\ \cos\frac{1}{\sqrt{LC}}\ t$$

$$V_C = -V_0\cos\frac{1}{\sqrt{LC}}\ t$$

$$\boxed{\begin{aligned} I_C = I_s &= V_0\sqrt{\frac{C}{L}}\ \sin w_0 t \\ V_C &= -V_0 \cos w_0 t \end{aligned}}$$

Class F commutation :-

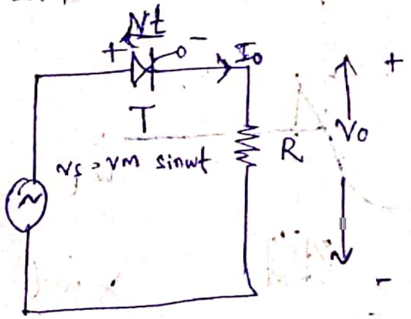
- It is also known as natural commutation or line commutation. because the SCR is turned off automatically during negative cycle of alternating supply.

- There are no commutating components used in this method therefore it is not called as forced commutation method.

- The time duration for the negative half cycle must be greater than the SCR specified turned off time.

- This method is applicable only for alternating supply.

- **Application :-** This method is used in the line commutator rectifiers, inverters and cyclo - converters.

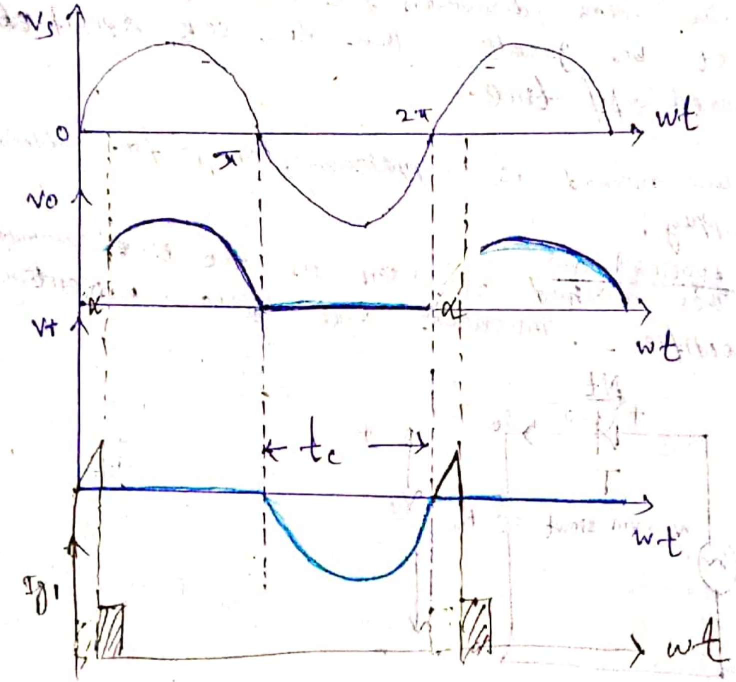


- When supply is ac, then anode current through the thyristor automatically pass through zero at the end of every positive half cycle i.e at wt = π such time of +ve half cycle the thyristor will conduct and the voltage across the thyristor Vt = 0.

- when it is -ve half cycle $v_s = -v_t$.

- So anode current becomes zero after positive half cycle ;

- The supply voltage also applies a reverse bias voltage across the SCR in the negative half cycle. This reverse bias ensures that SCR regains its blocking capability.

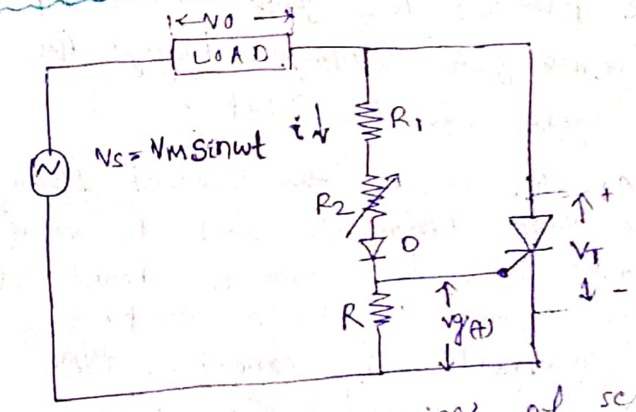


SCR Firing circuits :-

Some of the various triggering method is used to turn on the SCR, gate triggering is the most efficient and reliable method. Instant of SCR turning on is possible with gate triggering method. Some of various firing circuits of SCR.

- Resistance firing ckt.
- R-C firing ckt.
- UJT Pulse trigger ckt. or firing ckt.

Resistance Firing Circuit :-



- The Resistance triggering of SCR where it is employed to drive the load from the input AC supply.
- Resistance and diode combination ckt acts as a gate control ckt. to switch the SCR in the desired condition.
- As the +ve voltage applied, the SCR is forward biased and does not conduct until its gate current is more than minimum gate current of the SCR.

- when the gate current is applied, by varying the resistance R_2 such that the gate current should be more than the minimum value of gate current, the SCR is turned ON. AND the load current starts to flowing through the SCR.

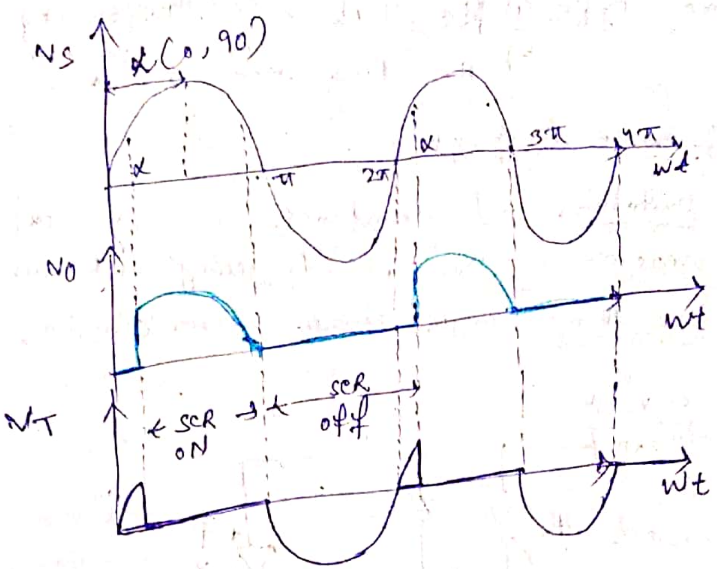
- ~~when the gate current is applied~~ The SCR remains ON until the anode current is equal to the holding current of the SCR. And it will switch off when the voltage applied is zero. So the load current is zero as the SCR acts as open switch.

- The diode protects the gate drive ckt from reverse gate voltage during the -ve half cycle of the input.

- And resistance R_1 limits the current flowing through the gate terminal and its value is such that the gate current should not exceed the maximum gate current.

- It is the simplest and economical type triggering but limited for few application due its disadvantages.

- In this, the triggering angle is limited to 90 degrees only, because the applied voltage is maximum at 90 degrees so the gate current has to reach minimum gate current value somewhere between zero to 90 degrees.



$$v_{g(t)} = \frac{R \cdot x\,(V_m \sin \omega t)}{R_1 + R_2 + R}$$

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

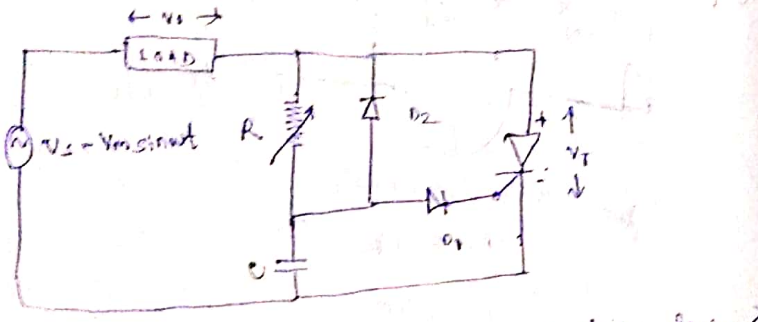
→ If R is more, α is high
→ if R is less, α is low
→ Range of α (firing angle) is in between 0 to 90°.

Rc firing circuit :-

It is two type ① Rc Half-wave triggen ckt
② " Full-wave " "

① Rc Half wave firing ckt :-

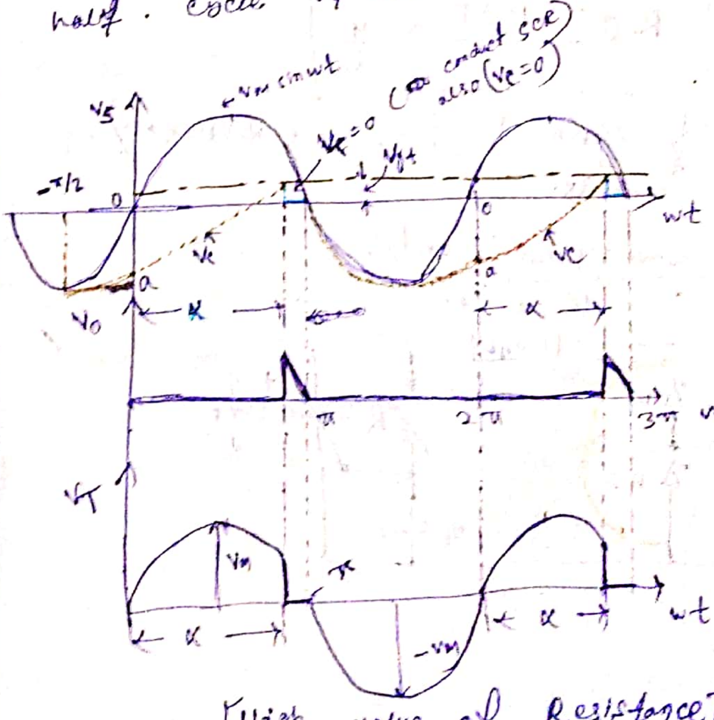
- The limitation of resistance firing ckt can be overcome by the Rc triggering ckt which provides the firing angle control from 0 to 180°,



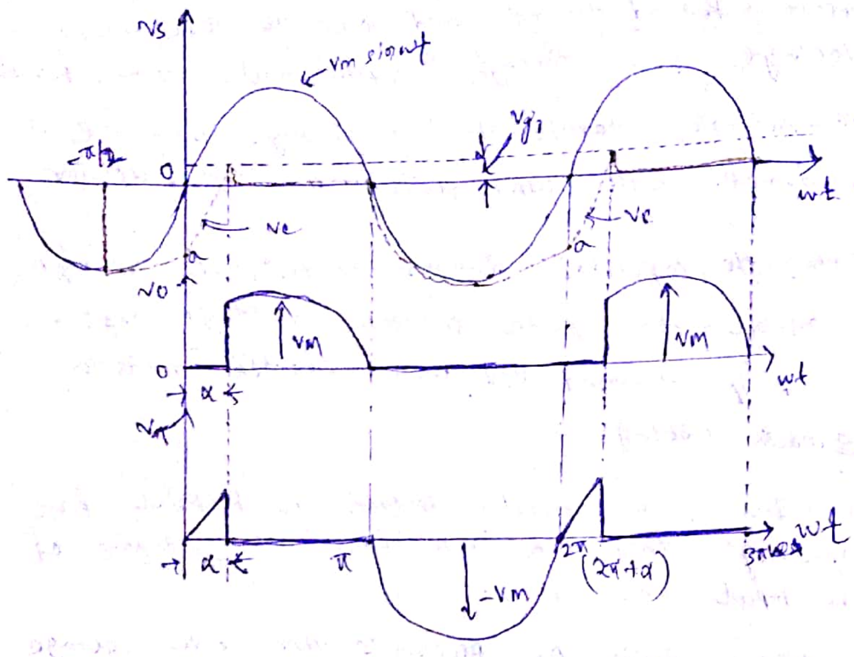
- In Rc ckt by varying the value of R, firing angle can be controlled from 0 to 180°. In the negative half cycle, capacitor C changes through D2 with lower plate positive to the peak supply voltage Vm at wt = -90°. After wt = -90°, sources voltage Vs decrease from -Vm at wt = -90° to zero at wt = 0°
- During this period the capacitor voltage Vc may fall from -Vm at wt = -90° to some lower value -oa at wt = 0°.

$V_C \simeq -V_m$

- During positive half cycle of the input, the scr becomes forward biased and Now the SCR anode voltage passes through zero and becomes positive
- The capacitor starts changing through variable resistance with upper plate positive, ~~to dee~~
- When the capacitor changes to positive voltage equal to gate triggen voltage Vgt. SCR is turned ON and capacitor holds a small voltage.
- Therefore the capacitor voltage is helpful for triggering the SCR even after 90° degrees of the input wave form.
- In this, diode D1 prevents the -ve voltage between the gate and cathode during the -ve half cycle of the input through diode D2.



[High value of Resistance]

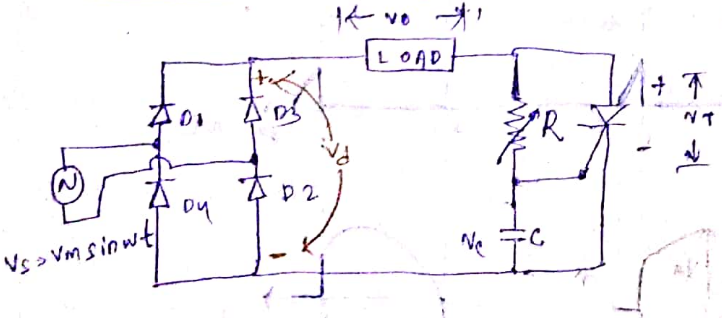


Low value of Resistance

$$\boxed{RC \geq \frac{1 \cdot 3T}{2} \cong \frac{4}{\omega}}$$

$T = \frac{1}{f}$ = period of ac line frequency in seconds.

③ RC full wave firing ckt:



- Here the AC voltage is converted in pulsating DC. by the full wave diode bridge. This allow the SCR to triggered "on" for both half cycle the line voltage, which doubles the available power to the load.

- Here Diode D_1–D_4 form a full wave diode bridge.

- In this ckt, the initial voltage from which capacitor "c" changes is almost zero. The capacitor c is set to this low positive voltage (upper plate positive) by the clamping action of SCR gates.

- when the capacitor changes to Vgt, SCR triggers on and rectified voltage Vd appears across Load as Vo.

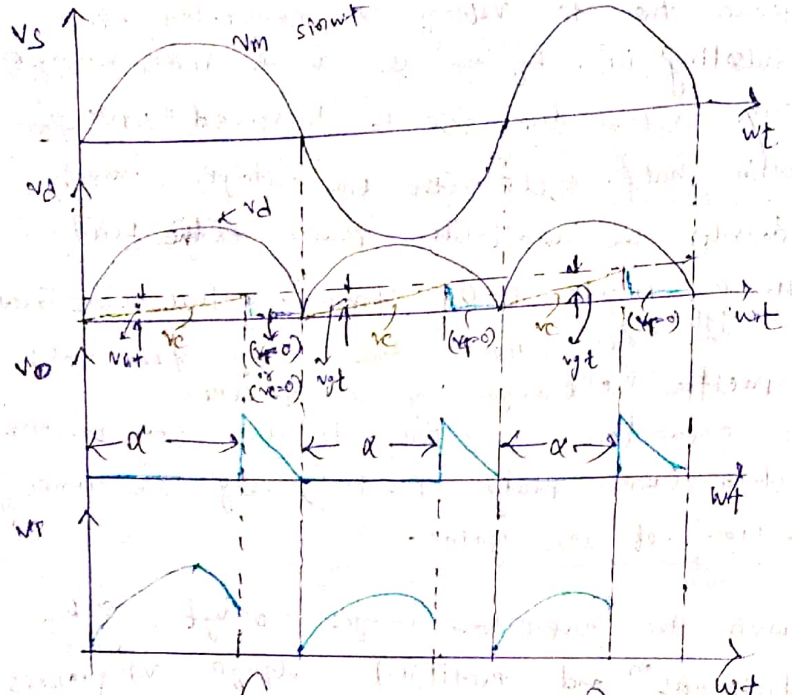
- The value of RC calculated from following relation $RC \geq 50\frac{T}{2} = \frac{157}{\omega}$

$(T = \frac{1}{f})$

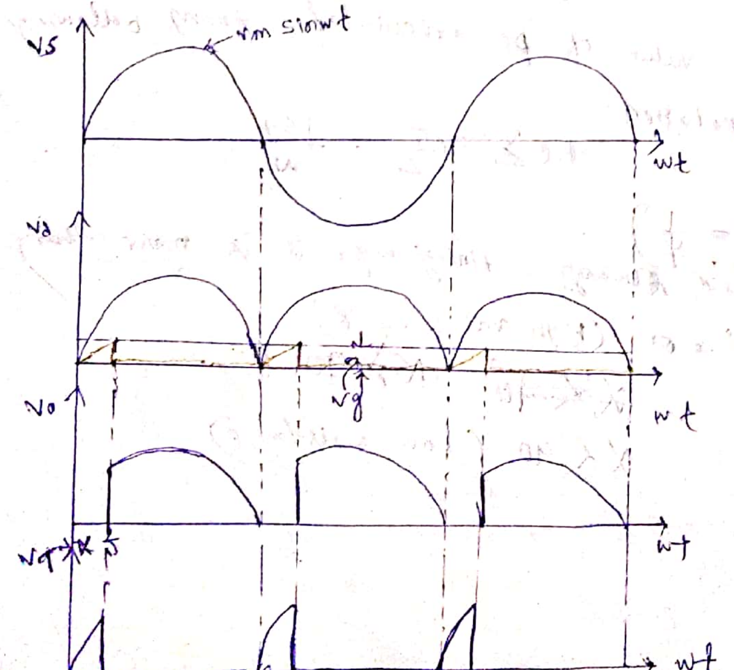
- Here ~~always~~ Firing angle α is more than 90° (high value of R) (α > 90°)

~~α < 90~~

α < 90 (Low resistance)



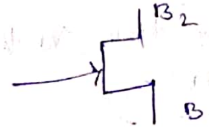
(High value of R)

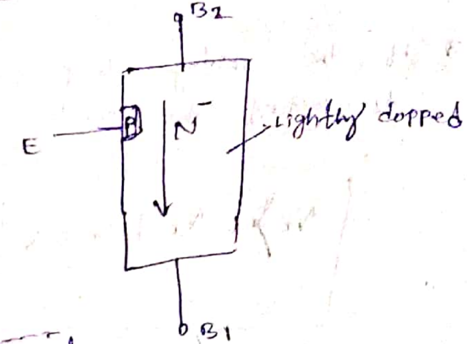


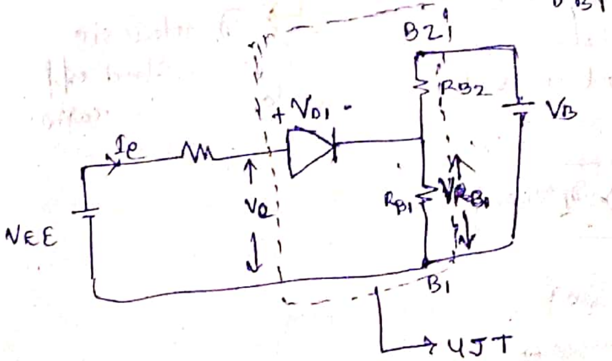
(Low value of R)

UJT :

Uni Junction transistor







RB1 → is the resistance between E - B1 Junction

RB2 → is the resistance between E - B2 Junction

$$V_{RB1} = V_{BB}\left(\frac{R_{B1}}{R_{B1}+R_{B2}}\right)$$

$$\left(V_e > V_{BB} \times \frac{R_{B1}}{R_{B1}+R_{B2}}\right) \rightarrow \text{in ideal case}$$

↓

Then it conduct (UJT)

- To conduct the diode. Ve should be greater than V_{RB1}.

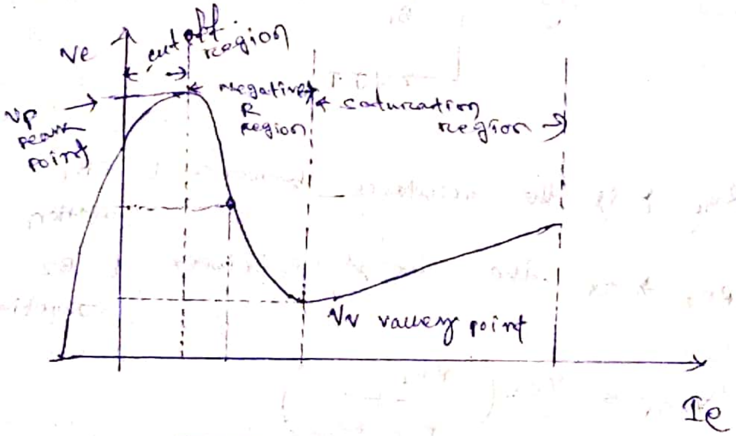
- If the voltage drop across the diode Vd then to conduct the diode $V_e > V_{RB1}$.

$$\boxed{V_E > V_d + V_{BB} \times \underbrace{\left(\frac{R_{B1}}{R_{B1}+R_{B2}}\right)}_{\eta}}$$

not in ideal

η intrinsic stand off ratio. eta

$$\boxed{V_e > \eta V_{BB}}$$



$$\boxed{V_P = \eta V_{BB} + V_d}$$

- In the cutt off zone current through the diode is -ve and after Ie = 0, current is +ve and voltage "Ve" will gradually increase upto the peak point.

i.) $\eta = \dfrac{R_{B1}}{R_{B1}+R_{B2}}$

as the diode gets forward biased, the voltage across it will be 0.7 V. So, this is constant and V_{B1} goes on decreasing. Hence VE goes on decreasing. It decrease at least value which may be denoted Vv called valley voltage.

- In the -ve resistance zone. as Ie will increase the voltage "Ve" will reduce because of R_{B1} will decrease.

$R = R_0 (1 + \alpha t)$

$\alpha \uparrow \; R \downarrow$ [α will be -ve]

- The voltage "Ve" will decrease upto valley voltage "Vv" after that the UJT will enter into saturation zone.

where it behaves like a diode as the emmiter current will increase voltage "Ve" also increase in the saturation zone.

$\uparrow V_e = V_e \uparrow$ [Ve also increase upto VBB But do not reach VBB upto η VBB.]

Application of UJT :-

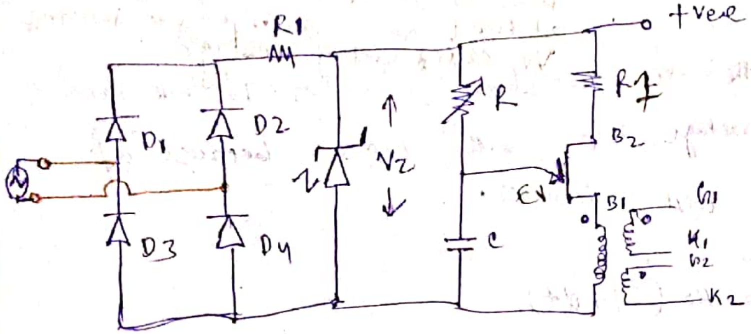
Its application as relaxation oscillator.

$$V_c = V_F + (V_{(i)} - V_{(F)})\, e^{-\frac{t}{\tau}}$$

$V_v = V_i$ = initial voltage of capacitor

$V_{BB} = V_F$ = Final voltage of the capacitor

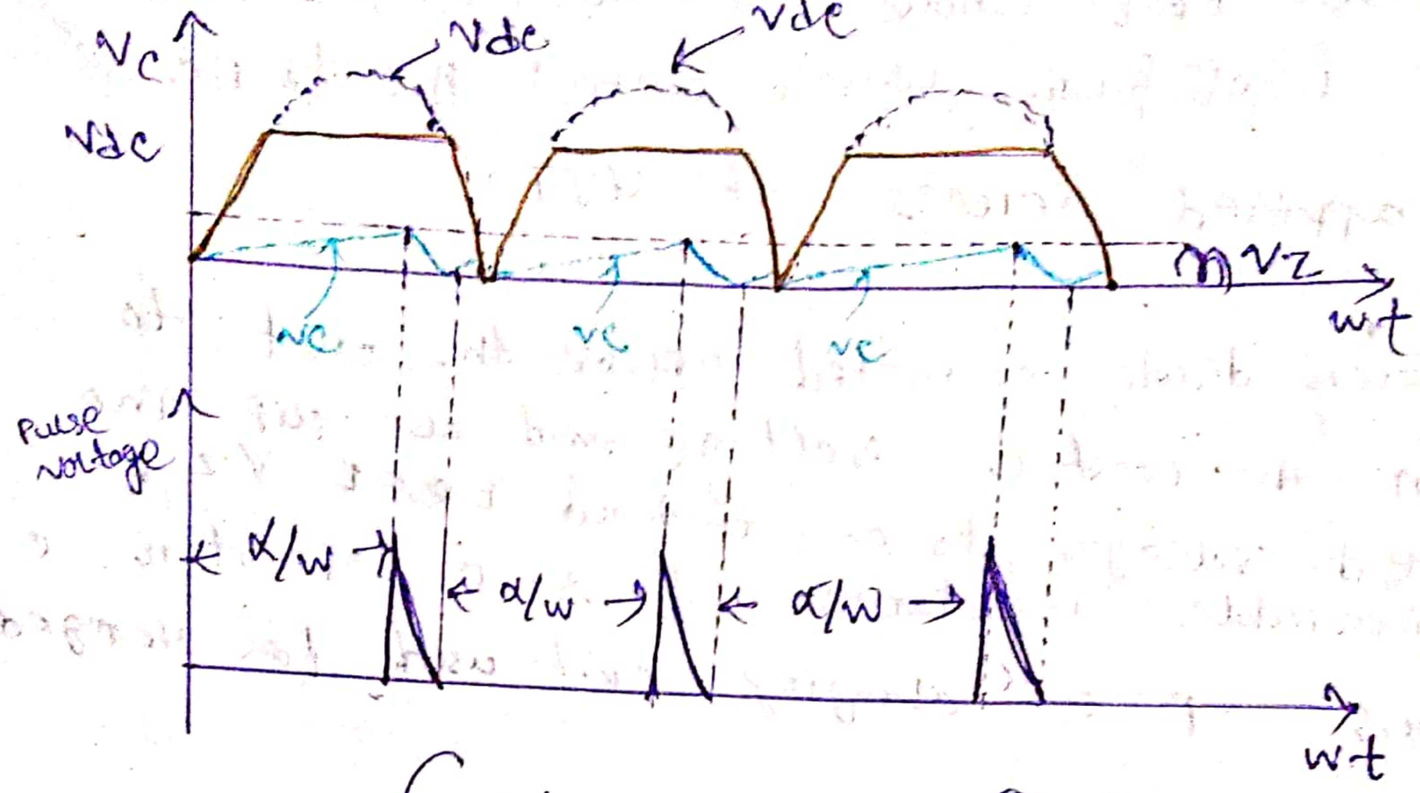
UJT triggering ckt :- or synchronized UJT triggering ckt



EB2 = Forward biased
EB1 = Reverse biased

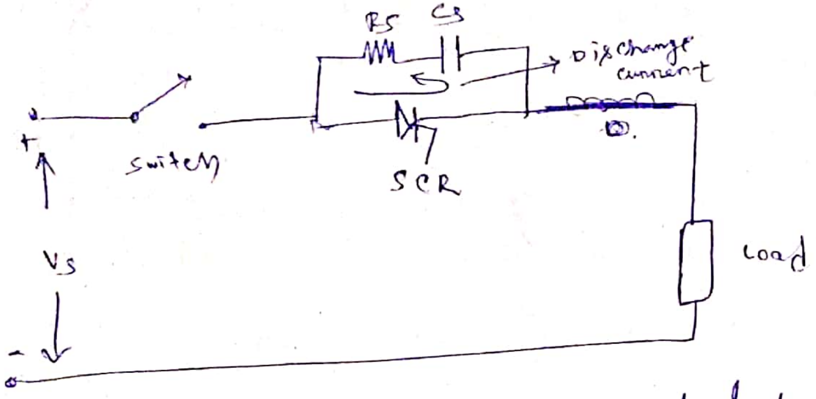
* The unijunction transistor UJT have 3 terminal device i.e Emitter, Base 1 & Base 2.
* It consist of lightly doped N layer as base and 2 heavily dopped P-type inside it.
* The leads are welded to the 3 layers. so there are 2 Junction form i.e EB1 & EB2 Junction.
* This 2 Junctions are acts 2 resistance i.e RB1 & RB2.
* The emitter leads is placed nearer to the B2 leads so EB2 Junction is forward biased as the B1 leads is away from 'E'. so EB1 Junction is Reverse biase.
* If EB1 Junction is break the conduction start through UJT.

* The above ckt shows 4 diode (D1, D2, D3, D4) acts as rectifier which convert A.C to DC & VDC applied across the UJT.
* A zener diode connected across the ckt to maintain the constant voltage and also clip the rectified voltage to a standard level Vz.
* A variable resistance 'R' & a capacitor C acts as R-C changing ckt used for charged the capacitor C.
* The variable resistance 'R' & capacitance 'C' acts as R-C changing ckt used for changed the capacitor 'C'.
* By variable resistance 'R' we control the firing angle α i.e if R value is high then capacitor takes more time to change and If R is low & hence α increase and vice versa.
* when the capacitor change reaches to 'Vc' which is acts between E & B1 result the breakdown of Junction.
* As a result current 'I2' flowing through R1 → B2 → E → B1 & the pulse transformer.
* The pulse transformer shows transmission in the secondary and voltage applied to the thyristor circuit.



(High resistance)

Snubber circuits :-



- It is circuit which is protect to the ckt.

- Snuber ckt consist of resistance Rs and capacitance Cs in parallel with the thyristor.

- To prevent the unwanted dv/dt triggering of SCR.

Working of Snuber ckt :-

Role of capacitor Cs :-

- when the switch S is closed, a sudden voltage appears across the circuit. capacitor does not allow the sudden change in voltage.

- Initially capacitor Cs behaves like a shorted path and hence the voltage across SCR is zero and also capacitor across is zero.

- But as time passes, voltage starts building up across capacitor C with a slow rate.

- Thus the rate of rise of voltage dv/dt across SCR terminals will also be slow and less than the specified dv/dt rating of SCR.

Role of resistance Rs :-

- Before SCR is triggered by gate pulse, the capacitor Cs is fully charged to supply voltage Vs.

- when SCR is turned on by gate pulse, this charged capacitor Cs discharges through SCR.

- Hence a current having magnitude Vs/Resistance flows of loop formed by SCR and capacitor Cs in the local path formed by SCR and capacitor C.

- Since the value of resistance of this local path is quite small.

- The magnitude of discharge current will be quite higher.

- This will lead to high value of di/dt which may exceed the specified di/dt rating of SCR.

- In order to limit the magnitude of the discharge current resistance should be connected in series with the capacitor.

* Selection of Rs, Cs and Load Parameters

Resistance R_s, capacitance C_s and load parameters are so chosen that the dv/dt during charging capacitor C is less than the specified dv/dt rating of SCR.

- The discharge current at the turn on of SCR is less than the specified di/dt rating.

- Normally Rs, Cs and load parameters forms an underdamped ckt so that dv/dt is limited to acceptable value as provided by the SCR rating.

Protection of SCR:-

- protection of a device is an important aspect for its reliable and efficient operation.
- SCR may face different type of fault during over voltage and over current.
- There are different type of thyristor ~~voltage~~ protection scheme available for operation given below

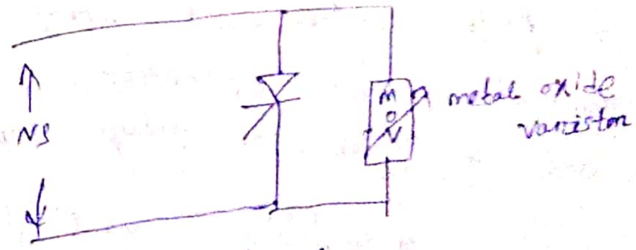
① over voltage protection
② over current "
③ High dv/dt "
④ High di/dt "
⑤ Thermal "
⑥ Gate protection

① over voltage protection:-

- The thyristor subjected to over voltage due to

① Load commutation (turn off)
② Short ckt condition. Clearing by ckt breaker,
③ Transient due to switching operation
④ Lightening stroke.

Clearing of over vatage:-



Non - linear resistor is varistor working
High resistance for low voltage
&
Low resistance for high voltage

(i) For protection of thyristor from over voltage a non-linear resistance (MOV- metal oxide varistor) connected parallel with thyristor to be protected.

(ii) This protective device have falling resistance characteristics with increase in voltage.

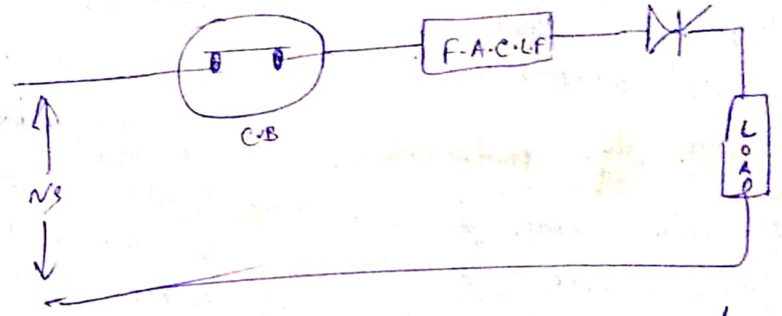
(iii) At normal operating condition MOV show high resistance, so load current slow through thyristor.

(iv) when over voltage condition arries at that time MOV offen low resistance which produce a short ckt across thyristor and high voltage surge dischange the MOV & protect the SCR from over voltage.

(v) generally MOV selenium thyristor diode are used for over voltage protection.
made up of ceramic mass of zinc oxide grains.

② over current protection:-

- The thyristor subiected to over current due to short ckt condition of any two lines, lightening stroke.
- Sudden increasing of loads
- line to ground faults.



F.A.C.L.F → First acting current limiting fuse.

- During over current a heavy current pass through thyristor
- As the junction have some resistance (J₁,J₂,J₃) across the device due to it produced heat for more time. If it circulate I^2Rt
- The temperature with standing capacity of SCR is very small if a high a temperature develop due to over current may damage device.

* So to Protect the SCR from over current a ckt breaker & FACLF are connecting in series with thyristor.

* The circuit breaker is used to protect the thyristor against continous over load for a long direction.

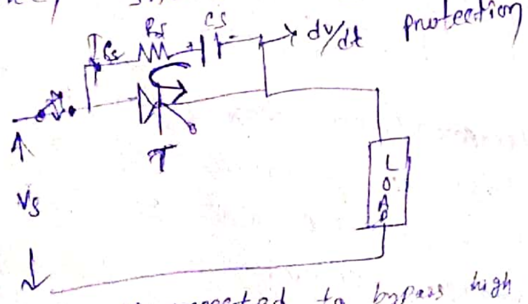
* The FACLF is used to Protect the thyristor from over current for short direction.

③ **High $\frac{dv}{dt}$ protection :-** (rate of change of voltage w.r.t time)

* when anode is +ve w.r.t cathode & no gate pulse is applied J2 behaves like a capacitor & the total source voltage Vs appears across "J2" Junction.

* Higher value of dv/dt may result into false turn ON of SCR.

* To Provide dv/dt protection we connect snubber ckt.



* capacitor is connected to bypass high dv/dt through SCR

* Result a changing current start flowing

If $\frac{dv}{dt}$ value is high, the Ic value is high which is able to turn on the SCR without giving any Gate Pulse.

* This is know as false operation of SCR which is called $\frac{dv}{dt}$ turn on.

* The Cs is parallel with device to prevent unwanted $\frac{dv}{dt}$ triggering, & Rs also connected in series with Cs to limit the changing current.

④ **High $\frac{di}{dt}$ protection :-**

* $\frac{di}{dt}$ is rate of change of current in device.

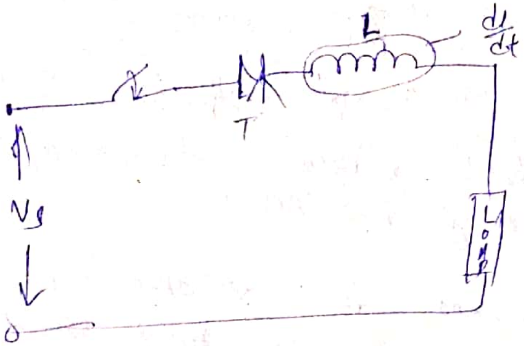
-* when SCR is in forward bias, and it is on by gate signal, there will be flow of anode current.

* The anode current requires some time to spread inside device.

* $\frac{di}{dt}$ > spread velocity of change. then it create hotspont in the J2 Junction and that may damage SCR.

* So, to maintain di/dt through SCR, we connected Inductor in series to the SCR.

$\frac{di}{dt}$ Protection



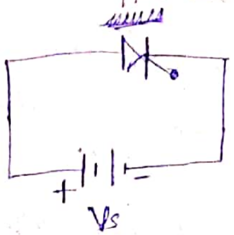
- voltage across inductor can be calculated by $V_s = L\frac{di}{dt}$

$$\Rightarrow L = \frac{V_s}{di/dt}$$

$$\boxed{L > \frac{V_s}{di/dt}}$$

(5) Thermal protection :-

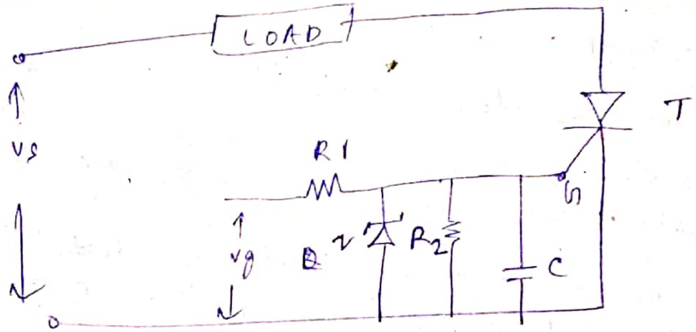
H.S (Heat sink)



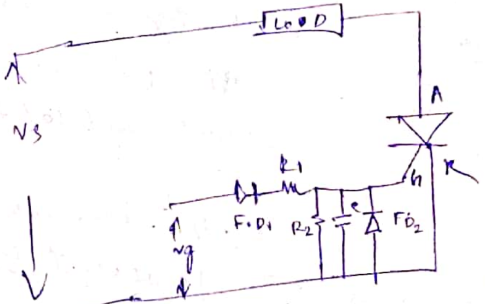
- when increase the leakage current near the Junction J_2, with the increase in the temperature of the Junction. insulation may get failed.
- So we have to take a proper measure to limit. the temperature rise.

- This can be achieve. this by mounting the thyristor on heat sink which is mainly made by high thermal conductivity metals like Aluminium (AL), copper (Cu) etc. mainly aluminium (Al) is used due to its low cost.

(6) Gate protection :-



or



F.D = free wheeling diode.

- For turn on the SCR by Gate ckt method we applied gate pulse between gate & cathode. So the necesity Gate pulse is given to Gate terminals in a control method.

- For giving Gate Pulse in control manner we used different ckt elements which are connected in the above diagram.

- In the standing of the ckt a free wheeling diode is connected in series with the supply for allow only +ve pulse.

- The R_1 connected series the diode which will limiting the current in safe value.

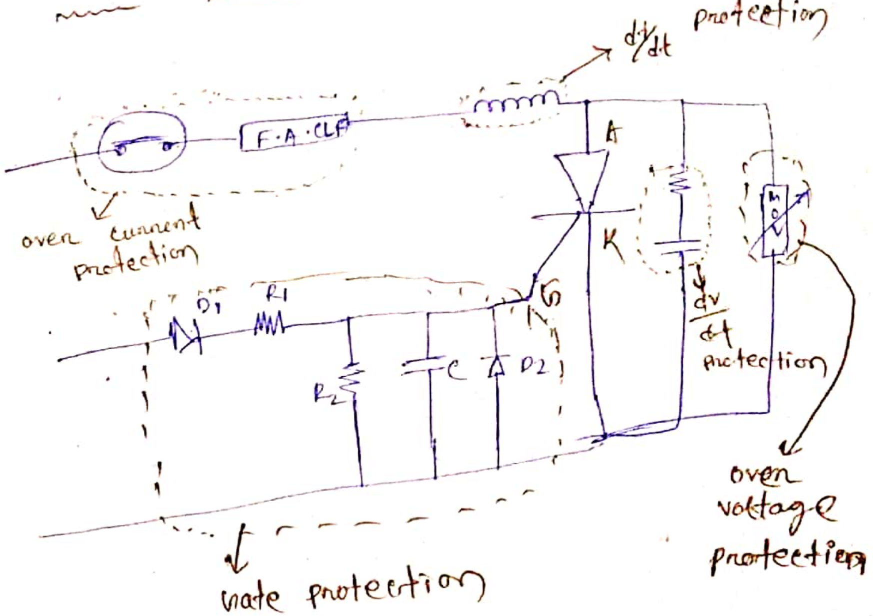
- Another resistance R2 connected parallel with Gate & cathode.

- For increasing $\frac{dv}{dt}$ capability of the SCR for reducing turn off time. And increasing the holding and latching current.

- capacitor 'c' removes high frequency component by connecting parallel which acts as filter ckt.

- The Diode FD2 avoids the flow of the -ve pulse from cathode to the gate.

Total Protection ckt of SCR:



2nd phase controlled CONVERTER :- / Rectifier :-

- The conversion of A.C to DC is know AS converter.

- For power ckt or power conversion ckt is form A.C to DC we use thyristor in place of Diode.

- There are two types of rectifier
  ① controlled rectifier
  ② un-controlled "

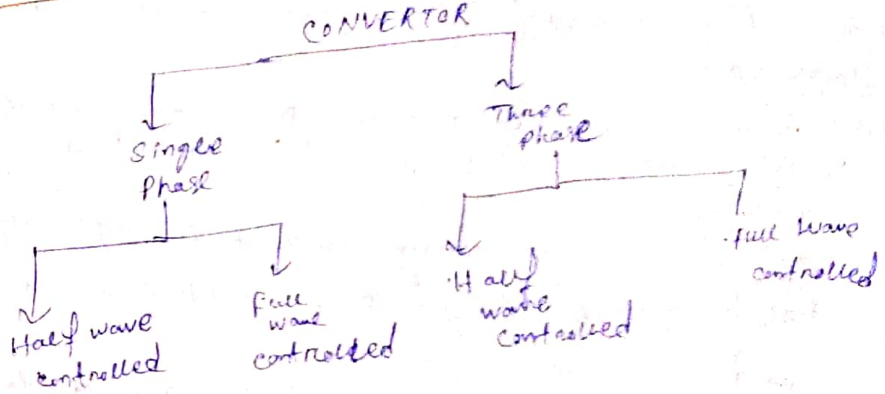
① **controlled rectifier :-**

- Rectifier ckt using thyristor known as control rectifier because thyristor is a control device.
- The o/p can be vary by varying the firing angle & hence o/p value of d.c also vary.
- since it is a control device. It is available in high current, high voltage, high power rating.
- It may be either 1Φ or 3Φ as I/P.
- It may be either semi convertor or fully converter having different quadrant operation.

(2) **un controlled rectifier :-**

- In case of un-controlled rectifier for rectification we used power Diode because the fixed value of A.C voltage converted into fixed value of D.C voltage.
- It is used increase of some low power device where control of o/p voltage is not required.
- It is low cost and simple ckt.

classification of converter :-



Application of converters!

(i) For High voltage D.C transmission.

(ii) speed control of DC motor.

(iii) It also used for battery charging,

(iv) magnetic power supply.

(v) Excitation control of alternator.

Working Principle of converter:

(i) A SCR can only conduct when anode voltage is +ve & cathode is -ve & Gate signal is applied.

(ii) The load current blocks upto it is not triggered.

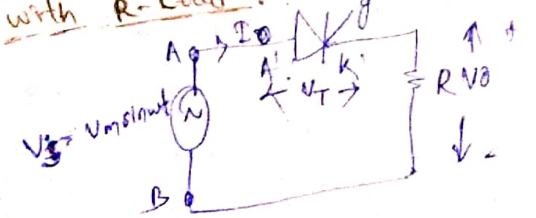
(iii) when we applied gate pulse with some delay angle / firing angle (α). it would start conducting,

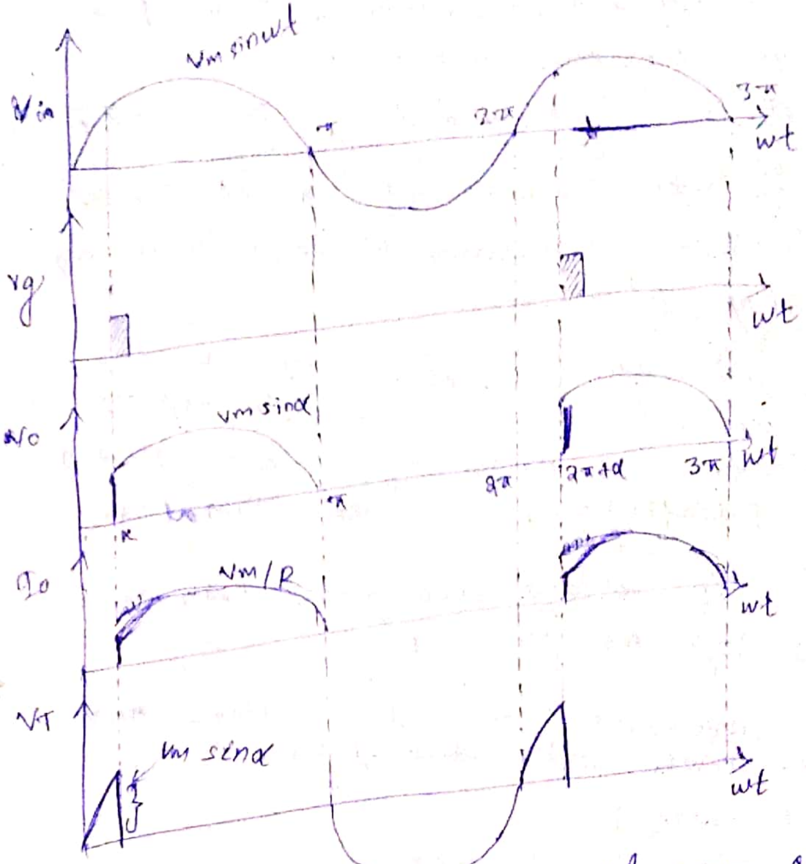
(iv) So a thyristor may conduct during +ve half cycle i.e α - π, 2π + α - 3π and so on.

(v) If thyristor is replaced by a diode then it conduct 0 - π, 2π - 3π & so on as it is uncontrolled device.

(vi) So by varying the firing angle α of thyristor which a varying trough o/p voltage as per requirement.

1ϕ Half wave control rectifier or converter with R-Load:





- The above ckt shows 1ϕ half wave converter with R. Load.
- The SCR is connected to a load resistance 'R' which is feed by a.c supply $V_s = V_m \sin \omega t$.
- So, the SCR is forward biased when the +ve half cycle appear across it i.e 0 - π and 2π - 3π and so on.
- During the half cycle A - point is +ve, B point is -ve & the thyristor is subjected to forward biased.

- So as soon as gate pulse is given with firing angle 'α' it start conducting and o/p voltage appear across the Load.
- So it is conduct upto $\alpha - \pi$ & $2\pi + \alpha - 3\pi$.
- when -ve cycle appears at π and 3π of SCR subjected to reverse biased conduction and hence it is off.
- And again able to trigger when +ve cycle of SCR seen across it so by the conduction of SCR and o/p seen eliminate -ve half cycle and o/p seen is pulsating dc or unidirectional a.c.
- The o/p voltage seen across Load is given by the $\boxed{V_0 = I_0 R}$
- The different current & voltages curve are shown in the above fig.

Average value:-

$$V_0 = \frac{1}{2\pi}\left[\int_0^{2\pi} V_m \sin\omega t \, d(\omega t)\right]$$

$$\begin{cases} V_m \sin\omega t & 0 < \alpha < \pi \\ 0 & \pi < 2\pi \end{cases}$$

$$= \frac{1}{2\pi} \int_\alpha^\pi V_m \sin\omega t \, d\omega t$$

$$= \frac{V_m}{2\pi}\left(-\cos\omega t\right)_\alpha^\pi$$

$$= \frac{V_m}{2\pi} - \left(\cos\pi - \cos\alpha\right)$$

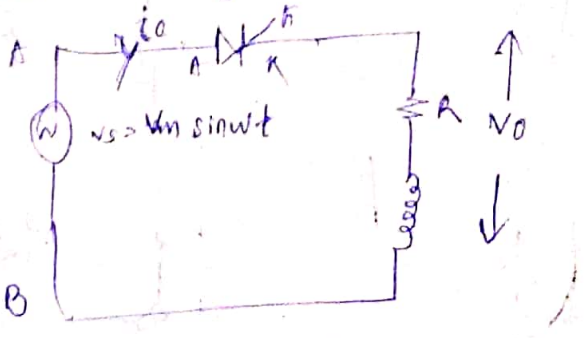
$$V_0 = \frac{V_m}{2\pi}\left(1 + \cos\alpha\right)$$

$$I_0 = \frac{V_0}{R} = \frac{V_m}{2\pi R}\left(1 + \cos\alpha\right)$$

$$V_{0\,r.m.s} = \frac{1}{2\pi}\sqrt{\int_\alpha^\pi V_m^2 \sin^2\omega t \, (d\omega t)}$$

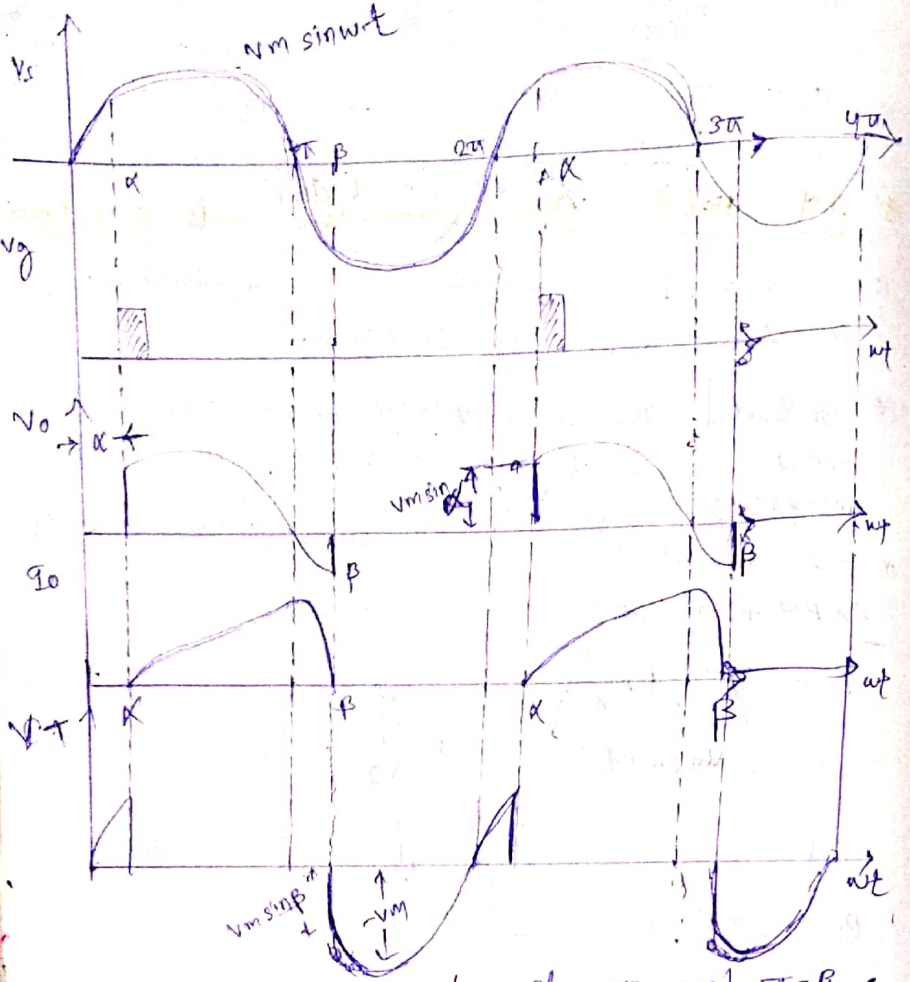
1ϕ Half wave converter with R-L Load:

- when Load have inductive then the resistance & inductance are fed by source.
- Inductor has a property which does not allow sudden changing of current i.e either increasing or decreasing.
- The current vary across inductor is according to exponentially.



operation:-

- The above ckt diagram show semi-converter or 1ϕ Half wave converter with R-L Load, so it is conduct only during +ve cycle.
- At angle "α" when gate pulse is given to SCR it start conducting & voltage across the load is same as the source voltage with R-L Load.



The SCR conducted upto π and π-β. Hence the load inductance L forces the load current to in gradually reaches maximum and then beings to decrease (inductor does not allow the sudden change of current), so even through the source voltage comes to zero and the current reduces to slowly to zero.

from α-π, 'i₀' and 'v₀' which is apearing Load from source and flowing through power flow from source is R +ve. hence to load.

From 'π-β', 'i₀' is +ve but V₀ is -ve. the power is hence -ve.

Hence the power is feed back to load to source this is called recycling.

The recycling is continous till the energy in the inductor given back to the source.

The average o/p voltage get reducess due to -ve signal.

If larger the inductance then larger the -ve area & hence lessen is the averagre o/p voltage & vice-versa.

When SCR is triggered due to V₀, i₀ starts flowing from ωt = α & gradually increases is reaches maximum.

And after 'π' it start decreasing upto 'β' known as extinction angle and lines the SCR conducts β − α = γ known as conduction angle.

α = Firing angle

β = extinction angle

Avg value of voltage :-

$$V_o = \frac{1}{2\pi}\int_{\alpha}^{\beta} V_m \sin \omega t \, d(\omega t)$$

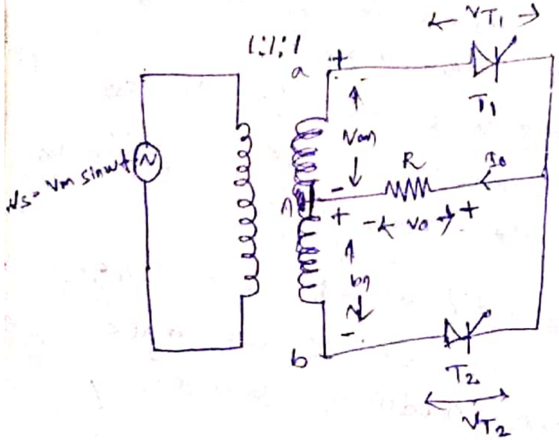
$$= \frac{V_m}{2\pi}\left(-\cos \omega t\right)_{\alpha}^{\beta}$$

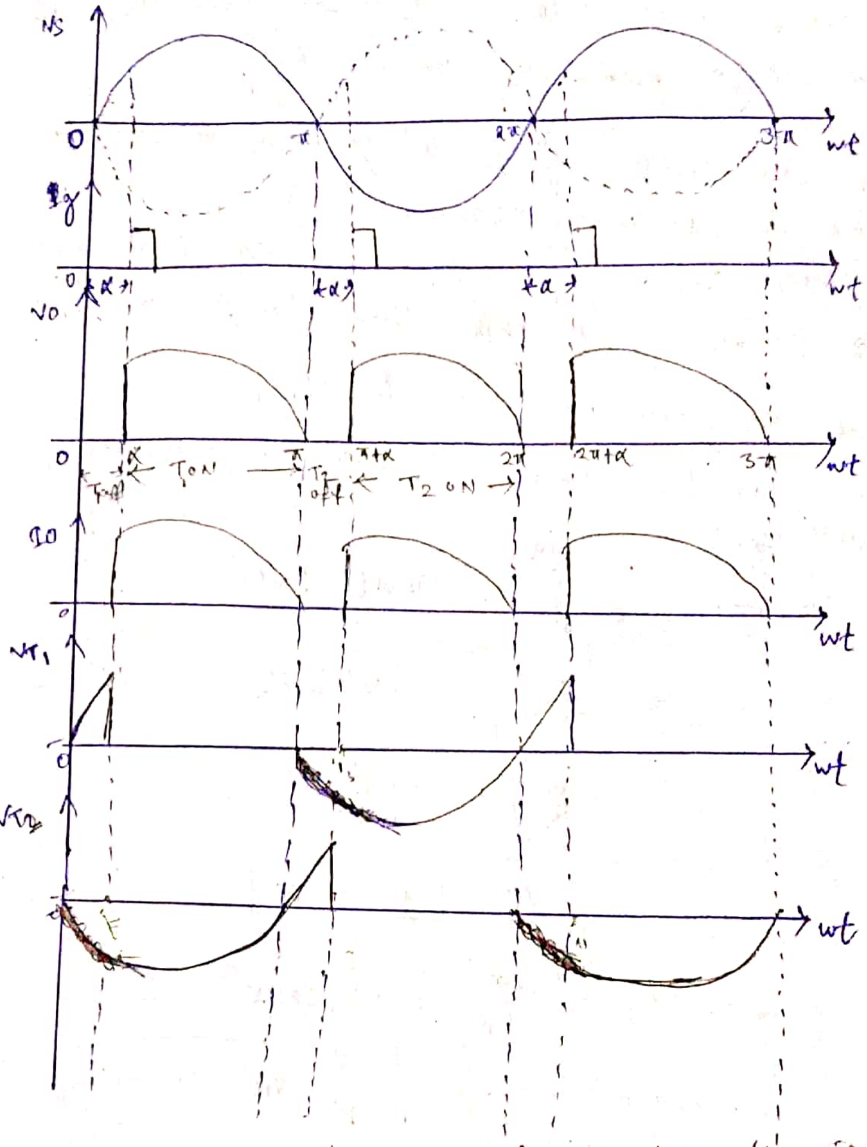
$$V_o = \frac{V_m}{2\pi}\left(\cos\alpha - \cos\beta\right)$$

$$I_o = \frac{V_m}{2\pi R}\left(\cos\alpha - \cos\beta\right)$$

$$V_{r.m.s} = \frac{1}{2\pi}\sqrt{\int_{\alpha}^{\beta} V_m^2 \sin^2\omega t \, d(\omega t)}$$

1-4 Full wave Midconverter with R-Load :-





→ A central tapped t/f and two thyristors are used in this converter.

→ In +ve half cycle 'a' is +ve w.r.t 'A' and terminal 'A' is +ve w.r.t 'b'.

→ when Vam is +ve, T1 is forward biased and T1 is on. At this time T2 is off.

In this case the thyristor is turn off by using natural commutation.

-> In -ve half cycle 'a' is -ve w.r.t 'n', and 'b' is +ve w.r.t 'n'

-> when Von is +ve., T2 is F.B and T2 is on. At this time T1 is off.

-> Here the turn ratio of t/f 1:1:1

-> For resistive load, current io is inphase with Vo.

$$V_{o\,avg} = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t\,(d\omega t)$$

$$= \frac{V_m}{\pi}\int_{\alpha}^{\pi} \sin\omega t\,(d\omega t)$$

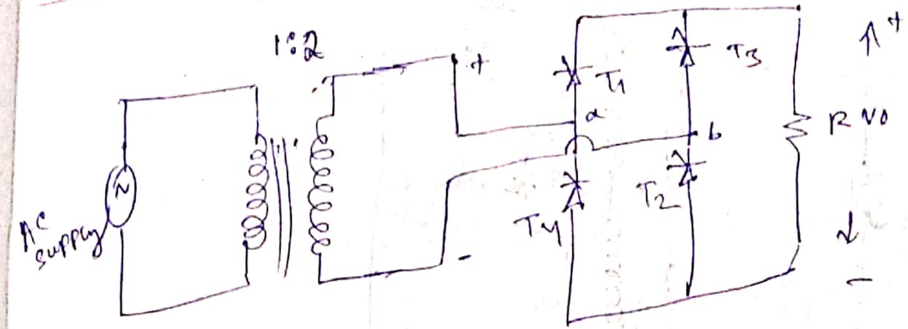
$$= \frac{V_m}{\pi}\Big[-\cos\omega t\Big]_{\alpha}^{\pi}$$

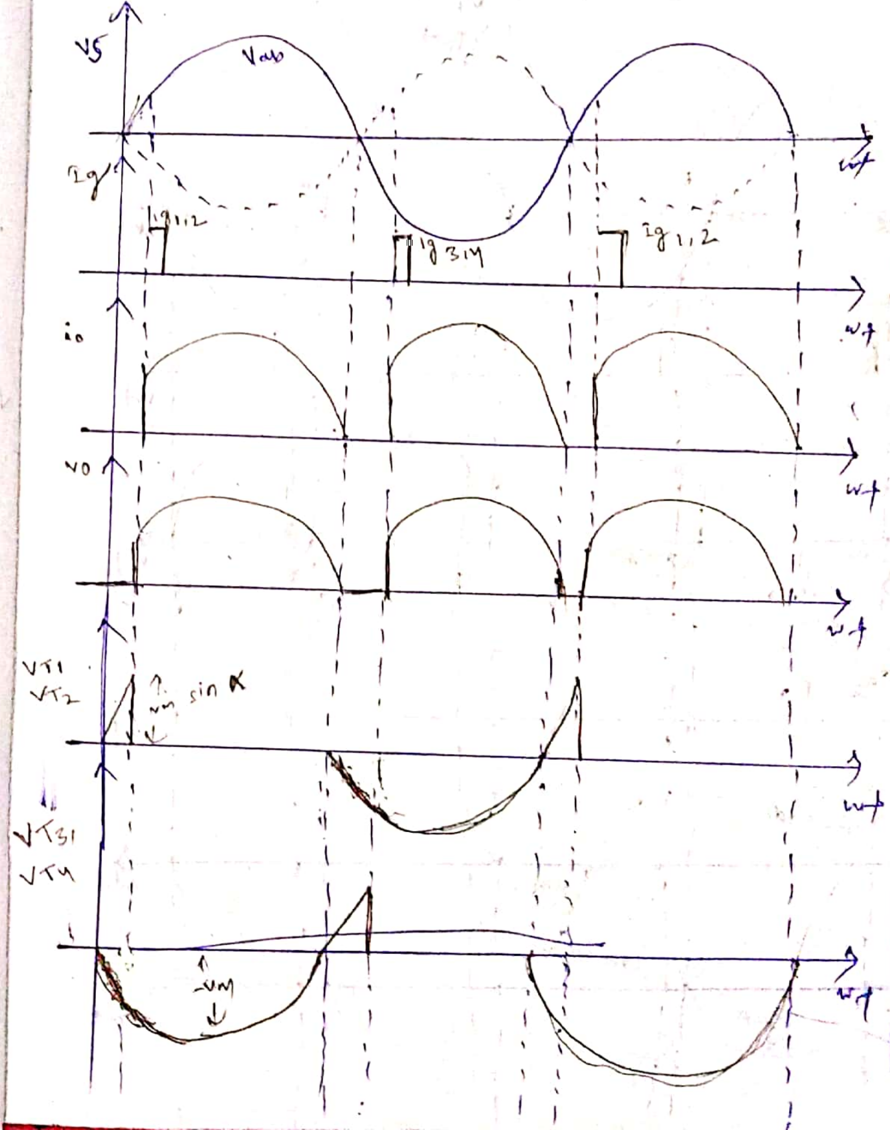
$$= \frac{V_m}{\pi}\Big[1+\cos\alpha\Big]$$

$$I_{o\,avg} = \frac{V_m}{\pi R}\left[1+\cos\alpha\right)$$

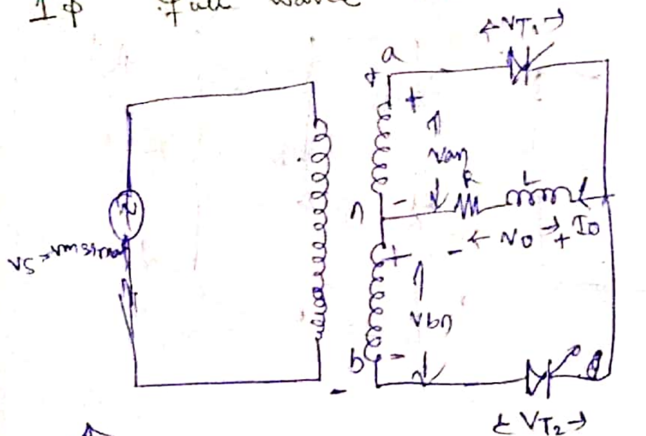
$$V_{o\,rms} = \frac{1}{\pi}\sqrt{\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t\,(d\omega t)}$$

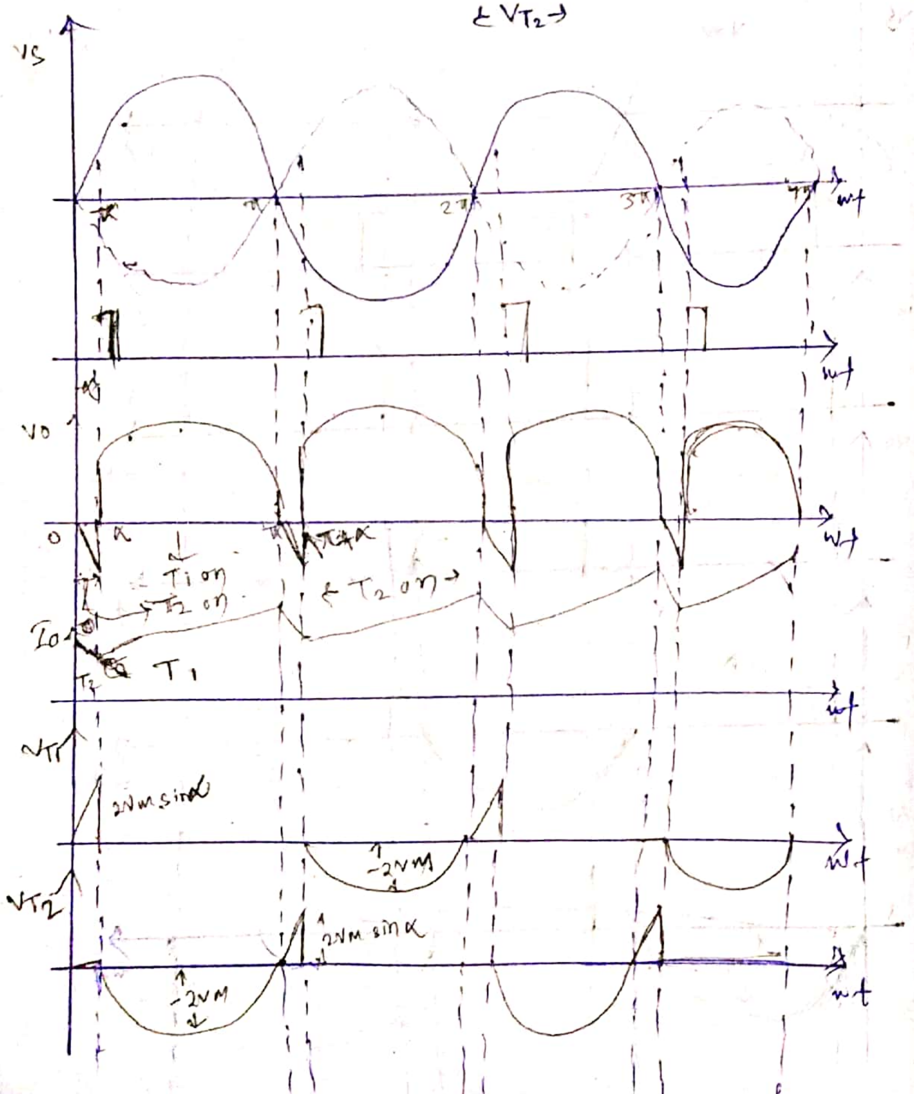
Bridge converter with R load:-





1φ full wave mid converter with RL load.





$$V_o\,avg = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \, d\omega t$$

$$V_o\,avg = \frac{2V_m}{\pi}\cos\alpha$$

$$V_{o\,r.m.s} = \sqrt{\frac{1}{\pi}\cdot\int_{\alpha}^{\pi+\alpha} V_m^2 \sin^2\omega t \, d\omega t}$$

$$= \frac{V_m^2}{2\pi}\left\{\omega t - \frac{1}{2}\sin 2\omega t\right\}_{\alpha}^{\pi+\alpha}$$

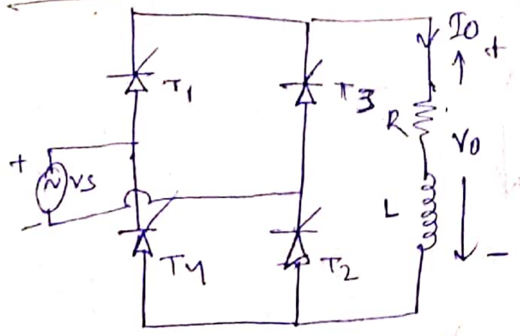
$$= \frac{V_m^2}{2\pi}(\pi)$$

$$V_{o\,r.m.s} = \frac{V_m^2}{2} = \frac{V_m}{\sqrt{2}}$$

$$V_o^2\,r.m.s = V_s^2$$

$$V_{o\,r.m.s} = V_s$$

1φ full wave bridge converter with R-L load.

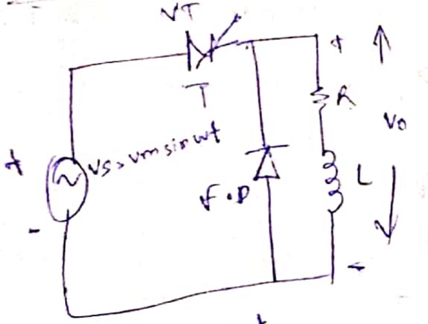


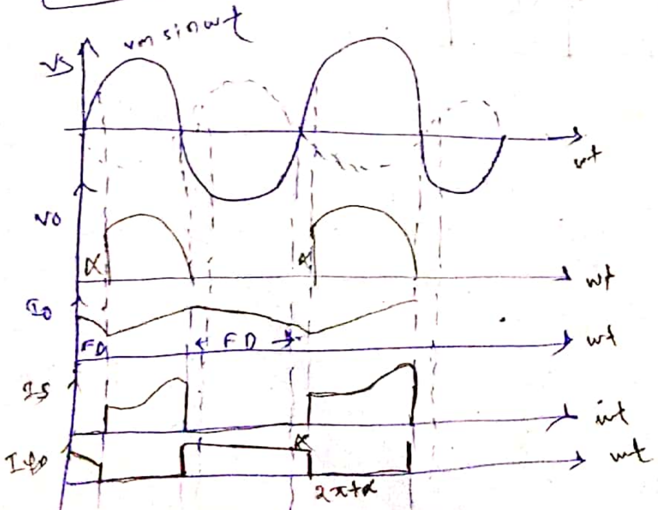
Free wheeling Diode:

✱ A free wheeling diode placed Parallel across the inductive load will provide a path for release of energy stored in the inductor while the load voltage drops to zero.

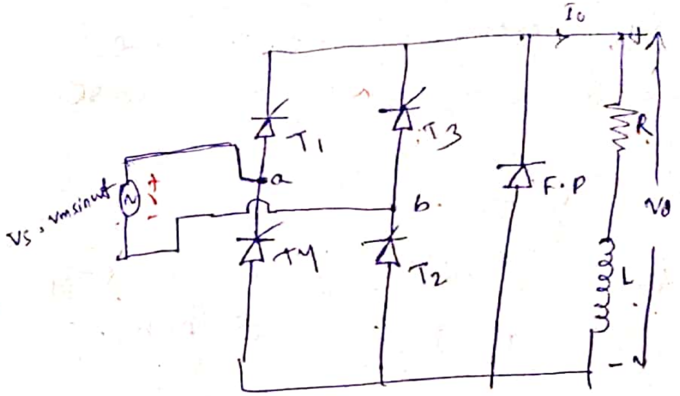
→ The freewheeling diode prevents the load voltage from becoming negative. whenever load voltage tends to go negative, F.D comes to play. It improves the line power factor. It is not ~~saupply~~ required but General diode require supply.

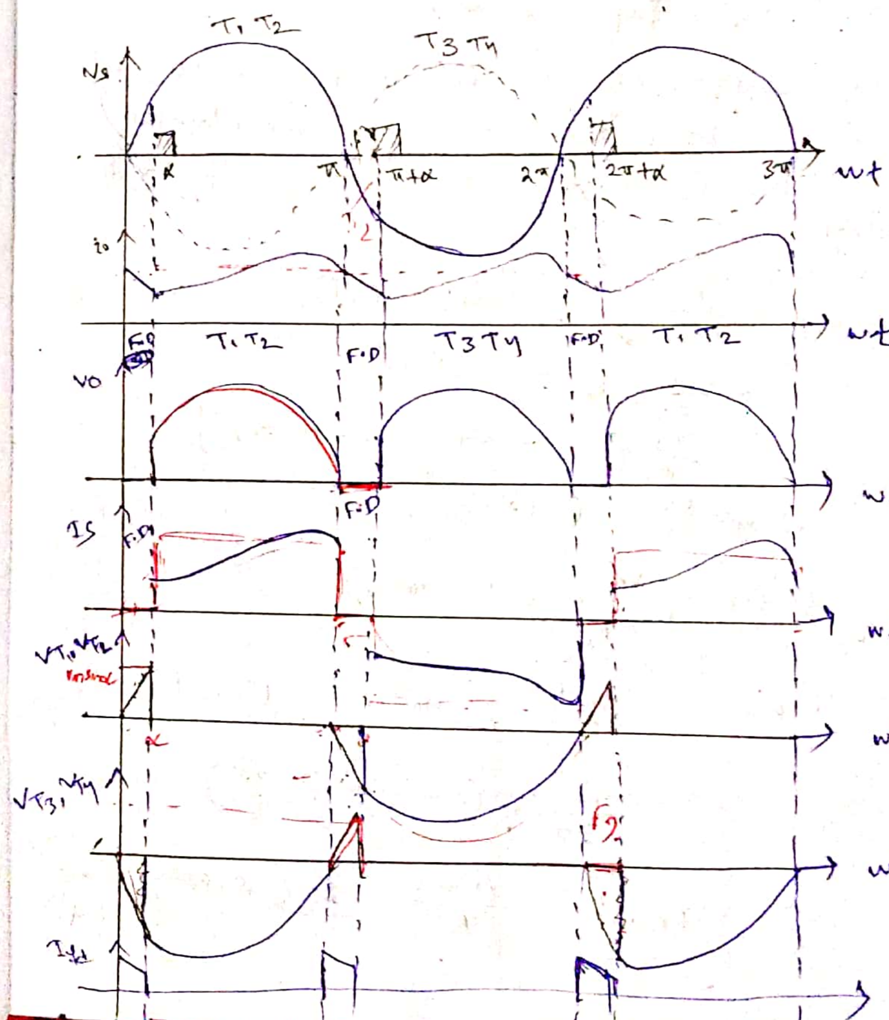
⑤ Single Phase Half wave thyristor with RL load and Freewheeling diode:





⑥ 1-ϕ full wave converter with RL load and free wheeling diode:





→ The ckt consist of four thyristor T_1, T_2, T_3, T_4, RL Load and free wheeling diode.

→ During +ve half cycle, T_1 & T_2 are forward biased & T_3 & T_4 are reverse biased.

→ So T_1 & T_2 is on.

→ During the -ve half cycle, T_3 & T_4 are f.b. & T_1 & T_2 are R.b.

→ So T_3 & T_4 is on.

→ By connecting a free wheeling diode, a continous load current is maintaining and it prevents the reversal of load voltage.

$$V_{o\,avg} = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin wt \,(dwt)$$

$$= \frac{V_m}{\pi}\left[-\cos wt\right]_{\alpha}^{\pi}$$

$$= \frac{V_m}{\pi}\left[-\cos\pi - (-\cos\alpha)\right]$$

$$V_{o\,avg} = \frac{V_m}{\pi}(1+\cos\alpha)$$

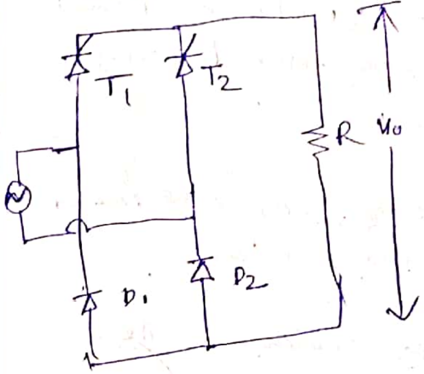
$$I_{o\,avg} = \frac{V_m}{\pi R}(1+\cos\alpha)$$

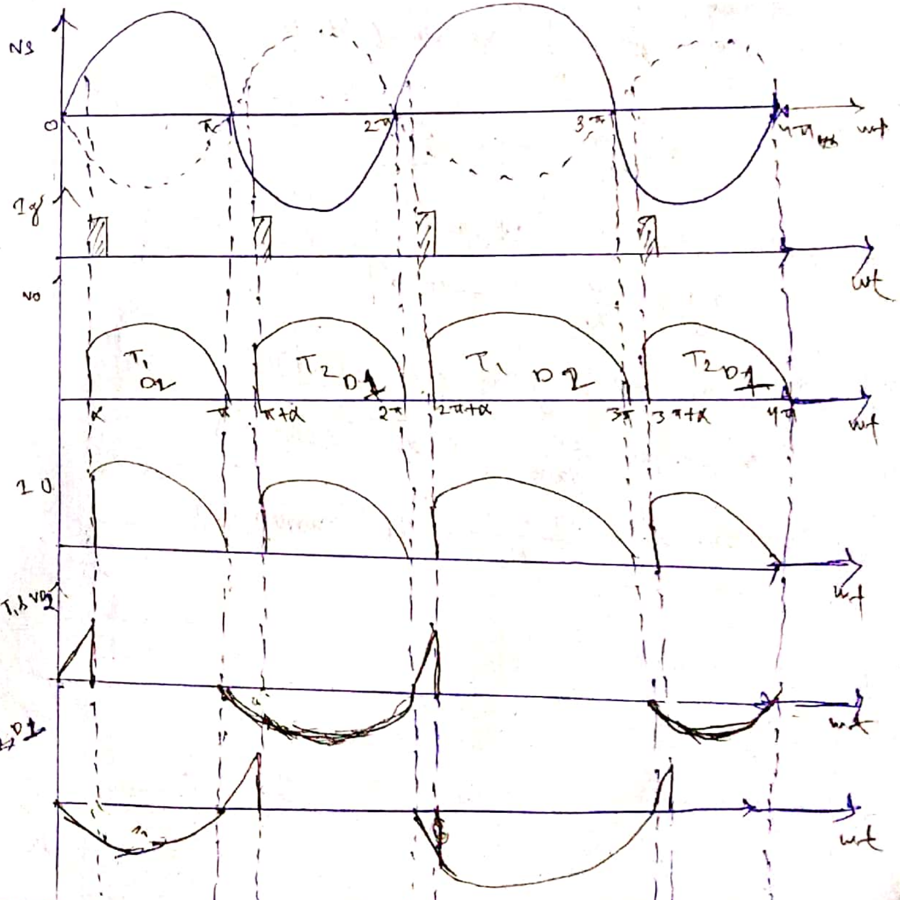
$$V_{o\,r.m.s} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2 wt \,(dwt)}$$

$$= \frac{V_m}{\sqrt{2\pi}}\sqrt{(\pi-\alpha) - \left(\frac{\sin 2\alpha}{2}\right)}$$

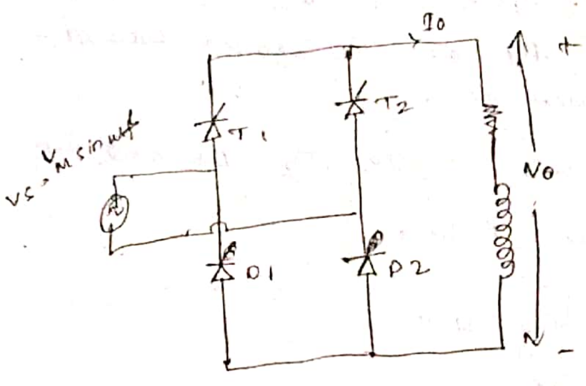
$$I_{r.m.s} = \frac{V_{r.m.s}}{R}, \ I_s \text{ (supply r.m.s current)}$$

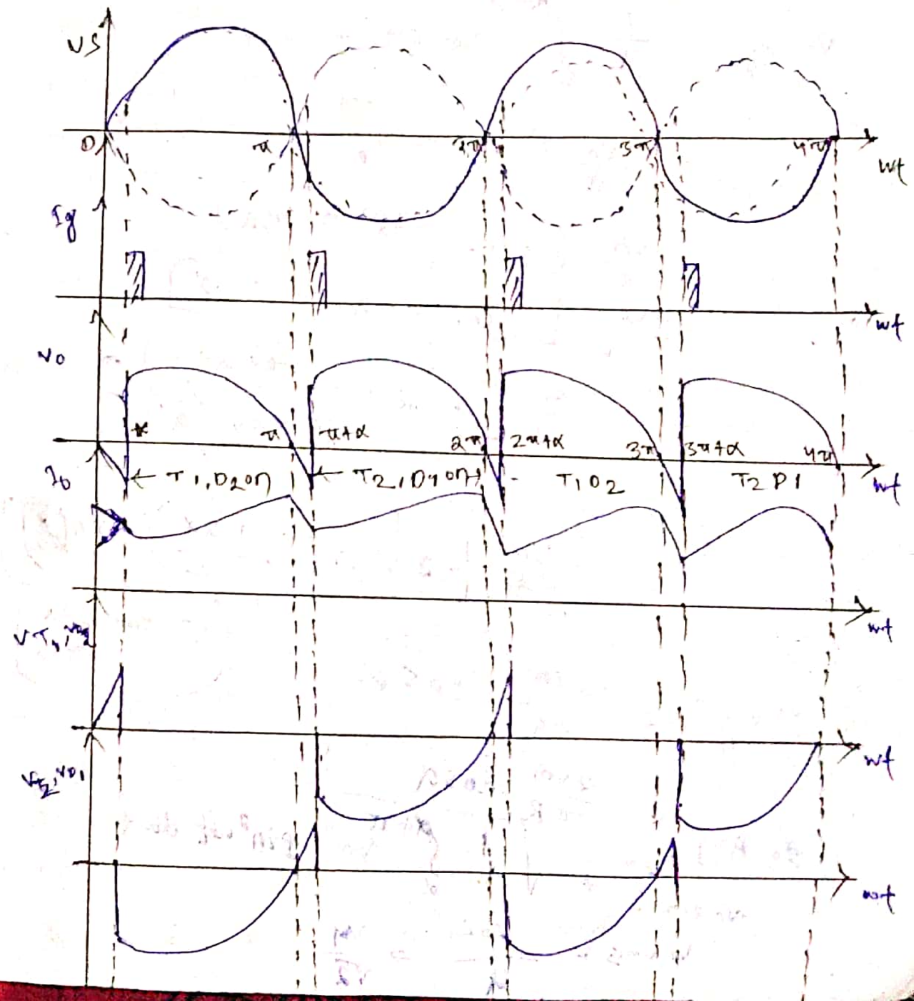
Ⓠ 1-φ half wave controlled bridge converter for R-load or 1-φ full wave semi-converter with R load. (symetric)





⑨ 1-φ half wave controlled bridge converter for R-L Load
OR
1-φ full wave semi converter with R-L Load.





The ckt consist of two thyristor T_1 & T_2 and two diode D_1, D_2.

- During +ve half cycle T_1, D_2 are Forward biased and T_2, D_1 are reversed biased.
- So T_1, D_2 are on,
- During -ve half cycle, T_2, D_1 are forward biased and T_1, D_2 are reversed biased.
- So T_2 & D_1 are on
- For resistive load, the current i_0 i_s in phase with V_0,

$$V_{0\,avg} = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \,(d\omega t)$$

$$= \frac{V_m}{\pi}\left[-\cos\omega t\right]_{\alpha}^{\pi}$$

$$= \frac{V_m}{\pi}\left[1+\cos\alpha\right]$$

$$I_{0\,avg} = \frac{V_m}{\pi R}\cdot\left(1+\cos\alpha\right]$$

$$V_{0\,rms} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t\,(d\omega t)}$$

$$V_{0\,r.m.s} = \frac{V_m}{\sqrt{2\pi}}\sqrt{(\pi-\alpha) - \left(\frac{\sin 2\alpha}{2}\right)}$$

$$I_{r.m.s} = \frac{V_{r.m.s}}{R} = I_s \text{ (supply } I_s)$$

→ The ckt consist of two thyristor T_1 & T_2 and two diode D_1, D_2.

→ During +ve half cycle T_1, D_2 are forward biased, and T_2, D_1 are reversed biased,

→ So T_1, D_2 are on,

→ During -ve half cycle T_2, D_1 are F.B and T_1, D_2 are R.B,

→ So T_2, D_1 are on,

$$V_0\,avg = \frac{1}{\pi}\int_{\pi}^{\pi+\alpha} V_m \sin\omega t\,(d\omega t)$$

$$= \frac{V_m}{\pi}\left(-\cos\omega t\right)_{\alpha}^{\pi+\alpha}$$

$$= \frac{V_m}{\pi}\left(-\cos(\pi+\alpha) + \cos\alpha\right)$$

$$= \frac{-V_m}{\pi}\left[\cos(\pi+\alpha) - \cos\alpha\right]$$

$$= \frac{-V_m}{\pi}\left[-2\sin\left(\frac{\pi+\alpha+\alpha}{2}\right)\cdot\sin\left(\frac{\pi+\alpha-\alpha}{2}\right)\right]$$

$$= -\frac{V_m}{\pi}\left[-2\sin\left(\frac{\pi+2\alpha}{2}\right)\sin\left(\frac{\pi}{2}\right)\right] \quad \left(\because \sin \pi/2+\alpha = \cos\alpha\right)$$

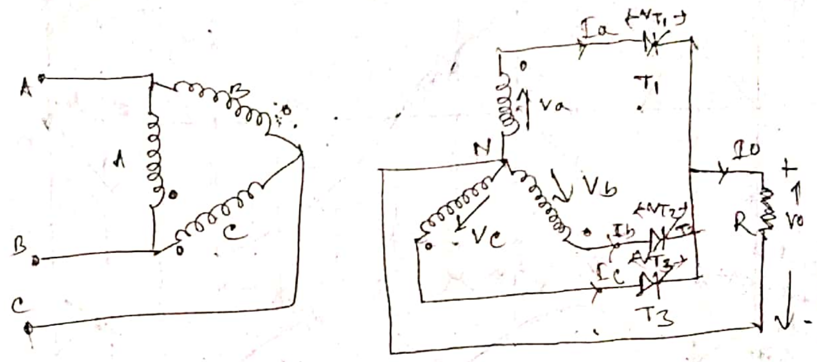
$$V_0\,Avg = \frac{2V_m}{\pi}\cos\alpha$$

$$I_0\,Avg = \frac{2V_m}{\pi R}\cos\alpha$$

$$V_0\,R.M.S = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\alpha+\pi} V_m^2 \sin^2\omega t\,d\omega t}$$

$$V_0\,R.M.S = \frac{V_m2}{2} \Rightarrow \frac{V_m}{\sqrt{2}}$$

3-ϕ Half-wave controlled converter with R load.



Here three phase are displaced by 120°.

$V_a = V_m \sin\omega t$

$V_b = V_m \sin(\omega t - 2\pi/3)$

$V_c = V_m \sin(\omega t - 4\pi/3)$

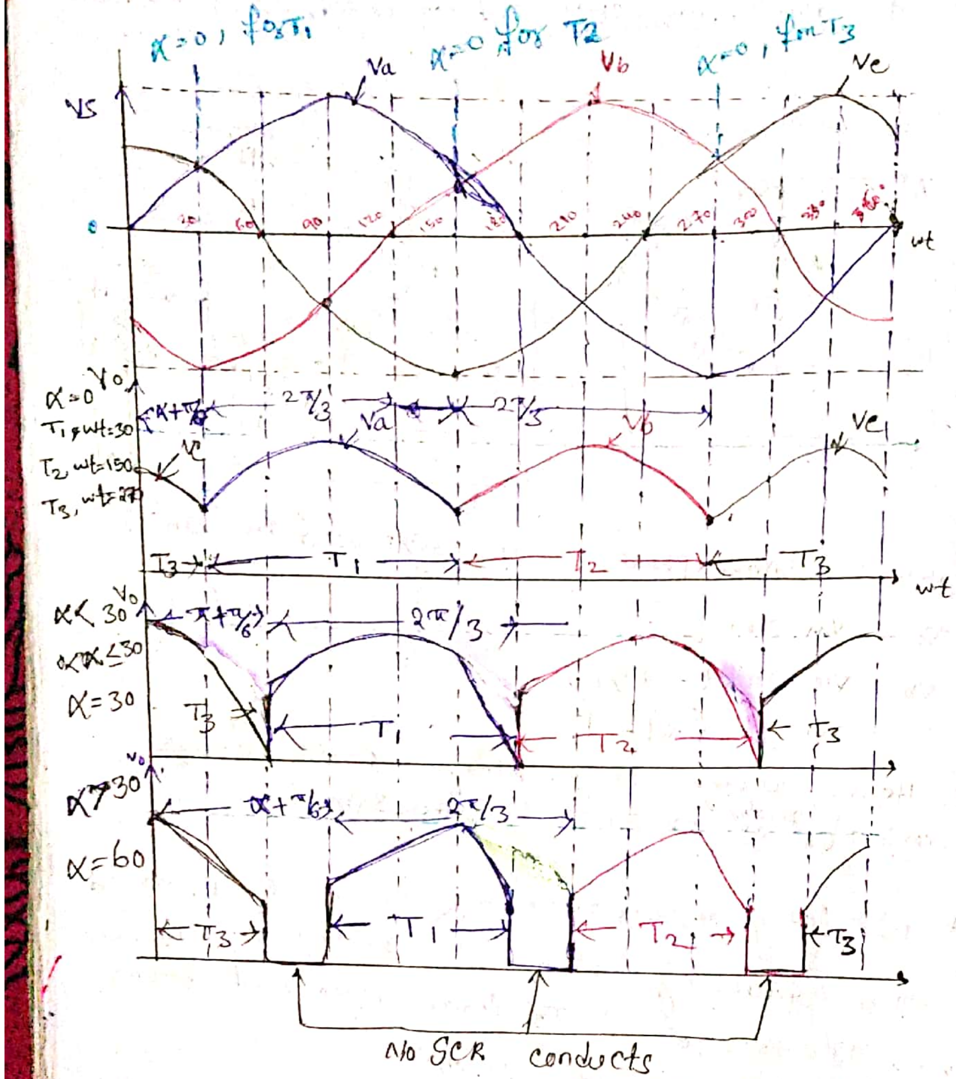
* Here always large voltage phase ~~always~~ thyristor conduct as compare to other 3-phase.

* If firing angle is zero degree, SCR T_1 would begin conducting from $\omega t = 30°$ to 150°, T_2 from measured from $\omega t = 150$ to 270° and T_3 from $\omega t = 270$ to 390° and so on.

* In other words, firing angle from this controlled converter would be measured from $\omega t = 30°$ for T_1, from $\omega t = 150°$ for T_2 and from $\omega t = 270°$ for T_3.

* For zero degree firing angle delay, thyristor behaves like as diode.

* The operation of this converter is now described for $\alpha < 30°$ and for $\alpha > 30°$



Firing angle < 30°

- The out put voltage wave form Vo, for firing angle less than 30°
- where T₁ conduct from wt = 30°+α to wt = 150+α, T₂ from 150°+α to 270°+α and so on.

Each SCR conducts for 120°.

- The wave form of Io is same as Vo wave form.

$0 < \alpha \leq 30$

$$V_{o\,avg} = \frac{1}{T}\int_0^T V_o(t)\,d(t)$$

$$= \frac{1}{2\pi/3}\int_{(\alpha+\frac{\pi}{6})}^{(\alpha+5\pi/6)} V_{mph}\sin wt\,dwt$$

$$= \frac{3}{2\pi}\times V_{mph}\int_{(\alpha+\pi/6)}^{(\alpha+5\pi/6)} \sin wt\,dwt$$

$$= \frac{3\times V_{mph}}{2\pi}\Big[-\cos wt\Big]_{(\alpha+\pi/6)}^{(\alpha+5\pi/6)}$$

$$= -\frac{3V_{mph}}{2\pi}\Big[\cos\left(\alpha+5\pi/6\right) - \cos\left(\alpha+\pi/6\right)\Big]$$

$$= -\frac{3V_{mph}}{2\pi}\Big[\cos\alpha\cdot\cos 5\pi/6 - \cancel{\sin\alpha\cdot\sin 5\pi/6} - \cos\alpha\cdot\cos\pi/6 + \cancel{\sin\alpha\cdot\sin\pi/6}\Big]$$

$$= \frac{3V_{mph}}{2\pi}\Big[\cos\alpha\left(\cos 5\pi/6 \mp \cos\pi/6\right)\Big].$$

$$= \frac{-3V_{mph}}{2\pi}\Big[-\sqrt{3}\cos\alpha\Big) \qquad (\because V_L = \sqrt{3}V_{ph})$$

$$V_{o\,avg} = \frac{3V_{mL}}{2\pi}\cos\alpha, \quad I_{o\,avg} = \frac{3V_{mL}}{2\pi\cdot R}\cos\alpha$$

V_{mph} = maximum value of phase voltage
V_{mL} = maximum value of line voltage.
α = firing angle delay

$$V_{o\,r.m.s} = \sqrt{\frac{1}{T}\int_0^T V_o^2(t)\,dt}$$

$$= \frac{3}{2\pi}\int_{\alpha+\pi/6}^{\alpha+5\pi/6} V_{mph}^2\sin^2\omega t\; d(\omega t)$$

$$(V_{o\,r.m.s})^2 = \frac{3V_{mph}^2}{2\pi}\int_{\alpha+\pi/6}^{\alpha+5\pi/6} \sin^2\omega t\;(d\omega t)$$

$$= \frac{3V_{mph}^2}{2\pi}\int_{\alpha+\pi/6}^{\alpha+5\pi/6}\frac{1-\cos2\omega t}{2}\,d\omega t$$

$$= \frac{3V_{mph}^2}{2\pi}\left[\frac{1}{2}(\omega t)_{\alpha+\pi/6}^{\alpha+5\pi/6} - \frac{1}{2}\left(\frac{\sin2\omega t}{2}\right)_{\alpha+\pi/6}^{\alpha+5\pi/6}\right]$$

$$= \frac{3v^2ph}{4\pi}\left[\cancel{\alpha}+5\pi/6-\cancel{\alpha}-\pi/6 - \left(\frac{\sin2\omega t}{2}\right)_{\alpha+\pi/6}^{\alpha+5\pi/6}\right]$$

$$= \frac{3v^2ph}{4\pi}(4\pi/6) - \frac{1}{2}\left[\sin\left(2\alpha+\frac{5\pi}{3}\right) - \sin(2\alpha+\pi/3)\right]$$

$$= \frac{3v^2ph}{4\pi}\Big[(2\pi/3) - \frac{1}{2}\Big(\cancel{\sin2\alpha\cos5\pi/3} + \cos2\alpha\sin5\pi/3 - \cancel{\sin2\alpha\cos\pi/3} - \cos2\alpha\cdot\sin\pi/3\Big)$$

$$= \frac{3v^2ph}{4\pi}\left[2\pi/3 - \frac{1}{2}\left(-\cos2\alpha\sqrt{3}\right)\right]$$

$$= \frac{3V^2ph}{4\pi}\left(\frac{2\pi}{3}+\frac{\sqrt3}{2}\cos2\alpha\right)$$

$$V_{r.m.s} = \sqrt{\frac{3v^2ph}{4\pi}\left(2\pi/3+\frac{\sqrt3}{2}\cos2\alpha\right)}$$

$$= V_{ph}\sqrt{\left[\frac{\cancel{6}\pi}{\underset{2}{\cancel{12}}\pi}+\frac{3\sqrt3}{8\pi}\cos2\alpha\right)}$$

$$= V_{ph}\sqrt{\left[\frac{1}{2}+\frac{3\sqrt3}{8\pi}\cos2\alpha\right)}$$

$$= V_{ph}\sqrt{3\left(\frac{1}{2\times3}+\frac{\sqrt3}{8\pi}\cos2\alpha\right.}$$

$$= \sqrt{3}V_{ph}\sqrt{\frac{1}{6}+\frac{\sqrt3}{8\pi}\cos2\alpha}$$

$$= V_{mL}\sqrt{\frac{1}{6}+\frac{\sqrt3}{8\pi}\cos2\alpha}$$

$$I_{r.m.s} = \frac{V_{o\,r.m.s}}{R} = \frac{V_{mL}}{R}\sqrt{\frac{1}{6}+\frac{\sqrt3}{8\pi}\cos2\alpha}$$

* Firing angle > 30°

when the firing angle is more than 30°, T1 would conduct from α+30 or 30+α to 180°, T2 from 150+α to 300° and so on. For R. load, when phase voltage Va reaches at zero at ωt = 180°, current Io = 0, T1 is therefore turned off.

Thus, T6 would conduct from 30 ~~to~~ to 180°. Same is true for other SCRs. This shows that each SCR, for firing angle > 30°, conducts for $(150° - \alpha)$ only.

→ This implies that for R load, maximum possible value of firing angle is 150°.

$$V_{o\,avg} = \frac{3}{2\pi} \int_{\alpha+\pi/6}^{\pi} V_{mph} \sin \omega t \, d(\omega t)$$

$$= \frac{3}{2\pi} V_{mph} \int_{\alpha+\pi/6}^{\pi} \sin \omega t \, d(\omega t)$$

$$= \frac{3}{2\pi} V_{mph} \left(-\cos \omega t\right)_{\alpha+\pi/6}^{\pi}$$

$$= \frac{-3}{2\pi} V_{mph} \left(\cos \pi - \cos(\alpha + \pi/6)\right)$$

$$= \frac{-3}{2\pi} V_{mph} \left(\cos \pi - \cos\alpha \cdot \cos \pi/6 + \sin\alpha \cdot \sin \pi/6\right)$$

$$= \frac{-3}{2\pi} V_{mph} \left[-1 - \cos(\alpha + 30°)\right]$$

$$V_{o\,avg} = \frac{3}{2\pi} V_{mph} \left[1 + \cos(\alpha + 30°)\right]$$

$$V_{o\,r.m.s} = \sqrt{\frac{3}{2\pi} \int_{\alpha+\pi/6}^{\pi} V_{mp}^2 \sin^2 \omega t \cdot d\omega t}$$

$$= \sqrt{\frac{3 V_{mp}^2}{2\pi} \frac{1}{2} \left[(\omega t)_{\alpha+\pi/6}^{\pi} - \left(\frac{\sin 2\omega t}{2}\right)_{\alpha+\pi/6}^{\pi}\right]}$$

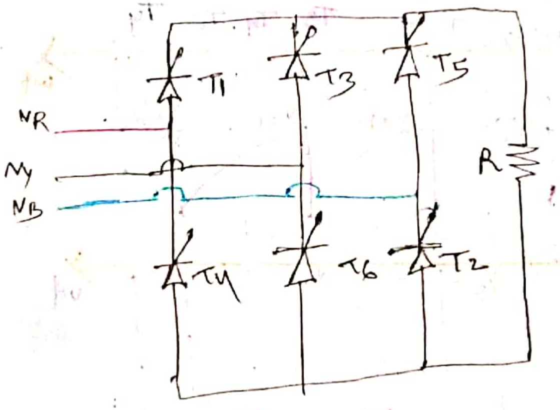
$$= \frac{\sqrt{3}}{2\sqrt{\pi}} V_{mph} \sqrt{\left(\pi - \alpha - \pi/6\right) - \frac{1}{2}\left[\sin 2\pi - \sin(2\alpha + \pi/3)\right)}$$

$$= \frac{\sqrt{3}}{2\sqrt{\pi}} V_{mph} \sqrt{\frac{5\pi}{6} - \alpha - \frac{1}{2}\left[-\sin(2\alpha + \pi/3)\right)}$$

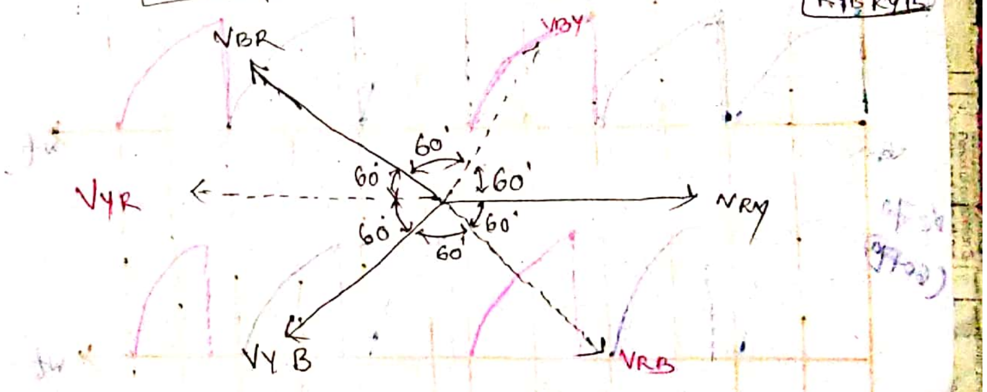
$$= \frac{\sqrt{3}}{2\sqrt{\pi}} V_{mph} \sqrt{\left(\frac{5\pi}{6} - \alpha\right) + \frac{1}{2} \sin(2\alpha + \pi/3)}$$

$$= \frac{V_L}{2\sqrt{\pi}} \sqrt{\left(\frac{5\pi}{6} - \alpha\right) + \frac{1}{2} \sin(2\alpha + \pi/3)}$$

3φ full wave controlled converter with R-load:

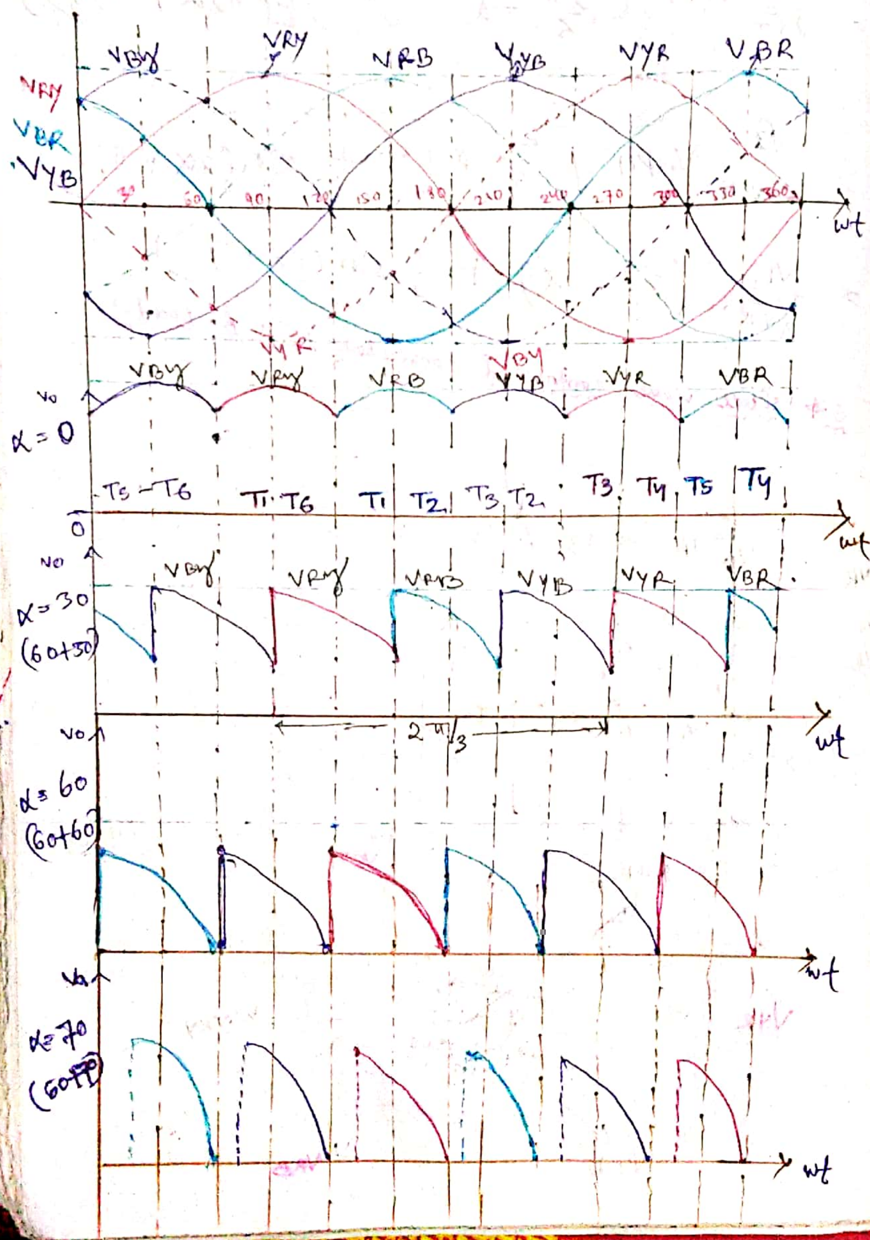


RYBRYB



If m is the number of pulse.

$$\frac{2\pi}{6} = \pi/3 \text{ (Pulse width)}$$



→ 3-φ supply is given to the terminal R, Y, B.

→ The ckt consists of six thyristor T_1, T_2, T_3, T_4, T_5 & T_6 and a R-load.

→ when α = 30°

T_1, T_6 is conduct from (60+30) = 90 to 150

T_1, T_2 is conduct from 150 to 210.

T_3, T_2 is conduct from 210 to 270

T_3, T_4 is conduct from 270 to 330

T_5, T_4 is conduct from 330 – 390 (Here, 30°)

T_5, T_6 is conduct from 390 – 450 (Here 90°)

* But when α value is greater than 60° for R load we will get discontinous conduction mode.

→ Each thyristor is fired after 60°.

→ Each thyristor conducts for 120°.

→ Here 6 curve comes into play, But in Half wave it is operated 3 curve only.

→ As T_1 & T_6 are connected to R and Y so V_{RY} appears at output.

→ As T_1 & T_2 are connected to R and B so V_{RB} appears at output.

$0 < \alpha \leq 60$

$$V_{o\,avg} = \frac{1}{T}\int_0^T V_o(t)\,d(t)$$

$$= \frac{1}{\pi/3}\int_{\alpha+\pi/3}^{\alpha+\frac{2\pi}{3}} V_{mL}\sin\omega t$$

$$= \frac{V_{mL}}{\pi/3}\,(-\cos\omega t)_{\alpha+\pi/3}^{\alpha+2\pi/3}$$

$$= \frac{3V_{mL}}{\pi}\left(\cos(\alpha+\pi/3) - \cos(\alpha+2\pi/3)\right)$$

$$= \frac{3V_L}{\pi}\left[\cos\alpha\cdot\cos\pi/3 - \cancel{\sin\pi\cdot\sin\pi/3} - \cos\alpha\cdot\cos 2\pi/3 + \cancel{\sin\alpha\cdot\sin 2\pi/3}\right]$$

$$= \frac{3V_L}{\pi}\left[\cos\alpha(\cancel{1})\right.$$

$$\boxed{V_{avg} = \frac{3V_L}{\pi}\cos\alpha}$$

$$I_{o\,avg} = \frac{3V_L}{\pi R}\cos\alpha$$

$$V_{rms} = \sqrt{\frac{1}{T}\int V_o^2 t\,dt}$$

$$V_{rms}^2 = \frac{3}{\pi}\int_{\alpha+\pi/3}^{\alpha+2\pi/3} V_{mL}^2\sin^2\omega t\,d\omega t$$

$$= \frac{3V_{mL}^2}{\pi}\int_{\alpha+\pi/3}^{\alpha+2\pi/3}\frac{1-\cos 2\omega t}{2}\,d\omega t$$

$$= \frac{3V_{mL}^2}{\pi}\,\frac{1}{2}\left[(\omega)_{\alpha+\pi/3}^{\alpha+2\pi/3} - \left(\frac{\sin 2\omega t}{2}\right)_{\alpha+\pi/3}^{\alpha+2\pi/3}\right]$$

$$= \frac{3V_{mL}^2}{2\pi}\left[(\alpha+2\pi/3-\alpha-\pi/3) - \frac{1}{2}\left(\sin(2\alpha+4\pi/3) - \sin(2\alpha+2\pi/3)\right)\right]$$

$$= \frac{3V_{mL}^2}{2\pi}(\pi/3) - \frac{1}{2}\left((\sin 2\alpha\cdot\cos 4\pi/3 + \cos 2\alpha\cdot\sin 4\pi/3) - (\sin 2\alpha\cdot\cos 2\pi/3 + \cos 2\alpha\cdot\sin 2\pi/3)\right)$$

$$= \frac{3V_{mL}^2}{2\pi}(\pi/3) - \frac{1}{2}\left[\sin\alpha\cdot\cancel{\cos 4\pi/3} + \cos 2\alpha\cdot\sin 4\pi/3 - \sin 2\alpha\cdot\cancel{\cos 2\pi/3} - \cos 2\alpha\cdot\sin 2\pi/3\right)$$

$$= \frac{3V_{mL}^2}{2\pi}(\pi/3) - \frac{1}{2}\left(\cos 2\alpha\left(\sin 4\pi/3 - \sin 2\pi/3\right)\right)$$

$$= \frac{3V_L^2}{2\pi}(\pi/3) - \frac{1}{2}\cos 2\alpha\,(-\sqrt{3})$$

$$= \frac{3V_L^2}{2\pi}\left[\pi/3 + \frac{\sqrt{3}}{2}\cos\alpha\right]$$

$$V_{r.m.s} = \sqrt{\frac{3V_L^2}{2\pi}\left(\pi/3 + \frac{\sqrt{3}}{2}\cos\alpha\right)}$$

$$= V_L\sqrt{\frac{3}{2\pi}\left[\pi/3 + \frac{\sqrt{3}}{2}\cos 2\alpha\right]}$$

Working of single phase AC regulator:-

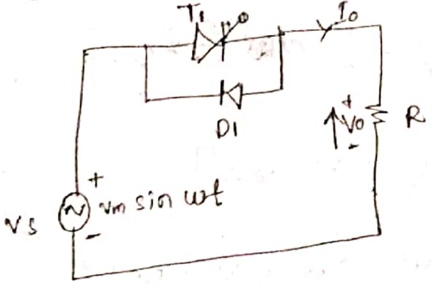
- It is a device which converts fixed single phase alternating voltage ~~with~~ directly to a variable alternating voltage without a change in frequency. The I/P and O/P of the device is single phase.

- There are two types of AC voltage controller:
  ① single phase Half wave
  ② single phase full wave.

Working principle of single phase AC voltage controller:

Half wave AC voltage controller:-

→ A single phase half wave AC voltage controller comprise of a thyristor connected anti-parallel with a power diode.



- Here the load is taken resistive load. The input source is $V_s = V_m \sin \omega t$.

→ For the +ve half cycle the thyristor is forward biased. Hence the thyristor stand to conduct when we provide gate pulse.

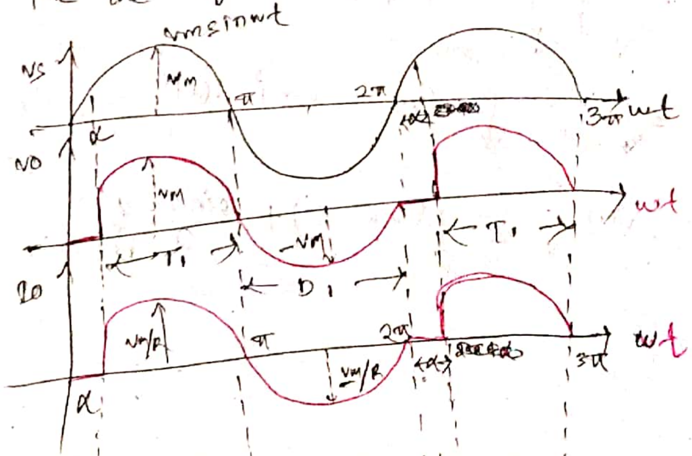
→ Suppose some firing angle "α" provide to the thyristor. Such time the thyristor stand to conducting through resistive load.

→ It makes load voltage $V_o = V_m \sin \omega t$,

$$I_o = \frac{V_m \sin \omega t}{R}$$

→ At a time after $\omega t = \pi$, thyristor T_1 becomes reversed biased. Such time the load current is zero and load voltage becomes zero and hence the thyristor "T_1" is naturally commutated.

→ After $\omega t = \pi$, Diode D_1 becomes forward biased and hence stand to conducting. This makes load voltage & current the supply voltage $V_m \sin \omega t$ and $(V_m \sin \omega t / R)$ respectively for the negative half cycle.



$V_0\ avg = \frac{1}{T}\int_{0}^{T} V_0(t)\,dt$

$V_0\ Avg = \frac{1}{2\pi}\int_{\alpha}^{2\pi} V_m \sin\omega t\, d\omega t$

$\Rightarrow \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin\omega t\, d\omega t + \int_{\pi}^{2\pi} V_m \sin\omega t\, d\omega t$

$= \frac{1}{2\pi}\left[V_m\left(-\cos\omega t\right)_{\alpha}^{\pi} - V_m\left(\cos\omega t\right)_{\pi}^{2\pi}\right]$

$\Rightarrow \frac{V_m}{2\pi}\left\{\left(\cos\alpha - \cos\pi\right) - \left(\cos 2\pi - \cos\pi\right)\right\}$

$\Rightarrow \frac{V_m}{2\pi}\left[1+\cos\alpha\right) + \left(\overset{-1}{\cancel{1}}\ \overset{-1}{\cancel{1}}\right)$

$\Rightarrow \frac{V_m}{2\pi}\left(1+\cos\alpha - 2\right)$

$$\boxed{V_{avg} \Rightarrow \frac{V_m}{2\pi}\left(\cos\alpha - 1\right)}$$

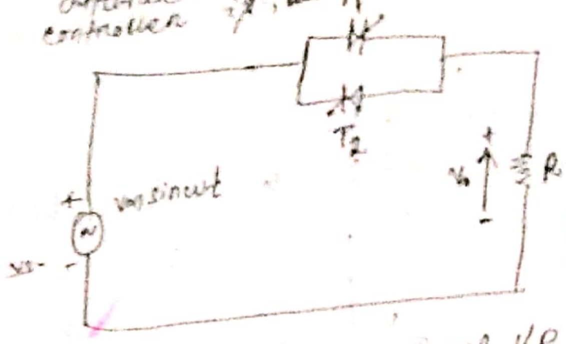
$V_0\ r.m.s \Rightarrow \sqrt{\frac{1}{T}\int_{0}^{T} V_0^2 t\, d\omega t}$

$= \sqrt{\frac{1}{2\pi}\int_{\alpha}^{2\pi}\left(V_m \sin\omega t\right)^2 d(\omega t)}$

$\Rightarrow \frac{V_m}{2}\sqrt{\frac{1}{\pi}\left\{\left(2\pi - \alpha\right) + \frac{\sin 2\alpha}{2}\right\}}$

⑧ Full wave AC voltage controller :-

It comprises of two thyristor are connected antiparallel, also known as 1ϕ full wave AC voltage controller i.e., single phase bidirectional voltage controller.



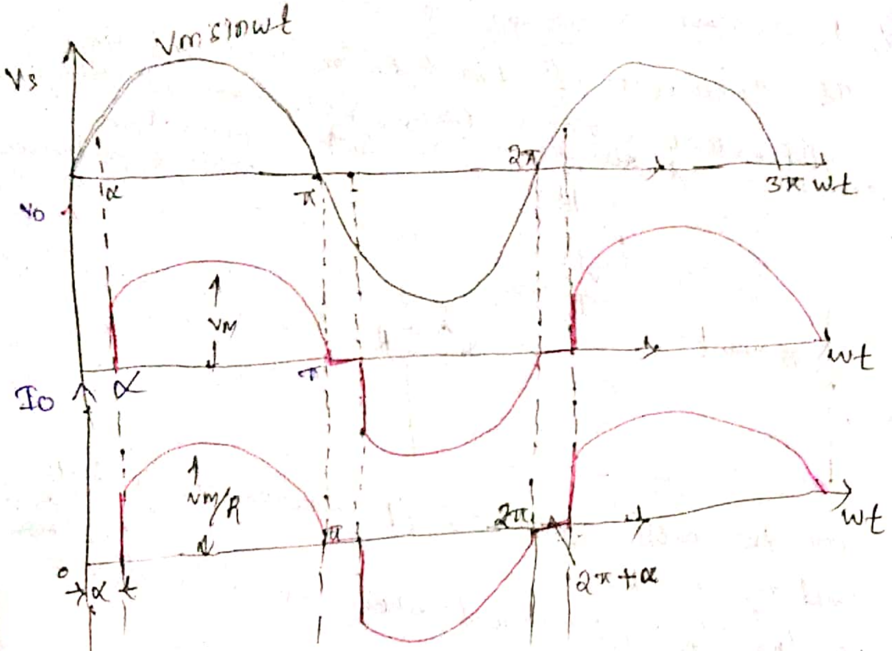
- For the half cycle of I/P source T_1 is F.B and T_2 is R.B. The thyristor T_1 conduct when we applied some gate pulse angle 'α'.

- This conducting process of thyristor makes load voltage $V_0 = V_m \sin\omega t$ and load current $I_0 = \left(\frac{I_m \sin\alpha}{R}\right)$

- At $\omega t = \pi$ the load voltage becomes zero and current also becomes zero. Since the thyristor 'T_1' is reversed biased, it gets naturally commutated.

- At $\omega t = (\pi+\alpha)$, forward biased thyristor t_2 is gated. Hence, it conducts and connected load to the source.

- Thus the r.m.s voltage may be controlled by control of firing angle.



:: The above wave form shows that the positive and negative half cycle of the load voltage & current are identical. so, it's o/p average voltage and current is zero.

$$V_{o\,r.m.s} = \sqrt{\frac{1}{T}\int_0^T v_o^2 t \, dt}$$

$$= \sqrt{\frac{1}{\pi}\int_\alpha^\pi (V_m \sin \omega t)^2 \, d\omega t}$$

$$= V_m \sqrt{\frac{1}{2\pi}\left\{(\pi-\alpha) + \frac{\sin 2\alpha}{2}\right\}}$$

$$I_{r.m.s} = \frac{V_{o\,r.m.s}}{R}$$

$$V_{o\,Avg} = 0$$

→ As a result, DC component is not introduced in the supply and load ckt. It is the big advantage of single phase full wave AC voltage controller.

→ It also overcomes the problem of dc component which is present in supply and load ckt of half wave voltage controller.

CHOPPERS :-

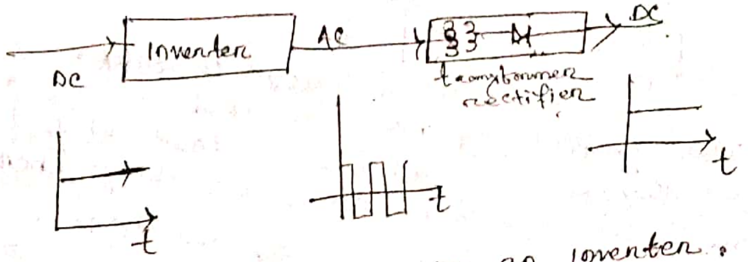
→ Chopper is a device which converts the constant DC to variable DC. It is equivalent to AC transformer.

chopper is converts the two types.

(a) AC link chopper

(b) DC chopper

(a) AC link chopper :-



→ DC is converted into AC by an inverter.

→ AC is step up or step down by the transformer.

→ Then it's again converted into AC to DC by rectifier.

→ As the process is two ~~state~~ step of component are required, ~~then~~ so the system becomes costly, bulky, less efficiency.

DC chopper :-

DC → CHOPPER → DC

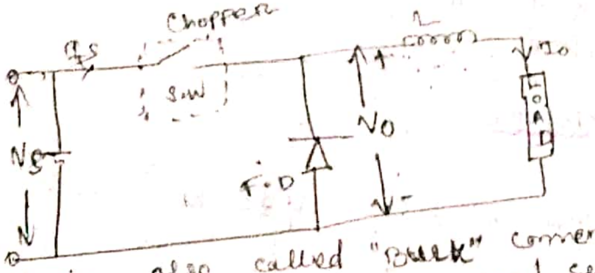
→ As it one step conversion so more efficiency ~~[illegible]~~.

→ it is used: machine hoist, trolley card.

chopper are converted into two types:

1. step up chopper (Boost)
2. step down chopper (BULK)
3. Bulk - Boost converter.

① step down chopper.



→ it is also called "BULK" converter.

→ when chopper is on. the load current Io flow through the inductor & load. At that time. the inductor store the charge/energy.

→ And output voltage Vo is also developed.
∴ Vo = Vs

→ when the chopper is off. At that time the inductor behaves as source. so the inductor release the energy through the free wheeling diode.

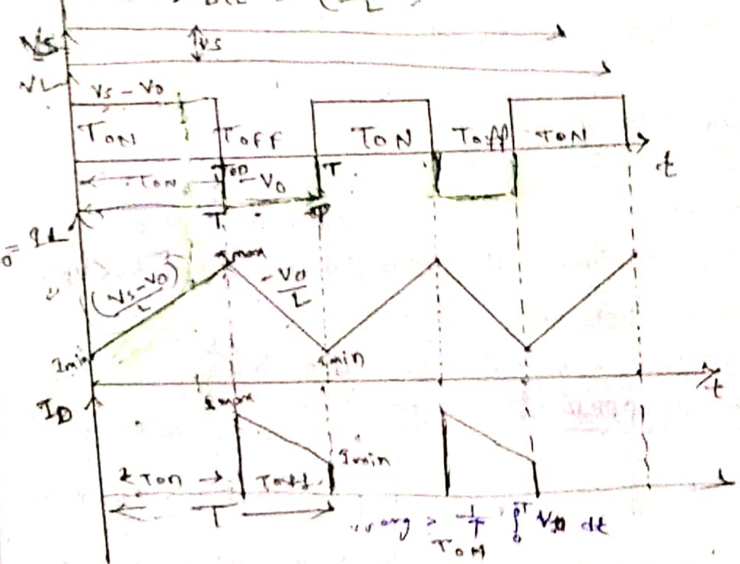
→ So the current flow through the freewheeling diode.

→ the diode has no. voltage drop. so it acts as the short ckted and output voltage is zero. ($V_0 = 0$)

when switch S, is ON.

$V_s - V_0 = V_L \Rightarrow V_s - V_0 = L\frac{di}{dt} \Rightarrow \frac{V_s - V_0}{L} = \frac{\Delta i_L}{\Delta t}$

$\Delta i_L = \left(\frac{V_s - V_0}{L}\right)\Delta t \Rightarrow \Delta i_L = \left(\frac{V_s - V_0}{L}\right)t_{on}$



when switch is off.

$V_L + V_0 = 0$

$V_L = -V_0$

$L\frac{di}{dt} = -V_0$

$L\frac{\Delta i_L}{\Delta t} = -V_0$

$\Delta i_L = \left(\frac{-V_0}{L}\right)\Delta t$

$\Delta i_L = \left(\frac{-V_0}{L}\right)t_{off}$

$v_{o\,avg} = \frac{1}{T}\int_0^T V_0\,dt$

$V_{o\,avg} = \frac{1}{T}\int_0^{T_{ON}} V_s\,dt$

(∵ $V_0 = V_s$ when t_{on})

$= \frac{V_s}{T}\int_0^{T_{ON}} 1\,dt$

$= \frac{V_s}{T}\left[T\right]_0^{T_{ON}}$

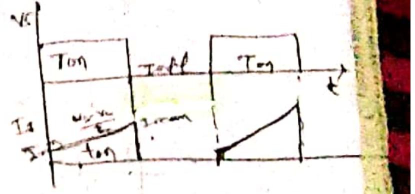
$= \frac{V_s}{T}(T_{ON})$.

$V_{o\,avg} = \frac{V_s\,T_{ON}}{T}$

$V_{o\,avg} = \frac{T_{ON}}{T} \times V_s$

$\therefore \left(D = \frac{T_{ON}}{T}\right)$

D = Duty cycle



$$\boxed{V_{o\,avg} = DV_s}$$

$$D = \frac{T_{on}}{T}$$

$$= \frac{T_{ON}}{T_{ON} + T_{OFF}}$$

D value 0 to 1

$$V_{o\,rms} = \sqrt{\frac{1}{T}\int_0^{T_{on}} V_s^2\,dt}$$

$$= \sqrt{\frac{V_s^2}{T}(T)_0^{T_{on}}}$$

$$= \sqrt{\frac{V_s^2}{T}(T_{on})}$$

$$\boxed{V_{o\,rms}\ V_S\sqrt{D}}$$

$$\boxed{V_{o\,avg} = D\,V_s}$$

$V_o < V_s$

→ If the D value is something value point 1 then the $V_o < V_s$.

$V_s \times I_s = V_o I_o \Rightarrow I_s = \left(\frac{V_o}{V_s}\right) I_o$

~~② step up chopper:~~

Note→

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

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

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

$$\int_0^T di = \int_0^T \frac{V_L}{L}dt$$

$$(I)_0^t = \int_0^T \frac{V_L}{L}dt$$

$$I(t) - I_0 = 0$$

$$L\int_0^T \frac{V_L}{L}dt = 0$$

$$\boxed{\int_0^T V_L\,dt = 0}$$

↓
volt sec balance expression

Average voltage across inductor will be zero for 1 time period.

connecting

$$\int_0^{T_{on}} V_L\,dt + \int_{T_{on}}^T V_L\,d(t) = 0$$

$$\int_0^{T_{on}} (V_s - V_o)dt + \int_{T_{on}}^T -V_o(T - T_{on})$$

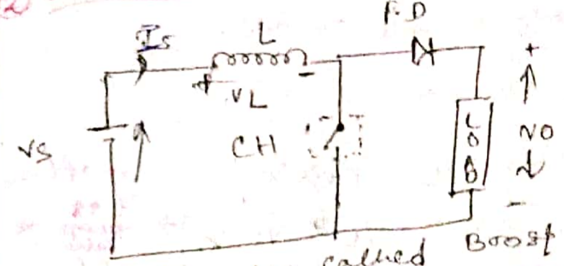
$$\Rightarrow (V_s - V_o)T_{on} = V_o(T - T_{on})$$

$$\Rightarrow V_s t_{on} - V_o t_{on} = V_o t - V_o t_{on}$$

$$= \frac{V_s t_{on}}{t} = V_o$$

$$\boxed{V_{o\,avg} = V_S D}$$

② stepup chopper:



- It is also called Boost converter.
- Average o/p voltage Vo greater than i/p voltage Vs so. it is called step up chopper.
- chopper is basically high speed turn ON/off switch.

Working Principle:

→ when the chopper CH is on, the closed current path completed through inductor & chopper 'CH'. ~~state~~ ~~stored~~ (o/p = 0) ~~(o/p voltage = 0)~~

→ inductor stores energy during Ton period.

→ when the CH is off, the inductor does not allow to sudden change in current. so the inductor change its polarity and flow its ~~state~~ discharge current forced fully through the diode and load for a time "Toff." such time the inductor current is decreasing in nature.

when. CH, on for on time

$$V_S - V_L = 0$$

$$V_S = V_L$$

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

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

$$\frac{V_S}{L} = \frac{\Delta i_L}{\Delta t}$$

$$\Delta i_L = \frac{V_S}{L}t_{on}$$

when CH.. off time.

such time Diode will conduct.

$-V_s - V_L + V_o = 0$

$V_s - V_L - V_0 = 0$

$\boxed{V_L > V_s - V_0}$

inductor

$V_o > V_s + V_L$ $\boxed{V_o > V_s}$

$\boxed{V_o - V_s > V_L} \rightarrow \boxed{V_L = V_s - V_o} \rightarrow$ in off time it is always -ve value.

discharging when switch is off

$V_o - V_s = L\frac{di}{dt}$

$\frac{V_o - V_s}{L} = \frac{\Delta i_L}{\Delta t}$

$$\boxed{\frac{V_o - V_s}{L} t_{off} = \Delta i_L}$$

$\boxed{\int_0^T V_L \, dt = 0} \rightarrow$ voltage balance expression

↳ Always voltage of the inductor will zero.

$\int_0^{T_{on}} V_L \, dt + \int_{T_{on}}^{T} V_L \, dt = 0$

$\int_0^{T_{on}} V_s \, dt + \int_{T_{on}}^{T} (V_s - V_o)_{t_{on}}^{T} \, dt = 0$

$V_s(t_{on}) + (V_s - V_o)(T - t_{on}) = 0$

$V_s \cancel{t_{on}} + V_s t - V_s \cancel{t_{on}} - V_o t + V_o t_{on} = 0$

$V_s t = V_o t - V_o t_{on}$

$V_s t = V_o (t - t_{on})$

$V_s t = V_o t_{off}$

⇒ $V_s T = V_o T(1-D)$

$V_o = \frac{V_s \cancel{T}}{(1-D)\cancel{T}}$

$$\boxed{V_{o_{avg}} = \frac{V_s}{1-D}}$$

$\boxed{V_o > V_s}$ (Assumed)

Buck Boost = $\left(\frac{D}{1-D}\right)$ $V_s = V_o$
Converter chopper

$T_{on} + T_{off} = T$

$T_{off} = T - T_{on}$

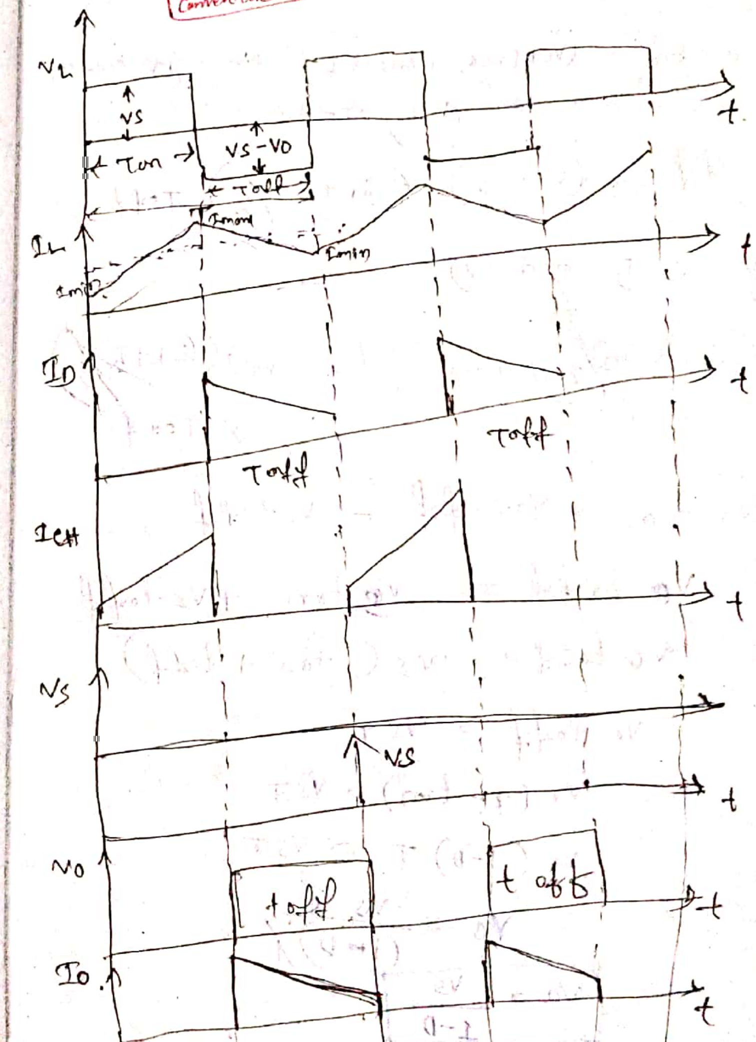
$D = \frac{T_{on}}{T}$

$T_{on} = TD$

$T_{off} = T - TD$

$\boxed{T_{off} = T(1-D)}$

$\boxed{0 < 1 - D < 1}$



connect

OR Avg of Vo.

During ON time

$CH_{ON} = (\text{Voltage across } L)(\text{average current through } L)\, T_{off}$.

$CH\ ON = V_s\left((I_1 + I_2)/2\right) T_{on}$ —①

During off time

$CH\ off = (\text{Voltage across } L)(\text{average current through } L)\, T_{off}$

$CH\ off = (V_0 - V_s)\left(I_1 + I_2/2\right) T_{off}$ —②

equating eq ① and ②

$$V_s\left(\cancel{(I_1 + I_2)/2}\right) T_{on} = (V_0 - V_s)\left(\cancel{(I_1+I_2)/2}\right) \times T_{off}$$

$$V_s T_{on} = V_0 T_{off} - V_s t_{off}$$

$$V_0 t_{off} = V_s t_{on} + V_s t_{off}$$

$$V_0 t_{off} = V_s (t_{on} + t_{off})$$

$$V_0 t_{off} = V_s T$$

$$V_0 (T - t_{on}) = V_s T$$

$$V_0 (1-D) T = V_s T$$

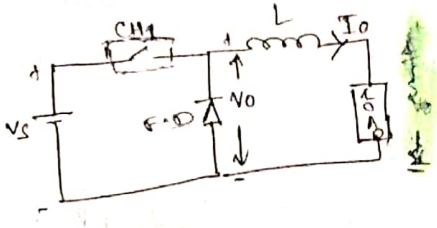
$$V_0 = \frac{V_s \cancel{T}}{(1-D)\cancel{T}}$$

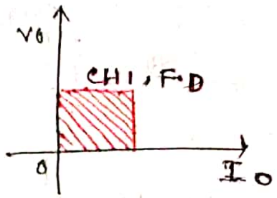
$$\boxed{V_0 = \frac{V_s}{1-D}}$$

According to quadrant rule choppers are classified

(1) Type 'A' or 1'st quadrant
(2) Type 'B' or 2nd quadrant
(3) Type 'C' or two quadrant type 'A'
(4) Type 'D' or two quadrant type 'B'.
(5) Four quadrant type 'E'

① First quadrant or, type A chopper.

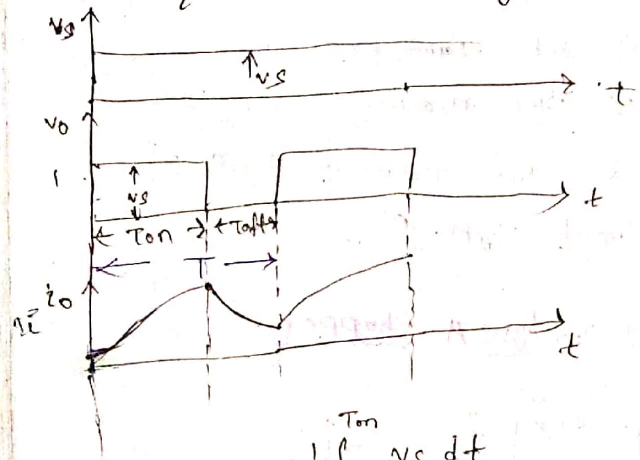




- when chopper CH1 is on, <u>Vo = Vs</u> and current Io is flow through the Load.
- when CH1 is off, <u>Vo = 0</u> but "io" in the load continues flowing in the same direction through free wheeling diode F.D.
- It is thus seen that average values of both load voltage and current i.e Vo and Io are always +ve. thats why it is called <u>1st</u> quadrant chopper.
- The power flow in type-A chopper is always from source to load. This chopper is also called. <u>Step down</u> chopper as average o/p voltage Vo is always less than the i/p dc voltage Vs.

~~② second quadrant, or type B chopper:~~

- It is called motoring mode of chopper.



$$V_o = \frac{1}{T}\int_0^{T_{on}} V_s\,dt$$

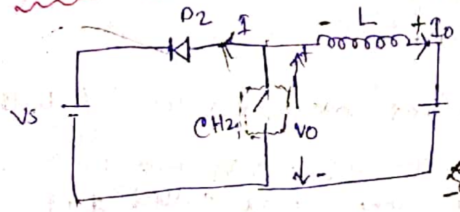
$$= \frac{V_s}{T}\int_0^{T_o} dt$$

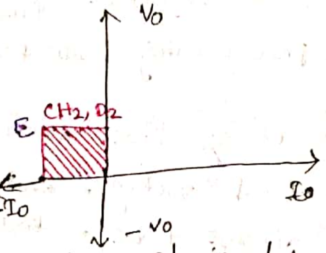
$$= \frac{V_s}{T} T_{on}$$

$$\boxed{V_o = D\,V_S}$$

$$\boxed{D = 0 \text{ to } 1}$$

② second quadrant, or type B chopper:

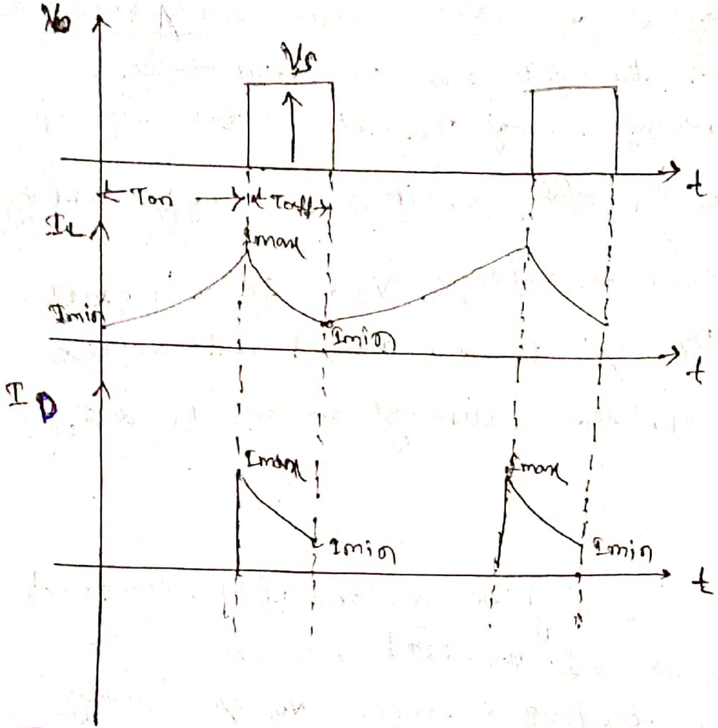




- In this chopper the load must contain a dc source E, like a battery (or a DC motor) in this chopper.

- when CH2 is on, $V_o = 0$ but load drives voltage E the current through L and CH2 inductance L stores energy during Ton .. on period of CH2.
- when CH2 is off, $V_o = (E + V_L)$ or $\left(V_o = E + L\frac{di}{dt}\right)$ exceeds source voltage Vs. As a result, Diode D2 is forward biased and begins conduction, thus allowing power to the source.

- Chopper CH2 may be on or off, current Io flows out of the load, current Io is treated as negative. since Vo is always positive and Io is negative, power flow is always from load to source. so it is operate in 2nd quadrant.
- As load voltage $V_o = \left(E + L\frac{di}{dt}\right)$ is more than source voltage Vs, type-B chopper is also called step-up chopper.
- Both type-A and type B chopper configuration have a common negative terminal between their I/P and O/P ckts.
- In second quadrant operation of class B chopper motor is in the regenerative breaking mode.



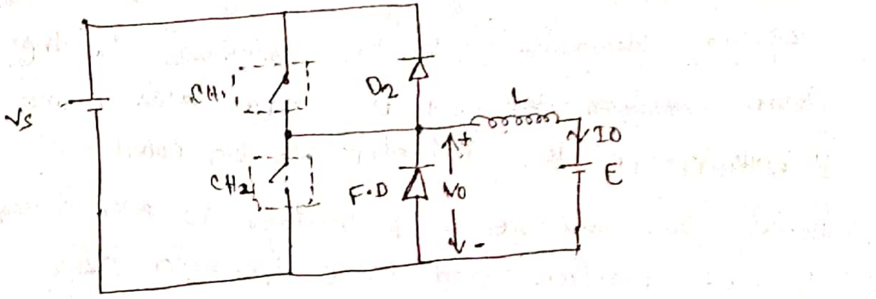
③ Two quadrant type-A chopper, or type-C chopper :-

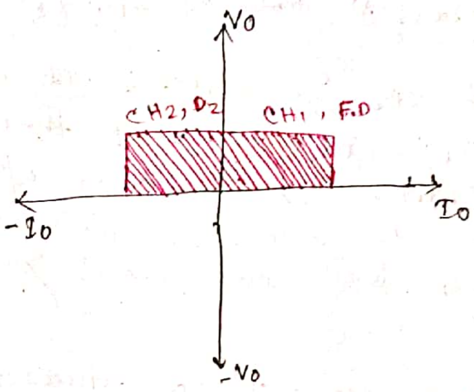
→ This type of chopper is obtained by connecting type-A and type B chopper in parallel.

→ The output voltage Vo is always positive because of the presence of free wheeling diode F.D across the load.

✱ ~~when switch is on or chopper CH2 is on~~ ~~freewheeling diode FD conducts~~

✱ To obtain first quadrant operation we should switch ON chopper CH1 and for getting second quadrant operation we should switch ON chopper CH2.





✱ case-1: when CH1 is switched ON/off :-

→ when chopper CH1 is switched ON, source Vs directly gets connected to the load and hence, load voltage Vo is equal to source voltage (Vo=Vs). The direction of load current is from source to load as shown in the ckt diagram which is assumed positive.

→ when CH1 is switched OFF, the free-wheeling diode FD comes in to the ckt as it gets forward biased and hence shorts the load.

→ Therefore, the output voltage Vo becomes zero. However, the "io" continues to die down through the F.D. and also same direction in the inductor to the load.

→ Hence the average o/p voltage Vo and current Io are positive and hence operation of chopper is in first quadrant. in fact it is the class 'A' mode of operation.

Case - 2 : when C2 is switched ON/OFF :

→ when chopper CH2 is switched ON, load DC source "E" drives current through CH2 and load. The direction of io current will be opposite direction, through the load, so it is assume negative.

→ out put voltage Vo is zero during this time.

→ when CH2 is made off, diode D2 gets forward beased and hence the current into the source from the load. The output voltage is Vs (Vo = Vs) in this time as the load is connected to the source through D2, during off time of chopper CH2.

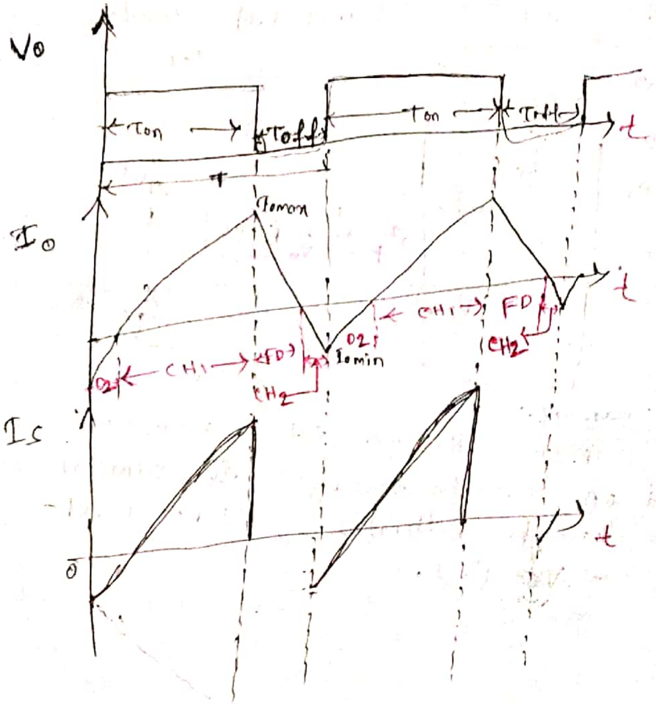
→ Thus the load current is always negative i.e. the operation of chopper is with in second quadrant. In fact it is the class-B mode of operation.

→ The average load voltage is always positive but the average load current may be positive or negative.

→ Therefore power flow may be from Source to load. (first quadrant operation) or load to source (second quadrant operation).

→ CHOPPERS CH1 and CH2 should not be ON simultaneously as this would lead to direct short circuit on the supply lines.

→ It is used for motoring and regenerative breaking of DC motors.



④ Type D chopper or two quadrant type B chopper :

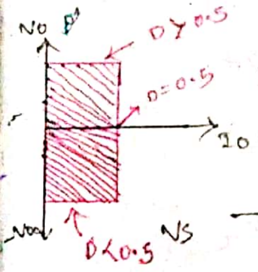
* This chopper works in first as well as fourth quadrant therefore the output current remain positive but output voltage may be either positive or negative.

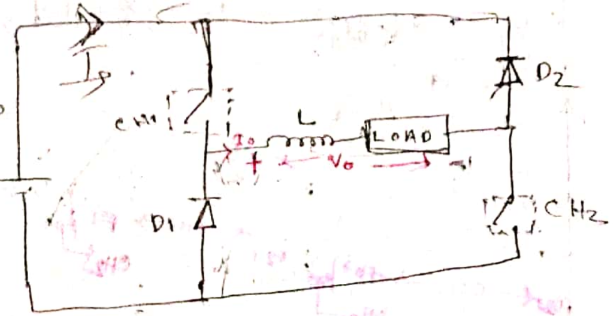
* The polarity of output voltage depends upon chopper ON time and chopper off time.

(D>0.5) if TON > Toff → out put voltage +ve.

(D<0.5) if TON < Toff → out put voltage negative

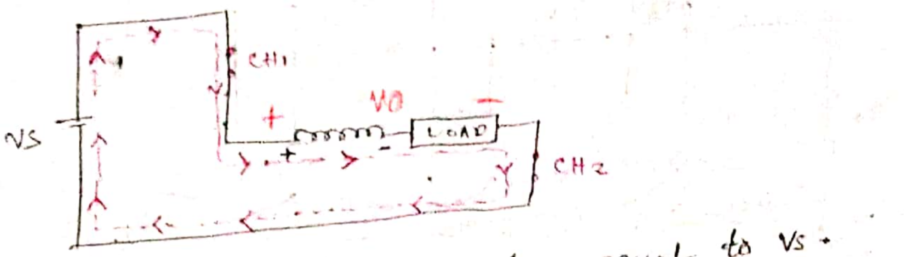
(D=0.5) if TON = Toff → out put voltage zero





First quadrant :

* when chopper CH1 and CH2 both are switched on simultaneously, the current flows through path (+)Vs — CH1 — Load — CH2 — Vs (−).

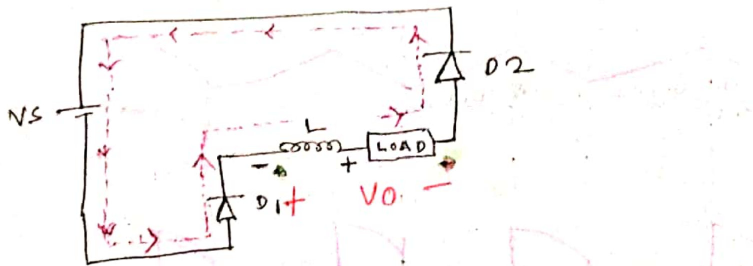


* The load across voltage equal to Vs. (Vo = Vs) and current increase exponentially.

* The chopper works in first quadrant because both the output voltage and output current are positive.

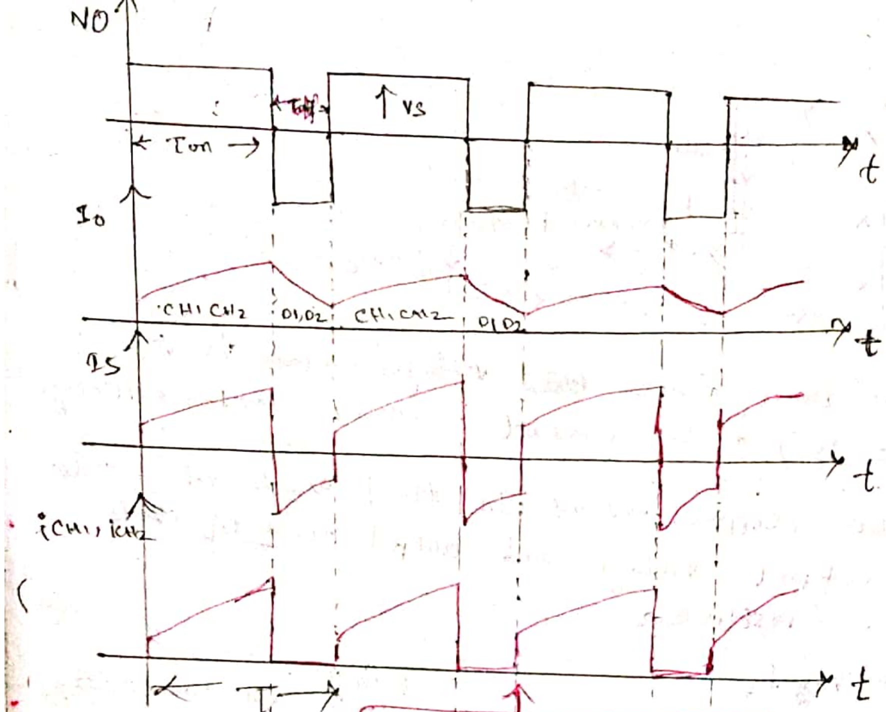
Fourth quadrant :

* when chopper CH1 and CH2 both are switched off simultaneously, the Diode D1 and D2 forward biased and current flows through path Load − D2 — (+)Vs. — Vs (−) — D1 — Load.

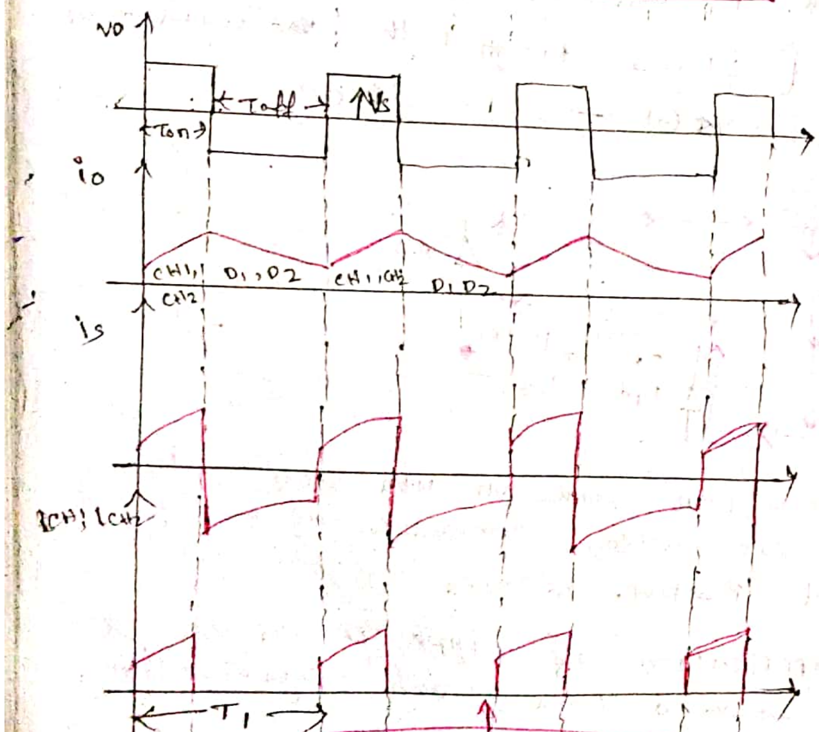


* The chopper works on 4th quadrant because the out put voltage negative and output current positive becomes positive.

* The application of type D chopper is in the forward motoring and regenerative braking of motor.



when TON > Toff



when TON < Toff

⑤ Four quadrant chopper, or type-E chopper :-

- A four quadrant chopper is a chopper which can operated in all the 4 quadrants.
- The power can flow either from source to load or load to source in this chopper.
- In first quadrant, a class E chopper acts as a step-down chopper, whereas in second quadrant it behaves as a step up chopper.
- It consist of four semiconductor switches CH1 to CH4 and four diodes D1 to D4 in antiparallel.
- Numbering of choppers CH1, ... CH4 corresponds to their respective quadrant operation.
- first quadrant operation, only CH1 is operated. and second quadrant operation, only CH2 is operated and so on.

First quadrant :-

For first quadrant operation, CH4 is kept ON, CH3 & CH2 is kept OFF and CH1 is operated.

when both CH1 & CH4 are ON simultaneously, the load gets directly connected to the source and hence the output voltage becomes equal to the source voltage. ($V_o = V_s$). It may be noted that the load current flows from source to load. as shown by the direction of i_o.

→ when CH1 is switched off, the load current (+ve) free wheels through CH4, D2.

→ During this period, the load voltage and current remains positive.

→ Thus, both the output voltage Vs and load current Io are positive and hence, the operation of chopper is in first quadrant.

→ It may be noted that, class-E chopper in operates as a step down chopper in this case.

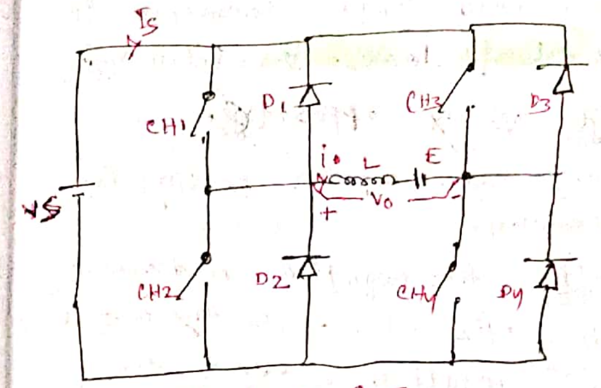
(second quadrant operation :

→ To obtain second quadrant operation, CH2 is operated while keeping the CH1, CH3 & CH4 off. when CH2 is ON, the DC source in the load drives current through CH2, D4, E and L. Inductor L stores energy during the on period of CH2.

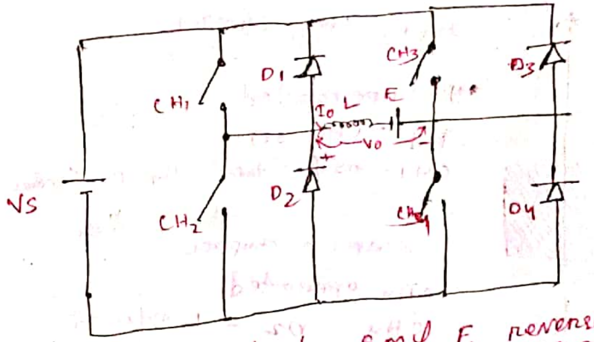
→ when CH2 is turned off, current is fed back to the source through D1, D4. it should be noted at this point that $(E + L\frac{di}{dt})$ ~~is more than the source voltage~~ Vs.

$(V < E + L\frac{di}{dt})$.

→ As load voltage "Vo" is +ve and "Io" is -ve, It is second quadrant operation of chopper. Here load is transferring power to the source. so it is the configuration of step-up chopper.



Load Emf E



Load Emf E reversed

Third quadrant operation :

→ To obtain third quadrant operation, both the load voltage and load current should be negative. It is due to by changing the polarity of Emf "E" in load.

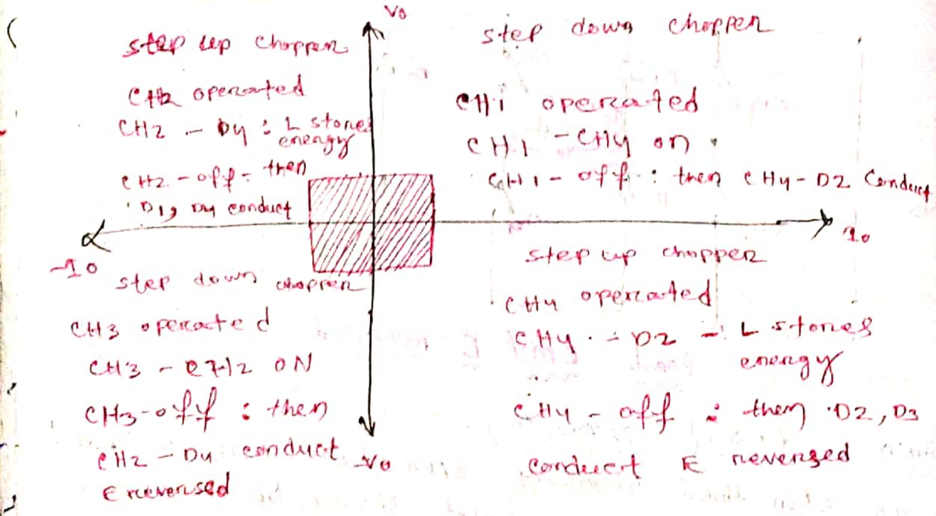
→ For third quadrant operation, CH1 & CH4 is kept off, CH2 is kept ON and CH3 is operated.

(Load → CH2 → Vs → CH3 → Load)

→ when CH3 is ON, Load gets connected to source voltage "Vs". But here the polarity of load voltage. Vo is opposite. so that both Vo, io are negative leading to 3rd quadrant operation.

→ when CH3 is off, the negative load current freewheels through CH2, D4. In this manner Vo, Io both are negative. Here the chopper operates in third quadrant and here chopper act as step down chopper.

Fourth quadrant operation-:



Fourth quadrant operation:

→ To obtain 4th quadrant operation, CH4 is operated while keeping CH1, CH2 & CH3 off. The polarity of load emf "E" need to reversed.

→ when CH4 is turned ON, positive current flows through CH4, D2, L and E.

→ inductance L stores energy during the time CH4 is ON.

→ when CH4 is off, current fed back to the source through diodes D2, D3.

→ Here load voltage is negative but the load current is always positive.

→ This leads the chopper operation in 4th quadrant. Here, power is fed back to the source from load and chopper act as a step up chopper.

Control modes of chopper-:

→ There are two kinds of control strategies used in DC chopper namely ① time ratio control and ② current limit control.

→ In all situations, the average o/p voltage can be changed. the differences between these two can be discussed below.

① **Time ratio control-:**

In the time ratio control the value of the duty ~~cycle~~ ratio $D = \frac{T_{ON}}{T}$ is changed. Here D is duty cycle.

→ There are two ways to achieve the time ratio control namely (a) variable frequency and (b) constant frequency operation.

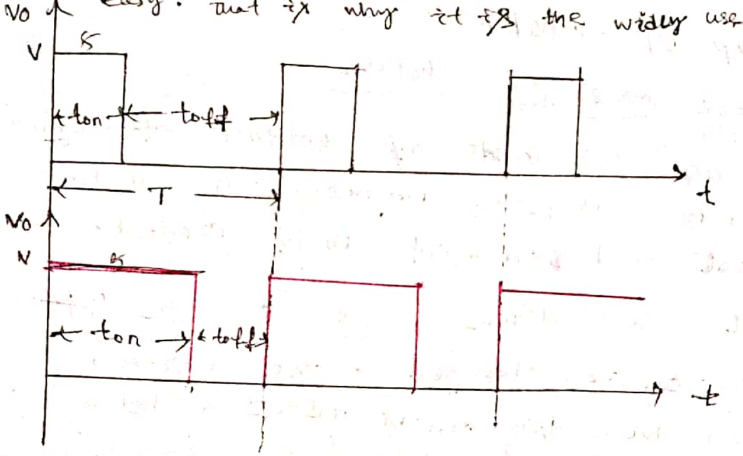
(b) constant frequency operation:

⇛ In contant frequency operation, the ON time "TON" is changed, keeping the frequency, i.e $f = \frac{1}{T}$, or time period "T" constant.

→ This operation is also named as PWM (Pulse width modulation control).

→ Hence the output voltage can be changed by changing ON time.

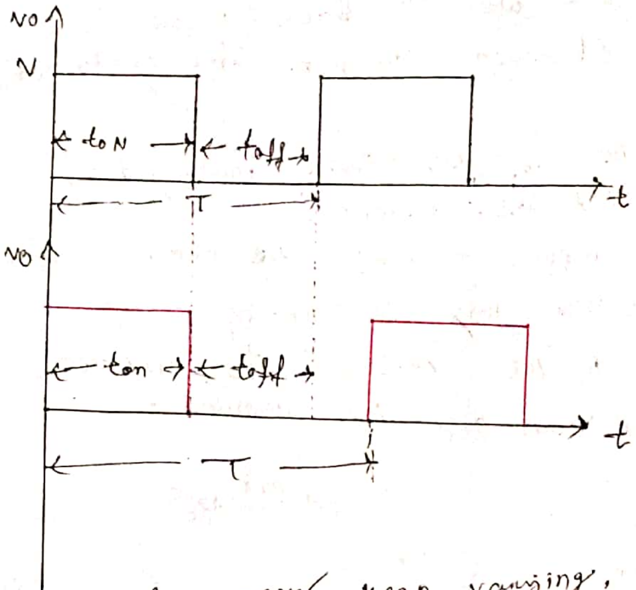
→ As the frequency is fixed the design of filter is easy. That is why it is the widely used method.



(a) variable frequency operation:

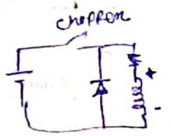
In this operation, frequency $(f = \frac{1}{T})$ is changed, then the time period 'T' is also changed.

→ This is also named as (FM) frequency modulation control. In both cases, the o/p voltage can be changed with the change in duty ratio.



* so frequency keep varying, that is why; it is difficult to design filter for this control.

② current limit control:



→ In a DC to DC converter, the current value varies between the maximum as well as the minimum level of constant voltage. In this method, the DC to DC converter is turned ON and off confirming that current is preserved constantly between the upper limits and also lower limits.

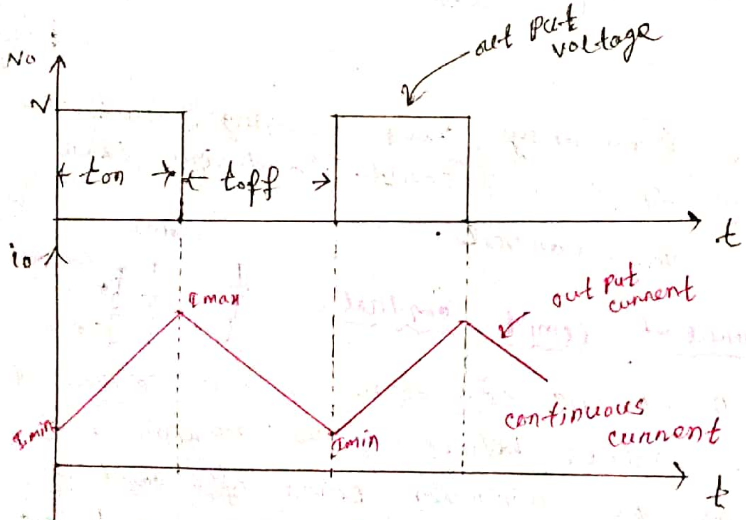
* it is satisfied of load is energy storage element.

→ The ON & off time of the chopper ckt adjust automatically.

→ when the current increase beyond the upper limit the chopper is turned off. The load current free wheels and starts to decrease. when it falls below the lower limit the chopper ckt is turned ON.

→ The amplitude of the ripple controlled by proper limits of current.

→ The lower ripple current, the higher chopper frequency. By this switching losses increase. In this process discontinuous conduction can also be avoided.



* Inverter :-

* Inverter is an electronic circuit which converts DC power into AC power.

Series inverter :-

→ The inverter ckt in which the commutating elements L and C are connected in series with the load to form under damped ckt. This ckt is called series inverter. This ckt is also called self commutated or load commutated inverter.

→ It is called load commutated inverter because the load components (L & C) is responsible to turn off the thyristor.

→ It is called self commutated inverter because in this ckt anode current itself become zero, resulting the thyristor turns off.

→ It's operation is same like as class - A commutation.

→ series inverter operating at high frequency 200 Hz to 100 KHZ.

→ Here, the value of L and C is choose in such a way the R, L & C formation underdamped ckt.

Power circuit diagram:

→ The power ckt diagram of the series inverter are shown in fig.

→ The SCR T_1 & T_2 are turned on at regular interval in order to achieve desirable output voltage and frequency.

→ The T_2 is kept off at starting condition. ~~and~~ and the polarity of capacitor is shown in figure(A).

→ The ckt consist of L and C connected in series with load (R).

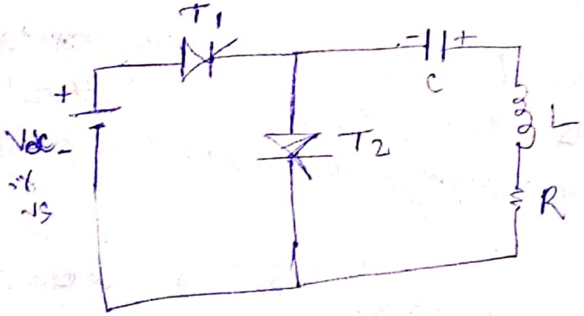


Fig-A

Operation:

Mode-1

→ The voltage Vs applied to RLC series ckt as soon as the SCR T_1 is turned on.

→ The polarity of capacitor changing is shown in the fig B.

→ T_2 is turned off.

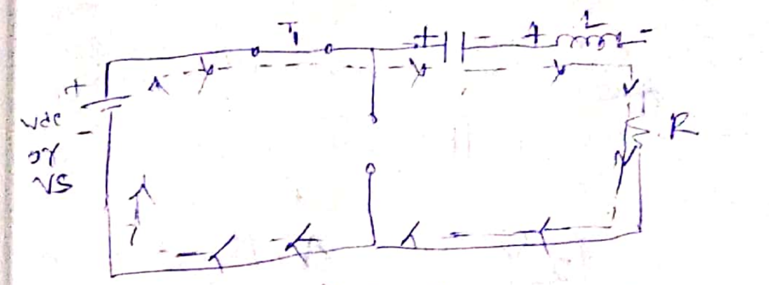


fig - B

→ So current flow from supply Vs to t_1 to load to back to Vs.

→ The nature of the load current is alternating due to under damped ckt. $\boxed{R^2 < \frac{4L}{C}}$

→ So this time the capacitor (C) starts charging gradually from (-Vs) to its maximum voltage. This time inductor also get charge.

→ when the load current becomes maximum the voltage across capacitor becomes +Vs. at load current becomes zero

→ when the load current the voltage across capacitor point "a". becomes +2Vs:

→ Then the load current becomes zero the thyristor T_1 automatically turns off at point "a".

mode-2 → The load current becomes **zero** from a to b as the SCR T_1 turns off in this time period.

→ The SCR T_1 and T_2 are turned off in this time duration and voltage across capacitor becomes equal to $2V_S$.

mode-3

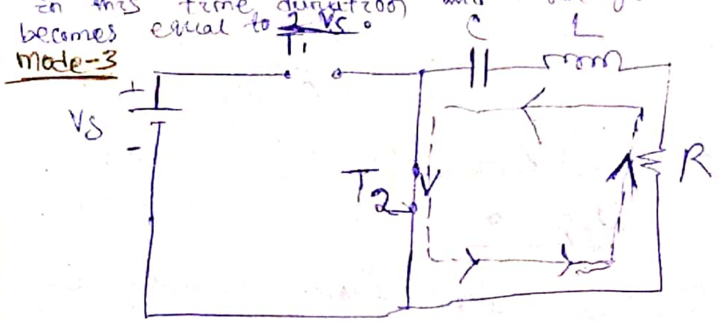


fig-e

→ In this mode we give firing pulse to thyristor T_2. So, T_2 get turned on.

→ In this time capacitor start discharge its energy from $+2V_S$ to $-V_S$ through thyristor T_2 and R-L ckt.

→ Due to capacitor discharging reverse current flow across the load.

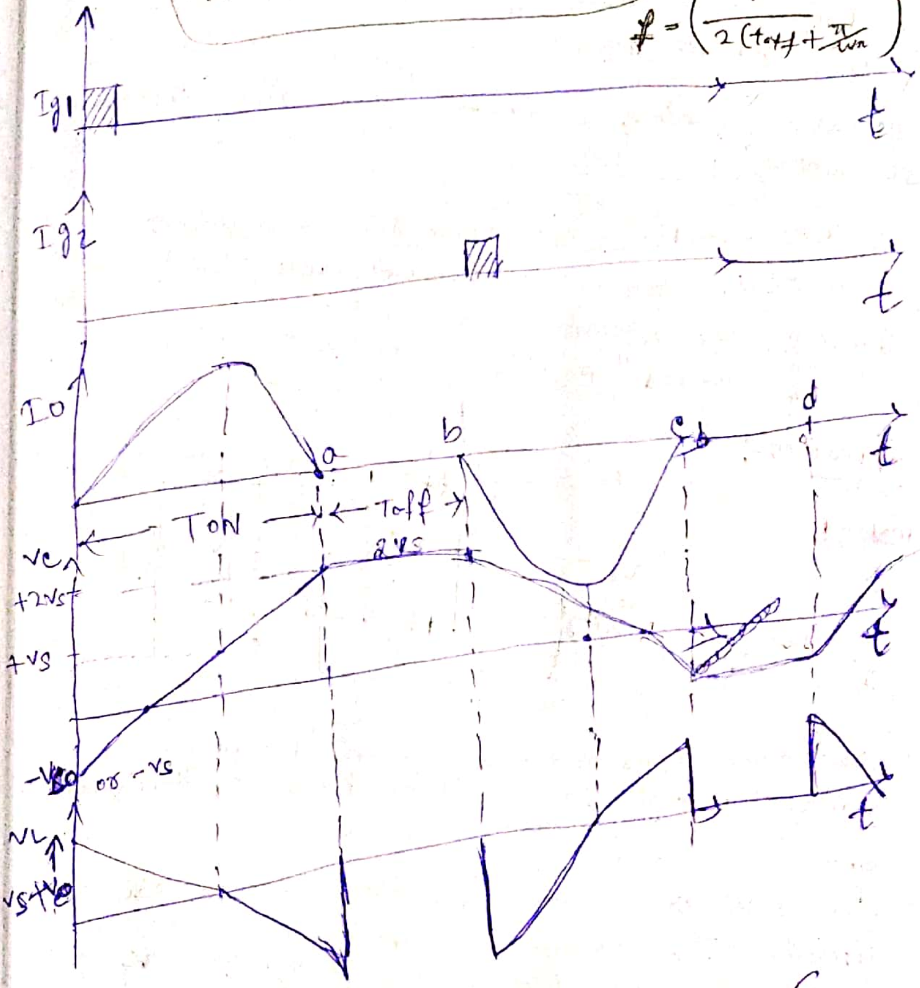
Now at point "C" the thyristor T_2 turns off due to the load current becomes zero.

→ The thyristor T_2 turns off during point c to D and thyristor T_1 again turns on. In this way cycle repeat.

→ Now we see in the waveform the time duration ab and cd is called as dead zone.

$$\boxed{w_r = \sqrt{w_0^2 - \xi^2} \qquad w_0 = \frac{1}{\sqrt{LC}}}$$

$$f = \left(\frac{1}{2\left(t_{off} + \frac{\pi}{w_r}\right)}\right)$$



Application:-

→ It is used high frequency applications (200 Hz to 100 KHz) because it generate high sinusoidal wave form.

→ frequency induction heating.

→ It is used for fluorescent lighting.

→ used in sonar transmitter.

→ used in ultrasonic generator.

Single Phase parallel inverter :-

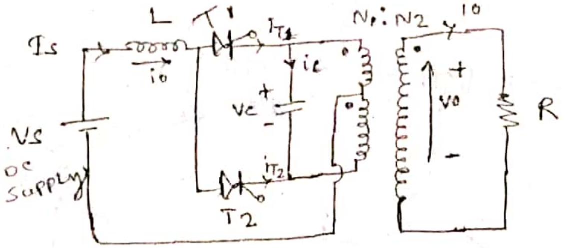
⇛ A Parallel inverter is used to ~~practice~~ convert from DC to AC.

→ It also produce a square - wave form from a dc supply.

→ In this inverter the commutating element capacitor comes in parallel with the Load during the operation of inverter. it is called " parallel inverter "

operation :-

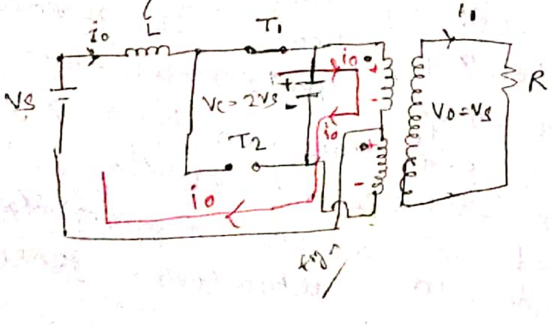
mode-1



→ This mode begins when T1 is fired and current flow's through the inductance L and the thyristor t1.

→ when SCR is turned on, a d.c voltage Vs appears across half of the transformer primary, which means, the total primary voltage is 2Vs. hence the capacitor is charged to 2Vs.

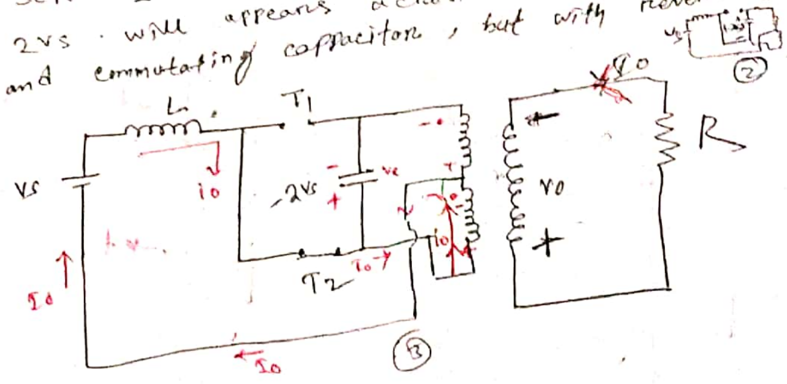
mode-2



mode-2

* This mode begins when thyristor T_2 is fired. when T_2 is turned on the commutating capacitor applies voltage $(-2V_s)$ (reverse voltage) appear across T_1, it will be turned off.

→ SCR T_2 will now be conducting and the voltage 2Vs will appears across the transformer primary and commutating capacitor, but with reverse polarity.

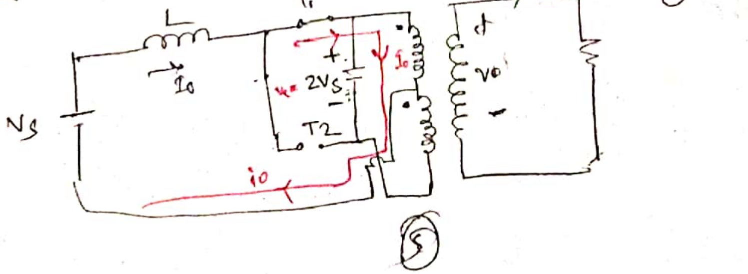


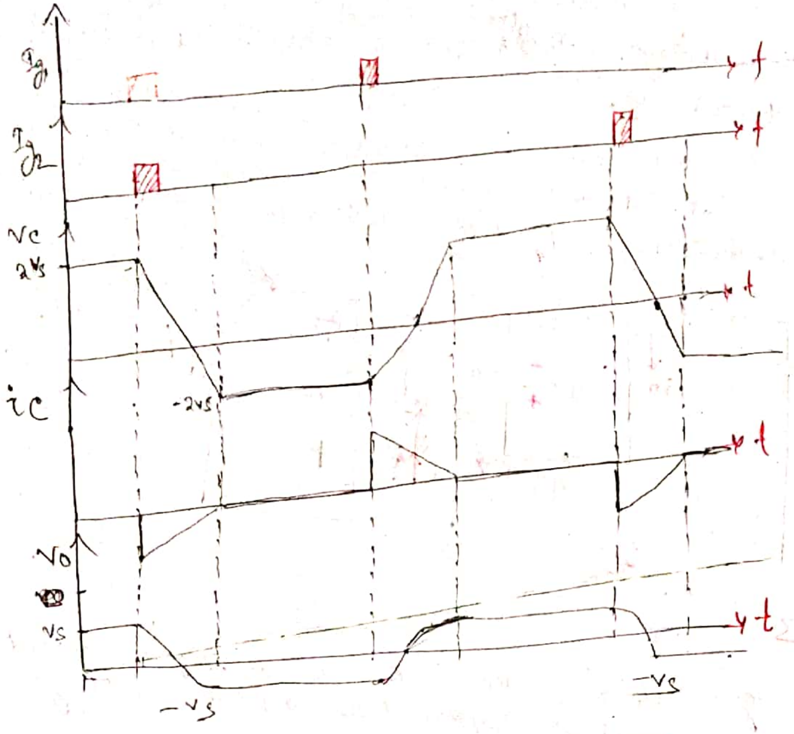
Mode - 3 :-

→ During mode 3, the SCR T_1 is again turned on. commuting capacitor applies voltage (reverse) $-2V_s$ to appear across T_2.

→ when this reverse voltage is applied for sufficient time across T_2, it will be turned off.

→ If trigger pulse applied periodically to alternate thyristors an approximately rectangular voltage wave form will be obtain at transformer out put terminals.





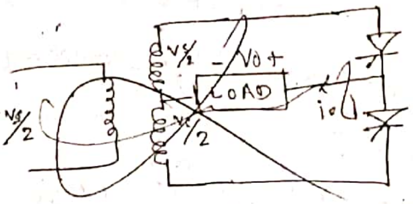
Single - Phase Bridge Inverters :-

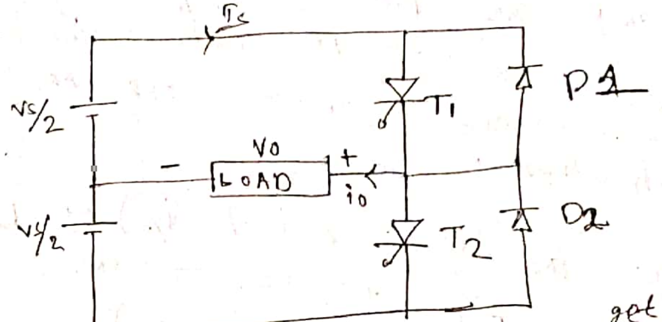
- There are two types (i) single phase half bridge inverter.
  (ii) single phase Full bridge inverter.

- In these circuits below two diagrams, the circuitary for turning on or turning off of the thyristors is not shown in the figure.

Single phase half bridge inverter :-

Here, two thyristors T_1 & T_2, two diodes D_1 & D_2 are used.





- First of all ; when we ~~getting~~ ~~A signal~~ get pulse applied trigger pulse I_{g1} to Thyristor T_1. Then the thyristor t_1 start to conducting from $0 < t \leq (t/2)$. or (0 to $t/2$ times)
- During this time T_1 conducts, load is directly connected to source "$V_s/2$" on the upper arm.

$$\boxed{V_o = \frac{V_s}{2}}$$

→ As soon as i_{g1} is removed at time $t = T/2$, thyristor T_1 gets turned off. It may be seen from the wave form,

→ Such time i_{g2} is applied and hence thyristor T_2 is turned ON.

→ Thus, the load gets directly connected to the source ($V_s/2$) on the lower arm,

→ Note that the polarity of o/p voltage across o/p terminal on the ~~source~~ upper arm & lower arm are opposite to each other.

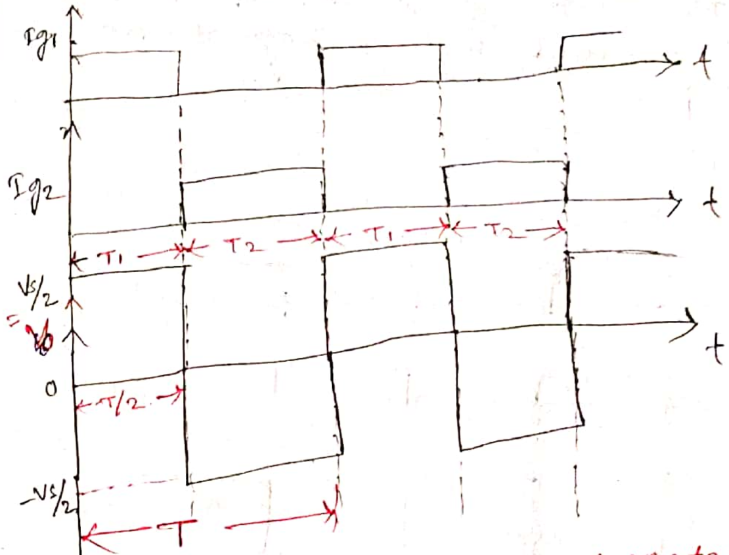
→ During the time period $(T/2) < t \leq T$ or $(T/2$ to $T)$, the T_2 thyristor is ON, the o/p voltage is $(-V_s/2)$.

$$\boxed{V_0 = -\frac{V_s}{2}}$$

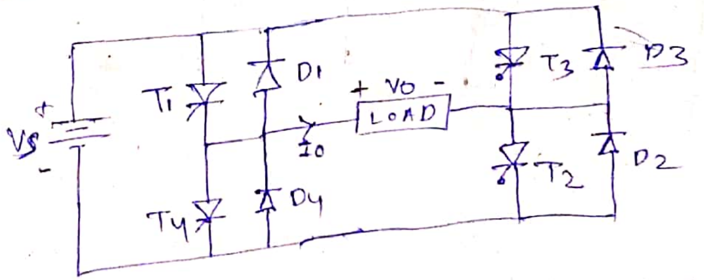
→ Here the frequency of the o/p voltage controlled by varying the time period "T".

→ Here there is no need to put D_1 & D_2 as o/p voltage and current are always in phase. Due to resistive Load.

→ But in other ~~load~~ than purely resistive load, i_0 and V_0 are not in phase to each other. For such case the diode connected in anti-parallel with the thyristor will allow the current to flow when main thyristor is turned off.



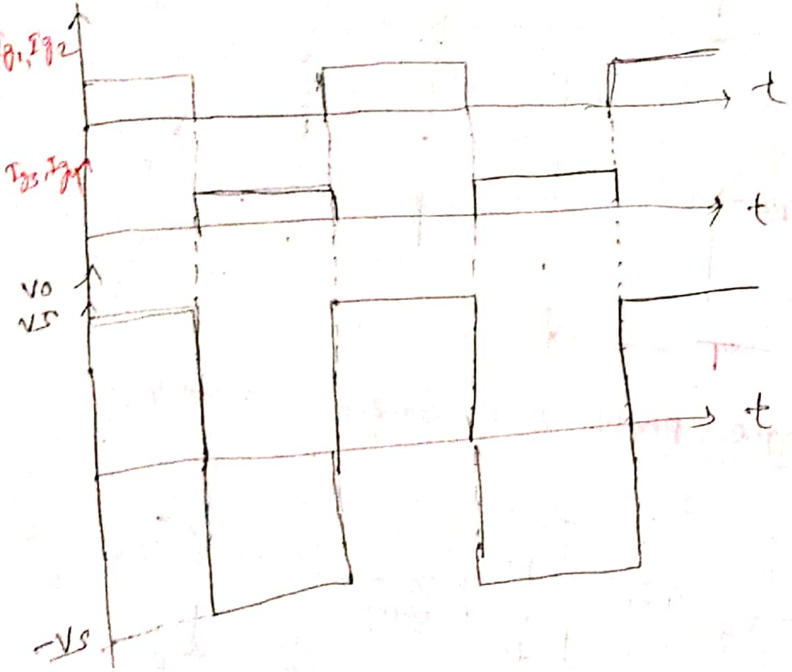
② Single phase full bridge inverter :-



→ Diode D_1, D_2, D_3 and D_4 are called feedback Diodes and they functions only when the load is other than Resistive Load.

* For Full Bridge inverter, when T_1, T_2 conduct, load voltage is V_s and when T_3, T_4 conduct load voltage is $-V_s$.

→ Here the frequency of the output voltage canbe controlled by varying the periodic time T.



cyclo · converter:

cyclo converter:

→ It is a device which converts input power at one frequency to output power at different frequency. It also known as cyclo inverter.

→ It converting AC Power from one frequency to AC Power at another frequency. This process is known as AC to AC conversion.

APPLICATION:

- → speed control of high power AC drive.
- → induction heating.
- → static Var compensator
- → For converting variable speed alternator voltage to constant frequency o/p for use as power supplies in Air crafts or ship boards.

→ There are two types of cyclo converter

① step up cycloconverter ($F_o > F_s$)

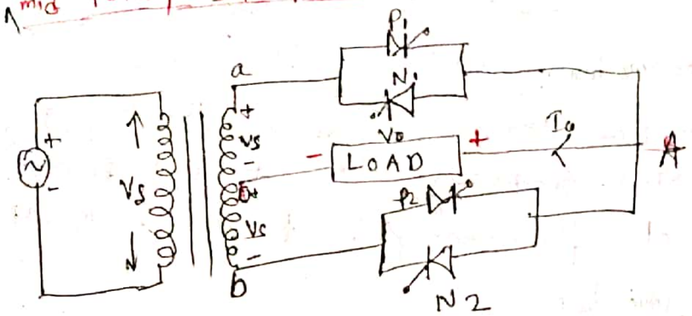
② step down " ($F_o < F_s$)

① step up cyclo converter:

① mid point type

② Bridge type

① 1φ mid point step up cyclo converter :-



→ It consist of a single Phase transfer, ~~with~~ centre tap of mid point on the secondary winding, and 4 thyristors,

→ Two of these P1, P2 are for +ve group and another two of these N1, N2 are for -ve group.

→ Load is connected between secondary winding mid point 0 and terminal A.

→ During +ve half cycle terminal "a" +ve with respective "b". This time both P1 and N2 are forward baised from wt = 0 to π.

→ So that Load voltage is +ve with terminal A positive and "0" negative.

→ At instant wt1, P1 is force commutated and Forward-biased thyristor N2 is turned on So that Load voltage is +ve with "0" terminal and "A" -ve terminal.

→ At wt2, N2 is force commutated and P1 is turned on, the load voltage is now +ve with "A" and -ve with '0' terminals.

→ again at wt3, N2 is on and P1 is now force commuted. Load voltage is now -ve with A and +ve with '0' terminal.

→ Such process continue from 0 to π.

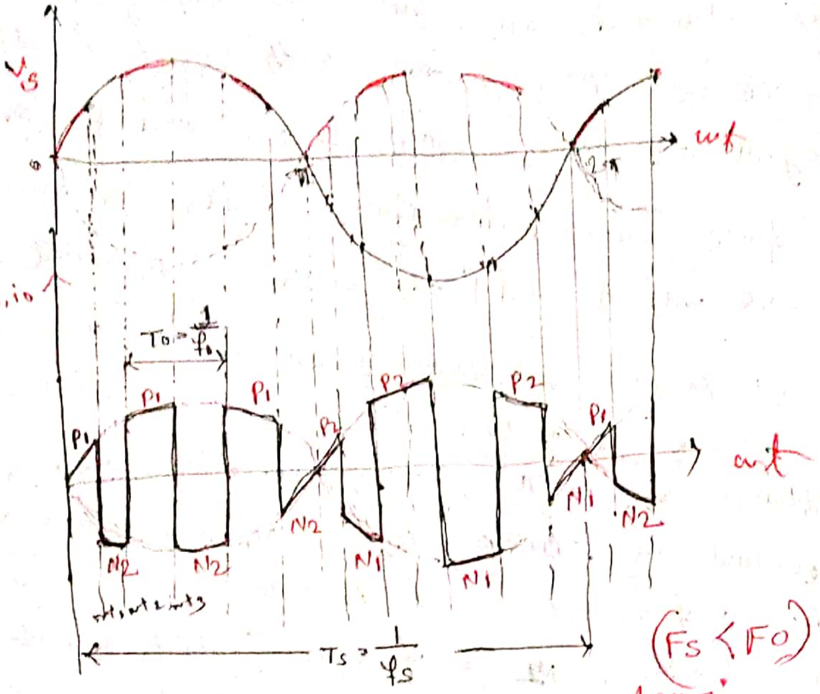
During -ve half cycle,

→ After wt = π, terminal 'b' is +ve w.r.t terminal 'a'. Both P2 and N1 are Forward biased from wt = π to 2π.

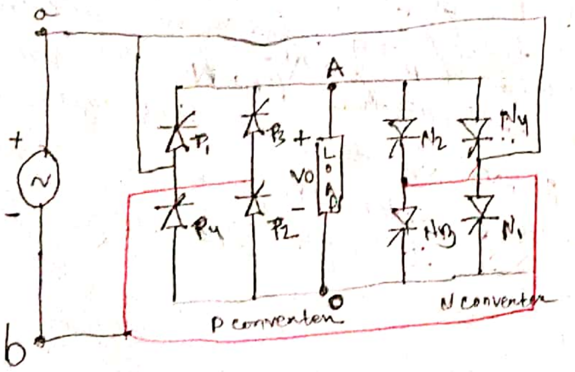
→ At wt = π, N2 is force commutated, then P2 is ON.

→ At time instant P2 is force commutated and after some time SCR N1 is turned on and the P2 is ON. P1, N2 for +ve N1 force commuted thyristor

→ In this manner, the -ve half cycle and P2, N1 in half cycle and so on are switched alternately between +ve and -ve cycle at a high frequency.



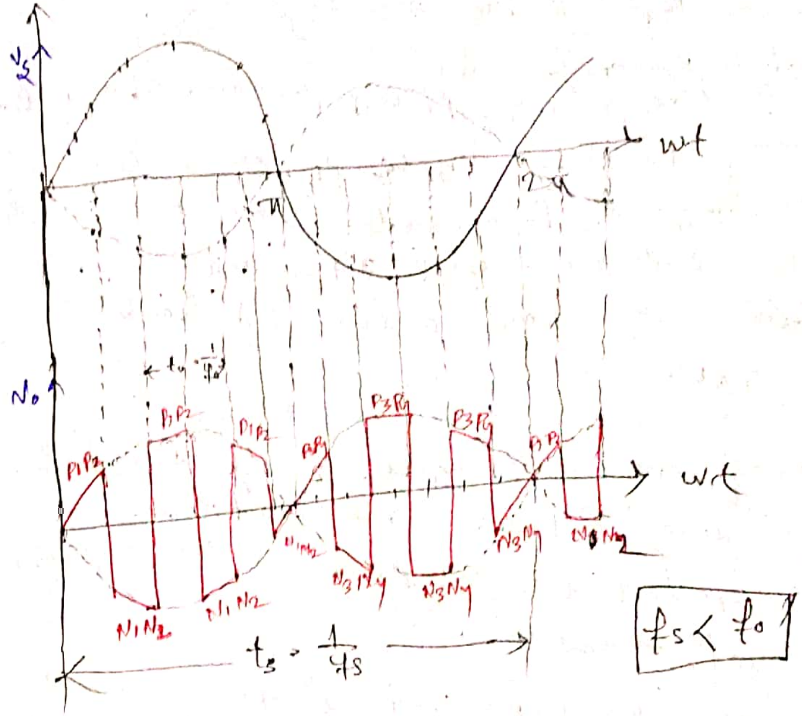
① Bridge type step up cyclo converter :



1st
$P_1\ P_2$ conduct
$N_1\ N_2$ force conduction
2nd
$N_1\ N_2$ conduct
$P_1\ P_2$ force conduct
3rd
$N_1\ N_2$ (b.c) then $P_3\ P_4$ conduct
$N_3\ N_4$ force conduction
4th $N_3\ N_4$ on
$P_3\ P_4$ force conduction

→ During +ve half cycle P_1, P_2 & N_1, N_2 are forward biased. (a +ve & b -ve)

→ During -ve half cycle P_3, P_4 & N_3, N_4 are f.B. (a -ve & b +ve)

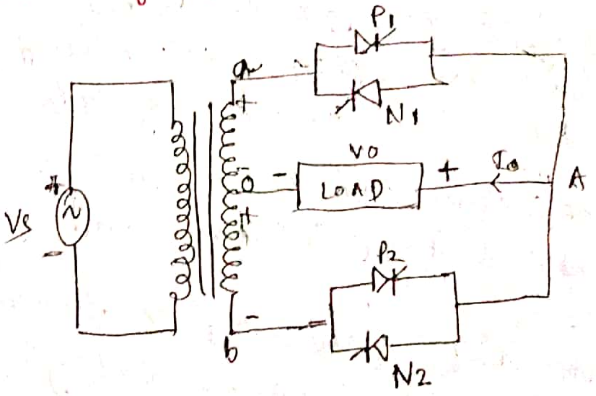


② Step down cyclo converter

(i) mid point step down c.c

(ii) Bridge point step down c.c

(i)



Here, we use a ~~step~~ single phase t/f with centre tap on the secondary side.

and 4 thyristor is used.

→ at time 0 to 2π P1 and P2 conduct or F.B.

→ During +ve half cycle P1 ~~is~~ F.B. and triggered P1 thyristor. such time the load across voltage A(+ve) and 'O' -ve. ~~[illegible]~~ Such time a +ve and -ve b terminal.

→ During -ve half cycle P1 is turned off by using natural commutation, then we applied +ve gate pulse to the thyristor P2 get turned ON.

→ Such time "a" (-ve) and "b" +ve terminal. The load across the voltage A +ve and 'O' -ve. ~~[illegible]~~

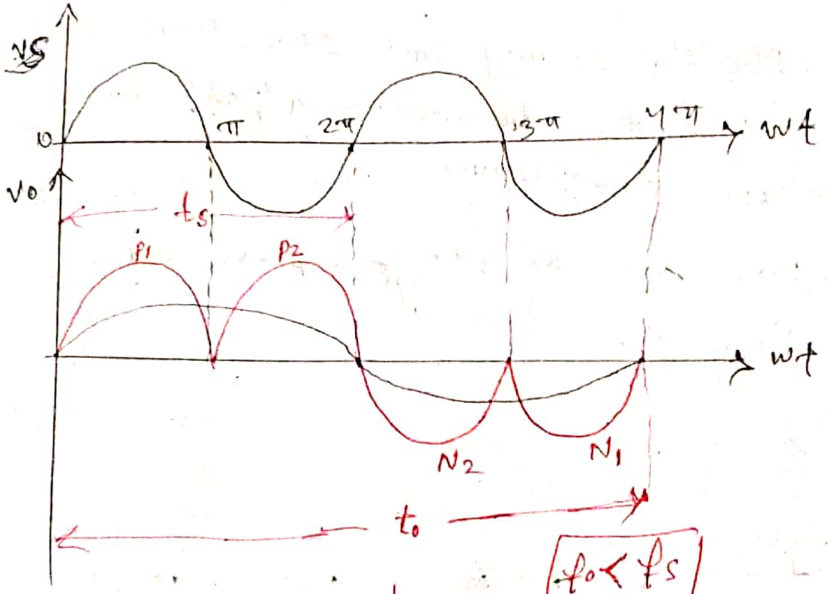
→ after the time instant from 2π to 4π,

→ During +ve half cycle N2 get turn on when we applied +ve get pulse to the N2 thyristor. such time a(+ve) and (b) -ve and load across voltage "O" +ve and A (-ve).

→ During -ve half cycle N1 is turn on, N2 is turn off Automatically by natural commutation.

→ Such time a(+ve) and b +ve terminal.

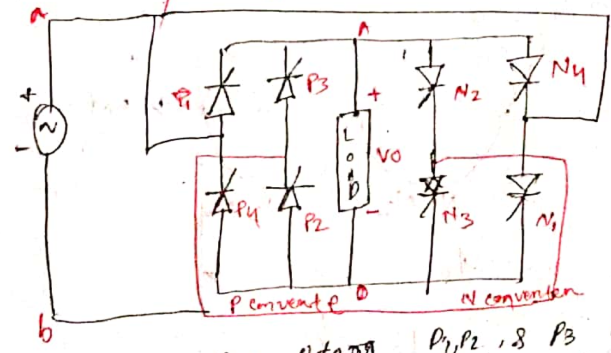
→ Load voltage across the Load "O" +ve and "A" -ve.



$f_o < f_s$

$t_s = \frac{1}{f_s}$, $t_o = \frac{1}{f_o}$

(ii) step down Bridge cyclo converter.



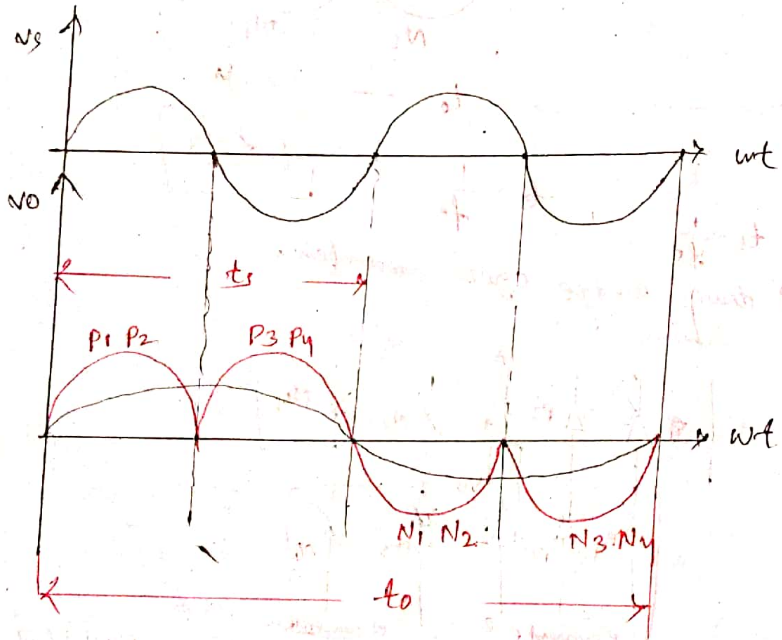
At a time 0 to 2π P1, P2, & P3 P4 conduct.

Hence, During +ve cycle P1 & P2 are conduct ~~[illegible]~~ and during -ve cycle P3, P4 conduct but P1 & P2 Automatically off by natural commutation. ~~[illegible]~~

→ the Load across Voltage 'A' +ve and 0-ve after the time instant 2π to 4π. $N_1 N_2$ & $N_3 N_4$ conduct.

→ During +ve half cycle N_1 & N_2 conduct and During -ve half cycle $N_3 N_4$ conduct but such time N_1 & N_2 Automatically turn off due to natural commutation.

→ Load across the voltage (A) -ve and 'O' +ve.



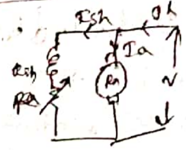
$t_s = \frac{1}{f_s}$ $t_o = \frac{1}{f_o}$

$\boxed{f_s > f_o}$

Power electronics-ckt use:

it is used Rolling mills, textile mills, cement mills, compressors, pumps, fans, elevator etc.

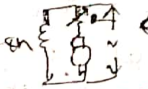
Factor affecting the speed of a d.c motor:



→ The flux ($\uparrow N \propto \frac{E_b}{\phi\downarrow}$)

→ E_b ($\uparrow N \propto E_b\uparrow$)

→ V_t



← $\boxed{E_b = V - I_a(R_a+R)}$

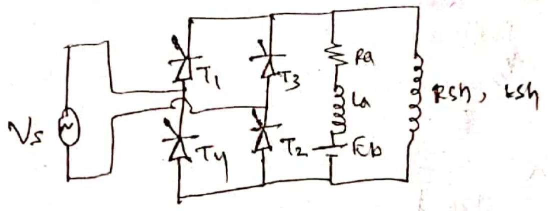
speed control of DC shunt motor using converter:

→ we know the the DC shunt motor is a constant flux motor like separately excited D.C motor.

→ so that the speed control of DC shunt ~~motor~~ method is similar to separately exicited D.C series motor.

Let take a 1φ full wave converter for the control of speed by varying armature voltage control method:

Let $V = V_{max} \sin\omega t$



- Here 4 thyristor are used for control the speed of D.C motor.
- At a time only two thyristor are operated.

Mode - I (+ve cycle)

when +ve half cycle is given T_1 & T_2 are conducted with providing gate pulse. So that the ~~control~~ current flows through Armature winding as well as field winding.

- but the armature ~~control~~ current is controlled by using external Resistance, similarly the field current is controlled by using external resitance their own.

→ For this mode the current path is
$V_s^+ \rightarrow T_1 \rightarrow$ armature & field winding $\rightarrow T_2 \rightarrow V_s^-$

mode - II (-ve half cycle)

when -ve half cycle is given the t_1 & t_2 are reversed baised and t_3, t_4 are forward biased & give to proper gate pulse with they are operated and again the current passes through both armature and field winding.

- And again both current are controlled by their external resistance.

We know: $E_b = \frac{P\phi NZ}{60A}$

$N \propto \frac{E_b}{\phi} \Rightarrow N = \frac{V - I_aR_a}{\phi}$

$N = \frac{KE_b}{\phi}$ $\quad N = \frac{V}{\phi} - \frac{I_aR_a}{\phi}$

$\Rightarrow T \propto \phi I_a$

$$\boxed{I_a \propto \frac{T_a}{\phi}}$$

$$\boxed{N = \frac{V}{\phi} - \frac{R_a \times T_a}{\phi^2}} \text{ — ①}$$

or $\boxed{N \propto \frac{V}{\phi} - \frac{R_a T}{\phi^2}}$

And for continous conduction

$$V_a = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_{max} \sin\omega t \, d(\omega t)$$

$$\boxed{V_a = \frac{2V_m}{\pi} \cos\alpha} \text{ — ②}$$

So the eqn. ② put in eqn ①.

$N = \frac{V}{\phi} - \frac{R_aT}{\phi^2}$ (For DC shunt motor ϕ is constant) $(K = \phi)$

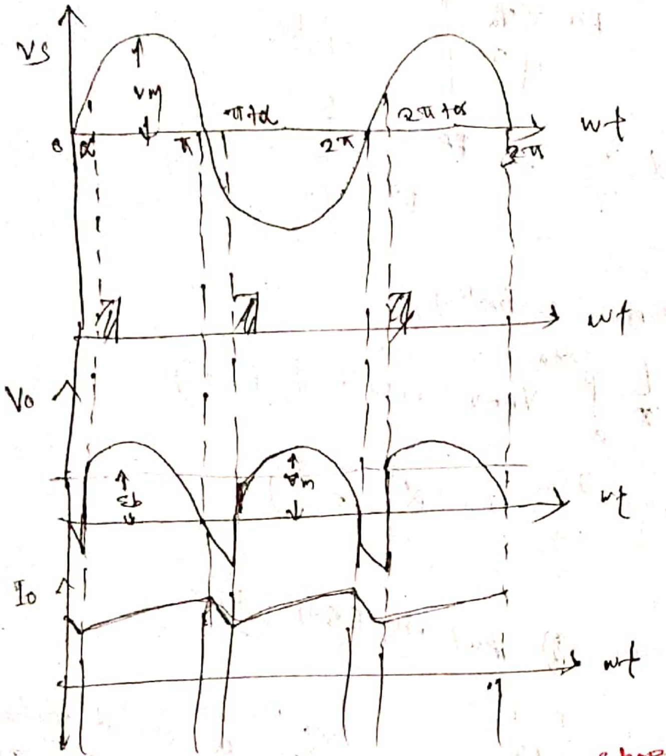
$= \frac{2V_m \cos\alpha}{K\pi} - \frac{R_aT}{K^2}$

$$\boxed{N = \frac{2V_m \cos\alpha}{K} - \frac{R_aT}{K^2}} \text{ — ③}$$

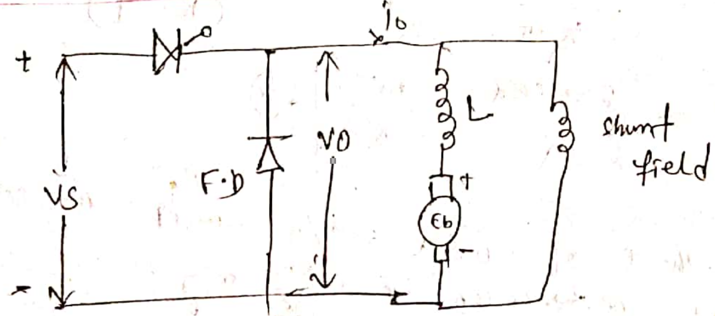
So that if $0 \leq \alpha \leq \pi/2$ then the speed of DC shunt motor. $N = \frac{V_m}{K}$ only.

If if $\pi/2 \leq \alpha \leq \pi$ then the speed of DC shunt motor $N = \frac{V_m \sin\alpha}{K}$

Let take $\frac{2V_m}{\pi}$ = max avg of DC shunt motor. this voltage value is equal to the rated terminal supplied voltage.



Speed Control DC motor using Chopper:

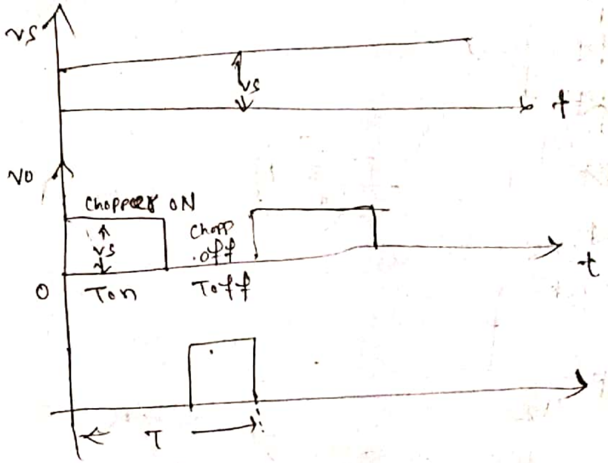


→ The fig shows the speed control of D.C shunt motor using chopper.

→ when the chopper is on, the output is applied to the motor and the energy will be stored in the inductance, which is connected in series with the armature winding.

→ It is expensive than the DC series motor.

→ During the off period of the chopper, the inductance energy will be utilized for the flow of current through the F.D.



The avg motor voltage

$$V_o = Vt = \frac{T_{on}}{t} \times V_s = DV_s$$

$V_o = D V_s$

D = Duty cycle

$$D = \frac{T_{on}}{t}$$

$$f = \frac{1}{t}$$

$V_o = f\, t_{on} V_s$

T_{on} = turn on time

V_o = o/p voltage

f = frequency

Vs = source voltage

List the factor effecting the speed of AC motor :-

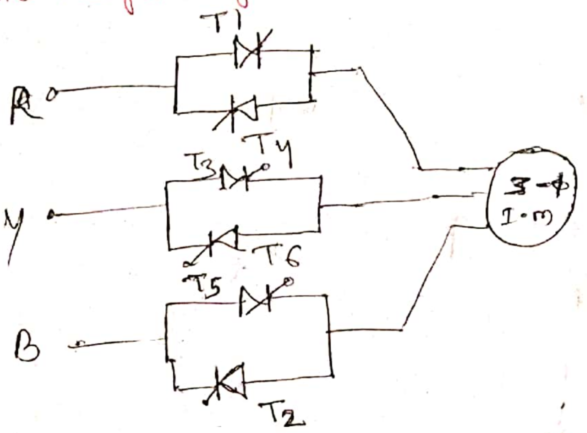
→ frequency and $\frac{V}{f}$

→ pole changing

→ Rotor resistance

→ Stator resistance

→ speed control of induction motor by using AC voltage regulator,



In 3φ I.m the voltage is control by using 3φ AC regulator.

$$T = \frac{3}{\omega_s} \cdot \frac{s E_2^2 \cdot R_2}{R_2^2 + (s X_2)^2}$$

$$T \propto E_2^2$$

→ AC voltage controlled are employed to vary the RMS value of the alternating voltage applied to a load ckt by ~~introducted~~ing introducing thyristors between the load and the constant voltage sources.

→ The RMS voltage applied load ckt is controlled by controlling the triggering angle of the thyristor in the ac voltage controller ckt.

→ An AC voltage controller is a type of thyristors is used to convert a fixed voltage, fixed frequency ac input supply to obtain a variable voltage AC o/p.

→ The AC power flow to the load and the RMS voltage is controlled by varying the trigger angle 'α'.

→ The 3φ load are connected in star or delta.

→ Resistance connected all 3φ are equal.

→ Two thyristor are connected back to back are used per phase, Here need six of 6 thyristors.

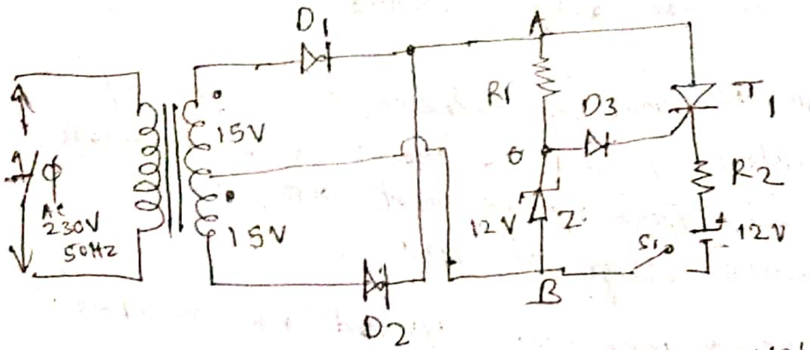
→ The current flow is bidirectional, with the current in one direction in positive half and other in negative half.

→ The thyristor are fired in the sequence of natural commutation time.

→ To turn the thyristors ON, the anode voltage must be higher than the cathode voltage. and also applied gate pulse to the thyristor.

→ The turning off the thyristor is its current falls to zero.

Battery charger ckt using SCR with the help of diagram.



- A 12V discharged battery is connected in series ~~the ckt~~ SCR: when switch S_1 is closed.

→ The single φ 230V supply is stepped down to (15-0-15 V) by a centre tapped transformer.

→ Diode D_1 and D_2 formes full-wave rectifier. Due to this, the pulsating d.c supply appears across terminals A and B.

→ The maximum voltage at point "o" is 12V due to zener Diode.

→ During each positive half-cycle when the potential of point o rises to sufficient level so as forward bias diode D_3 and gate-cathode junction of SCR F.B.

→ when the SCR is turn on, the charging current flows through battery & starts charging.

- when the battery is fully charged, the cathode of SCR is held at 12V.

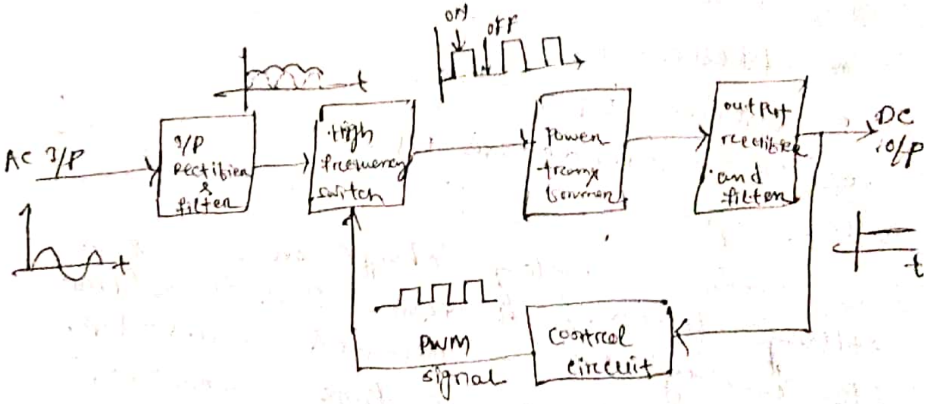
→ so, diode D_3 and gate-cathode junction of SCR cannot forward biased.

- Hence, no gate current is supplied and SCR is not triggered.

- In this way, after full charging further charging is automatically off.

what is smps :-

it stands of switch mode power supply. it is a device which provides power to any electrical load and involves some kind of switching action, it works on high frequency.

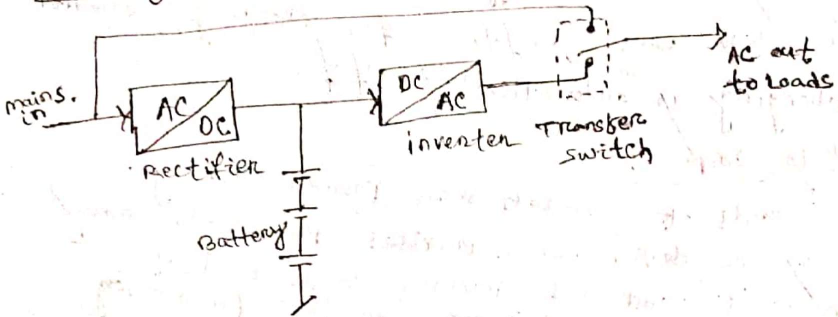


Working of UPS with block diagram.

Introduction -:

An uninterrupted Power supply. is an electrical apparatus. that provides emergency Power to a Load when the input Power source fails.

BLOCK diagram UPS -:



Types of UPS -:

There are three types of UPS are available.

- offline UPS
- online UPS.
- Line, interactive UPS

offline UPS -:

→ The mains to battery change over time or battery to mains changeover time in offline UPS is very Low as compared to Inverter.

→ In inverters change over time 500 mili sec. But offline UPS have of 3-8 mili sec.

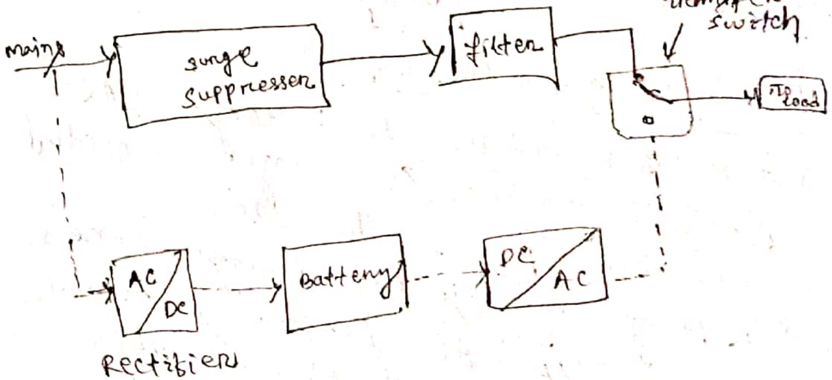
→ In a time when mains ac is present, inverter provides the output as is the input mains.

→ While, offline UPS has built Automatic Voltage Regulator (AVR) to regulate the output Voltage close to 220V ac.

→ offline UPS are normal weight UPS and are widely used for domestic computers.

→ when the Power failure occurs, the transfer switch will select the back-up source. Thus we can clearly see that the stand by system will start working only when there is any failure in mains. In this system, the AC voltage is first rectified and stored in the storage battery connected to the rectifier.

→ when Power breakage occurs, this DC voltage is converted to AC voltage by means of a power converter, and is transferred to the Load connected to it.

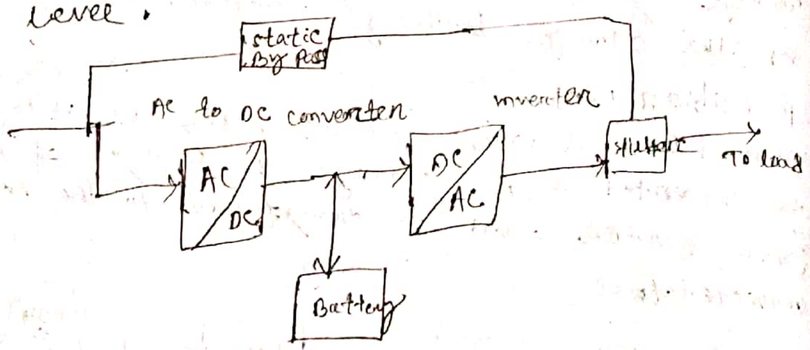


on-Line UPS -:

→ In this system of UPS, the system always remains on battery, whether mains ac is present or not.

→ When mains ac is present, it provides power to DC supply of inverter section as well as charger the battery simultaneously.

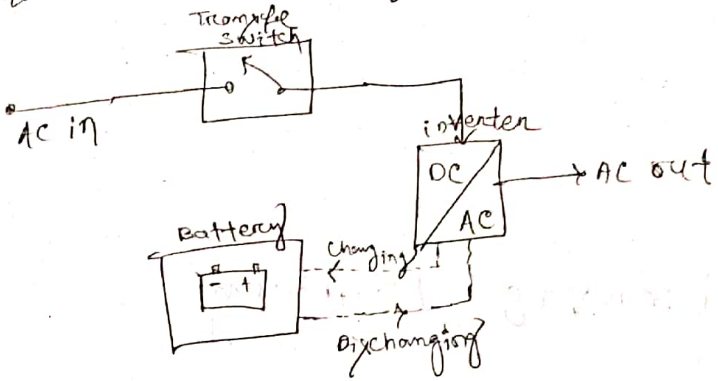
→ When mains ac is not present, it will run the connected load till the battery has a recommended dischargeable level.



→ Line Interactive UPS -:

→ In this design the battery is always connected to AC power converter to the o/p of the UPS.

→ battery charging is done during times when the i/p AC power is normal when the I/P AC fails, transfer switch opens and then the inverter standby functioning to provide power to load immediately.



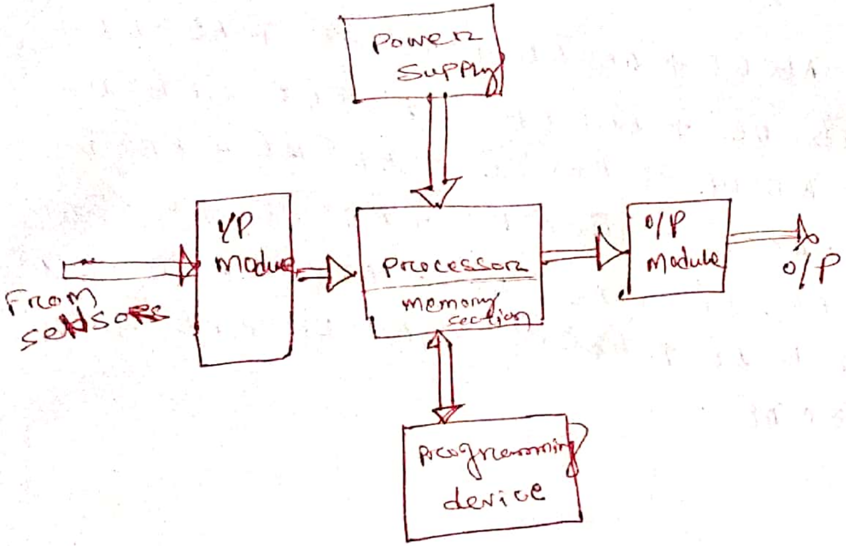
Latch coil -
when the ON. button is momentarily actuated, the latch coil is energized to set the relay to its latched position.

N.O. = Normally open
it is a contact that does not flow current in its normal state.

Energized o/p -
energized a single bit of data if the input leading to it is true.

Branching -:
adding more rungs that are associated with the same output or having multiple outputs for the same inputs.

BLOCK DiAGRAM of PROGRAMMABLE LoGic controller:-



*** Processor section (CPU) :-**

The processor section is brain of PLC which consists of RAM, Rom, Logic solver and user memory. The central processing unit is heart of PLC. CPU controls monitors and supervises all operation with in PLC. The CPU makes decision and executes control instructions based on the program instruction in memory.

→ Input and out put module:-

→ The input module is a mediator between input devices and central processing unit (CPU) which is used to convert analog signal into digital signal.

→ The out put module is a mediator between o/p devices and central processing unit which is converts digital signal into analog signal.

*** Power supply:-**

Power supply is provided to the processor unit, input and output module unit. Power supply may be separately mounted unit. most integral on of the PLC operated on 0 volts DC and 24 volts.

→ memory section:-

The memory section is the area of the CPU in which data and information is stored and retrieved. Data memory is used to store numerical data required in match calculation, bar code data etc. user memory contains user's application program.

→ programming device:-

Programming devices are dedicated devices used for loading the user program into the program memory or edit it and to monitor the execution of the program of the PLC. It is also used to troubleshoot the PLC ladder logic program. Hand held terminal (HHT) or dedicated terminal or personal computer are programming devices commonly used in most of PLCS.