Vikash Polytechnic, Bargarh

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Lecture Note on
POWER ELECTRONICS & PLC

Diploma 5th Semester

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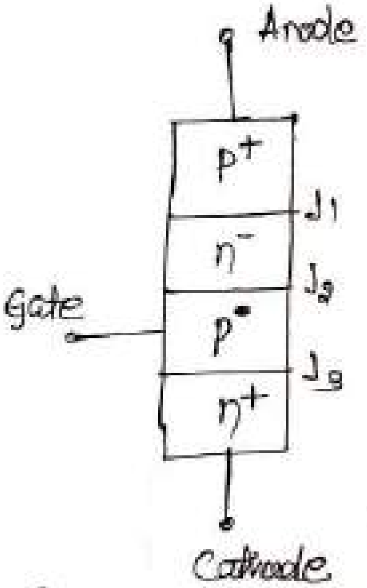
Thyristors

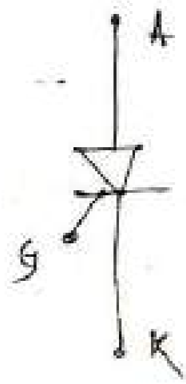
→ Thyristor is a four layer three junction p-n-p-n semiconductor switching device.

→ It has three terminal Anode, cathode & gate

→ SCRs ratings : 10 KV
3000 A
30 MW



(Schematic Diagram)



(Symbol)

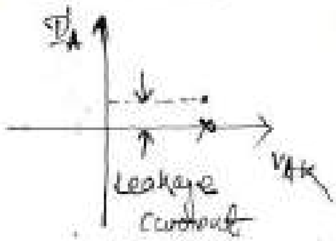
SCR ⇒ Silicon Controlled Rectifier

↳ Unidirectional - only one direction current will flow

↳ Bipolar (Forward & Reverse two side voltage block)

★ Four Modes of Ideal & Practical Switches →

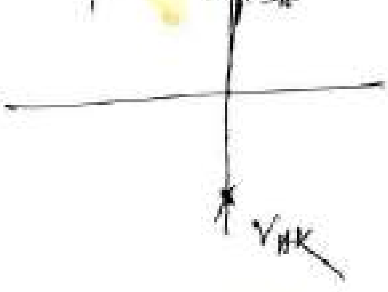
① Forward Blocking Modes - +ve voltage but no current flow



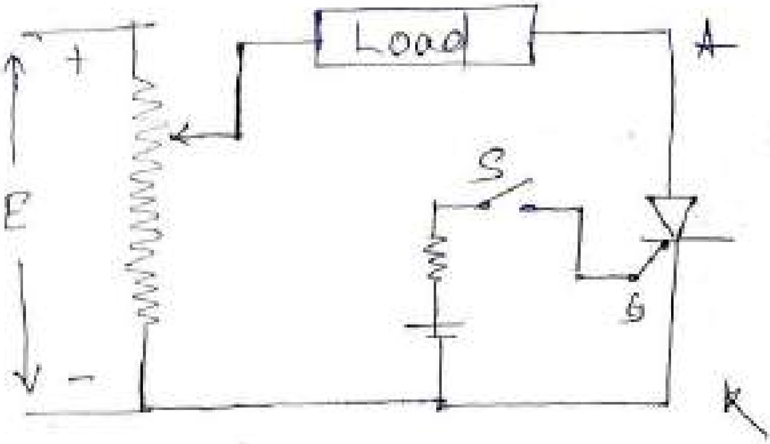
② Forward Conduction Modes -

③ Reverse Blocking Modes

④ Reverse Conduction Modes



Static I-V characteristics of a thyristor :⇒



→ Thyristor has three basic modes of operation
1. Reverse Blocking Mode
2. ~~Reverse~~ Forward Blocking Mode
3. Forward conduction Mode

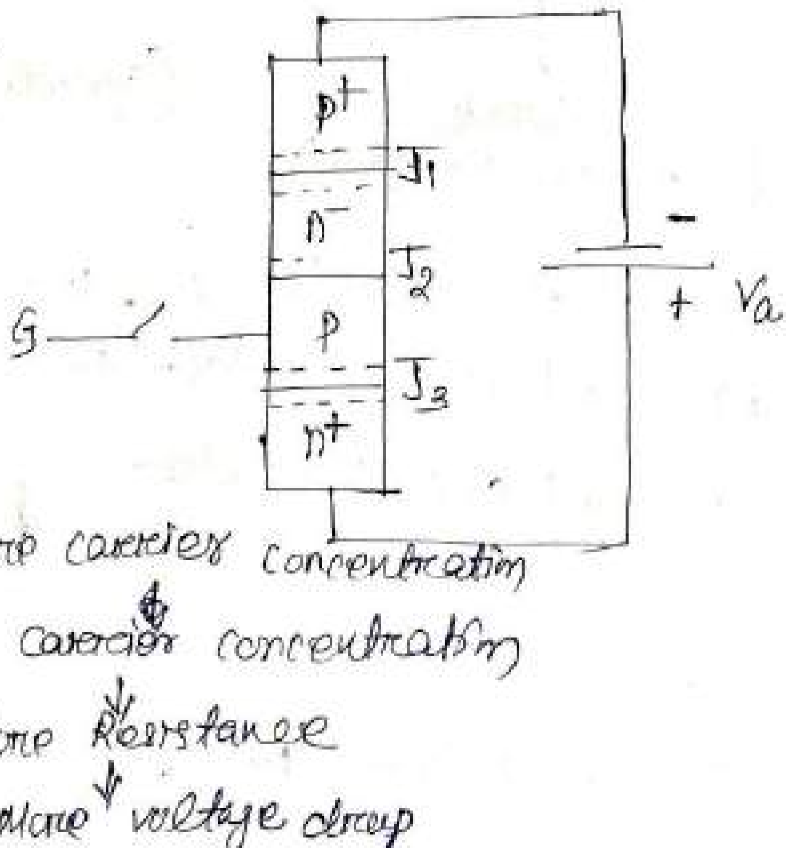
1. Reverse Blocking Mode →

$J_1 \rightarrow$ RB

$J_2 \rightarrow$ FB

$J_3 \rightarrow$ RB

$I_g = 0$



J_1 & $J_3 \rightarrow$ voltage drop.

$J_1 \rightarrow$ More voltage drop

↓

Because

↓

$p^+ \rightarrow$ heavily doped → more carrier concentration

$n^- \rightarrow$ lightly doped → less carrier concentration

↓

More Resistance

↓

More voltage drop

$V_a \uparrow \rightarrow J_1$ & J_3 Barrier width will be increased

→ when Cathode is made positive with respect to anode with 'S' open thyristor is reversed biased.

→ Junction J_1 & J_3 reversed biased whereas J_2 is forward biased.

→ the device behaves as if two diodes are connected in series with reverse voltage applied across them.

→ A small leakage current of few milliampere flows.

→ this reverse blocking mode called off state of the thyristor.

→ if the reverse voltage is increased, then at a critical breakdown level called reverse breakdown voltage V_{BR}, an avalanche occurs at J_1 & J_3 and the reverse current increases rapidly.

→ A large current associated with V_{BR} gives rise to more losses in SCR. this may lead to thyristor damage as the junction temperature may exceed its permissible temperature rise.

→ so maximum working reverse voltage across a thyristor does not exceed V_{BR}

→ when reverse voltage applied across a thyristor is less then V_{BR} the device offers a high impedance in the reverse direction

→ SCR reverse blocking mode may be treated as an open switch.

(2) Forward blocking Mode ⇒

$J_1 \rightarrow FB$ $\quad I_g = 0$

$J_3 \rightarrow FB$

$J_2 \rightarrow RB$

→ Forward leakage current will flow

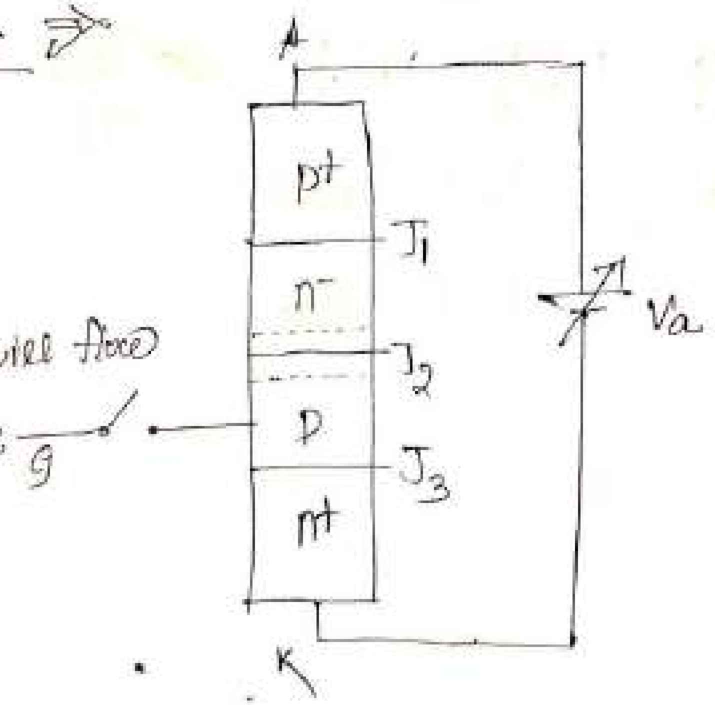
V_{BO} ⇒ Forward breakover voltage (max^m)

⇓

$n^- p$ → Barrier breakdown

⇓

heavy current flow



→ When anode is positive with respect to the cathode, with gate ckt open, thyristor is said to be forward biased.

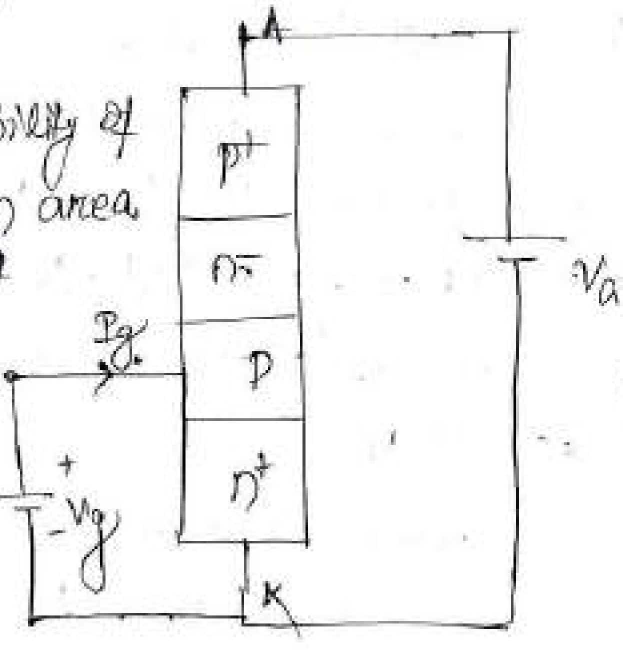
→ ~~A forward~~ J_1 & J_3 are forward biased but junction J_2 is reverse biased.

→ A small current called forward leakage current flows.

→ As the forward leakage current is small, SCR offers a high impedance.

→ Thyristor can be treated as an open switch.

③ Forward Conduction Mode →



★ I_g ↑ → Temp. in p layer ↑ → Mobility of carrier will occur → conduction area increases → current → rate of increasement of current

★ $\frac{dI_g}{dt}$ ↑ → initial conduction area ↑

⇓

$\left(\frac{dI_A}{dt}\right)_{initial}$ ↑

★ I_A ↑ t_{on} ↓ V_B ↓ . ★ I_g ↑ SCR → fast on

T_{on} → less

$I_{g_{min}} \leq I_g \leq I_{g_{max}}$

$V_{g_{min}} < -V_g < V_{g_{max}}$

→ when anode to cathode forward voltage is increased with gate circuit open, reverse biased J_2 will be have avalanche breakdown at a voltage called forward breakover voltage V_{BO}.

→ After this breakdown thyristor get turn on.

→ SCR can be brought from forward blocking mode to forward conduction mode by turning it on by Applying

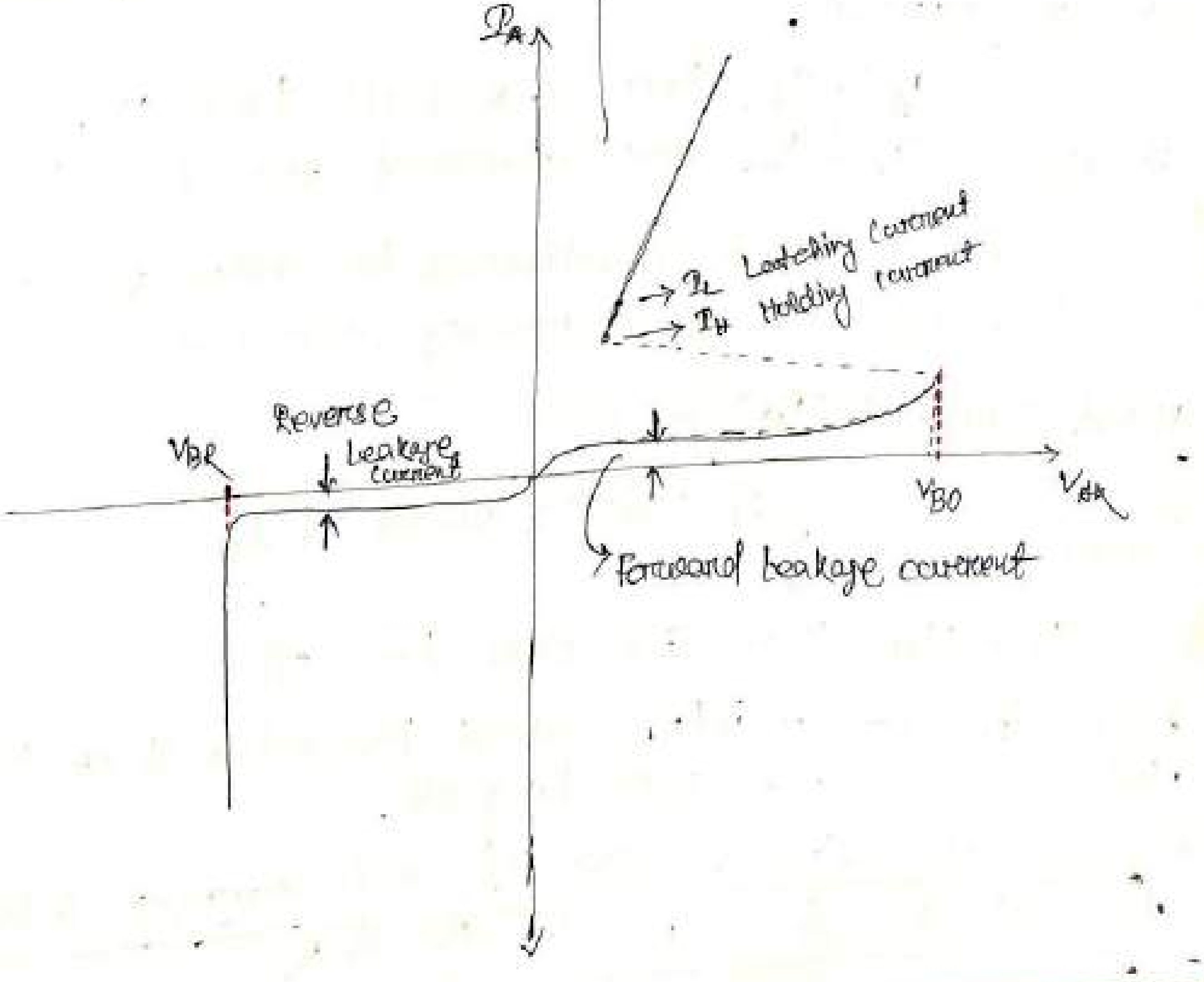
(i) A positive gate pulse between gate & cathode

(ii) Forward breakover voltage across anode & cathode

→ Forward conduction mode shows that voltage drop across SCR is of the order of 1 to 2V depending upon the rating of SCR

→ This small voltage drop V_T across the device is due to ohmic drop in the four layer

→ In forward conduction mode, SCR is treated as a closed switch



Latching Current (I_L) ⇒
(turn on process)

→ How much minimum gate pulse we applied

→ when we keep increasing I_g then loss will increase this loss is unnessary loss so

I_L gives information about the how much gate pulse required to turn on the SCR.

★ It is the minimum value of anode current which it must attain during turn on process to maintain conduction.

→ when we applies gate current I_g, keep increasing I_g so anode current I_A will increase. so latching current informs about the how much gate current we required.

$I_A > I_L$ then SCR will turn on.

$I_A < I_L$ Max^m chances of SCR fails to turnon.

★ ~~Holding~~ when $I_g = 0$ SCR contineous to conduct so gate loss contineous increasing, this loss is unwanted.

Holding Current (I_H) ⇒

$I_L = 2$ to 3 times of I_H

(turn off process)

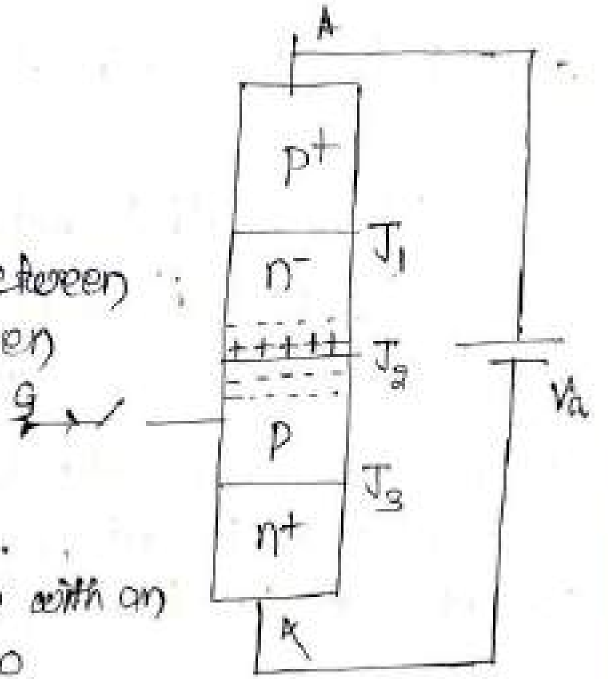
$I_A < I_H$ then SCR will turn off

so holding current informs about the value of anode current below which SCR gets turn off.

★ It is the minimum value of anode current below which it must fall for turning off the SCR

Turn on Method of SCR :→

① Forward voltage triggering →



→ when forward voltage is applied between anode & cathode with gate circuit open J_2 is reverse biased.

→ Depletion layer is formed across J_2.

→ width of depletion layer decreases with an increase in anode - cathode voltage.

→ if forward voltage across anode - cathode is gradually increased a stage comes when the depletion layer across J_2 vanishes. At this moment, reverse biased junction J_2 is said to have avalanche breakdown and the voltage at which it occurs is called forward breakover voltage (V_{BO}).

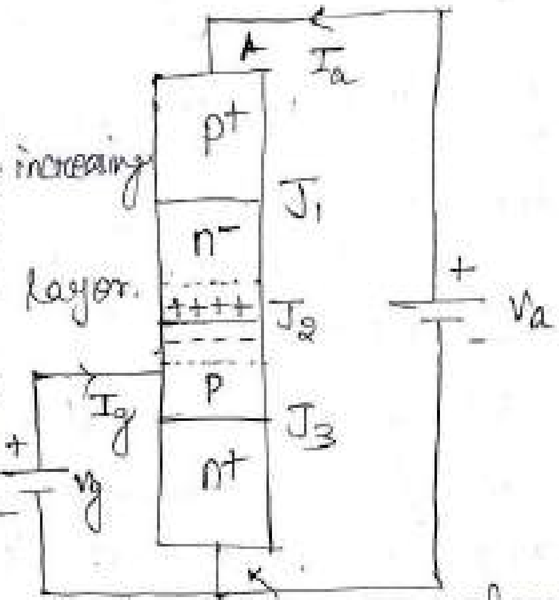
→ At V_{BO} SCR changes from off state to on state by low voltage across SCR with large current (forward).

→ J_1 & J_3 are already forward biased, breakdown J_2 will allows free movement of carriers across three junctions and large forward anode current flows.

→ After the breakdown J_2 loses its reverse blocking capability if the anode voltage is reduced below V_{BO} SCR will continue conduction of the current.

→ Now the SCR can be turn off only by reducing the anode current below a certain value called holding current.

② Gate Triggering →



→ when V_a is applied and V_g keep increasing I_g current will start flowing then charge mobilization occurs in n^+ layer.

→ The n^+ layer is heavely doped the electrons from the n^+ layer starts combining with the holes of the p layer.

→ After combination done, rest of electron from the p layer tries to combining with the holes of the drift region, due to which current will flow then drift region becomes decreasing.

→ After drift region becomes decreasing, anode current will flow and SCR gets turn on.

Book:

→ SCR will remain in forward blocking state with normal working voltage across anode and cathode and with gate open

→ when turn on of a SCR is required, a positive gate voltage between gate and cathode is applied.

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

→ The forward voltage at which the device switches to on state depends upon the magnitude of gate current Higher the gate current, lower is the forward breakover voltage.

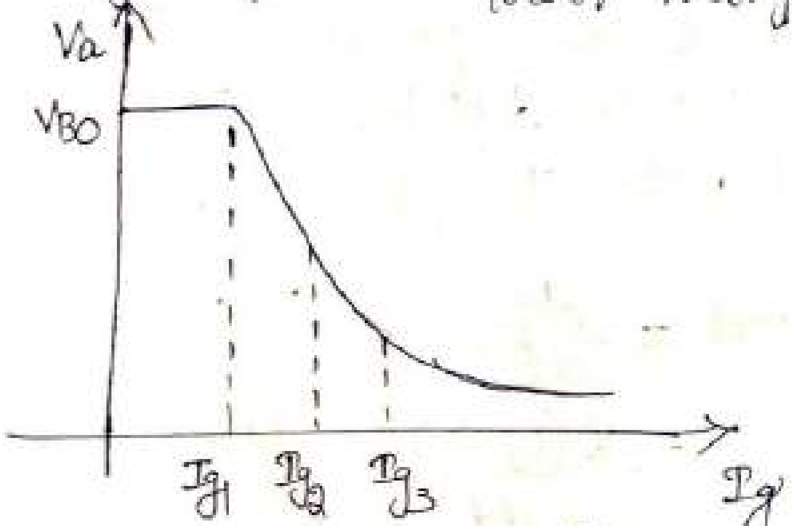
→ when positive gate current is applied, gate p layer flooded with electron from the cathode. This is because cathode n layer is heavily doped as compared to gate p layer.

→ As the SCR is forward biased, some of these electrons reach junction J_2. As a result, width of depletion layer near junction J_2 is reduced.

→ Junction J_2 is reduced causes the J_2 to breakdown at an applied voltage lower then the forward breakover voltage V_{BO}.

→ if magnitude of gate current is increased, more electrons would reach J_2 as a consequence SCR would get turned on at much lower forward applied voltage.

$V_g \uparrow \rightarrow I_g \uparrow \rightarrow V_{BO} \downarrow$ SCR will turn on at very lower voltage



(10-200 mA)

③ Thermal Triggering →

J_2 → temp ↑ → no. of Carrier ↑ → Forward leakage current ↑

→ I^2R loss → heating → temp ↑

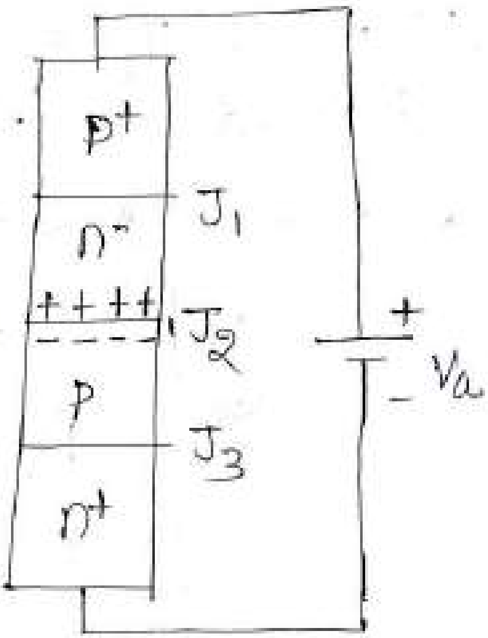
→ During forward blocking most of the applied voltage appears across reverse biased junction J_2.

→ voltage across J_2 associated with leakage current would raise temperature of the junction.

→ with increase in temperature, width of depletion layer decreases.

→ with decreases the depletion layer more leakage current and therefore more junction temperature.

→ with the cumulative process, at some high temperature depletion layer of reverse biased junction vanishes and the device gets turned on.



④ $\frac{dv}{dt}$ triggering →

Reversed biased J_2 behaves like a capacitor because charge present in the junction due to depletion layer created in the J_2, so

$$i_C \text{ charging current} = \frac{dQ}{dt}$$

$$= \frac{d(C_j V_a)}{dt} \qquad Q = CV$$

C_j = junction capacitance

V_a = forward voltage applied to the SCR

$$= C_j \frac{dV_a}{dt} + V_a \cancel{\frac{dC_j}{dt}}^{0} \qquad C_j = \text{Appx. constant}$$

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

$$\Rightarrow i_C \uparrow \propto \frac{dV_a}{dt} \uparrow \qquad \uparrow i_C \rightleftharpoons I_g \uparrow$$

→ with forward voltage across the anode and cathode of a SCR the two junction J_1 & J_3 are forward biased but inner junction J_2 is reverse biased.

→ Reverse biased J_2 has the characteristics of a capacitor due to charges existing across the junction.

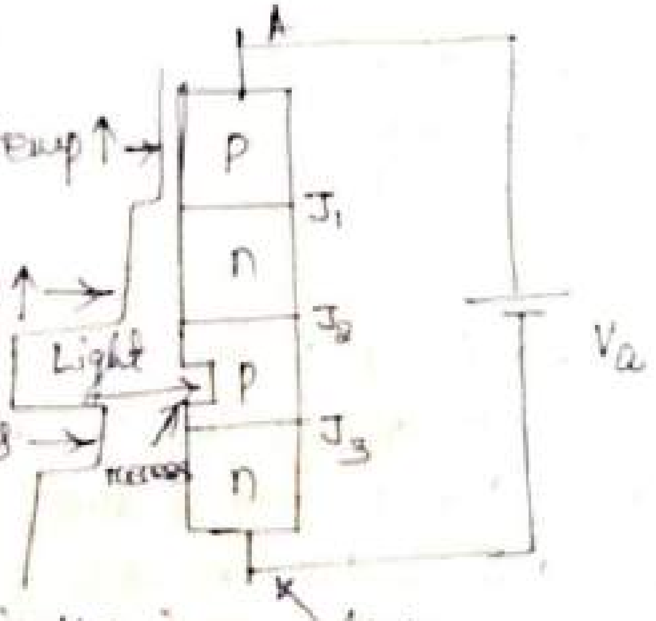
→ if forward voltage is suddenly applied a charging current through junction capacitance C_j may turn on the SCR.

→ if $\frac{dv_a}{dt}$ is high, the charging current i_c would be more.

→ V_a is small, it is the rate of change of V_a that plays the role of turning on the device.

(5) Light Triggering →

absorbed light energy → temp ↑ →
no of carrier increase →
forward leakage current ↑ →
losses ↑ → temp ↑ →
Barrier width decreases →
SCR conducts.



→ A recess is made in the inner p layer.

→ when this recess 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 fibers for irradiation.

→ if the intensity of this light thrown on the recess exceeds a certain value forward biased SCR is turned on.

Switching characteristics of SCR :⇒

→ ON → OFF turn off characteristics

→ OFF → ON turn on characteristics

→ FB → FC $I_a > I_L$

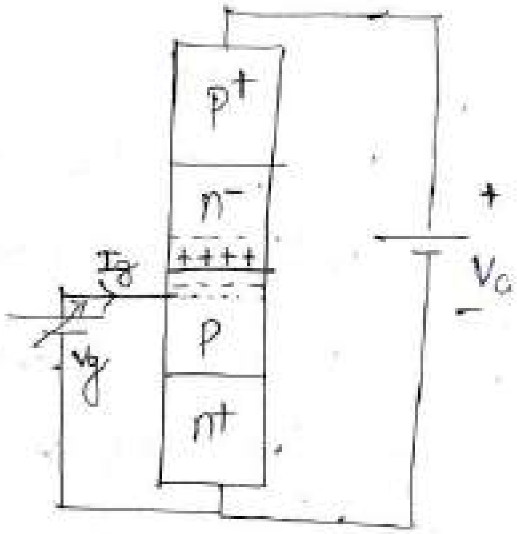
→ FC → FB $I_a < I_H$

① Turn on characteristics ⇒

$t_{ON} = (1 \text{ to } 4\ \mu s)$

↳ $t_d + t_r + t_s$

t_d = Delay time
t_r = rise time
t_s = spread time



→ A forward biased thyristor is usually turned on by Applying a positive gate voltage between gate and cathode. This transition time called thyristor turn on time.

→ Thyristor turn on time is defined as the time during which it changes from forward blocking mode to final on state.

(i) Delay time t_d :-

→ The delay time t_d is measured from the instant at which gate current reaches $0.9\ I_g$ to the instant at which anode current reaches $0.1\ I_a$.

→ It is also be defined as the time time during which anode voltage falls from V_a to $0.9\ V_a$

$\downarrow t_d \rightarrow$ initial conduction area $\uparrow \rightarrow I_g \uparrow \rightarrow \frac{di_g}{dt} \uparrow$

(ii) Rise time t_r :→

→ The rise time t_r is the time taken by the anode current to rise from $0.1\, I_a$ to $0.9\, I_a$

→ It is also be defined as the time required for the forward blocking off state voltage to fall from 0.9 to 0.1 of its initial value.

$$\downarrow t_r \propto \frac{1}{I_g \uparrow} \propto \frac{1}{\frac{dI_g}{dt}} \text{ (build up rate of } I_g)$$

t_r ⟶ depends on load parameter

RL → load → $t_r \uparrow$

RC → load → $t_r \downarrow$

(iii) Spread time t_s :→

→ The spread time is the time taken by the anode current to rise from $0.9\, I_a$ to I_a

→ It is also defined as the time for the forward blocking voltage to fall from 0.1 of its initial value to the on state voltage drop

→ during this time conduction spreads over the entire cross-section of the cathode of SCR. The spreading interval depends on the area of cathode and on gate structure of the SCR

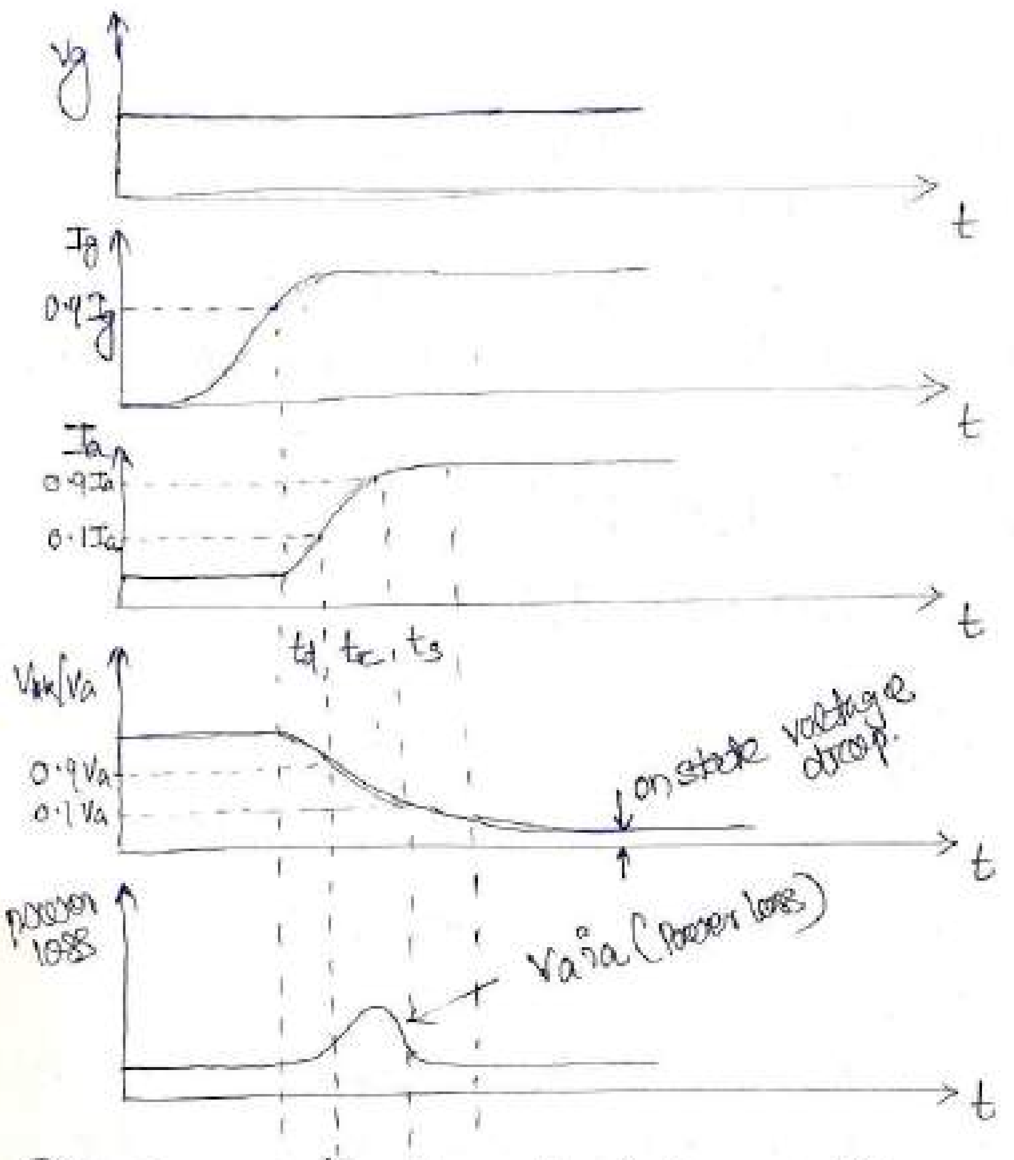
* I_g = 3 to 5 times the minm gate current required to trigger an SCR

* The turn on time can be reduced by using higher value of gate current.

* Delay time = $0.9\, I_g$ to $0.1\, I_a$ / V_a to $0.9\, V_a$

Rise time = $0.1\, I_a$ to $0.9\, I_a$ / $0.9\, I_a$ to $0.1\, V_a$

Spread time = $0.9\, I_a$ to I_a / $0.1\, V_a$ to V_a



$V_{AK}/V_a \rightarrow$ voltage across J_2 junction

② Turn off characteristics ⇒ (Reverse Recovery characteristics)

$I_a = 0 \rightarrow$ SCR will not come into Forward blocking

↓ because

Excess Carriers in 4 layers

↓

SCR may go in conduction

↓

with out gate pulse Apply

→ To Remove Carrier

↓

$I_G = 0 \rightarrow$ for some time Reverse biased voltage applied

↓

J_1 & $J_3 \rightarrow$ Reverse biased

↓

Drift barrier increases

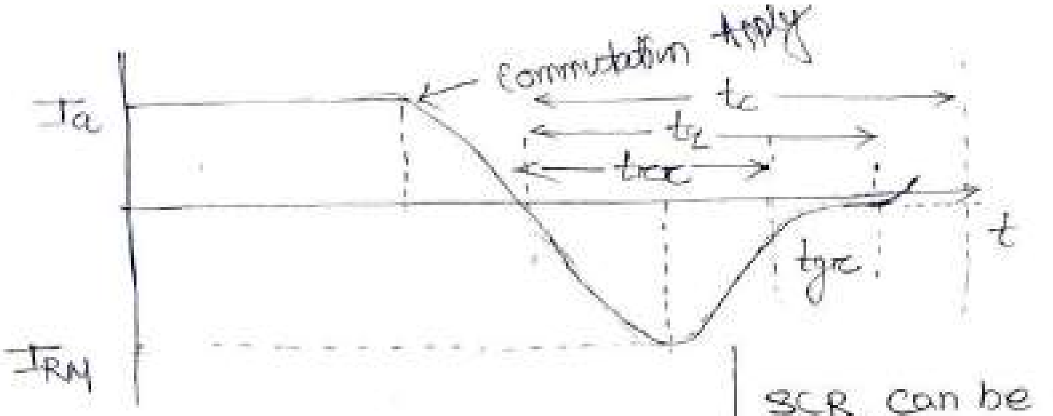
↓

Anode current to zero.

$t_q \propto \frac{di}{dt} \propto I_a \leftarrow$ trapped charges around J_2 is more ∴ Recombination time ↑

∝ junction temp.

∝ $\frac{1}{\text{Reverse voltage applied}}$



SCR can be turned off by reducing current below I_H using any commutation method.

t_{rr} → Reverse Recovery time
t_{gr} → Gate Recovery time
t_c → Circuit turn off time
t_q → turn off time.

t_{rr} → During this time excess charge present in the outer layer is removed (J_1 & J_3)

t_{gr} → During this time excess charge present near the junction J_2 is removed.

t_q → During this time excess charge removal from all four layer

$$t_q = t_{rr} + t_{gr}$$

t_c → It is the time for which the commutation circuit Applied reverse voltage across the SCR after anode current becomes zero.

★★ $\boxed{t_c \geq t_q}$ $\quad t_c = (SF)\, t_q \quad SF > 1$

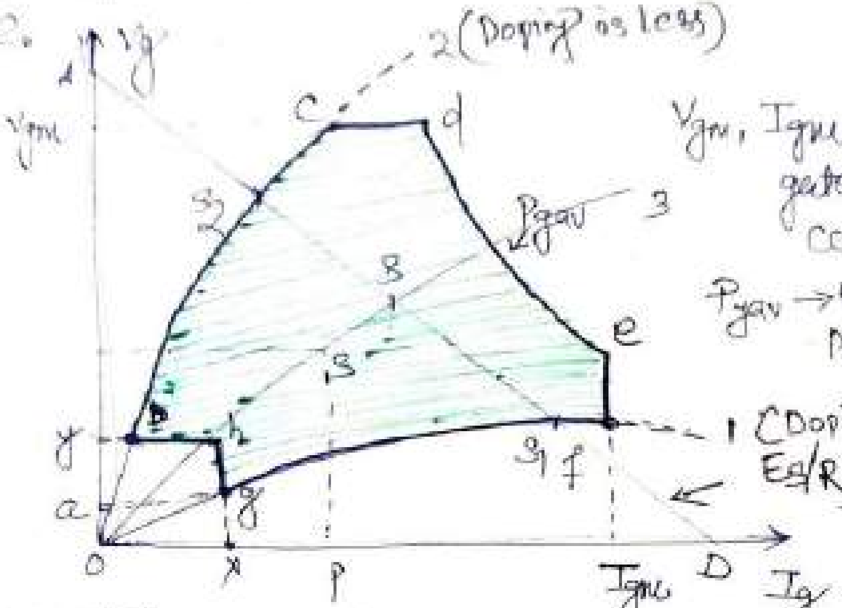
→ once the SCR is on gate loses control. The SCR can be turned off by reducing the anode current below holding current if forward voltage is applied to the SCR at the moment its anode currents fall to zero, the device will not be able to block this forward voltage as the carriers in the four layer are still favourable for conduction.

→ The device will therefore go into conduction immediately even through gate signal is not applied.

→ In order to obviate such an occurrence, it is essential that the thyristor is reverse biased for a finite period after the anode current has reached zero.

Gate characteristics of SCR :→

→ As gate cathode circuit of a thyristor is a p-n junction, gate characteristics of the device are similar to that of a diode.



V_{gm}, I_{gm} → Max^m permissible gate voltage and current.

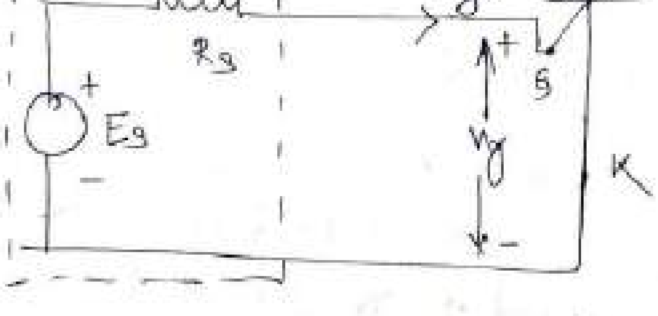
P_{gav} → Rated average gate power dissipation.

ox, oy → Minimum gate voltage and current to trigger on SCR

→ if V_{gm}, I_{gm} and P_{gav} are exceeded the thyristor can be destroyed

→ Preferred gate drive area for an SCR is bcdefghb.

→ All spurious or noise signal should be less than the voltage 'oa'.



$$E_s = V_g + I_g R_s$$

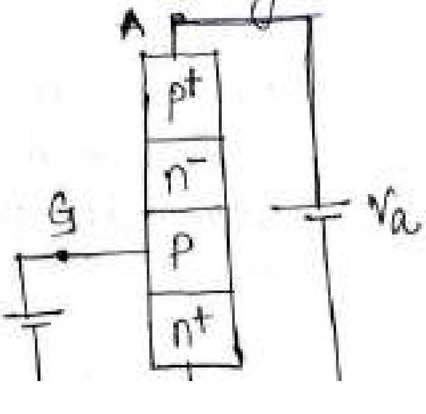
E_s = Gate source voltage

V_g = Gate cathode voltage

I_g = Gate current

R_s = Gate source resistance

preferred gate area = bcdefghb



A load line of gate source voltage $E_s = OA$ is drawn as AD

OD = trigger circuit short circuit current = E_s/R_s

~~OA =~~

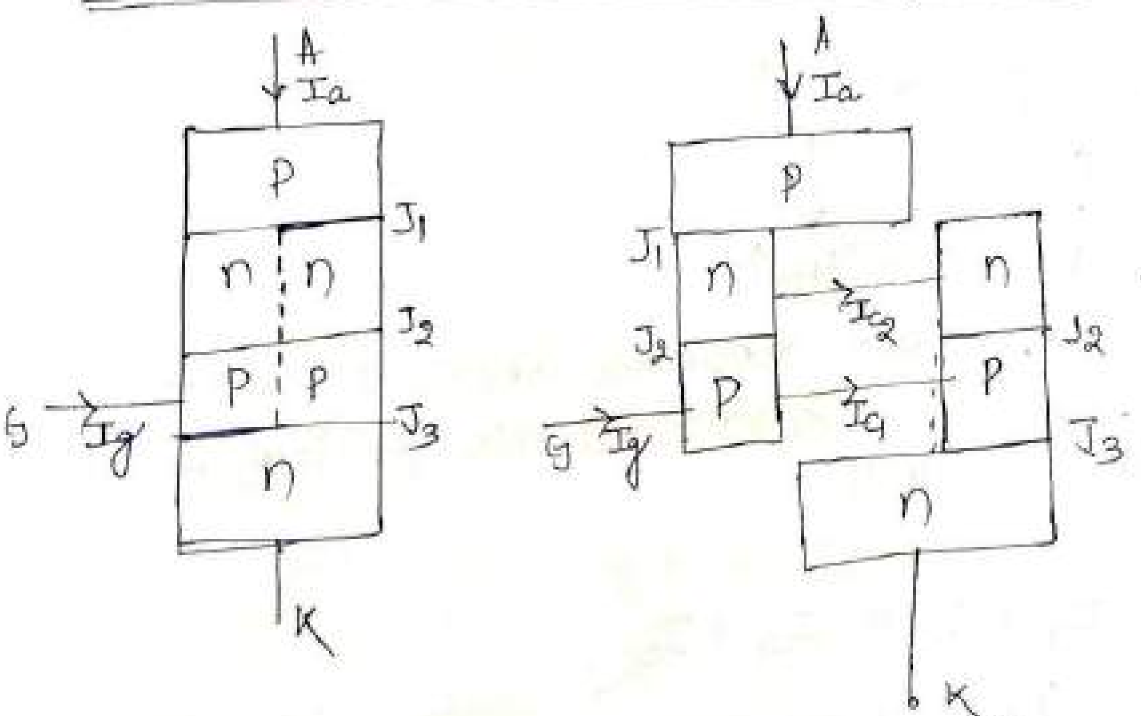
→ A thyristor whose $V_g - I_g$ characteristics is curve 3 gives the operating point S.

SCR gate voltage = PS
gate current = OP

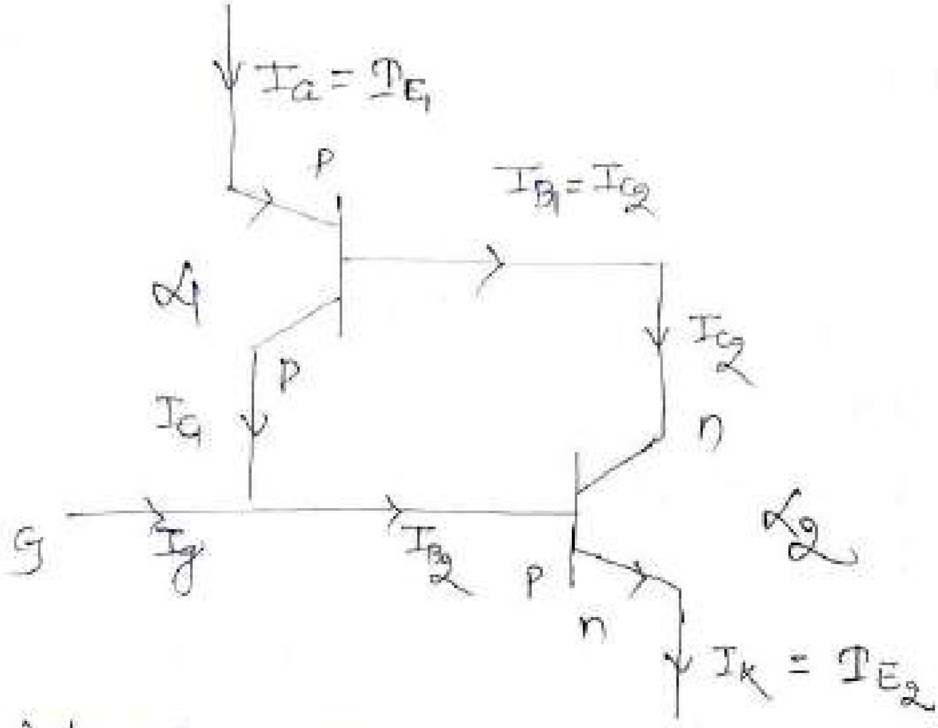
→ In order to minimise turn on time and unreliable turn on the load line and hence the operating point S, which may change from S_1 to S_2, must be as close to the P_{gav} curve, as possible.

→ The operating point S must be lie within the limit curves 1&2.

Two Transistor Model of a Thyristor :→



The two transistor model of an SCR is a way to understand and analyze its operation by representing the SCR as a combination of two interconnected BJT.



→ When we apply gate current it increases I_{B_2} by which I_{C_2} automatically increases.

→ $I_{B_1} = I_{C_2}$ I_{B_1} also increases

$I_{C_1} = \beta I_{B_1}$

$I_{B_2} = I_{C_1} + I_g$ I_{B_2} also increases

$$\begin{array}{ccc} I_g \longrightarrow I_{B_2}\uparrow & \longrightarrow & I_{C_2}\uparrow \\ \uparrow & & \downarrow \\ I_{C_1} & \longleftarrow & I_{B_1}\uparrow \end{array}$$

when anode current reaches above a certain value we can remove gate current & this positive feed back circuit will continue.

for T_1

$I_A = I_{C_1} + I_{B_1} = I_{C_1} + I_{C_2}$

$I_C = \alpha I_E + I_{CBO}$

αI_E is component of collector current due to charges coming from emitter.

α = common base current gain (<1)

I_{CBO} = reverse saturation current of collector base junction

$$I_A = I_{C_1} + I_{C_2}$$
$$= \alpha_1 I_{E_1} + I_{CBO_1} + \alpha_2 I_{E_2} + I_{CBO_2}$$
$$= \alpha_1 I_A + \alpha_2 I_K + I_{CBO_1} + I_{CBO_2}$$

By KCL
$$I_A + I_g = I_K$$

So $I_A = \alpha_1 I_A + \alpha_2 (I_A + I_g) + I_{CBO_1} + I_{CBO_2}$

$$\Rightarrow I_A (1 - \alpha_1 - \alpha_2) = \alpha_2 I_g + (I_{CBO_1} + I_{CBO_2})$$

$$\Rightarrow I_A = \frac{\alpha_2 I_g + I_{CBO_1} + I_{CBO_2}}{1 - \alpha_1 - \alpha_2}$$

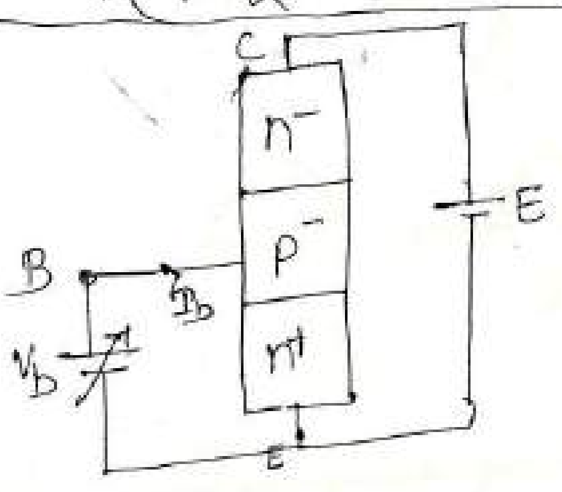
α = Common base current gain
β = Common emitter current gain

When I_g is suddenly applied say 0 to 1 mA

$I_{E_2} \uparrow$ (or) $I_K \uparrow \Rightarrow \alpha_2 \uparrow \Rightarrow I_{C_2} \uparrow \Rightarrow I_b \uparrow \Rightarrow I_{E_1}$ or $I_A \uparrow \Rightarrow \alpha_1 \uparrow \Rightarrow I_{C_1} \uparrow$.

α_1 varies with $I_A = I_{E_1}$
α_2 varies with $I_K = I_A + I_g$

When $(\alpha_1 + \alpha_2) = 1 \Rightarrow I_A = \infty$ & thyristor turns on.



$V_b \uparrow \Rightarrow I_b \uparrow \Rightarrow$ Barrier width $\downarrow \Rightarrow I_E \uparrow$

Commutation

→ The process of turning off a device is called as commutation.

→ Once thyristor starts conducting, gate loses control over the device therefore, external means may have to be adopted to commutate the thyristor

Natural Commutation →

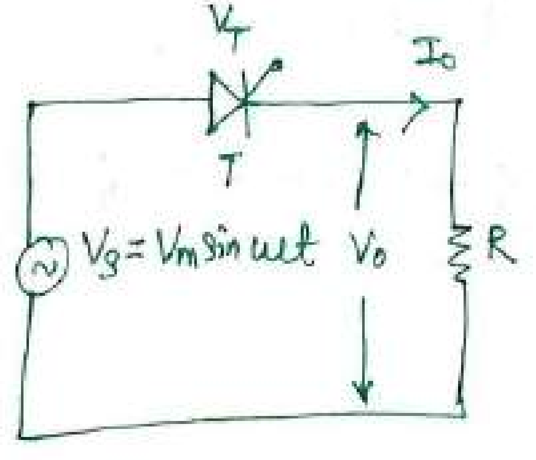
→ If the device is turned off due to alternating supply then it is called natural commutation.

Class F – a.c line commutation →

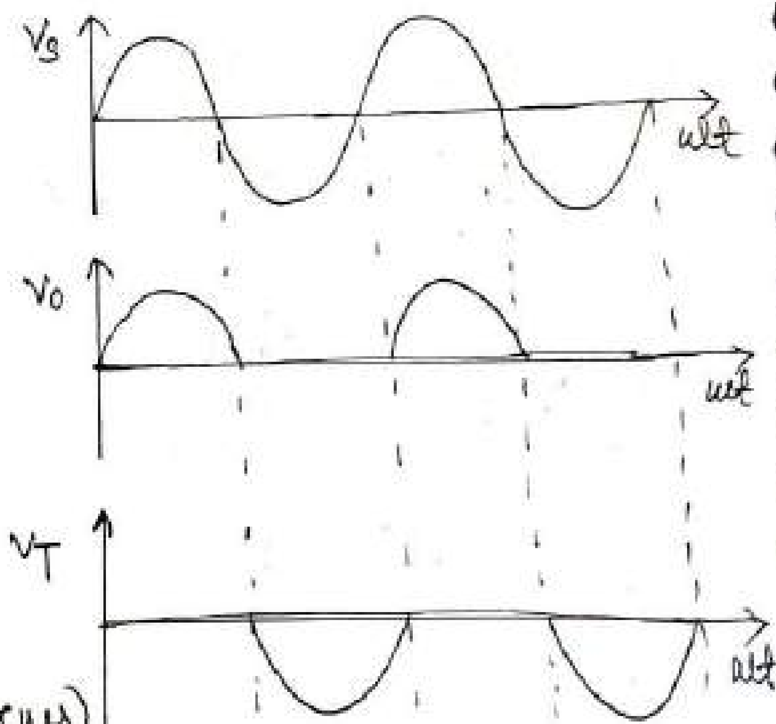
→ this can occur only when the source is a.c

→ when an SCR circuit is energised from ac source, current has to pass through natural zero at the end of every positive half cycle. then ac source applies a reverse bias across SCR automatically. As a result SCR is turned off.

→ used in
- phase controlled converter
- line commutated Inverter
- ac voltage controllers
- step down cycloconverters.



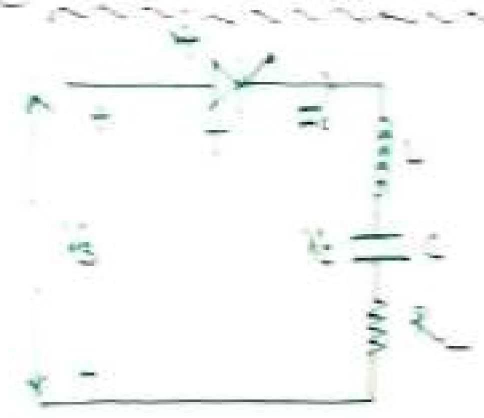
(Circuit Diagram)

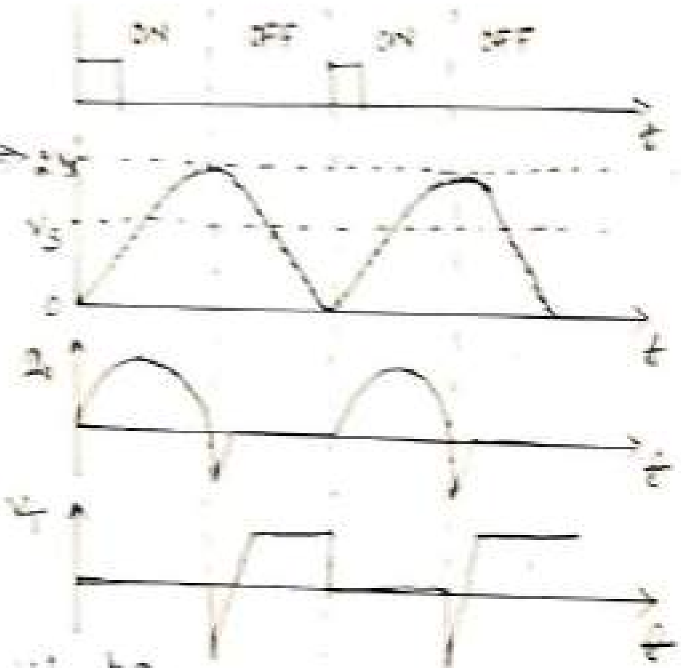


(waveforms)

Forced Commutation :⇒

① Class A : Load Commutation :⇒





- when T on current direction will be

$$+V_s \rightarrow T \rightarrow L \rightarrow C \rightarrow R \rightarrow -V_s$$

Inductor stores energy

capacitor start charging 0 + V_s

when capacitor charges to $V_c = V_s$ then slowly decay current and current will zero.

when no current will flow energy stored by the inductor will released and charging the capacitor to avg. now $V_c = 2V_s$

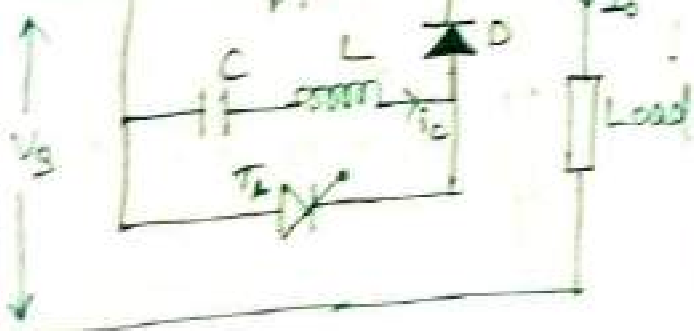
then the capacitor discharges through

$$V_c \rightarrow L \rightarrow T \rightarrow V_s \rightarrow V_c$$

now a reversed current flows through the thyristor and the thyristor is reverse biased and work as an open switch.

thyristor is to off condition.

② Class B : Resonant pulse Commutation :⇒



(Circuit diagram)

→ In this technique SCR is turned off by gradual build up of resonant current in the reverse direction i.e from cathode to anode of SCR.

→ occurs in DC Circuit.

Description

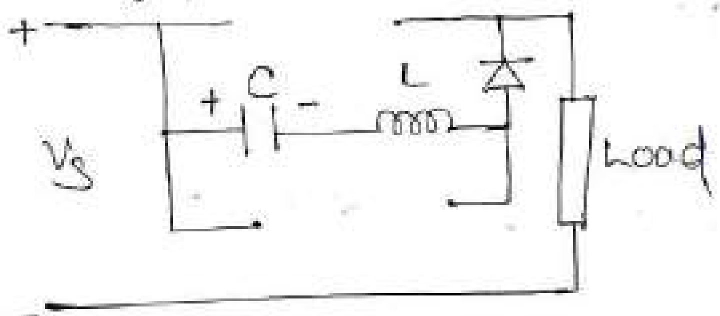
I_0 = constant

LC Circuit is resonating in nature

$V_C = V_S$ at $t = 0$

Operation

Initially T_1 & T_A are OFF



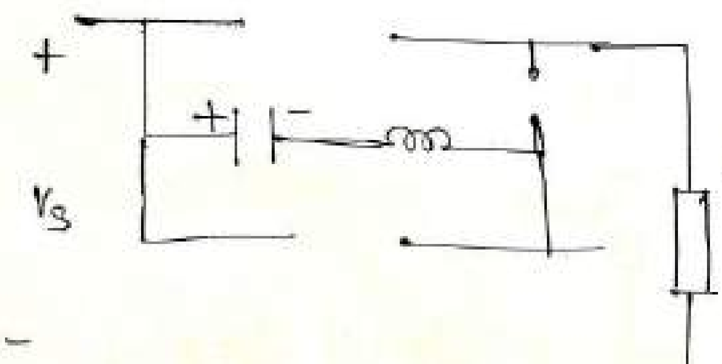
→ Current flows $+V_S \rightarrow C \rightarrow L \rightarrow D \rightarrow -V_S$

→ Capacitor charges to Vs →. after some time capacitor charges to Vs fully.

→ when capacitor fully charges the diode will be reversed biased.

Diode work as open Circuit.

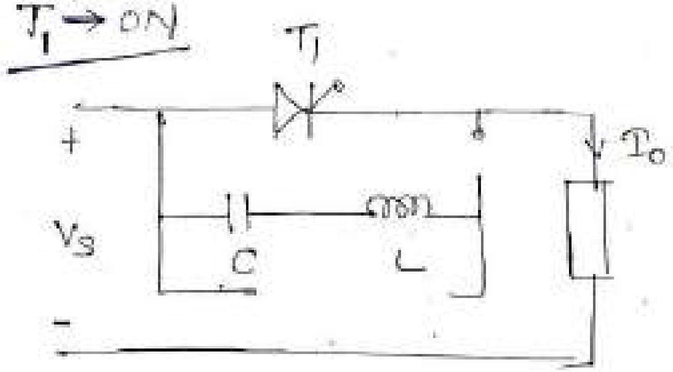
when capacitor fully charged no current will be flow



Here T_1→OFF T_2→OFF there D → OFF

to Discharge the capacitor their is a no path.

$T_1 \rightarrow ON$

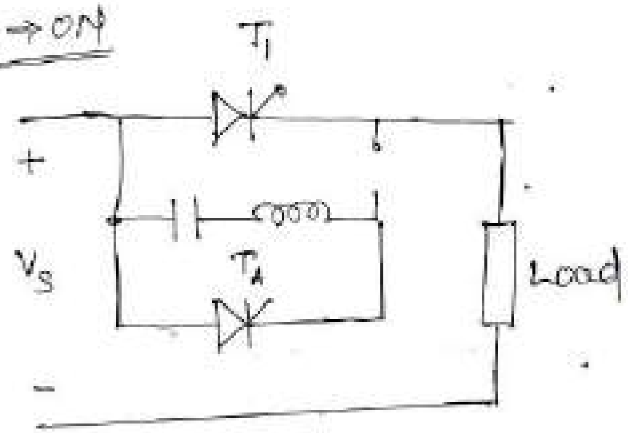


when $T_1 = ON$ current flows from

$+V_S \rightarrow T_1 \rightarrow Load \rightarrow -V_S$

$I_0 = I_S$

$T_A \rightarrow ON$



Current flows through the $+V_S \rightarrow T_1 \rightarrow Load \rightarrow -V_S$

when T_A is turned on capacitor having a closed path to discharge the stored energy

then capacitor will released its energy through

$C \rightarrow T_A \rightarrow L \rightarrow C$

this time inductor will charged from capacitor voltage

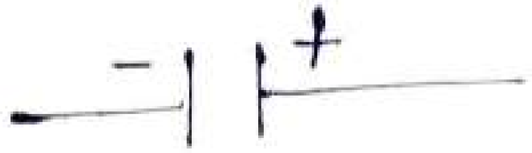
inductor across polarity $-\text{mm}^{+}$

when $V_C = 0$ capacitor across voltage is zero at this time inductor will be charged fully.

then after inductor released its energy and changes its polarity $+\text{mm}^{-}$

then inductor tr

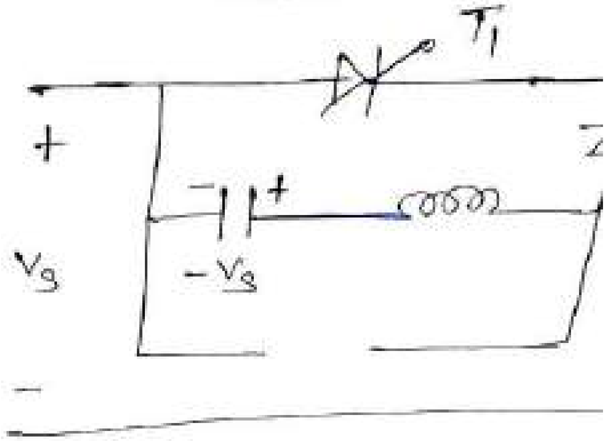
and the capacitor



when capacitor fully

is $-V_s$ diode will

thyristor T_A in rev



This time capacitor discha

$C \rightarrow L \rightarrow D \rightarrow T$ -

thyristor across current

capacitor current flow

when $I_O = I_C$ then $I_O - I$

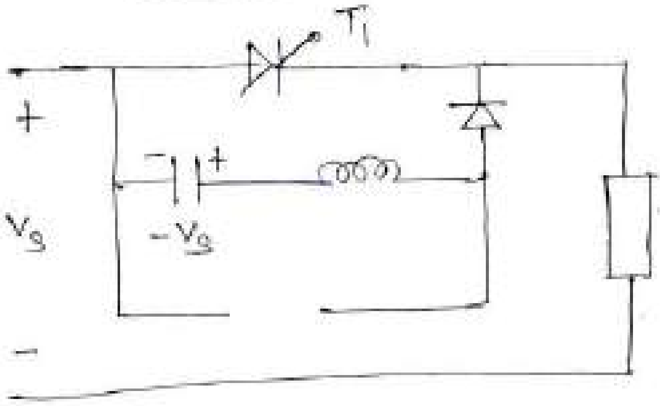
thyristor T_1 across current

thyristor T_1 will be turned

than inductor transfer all the energy to the capacitor, and the capacitor is charging and the polarity becomes

$v_C = -V_S$

when capacitor fully charged and the voltage across capacitor is $-V_S$ diode will be forward biased and the thyristor T_A in reversed biased because



This time capacitor discharges its energy through

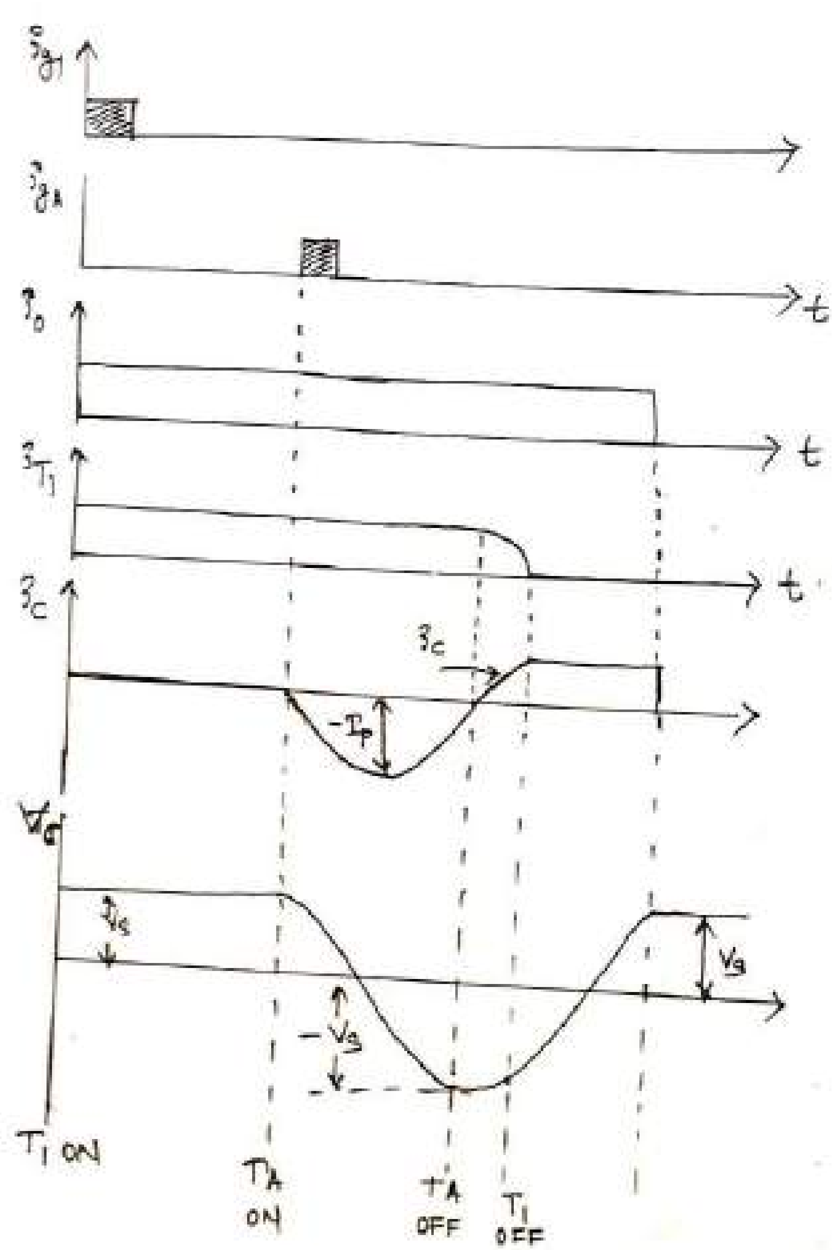
$C \rightarrow L \rightarrow D \rightarrow T \rightarrow C$

thyristor across current I_0.

capacitor current flow I_C

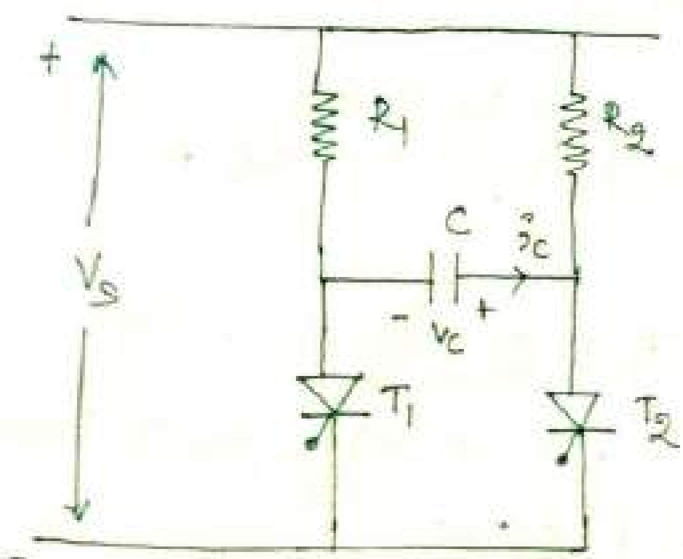
when $I_0 = I_C$ then $I_0 - I_C = 0$

thyristor T_1 across current is 0 then after thyristor T_1 will be turned off.



(wave form)

⑤ Class C : Complementary Commutation :→



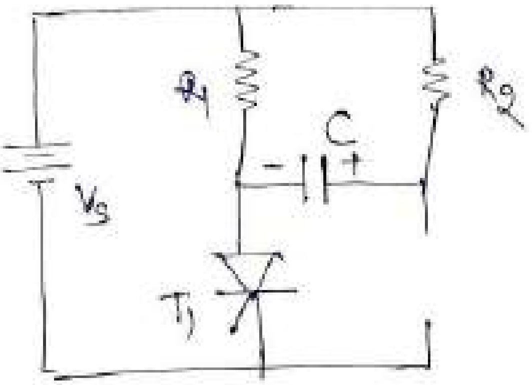
(Circuit Diagram)

T_1 & T_2 ⇒ OFF

no current will flow in the circuit

$$V_C = 0$$

T_1 ⇒ ON



Current flows in two loop

① $+V_S \rightarrow R_1 \rightarrow T_1 \rightarrow -V_S$

② $+V_S \rightarrow R_2 \rightarrow C \rightarrow T_1 \rightarrow -V_S$

Current through T_1

loop 1 $\quad I_1 = \dfrac{V_S}{R_1}$

loop 2 $\quad I_2 = \dfrac{V_S}{R_2}$

total current flow through $T_1 = \dfrac{V_S}{R_1} + \dfrac{V_S}{R_2}$

Capacitor C will get charged by the supply voltage with the polarity —| |+— .

when capacitor get fully charged with V_S voltage, loop 2 current is zero

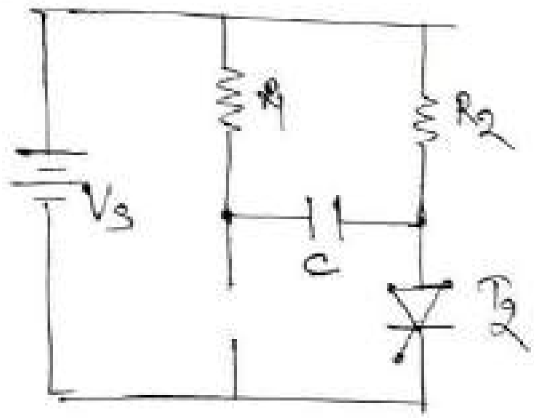
so, $I_2 = 0$

total current flow through T_1 is $= \dfrac{V_S}{R_1} + 0 = \dfrac{V_S}{R_1}$

Capacitor polarity —| |+— , this polarity gets T_1 turned off because

-ve of capacitor connected to Anode of T_1 & +ve of capacitor connected to Cathode of T_1 so T_1 get reversed biased & turned off.

$T_2 \rightarrow$ ON



current flows through

① $+V_s \rightarrow R_2 \rightarrow T_2 \rightarrow -V_s$

② $+V_s \rightarrow R_1 \rightarrow C \rightarrow T_2 \rightarrow -V_s$

current through T_2 loop 1 $= \frac{V_s}{R_2}$

loop 2 $= \frac{2V_s}{R_1}$

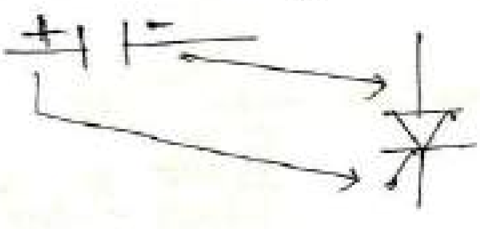
→ during this process capacitor again charging.

→ first capacitor charged with V_s during T_1 ON then again charging with V_s when T_2 ON so capacitor voltage $V_c = 2V_s$

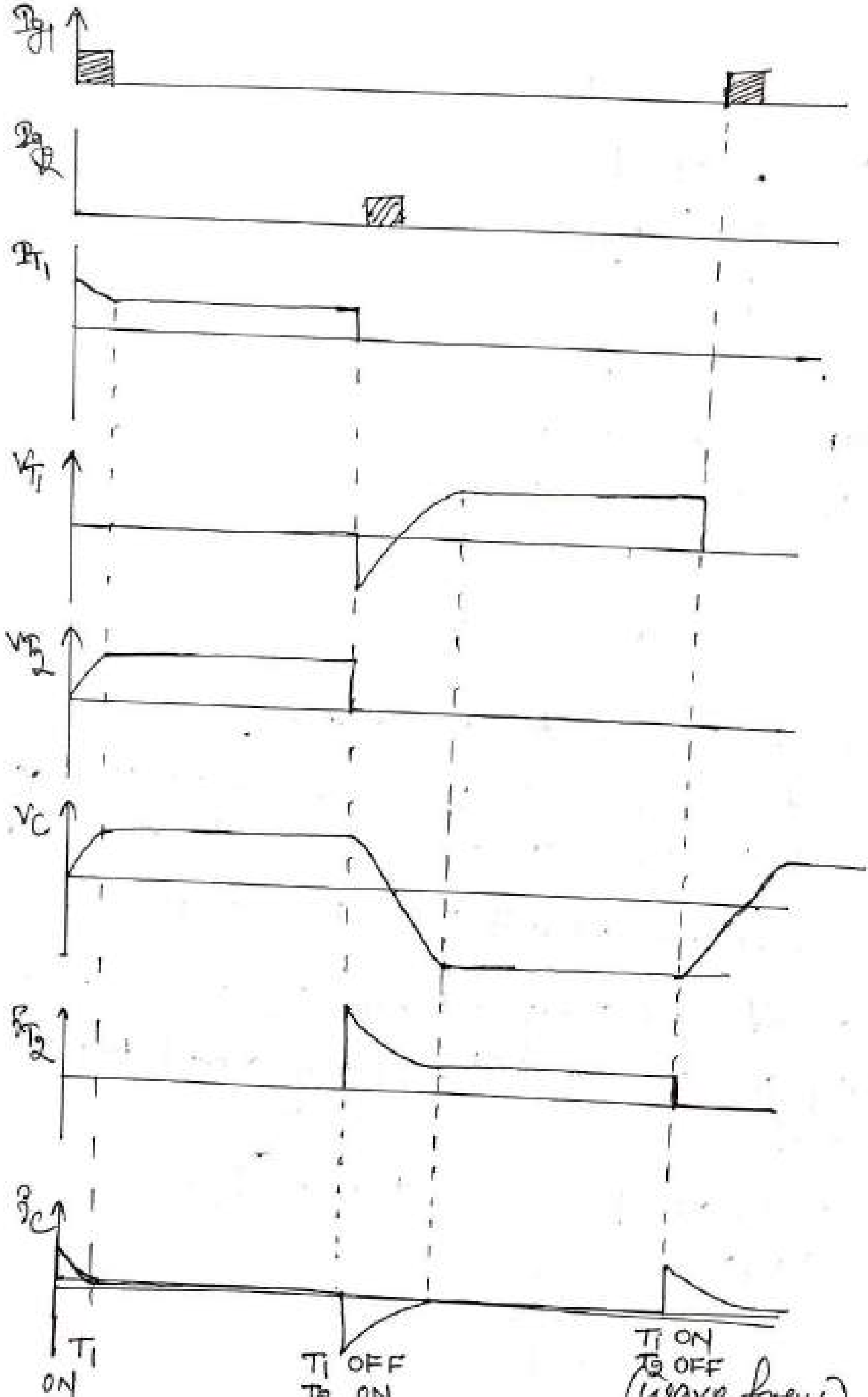
→ capacitor terminal polarity will be +| |−

→ when capacitor get charging with $-V_s$ loop 2 current will decreasing and when capacitor get fully charged loop 2 current will zero.

→ only current will pass through T_2 is $= \frac{V_s}{R_2} + 0 = \frac{V_s}{R_2}$

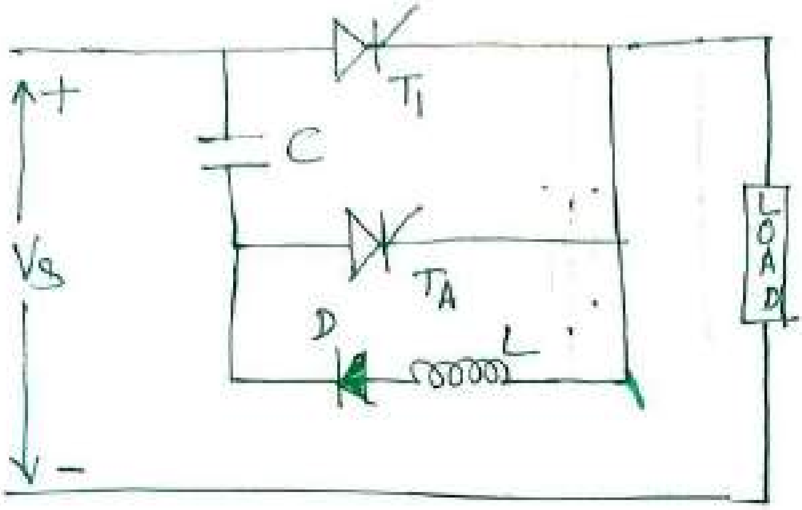


→ This polarity of capacitor get T_2 turned off because -ve side is connected with anode of T_2 and +ve side is connected with cathode of the T_2 so T_2 get reversed biased & turned off.



(wave form)

(i) Class D : Impulse Commutation :→

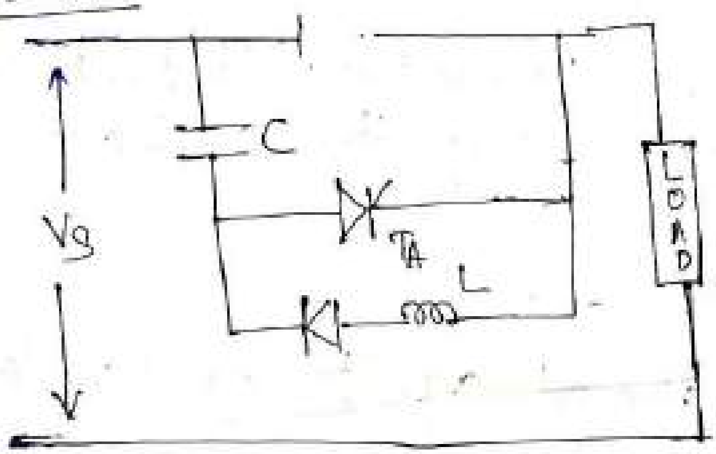


Assumption
I_0 = constant
$V_C = V_S$ ($t = 0$)

T_1 & T_A = OFF

no current will flow $V_C = 0$

T_A = ON



current flow through.

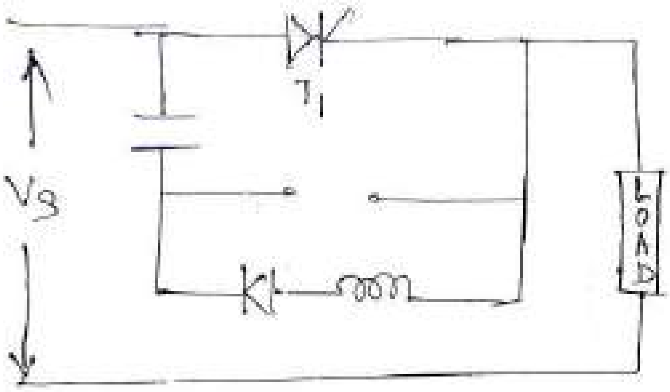
$+V_S \rightarrow C \rightarrow T_A \rightarrow$ Load $\rightarrow -V_S$

capacitor gradually charging, when capacitor get fully charged with V_s i.e $V_C = V_S$, capacitor across polarity

this polarity of capacitor gets T_A turned off. because

anode of the T_A is connected to the -ve polarity of the capacitor & cathode of T_A is connected to the +ve polarity of the capacitor this gets T_A reversed biased.

T_1 = ON



current flows in two loop

① $+V_S \rightarrow T_1 \rightarrow$ Load $\rightarrow -V_S$

capacitor current I_C flows through.

② $C \rightarrow T_1 \rightarrow L \rightarrow D \rightarrow C$

→ when capacitor current flows through the inductor, then inductor will stores energy & capacitor gradually released its energy.

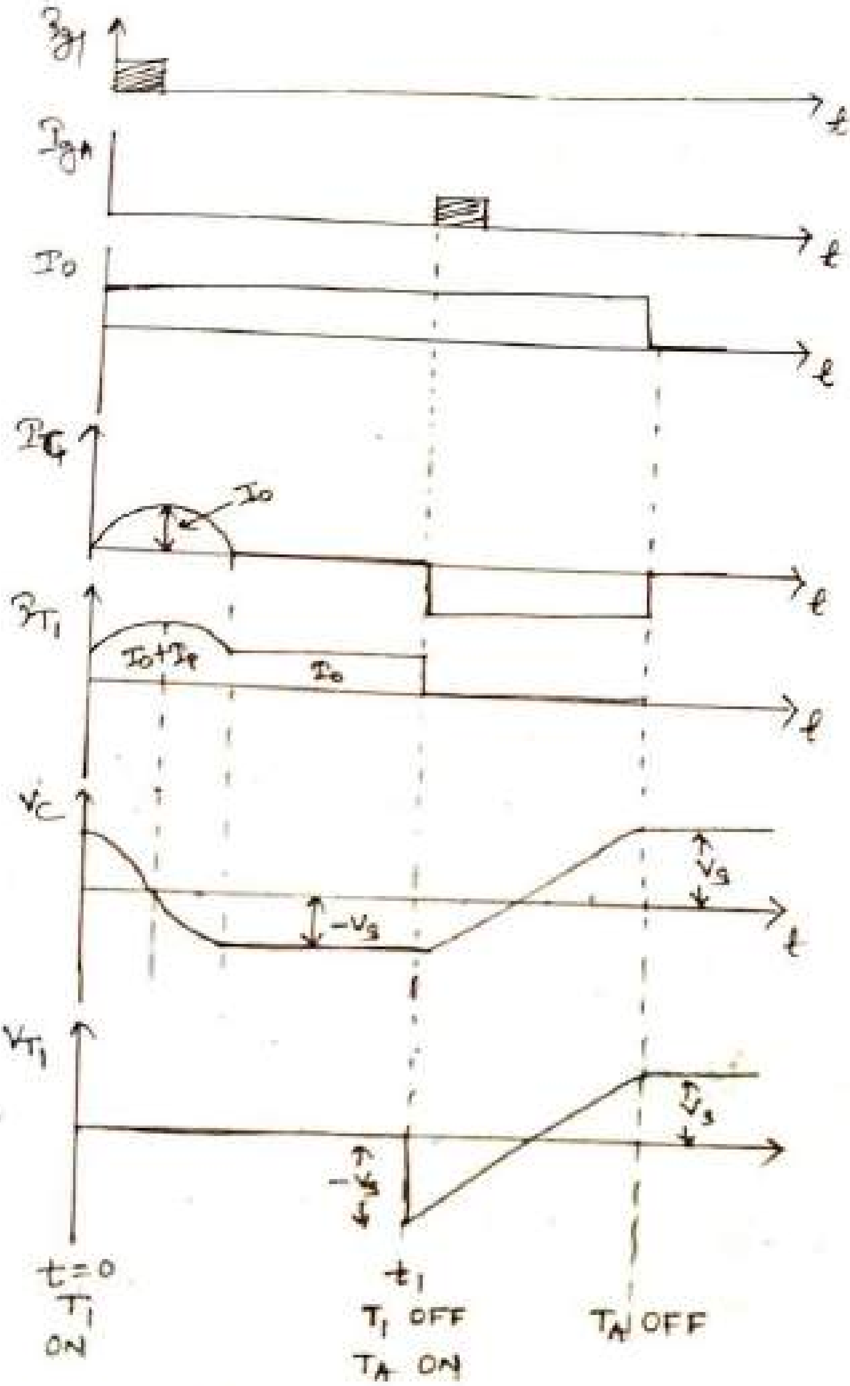
Inductor polarity will be $-$ ooo $+$.

→ when inductor gets fully charged capacitor across voltage will be zero, $V_C = 0$

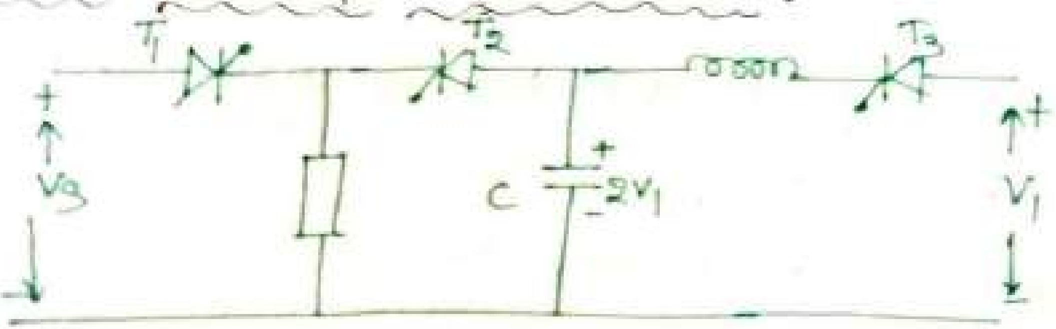
→ After inductor gets fully charged, inductor will released its energy and changes its polarity $+$ ooo $-$

→ After inductor changing its polarity inductor delivers its energy to the capacitor. & capacitor voltage will be $V_C = -V_S$ & the polarity be $\frac{-}{+}$. 5

→ when capacitor get fully charged and polarity become $\frac{-}{+}$ then this polarity of capacitor get T_1 turned off because -ve of capacitor connected to Anode and +ve of capacitor is connected to cathode so T_1 get reversed biased.



⑤ Class E : External pulse commutation :→



(Circuit Diagram)

- V_S = Main source voltage
- V_1 = auxiliary source voltage
- $V_1 > V_S$ for successful commutation.

T_1, T_2, T_3 = OFF

no current will flow.

T_1 = ON

Current flow $+V_S \rightarrow T_1 \rightarrow$ Load $\rightarrow -V_S$

$$V_0 = V_S$$

T_3 = ON

→ current flow $+V_1 \rightarrow T_3 \rightarrow L \rightarrow C \rightarrow -V_1$

→ Inductor will charge with polarity $-\text{ooo}+$

→ Capacitor also charged with V_1 with polarity, $V_C = V_1$

→ when inductor fully charged then released its energy and changes its polarity $+\text{ooo}-$.

→ Inductor delivered its all energy to the capacitor so previously capacitor charged with V_1 voltage again inductor delivered its all energy to the capacitor so the voltage across the capacitor becomes $2V_1$, so

$$V_C = 2V_1$$

T_2 = ON

when T_2 ON capacitor will be discharges a path to released its energy.

capacitor released its energy through

$$+2V_1 \rightarrow T_2 \rightarrow \text{Load} \rightarrow -2V_1$$

voltage across load will be $V_0 = 2V_1$.

In this case

anode terminal voltage of $T_1 = V_s$

cathode terminal voltage of $T_1 = 2V_1$

cathode more +ve with respect to anode.

Reversed biased voltage gets T_1 turned off.

$\boxed{V_1 > V_s}$

Voltage & Current Rating of SCR :- ⇒

① Voltage Rating :- ⇒

(i) V_{DWM} (peak working forward blocking voltage) ⇒
Its specifies the maximum forward blocking voltage that a thyristor can withstand during working.

(ii) V_{DRM} (Peak repetitive forward blocking voltage) ⇒
Its refers to the peak transient voltage that a thyristor can withstand repeatedly or periodically in its forward blocking mode. The rating is specified at a maximum allowable junction temp. with gate circuit open or with a specified biasing resistance between gate and cathode.

(iii) V_{DSM} (peak surge (non repetitive) forward blocking voltage) ⇒
It refers to the peak value of the forward surge voltage, that does not repeat. Its value about 130% of V_{DRM}

(iv) V_{RWM} (Peak working reverse voltage) ⇒
It is the maximum reverse voltage that a thyristor can withstand repeatedly.

(V) V_{RRM} (Peak repetitive reverse voltage) ⇒

It specifies the peak reverse transient voltage that may occur repeatedly in the reverse direction at the allowable maximum junction temperature.

(VI) V_{RSM} (peak surge non repetitive reverse voltage) ⇒

It represents the peak value of the reverse surge voltage that does not repeat. Its value is about 130% of V_{RRM}

$V_{RSM} < V_{BR}$

(VII) V_T on state voltage drop ⇒

It is the voltage drop between anode and cathode with specified forward on state current and junction temperature. Its value is of the order of 1 to 1.5 V.

(VIII) Forward $\frac{dv}{dt}$ rating ⇒

If rate of rise of forward anode to cathode voltage is high thyristor may turn on even when

(a) no gate signal

(b) anode to cathode is less then forward breakover voltage.

(IX) voltage safety factor (V_{SF}) ⇒

It is defined as the ratio of peak repetitive reverse voltage (V_{RRM}) to the maximum value of input voltage

$$V_{SF} = \frac{\text{peak repetitive reverse voltage } (V_{RRM})}{\sqrt{2} \times \text{rms value of input voltage}}$$

voltage safety factor = 2 to 3.

(X) finger voltage ⇒

It is the minimum value of forward bias voltage between anode and cathode for turning on the device by gate triggering. The magnitude of finger voltage is some what more than the normal on state voltage drop in the thyristor

→ The voltage drop across SCR during on condition with specified forward on state current and specific junction temperature.

(2) Current Rating :=>

(i) Average on state current (I_{TAV}) => The maximum average current value that can be carried by the SCR in its on state.

As the forward voltage drop across conducting SCR is very low, the power loss in an SCR depends mainly on forward average on state current.

This current rating is of repetitive type and is specified at the maximum junction temperature.

(ii) RMS on state Current (I_{RMS}) => The maximum repetitive RMS current specified at a max^m junction temp that can flow through the SCR.

The rms current rating can be of importance when applying thyristors to high peak current, low duty cycle wave forms.

This current rating is also of repetitive type and is specified at the maximum junction temperature.

(iii) Surge Current Rating (I_{TSM}) =>

The surge current rating indicates the maximum possible non repetitive or surge current, the device can withstand and this may occur due to non repetitive faults or short circuit during the life span of a thyristor.

(iv) I^2t rating :=>

I^2t is the maximum allowable non-recurring value of the square of the instantaneous current integrated with respect to the time.

This rating is required to co ordinate with the fast acting fuse for protecting the device during an overload or fault conditions.

(v) di/dt rating =>

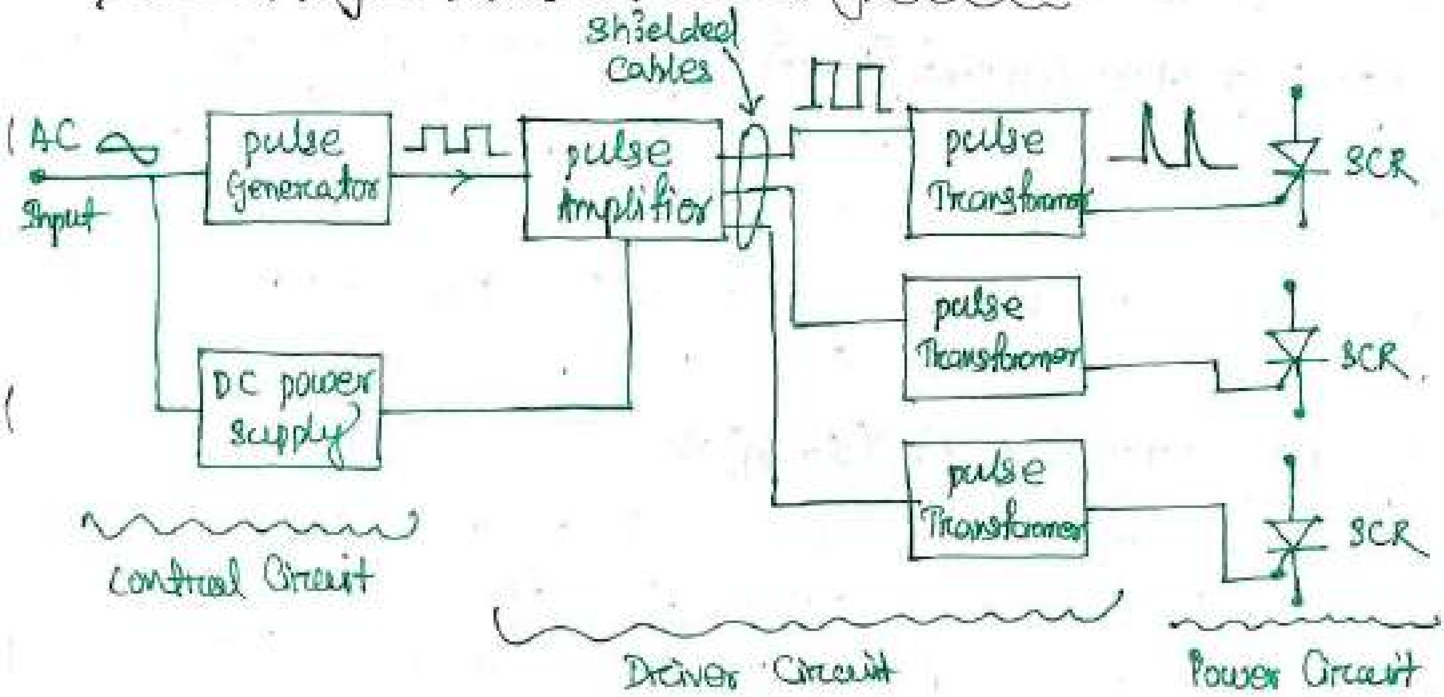
This rating of thyristor indicates the maximum rate of rise in anode to cathode current.

(vi) Gate Current :⇒

The current which is applied to the gate of the thyristor for control purposes is known as its gate current.

Firing Circuit :⇒

① General layout diagram of firing Circuit :⇒



→ The most common method for controlling the onset of conduction is an SCR is by means of gate voltage control

→ the gate control circuit is also called firing circuit or triggering circuit.

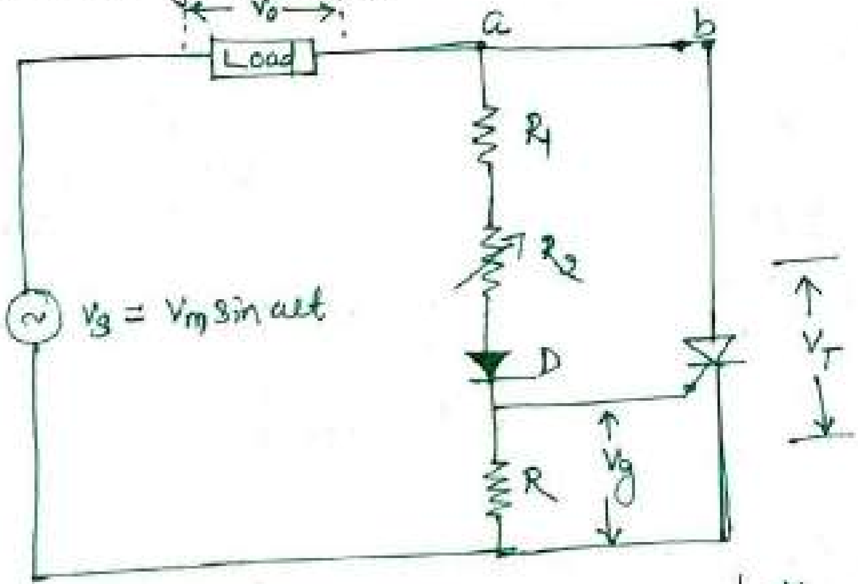
→ Gate triggering circuit usually low power electronics circuit.

→ A firing circuit should have two function.–

(i) if power circuit has more than one SCR, the firing circuit should produce gating pulses for each SCR at the desired instant for proper operation of the power circuit. These pulses must be periodic in nature and the sequence of firing must be correspond with the type of thyristorised power controller

(ii) the control signal generated by a fireing circuit may not be able to turn on an SCR. It is therefore common to feed the voltage pulses to a driver circuit and then to gate cathode circuit. A driver circuit consists of a pulse amplifier and a pulse transformer.

② R – Fireing Circuit :⇒



→ R_1 current limiting resistor

$$I_{g(min)} < I_g < I_{g(max)}$$

if we ignore current through R

$$i = \frac{V_m \sin \omega t}{R_1 + R_2}$$

→ R_2 is variable $R_2 = 0$ (max^m current)

$$I_{max} = \frac{V_m}{R_1} < I_{g(max)}.$$

→ R_2 variable to vary firing angle

→ R voltage limiting resistor

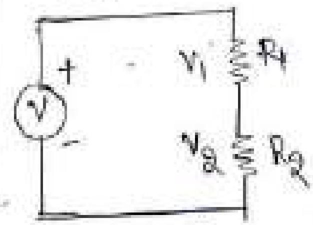
if we ignore gate current of SCR

$$V_g = \frac{(V_m \sin \omega t) \times R}{R_1 + R_2 + R}$$

$$V_g = V_{gm} \sin \omega t \quad (1)$$

$$V_{gm} = \frac{V_m R}{\ldots} \quad (2)$$

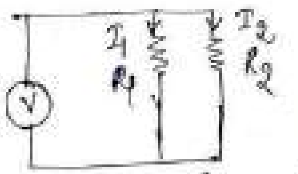
★ Voltage Division Rule



$$V_1 = \frac{R_1}{R_1 + R_2} V$$

$$V_2 = \frac{R_2}{R_1 + R_2} V$$

★ Current Division Rule



$$I_1 = \frac{R_2}{R_1 + R_2} I$$

$$I_2 = \frac{R_1}{R_1 + R_2} I$$

Gate cathode voltage is depends on value of R.

$V_g \uparrow \rightarrow R \uparrow \quad R \downarrow \rightarrow V_g \downarrow$

Diode prevents reverse flow of gate current.

→ SCR gets triggered when V_g exceeds a threshold voltage. V_{gt}

$V_g \geq V_{gt}$ SCR ON

V_{gt} = threshold voltage ↓ very close to something

$V_{gm} \sin \omega t \geq V_{gt}$

$V_{gm} \sin \alpha \geq V_{gt}$

$\alpha \geq \sin^{-1} \frac{V_{gt}}{V_{gm}}$

$R_2 \downarrow \quad V_{gm} \uparrow$

$R_2 \uparrow \quad V_{gm} \downarrow$

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

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

3

V_{gm} = peak gate voltage

As V_{gt}, R_1, R & V_m are fixed

$\alpha \propto \sin^{-1}(R_2)$

α = firing angle

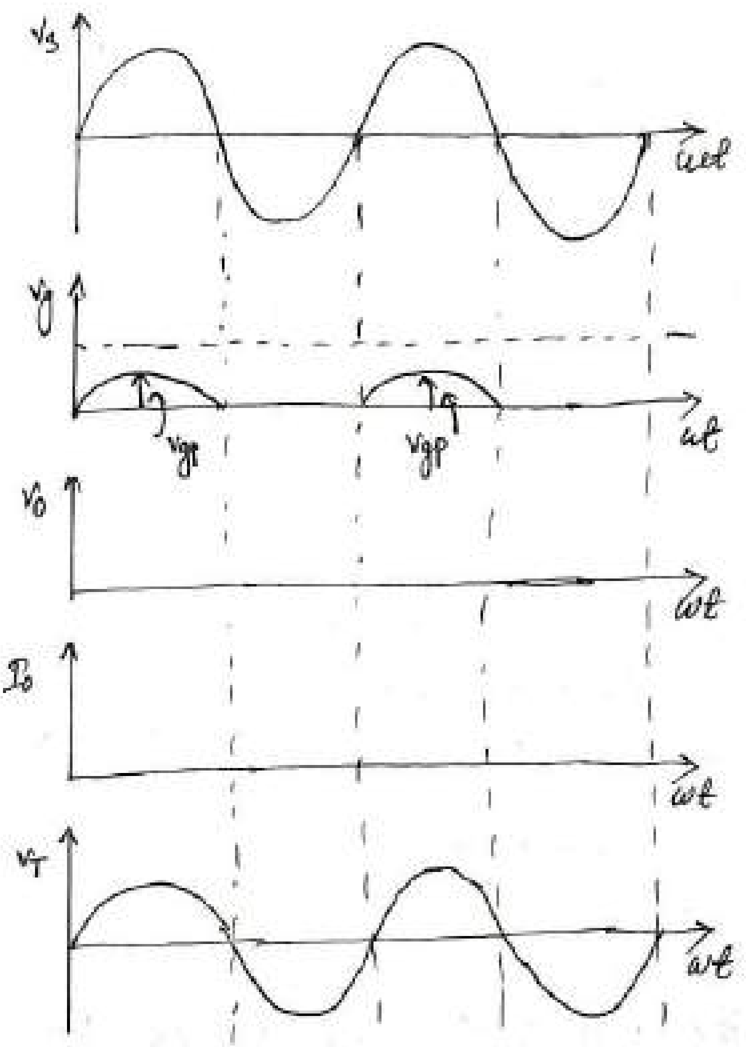
$$\boxed{\alpha \propto R_2}$$

this shows that firing angle is proportional to R_2

R_2 is increased from small value, firing angle will increase.

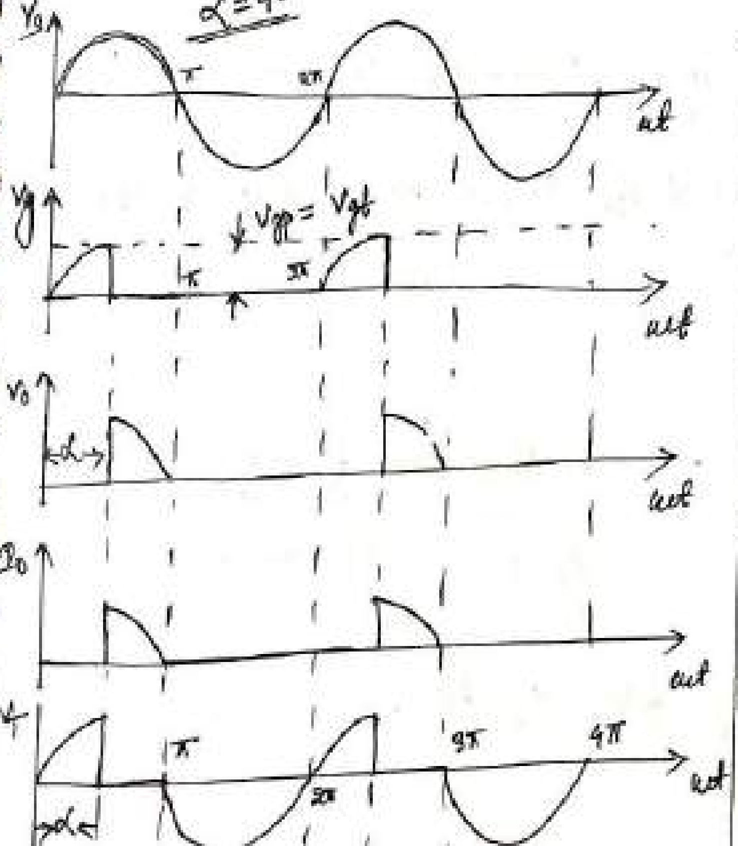
$R_2 \rightarrow V_{gm} \rightarrow V_g$

* In this the triggering angle is limited to 90° only. Because the applied voltage is maximum at 90° so the gate current has to reach minimum gate current value some where between zero to 90° degree.

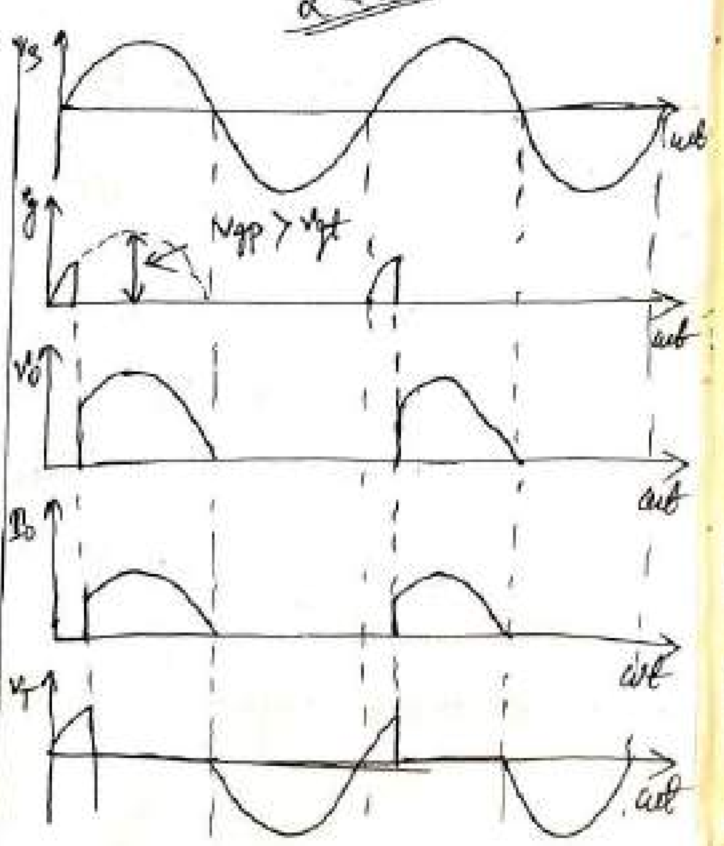


(No triggering of SCR)

$\alpha = 90^\circ$

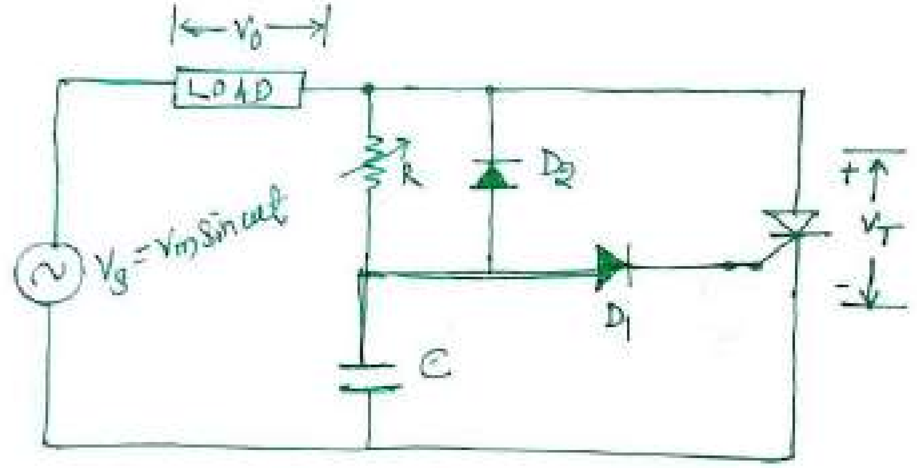


$\alpha < 90^\circ$



③ RC firing Circuit :⇒

→ Limitation of resistance firing : α can not be greater than $90°$.



- R : variable, changes the time constant of ckt →
  Rate of charging of capacitor varies →
  the angle or time at which V_g exceeds V_{gt} will vary
- D_1 : prevents flow of Reverse current
  D_2 : helps in discharging of capacitor. $V_C = V(1 - e^{-t/RC})$

→ when SCR is off capacitor charges to a -ve voltage through D_2 during -ve half cycle. thats why capacitor graph starts from -ve value

→ During the cycle capacitor charges towards +ve voltage through R.

→ As soon as V_C exceeds $V_{gt} + V_D$ then SCR turns on

$$V_S > iR + V_C$$

$$V_S > I_g R + V_C$$

$$V_S > I_g R + V_{gt} + V_D \rightarrow \text{at the time of triggering}$$

$$R \leq \frac{V_S - V_{gt} - V_D}{I_g} \qquad V_{gt} = \text{gate trigger voltage}$$

- D_2 charges capacitor during -ve cycle.

→ The limitation R firing circuit can be overcome by the RC triggering circuit which provides the firing angle control from 0 to 180°. By changing the phase and amplitude of gate current a large variation of firing angle is obtained using this circuit

→ By varying the variable resistance, triggering or firing angle is controlled in a full positive half cycle of the input signal.

→ During the negative half cycle the input signal, capacitor charges with lower plate positive through diode D_2 up to maximum supply voltage V_{max}. This voltage remains at $-V_{max}$ across the capacitor till supply voltage attains zero crossing.

→ During positive half cycle of the input, the SCR becomes forward biased and the capacitor starts charging through variable resistance to the triggering voltage value of SCR.

→ When the capacitor charging voltage is equal to the gate trigger voltage SCR is turned on and the capacitor holds a small voltage. Therefore the capacitor voltage is helpful for triggering the SCR even after 90 degree of the input wave form.

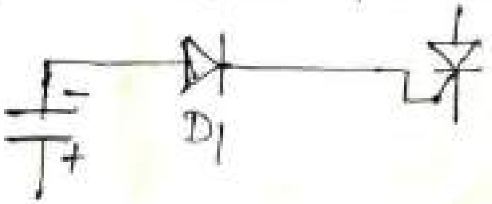
→ In this diode D_1 prevents the negative voltage between the gate and cathode during the negative half cycle of the input through diode D_2.

(−ve) half cycle

Current flows $V_s \rightarrow C \rightarrow D_2 \rightarrow \text{Load} \rightarrow V_s$

Capacitor gets charged & polarity of capacitor becomes

After the charging of capacitor diode $D_1 \rightarrow$ RB no current flows through the SCR



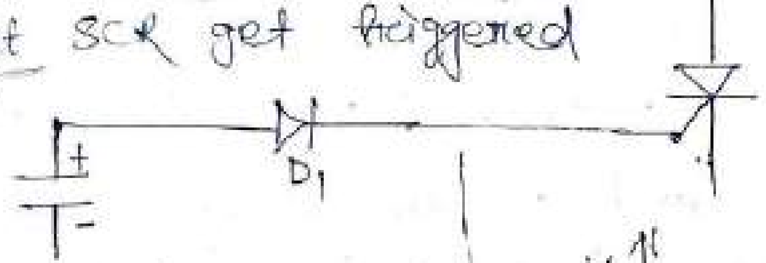
(+ve) half cycle

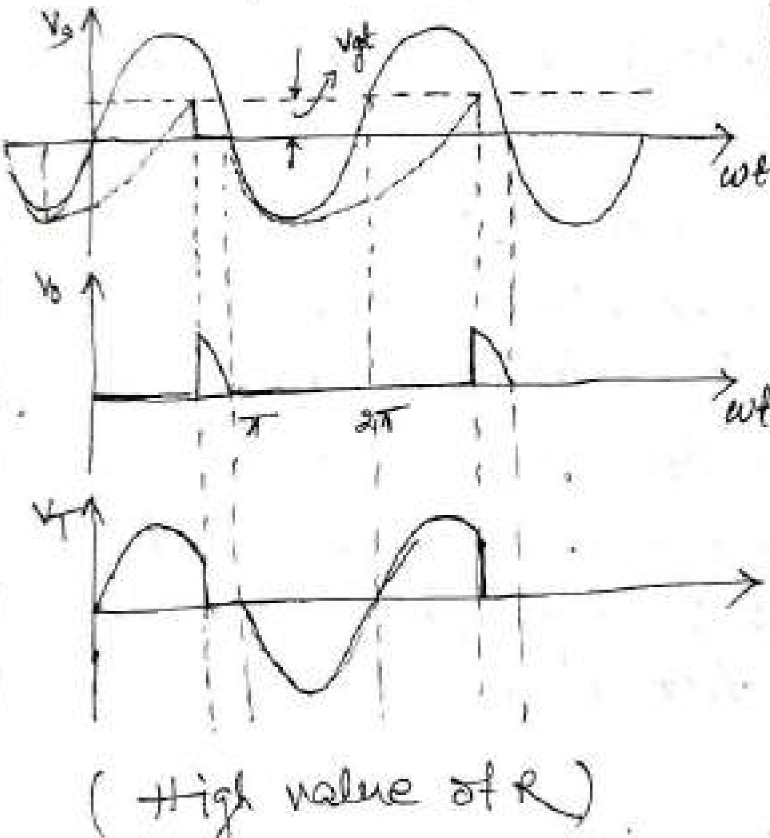
current flow in $V_s \rightarrow$ Load $\rightarrow R \rightarrow C \rightarrow V_s$

capacitor get charged & polarity of capacitor becomes

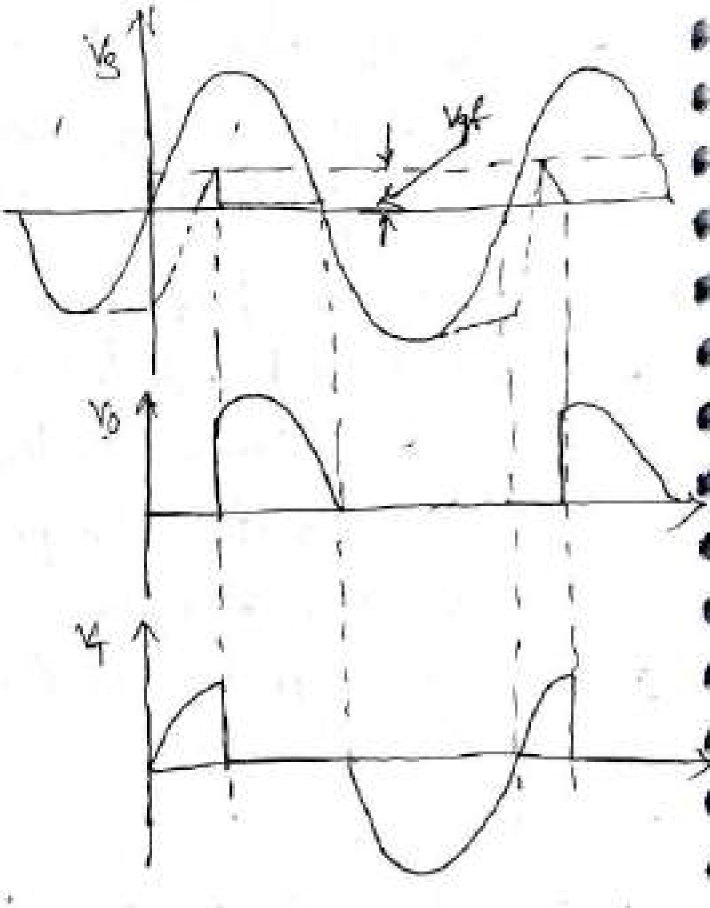
This positive voltage pass through the diode D_1

$V_C = V_{gt}$ SCR get triggered





(High value of R)

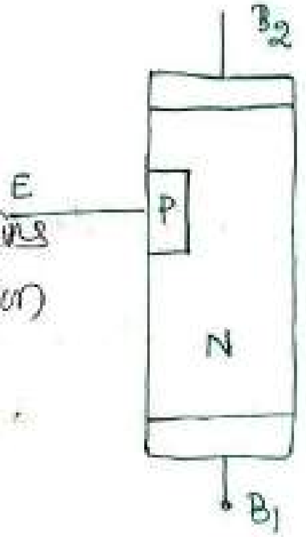


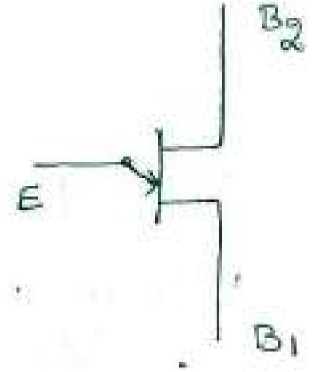
(low value of R)

→ High value of R the charging of capacitor value is increases because low current flow.

→ low value of R the charging of capacitor value is decreases because more current flow.

④ UJT :⇒





→ This transistor contains only one PN junction

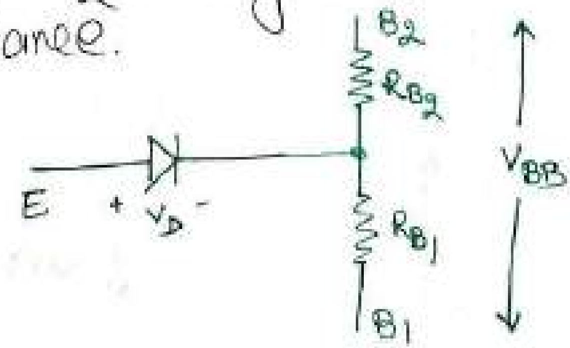
→ 3 terminal device
P: Emitter
N: B_1 & B_2

→ In off state due to depletion region a small area is avelable for current to flow due to which resistance between B_2 & B_1 is high.

→ Base is lightly doped so conducting is small & resistance is high.

→ current flow betwo B_2 & B_1 the path of current flow is controlled by emitter.

→ Since the path between B_1 & B_2 is only n-type semiconductor so we model it as resistance.



→ until emitter diode gets FB the cross section area of current flow is very low hence resistance is high almost negligible current flows through device.

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

→ V_E most exceed $\underbrace{\eta V_{BB} + V_D}_{V_P}$ for diode to turn on.

→ emitter voltage is greater then peak voltage i.e $\eta V_{BB} + V_D$ then UJT is turn on.

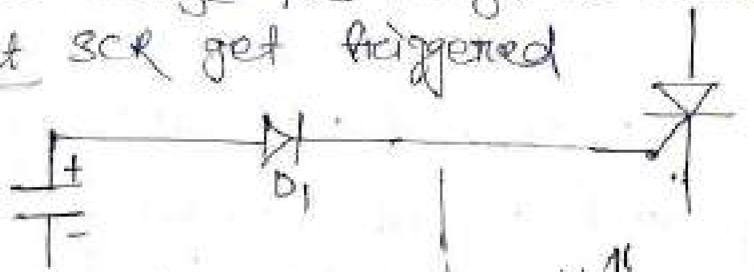
(+ve) half cycle

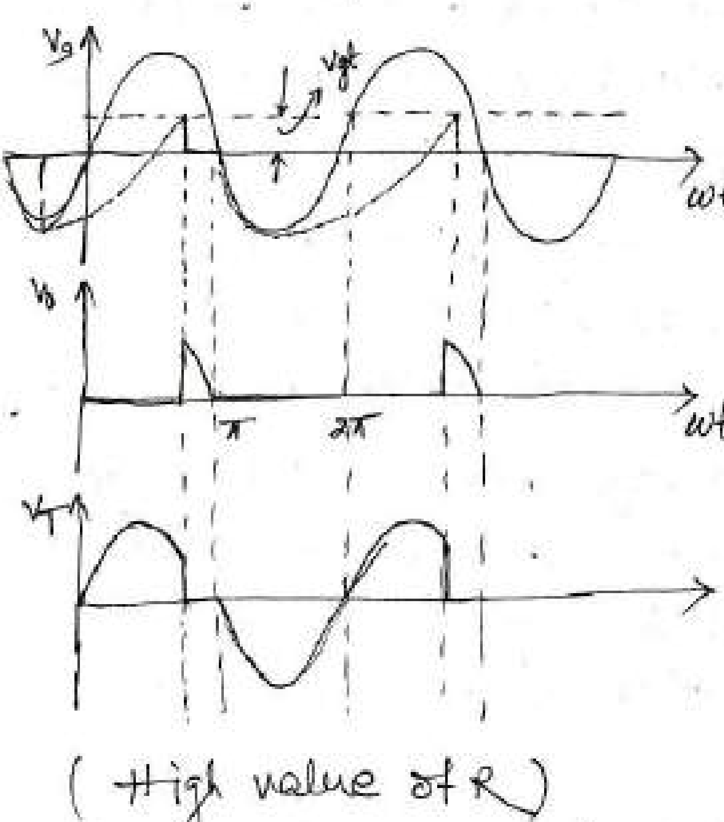
current flow in V_s → Load → R → C → V_s

capacitor get charged & polarity of capacitor becomes

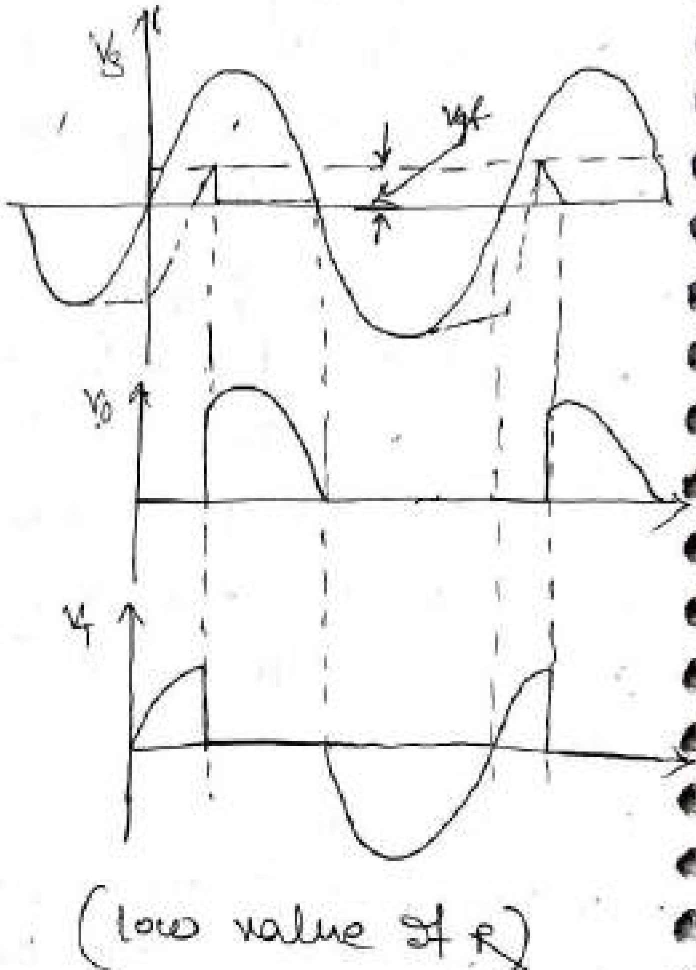
This positive voltage pass through the diode D_1

$V_C = V_{gt}$ SCR get triggered





(High value of R)



(low value of R)

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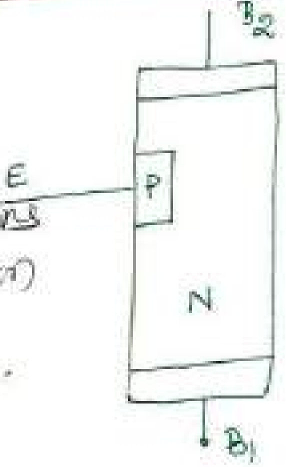
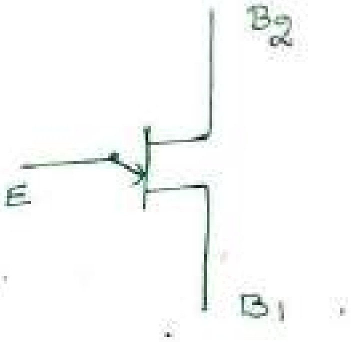
④ UJT :⇒





→ This transistor contains only one PN junction

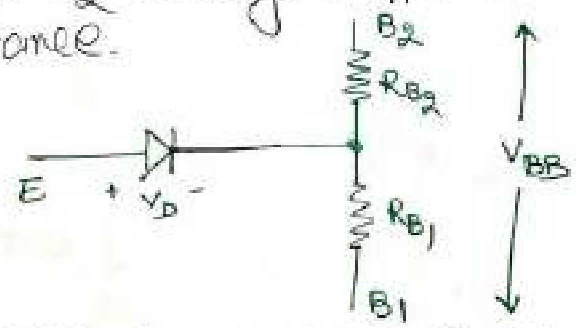
→ 3 terminal device.
P: Emitter
N: B_1 & B_2

→ In off state due to depletion region a small area is avalable for current to flow due to which resistance between B_2 & B_1 is high.

→ Base is lighly doped so conducting is small & resistance is high.

→ current flow below B_2 & B_1 the path of current flow is controlled by emitter.

→ Since the path between B_1 & B_2 is only n-type semiconductor so we model it as resistance.



→ untill emitter diode gets FB the cross section area of current flow is very low hence resistance is high almost negligible current flows through device.

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

→ V_E most exceed $\underbrace{\eta V_{BB} + V_D}_{V_P}$ for diode to turn on

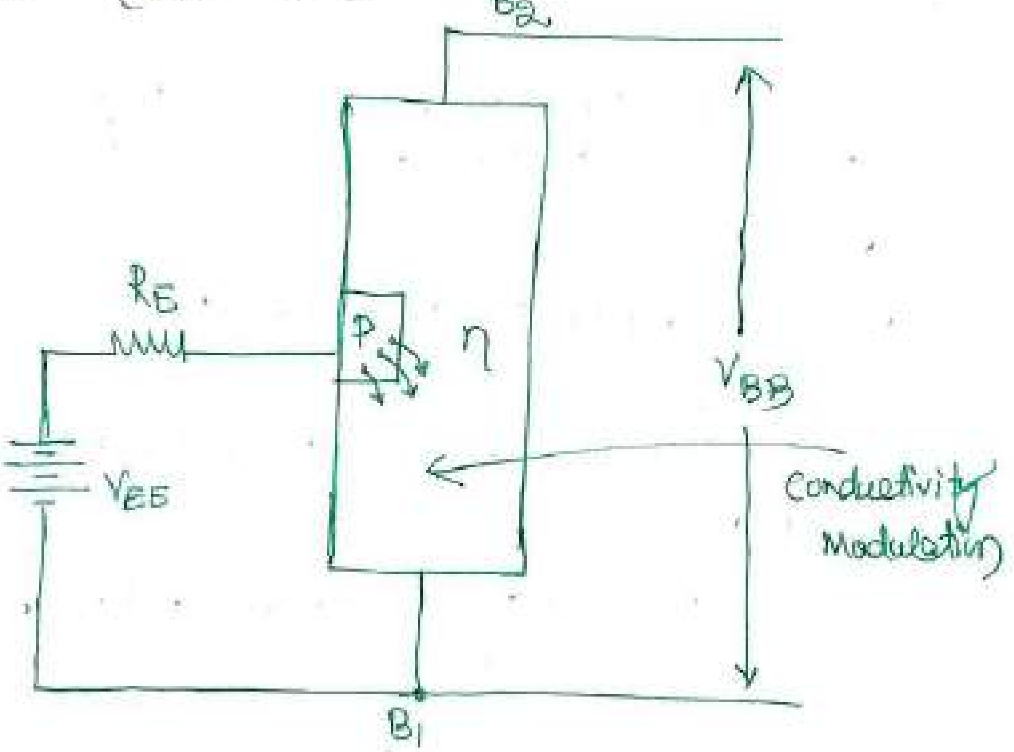
→ emitter voltage is greater then peak voltage i.e $\eta V_{BB} + V_D$ then UJT is turn on.

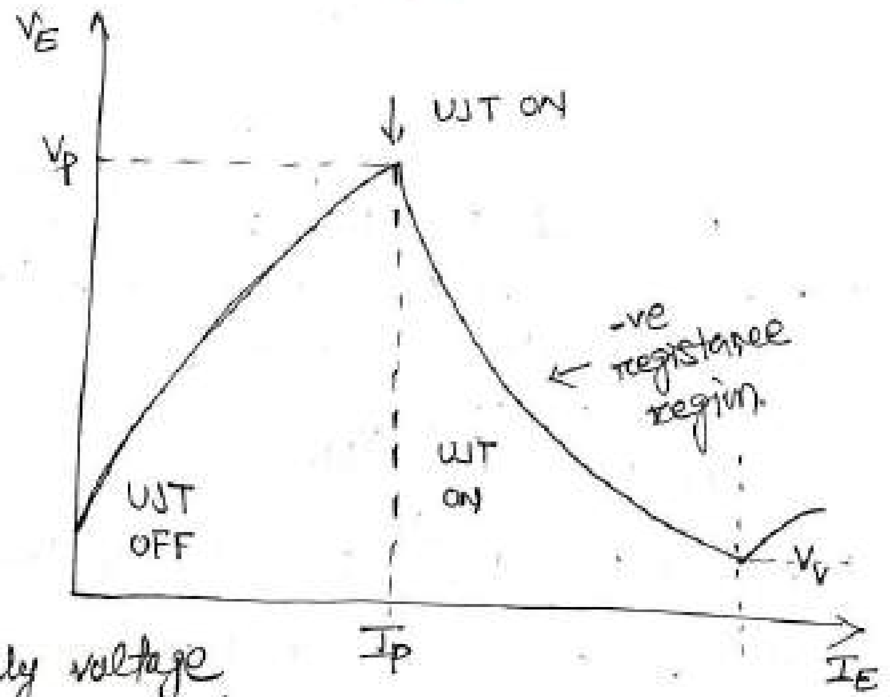
$$\eta = \frac{R_{B1}}{R_{B1} + R_{B2}}$$

$V_E > \eta V_{BB} + V_D = V_P$ (peak voltage)

→ As soon as $V_E > V_P$ charges flow from emitter to base and due to conductivity modulation R_{B_1} reduces

$\eta \downarrow \quad V_E = \eta V_{BB} + V_D \downarrow$





V_V = vally voltage

I_V = vally current

→ In OFF state even if we increase V_E current does not increase much.

→ onces UJT is on current flows from emitter - charges enter, conductivity modulation happens

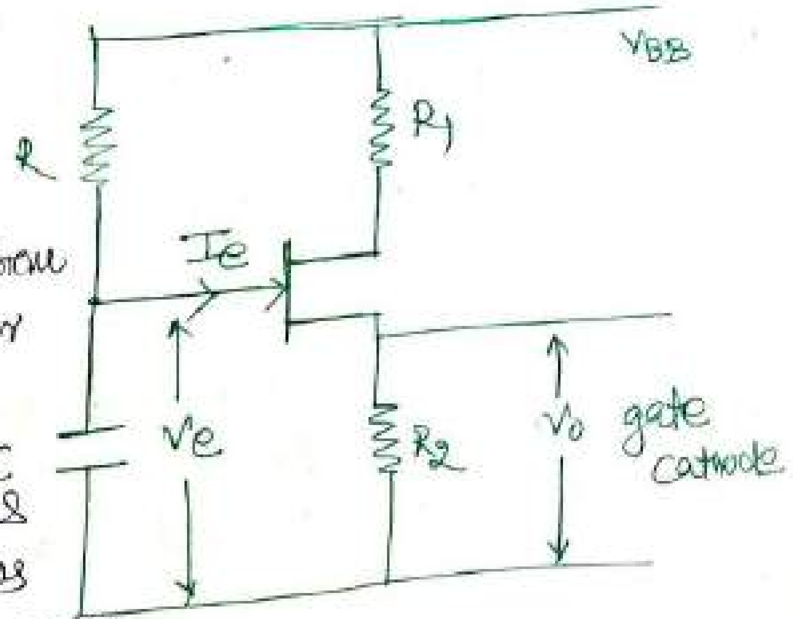
$R_B \downarrow,\ \eta \downarrow,\ \eta V_{BB} + V_D = V_E \downarrow$

→ After a certain current base region becomes saturated charge carriers.

$R \simeq$ constant so with further increase of voltage - current increases slightly.

→ $\dfrac{V_{EE} - V_P}{I_P} < R_E < \dfrac{V_{EE} - V_V}{I_V}$

⑤ UJT Triggering :→



→ when UJT OFF

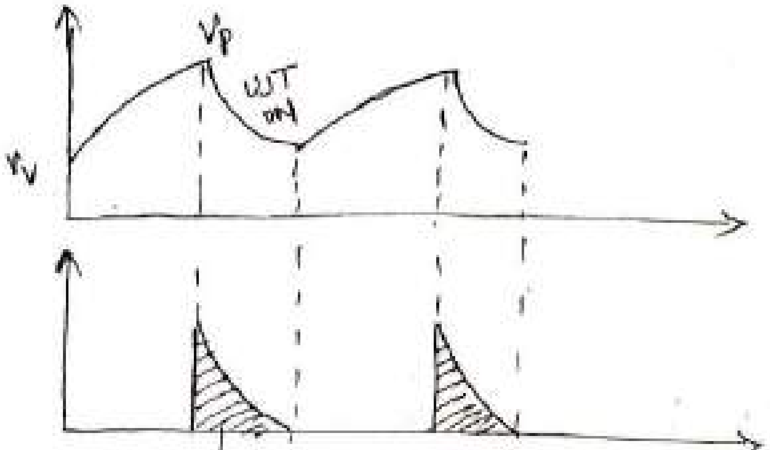
$I_E \simeq 0$

→ RC series circuit is form with voltage V_{BB} capacitor start charging.

→ Capacitor charges towards V_{BB} through R as soon as V_C exceeds V_P UJT turn on.

→ Capacitor discharges through UJT & Resistor R_2

→ Due to current through R_2, V_O is developed which triggers SCR.



$\rightarrow$ Current flows through R_2

$\rightarrow$ V_C oscillate between peak & valley voltage

$$V_C(0) = V_V \qquad V_C(\infty) = V_{BB}$$

$$V_C(t) = V_{BB} + (V_V - V_{BB})e^{-t/\tau}$$

at $t = T$, $V_C = V_P = \eta V_{BB} + V_D \simeq \eta V_{BB}$

$$\eta V_{BB} = V_{BB}(1 - e^{t/\tau}) \text{ ignoring } V_V$$

$$1 - \eta = e^{-T/\tau}$$

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

$\rightarrow$ By help of UJT we perform pulse triggering.

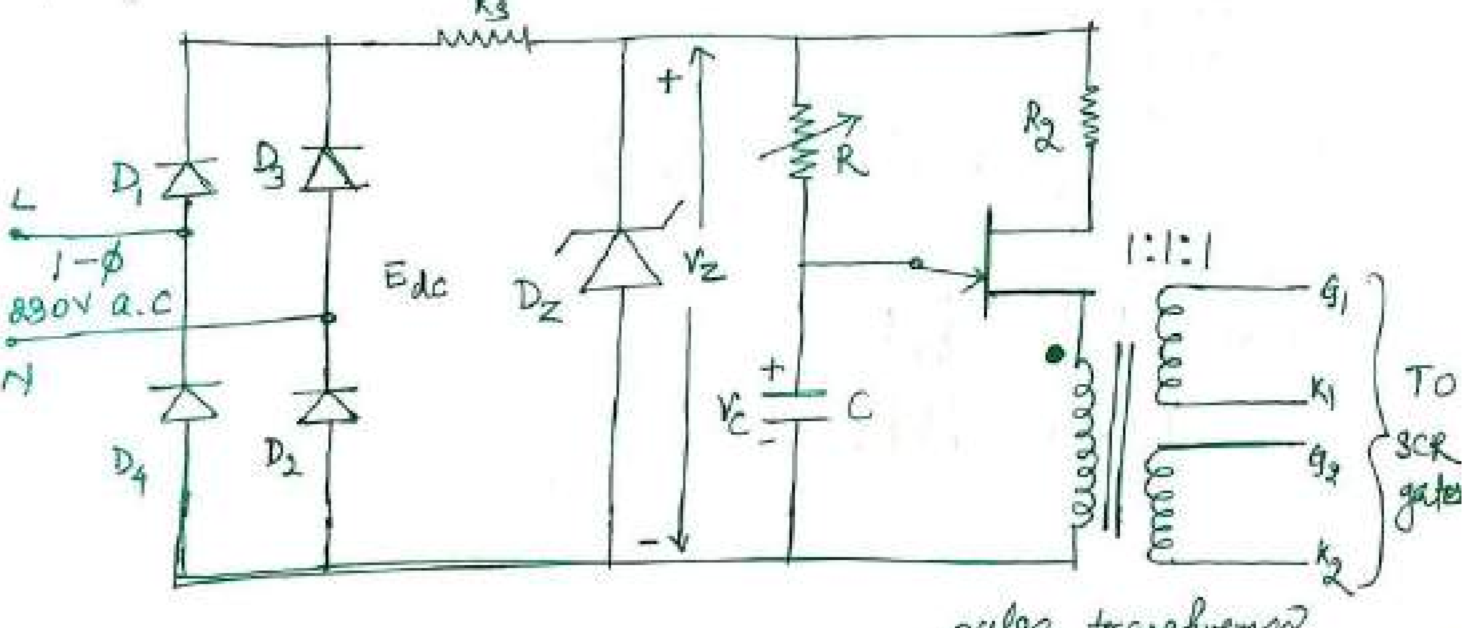
$\rightarrow$ It is the most common method of triggering the SCR because the prolonged pulses at the gate using R and RC triggering methods cause more power loss is limited as it produce a train of pulses.

$\rightarrow$ The RC network is connected to the emitter terminal of the UJT which forms the timing circuit. The capacitor is fixed while the resistance is variable and hence the charging rate of the capacitor depends on the variable resistance means that the controlling of the RC time constant.

→ when the voltage is applied the capacitor starts charging through the variable resistance. By varying the resistance value voltage across the capacitor get varied. once the capacitor voltage is equal to the peak value of the UJT, it starts conducting and hence produce a pulse output till the voltage across the capacitor equal to the valley voltage V_V of the UJT. This process repeats and produces a train of pulses at base terminal 1.

→ The pulse output of the base terminal 1 is used to turn ON the SCR at predetermined time intervals.

⑤ Synchronized UJT Triggering (Ramp Triggering) :→



pulse transformer

→ The diode bridge $D_1 - D_4$ rectifies ac to DC.

→ R_S lowers E_{dc} to a suitable value for the zener diode & UJT.

→ D_Z is to clip the rectified voltage to a fixed voltage V_Z.

→ V_Z is applied to charging circuit RC. Capacitor C charges through R until it reaches the UJT trigger voltage V_P.

→ UJT turns on and C discharges through UJT emitter and primary of the pulse transformer.

→ The windings of the pulse transformer have pulse voltage at their secondary terminals. pulses at the two secondary windings feed the same inphase pulse to two SCRs of a full wave circuit.

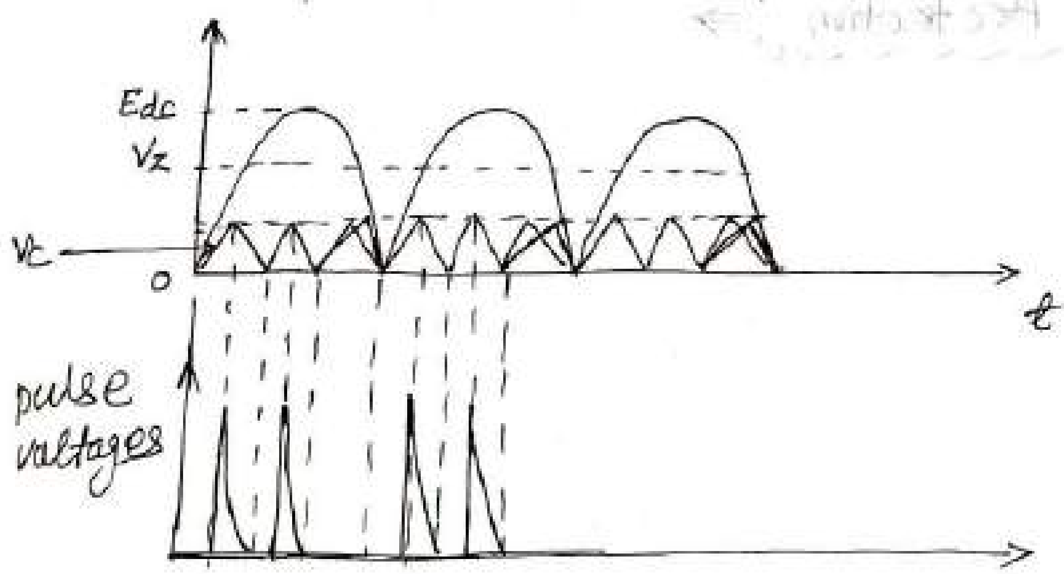
→ SCR with positive anode voltage would turn ON.

→ Rate of rise of capacitor voltage can be controlled by varying R.

→ The firing angle can be controlled up to about 150°.

→ V_z goes to zero at the end of each half cycle, the synchronized of the trigger circuit with the supply voltages across SCRs is achieved.

→ Time 't' equal to α/ω when the pulse is applied to SCR for the first time, will remain constant for the same value of R.



SCR Protection :-

① $\frac{di}{dt}$ protection ->

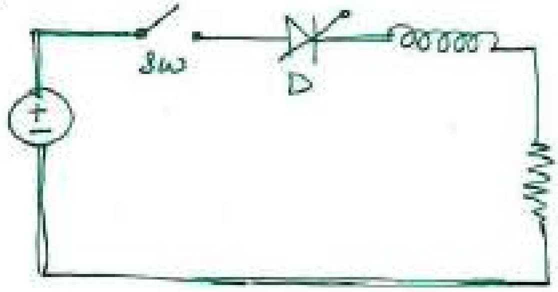
-> if current increases rapidly, then current may become high in a very short duration of time.

-> In such time, if conduction area does not increase rapidly then high current flows through small area

-> temperature of such small area increases to a very high value leading to formation of local hotspot.

connect an inductor in series with SCR $V = L\frac{di}{dt}$

-> Inductor opposes change of current & hence reduces $\frac{di}{dt}$ to a safe value



$$\frac{di}{dt} < \left(\frac{di}{dt}\right)_{rating}$$

-> increasing conduction area

-> when we apply gate current then charges from gate terminal lead to conductivity modulation

-> The region through which gate charges pass has higher conductivity & lower resistance so we call as conducting area.

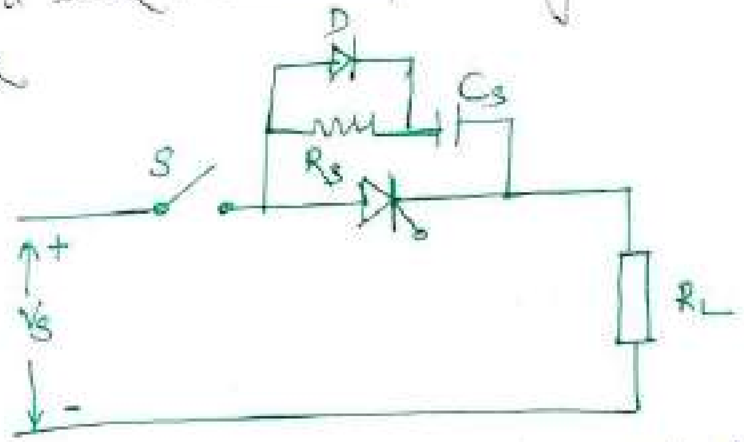
-> To increase conduction area

- -> charges from gate terminal should increase
- -> we must design such that gate charges spread through larger area.

center gated SCR has more conduction area & hence higher $\frac{di}{dt}$ rating.

(2) $\frac{dv}{dt}$ protection ⇒ $i = C\frac{dv}{dt}$ $C = \frac{q}{V}$

→ high $\frac{dv}{dt}$ across a SCR in forward blocking mode falsely triggers the SCR



→ Capacitor opposes change of voltage so it is connected across SCR.

SCR : Forward blocking mode (C_j)

due to positive terminal of V_s D is ON

→ when D is ON C_s & C_j in parallel $C = C_s + C_j$

RC series ckt is formed through V_s, R_L & C

$$V_C = V_T = V_s\left(1 - e^{-t/\tau}\right)$$

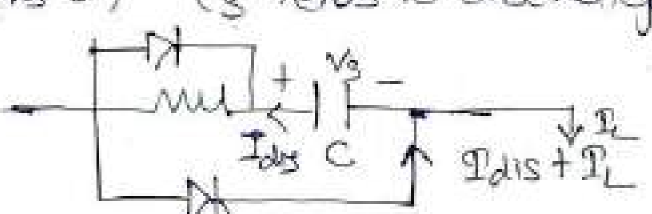
$$\frac{dV_T}{dt} = \frac{V_s}{\tau} e^{-t/\tau}$$

$$\left.\frac{dV_T}{dt}\right|_{max} = \frac{V_s}{\tau} = \frac{V_s}{R_L C} \leqslant \left(\frac{dv}{dt}\right)_{rated}$$

→ By use of C_s, C increases & $\frac{dv}{dt}$ decreases.

→ Capacitor C_s charges to V_s in steady state.

now when SCR turns on C_s tends to discharge



→ capacitor discharges through $C_S \rightarrow R_S \rightarrow T \rightarrow C_S$

→ Now I_{dis} should not be very high else SCR can get damaged.

$$(I_{dis})_{max} = \frac{V_S}{R_S}$$

SCR current = $I_{dis.cu} + I_L$

from this we can compute R_S

→ R_S limits the value of discharging current.

③ Over voltage Protection ⇒

→ If voltage across SCR is more than rated voltages, then SCR may get damaged.

→ we connect a non liner resistor across (parallel) SCR whose I-V curve is such that resistance falls at higher voltage

→ such resistor is made of metal oxide

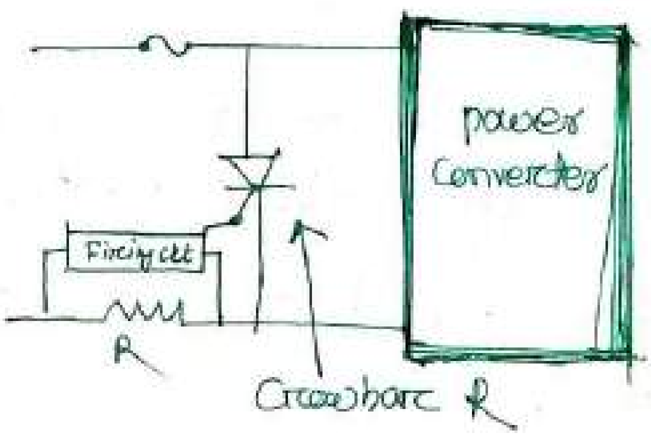
→ As resistance is low at high voltage, then high voltage surge bypasses SCR & flows through resistor.

④ Over current Protection ⇒

→ High current can thermaly damage a device.

→ SCR has high surge current rating which means it can tolerate high current for short duration.

→ To protect the SCR we use CB or Fuse.



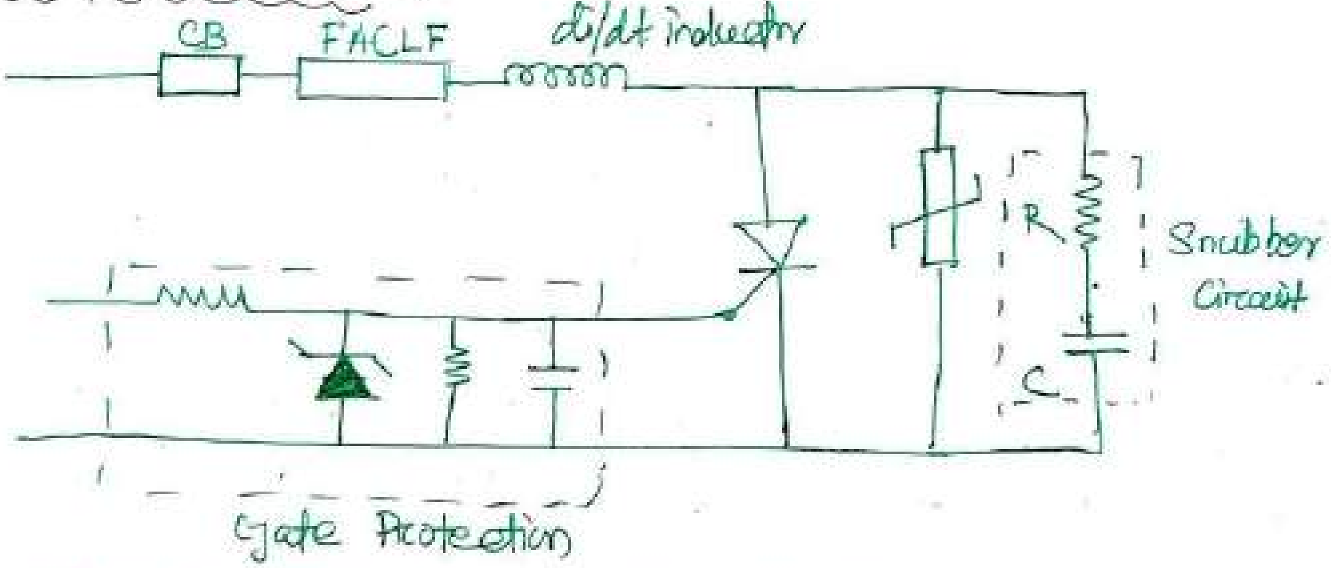
→ In event of high current if we short supply then it is called as crowbar protection

→ when I is high, firing ckt senses high voltage across R & triggers SCR.

→ SCR get shorted & thus protects all other devices inside power converter.

→ Before SCR gets damaged fuse or CB in series with supply operates.

⑤ Gate Protection ⇒



FACLF → Fast acting Current Limiting fuses

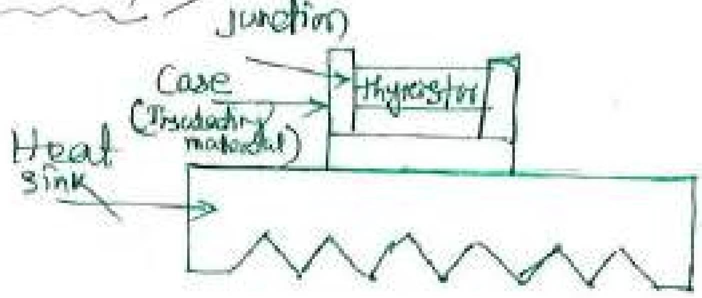
→ voltage induced across gate cathode junction in the form of noise from near by devices can trigger SCR

→ RC filter protects gate cathode junction from any such noise

→ to protect against over voltage we connect a zener diode across gate cathode junction.

→ To protect against over current we connect a resistor in the ckt.

⑥ thermal protection →



→ if temp of device goes above thermal limit then device may get damaged.

→ Device is mounted on a metal heat sink.

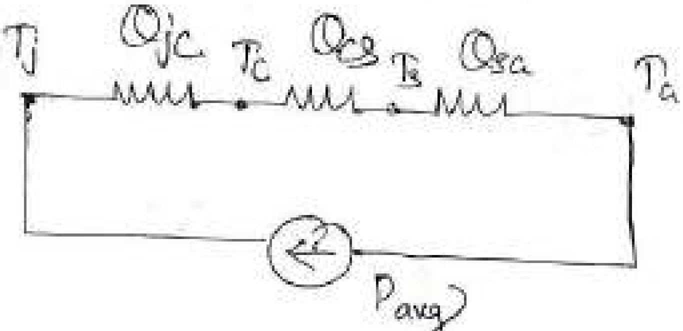
→ Metal radiates heat more effectively

→ It increases surface area of device.

→ Thermal resistance → opposition to flow of heat

$$\theta = \frac{l}{KA} \qquad K = \text{thermal conductivity}$$

θ : °C/W



↳ average conduction loss

- temp → voltage
- power → current

θ_{JC} : junction to case

θ_{CS} : case to sink

θ_{SA} : sink to ambient

Under steady state T = constant

↳ Heat flow is constant

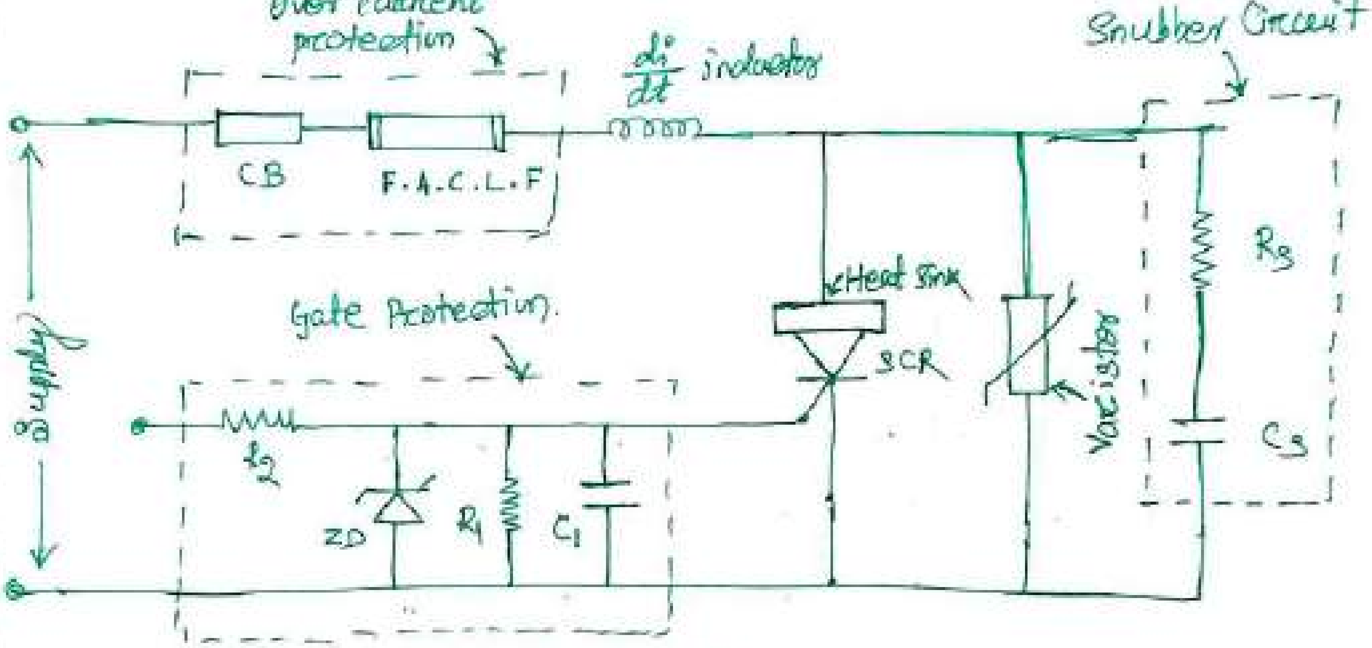
↳ all thermal resistance are connected in series.

T_J → junction temp T_a → ambient temp.

T_C → case temp

T_S → sink temp

$$T_J - T_A = P_{av}(\theta_{jc} + \theta_{cs} + \theta_{sA})$$

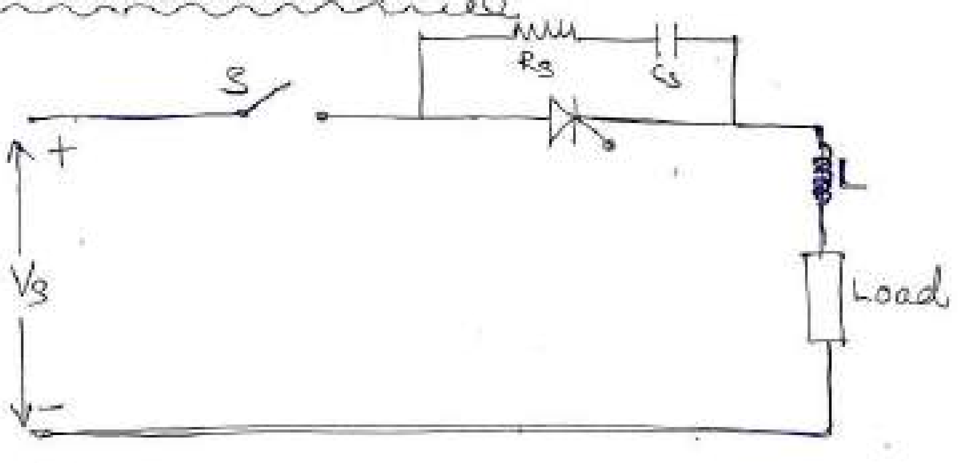


CB → Circuit Breaker

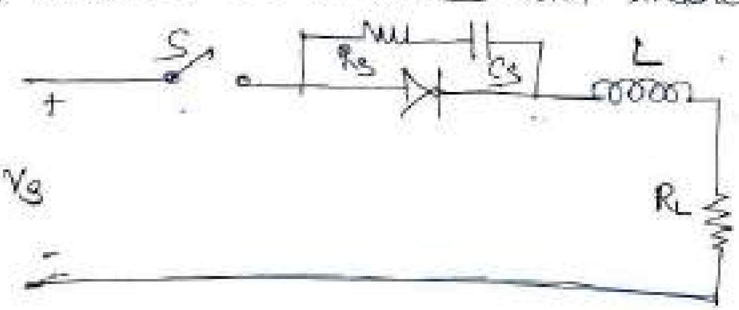
F.A.C.L.F → Fast acting current limiting fuse

(Circuit Components showing the Thyristor protection)

Design of Snubber Circuits :→



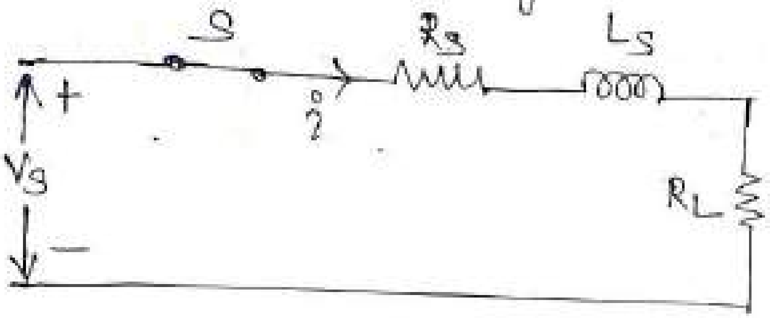
Snubber Circuit parameter R_s & C_s are connected across SCR and di/dt inductor L in series with anode of circuit



when S is closed

→ capacitor behaves like short circuit

→ SCR in the forward blocking state offers a very high resistance



For this circuit the voltage eqn

$$V_S = (R_S + R_L) i + L \frac{di}{dt}$$

$$i = I(1 - e^{-t/\tau})$$

$$I = \frac{V_S}{R_S + R_L} \qquad \tau = \frac{L}{R_S + R_L}$$

t is the time in seconds measured from the instant of closing the switch

$$\frac{di}{dt} = I e^{-t/\tau} \frac{1}{\tau}$$

$$= \frac{V_S}{R_S + R_L} \cdot \frac{R_S + R_L}{L} e^{-t/\tau}$$

$$= \frac{V_S}{L} e^{-t/\tau}$$

$\frac{di}{dt}$ is maximum when $t = 0$

$$\boxed{\left(\frac{di}{dt}\right)_{max} = \frac{V_S}{L} \qquad L = \frac{V_S}{(di/dt)_{max}}}$$

The voltage across SCR

$$V_a = R_S i$$

$$\left(\frac{dV_a}{dt}\right)_{max} = R_S \frac{di}{dt}$$

$$\left(\frac{dV_a}{dt}\right)_{max} = R_S \left(\frac{di}{dt}\right)_{max}$$

$$\boxed{\left(\frac{dV_a}{dt}\right)_{max} = \frac{R_S V_S}{L} \qquad R_S = \frac{L}{V_S}\left(\frac{dV_a}{dt}\right)_{max}}$$

The circuit consists of R L C should be fully analysed to determine the values of snubber circuit parameter

$$\boxed{\begin{aligned} R_s &= 2\xi_e\sqrt{\frac{L}{C_s}} \\ C_s &= \left(\frac{2\xi_e}{R_s}\right)^2 L \\ L &= \frac{R_s V_s}{(dv_a/dt)_{max}} \end{aligned}}$$

ξ_e = damping factor
= 0.65

Q. Fig shows a thyristor controlling the power in a load resistance R_L. The supply voltage is 240 V dc and the specified limits for $\frac{di}{dt}$ and $\frac{dv}{dt}$ for the SCR are 50 A/μsec and 300 V/μsec respectively. Determine the values of the $\frac{di}{dt}$ inductance and the snubber circuit parameter R_s & C_s

$V_s = 240$ V $\qquad \frac{dv}{dt} = 30$ V/μsec

$\frac{di}{dt} = 50$ A/μsec

S = ON

$$L = \frac{V_s}{(di/dt)_{max}} = \frac{240\times10^{-6}}{50} = 4.8\ \mu H$$

$$R_s = \frac{L}{V_s}\left(\frac{dv_a}{dt}\right)_{max} = \frac{4.8}{240}\times 300 = 6\ \Omega$$

RLC

$$C_s = \left(\frac{2\xi_e}{R_s}\right)^2 L = \left(\frac{2\times0.65}{6}\right)^2 \times 4.8\times10^{-6} = 0.2253\ \mu F$$

$$R_s = 2\xi_e\sqrt{\frac{4.8}{0.2253}}$$
$$= 2\times0.65\sqrt{\frac{4.8}{0.2253}}$$
$$= 6\ \Omega$$

$L = 4.8\ \mu H$
$C_s = 0.2253\ \mu F$

Assume $R_s = 10$

$$L = \frac{R_s V_s}{(dv_a/dt)_{max}}$$
$$= \frac{10\times240}{300}$$

Q. The SCR is used to control power in resistance R. supply is 400 V and the maximum allowable $\frac{di}{dt}$ and $\frac{dv}{dt}$ the SCR are 50 A/μsec and 200 V/μsec respectively. compute the values of the $\frac{di}{dt}$ inductor and the snubber circuit parameter R_s and C_s

$$L = \frac{V_s}{\left(\frac{di}{dt}\right)_{max}} = \frac{400 \times 10^{-6}}{50} = 8\ \mu H$$

$$R_s = \frac{L}{V_s}\left(\frac{dv_a}{dt}\right)_{max} = \frac{8}{400} \times 200 = 4\ \Omega$$

$$C_s = \left(\frac{2\xi}{R_s}\right)^2 L = \left(\frac{2 \times 0.65}{4}\right)^2 \times 8 \times 10^{-6}$$
$$= 0.845\ \mu F$$

Assume $R_s = 10$

$$L = \frac{R_s V_s}{\left(\frac{dv_a}{dt}\right)_{max}} = \frac{10 \times 400}{200} = 20\ \mu H$$

Q. To provide reliable $\frac{dv}{dt}$ protection to an SCR used in a 1-ϕ fully controlled bridge, compute the required parameters for a snubber circuit. The SCR has maximum $\frac{dv}{dt}$ capability of 50 V/μs. The input line to line voltage has a peak value 380V and source inductance is 0.1 mH.

$$C = \frac{1}{2L}\left(\frac{0.564\ E_m}{\frac{dv}{dt}}\right)^2 = \frac{10^4}{2} \times \left(\frac{0.564 \times 380 \times 10^{-6}}{50}\right)^2$$
$$= 0.092\ \mu F$$

$$R = 2 \times \xi\sqrt{\frac{L}{C}}$$
$$= 2 \times 0.65 \times \sqrt{\frac{0.1 \times 10^{-3}}{0.092 \times 10^{-6}}}$$
$$= 42.86\ \Omega$$

Ch-2

phase controlled rectifiers :⇒

⇒ Unlike diode rectifiers, PCR's or phase controlled rectifiers has an advantage of regulating the output voltage. The diode rectifier are termed as Uncontrolled rectifiers. when these diodes are switched with thyristor, then it becomes phase control rectifier. The o/p voltage can be regulated by changing the firing angle of the thyristor. The main application of those rectifiers is involved in speed control of DC motor.

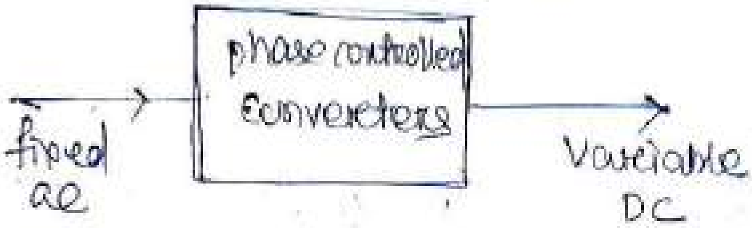
⇒ Thyristor can be used to differ the output voltage by adjusting the firing angle or delay

→ A phase control thyristor is activated by applying a short pulse to its gate terminal and it is deactivated due to line communication or natural. In case of heavy inductive load. it is deactivated by firing another thyristor of the rectifier during the negative half cycle of input voltage.

Types of Rectifiers ⇒

- 1-φ
  - Uncontrolled
    - Half wave
    - Full wave
      - Split supply
      - Bridge
  - Half controlled
  - Fully controlled
- 3-φ
  - Uncontrolled
    - Half wave
    - Full Bridge
  - Half controlled
  - Full controlled
    - Half wave
    - Full bridge

Phase controlled Converters :→



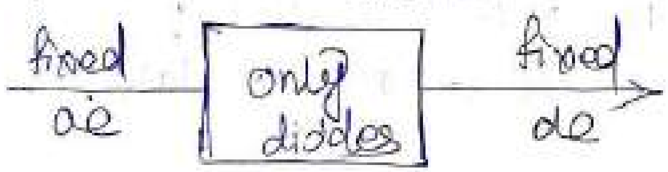
→ By varying the firing angle of SCR, we can vary the level of DC output.

→ varying dc voltage implies varying the level of voltage

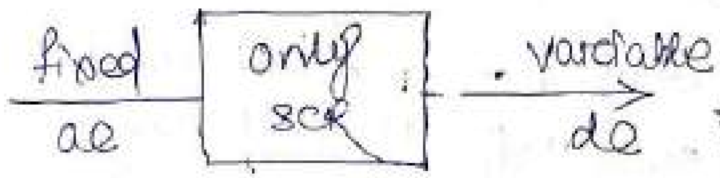
Application :→

→ Battery charger
→ speed control of DC Motor
→ HVDC Transmission
→ Portable hand instrument drives
→ Traction system working on DC
→ Electrochemical and Electrometallurgical processes
→ Magnet power supplies

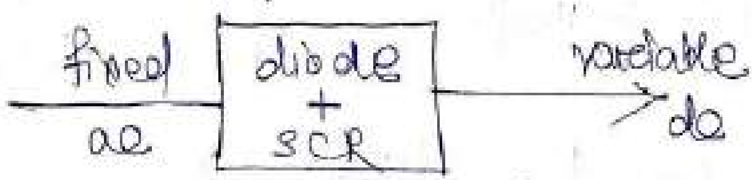
Based on devices used :→



⇒ Uncontrolled rectifier



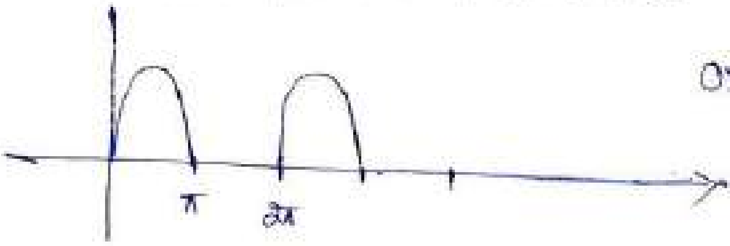
⇒ Fully controlled rectifier



⇒ Semi controlled rectifier
or
Half controlled rectifier

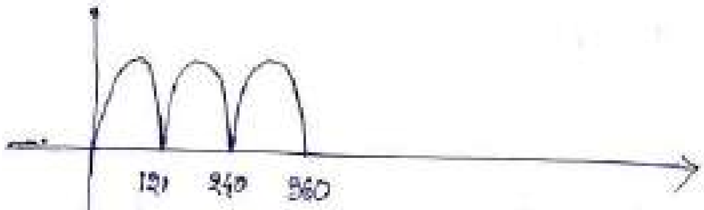
☆ phase controlled converter converts AC to DC energy line commutated. In other words, it is used in the conversion of fixed-frequency and fixed voltage AC power into variable DC voltage output.

Based on number of pulses →

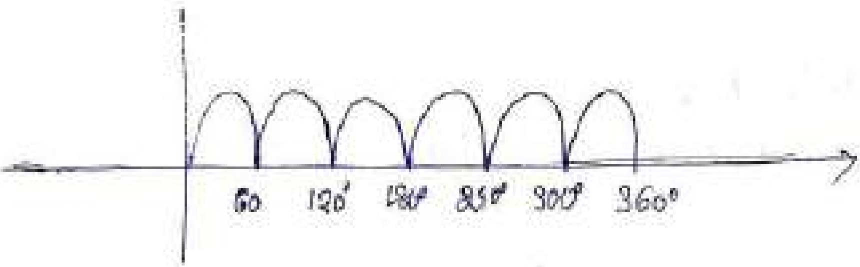


one phase converter
(1-ϕ HWR)

two pulse converter
(1-ϕ FWR)



three pulse converter
(3ϕ HWR)



six pulse converter
(3ϕ FWR)

pulse number :→ The numbers of times V_o repeates itself in one cycle of input voltage or we can say no. of cycles of v_o in one cycle of v_{in}.

$$T_o = \frac{T_i}{\text{pulse no}(P)}$$

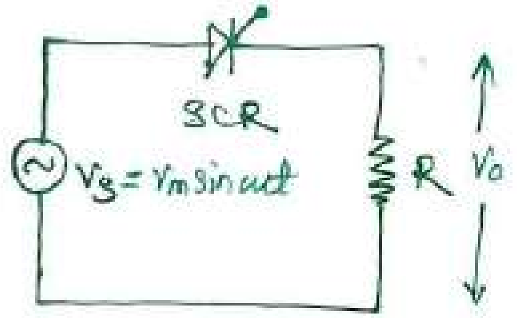
$$\boxed{f_o = pf_i}$$ → output frequency or ripple frequency of o/p

→ As no. of pulses increases, the harmonic content in V_o or ripple in v_o reduces.

→ For higher pulses no. of more devices are required so cost increases

→ In HVDC, 12 pulse converter is used

① 1-ϕ half wave controlled with R Load :⇒



→ Diode has been replaced by SCR

→ SCR does not conduct just by being forward biased but it waits for gate pulse to arrive.

Firing Angle (α) :⇒

★ The angular delay after a SCR get forward biased at which gate pulse is applied

★ Firing angle may be defined as the angle measured from the instant SCR gets forward biased to the instant it is trigged.

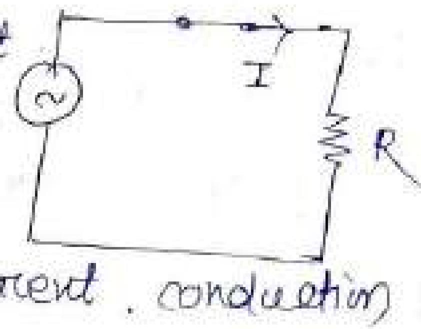
★ $V_T = V_S = V_m \sin \omega t$

$V_T > 0 \quad \omega t > 0$ is SCR gets FB at $\omega t = 0$

though SCR gets forward biased at $\omega t = 0$ but it begins to conduct at $\omega t = \alpha$. α = firing angle delay

case-I : SCR ON

$$I = \frac{V_m \sin \omega t}{R} \qquad V_0 = V_m \sin \omega t$$



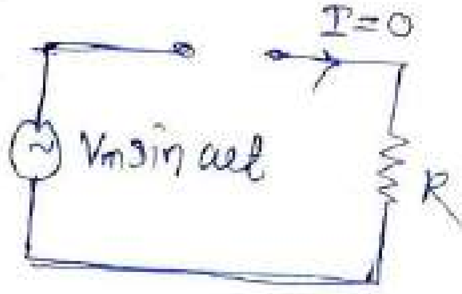
for $\omega t > 180°$, $\sin \omega t < 0$, $I < 0$

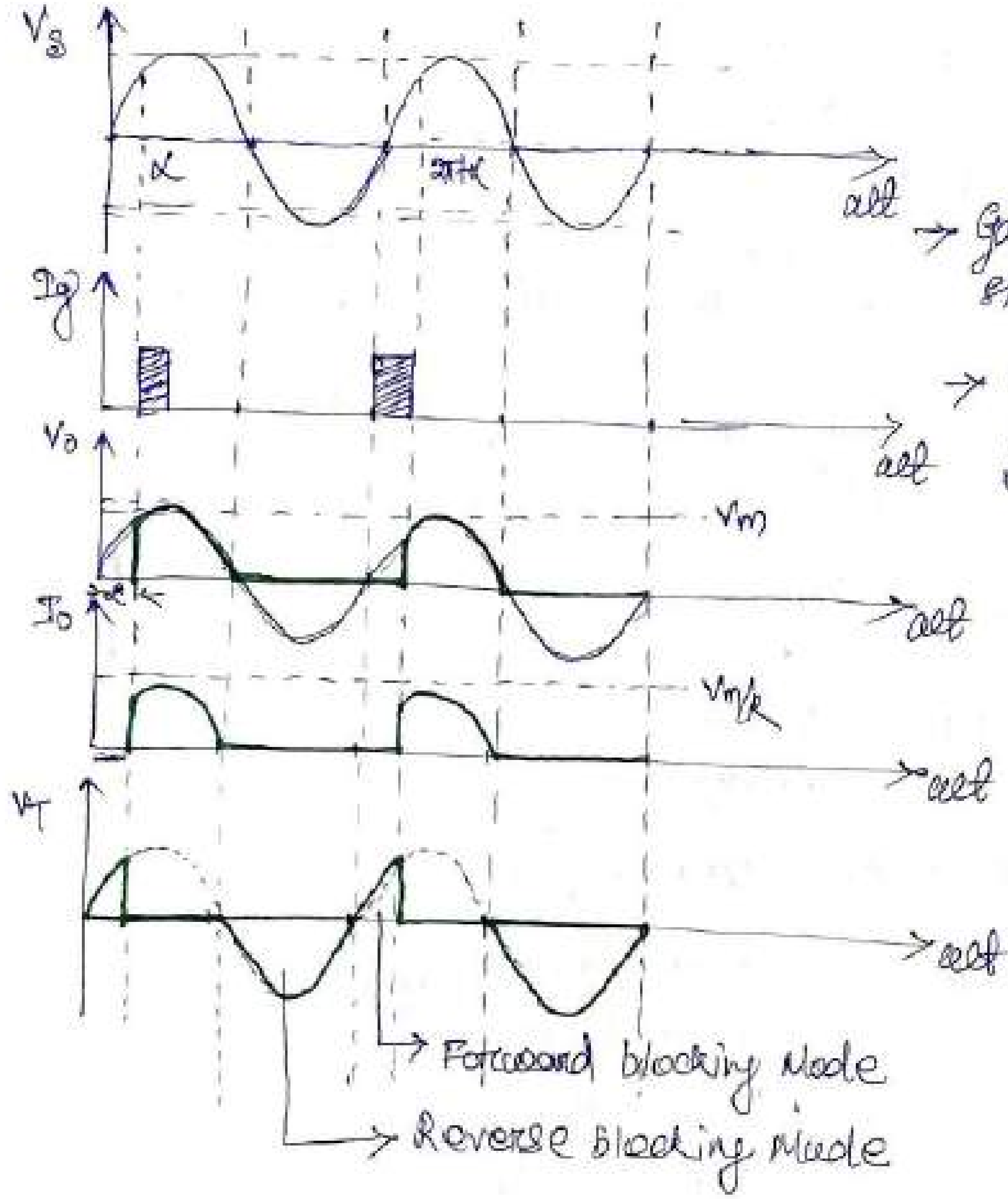
SCR does not allow -ve current. conduction stops at π

case-II : SCR OFF

$V_0 = 0$

$V_T = V_m \sin \omega t$





→ Gate pulse is for short duration

→ when current goes to Latching then gate pulse is removed

$$I_0 = \frac{V_0}{R}$$

- Extinction angle $\beta = \pi$
- Conduction angle $\gamma = \pi - \alpha$

$$V_{RMS} = \frac{V_m}{\sqrt{2}}$$

$$V_{RMS} = 0.707\, V_m$$

- PIV $= V_m$
- Circuit turn off time (t_c)
  ↳ Time for which SCR remain reverse biased
- SCR is reversed biased π to 2π

$$t_c = \frac{\pi}{\omega}$$

- Average $V_0 = \dfrac{1}{2\pi}\displaystyle\int_{\alpha}^{\pi} V_m \sin \omega t$

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

- Average $I_o = \frac{V_{o(avg)}}{R}$

- RMS value of V_o

$$V_{o(rms)} = \left[\frac{1}{2\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

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

- RMS I_o

$$I_{o(rms)} = \frac{V_{o(rms)}}{R}$$

- Form factor $FF = \frac{V_{o(rms)}}{V_{o(avg)}}$

- voltage ripple factor $VRF = \sqrt{FF^2 - 1}$

- Rectification $\eta = \frac{V_{o(avg)} I_{o(avg)}}{V_{o(rms)} I_{o(rms)}} \times 100$

$$= \frac{V_{o(av)} \times V_{o(av)}/R}{V_{o(rc)} \times V_{o(rc)}/R} \times 100$$

$$= \left(\frac{V_{o(avg)}}{V_{o(rms)}}\right)^2 \times 100$$

$$= \frac{1}{FF^2} \times 100\%$$

- Transformer utilization factor

$$TUF = \frac{V_{o(avg)} I_{o(avg)}}{V_{sr} I_{sr}}$$

$\because I_s = I_o$

$I_{sr} = I_{or}$

$$TUF = \frac{V_{o(avg)} \times \frac{V_{o(avg)}}{R}}{V_{sr} \times \frac{V_{o(rms)}}{R}}$$

- Input P.F

$$IPF = \frac{P}{V_{SR}\, I_{SR}}$$

$$= \frac{V_{or}^2 / R}{V_{sr} \cdot I_{or}}$$

$$= \frac{V_{or}^2 / R}{V_{sr} \cdot V_{or}/R}$$

$$IPF = \frac{V_{or}}{V_{sr}}$$

Phase Angle :⇒ (α)

→ whenever we talk of phase angle we generally means the angle of a sinusoidal quantity at any instant of time.

→ phase control of SCR means the phase angle with reference to source voltage where it is getting turned on by the application of gate signal

Extinction Angle :⇒ (β)

→ The extinction angle where thyristor gets switched off in spite of being reverse biased

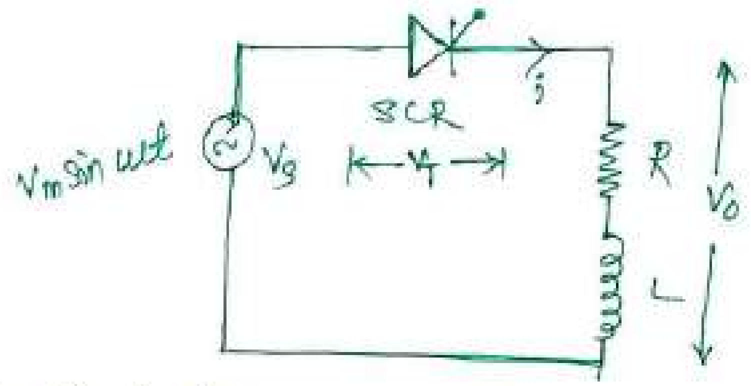
→ Refers to the time interval from the instant when the current through an outgoing thyristor becomes zero and a negative voltage applied across it to the instant when a positive voltage is reapplied.

Conduction Angle :⇒ (γ)

→ The duration where the thyristor is in on state where the output load gets powered.

→ The number of degree's in a half cycle for which SCR is turned ON is known as conduction angle.

② 1-ϕ Half wave controlled with RL Load :→



→ Conduction will starts at $\omega t = \alpha$ & will end $\omega t = \beta$ where β depends on load inductance.

→ thyristor turns on at $\omega t = \alpha$

$$i(t) = Ce^{-t/\tau} + \frac{V_m}{|Z|} \sin(\omega t - \phi)$$

$$|Z| = \sqrt{R^2 + \omega^2 L^2} \qquad \phi = \tan^{-1} \frac{\omega L}{R}$$

at $\omega t = \alpha$ T: turns on

$$i(\alpha^-) = i(\alpha^+) = 0$$

$$0 = Ce^{-\alpha/\omega\tau} + \frac{V_m}{Z} \sin(\alpha - \phi)$$

$$C = \frac{V_m}{Z} \sin(\phi - \alpha) e^{\alpha/\omega\tau}$$

$$i(t) = \frac{V_m}{|Z|} \sin(\phi - \alpha) e^{\alpha/\omega\tau} \cdot e^{-t/\tau} + \frac{V_m}{|Z|} \sin(\omega t - \phi)$$

$$= \frac{V_m}{|Z|} \sin(\phi - \alpha) e^{-(\omega t - \alpha)/\omega\tau} + \frac{V_m}{|Z|} \sin(\omega t - \phi)$$

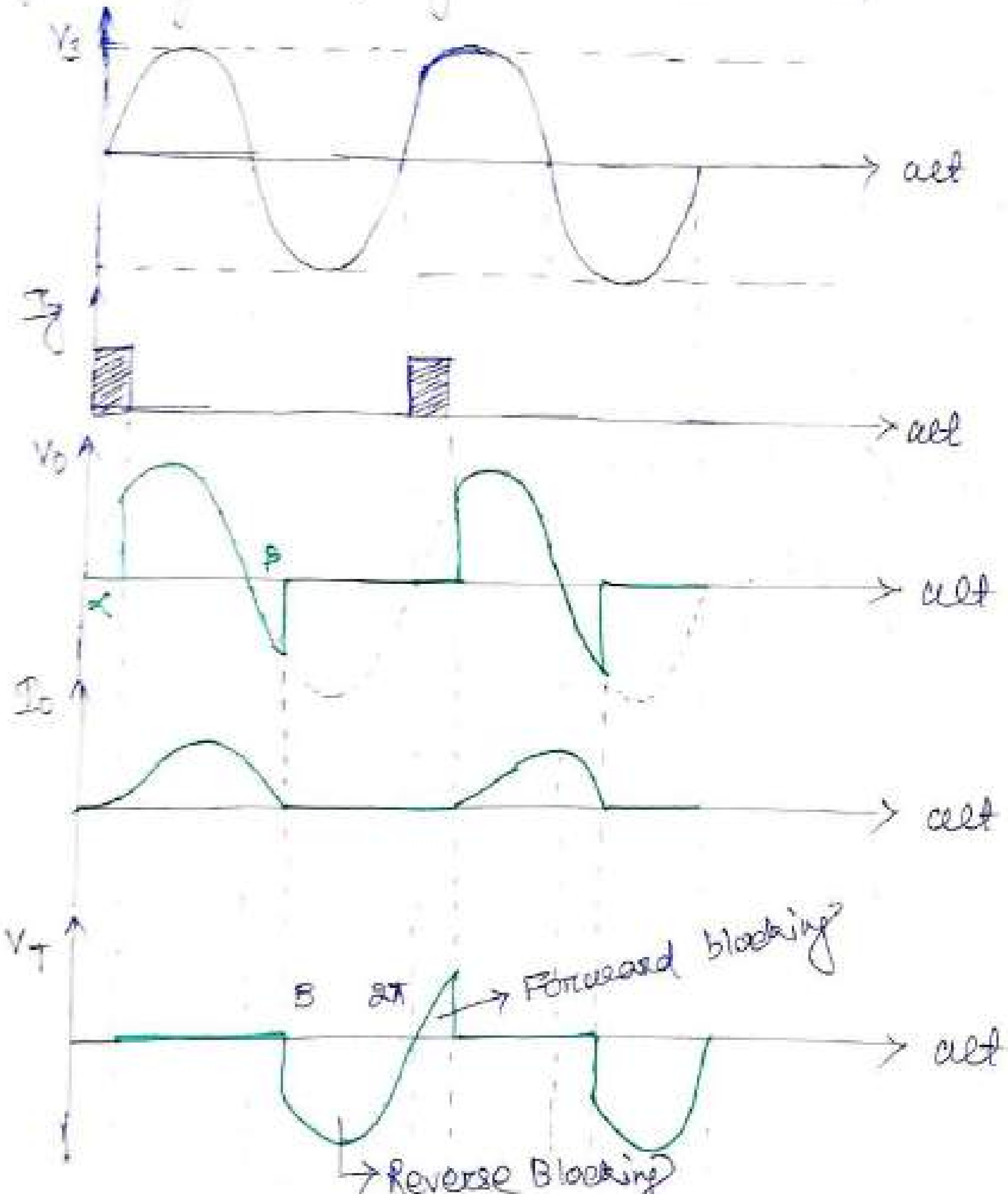
$e^{-(\omega t - \alpha)/\omega\tau}$: right shift by α

To determine extinction angle

at $\omega t = \beta$ $\quad i(\omega t) = 0$

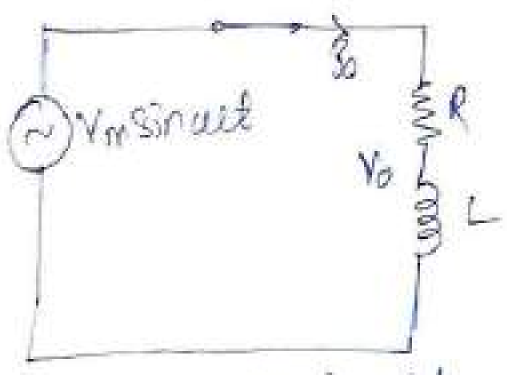
$$i = \frac{V_m}{|Z|}\sin(\phi-\alpha)\,e^{-(\beta-\alpha)/\omega\tau} + \frac{V_m}{|Z|}\sin(\beta-\phi)$$

By solving the eqn by numerical method to compute β.



Case-I : SCR ON

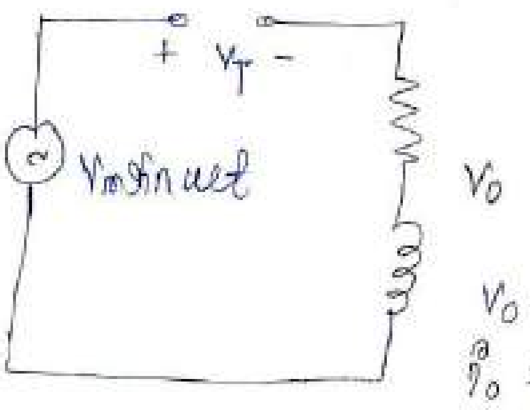
$\alpha < \omega t < \beta$



$V_0 = V_s = V_m \sin \omega t$

Case-II : SCR OFF

$\beta < \omega t < 2\pi + \alpha$



$V_0 = 0$

$i_0 = 0$

$V_T = V_m \sin \omega t$

- Conduction angle $\gamma = \beta - \alpha$
- Extinction angle $\beta > \pi$
- $PIV = V_m$
- Circuit turn off time $t_c = \dfrac{2\pi - \beta}{\omega}$ → Extinction angle

How much time SCR Reverse biased

> Angle of second forward biased

- $$V_o(avg) = \frac{1}{2\pi}\int_\alpha^\beta V_m \sin \omega t$$
$$= \frac{V_m}{2\pi}(\cos\alpha - \cos\beta)$$
- $$V_o(rms) = \left[\frac{1}{2\pi}\int_\alpha^\beta V_m^2 \sin^2 \omega t \, d(\omega t)\right]^{1/2}$$
$$= V_m\left[\frac{1}{4\pi} \quad \beta - \alpha + \tfrac{1}{2}\sin 2\alpha - \tfrac{1}{2}\sin 2\beta\right]^{1/2}$$
- $I_o(avg) = V_o(avg)/R$ L: short

due to inductor, RMS current can't be directly computed
(L: $n\omega_0 L$)

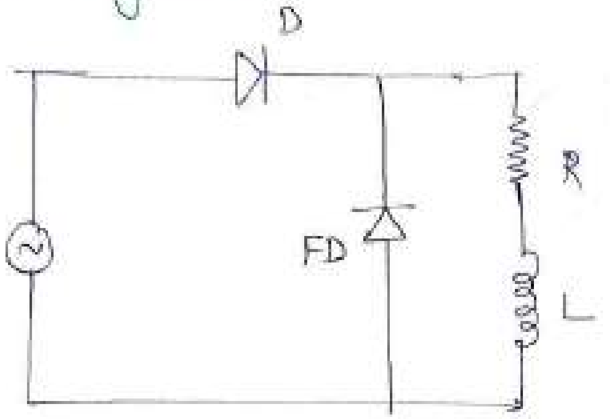
$I_o(rms) \neq \dfrac{V_o(rms)}{R}$

- $FF = \dfrac{V_o(rms)}{V_o(avg)}$

- $VRF = \sqrt{FF^2 - 1}$

(8) 1-ϕ Half wave controlled R-L Load with free wheeling Diode :⇒

★ Free wheeling Diode ⇒

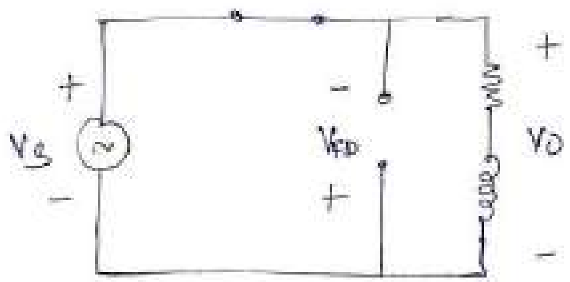


→ A diode that is connected across an inductor to eliminate the fly back

→ Fly back ⇒ Flyback is the sudden voltage spike that occurs across an inductor due to interruption of supply current.

→ when an antiparallel diode is connected across load and when ON short circuits the load so that current can flow freely through diode is called as free wheeling diode

when D_1 : ON



$V_0 = V_s$

$V_{FD} = -V_0 = -V_s$

→ during +ve half cycle of V_s $V_s > 0$ $V_{FD} < 0$ (Reverse Biased)

→ during −ve half cycle $V_s < 0$ $V_{FD} > 0$ (Forward Biased)

→ during +ve half cycle D_1 : ON

$V_0 = V_s$, $V_{FD} = -V_s$

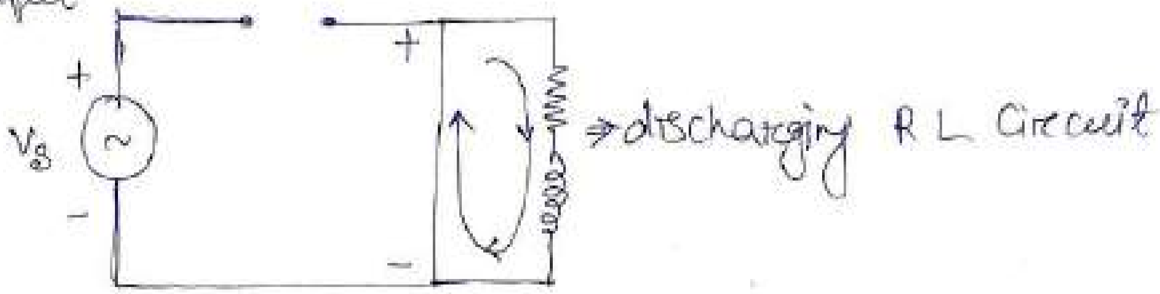
→ during −ve half cycle FD : ON

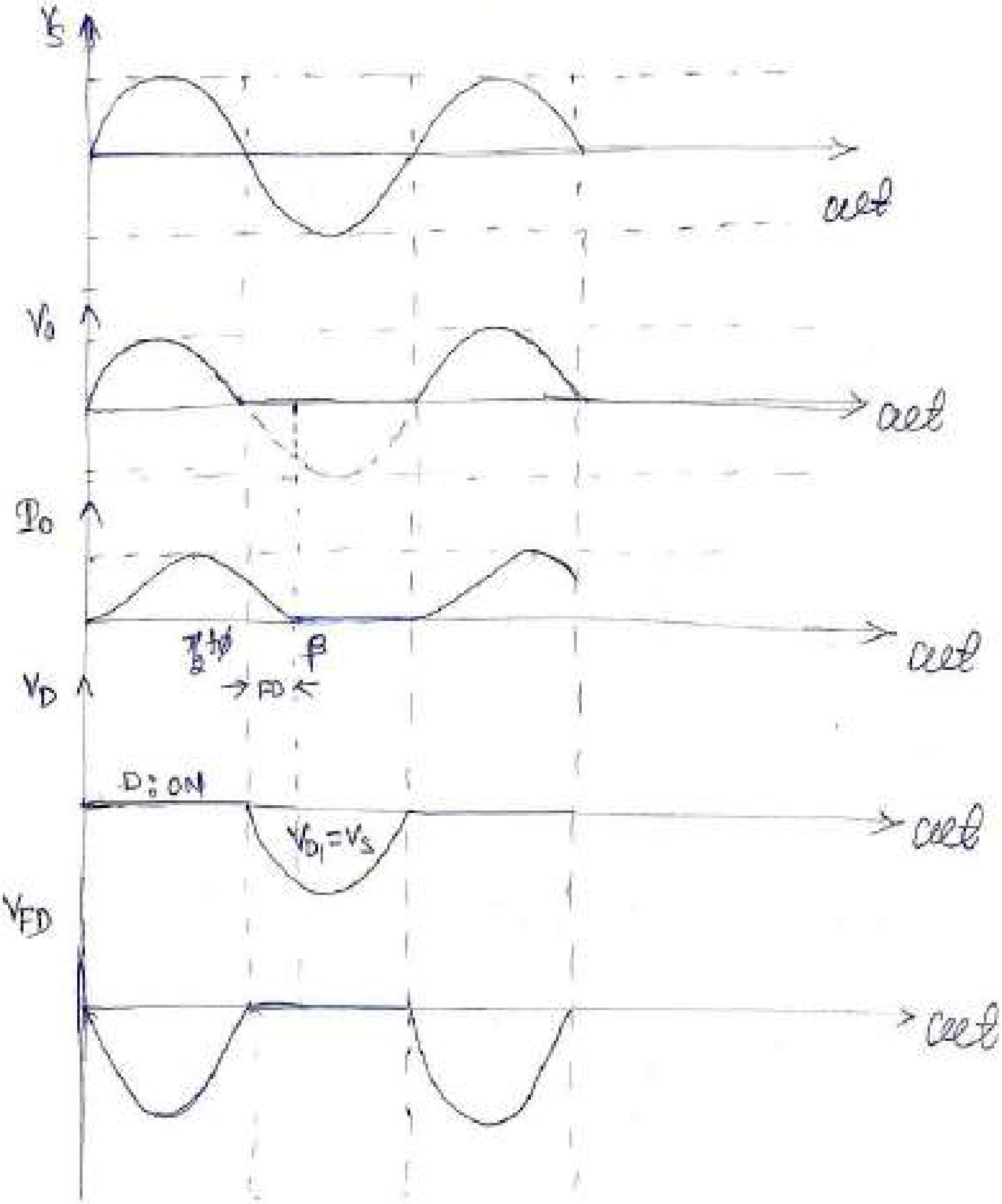
$V_0 = 0$

$V_{D_1} = V_s - 0 = V_s$

→ Due to inductor present in load conduction goes beyond π as inductor takes times to discharge.

→ As soon as conduction goes about π FD turns ON & SC output





→ FD turned ON at $\omega t = \pi$ & it remains ON till current becomes 0 at $\omega t = \beta$

→ voltage across FD is always $-V_0$

→ conduction angle $\gamma_{D_1} = \pi - 0 = \pi$

$\gamma_{FD} = \beta - \pi$

→ $PIV = V_m$ (FD & D_1)

<u>case-1</u> $0 < \omega t < \frac{\pi}{2} + \phi$

$V_0 > 0$ $I_0 > 0$

I_0 increases

$P_0 = V_0 I_0 > 0$

→ power goes from source to load

→ source supplies power to both R&L & inductor gradually charges

<u>case-2</u> $\frac{\pi}{2} + \phi < \omega t < \pi$

$V_0 > 0$ $I_0 > 0$

$P_0 > 0$ but $I_0 \downarrow$

→ source supplies power

→ Both source & inductor deliver power to R

<u>case-3</u> $\pi < \phi < \beta$

$V_0 = 0$ $I_0 > 0$

→ source does not supplies any power

→ $I_0 \downarrow$ inductor discharges through resistance

→ with out freewheeling diode inductor discharges faster inductor stored energy goes to resistence & source

∴ with free wheeling diode it takes more time to discharges

$\beta(RL + FD) > \beta(RL)$

→ Effect of connecting FD :-

→ the negative portion of V_0 vanishes

area (V_0) ↑

$$V_{0(avg)} = \frac{area(V_0)}{period} \uparrow$$

→ Continuity of I_0 increases

↳ Ideally dc current must be constant but it goes to 0 at β. as β increases & goes near 2π conduction tends to become continuous

→ RMS value of V_0 decreases

↳ For RMS we take square of V_0 but since a portion of V_0 vanishes area under V_0^2 decreases. so RMS V_0 reduces.

→ $FF = \dfrac{V_{0(rms)}}{V_{0(avg)}} \downarrow$

→ voltage ripple factor $VRF = \sqrt{FF^2 - 1}$, VRF → Reduces

→ $IPF = \dfrac{V_{0(avg)} I_{0(avg)}}{V_{S(rms)} I_{S(rms)}}$ IPF → increases

$$V_{0(avg)} = \frac{1}{2\pi}\int_0^{\pi} V_m \sin\omega t \, d(\omega t)$$

$$= \frac{V_m}{2\pi}\left(-\cos\omega t\right)_0^{\pi}$$

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

$$V_{0(rms)} = \frac{V_m}{\sqrt{2}}\left(\frac{\pi}{2\pi}\right)^{1/2} = \frac{V_m}{2}$$

Ripple → The fluctuating ac component in the rectified DC output.

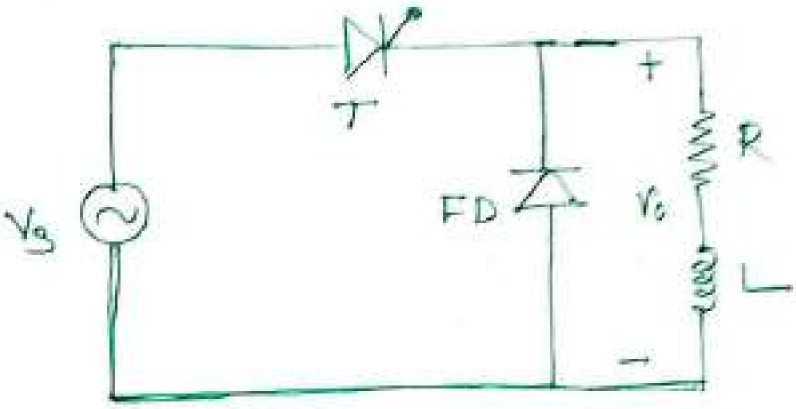
For avg or dc component of current L : short

$$I_{o(avg)} = \frac{V_{o(avg)}}{R} = \frac{V_m}{\pi R}.$$

L cannot be shorted for AC component

$$I_{o(rms)} \neq \frac{V_{o(rms)}}{R}.$$

The waveform of V_o is same as that of R-Load



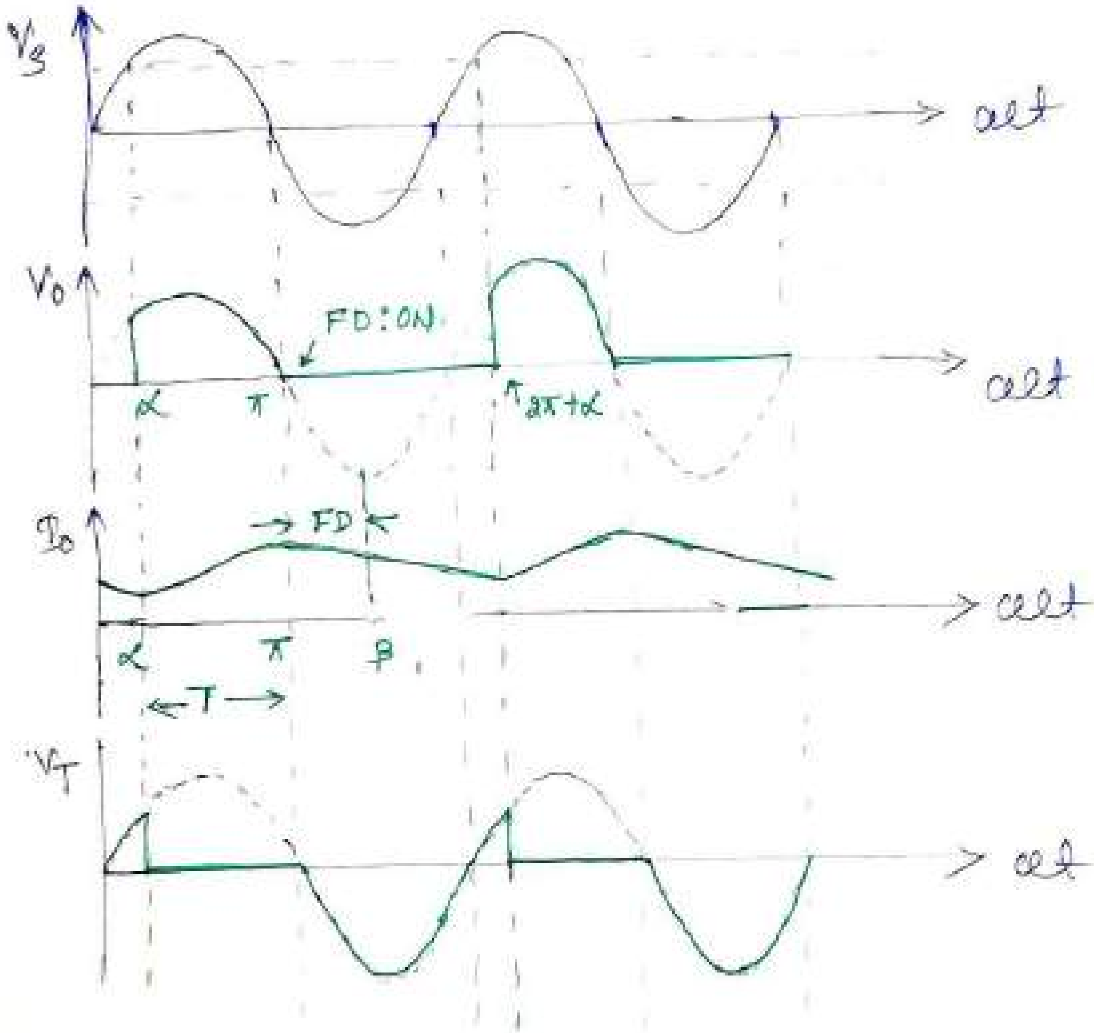
→ can be called as semi converter
T : can be controlled
D : uncontrolled,

→ $V_{FD} = -V_o$ if $V_o > 0$ $V_{FD} < 0$ FD ⇒ RB
if $V_o < 0$ $V_{FD} > 0$ FD ⇒ FB ⇒ short output

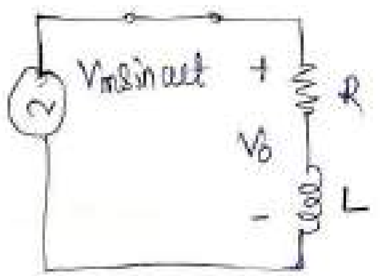
→ In RL Load waveform of V_o extends from α to β where $\beta > \pi$

→ As soon as V_o goes beyond π, V_o become -ve FD get forward biased
↳ o/p terminal get shorted $V_o = 0$

→ wave form of V_o is similar to R-Load.

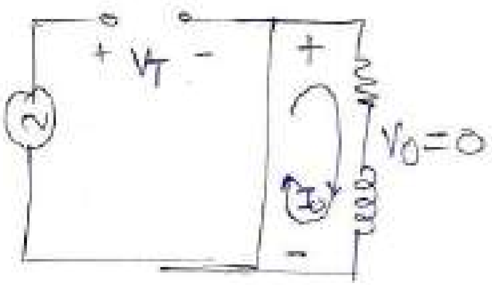


T: ON



$V_0 = V_m \sin \omega t$

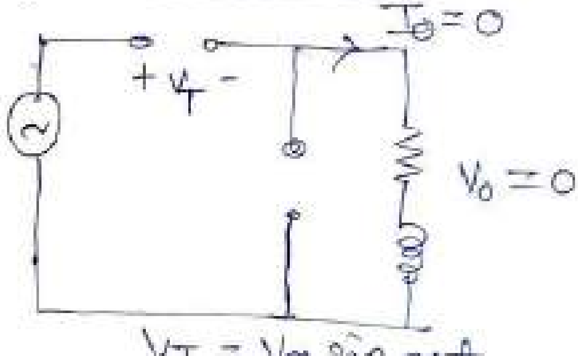
T: OFF



$V_T = V_m \sin \omega t$

$\pi < \omega t < \beta$

T: OFF , FD: OFF



$V_T = V_m \sin \omega t$

→ Extinction angle $\beta(RL+FD) > \beta(RL)$

→ conduction angle $\gamma = \beta - \alpha$

→ $PIV = V_m$

→ Circuit turn off time $t_c = \frac{2\pi - \pi}{\omega} = \frac{\pi}{\omega}$

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

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

→ $V_{0(rms)} = \left[\frac{1}{2\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \, d\omega t\right]^{1/2}$

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

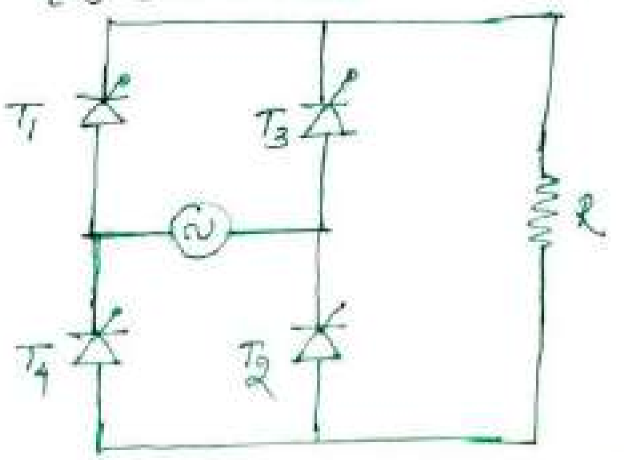
→ $I_{0(avg)} = \frac{V_{0(avg)}}{R}$

→ $I_{0(rms)} \neq \frac{V_{0(rms)}}{R}$

→ $FF = \frac{V_{0(rms)}}{V_{0(avg)}}$

→ $VRF = \sqrt{FF^2 - 1}$

(4) 1-ϕ Full wave Rectifier (Bridge Rectifier) with R-Load :→



→ For R Load V_0 can not become negative
if $V_0 < 0$, $I_0 < 0$ but SCR does not allow -ve current

→ T_1, T_2 : ON $\alpha \to \pi$
T_3, T_4 : ON $\pi + \alpha \to 2\pi$

→ 0 to α & π to $\pi+\alpha$ no device will conduct

→ $\gamma_T = \pi - \alpha$ → $t_C = \pi/\omega$

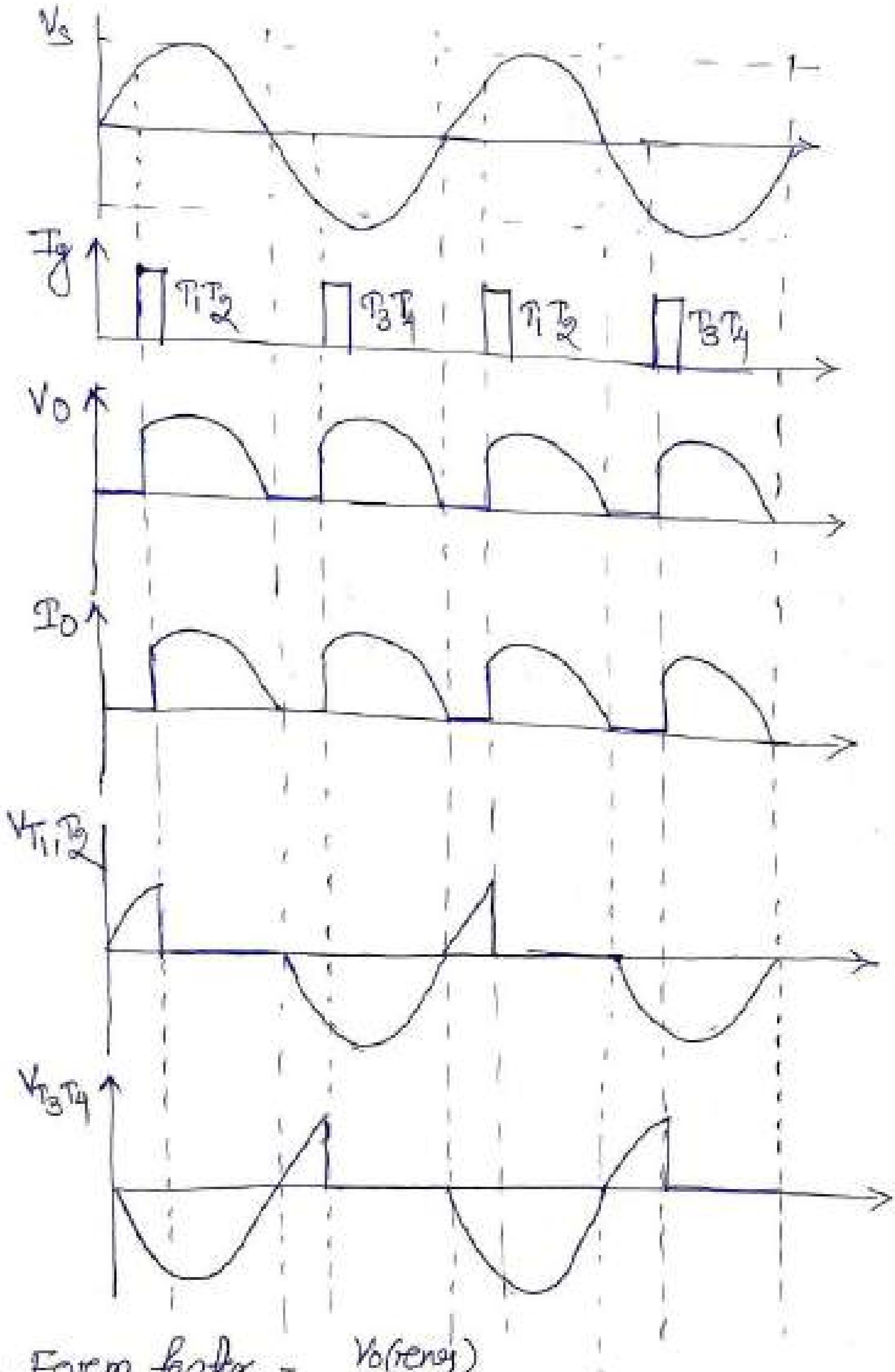
→ PIV = V_m

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

→ $V_{0(rms)} = \left[\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2} = V_m\left[\frac{1}{2\pi}\left\{\pi - \alpha + \frac{1}{2}\sin 2\alpha\right\}\right]^{1/2}$

→ $I_{0(avg)} = \frac{V_{0(avg)}}{R}$

→ $I_{0(rms)} = \frac{I_{0(rms)}}{R}$



→ Form factor $= \dfrac{V_{0(rms)}}{V_{0(avg)}}$

→ voltage ripple factor $= \sqrt{FF^2 - 1}$

→ Load power $= \dfrac{V_{0(rms)}^2}{R}$

→ Rectification efficiency $= \dfrac{V_{0(avg)}\, I_{0(avg)}}{I_{0\,rms}\, V_{0(rms)}} = \dfrac{1}{FF^2}$

→ Transformer utilization factor (TUF)

$$TUF = \frac{V_{0(avg)}\, I_{0(avg)}}{V_{sc}\, I_{sc}}$$

$I_{sr} = I_{or}$

$$TUF = \frac{V_{o(avg)} \times V_{o(avg)}/R}{V_{sr} \times V_{or}/R}$$

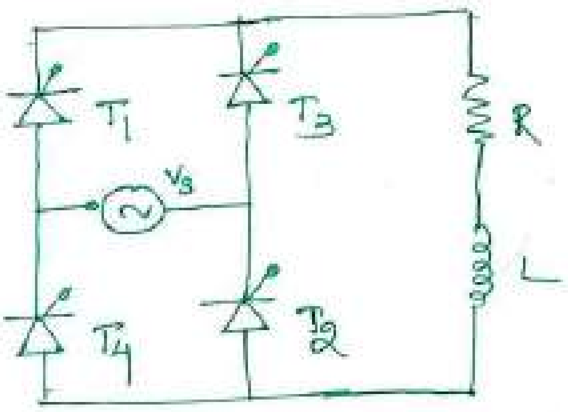
$$= \frac{V_o^2(avg)}{V_{sr}\, V_{or}}$$

$\rightarrow$ I/p p.f $= \dfrac{P}{V_{sr}\, I_{sr}}$

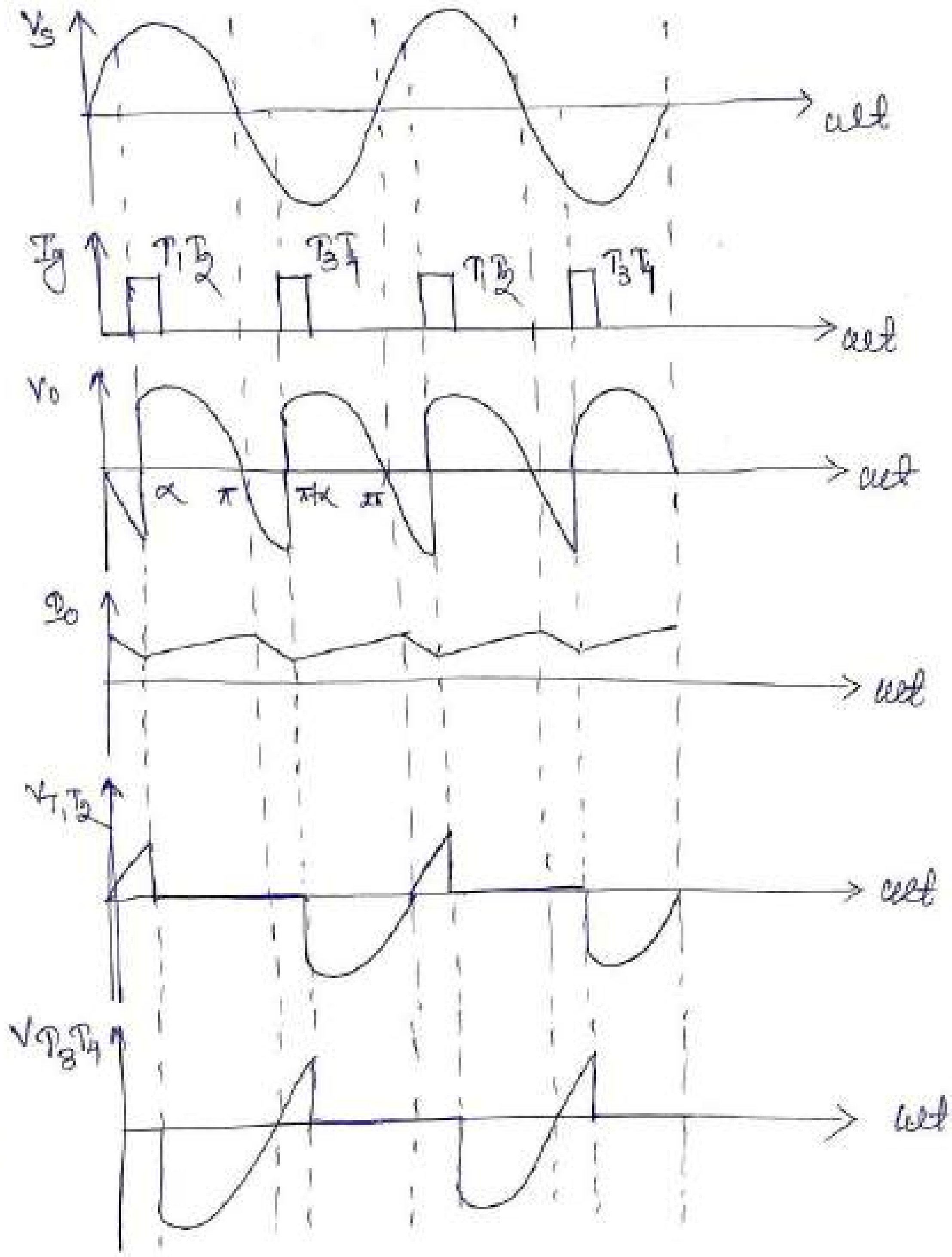
$$= \frac{V_o^2(rms)/R}{V_{sr} \times I_{or}} = \frac{V_o^2(rms)/R}{V_{sr} \times V_{or}/R}$$

$$= \frac{V_{or}}{V_{sr}}$$

⑤ 1-ϕ Full wave rectifier with RL load :→



→ Contineous conduction mode (Large L & small α)



→ $V_{0(avg)} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t \, d\omega t = \frac{2V_m}{\pi}\cos\alpha$

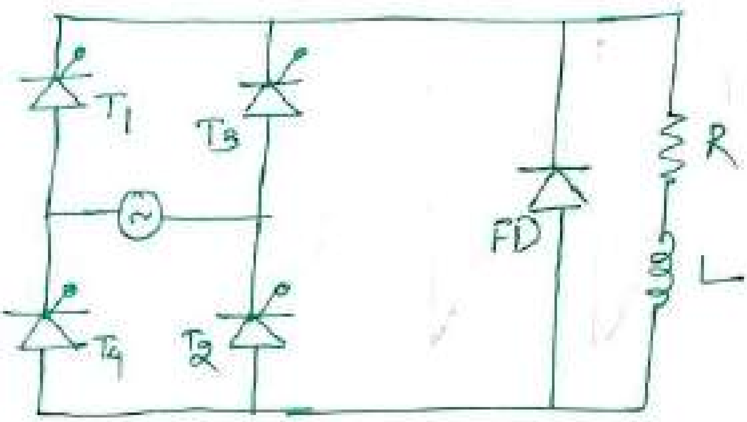
→ $V_{0(rms)} = \left[\frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m^2 \sin^2\omega t \, d\omega t\right]^{1/2} = \frac{V_m}{\sqrt{2}}$

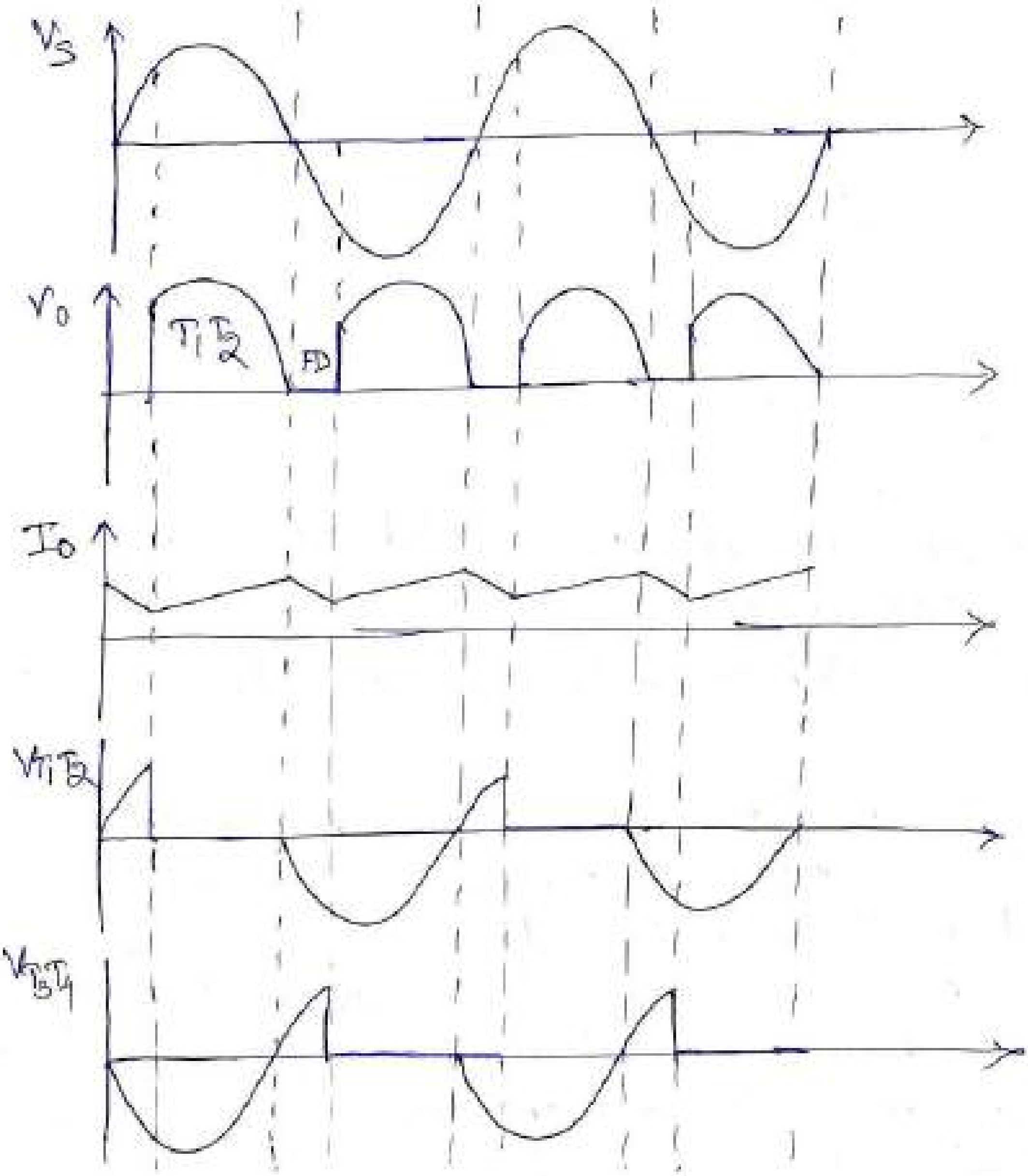
→ PIV = $+V_m$

→ Circuit turn off time $t_c = \frac{2\pi - (\pi+\alpha)}{\omega}$

$t_c = \frac{\pi-\alpha}{\omega}$

⑥ 1-ϕ Full wave rectifier with RL load and free wheeling diode :⇒





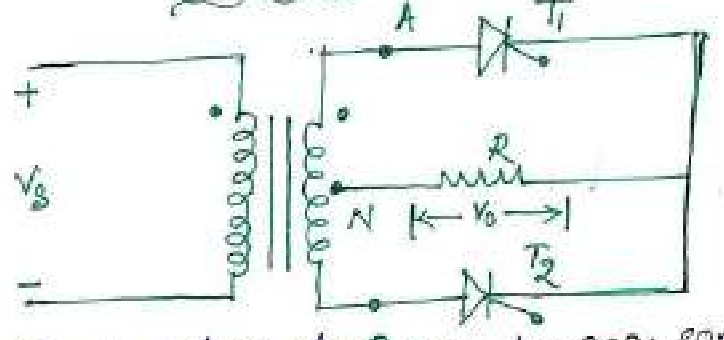
$$V_{0(avg)} = \frac{V_m}{\pi}\int_{\alpha}^{\pi} \sin \omega t \, d\omega t = \frac{V_m}{\pi}(1+\cos\alpha)$$

$$V_{0(rms)} = \left[\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2 \omega t \, d(\omega t)\right]^{1/2} = \frac{V_m}{\sqrt{2\pi}}\left[(\pi-\alpha)+\frac{\sin 2\alpha}{\alpha}\right]^{1/2}$$

$$PIV = V_m$$

$$t_c = \frac{\pi}{\omega}$$

(7) 1-ϕ Full wave Rectifier with R Load :→
(Mid point connection).



→ This type of Rectifier uses two SCR's connected to the centre tapped secondary of a transformer

→ The I/p signal is coupled through the transformer to the centretapped secondary.

→ During the +ve half cycle of AC supply i.e when A of the T/F is +ve w.r.t B or the secondary winding terminal A is +ve w.r.t N, T_1 is forward biased and T_2 reversed biased. Since no triggering pulses are given to the gate of the SCRs initially they are in off state.

→ when T_1 is triggered at α, current would flow from $A \to T_1 \to R \to N$ the current continues to flow up to π when the line voltage reverse its polarity and T_1 is turned off.

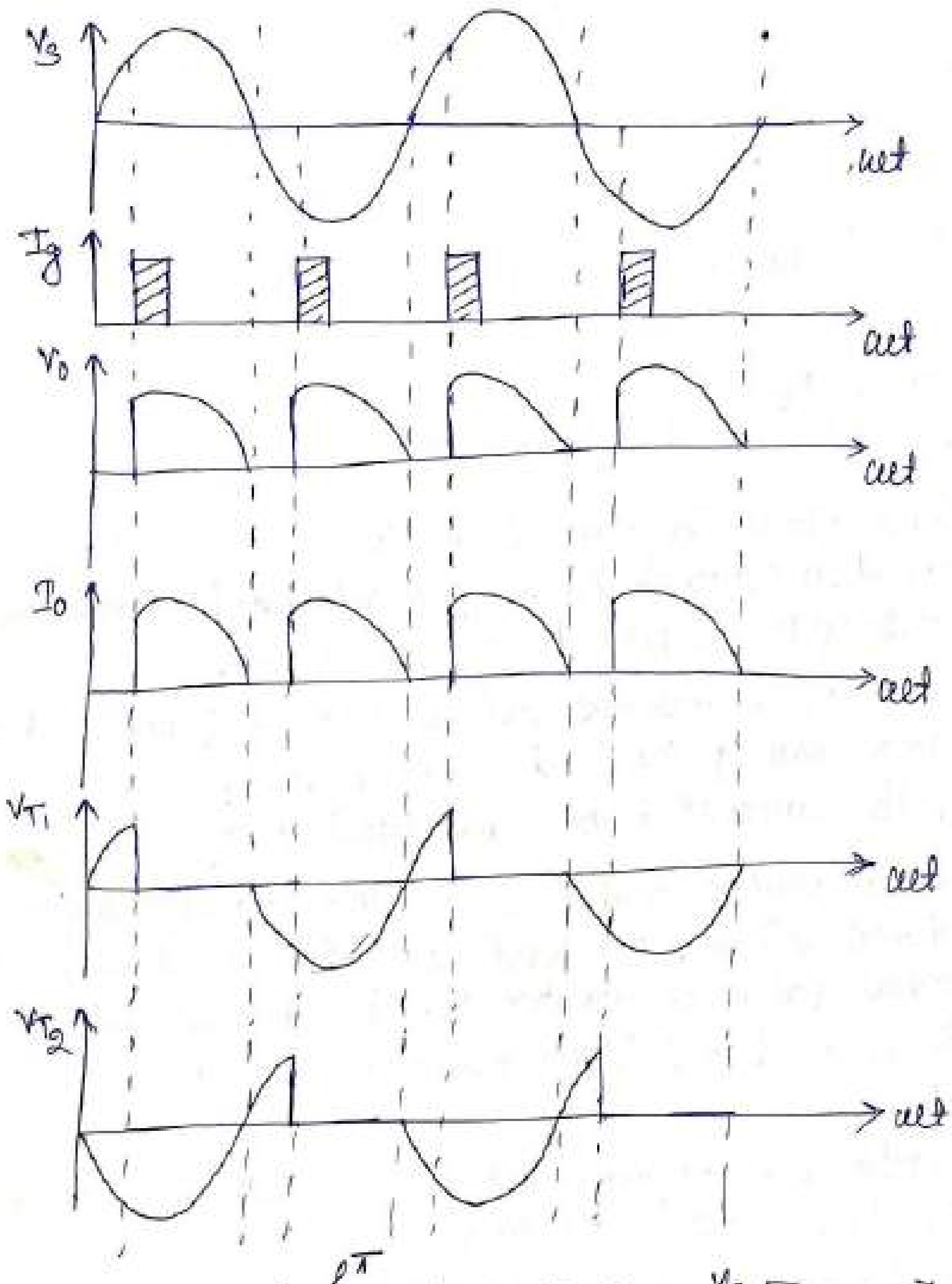
→ During -ve half cycle of a.c supply B of T/F is +ve w.r.t N T_2 is forward biased. when T_2 is triggered at an angle $(\pi+\alpha)$ current flow from $B \to T_2 \to R \to N$. This current continues till angle 2π then T_2 is turned off.

→ Here it is assumed that both T_1 & T_2 are triggered with the same firing angle.

→ Each half of the input wave is applied across the Load. Thus across the Load there are two pulses of current in the same direction.

→ The Ripple frequency across the load is twice that of the input supply frequency.

→ It is clear from the waveform that with purely resistive load the load current is always discontinuous.



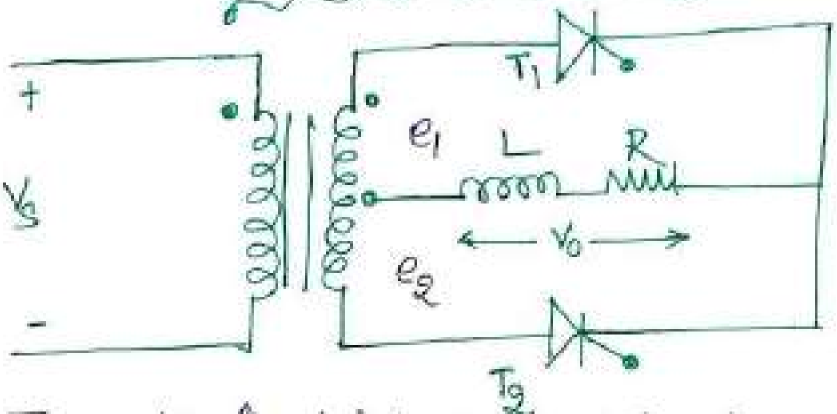
$\rightarrow$ $V_{0(avg)} = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin\omega t \, d(\omega t) = \frac{V_m}{\pi}\left[1+\cos\alpha\right]$

$\rightarrow$ $I_{0(avg)} = \frac{V_m}{\pi R}(1+\cos\alpha)$

$\rightarrow$ $V_{0(rms)} = \left[\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$

$= V_m \left[\frac{\pi-\alpha}{2\pi} + \frac{\sin 2\alpha}{4\pi}\right]^{1/2}$

8) 1-Ø Full wave Rectifier with R L load :→
(Mid point connection)



→ T_1 can be fired into the on state at any time after e_1 +ve. Once T_1 is turned on current builds up in inductive load maintaining T_1 in the on state up to the period when e_1 goes -ve.

→ once e_1 goes -ve e_2 becomes +ve and the firing of T_2 immediately turn on T_2 which takes up the load current placing a reverse voltage on T_1, its current being commutated to T_2.

→ The load current may be continuous or discontinuous, depending on the inductance value. The load current is continuous if the inductance value is greater than its critical value. It is discontinuous if inductance value is less than its critical value.

→ Both the thyristor are trigged with the same delay angle, hence they share the load current equally.

→ Due to large inductance in the circuit and continuous current conduction, the thyristors continue to conduct even when their anode voltage are negative with respect to the cathode.

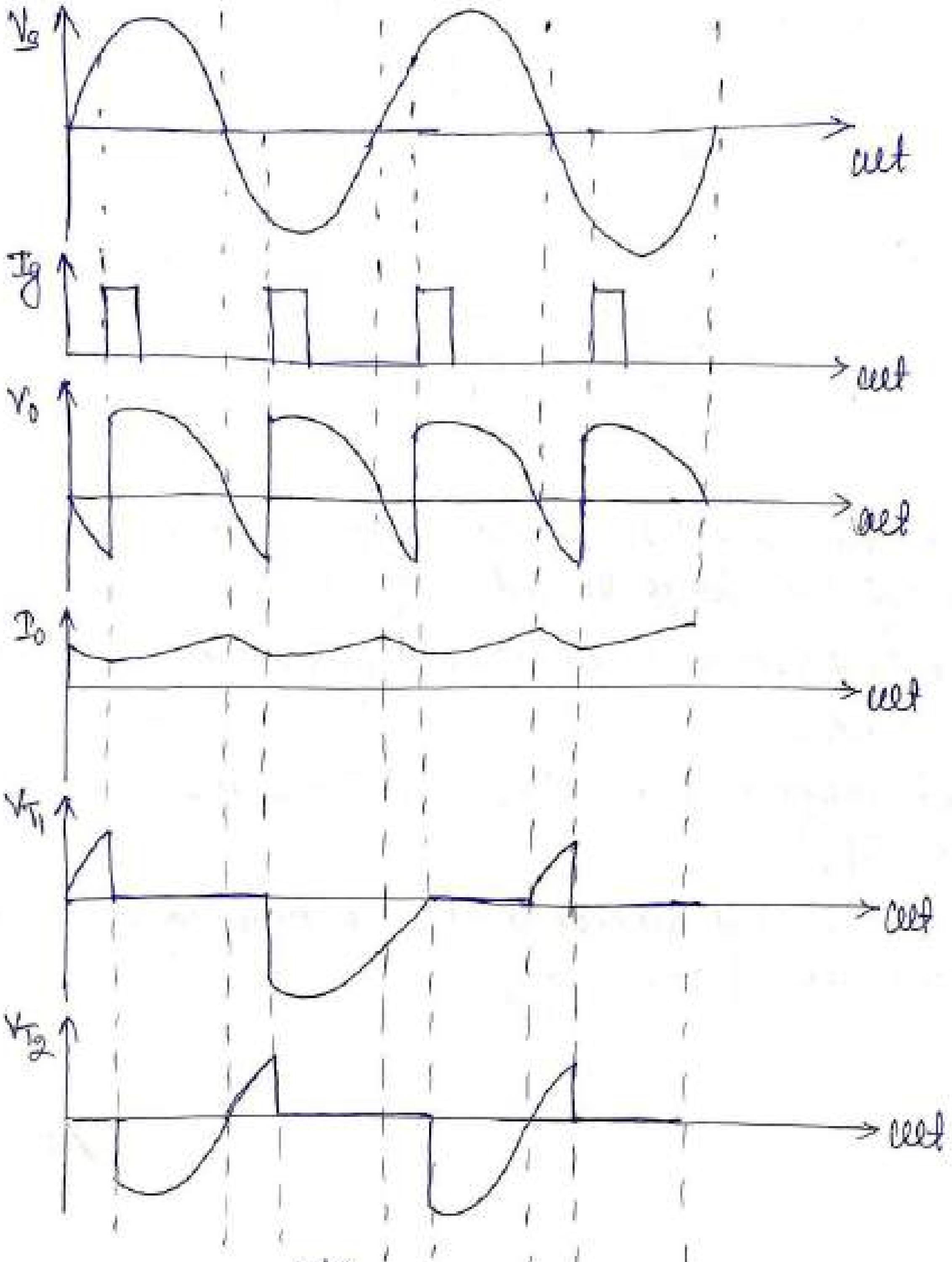
★ from the wave form

→ $\alpha = 30°$ ⇒ More power is fed into load than is received back into the supply

→ $\alpha = 90°$ ⇒ zero output voltage

→ $\alpha > 90°$ ⇒ d.c voltage goes negative

→ $\alpha = 180°$ ⇒ negative dc voltage is maximum



$$\rightarrow V_0(avg) = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin \omega t \, d(\omega t) = \frac{V_m}{\pi}\left[\cos\alpha - \cos(\pi+\alpha)\right]$$

$$V_0(avg) = \frac{2V_m}{\pi}\cos\alpha$$

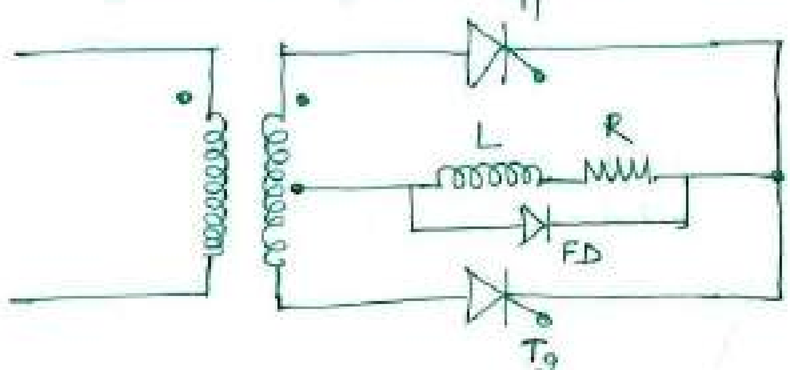
From the equation

$\alpha = 0 \Rightarrow$ Highest value of the voltage

$\alpha = 90^\circ \Rightarrow$ voltage is zero

$\alpha = 180^\circ \Rightarrow$ the voltage is negative

(9) 1-ϕ Full wave Rectifier with RL load effect of free wheeling diode (Mid point connection) :→

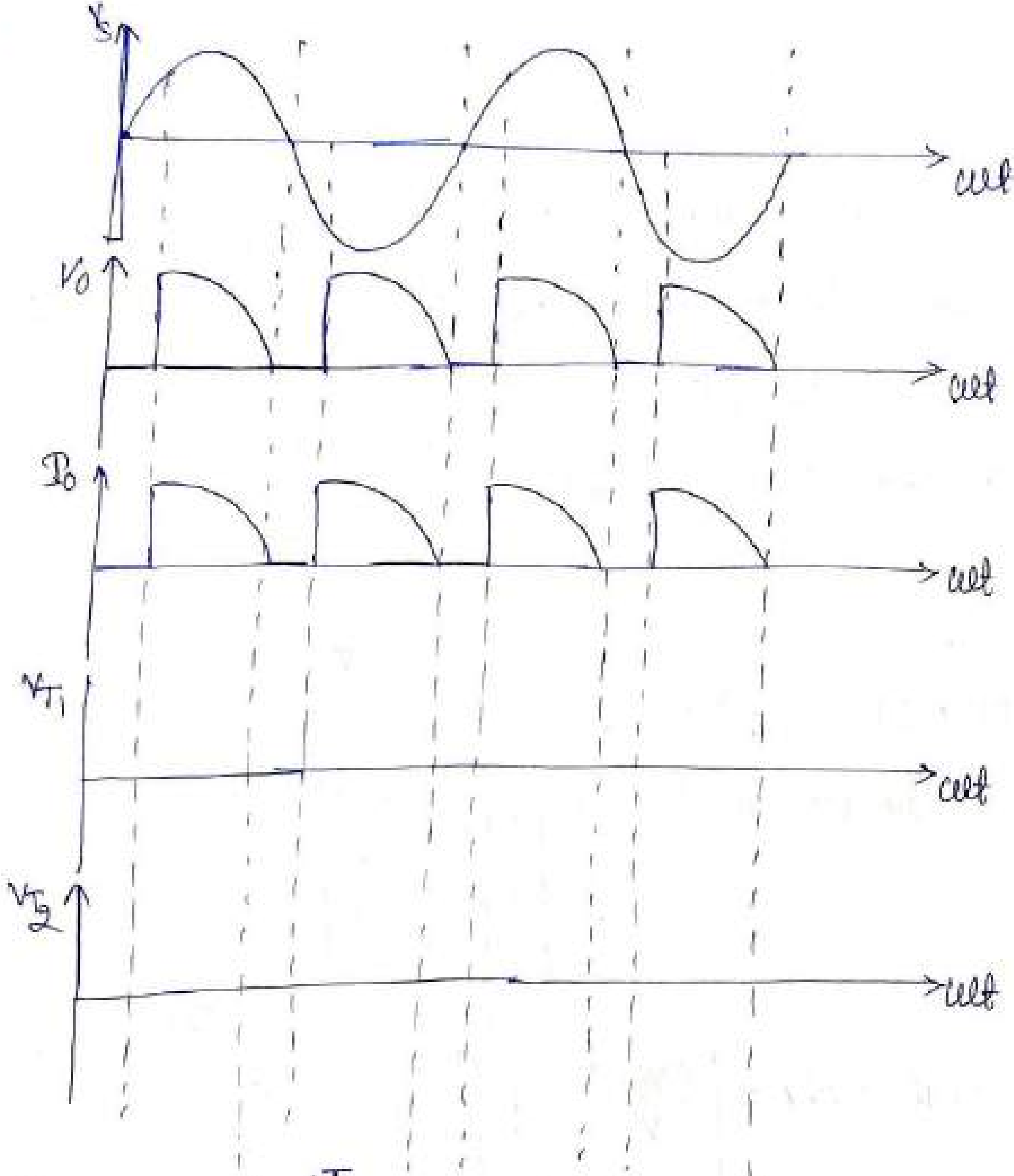


→ The load voltage cannot be negative since the freewheeling diode starts conducting and clamps the load voltage to zero volts.

→ A constant load current is maintained by freewheeling current through the diode.

→ The stored energy in the inductive load circulates current through the Df.

→ Df carries the load current during the firing angle α when the thyristors are not conducting.



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

$$\rightarrow I_{0(avg)} = \frac{V_m}{\pi R}(1+\cos\alpha)$$

Performance Parameters of two pulse converters :⇒

* The rms value of nth harmonic input current $I_{sn} = \frac{4I_0}{\sqrt{2}\,n\pi} = \frac{2\sqrt{2}\,I_0}{n\pi}$

* The rms value of fundamental current $I_{s1} = \frac{2\sqrt{2}\,I_0}{\pi} = 0.90032 I_0$

* The rms value of total input current $I_s = \left[\frac{I_0^2\pi}{\pi}\right]^{1/2} = I_0 \quad \phi_1 = -\alpha$

* Displacement factor $DF = \cos\phi_1 = \cos(-\alpha) = \cos\alpha$

* Current distortion factor $CDF = \frac{I_{s1}}{I_s} = \frac{2\sqrt{2}\,I_0}{\pi} \times \frac{1}{I_0}$

$$= \frac{2\sqrt{2}}{\pi} = 0.90032$$

* $PF = CDF \times DF = \frac{2\sqrt{2}}{\pi}\cos\alpha$

* Harmonic factor HF or THD $= \left[\frac{1}{CDF^2} - 1\right]^{1/2}$

$$= \left[\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1\right]^{1/2}$$

$$= 0.48343 = 48.34\%$$

* voltage ripple factor $= \left[\left(\frac{V_{or}}{V_0}\right)^2 - 1\right]^{1/2} = \left[\frac{\pi^2}{8\cos^2\alpha} - 1\right]^{1/2}$

* Active power input P_i = rms value of source voltage × rms fundamental component of source current × displacement factor

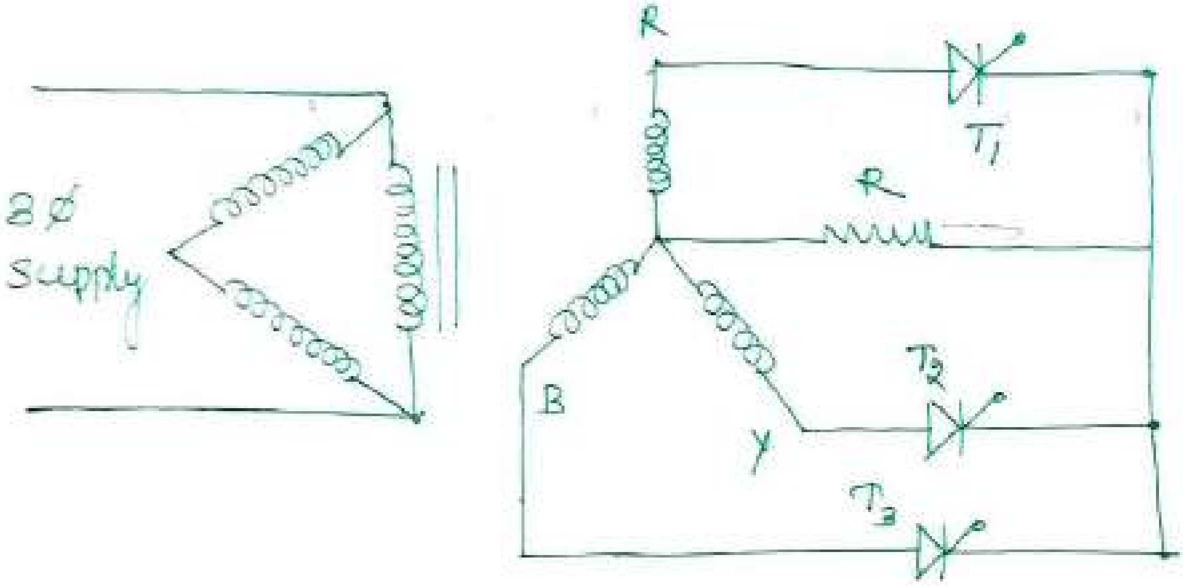
$$= \frac{2V_m}{\pi} I_0\cos\alpha = V_0 I_0 = V_s I_{s1}\cos\phi_1$$

* Reactive power input $= Q_i = V_s I_{s1}\sin\alpha$

$$= \frac{\pi V_0}{\cos\alpha} I_0\sin\alpha$$

$$= V_0 I_0 \tan\alpha$$

★ 3ϕ Halfwave Controlled Converter with R-Load :→



→ The thyristor with max voltage at anode terminal gets forward biased but it does not conduct until it receive firing pulse.

→ Forward bias

T_1 : 30 - 150

T_2 : 150 - 270

T_3 : 270 - 390°

→ conduction

T_1 : $30+\alpha - 150+\alpha$

T_2 : $150+\alpha - 270+\alpha$

T_3 : $270+\alpha - 390° + \alpha$

→ Firing angle is measured after device gets forward biased

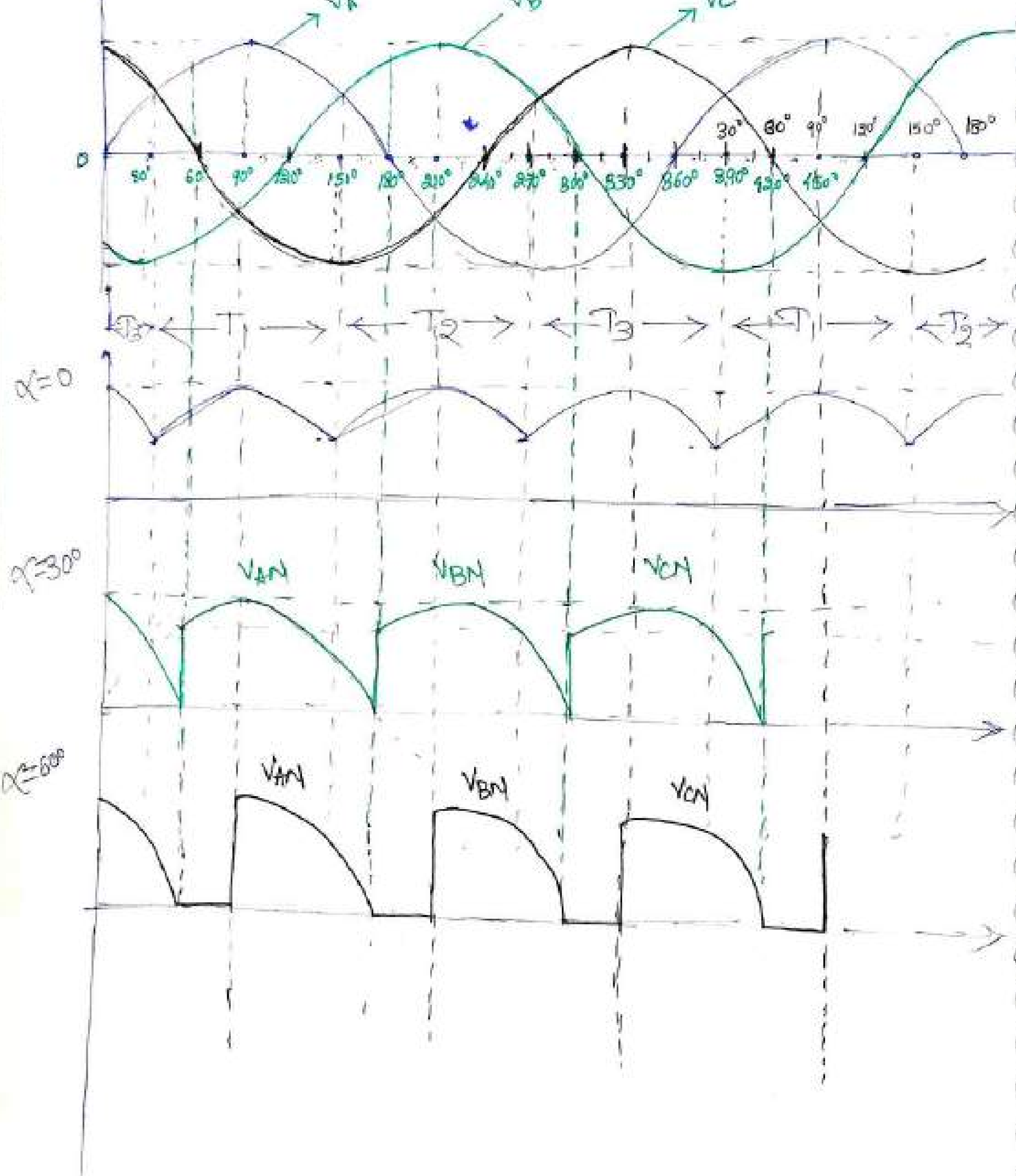
→ $V_{AN} = V_{mp} \sin \omega t$

$V_{BN} = V_{mp} \sin(\omega t - 120°)$

$V_{CN} = V_{mp} \sin \omega t(\omega t + 120°)$

→ all voltages exist at output for 120° each

→ each thyristor conducts for 120°



VA
VB
VC
0
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
360°
390°
420°
450°
T3
T1
T2
T3
T1
T2
α=0
α=30°
VAN
VBN
VCN
α=60°
VAN
VBN
VCN

$\alpha = 0$

$V_{AN} = V_{mp}\sin\omega t$: $30 - 150°$

$V_{BN} = 150 - 270°$

$V_{CN} = 270° - 390°$

$\left\{ \begin{matrix} 270° - 360° \\ 0 - 30° \end{matrix} \right\}$

$\alpha = 30°$

$V_{AN} = V_{mp}\sin\omega t$? $60° - 180°$

$V_{BN} = 180° - 300°$

$V_{CN} = 300 - 420°$ $\left\{ \begin{matrix} 300 - 360° \\ 0 - 60° \end{matrix} \right\}$

$\alpha = 60°$

$V_{AN} = V_{mp}\sin\omega t$: $90° - 210°$

$V_{BN} = 210 - 330$

$V_{CN} = 330° - 450°$

Analysiss

$V_{AN} = V_{mp}\sin\omega t$: $30+\alpha - 150+\alpha$

For R Load discontinuous conduction if

$150+\alpha > 180°$! $\alpha > 30°$

$\alpha = 30°$: boundary of cont. & discont. conduction.

For cont. conduction

$\alpha \leq 30°$ R Load

$$V_{o(avg)} = \frac{1}{\frac{2\pi}{3}} \int_{30+\alpha}^{150+\alpha} V_{mp} \sin\omega t \, d(\omega t)$$

$$= \frac{3V_{mp}}{2\pi}\left[\cos(30+\alpha) - \cos(150+\alpha)\right]$$

$$= \frac{3V_{mp}}{2\pi}\left[\cos 30 \cos\alpha - \cos 150 \cos\alpha\right]$$

$$= \frac{3\sqrt{3}V_{mp}}{2\pi}\cos\alpha$$

$$= \frac{3V_{ml}}{2\pi}\cos\alpha$$

$$V_0(rms) = \left[\frac{1}{2\pi/3}\int_{30+\alpha}^{150+\alpha} V_{mp}^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

$$= V_{mp}\left[\frac{3}{4\pi}\left\{\frac{2\pi}{3} - \frac{1}{2}\left(\sin(300+2\alpha) - \sin(60+2\alpha)\right)\right\}\right]^{1/2}$$

$$= V_{mp}\left[\frac{3}{4\pi}\left\{\frac{2\pi}{3} - \frac{1}{2}\left(\sin 300 \cos 2\alpha - \sin 60 \cos 2\alpha\right)\right\}\right]^{1/2}$$

$$= V_{mp}\left[\frac{3}{4\pi}\left\{\frac{2\pi}{3} + \frac{\sqrt{3}}{2}\cos 2\alpha\right\}\right]^{1/2}$$

$\alpha > 30°$: R Load (discont.)

$V_{AN} = V_{mp}\sin\omega t$: $30+\alpha - 180°$

$$V_0(avg) = \frac{1}{2\pi/3}\int_{30+\alpha}^{180} V_{mp}\sin\omega t \, d(\omega t)$$

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

$$V_0(rms) = \left[\frac{1}{2\pi/3}\int_{30+\alpha}^{180} V_{mp}^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

1-ϕ AC Regulator :→

→ AC voltage regulator is a thyristor based device which converts fixed alternating voltage without a change in frequency

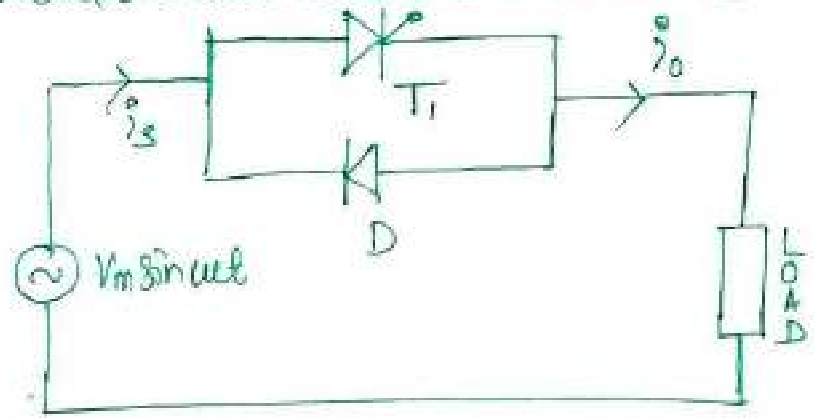
fixed AC	variable ac
fixed V	fixed f
fixed f	variable V

→ Room heater

→ speed control of low power IM eg fan

→ voltage control

① 1-ϕ Half wave AC voltage controller :→



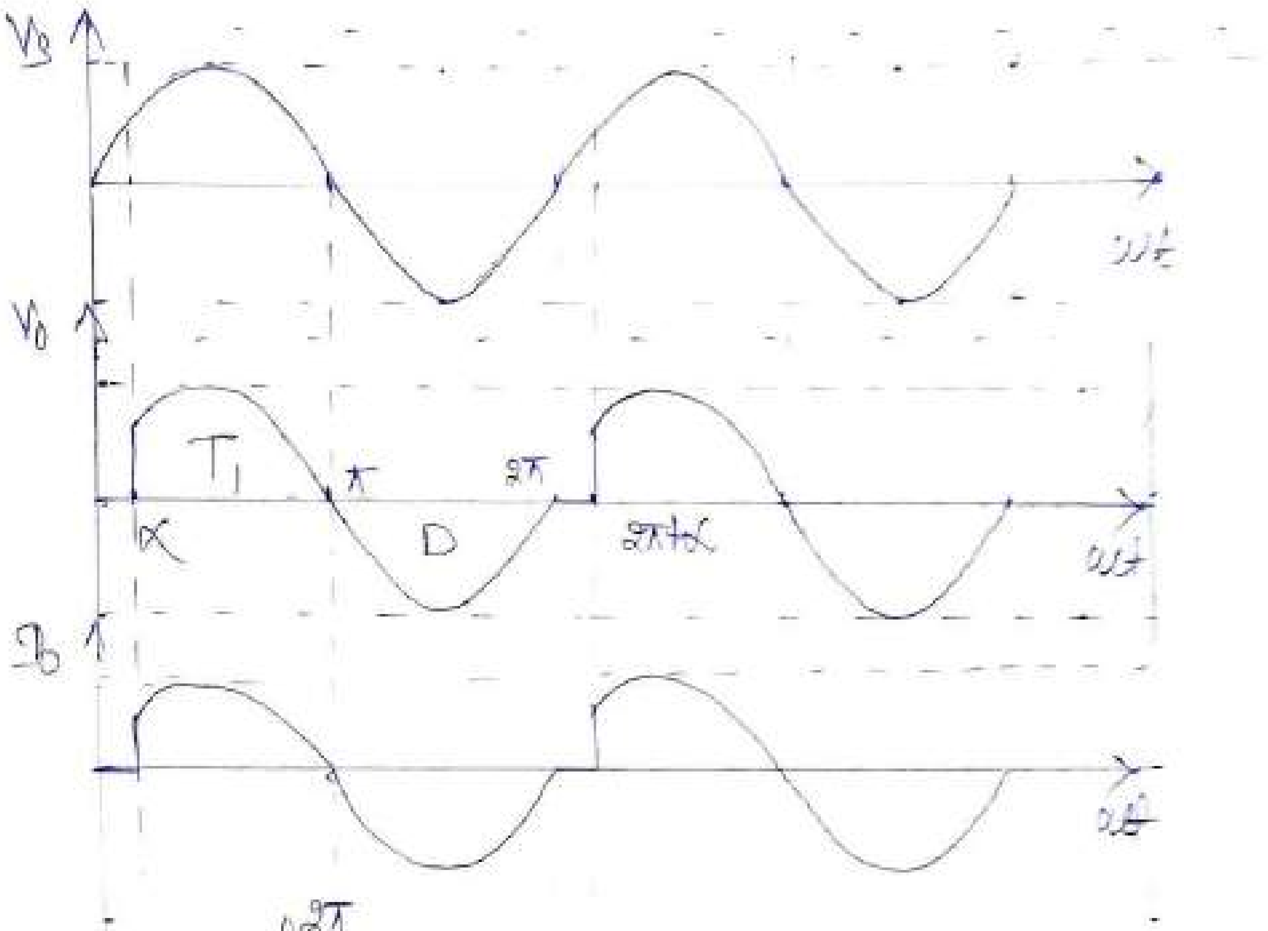
→ In positive half cycle T_1 : FB ($0 \to \pi$) but it starts to conduct at $\omega t = \alpha$ when it receives firing pulse

→ In negative half cycle diode : FB ($\pi \to 2\pi$).

→ Either T : ON or D : ON

$$V_0 = V_m \sin \omega t$$

Wave form



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

$$= \frac{V_m}{2\pi}(\cos\alpha - 1) < 0$$

$$I_0(avg) = \frac{V_m}{2\pi R}(\cos\alpha - 1)$$

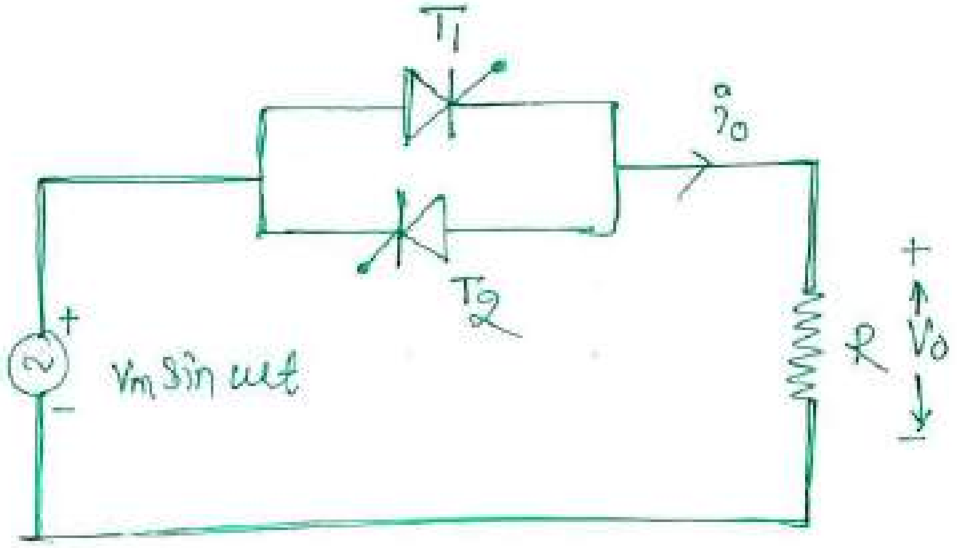
$$V_0(rms) = \left[\frac{1}{2\pi}\int_{\alpha}^{2\pi} V_m^2 \sin^2 \omega t \, d(\omega t)\right]^{1/2}$$

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

$$V_0(rms) = f(\alpha)$$

→ DC current may cause i/p transformer to saturate.

(2) 1-ϕ Full wave AC voltage Controller :→



→ High power application 2 SCR in antiparallel.
→ low or medium power application used triac.

→ during +ve half cycle

T_1 : FB $(0 \to \pi)$

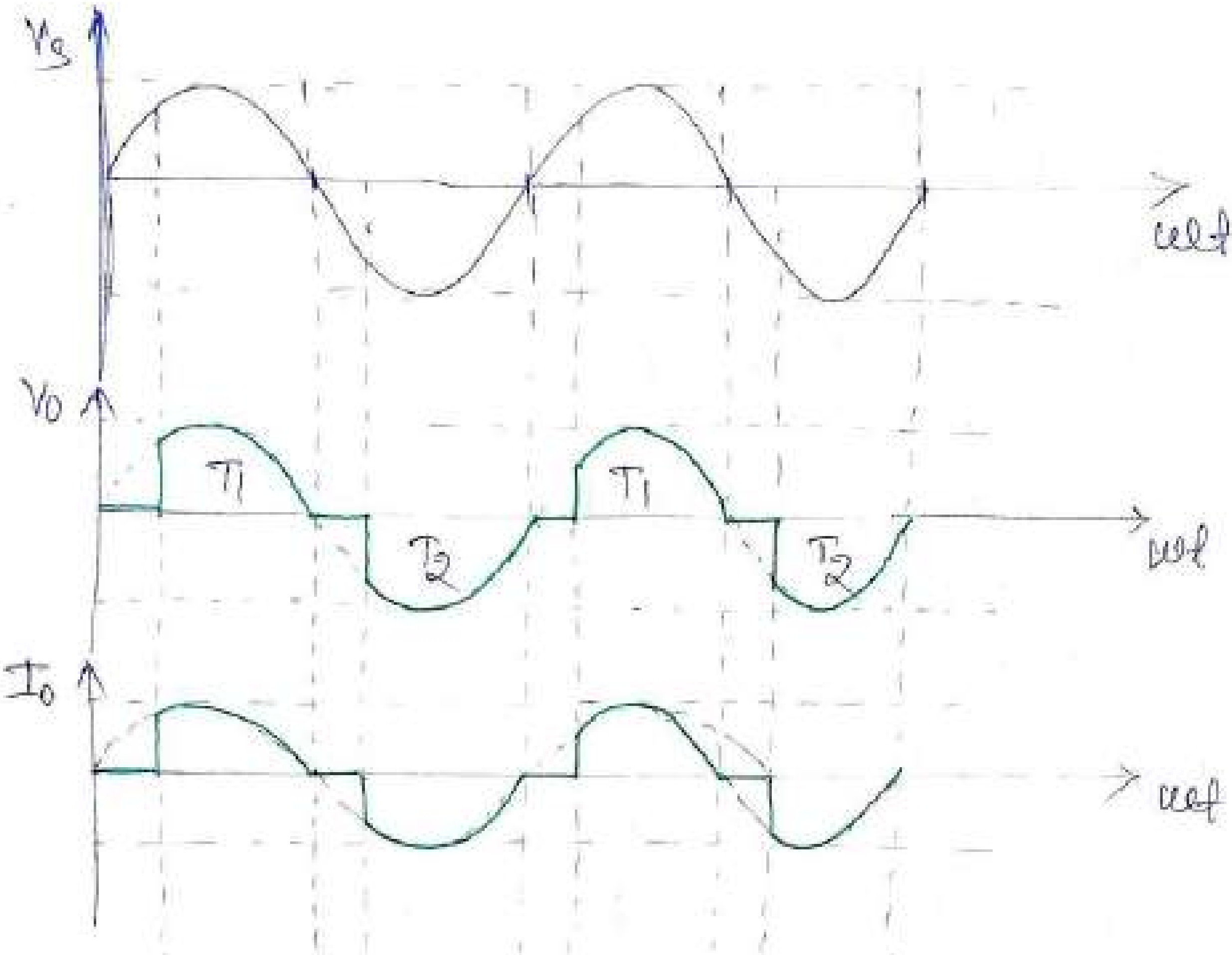
conduction : $(\alpha \to \pi)$

→ during -ve half cycle

T_2 : FB $(\pi \to 2\pi)$

conduction : $(\pi + \alpha \to 2\pi)$

wave form



$$V_{0(rms)} = \left[\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2 \omega t \; d(\omega t)\right]^{1/2}$$

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

$V_{0(avg)} = 0$

Chopper machine :→

★ **Application**

→ speed control of DC Motor
→ Position control in robotics
→ Regulated power supply (SMPS)
→ Input to inverter
→ solar power converter

★ A chopper is a high speed on/off semiconductor switch. It connects source to load and disconnects the load from source at a fast speed. In this manner a chopped load voltage is obtained from constant dc supply of magnitude V_s.

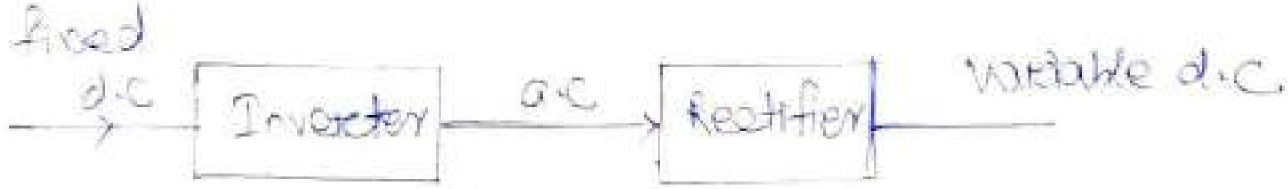
★ The conversion of fixed dc voltage to an adjustable dc output voltage through the use of semiconductor devices.

★ power semiconductor devices used for chopper circuit are SCR, BJT, PMOSFET, GTO, IGBT etc.

★ Following techniques are available for obtaining the variable d.c voltage from a fixed d.c voltage

1. Line commutated converters
2. AC link chopper (inverter - rectifier)
3. DC chopper (d.c to d.c power converter)

AC link chopper :→



→ In this case conversion is two state dc to ac and ac to dc

→ This technique is therefore costly, bulky and less efficient

→ the transformer provides isolation between load and source.

DC chopper :→

→ A dc chopper is a static device used to obtain variable d.c voltages from source of constant d.c voltage.

→ therefore chopper may be thought as d.c equivalent of an a.c transformer since they behaves in an identical manner.

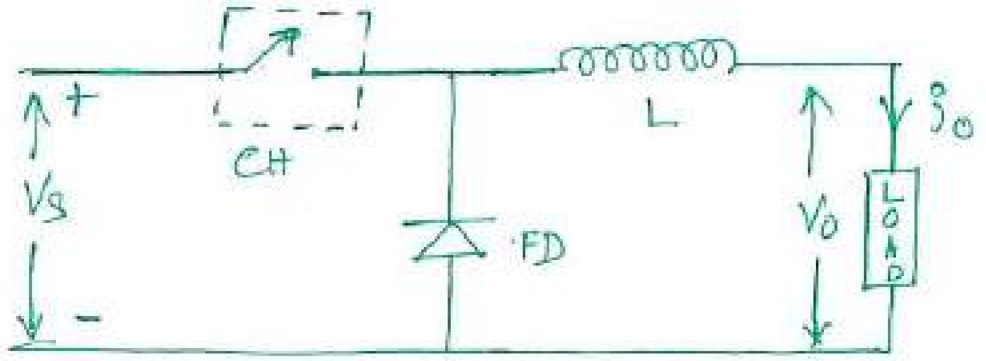
Types of chopper

(1) According to the input/output voltage levels
(i) step down (ii) step up

(2) According to the direction of output voltage & current
(i) Type A (ii) Type B (iii) Type C (iv) Type D (v) Type E

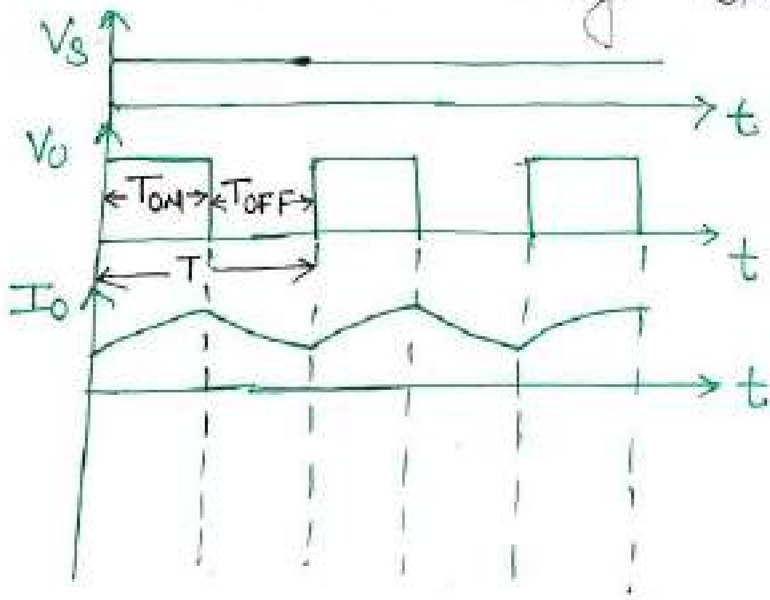
(3) According to commutation method
(i) voltage commutated
(ii) current commutated
(iii) load commutated
(iv) impulse commutated

(1) Step down chopper ⇒



→ During the period T_{ON} chopper is ON and Load voltage is equal to source voltage.

→ During the interval of T_{OFF} chopper is OFF, load current flows through the freewheeling diode FD as a result load terminal are short circuited by FD and Load voltage is therefore zero during T_{OFF}.



$$V_0 = \frac{1}{T}\left[\int_0^{T_{ON}} V_s\,dt + \int_{T_{ON}}^{T} 0\,dt\right]$$

$$= \frac{1}{T} V_s T_{ON}$$

$$\Rightarrow V_0 = V_s \frac{T_{ON}}{T}$$

D = Duty cycle

$$\Rightarrow V_0 = D V_s$$

$$\Rightarrow D = \frac{T_{ON}}{T}$$

$$\Rightarrow V_0 = f\, T_{ON}\, V_s$$

$T = T_{ON} + T_{OFF}$

f = chopping frequency

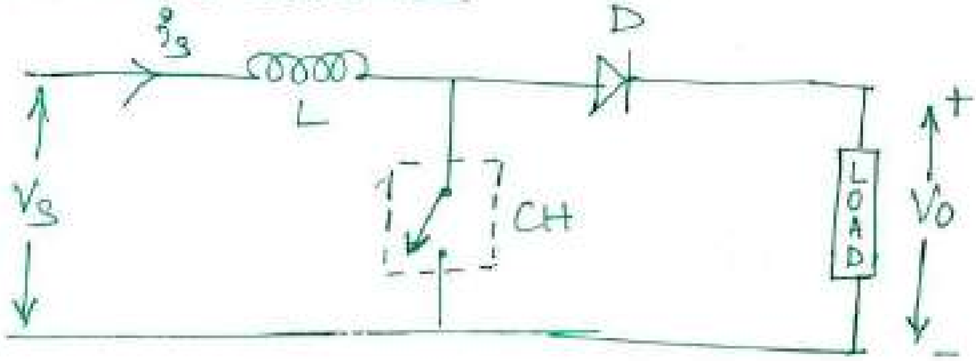
= chopping period

Duty cycle :→

→ The ratio of the ON time to the total switching period of the chopper.

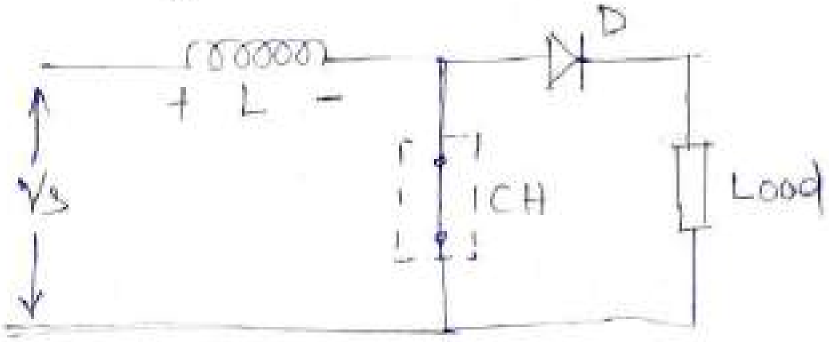
→ The time during which the chopper is ON relative to the whole period.

② Step up chopper →



→ In this chopper a large inductor L in series with source voltage V_s is essential.

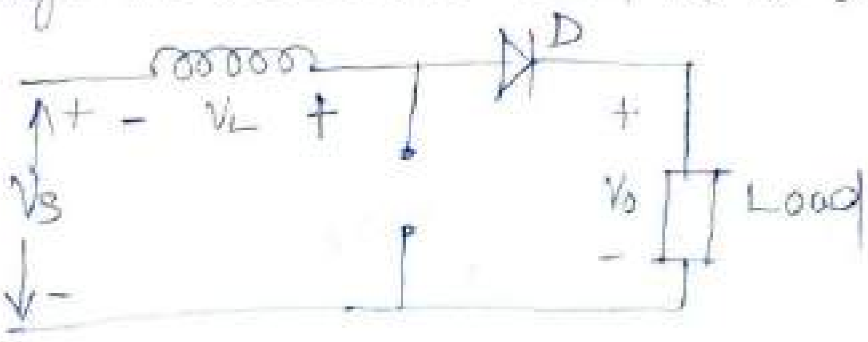
→ when the chopper CH is on the closed current path is



$0 \le t < T_{ON}$

inductor stores energy during T_{ON} period.

→ when the chopper CH is OFF, as the inductor current cannot die down instantaneously, this current is forced to flow through the diode and load for a time T_{OFF}.



$T_{ON} \le t < T$

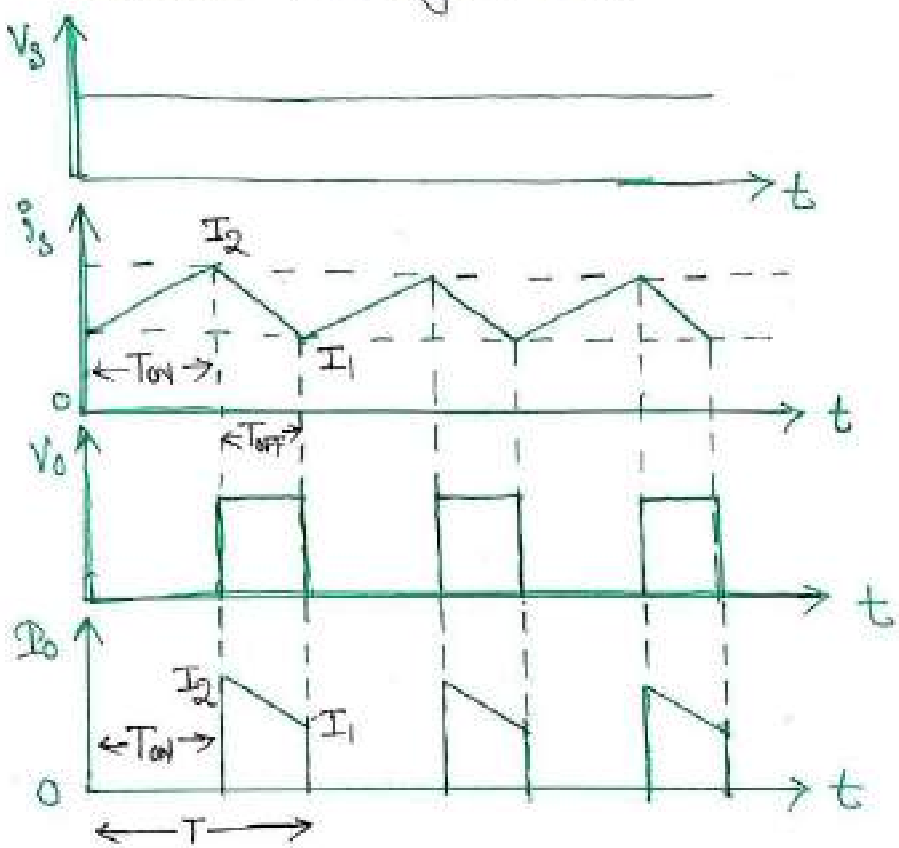
As the current tends to decrease, polarity of the emf induced in L is reversed. As a result voltage across the load, given by $V_L - V_0 + V_S = 0$

$$\Rightarrow -V_0 = -V_L - V_S$$

$$\Rightarrow V_0 = V_L + V_S$$

$$\Rightarrow V_0 = L\left(\frac{di}{dt}\right) + V_S$$

V_0 exceeds the source voltage V_S.



→ When CH is ON, current through the inductor L would increase from I_1 to I_2.
source voltage is applied to L i.e $V_L = V_S$

→ When CH is OFF current fall from I_2 to I_1

$$V_L - V_0 + V_S = 0 \Rightarrow V_L = V_0 - V_S$$

★ Energy $E = VIT$ joules

Assuming liner variation of output current, the energy input to inductor from the source, during the period T_{ON} is

$$W_{ON} = (\text{voltage across } L)(\text{average current through } L) T_{ON}$$

$$= V_S \left(\frac{I_1 + I_2}{2}\right) T_{ON}$$

During the time T_{OFF} when chopper is off the energy released by the inductor to the Load is

$$W_{OFF} = (\text{Voltage across } L)(\text{average current through } L) T_{OFF}$$

$$= (V_0 - V_S)\left(\frac{I_1 + I_2}{2}\right) T_{OFF}$$

considering the system to be lossless

$$W_{ON} = W_{OFF}$$

$$\Rightarrow V_S \left(\frac{I_1 + I_2}{2}\right) T_{ON} = (V_0 - V_S)\left(\frac{I_1 + I_2}{2}\right) T_{OFF}$$

$$\Rightarrow V_S T_{ON} = (V_0 - V_S) T_{OFF}$$

$$\Rightarrow V_S T_{ON} = V_0 T_{OFF} - V_S T_{OFF}$$

$$\Rightarrow V_S T_{ON} + V_S T_{OFF} = V_0 T_{OFF}$$

$$\Rightarrow V_S (T_{ON} + T_{OFF}) = V_0 T_{OFF}$$

$$\Rightarrow V_0 T_{OFF} = V_S T$$

$$\Rightarrow V_0 = V_S \frac{T}{T_{OFF}}$$

$$= V_S \frac{T}{T - T_{ON}}$$

$$= V_S \frac{1}{1 - \frac{T_{ON}}{T}}$$

$$\Rightarrow V_0 = V_S \frac{1}{1 - D}$$

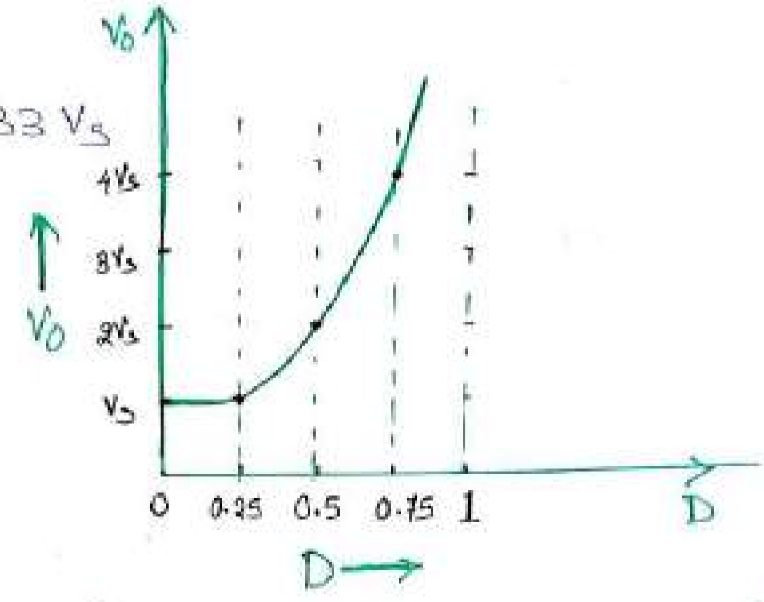
$D = 0 \quad V_0 = V_s$

$D = 0.25 \quad V_0 = \frac{4V_s}{3} = 1.33\,V_s$

$D = 0.5 \quad V_0 = 2V_s$

$D = 0.75 \quad V_0 = 4V_s$

$D = 1 \quad V_0 = \infty$



(Variation of load V_0 with D)

③ Control Modes of chopper ⇒

→ It seen from eq^{n}① and eq^{n}② that average value of output voltages V_0 can be controlled by periodic opening and closing of the switches.

→ Two types of control strategies for operating the switches are employed in d.c choppers they are

① Time ratio control

② Current limit control

① Time ratio control ⇒

→ In this control the value of $\frac{T_{on}}{T}$ is varied.

→ It is done is two ways

(i) Variable frequency operation

(ii) Constant frequency operation.

(i) constant frequency system →

→ In this type of control strategy the ON time T_{ON} is varied but the chopping frequency $f = \frac{1}{T}$ is kept constant.

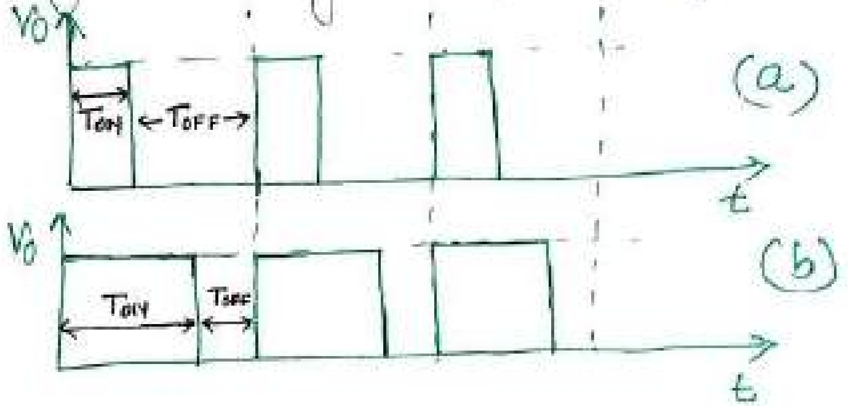


Fig (a) $T_{ON} = \frac{1}{4} T$ $D = 25\%$

fig (b) $T_{ON} = \frac{3}{4} T$ $D = 75\%$

Hence the output voltage can be varied by varying the on time T_{ON}.

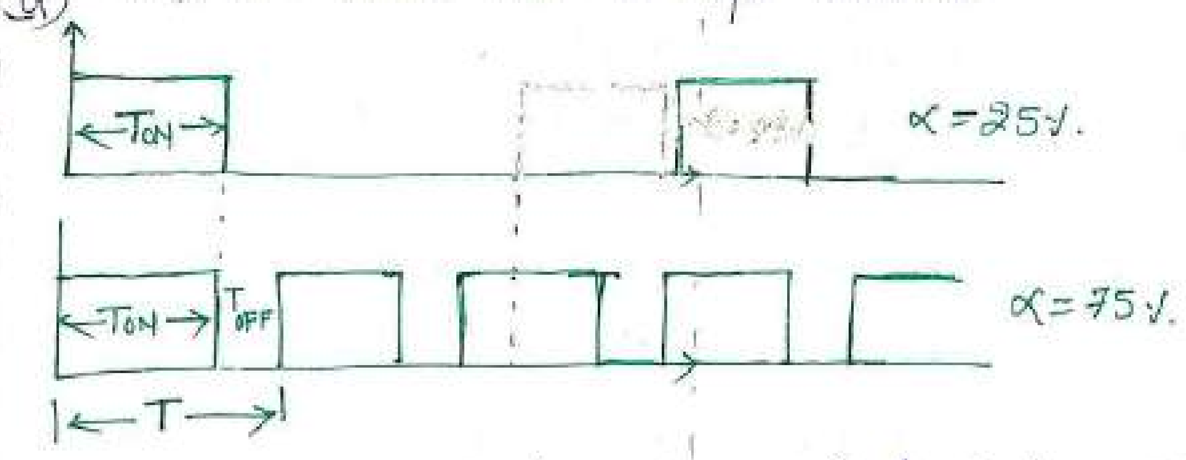
(ii) variable frequency system ⇒

→ In this type of control strategy the chopping frequency f is varied. by

(a) ON time T_{ON} is kept constant

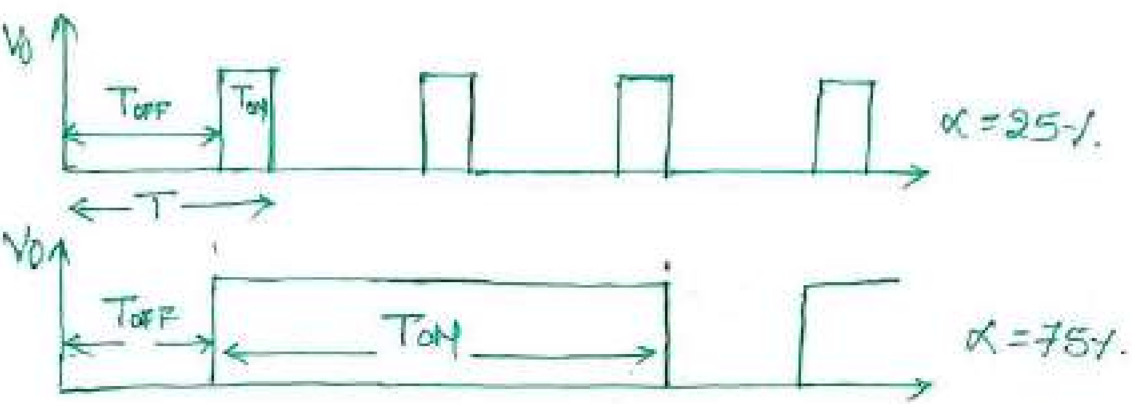
(b) OFF time T_{OFF} is kept constant

(a)



→ Chopping period T is varied but on time T_{ON} is kept constant.

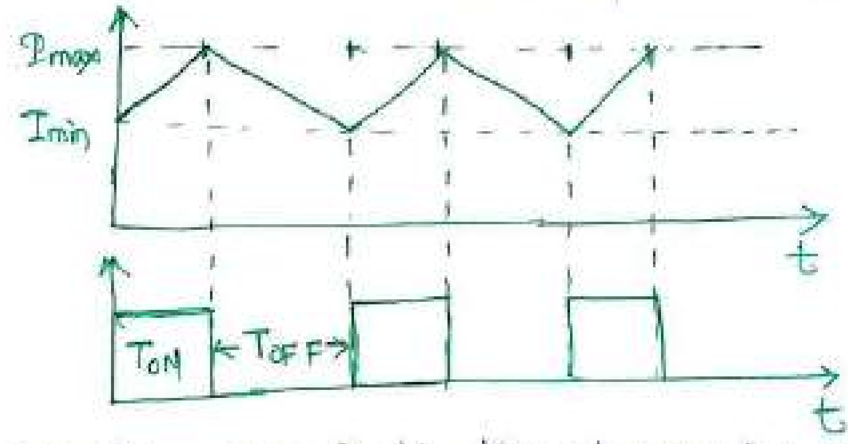
(b)



In this case chopping period T is varied by T_{OFF} is kept constant.

(2) Current limit control ⇒

→ In current limit control strategy the chopper is switched ON and OFF so that the current in the load is maintained between two limits.



→ when current exceeds upper limit, the chopper is switched OFF. During switch OFF period, the load current freewheels and decreases exponential.

→ when it reaches the lower limit the chopper is switched ON.

→ current limit control is possible either with constant frequency or with constant T_{ON}

→ The current limit control is used only when the load has energy storage elements.

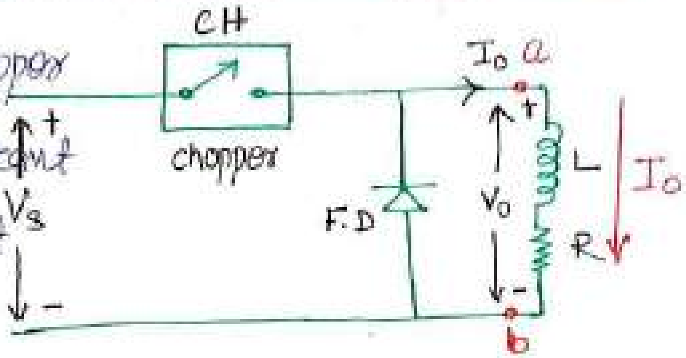
(4) Operation of chopper in all four Quadrants :→

(i) Type-A chopper or First Quadrant chopper :→

→ It is a step down chopper

→ It's working in 1st Quadrant

→ o/p voltage & o/p current is positive



→ CH : ON

→ Current will flow $+V_s \to CH \to L \to R \to -V_s$

→ Inductor get energised (+ −) and current will increased gradually

→ output voltage is $V_s = V_0$

→ CH : OFF

→ Inductor released its energy, polarity of inductor will change (− +)

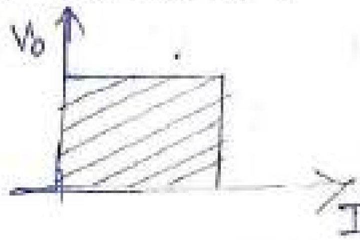
→ Current flows $+L \to R \to FD \to -L$

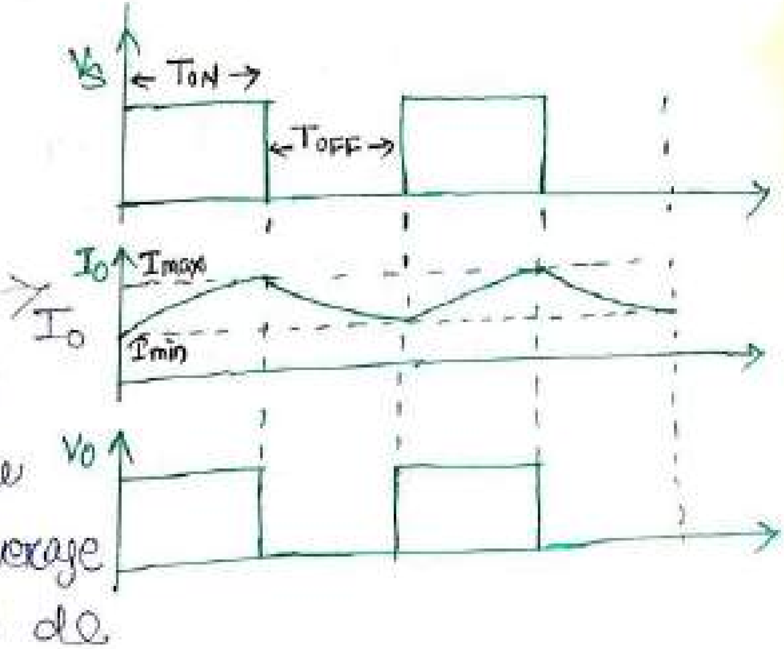
→ output $V_0 = 0$

→ FD will conduct.

→ $V_0 = +ve$

$I_0 = +ve$





→ In type A chopper the power flow will be always from source to load. As the average voltage V_0 is less than the dc input voltages V_s.

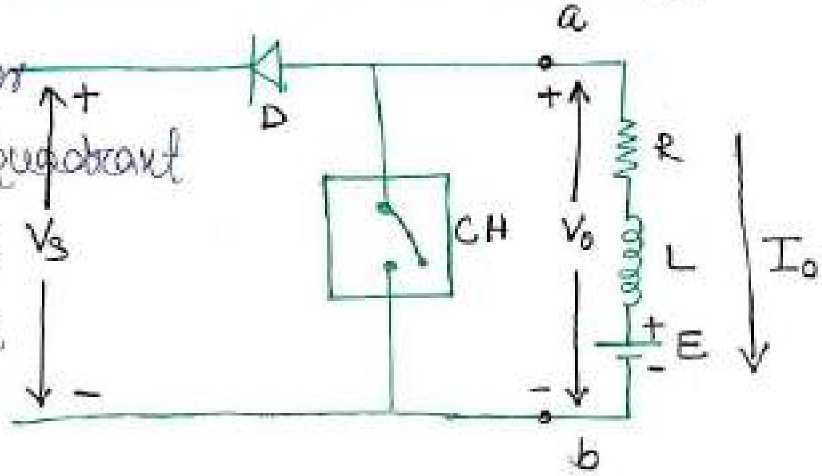
→ It is used in Forward Motoring of DC Motor.

(ii) Type-B chopper or Second Quadrant chopper :->

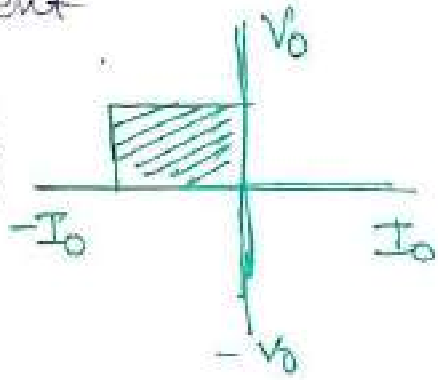
→ It is step up chopper

→ It working in 2nd Quadrant

→ o/p voltage +ve
o/p current −ve



CH: ON
→ Diode D is reversed biased
→ Battery E that will flow current
$+E \rightarrow L \rightarrow R \rightarrow CH \rightarrow -E$
→ Inductor get energised ⇒
→ o/p current $I_0 = -ve$
o/p voltage $V_0 = +ve$

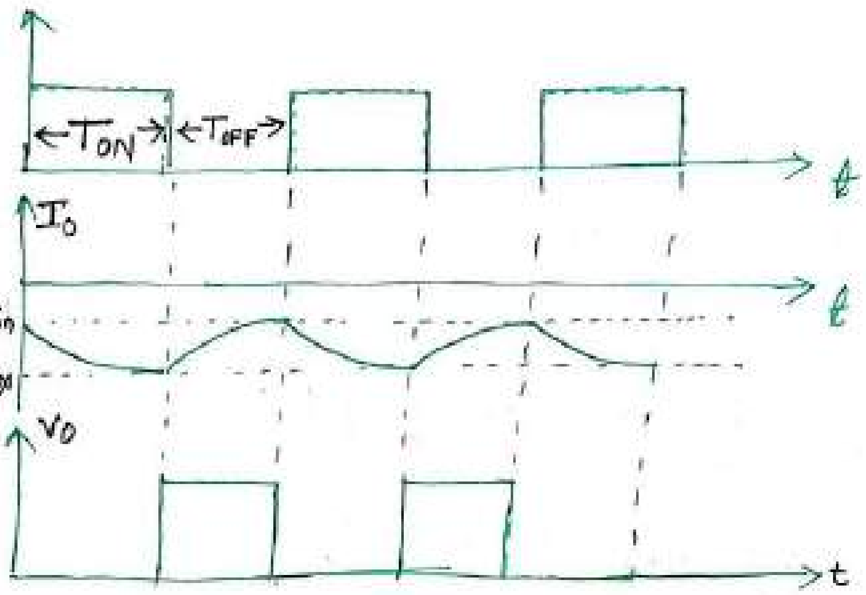


CH: OFF
→ Diode D is Forward biased
→ Inductor released of energy and the polarity of inductor will charge → $V_s = V_0$

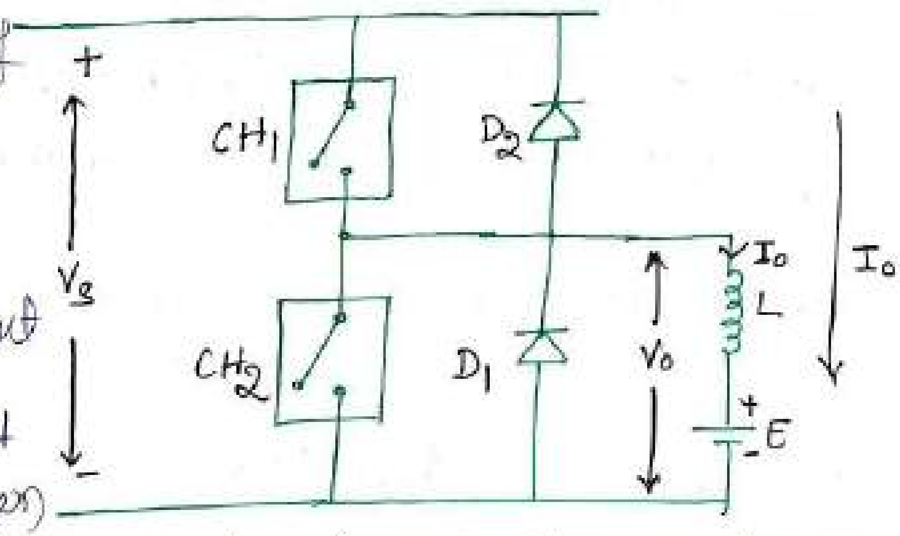
→ current flow from
$+L \rightarrow R \rightarrow D \rightarrow V_s \rightarrow E \rightarrow -L$

→ o/p voltage $V_0 = +ve$
o/p current $I_0 = -ve$

→ It is used for regenerative breaking of DC Motor



(8) Type-C chopper or Two Quadrant Type-A chopper :→



→ It is combination of type A & type B chopper

→ It functions in 1st and 2nd quadrant

→ In 1st quadrant it acts as a step down chopper and in 2nd quadrant acts as a step up chopper.

→ O/P voltage is always positive and output current can be positive or negative

→ choppers CH1 & CH2 should not be ON simultaneously as this lead to direct short circuit on the supply line

→ used for motoring & regenerative breaking of DC motor.

CH1: ON
CH2: OFF

→ current flows from
$+V_s \rightarrow CH_1 \rightarrow L\ C \rightarrow E \rightarrow -V_s$

→ Inductor will stored energy and the inductor polarity becomes ( )

→ o/p current $I_o = +ve$
o/p voltage $V_o = +ve$

CH1: OFF
CH2: OFF

→ Diode D_1 is forward biased

→ Energy stored by inductor will be released & polarity of inductor will change ( )

→ The direction of current flow is
$+L \rightarrow E \rightarrow D_1 \rightarrow -L$

→ o/p current $I_o = +ve$
o/p voltage $V_o = 0$

CH2: ON
CH1: OFF

→ Diode D_1 reversed biased
D_2 reversed biased

→ Battery E that will flow current

→ The direction of current flow is
$E \rightarrow L \rightarrow CH_2 \rightarrow E$

→ Inductor will stored energy and the polarity of inductor will be ( )

→ o/p current $I_o = -ve$
o/p voltage $V_o = 0$

CH_2: OFF
CH_1: OFF

→ D_2 gets forward biased

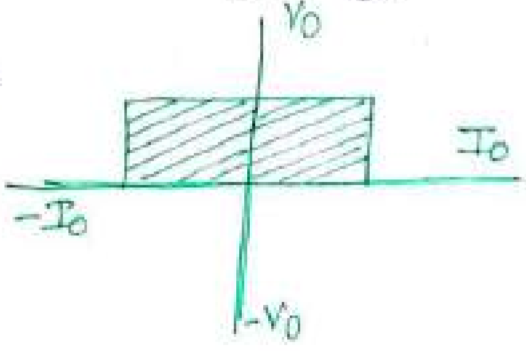
→ energy stored by the inductor will be released through D_2 and the polarity of inductor will be change $\left(L^{+}_{-}\right)$

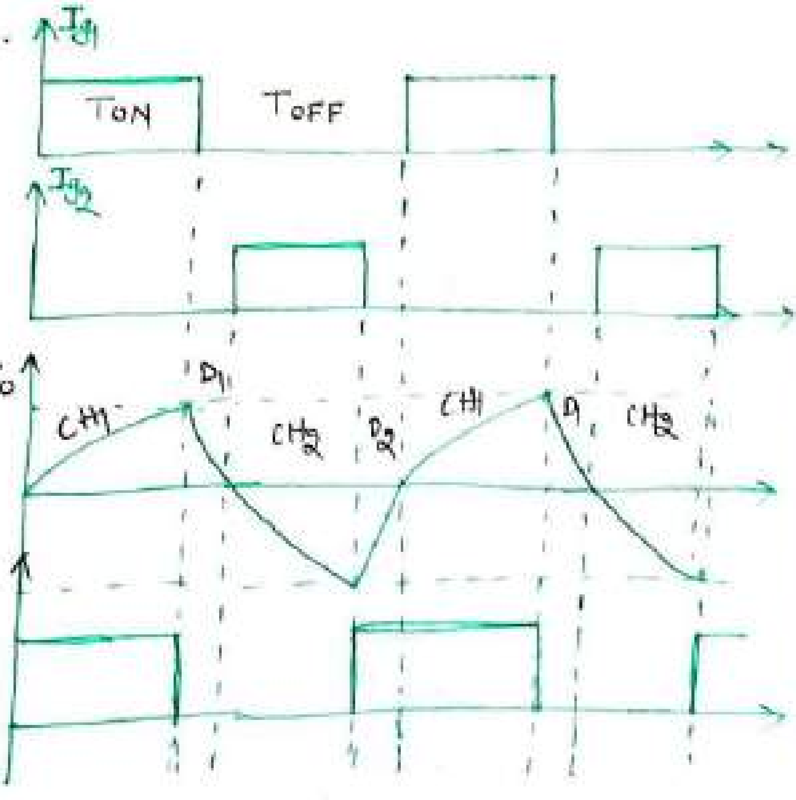
→ the direction of flow of current be
$L \rightarrow D_2 \rightarrow +V_s \rightarrow E \rightarrow L$

→ o/p current $I_0 = -ve$
o/p voltage $V_0 = +ve$

→ when CH_1 & D_1 ON $I_0 = +ve$ $V_0 = +ve$
when CH_2 & D_2 ON $I_0 = -ve$ $V_0 = +ve$

→





from the above cases we can conclude the following points

→ The output voltage V_0 is zero when chopper CH2 is ON or FD D_1 conducts

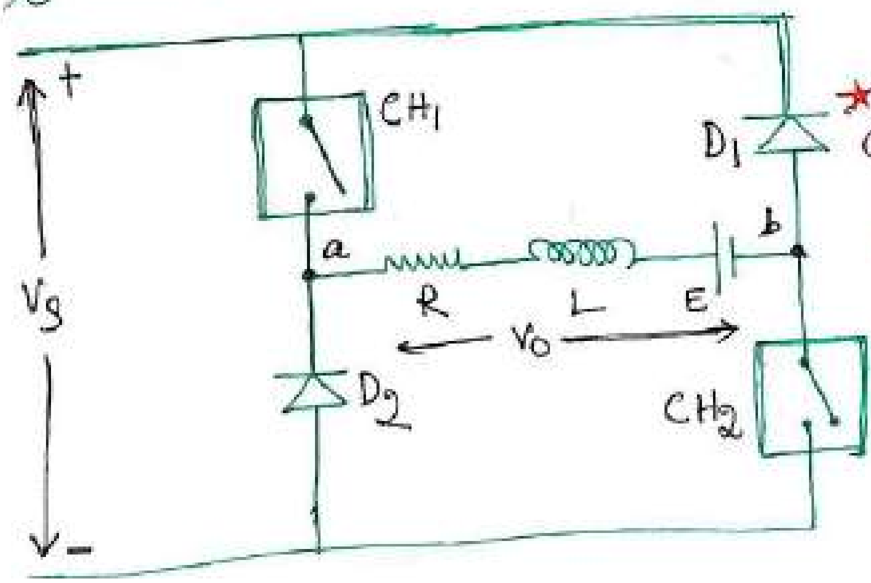
→ The output voltage V_0 is equal to source voltage V_S when chopper CH1 is ON or diode D_2 conducts

→ The load current flows in the direction shown in ckt diagram i.e I_0 is positive when CH1 is ON or FD D_1 conducts

→ The load current flows opposite to the direction shown in the ckt diagram i.e I_0 is negative when CH2 is ON or D2 conducts.

→ 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).

④ Type-D chopper or two Quadrant type B chopper :-



★ Reference current direction

$I_0 = +ve$ →

← $I_0 = -ve$

★ voltage

$\left.\begin{array}{l} a = +V_S \\ b = -V_S \end{array}\right\} V_0 = +ve$

$\left.\begin{array}{l} a = -V_S \\ b = +V_S \end{array}\right\} V_0 = -ve$

→ It is a two quadrant chopper

→ It function in 1^{st} and 4^{th} quadrant

→ o/p current always +ve & o/p voltage be positive or negative.

→ 1^{st} quadrant working with when CH_1 & CH_2 : ON

→ 4^{th} quadrant working with when D_1 & D_2 : ON

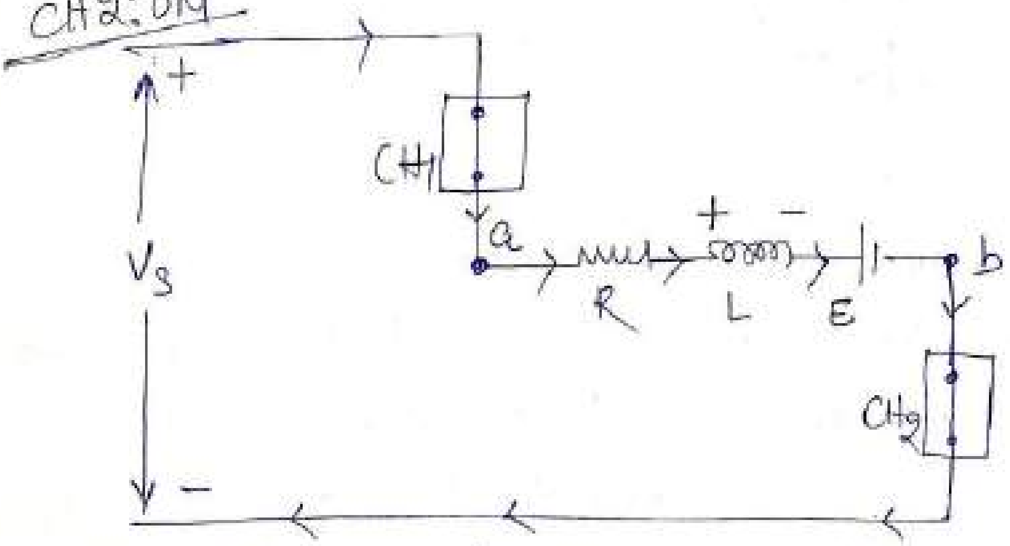
→ the average output voltage is depends on chopper ON time & OFF time

$T_{ON} > T_{OFF}$ $V_0 = +ve$

$T_{ON} < T_{OFF}$ $V_0 = -ve$

$T_{ON} = T_{OFF}$ $V_0 = 0$

CH1: ON
CH2: ON



→ when both the choppers are switch ON the load is directly connected to source and hence the output voltage V_0 will become equal to the source voltage V_s.

→ the current flows from source to load in this case.

→ direction of current will be

$+V_s \rightarrow CH_1 \rightarrow R \rightarrow L \rightarrow E \rightarrow CH_2 \rightarrow -V_s$

In this case inductor will be stored energy and the polarity of the inductor be (+ ⌇⌇⌇ -)

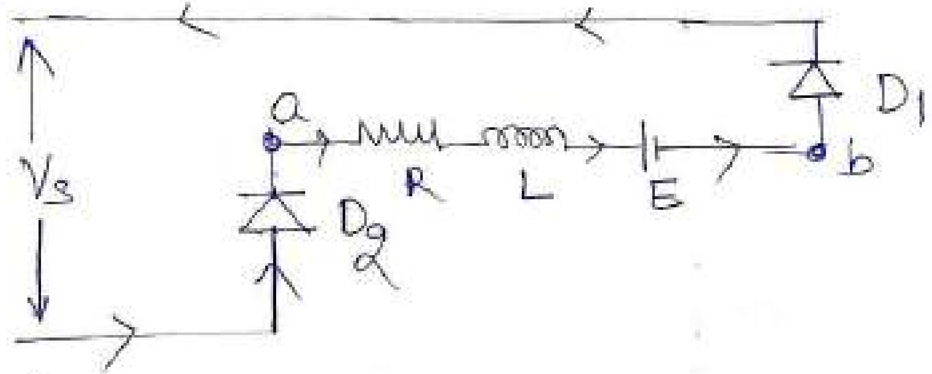
→ the supply voltage appears at $+V_s$ at a and $-V_s$ at b so V_0 = +ve

→ current flows from a → b so I_0 = +ve

→ Here V_0 = +ve & I_0 = +ve hence the operation is in first quadrant.

→ In this case diode D_1 & D_2 are reversed biased and hence they can be treated as an open circuit.

CH1 : OFF
CH2 : OFF



→ when both the choppers are made OFF simultaneously the current through the load doesn't suddenly drops to zero due to inductive nature of load. However it decays gradually and hence a huge amount of voltage is induced in the inductor in the reverse direction. This makes diode D_1 & D_2 forward biased. thus D_1 & D_2 starts conducting.

→ Energy stored by the inductor get released by changing its polarity ($-$ $+$)

→ The direction of flow of current

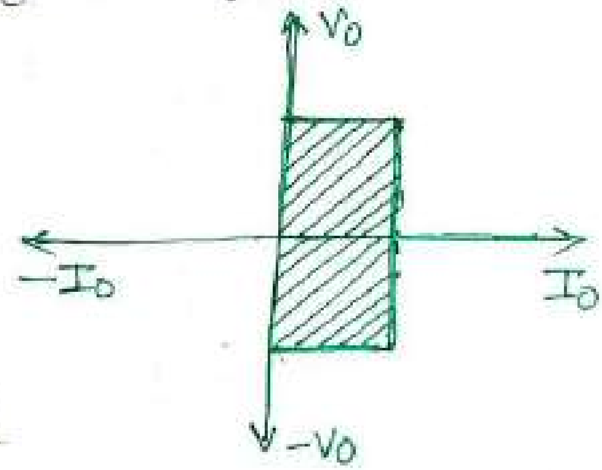
$+L \rightarrow E \rightarrow D_1 \rightarrow +V_s \rightarrow -V_s \rightarrow D_2 \rightarrow R \rightarrow -L$

→ The current flows from load to source. It shall be noted that the direction of load current has not changed. The current is still flowing as shown by the direction of I_0 in the diagram but the polarity of V_0 has changed.

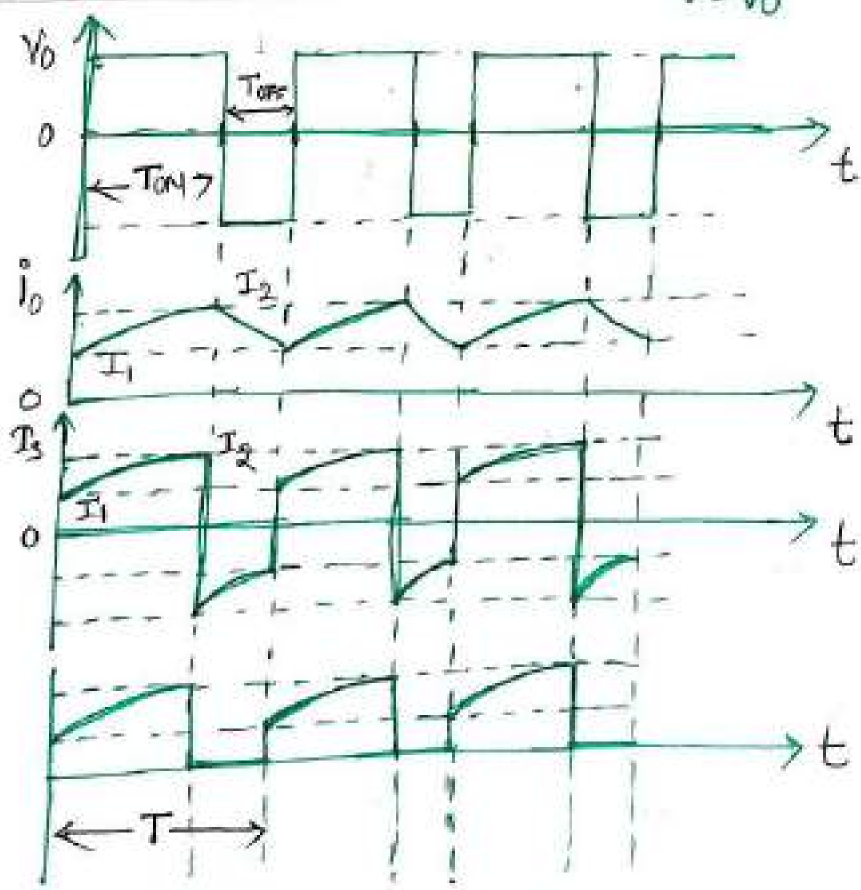
→ supply voltage appears $+V_s$ at b & $-V_s$ at a so $V_0 = -ve$

→ current flows from $a \longrightarrow b$ so $I_0 = +ve$

→ Here $V_0 = -ve$ & $I_0 = +ve$ hence the operation of chopper is in fourth quadrant.



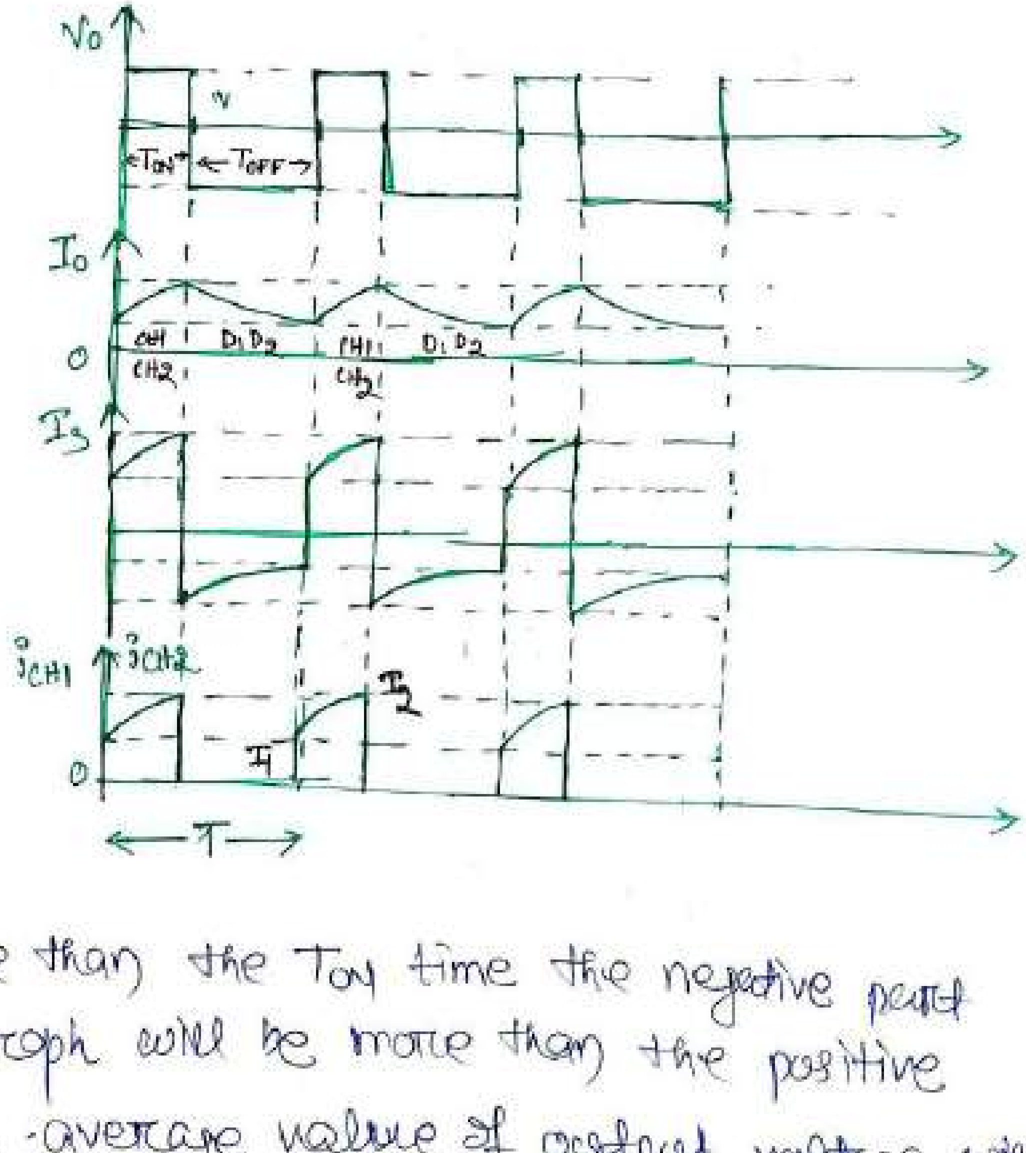
Both CH1: ON & CH2: ON



→ During ON time of CH1 & CH2 output voltage V_0 is +ve and equal to V_s.

→ It may be noticed that the average value of output V_0 may either be positive or negative. It depends on T_{ON} and T_{OFF} time.

→ If T_{ON} time is more than T_{OFF} time then positive part of V_0 Vs t graph will be more than the negative part and hence average value will be positive.

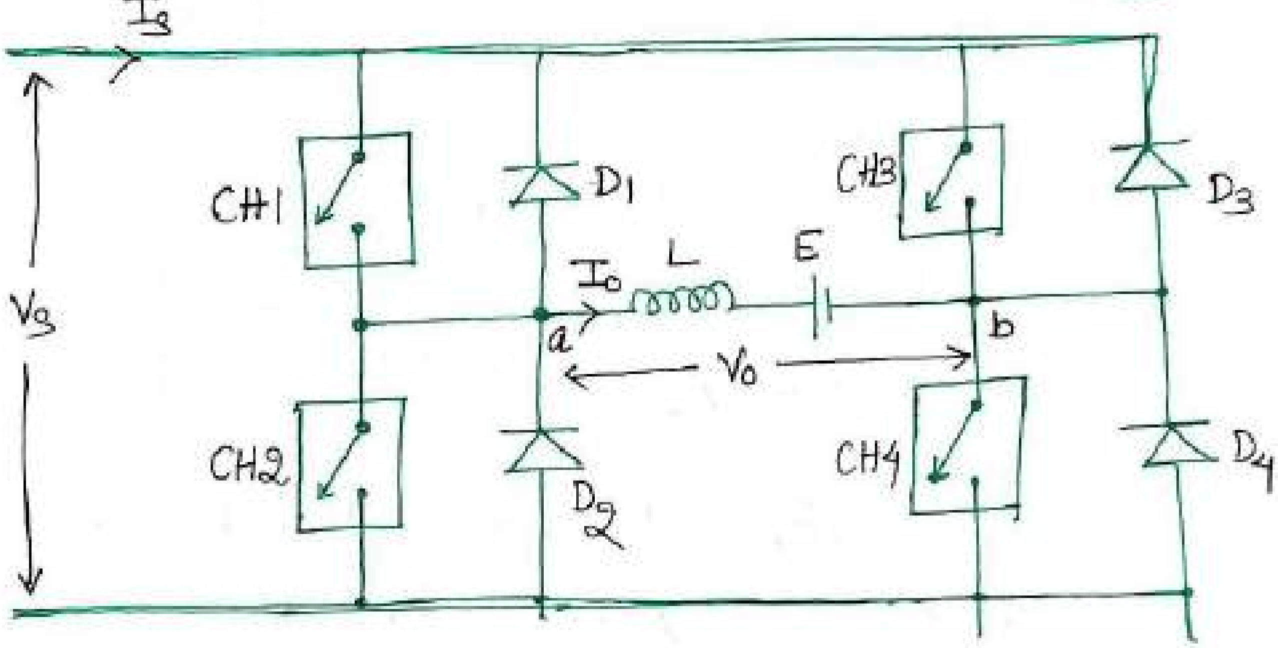


If T_{OFF} is more than the T_{ON} time the negative part of V_0 Vs t graph will be more than the positive part and hence average value of output voltage will be negative.

$$V_0 = V_s\left[\left(T_{ON} - T_{OFF}\right)/T\right]$$

the waveform of load current. It can be see that load current is always positive irrespective of CH1 & CH2 are ON or OFF. thus the average value of load current I_0 will always be positive.

(5) Type-E chopper or Four Quadrant chopper :→



→ It works on all the four Quadrants

→ parallel combination of two class-C chopper.

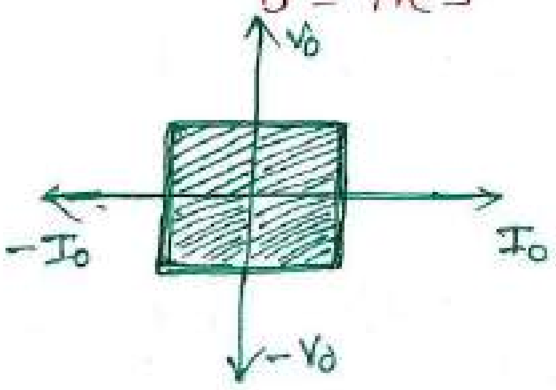
Reference

* Direction of Current $a \xrightarrow{I_0 = +ve} b$

$a \xleftarrow{I_0 = -ve} b$

* voltage $\left.\begin{array}{l} a = +ve \\ b = -ve \end{array}\right\} V_0 = +ve$

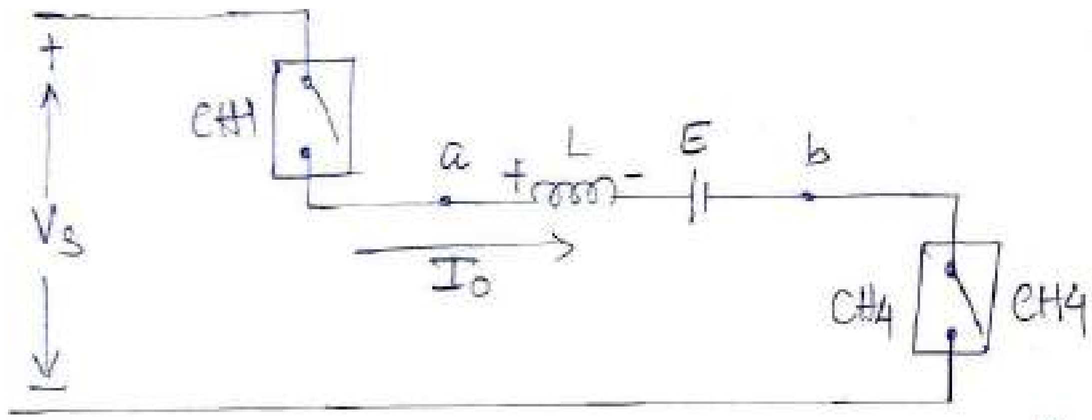
$\left.\begin{array}{l} a = -ve \\ b = +ve \end{array}\right\} V_0 = -ve$



CH_2 operated CH2 D4 : L stores energy CH2 off then D1 - D4 conducts	CH1 operated CH1, CH4 : ON CH1 OFF then CH4 D2 conducts
CH3 operated CH3 - CH2 : ON CH3 off then CH2 - D4 conducts E reversed	CH4 operated CH4 D2 : L stores energy CH4 off then D2 D3 conducts E reversed

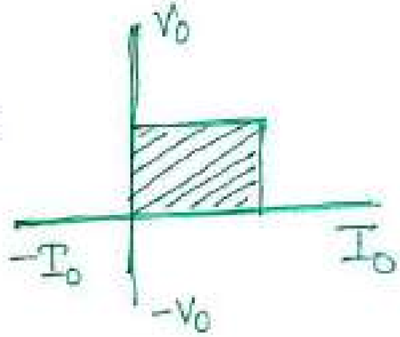
CH1 : ON
CH4 : ON

1st Quadrant operation



→ current direction

$+V_s \rightarrow CH_1 \rightarrow L \rightarrow E \rightarrow CH_4 \rightarrow -V_s$



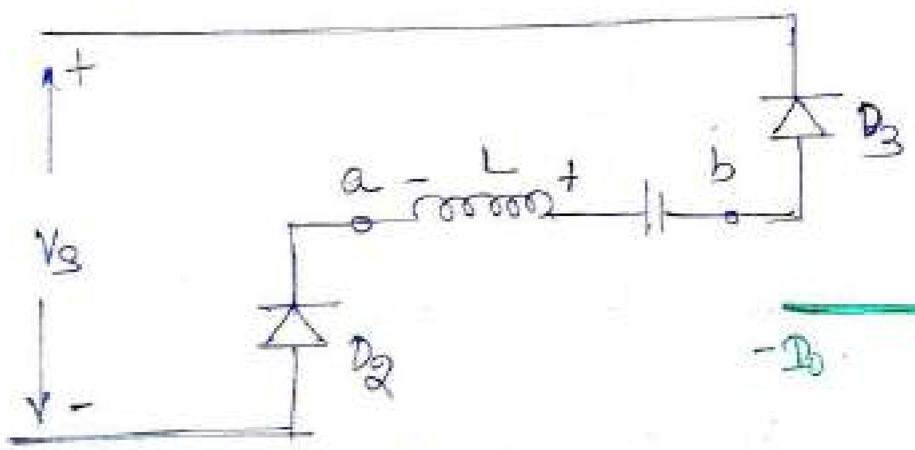
→ O/p current $I_0 = +ve$

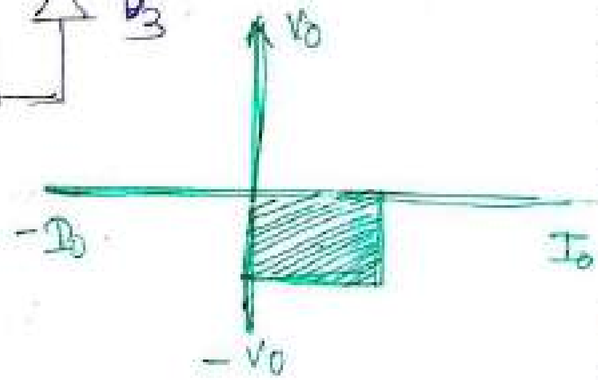
o/p voltage $V_0 = +ve$ $\begin{cases} a \rightarrow +V_s \\ b \rightarrow -V_s \end{cases}$

→ During this inductor get energised and stores energy the polarity of inductor be (+ᴗᴗᴗ−).

CH1 : OFF
CH4 : OFF

4th Quadrant operation.





→ current direction be

$L \rightarrow E \rightarrow D_3 \rightarrow +V_s \rightarrow -V_s \rightarrow D_2 \rightarrow L$

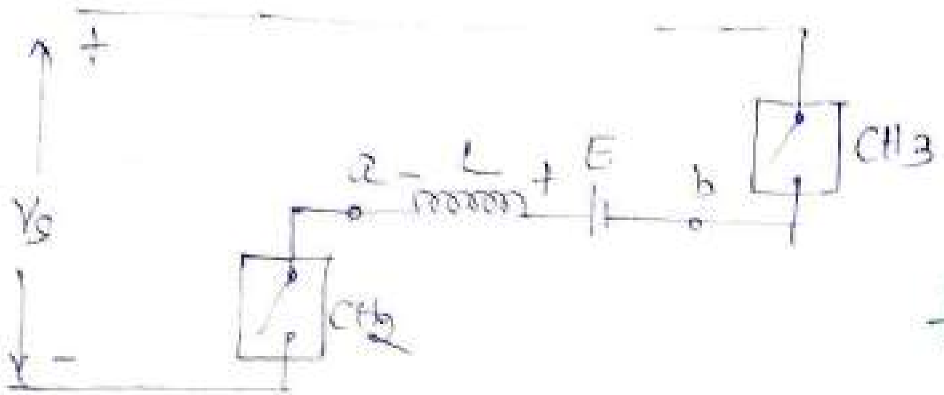
→ O/p current $I_0 = +ve$

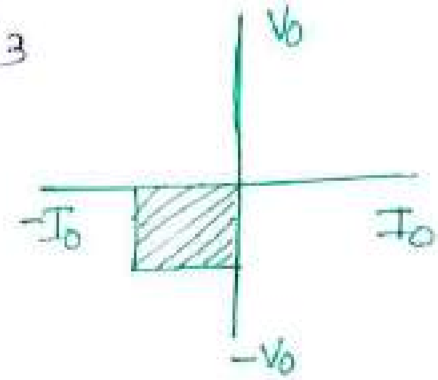
o/p voltage $V_0 = -ve$ $\begin{cases} a \rightarrow -V_s \\ b \rightarrow +V_s \end{cases}$

→ During this energy stored by the inductor get released
the diode. polarity of inductor be (−ᴗᴗᴗ+).

CH_2 : ON
CH_3 : ON

3rd Quadrant operation





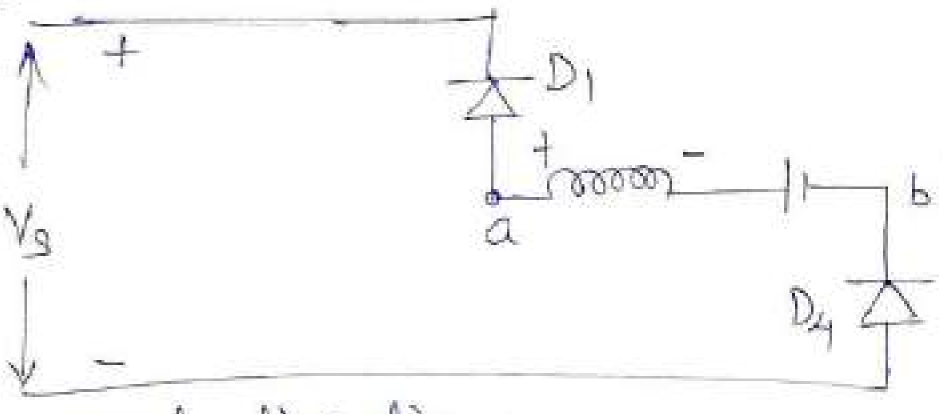
→ Current direction
$+V_s \to CH_3 \to E \to L \to CH_2 \to -V_s$

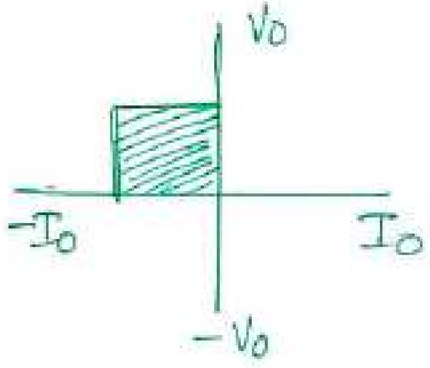
→ during this inductor gets energised and stores energy and the polarity of the inductor be (- ⌇⌇⌇ +)

→ o/p current $I_0 = -ve$
o/p voltage $V_0 = -ve$ $\begin{cases} a \Rightarrow -V_s \\ b \to +V_s \end{cases}$

CH_2 : OFF
CH_3 : OFF

2nd Quadrant operation





→ current direction $L \to D_1 \to +V_s \to -V_s \to D_4 \to L$

→ Energy stores by the inductor get released through the diode and the polarity of inductor will change (+ ⌇⌇⌇ -)

→ o/p current $I_0 = -ve$
o/p voltage $V_0 = +ve$ $\begin{cases} a = +V_s \\ b = -V_s \end{cases}$

→ The DC supply is short circuited if chopper CH1 & CH4 and CH2 & CH3 is simultaneously switched on.

→ When the chopper works in first and third quadrant, the output voltage is always less then the input voltage resulting it is step down type chopper.

→ When the chopper works in second and fourth quadrant the output voltage is always greater than the input voltage resulting it is step up chopper.

Ch-3

INVERTERS :→

A device that converts dc power into ac power at desired output voltage and frequency is called an inverters.

Application :→

→ Adjustable speed ac drives
→ induction heating
→ stand by air craft power supplies
→ UPS for computers
→ HVDC Transmission line

Types of Inverters :→

① According to the source of inverter
(i) Current source inverter
(ii) voltage source inverter

② According to the types of load
(i) 1-ϕ Inverter → Half bridge
→ Full bridge
(ii) 3-ϕ Inverter → 180° conduction mode
→ 120° conduction mode

③ According to the output characteristics
(i) square wave Inverter
(ii) Sine wave Inverter
(iii) Modified sine wave Inverter

④ According to the Number of output level
(i) Regular Two level Inverter

(5) According to different PWM technique

(i) Simple pulse width Modulation (SPWM)

(ii) Multiple pulse width modulation (MPWM)

(iii) Sinusoidal pulse width modulation (SPWM)

(iv) Modified Sinusoidal pulse width modulation (MSPWM)

(6) According to the connection

(i) Bridge inverters

(ii) Series Inverters

(iii) Parallel Inverters

(7) Multilevel Inverters

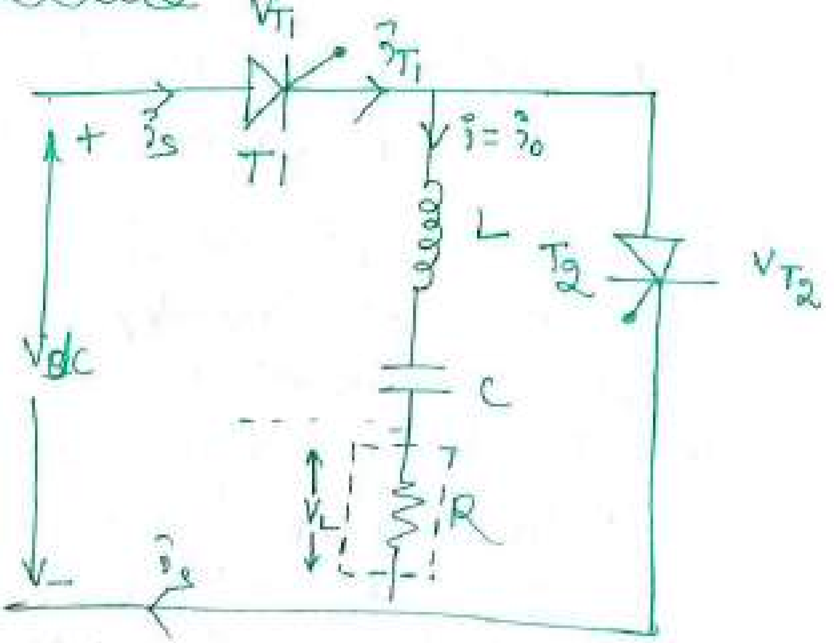
→ Flying Capacitor Inverter

→ Diode clamped Inverter

→ Hybride Inverter

→ cascade H-type Inverter

Series Inverter :⇒



→ Commutation Circuit remais permanently connected in series with the Load.

→ RLC underdamped Circuit

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

→ damped oscillation

$$i = I_P e^{-\xi \omega n t} \sin(\omega_d t)$$

→ A series inverter employs class-A commutation since the current decays to zero naturally by Load commutation but not by forced commutation.

→ In Circuit diagram inductor (L) and capacitor (C) are commutating components, T_1 & T_2 are two thyristors that conductor for positive and negative half-cycle of Load current.

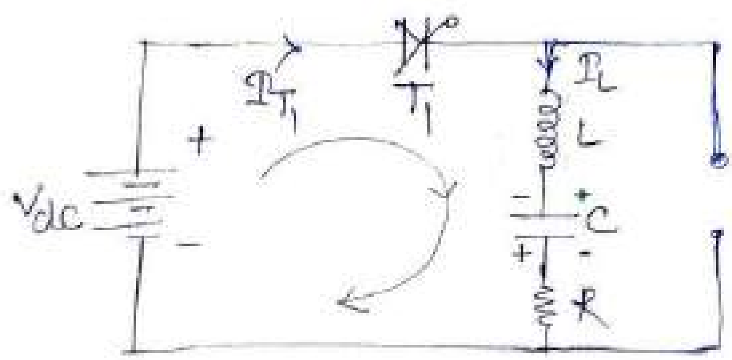
→ series inverter are capable of producing the output waveform ranging from 200Hz to 100 kHz frequencies.

Mode-I T_1: ON, T_2: OFF

→ T_1 is triggered at instant $t = t_0$

→ the Load current flows through the path

$$+V_{dc} \rightarrow T_1 \rightarrow L \rightarrow C \rightarrow R \rightarrow -V_{dc}$$



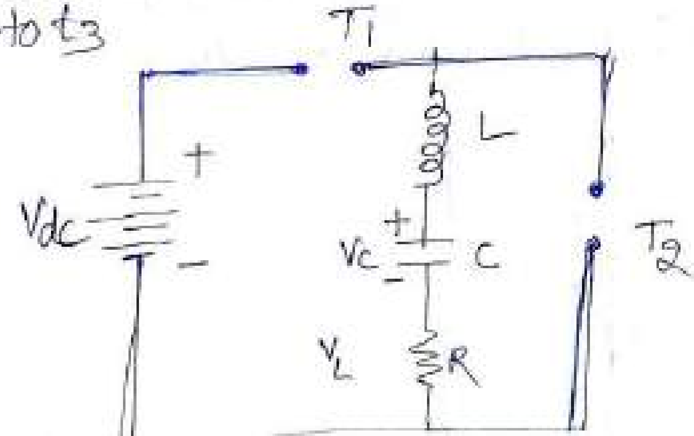
→ Initially, the capacitor is charged to a negative voltage $-V_c$ but once T_1 is triggered capacitor starts charging to positive voltage with upper plate positive and lower plate negative. As the current increases and reaches its positive maximum value, the voltage across the capacitor becomes equal to supply voltage V_{dc}.

→ Now the current starts decreasing after reaching its positive maximum value but the voltage across the capacitor does not decreases. Instead of decreasing it increases further and reaches a value higher than V_{dc} and the capacitor retains this voltage for some time.

→ At $t = t_2$ T_1 is turned OFF when the current reaches zero by natural commutation, but still the capacitor holds the voltage $(V_c + V_{dc})$ in it.

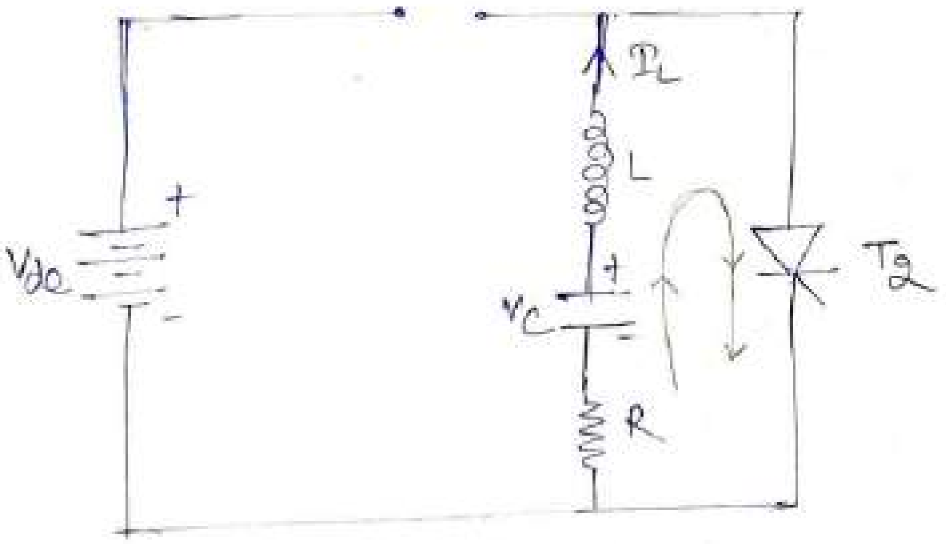
Mode-II T_1: OFF T_2: OFF

→ This mode starts from t_2 when T_1 is commutated and it remains in OFF state for a sufficient period of time (t_2 to t_3) as shown in the waveform. Hence in this mode both T_1 & T_2 are in OFF state and the capacitor voltage is maintained at a constant value of $(V_c + V_{dc})$ and the load current I_L remains zero in this mode i.e from t_2 to t_3

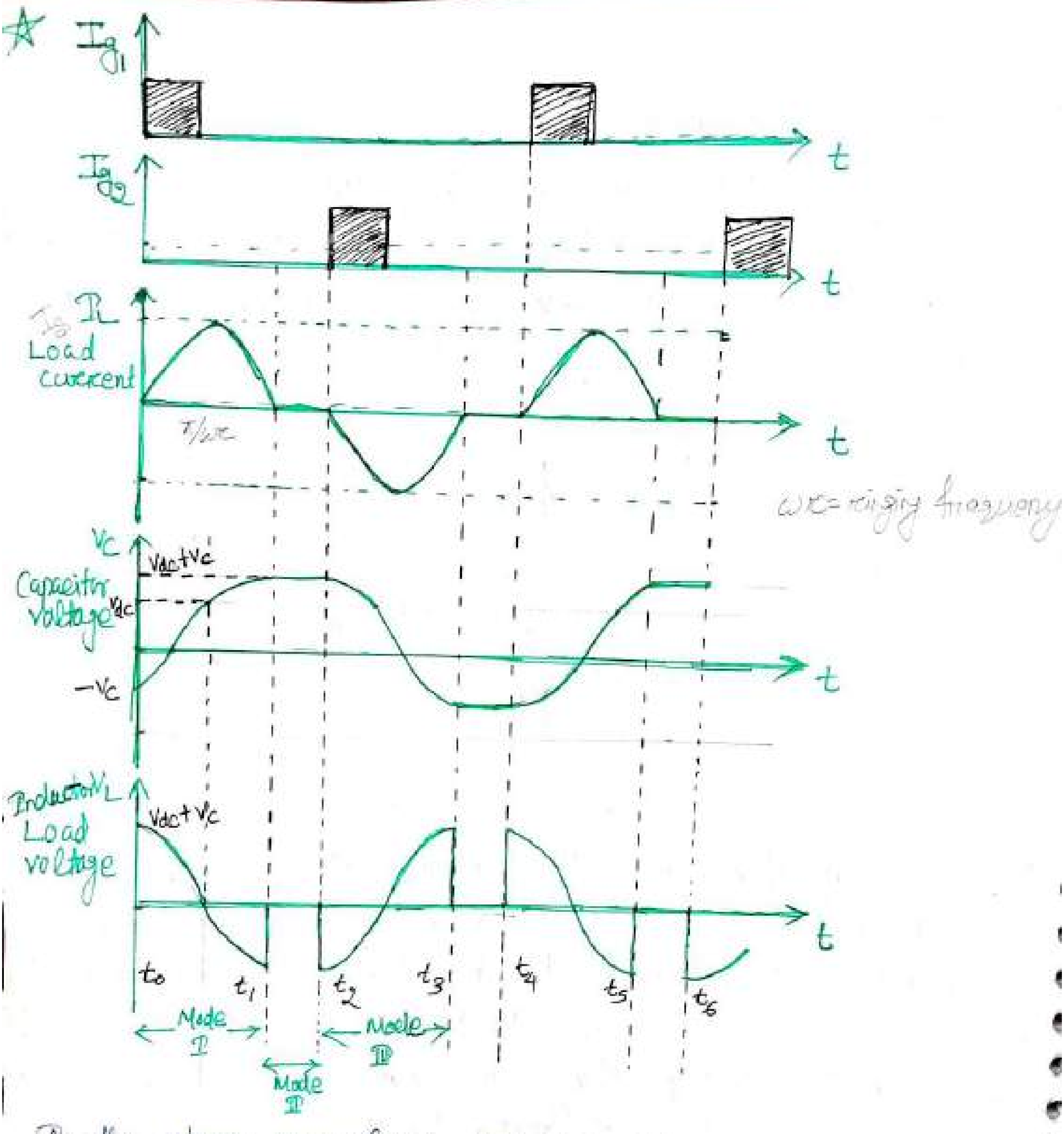


Mode-II T_1: OFF T_2: ON

In this mode of operation T_2 is triggered at instant t_3 since the positive polarity of the capacitor appears across the anode of T_2 and it starts conducting. T_2 conducts, the load current starts flowing in the negative direction through the path $C^+ \rightarrow L \rightarrow T_2 \rightarrow R \rightarrow C^-$.



Now the capacitor starts discharging and the Load current I_L flows in the reverse direction and reaches its negative maximum value, then load current starts decreasing and becomes zero at t_3, due to this T_2 gets turned OFF at t_3. Then after capacitor again charges to negative voltage $-V_C$ as shown in wave form. Again after maintaining a certain amount of time delay T_1 is triggered and the cycle repeats.



In the above waveforms, we can observe that the positive half cycle of the load current is exactly equal to the negative half cycle of load current since the capacitor stores charge during one half cycle and release the equal charge in the next half cycle.

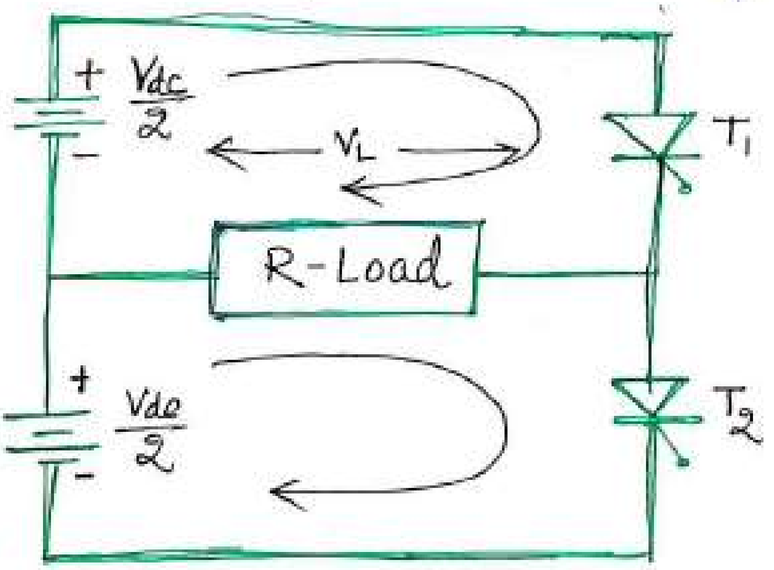
Bridge Inverter :-

① Half Bridge Inverter :-

(i) R-Load :-

→ Bridge inverter are basically voltage source inverters that consists of small impedance in the input dc voltage source.

→ In half bridge inverter only two thyristors are used to convert dc power into ac power.



→ The circuit diagram of 1-ϕ half bridge inverter with resistive load shown in the figure.

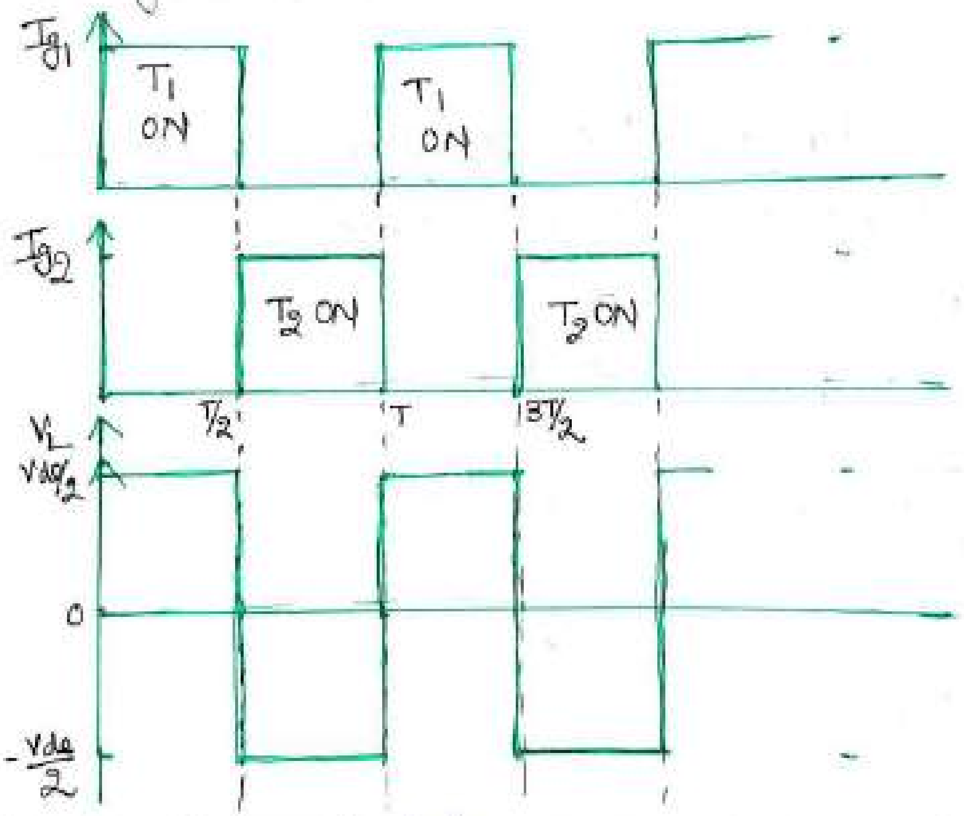
→ The input to the inverter given from a split dc power supply.

→ The components T_1 & T_2 are gate triggered thyristors that produce positive and negative half cycles of the ac power at the output side.

→ The working of the half bridge inverter is divided into two periods

- $0 \le t \le T/2$: T_1 will conduct
- $T/2 \le t \le T$: T_2 will conduct

→ The circuit operation should be in such a way that both the thyristors should not conduct at the same time.



→ During the interval between 0 and $T/2$, T_1 is triggered and the instantaneous voltage across the load will be $\frac{V_{dc}}{2}$ at the instant $t = T/2$, the triggering pulses are removed for T_1 due to which it is turned OFF.

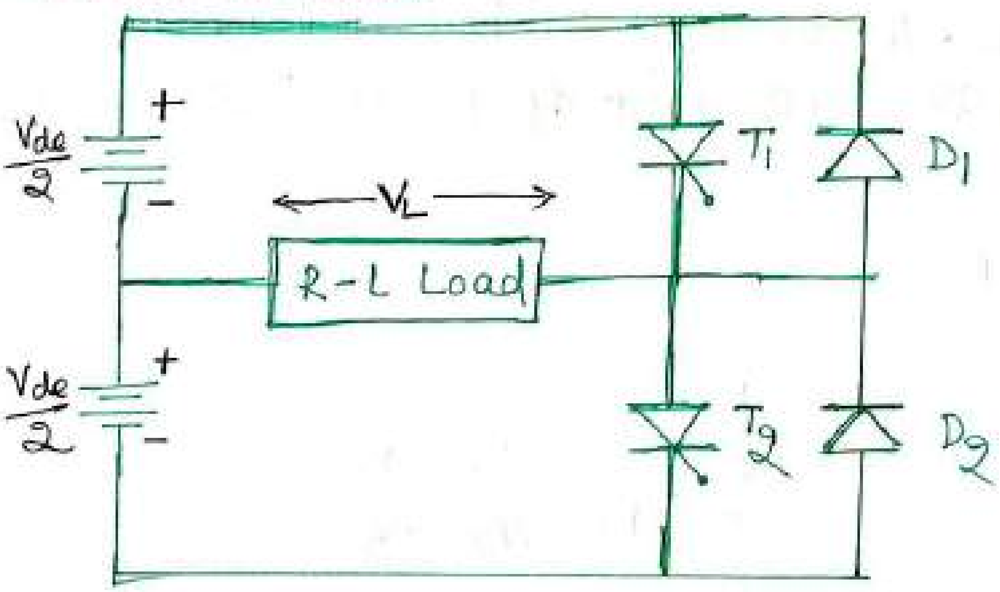
→ Also at the same instant i.e at $t = T/2$ pulses are given to T_2 and thus it is turned ON at $t = T/2$. During the interval between $T/2$ and T, T_2 which turned ON conducts and the voltage across the load will be $-\frac{V_{dc}}{2}$.

→ Again thyristor T_1 is triggered at $t = T$ and T_2 is turned OFF. Hence in this way the cycle repeats.

→ T_1 conduct for $(0 - T/2)$ and produce +ve half cycle
T_2 conduct for $(T/2 - T)$ and produce -ve half cycle.

→ The triggering pulses applied for both thyristors differ in phase by 180°. The frequency of the output wave is given by $(1/T)$. By changing the value of T, the frequency as well as the magnitude of output voltage can be controlled.

(ii) R-L Load :-



Here two thyristor with 2 antiparallel diode D_1 & D_2 are connected.

Reference

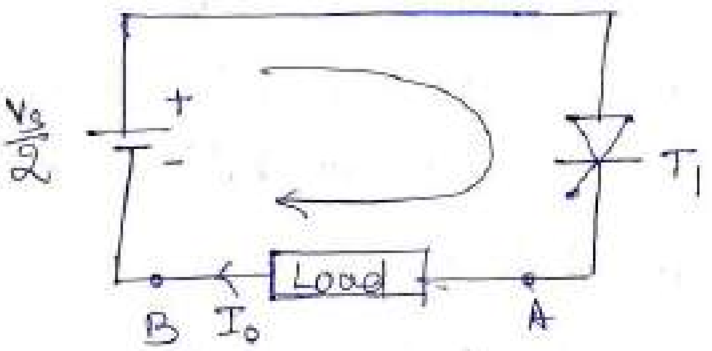
$I_0 = +ve$ ←

$I_0 = -ve$ →

$$\left.\begin{array}{l} A \rightarrow +\frac{V_s}{2} \\ B \rightarrow -\frac{V_s}{2} \end{array}\right\} V_0 = +ve$$

$$\left.\begin{array}{l} A \rightarrow -\frac{V_s}{2} \\ B \rightarrow +\frac{V_s}{2} \end{array}\right\} V_0 = -ve$$

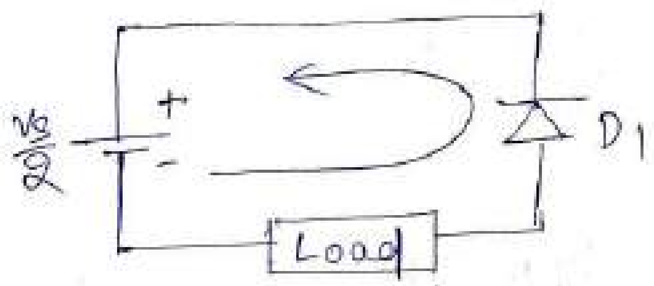
Mode-I T_1: ON



$I_0 = +ve$
$V_0 = +ve$

Thyristor T_1 is turned on at instant t_1, at this instant the voltage at the load will be equal to $-V_{dc}/2$ and positive load current increases. This load current increases till the T_1 is turned off. At this instant t_2 T_1 is turned off and the load current reaches the maximum value. As the load voltage and load current both are having the same polarity, the load stores the energy in it.

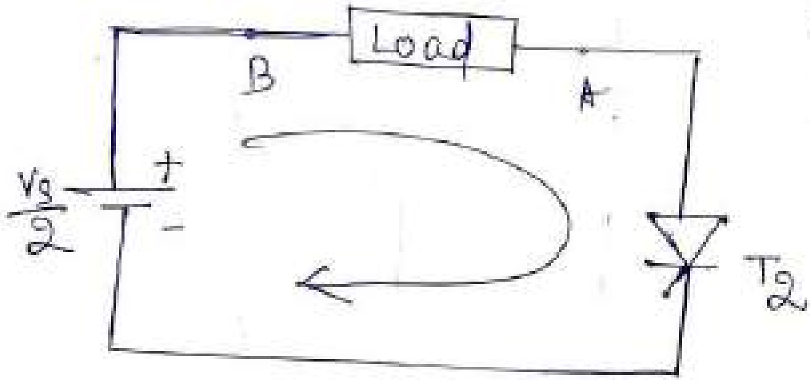
Mode-II D_1: ON



$I_0 = -ve$
$V_0 = +ve$.

The load current will maintain its direction even after turning off the T_1. This is due to the inductive load and this inductive load will develop a negative induced voltage which in turn makes the D_2 to forward biases. Thus the energy stored by the load is now feedback to the source through the lower half of the supply and D_2 shown in fig.

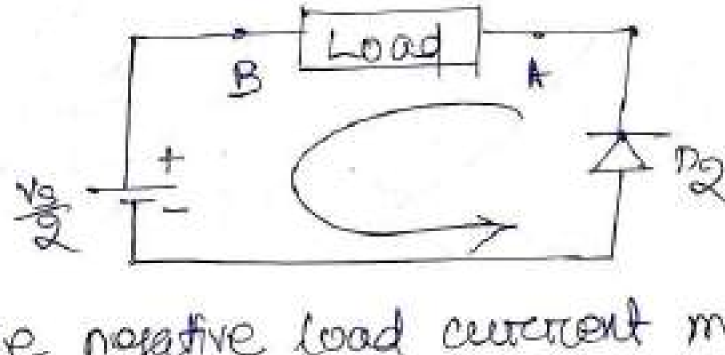
Mode-III T_2: ON



$V_0 = -ve$
$I_0 = -ve$

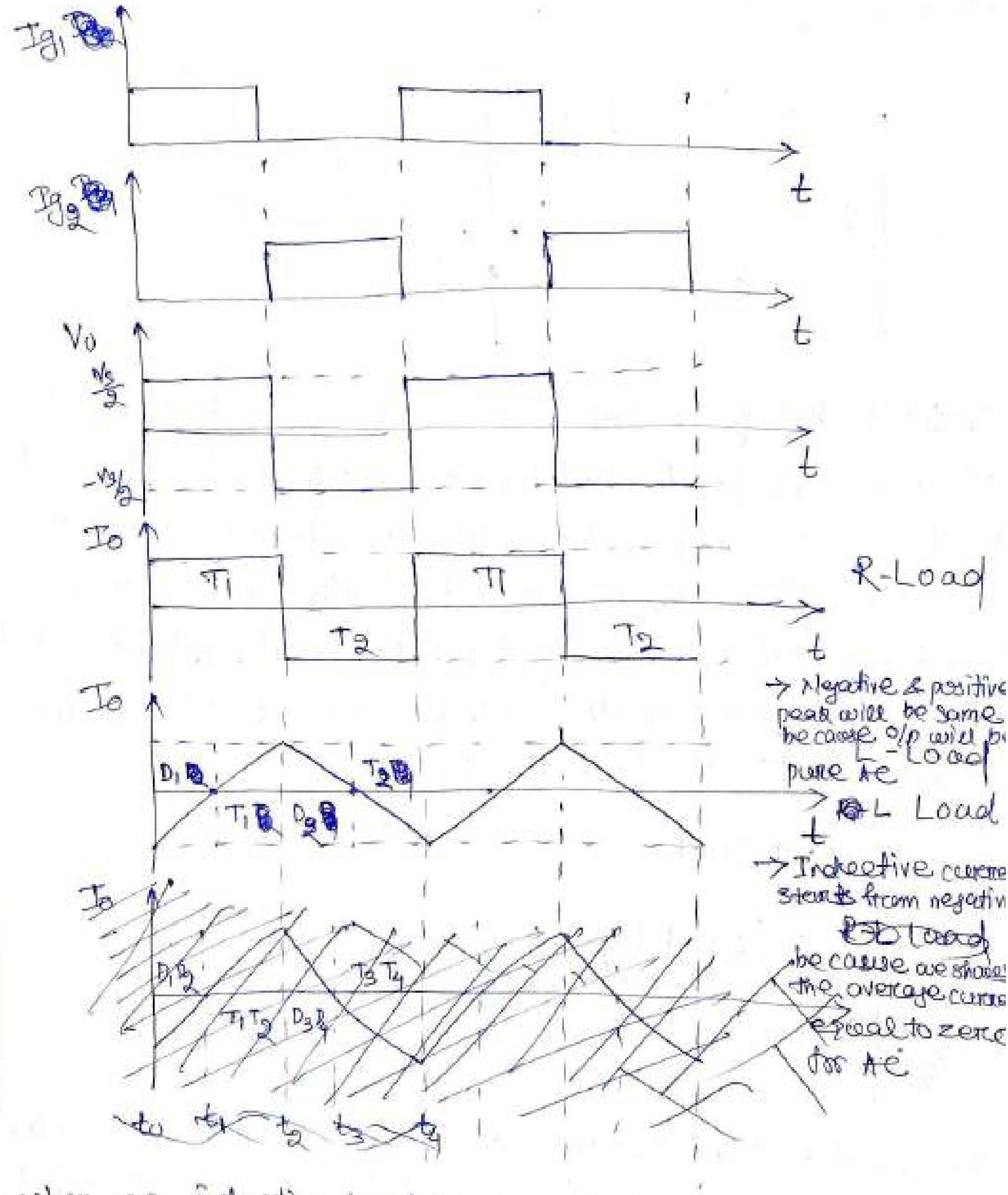
In this mode T_2 is ON at an instant t_3. At this instant the inductive load stored energy will be transferred to the lower half of the supply and becomes zero. Now the load voltage will be equal to $-V_{dc}/2$ and also the load current will be negative. The negative load current reaches maximum value till T_2 is turned OFF. At the instant t_4, T_2 is turned OFF.

Mode-IV : D_2: ON



$V_0 = -ve$
$I_0 = +ve$

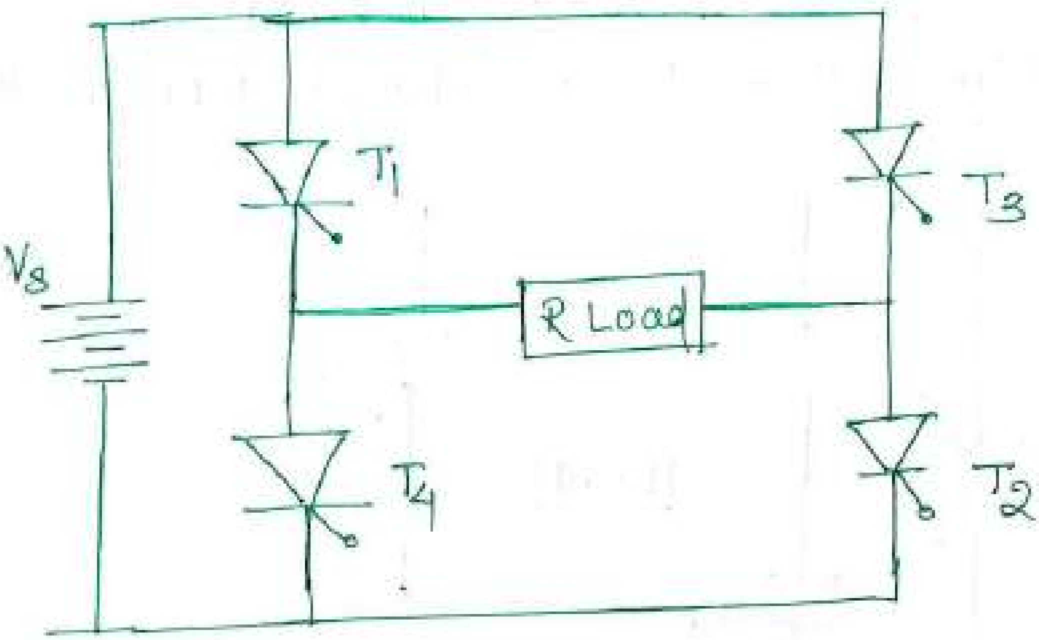
The negative load current maints its direction even after turning off the T_2. This is due to inductive load and the inductive load will now develop inductive voltage which in turn makes the load current flows through the upper half of the supply and diode D_1. thus the energy stored by the load is now fed back to the source and the load voltage changes its polarity.



when an inductive load is connected to the inverter, the load current lags behind the voltage. In order to provide a path for load current when the thyristor are turned off, diodes are connected in antiparallel with the thyristor. thus stored energy due to inductive load is fed back to the dc source through diodes and hence they are called feedback diodes.

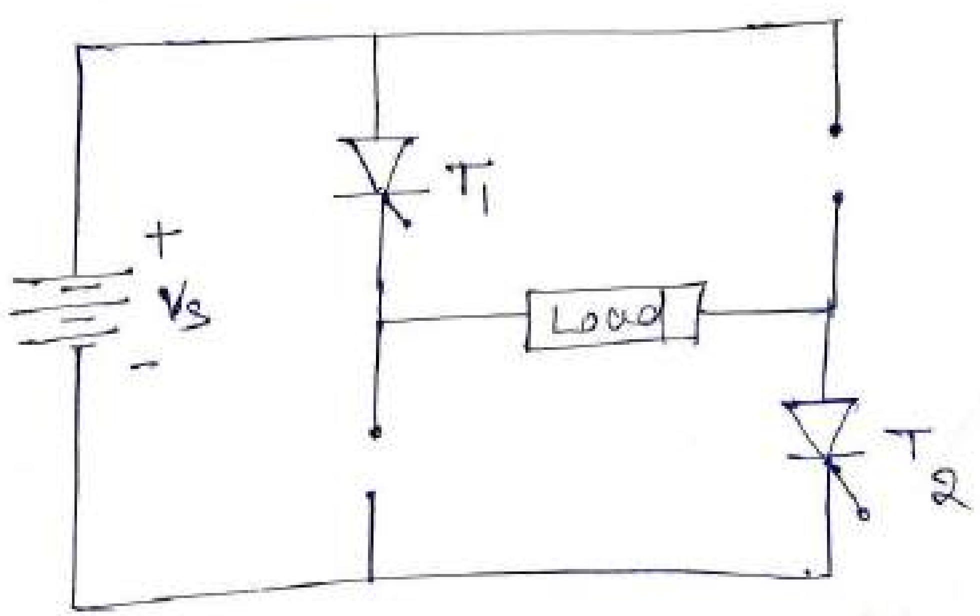
② Full Bridge Inverter →

(i) R-Load :-



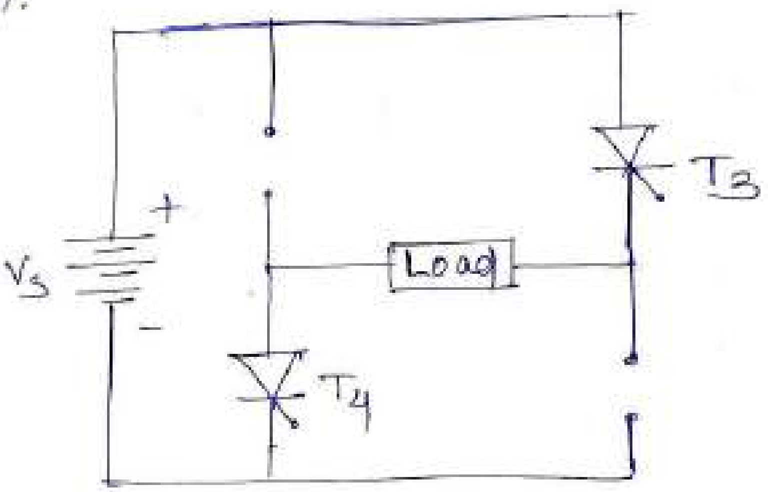
Mode-I

During the interval between 0 and T/2 i.e for $0 \le t \le T/2$ T_1 & T_2 are triggered and they start conducting, when T_1 & T_2 are turned ON, the load voltage follows the positive source voltage V_{dc}. At the instant $t = T/2$ the triggering pulses are removed for both T_1 & T_2 and are turned off.

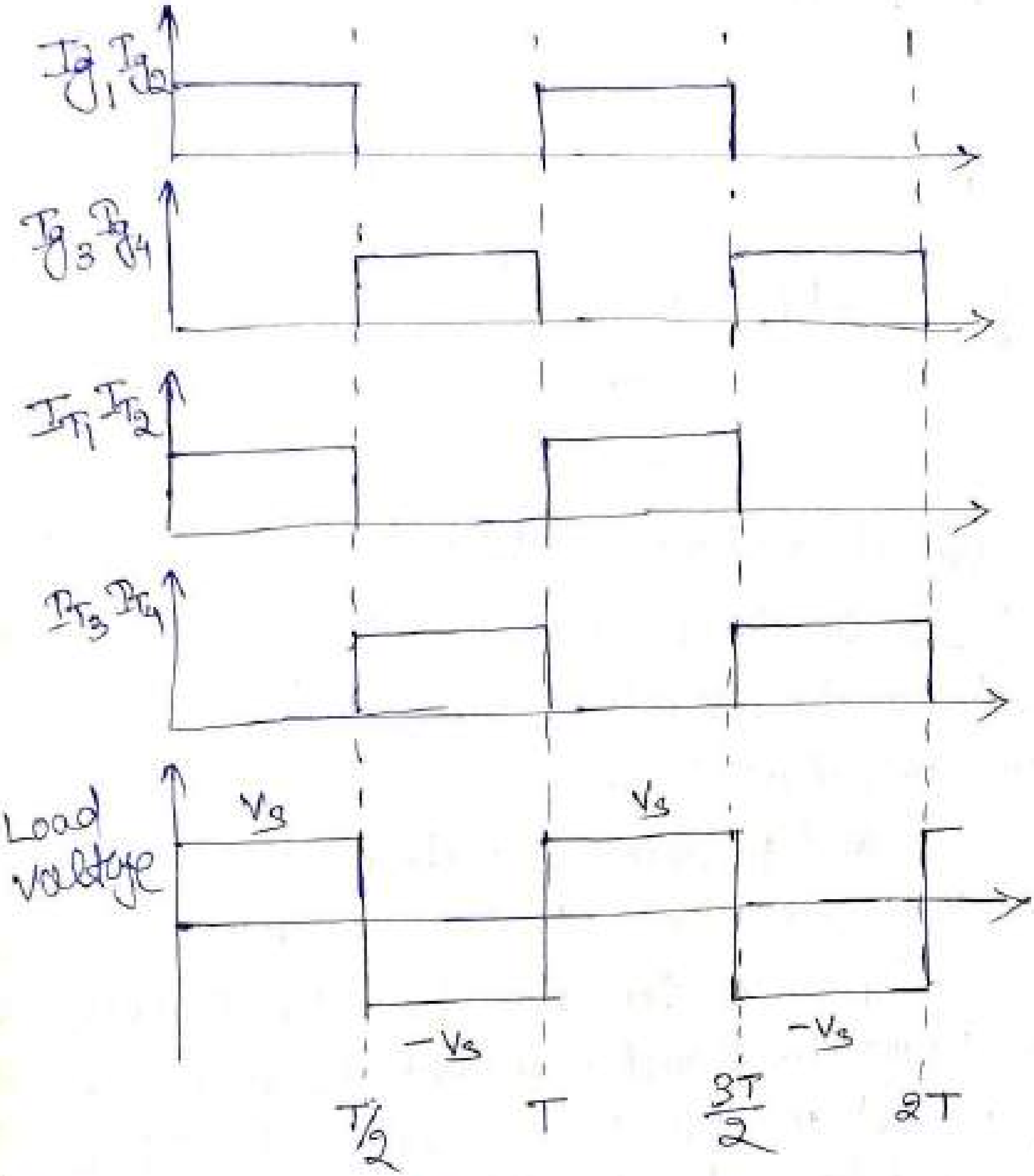


Mode-II

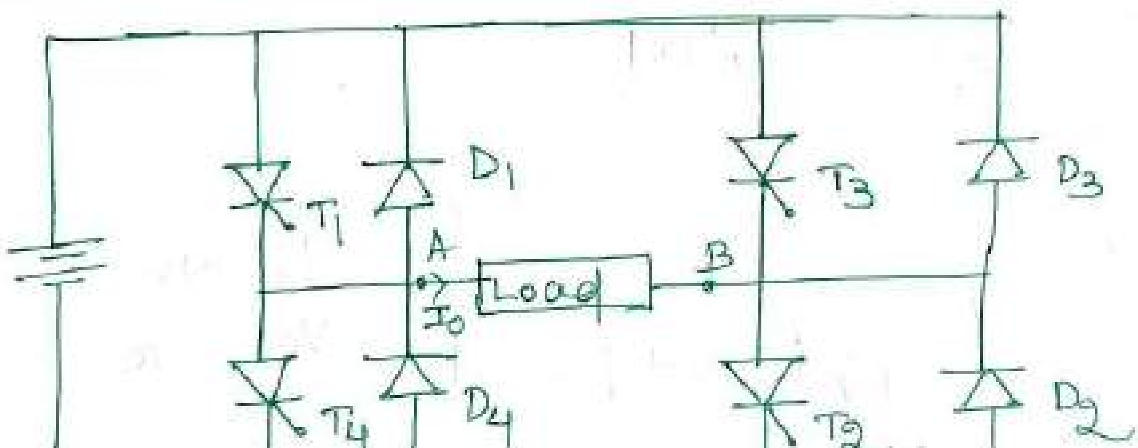
At the same time i.e at $t = T/2$ when T_1 and T_2 get turned off, the triggering pulses are given to T_3 & T_4. This pair will conduct for the interval between $T/2$ and T and the load voltage follows the negative source voltages $-V_S$ as shown.



$T_3 . T_4$ conducts untill thyristor pair T_1 & T_2 have triggered again at $t = T$ and the cycle repeats. The below shows the waveforms of gating signals output voltage and current of thyristors and diodes since the load is assumed to be purely resistive the load current will be equal to load voltage



(ii) RL Load :-



Reference

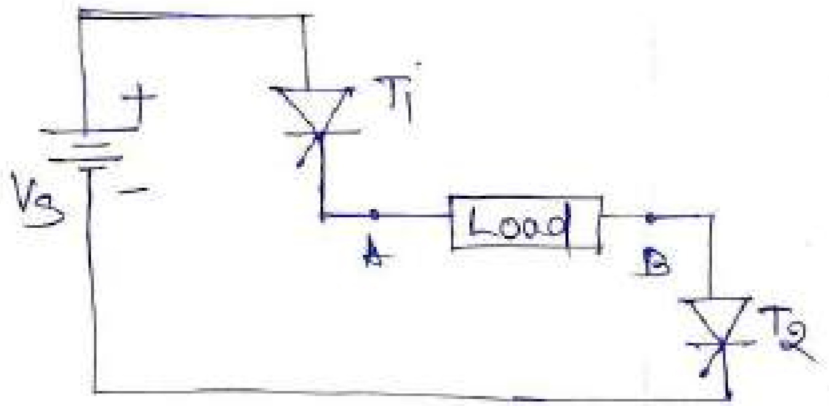
$I_0 = +ve$ $\longrightarrow$

$I_0 = -ve$ $\longleftarrow$

$\left.\begin{array}{l} A \rightarrow +V_s \\ B \rightarrow -V_s \end{array}\right\} v_0 = +ve$

$\left.\begin{array}{l} A \rightarrow -V_s \\ B \rightarrow +V_s \end{array}\right\} v_0 = -ve$

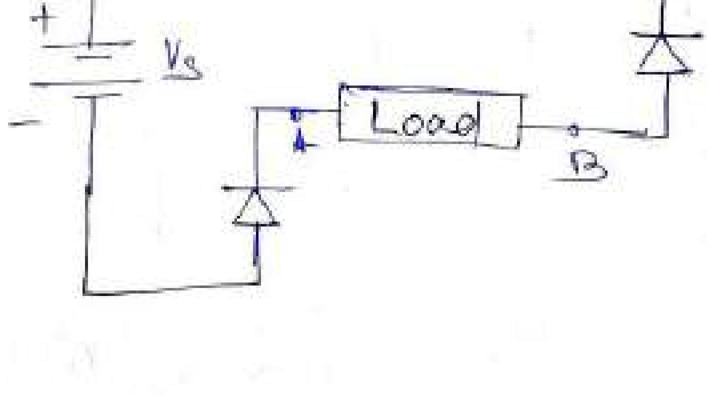
Mode-I T_1: ON T_2: ON



I_0 = +ve
V_0 = +ve

T_1, T_2 are trigged at instant $t = t_0$ but these thyristors will not turned ON as these are reversed biased by the self induced negative voltages across the inductive Load. Due to this negative load current diode D_1 and D_2 are forward biased and provide a path to feed it back to the source. the thyristors T_1 T_2 will start conducting from $t = t_1$ once the negative load current becomes zero. Again the load current flows in the positive direction and increases from zero to I_{max} and load voltages follows the positive source voltages V_S.

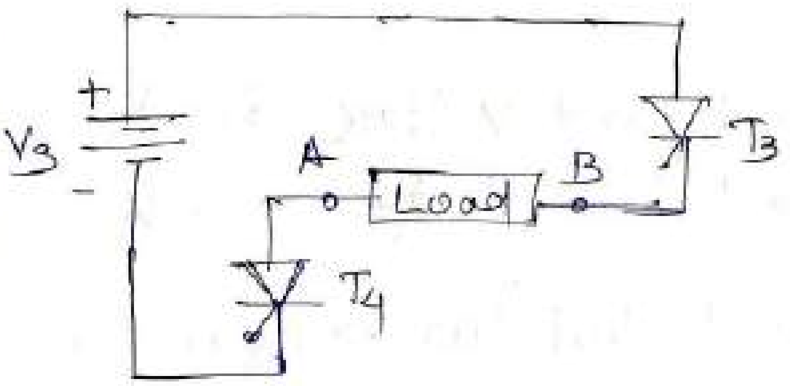
Mode-II D_3: ON D_4: ON



I_0 = +ve
V_0 = -ve

At instant $t = t_2$ the triggering pulses are removed from T_1 & T_2 and are given to T_3, T_4. Now T_3 & T_4 are triggered but these thyristors will not conduct as these are reverse biased by the self induced positive voltages across the inductive load. The inductive load develops a large voltage by releasing its stored energy in Mode-I. Due to this diodes D_3 & D_4 are forward biased and the positive load current is fed back to the supply through diodes D_3 & D_4 as shown.

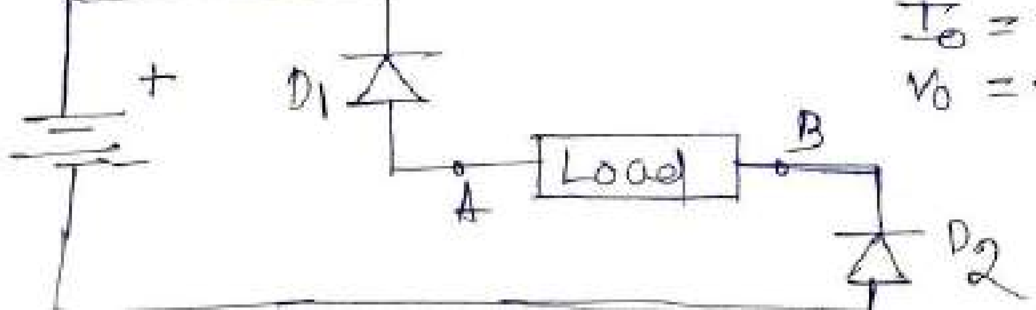
<u>Mode-III</u> <u>T_3: ON T_4: ON</u>



$I_o = -ve$
$v_o = -ve$

· At t_3 the stored energy in the inductor becomes zero. Hence thyristors T_3 & T_4 start conducting and the load current start flowing in negative direction through the path shown in fig and increases from zero to $-I_{max}$.

<u>Mode-IV</u> <u>D_1: ON D_2: ON</u>



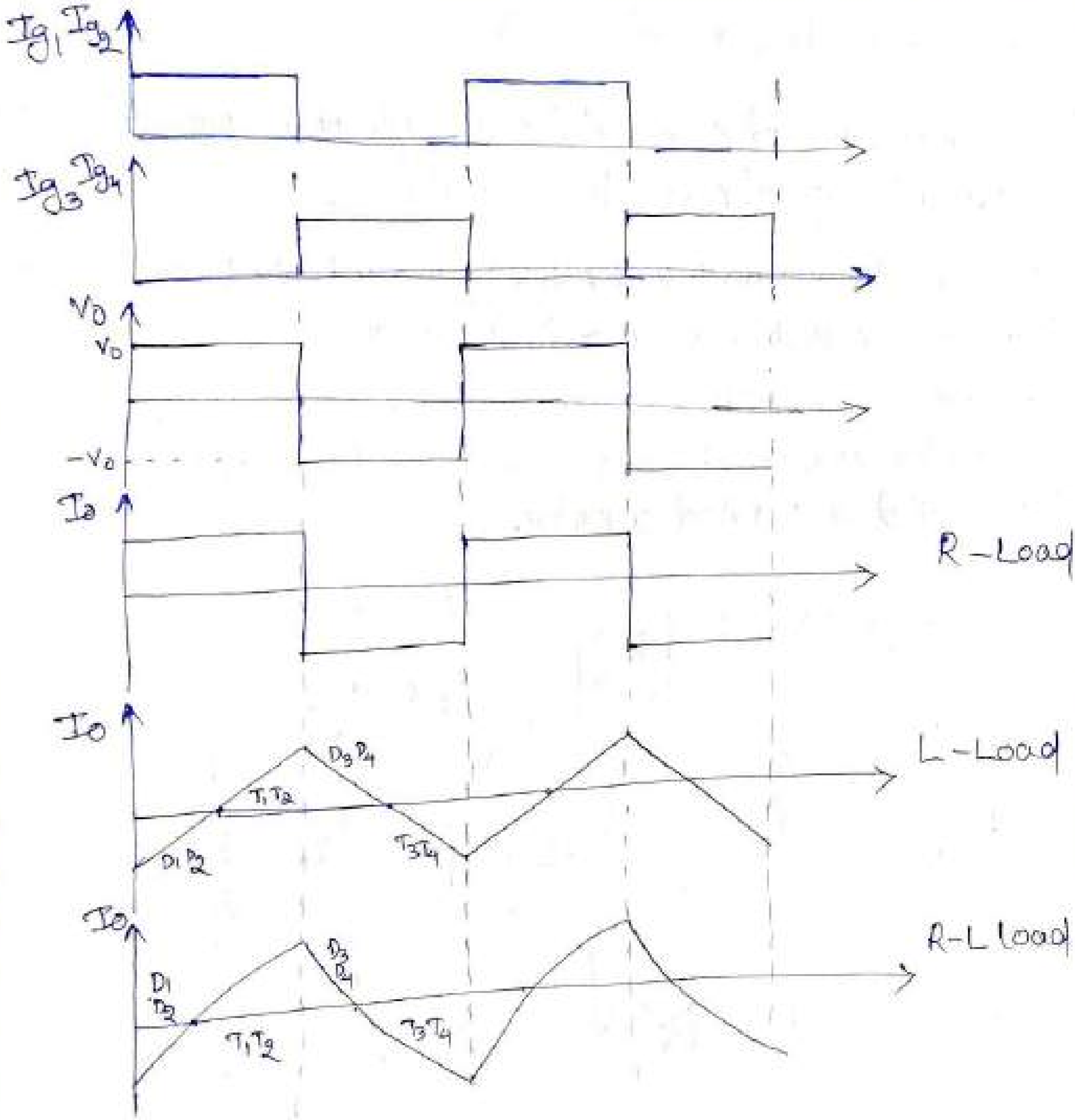
$I_o = +ve$
$v_o = +ve$

at t_4 the triggering pulses are removed from T_3, T_4 and given to T_1, T_2 but T_1, T_2 don't start conducting due to inductive load which does not allow a sudden change in current. Thus the load current doesn't becomes zero instantaneously and it starts releasing stored energy in mode-III through diodes D_1 & D_2 as shown in fig.

At $t = t_5$ the load current due to inductance becomes zero, thyristors T_1, T_2 will start conducting. From t_5 the cycle repeats i.e. the whole operation from mode-I to mode-IV will repeat.

→ when T_1 & T_2 conduct load voltage is $\underline{V_s}$
when T_3 & T_4 conduct load voltage is $-V_s$

→ It should be ensured that two SCRs in the same branch do not conduct simultaneously as this would lead to a direct short circuit of the source.

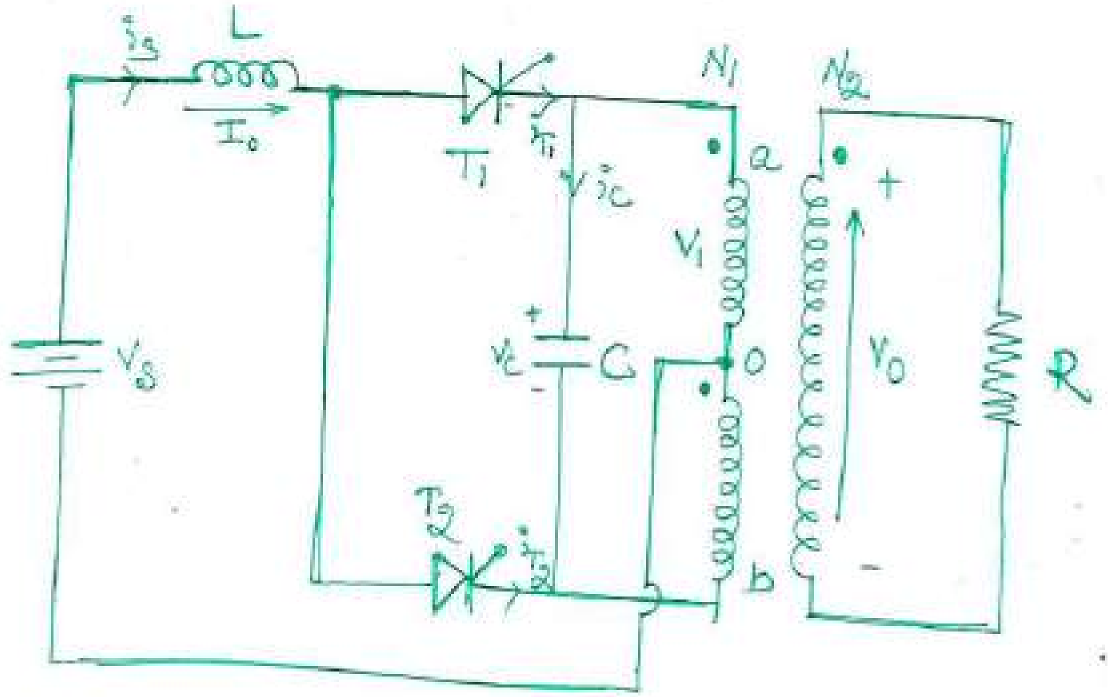

$Ig_1\ Ig_2$
$Ig_3\ Ig_4$
V_0
V_0
$-V_0$
I_0
R-Load
I_0
$D_3\ D_4$
$T_1\ T_2$
$D_1\ D_2$
$T_3\ T_4$
L-Load
I_0
$D_3\ D_4$
$D_1\ D_2$
$T_1\ T_2$
$T_3\ T_4$
R-L load

Parallel Inverter :→

→ The basic inverter circuit for a single phase parallel inverter utilizing capacitor for its commutation.

→ It consists of two thyristor T_1 & T_2 and inductor L, an output transformer and a commutating capacitor C.

→ during the working of this inverter, capacitor C comes in parallel with the load via the transformer. that is why it is called a parallel inverter.

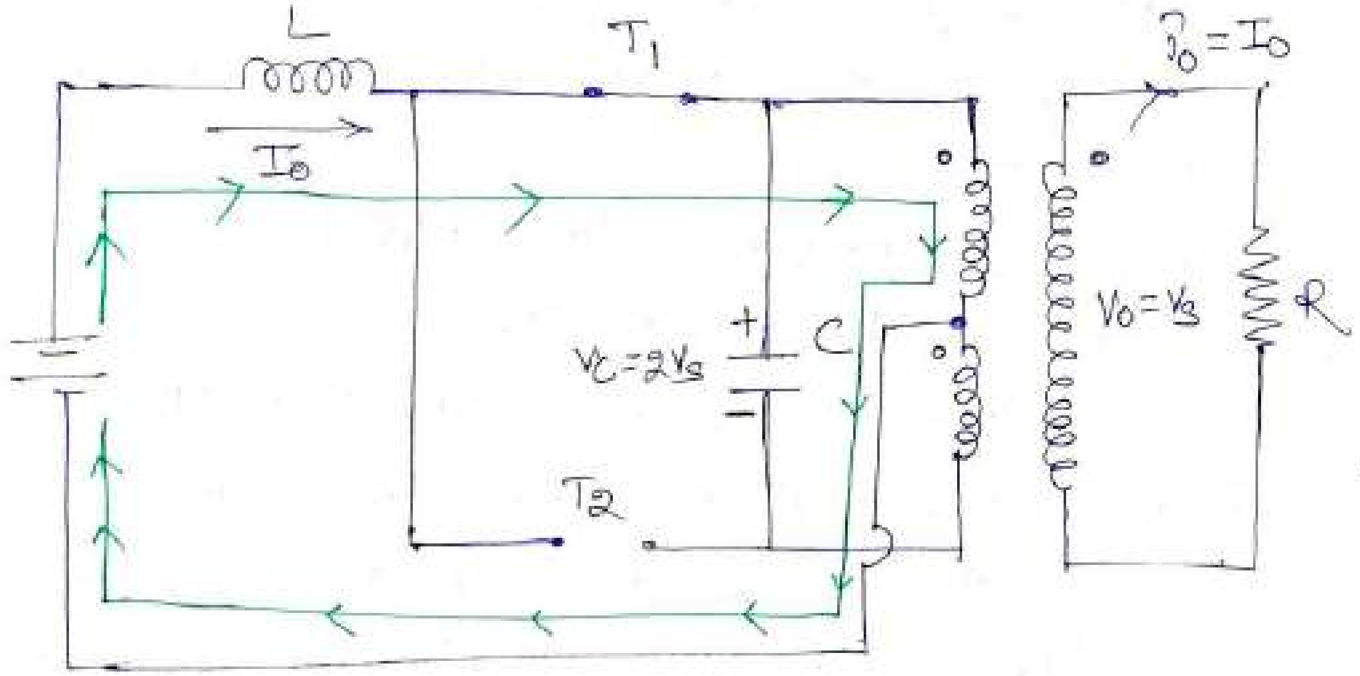


Mode-I

In the mode thyristor T_1 is conducting and current flows in the upper half of primary winding. thyristor T_2 is off. this current establishes magnetic flux that links both the halves of primary winding. As a result an emf V_s is induced across upper as well as lower half of primary winding. In other words total voltage across primary winding is $2V_s$. This voltage charges the commutating capacitor C to a voltage of $2V_s$ with upper plate positive as shown in fig below.

→ steady state current I_0 flows through
$V_s \rightarrow L \rightarrow T_1 \rightarrow a \rightarrow 0 \rightarrow V_s$

$v_0 = V_s$ $\quad v_C = 2V_s$ $\quad i_0 = I_0$ $\quad v_{T_1} = 0$ $\quad i_C = 0$ $\quad i_{T_1} = I_0$



Mode-I $t<0$

Mode-II

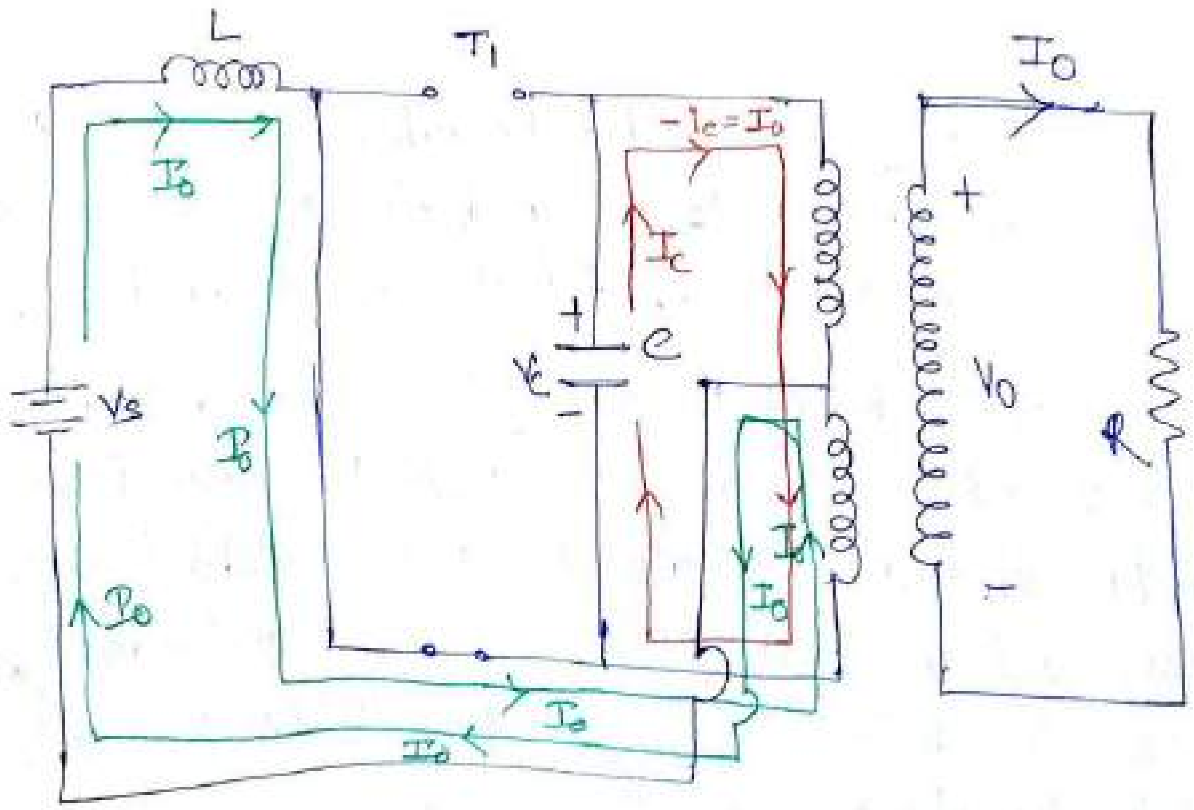
→ At time $t=0$ T_2 is turned on by applying a triggering pulse to its gate. At the time $t=0$ capacitor voltage $2V_s$ appears a reverse bias across T_1, it is therefore turned off.

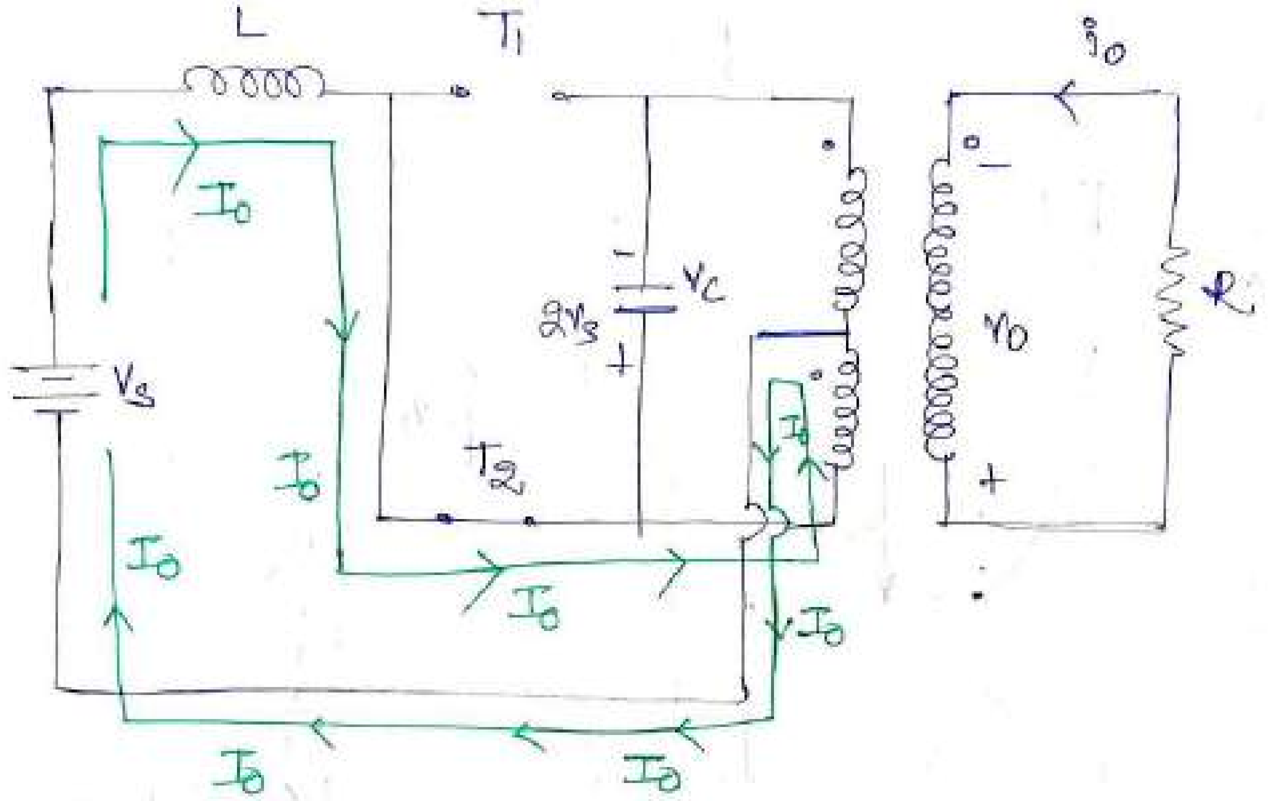
→ A current I_0 begins to flow T_2 lower half of primary winding V_s and L as shown in fig. At the same time capacitor voltage $2V_s$ is applied across the total transformer primary and a capacitor current $-i_C$ is established. Negative sign before i_C means that current i_C flow opposite to its positive direction.

→ Before T_2 is on i.e at $t=0-$, mmf in upper primary winding is $I_0 N_1$ and zero in the lower primary winding.

→ soon after T_2 is on i.e at $t=0+$ mmf linking both upper and lower halves can not change suddenly. therefore at $t=0+$, $-i_c = I_0$ such that mmf in the lower half remains zero and mmf in the upper half is equal to mmf at $t=0-$.

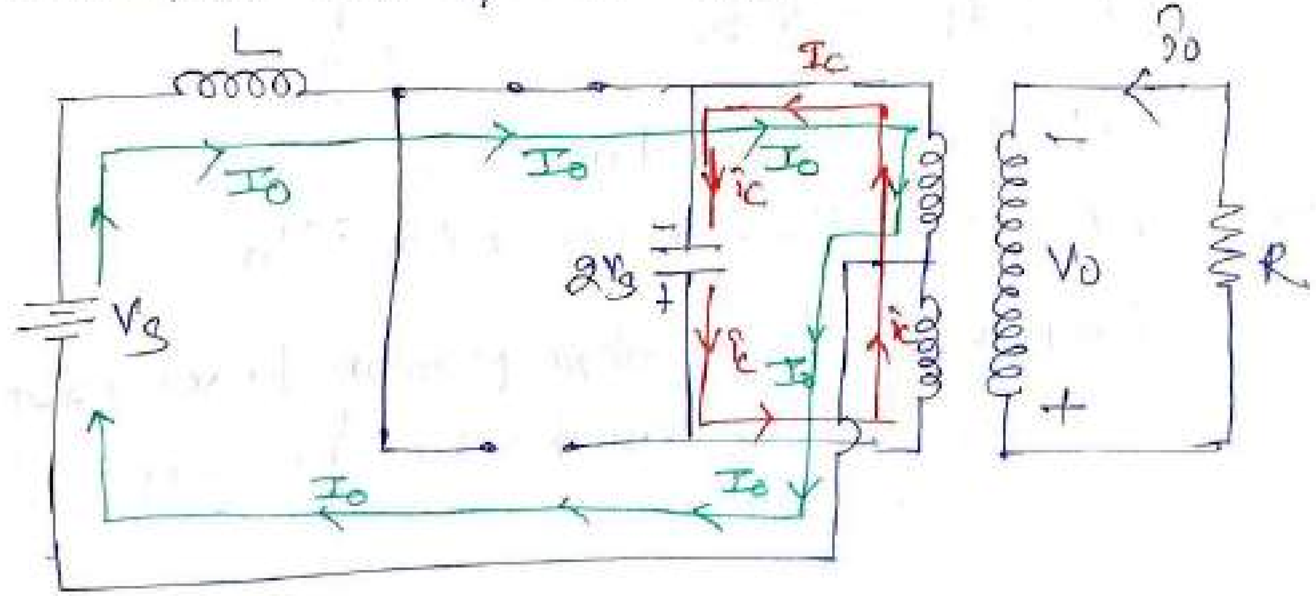
→ After $t=0+$ capacitor C discharges and current i_c is such that it supplies the load current i_0 and balances the primary and secondary ampere turns of the transformer. capacitor current continues flowing till capacitor has charged from $+2V_s$ to $-2V_s$ at time $t=t_1$. Load voltage also changes from V_s at $t=0$ to $-V_s$ at $t=t_1$.

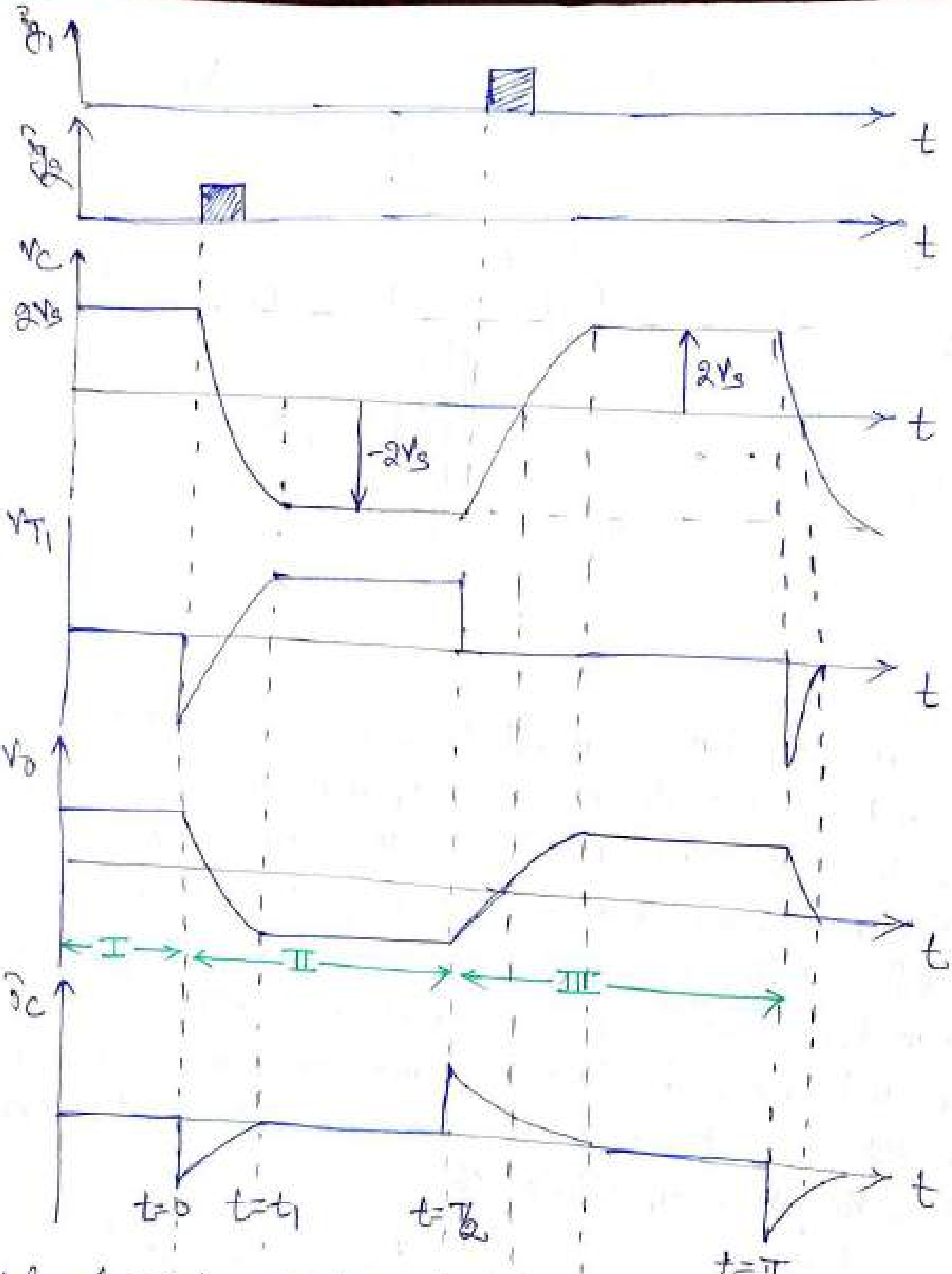




Mode-III

When capacitor has charged to $-2V_s$ with upper plate negative and lower plate positive, T_1 may be turned on at any time. T_1 is triggered at $t = T/2$. Capacitor voltage $2V_s$ applies a reverse bias across T_2, it is therefore turned off. After T_2 is off capacitor starts discharging as shown in fig. Current i_C is now positive. mmfs in the upper and lower halves remains unchanged from their values just before $T/2$. When i_C decays to zero $V_C = +2V_s$, $V_0 = V_s$, $i_{T_1} = I_0 = V/R$





At $t=0+$ when T_2 is turned on
$v_{T_1} = -2V_s$, $i_C = -I_0$, $i_{T_1} = 0$ and $i_{T_2} = I_0$

As the turns ratio from whole primary to secondary winding is 2 the load voltage has half the amplitude of the capacitor voltage.

Cycloconverters

(A device which converts input power at one frequency to output power at a different frequency with one-stage conversion is called a cycloconverter.)

→ A cycloconverter is thus a one stage frequency changer.

→ Cycloconverters are two types

(i) step down cycloconverter. ($f_0 < f_s$)

(ii) step up cycloconverter. ($f_0 > f_s$)

Applications

(i) Speed control of high power ac drives

(ii) Induction heating

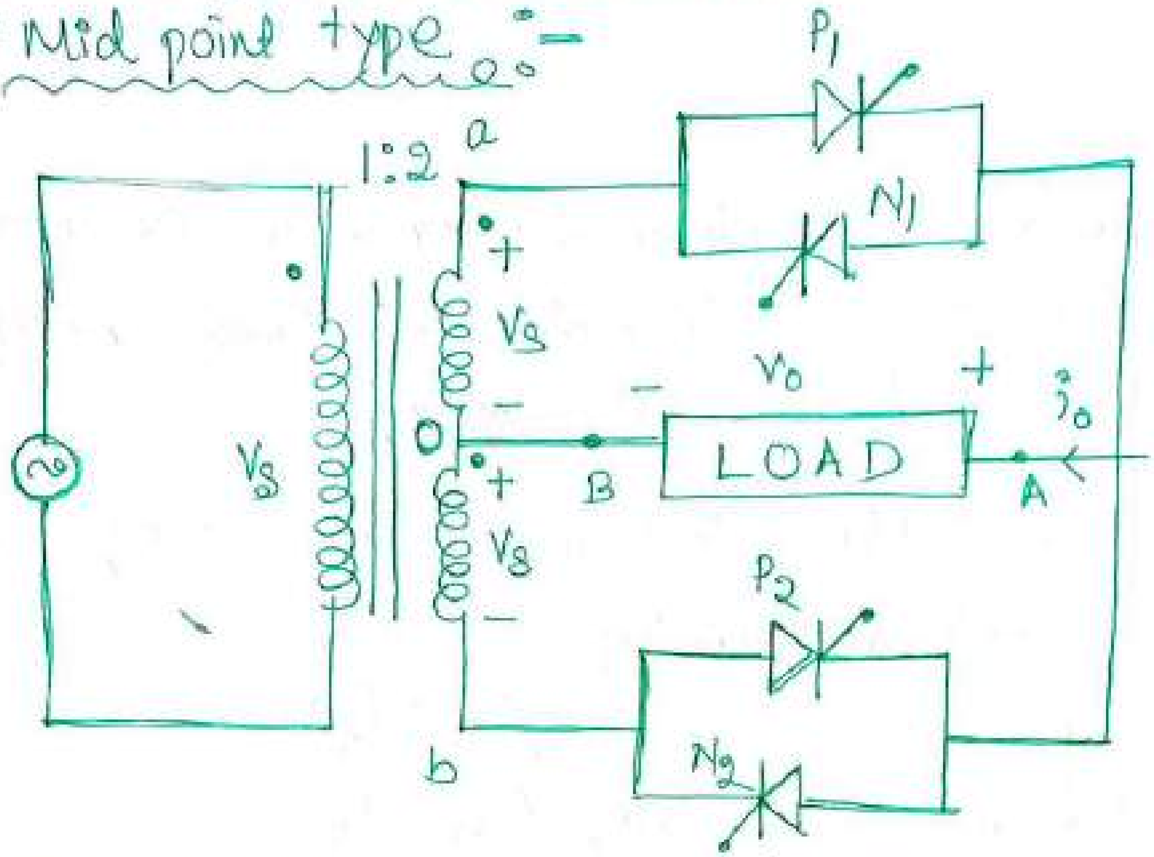
(iii) Static VAR compensation.

(iv) For converting variable speed alternator voltage to constant frequency output voltage for use as power supply in aircraft or shipboards.

★ The general use of cycloconverter is to provide either a variable frequency power from a fixed input frequency power (as in a.c motor speed control) or a fixed frequency power from a variable input frequency power (as in aircraft or shipboard power supplies or wind generators)

1-ϕ step up cycloconverter :→

★ Mid point type :-



→ It consists of single phase transformer with mid tap on the secondary winding and four thyristors.

→ Two of these thyristors P_1, P_2 are for positive group and other N_1, N_2 are for the negative group

→ Load is connected between secondary winding mid point O and terminal A.

→ During the positive half cycle of the supply voltage terminal a positive with respect to terminal b. therefore in this positive half cycle both SCRs P_1 & N_2 are forward bias from $\omega t = 0$ to $\omega t = \pi$.

→ SCR P1 is turned on at $\omega t = 0°$ so that load voltage is positive with terminal A positive and O negative. The Load voltage now follows the positive envelope of the supply voltage.

→ At instant ωt_1, P_1 is force commutated and forward biased thyristor N_2 is turned on so that load voltage is negative with terminal O positive and A negative. The load or o/p voltage now traces the negative envelope of the supply voltage.

→ At ωt_2 N_2 is force commutated and P_1 is turned on i.e. Load voltage is now positive and follows the positive envelope of supply voltage.

→ After $\omega t = \pi$ terminal b is positive with respect to terminal a both SCR P2 and N1 are therefore forward biased from $\omega t = \pi$ to 2π.

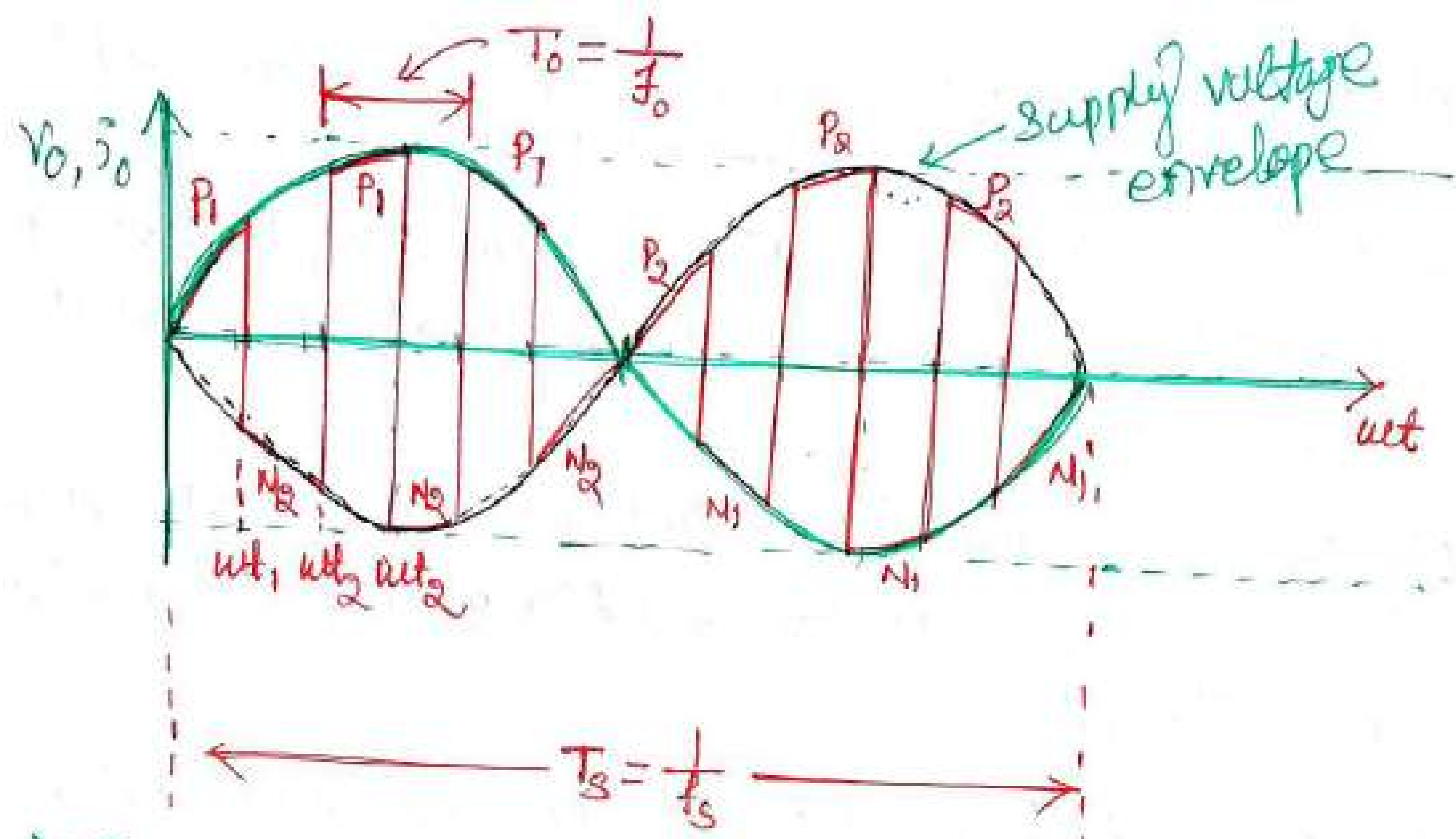
→ At $\omega t = \pi$, N_2 is force commutated and forward biased SCR P2 is turned on.

→ At $\omega t = \frac{1}{2f_s} + \frac{1}{2f_0}$, P_2 is forced commutated and forward biased SCR N1 is turned on.

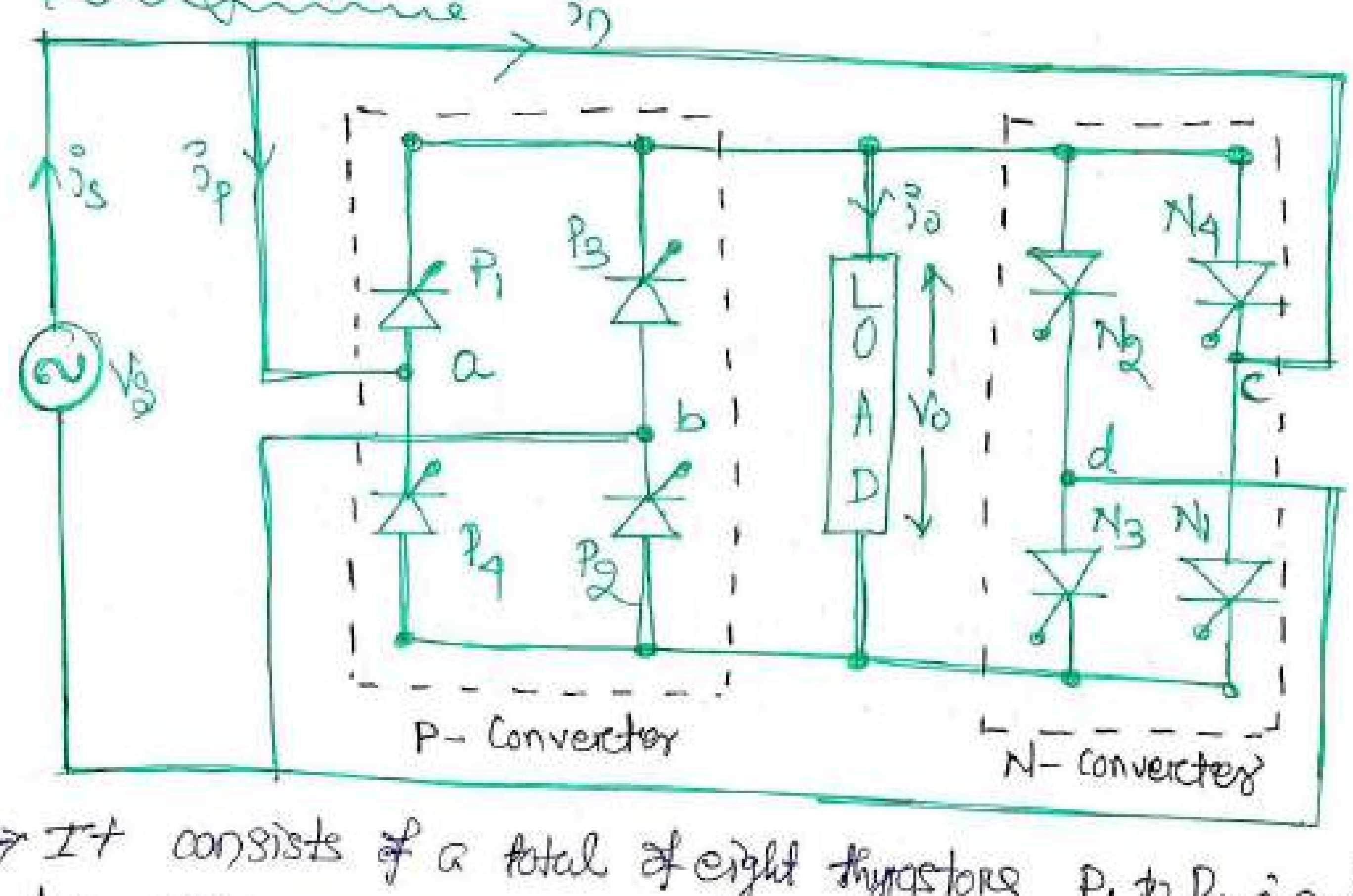
→ In this manner thyristor P1, N2 for first half cycle, P2 N1 in the second half cycle and so on are switched alternately between positive and negative envelops at a high frequency.

→ As result output voltage of frequency f_0 higher than the supply frequency f_s is obtained.

$$f_0 = 6 f_s.$$



★ Bridge type :-



→ It consists of a total of eight thyristors P_1 to P_4 i.e four for positive group and the remaining four for the negative group.

→ when a is positive with respect to b i.e during positive half cycle of supply voltage thyristor pairs P1, P2 and N1 N2 are forward biased from $\omega t = 0°$ to $\omega t = \pi$.

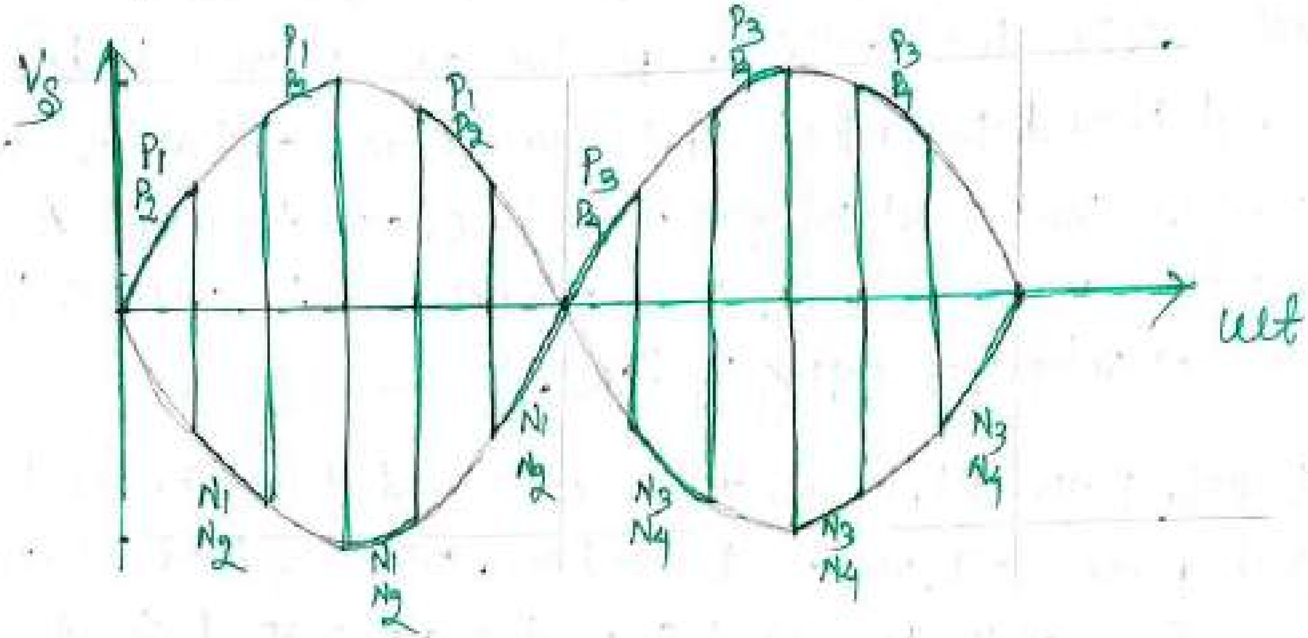
→ when forward biased thyristors P1, P2 are turned on together at $\omega t = 0°$, the load voltage is positive with respect to b. forward biased thyristors P1, P2 are turned on together at $\omega t = 0°$ so that load voltage is positive with terminal A positive with respect to O. Load voltages now traverses the positive envelope of supply voltage.

→ At ωt_1 pair P1, P2 is force commutated and forward biased pair N1, N2 is turned on. with this load voltage is negative with terminal O positive with respect to A. Load voltage now follows the negative envelope of source voltage.

→ At ωt_2 N1, N2 are force commutated and P1 P2 are turned on. The load voltage is now positive and follows the positive envelope of source voltage.

→ After $\omega t = \pi$ thyristor pairs P3, P4 and N3 N4 are forward biased, these can therefore be turned on and force commutated from $\omega t = \pi$ to $\omega t = 2\pi$.

→ In this manner, a high frequency turning on and force commutation of pairs P1, P2, N1 N2 and pairs P3 P4, N3 N4 gives a carrier frequency modulated output voltage across load terminals.



1-ϕ step down cycloconverter :→

★ Mid point type :-

(a) Discontinuous Load current :-

★ When a is positive with respect to O forward biased SCR P1 is triggered at $\omega t = \alpha$. with this Load current i_0 starts building up in positive direction from A to O.

→ Load current i_0 becomes zero at $\omega t = \beta > \pi$. but less than $(\pi + \alpha)$. Thyristor P1 is thus naturally commutated at $\omega t = \beta$ which is already reverse biased after π.

→ After half a cycle B is positive with respect to O. Now forward biased thyristor P2 is triggered at $\omega t = \pi + \alpha$ Load current is again positive from A to O and builds up from zero.

→ At $\omega t = \pi + \beta$, i_0 decays to zero and P2 is naturally commutated.

→ At $2\pi + \alpha$, P1 is again turned on. Load current is seen to be discontinuous.

→ After four positive half cycle of load voltage and load current thyristor N2 is gated at $4\pi+\alpha$ when O is positive with respect to b.

→ As N2 is forward biased, it starts conducting but load current direction is reversed i.e it is now from O to A. After N2 is triggered load current builds up in the negative direction.

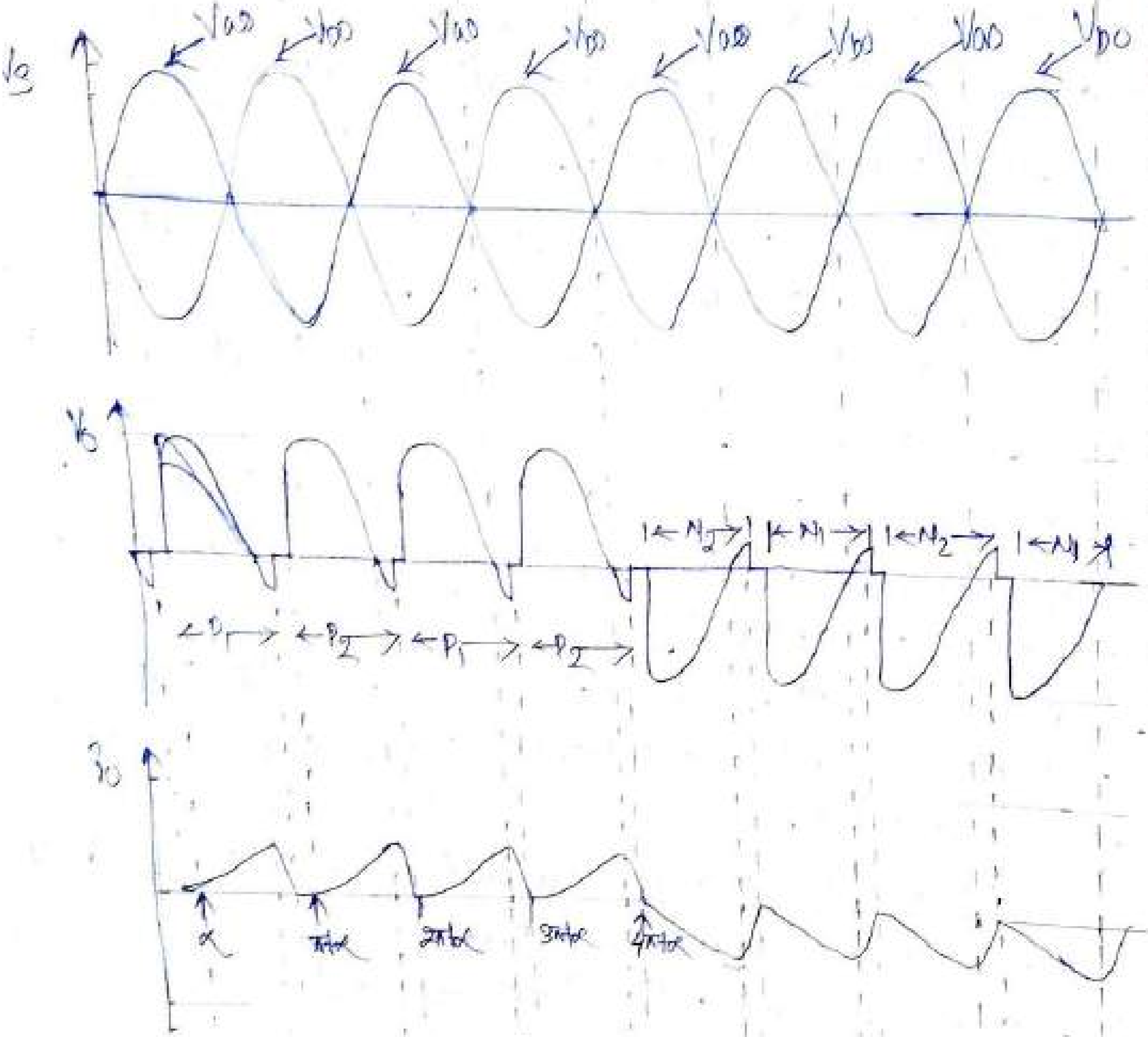
→ In the next half cycle O is positive with respect to a but before N1 is fired, i_0 decays to zero and N2 is naturally commutated.

→ Now when N1 is gated at $(5\pi+\alpha)$ i_0 again builds up but it decays to zero before thyristor N2 in sequence is again gated.

→ In this manner, four negative half cycles of load voltage and load current equal to the number of four positive half cycles of load voltage and so on.

→ For discontinuous load current natural commutation is achieved i.e P1 goes to blocking state before P2 is gated and so on.

→ mean output voltage and current waves are also shown. It is seen from this figure that frequency of output voltage and current is $f_0 = \frac{1}{4} f_s$.



V_{AO}
V_{BO}
V_S
V_O
P_1
P_2
N_1
N_2
i_O
α
$\pi+\alpha$
$2\pi+\alpha$
$3\pi+\alpha$
$4\pi+\alpha$

(b) Continuous Load current —

→ When a is positive with respect to O P1 is triggered at $\omega t = \alpha$ positive output voltage appears across load and load current starts building up

→ At $\omega t = \pi$ supply and load voltage are zero. After $\omega t = \pi$ P1 is reverse biased as load current is continuous P1 is not turned off at $\omega t = \pi$.

→ when P2 is triggered in sequence at $\pi + \alpha$ a reverse voltage appears across P1 it is therefore turned off by natural commutation.

→ when P1 is commutated load current has built up to a value equal to RR. with the turning on of P2 at $(\pi + \alpha)$ output voltage is again positive as it was with P1 on. As a consequence load current builds up further than RR.

→ At $(2\pi + \alpha)$ when P1 is again turned on P2 is naturally commutated and load current through P1 builds up beyond RS.

→ At the end of four positive half cycles of output voltage load current is RU.

→ when N2 is now triggered after P2 load is subjected to a negative voltage cycle and load current i_0 decreases from positive RU to negative AB.

→ Now N2 is commutated and N1 is gated at $(5\pi + \alpha)$ Load current i_0 becomes more negative than AB at $(6\pi + \alpha)$ this is because with N1 on load voltage is negative.

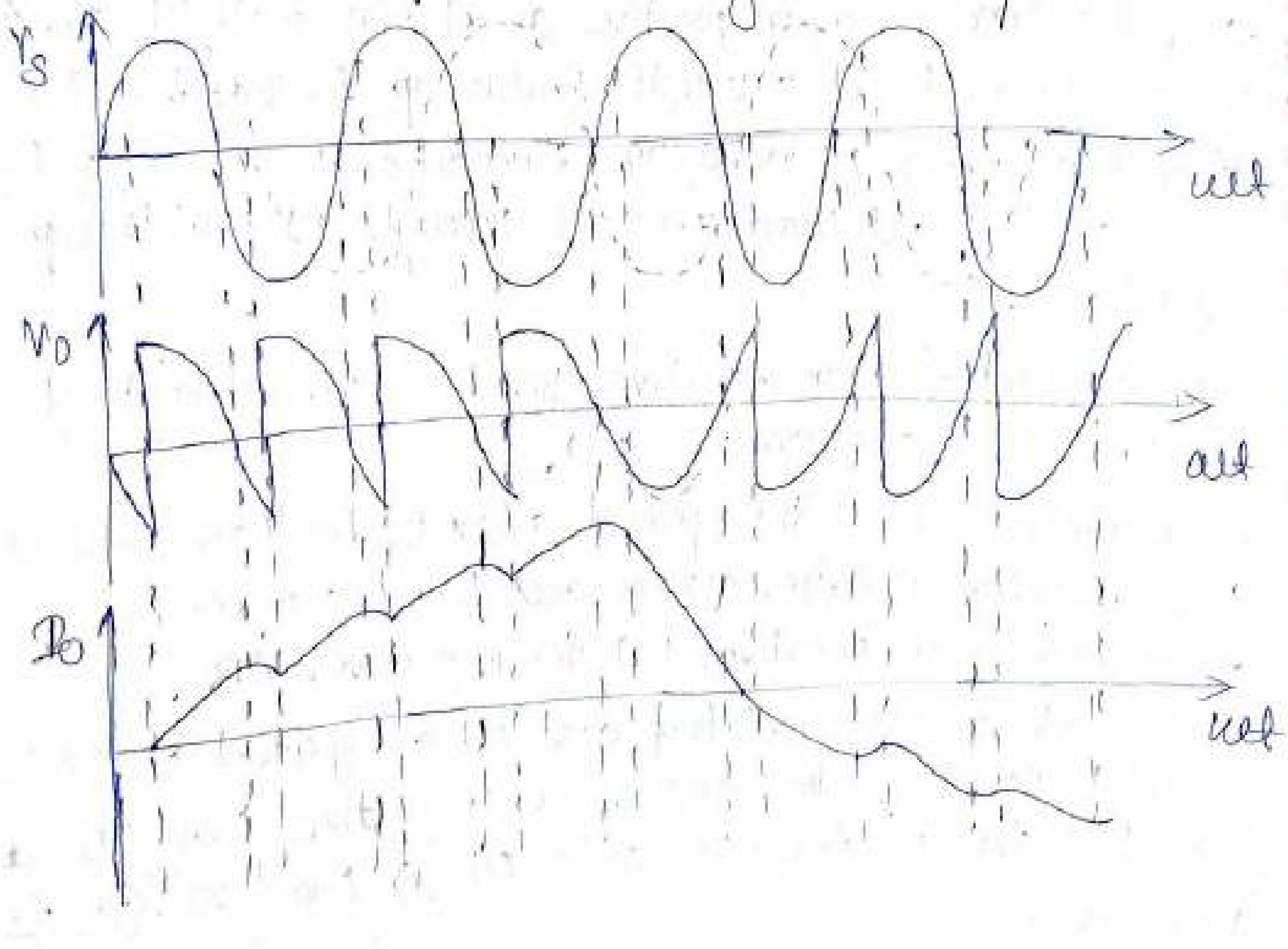
→ For four negative half-cycles of output voltage current i_0. Load current waveform is redrawn under steady state condition.

→ It is seen from load current waveform that i_0 is symmetrical about cut axis.

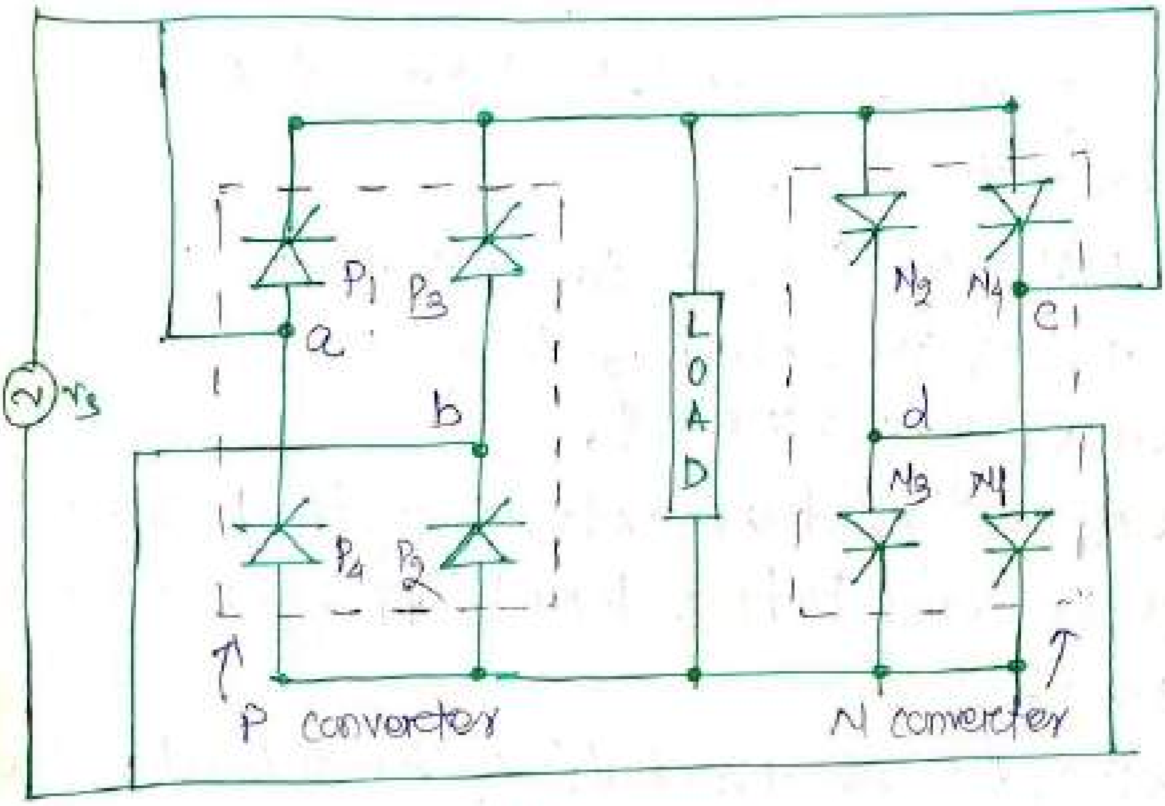
→ The positive group of voltage group and current wave consists of four pulses and same is true for negative group of wave.

→ One positive group of pulses along with one negative group of identical pulses contitute one cycle for the Load voltage and Load current.

→ The supply voltage has however gone through four cycles. The output frequency is $f_0 = \frac{1}{4} f_s$.



* Bridge type :-



(a) Discontinuous Load Current :-

→ When 'a' is positive with respect to 'b' in fig forward biased thyristor P_1 & P_2 is triggered at $\omega t = \alpha$ with this load current i_0 starts building up in positive direction from A to O. Load current i_0 becomes zero at $(\omega t = \beta) > \pi$ but less then $(\pi + \alpha)$.

→ Thyristor P_1 & P_2 are thus commutated at $\omega t = \beta$ which is already reversed biased after π. After a half cycle 'a' is positive with respect to 'b'. Now forward biased thyristor P_3 & P_4 is triggered at $\omega t = \pi + \alpha$.

→ Load current is again positive from A to O builds up from zero. At $\omega t = \pi + \beta$, i_0 decays to zero and P_3 & P_4 is naturally commutated. Load current is to be seen discontinuous.

→ After two positive half cycles of load current and load voltage, thyristor N_1 and N_2 is gated at $(2\pi + \alpha)$ when C is positive with respect to d.

→ As N_1 & N_2 are forward biased. It starts conducting but Load direction is reversed i.e it is now from O to A

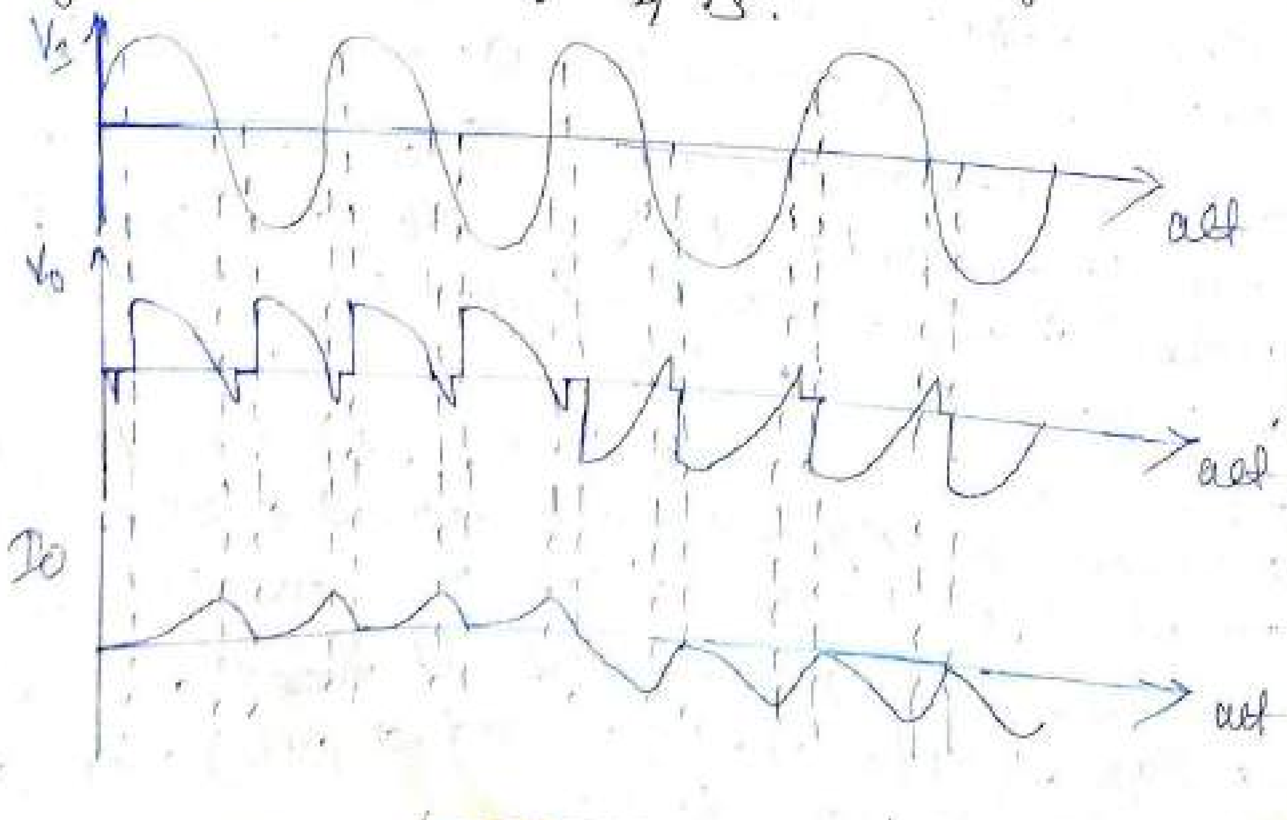
→ After N_1 & N_2 are triggered, load current builds up in the negative direction.

→ In the next half cycle b is positive with respect to a but before N_3 & N_4 are fired i_0 decays to zero and N_1, N_2 is naturally commutated.

→ Now N_3 & N_4 are gated at $5\pi+\alpha$, i_0 again builds up and decays to zero before thyristor P_1 & P_2 is sequence is again gated.

→ In this manner, two negative half cycles of load voltage and current, equal to the two positive half cycle are generated.

→ It is seen from the figure that frequency of output voltage and current is $f_0 = \frac{1}{4} f_s$.



(b) Continuous load current —

→ when a is positive with respect to b. P_1 & P_2 are triggered at $\omega t = \alpha$, positive output voltage appears across the load the load and load current starts building up as.

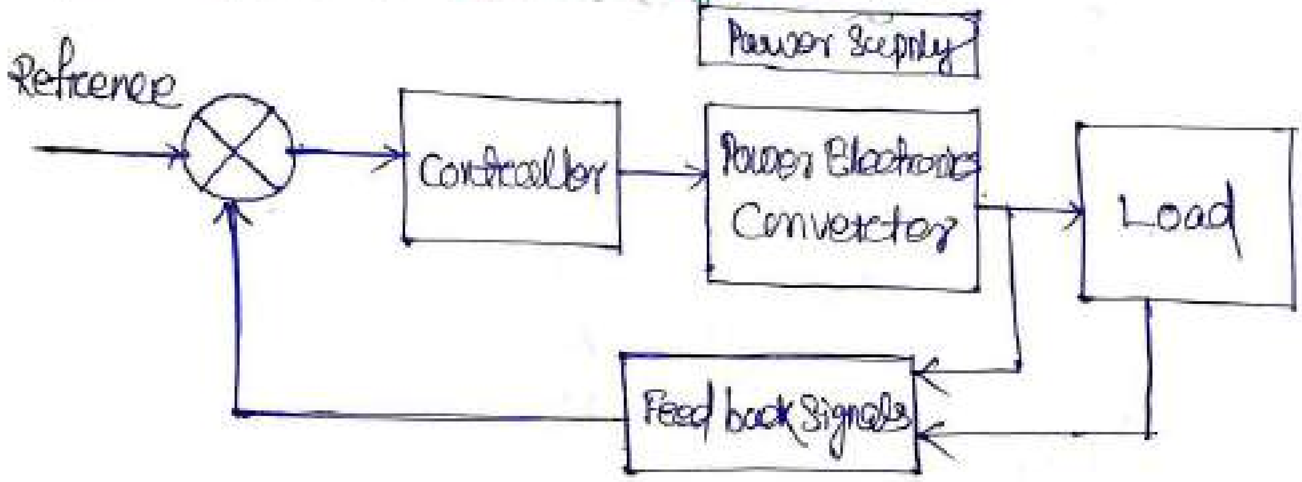
→ At $\omega t = \pi$ load voltage are zero. After $\omega t = \pi$ P_1 & P_2 are reversed biased. As load current is continuous P_1 & P_2 are not turned off at $\omega t = \pi$. when N_3 & N_4 are triggered in sequence at $\omega t = \pi + \alpha$, a reverse voltage appears across P_1 & P_2 are therefore turned off by natural line commutation.

→ when P_1 & P_2 are commutated load current has built up to a value equal to AB as shown in wave form. with turning on of P_3 and P_4 at $\pi + \alpha$ output voltage is again positive as it was with P_1 & P_2 on. As a sequence load current builds up further then AB.

→ At $2\pi + \alpha$ when P_1 & P_2 are again turned on P_3 & P_4 is naturally commutated and load current through P_1 & P_2 builds up. beyond ~~R~~

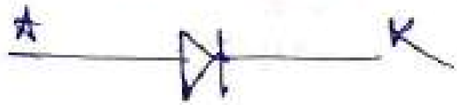
→ At the end of two positive half cycles of output voltage. Load current current is beyond KL. After 2π c is positive with respect to d but as due to inductive Load P_3 & P_4 will remain in conduction till the current reaches to zero at M. N_1 N_2 is already triggered at $2\pi + \alpha$ with prolonged pulse. when current goes to zero at point M. P_3 P_4 turns off and N_1 N_2 starts conducting when N_1 N_2 is now conducting after P_3 P_4 load is subjected to negative voltage and load current i_0 increases from zero.

Schematic Block diagram of basic structure of a power electronic based system :→



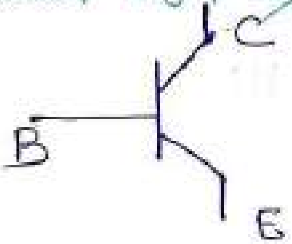
Power Semiconductor Devices :→

① Power Diode →



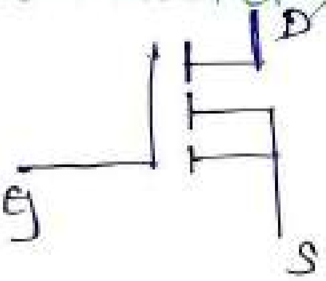
Voltage Rating = 5KV
Current Rating = 5KA
operating frequency = 100-800KHZ

② Power BJT →



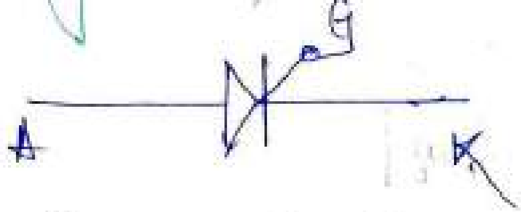
V.R = 1400V
C R = 400A
O P = 10KHZ

③ power MOSFET →



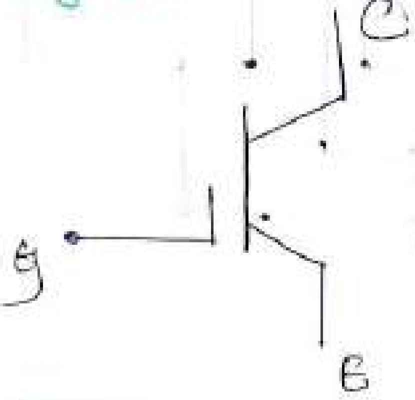
VR = 1KV
CR = 50A
OF = 100KHZ-1MHZ

(4) Thyristor →



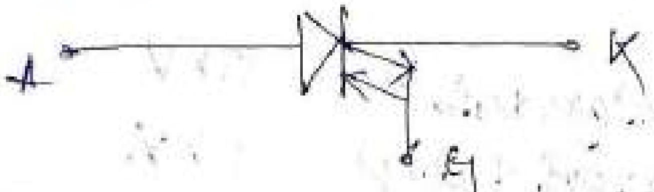
VR = 10KV
CR = 5KA
OP = 1KHZ

(5) IGBT



VR = 3.3KV
CR = 1200 A
OF = 50KH

(6) GTO



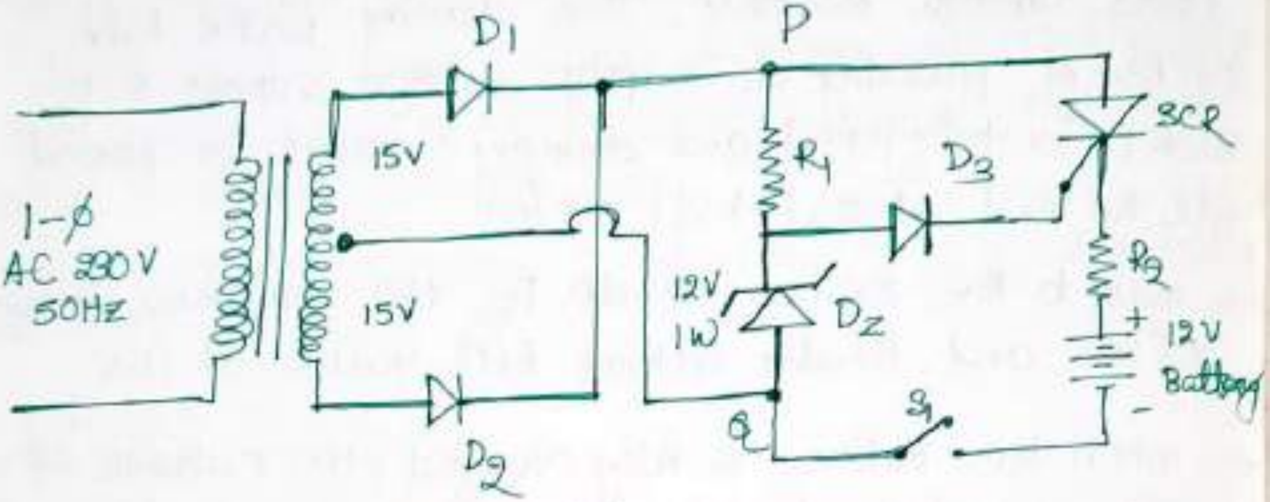
VR = 5KV
CR = 3KA
OP = 2KHZ

(7) TRIAC

VR = 1200V
CR = 300 A
OP = 0.5KHZ

CH-4

Battery Charger Circuit using SCR with help of Diagram



→ Automatic battery charging circuit using SCR is shown in figure.

→ A 12V discharged battery is connected in the circuit as shown.

→ When S_1 is closed the 1-ϕ 230V AC supply is stepped down to (15-0-15) V by a centre tapped transformer. Diodes D_1 & D_2 formers full wave rectifier. Due to this the pulsating dc supply appears across terminal P & Q.

→ When SCR1 is OFF its cathode is held at the potential of discharged battery.

→ During each positive half cycle when the potential of point O rises to sufficient level so as to forward bias diode D_3 and gate-cathode junction of SCR1 the gate pulse is provided to SCR1 and it is turned on.

→ When SCR1 is turned on the charging current flows through battery. Thus during positive half cycle of pulsating dc supply voltage across P-Q, SCR1 is triggered and charging current is passed till the end of that half cycle.

→ Due to the zener diode D_Z the maximum voltage rises and finally attains full value of 12V.

→ When the battery is fully charged, the cathode of 3CR1 is held at 12V. Therefore diode D_3 and ate cathode junction of SCR1 can not be forward iased since the potential of point O can reach p to 12V. Hence no gate current is supplied and CR1 is not triggered. In this way after full harging further charging is automatically stopped.

(UPS) Uninterruptible Power supply :→

→ It is an electrical device used to provide emergency electrical power to different electrical loads in the case of main power supply failure.

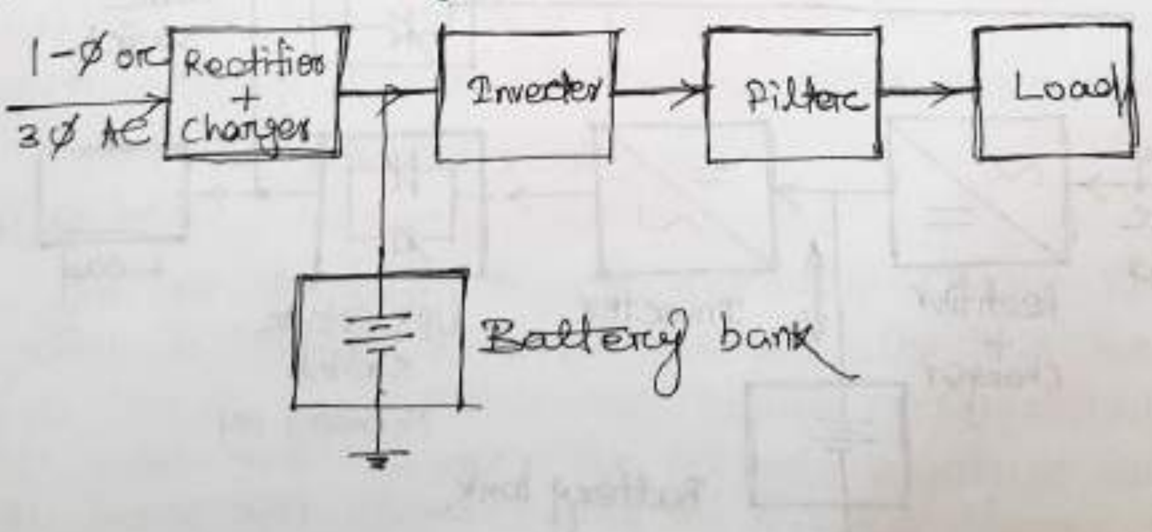
→ A UPS or uninterruptible power supply uses batteries and super capacitor to store electrical energy and delivers this stored electrical energy when the main input power supply fails.

→ UPS are mostly used as short run time backup power sources for small loads.

Application of UPS :-

→ Data centers
→ Medical Facilities
→ Manufacturing Industries
→ Financial Institutions
→ Telecommunication.

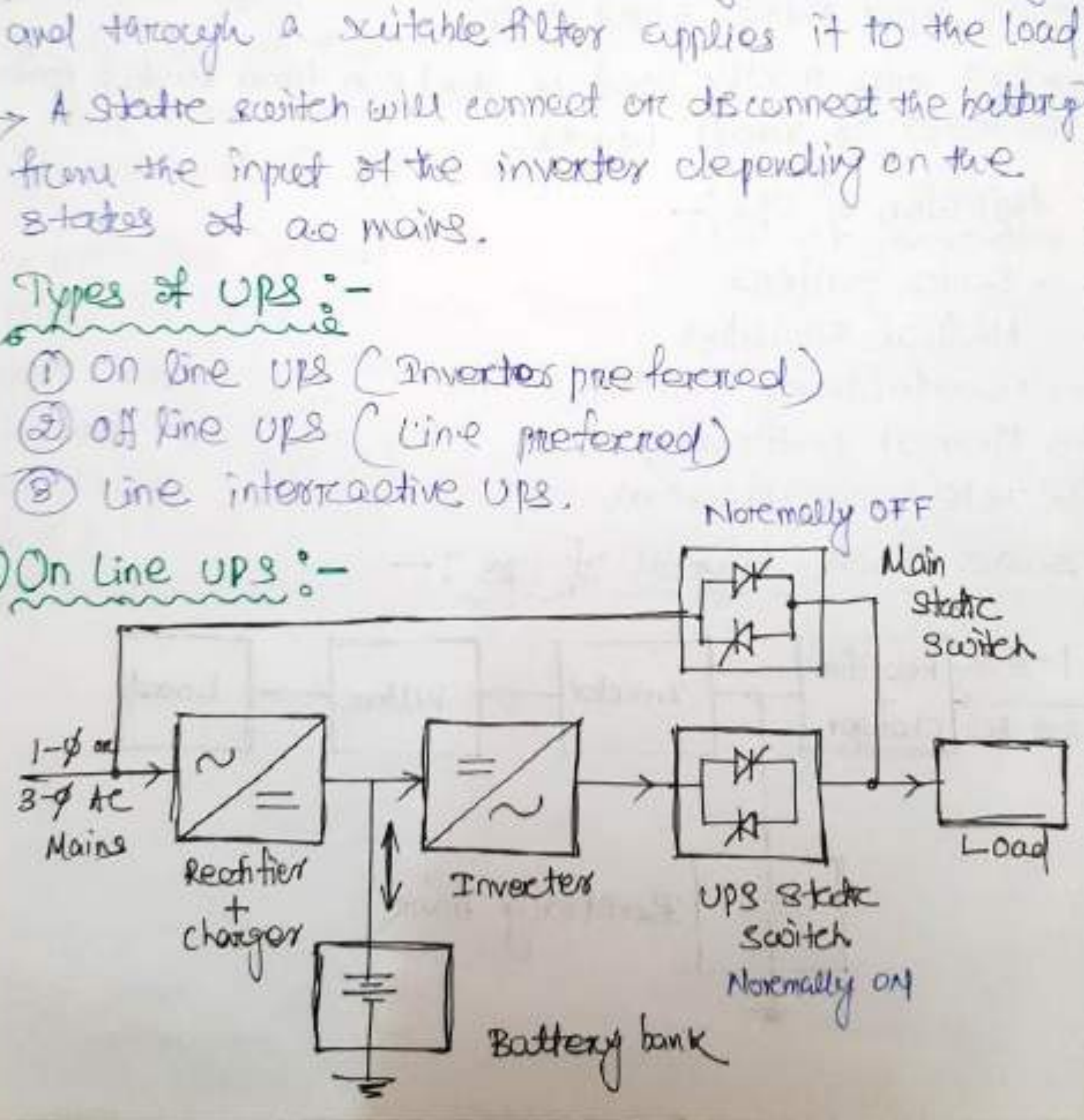
Basic Block diagram of UPS :-



→ Figure shows the block diagram of typical ups system.
→ A rectifier converts a single phase or three phase ac voltage in to dc which supplies power to the inverter as well as the battery bank to charge it.
→ The inverter gets a d.c input voltage from the rectifier when the ac mains is ON and from the battery bank when the a.c mains is OFF.
→ Inverter converts this d.c voltage into a.c voltage and through a suitable filter applies it to the load
→ A static switch will connect or disconnect the battery from the input of the inverter depending on the states of ac mains.

Types of UPS :-
① on line UPS (Inverter preferred)
② off line UPS (Line preferred)
③ Line interactive UPS.

① On Line UPS :-



⇒ Block diagram shows the online UPS system. On this mode of operation the load is always connected to the inverter through the UPS static switch.

→ The UPS static switch is a normally ON switch. It turns off only when the UPS system fails. In that case the main static OFF switch and used only when UPS is to be bypassed..

Mode-I:

when the AC mains is ON the rectifier circuit will supply the power to the inverter as well as to the battery therefore it acts as a rectifier cum charger. Hence its ratings are usually higher. The inverter output is connected to the Load via UPS static switch. Battery will be charged in this mode.

Mode-II:

if the supply power fails suddenly the rectifier output will be zero and hence the battery bank now supplies power to the inverter without any interruption and delay. there will not be any change in inverter as well as the load.

After restoration of the line supply the charger supplies the inverter and recharges the battery automatically first in constant current mode and then in constant potential mode.

Mode-III:

If the UPS fails, then the normally OFF main static switch is turned-on which automatically transfers the A.C. line to the load in less than 1/4 cycle period with no phase discontinuity. This not only maintains power to the load but also actuates the failure alarm signal to draw of the attendant.

→ This type of system is more popular because it can provide full isolation of the critical load from the a.c line and also provides power conditioning.

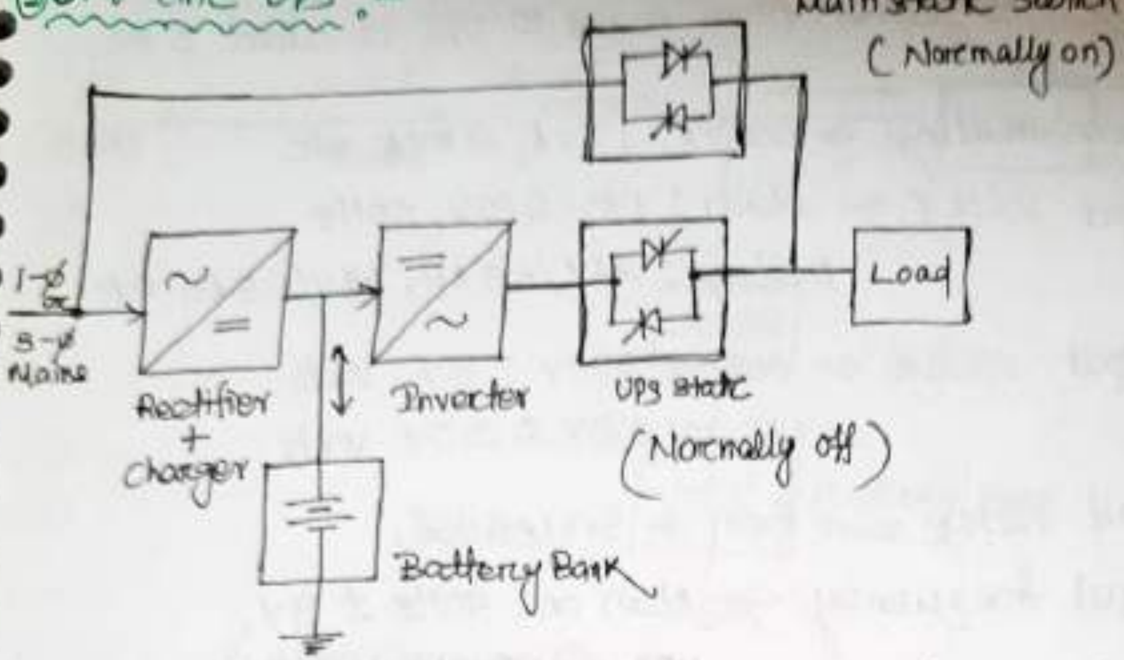
→ Mode of operation does not change during the failure of power. Its change over time is very less and there is no interruption during transfer from line to battery and vice versa.

→ This system protects the critical load gainst surges spikes, line noise, frequency and voltage variation, brown out and outages

Specification

1. power rating ⇒ 500 VA, 1 KVA, 5 KVA, 50 KVA etc
2. output voltage ⇒ 230V ± 0.1 %.
3. output frequency ⇒ 50 Hz ± 0.1 Hz
4. input voltage ⇒ 230V ± 15 %.
5. output voltage waveform ⇒ sine wave
6. power factor ⇒ > 0.8 Lagging
7. Back up time ⇒ 30 min to 4 hr
8. Total harmonic Distortion ⇒ < 3 %.
9. Efficiency ⇒ > 85 %.
10. protection provided ⇒ (i) over voltage / under voltage cutout
    (ii) over current trip with reset.

(3) OFF Line UPS :-



→ Only difference between the offline and online UPS is that mainstatic switch here is a normally ON switch.

→ Main static switch connects the a.c mains directly to the Load when mains is ON.

→ The battery charger is stabilized one which maintains the battery on float at fully charged condition and at the same time provides stabilized power to the inverter.

→ the UPS static switch is normally OFF switch. It is closed when mains fails. Thus in the offline UPS the inverter comes into the circuit only when the mains fails.

→ the rectifier/charger has to do only one function to charge the battery bank.

→ under the condition of mains failure the static switch operate to disconnects the mains from the load and connect the load to the UPS output. The battery will then supply the power to the load via the inverter.

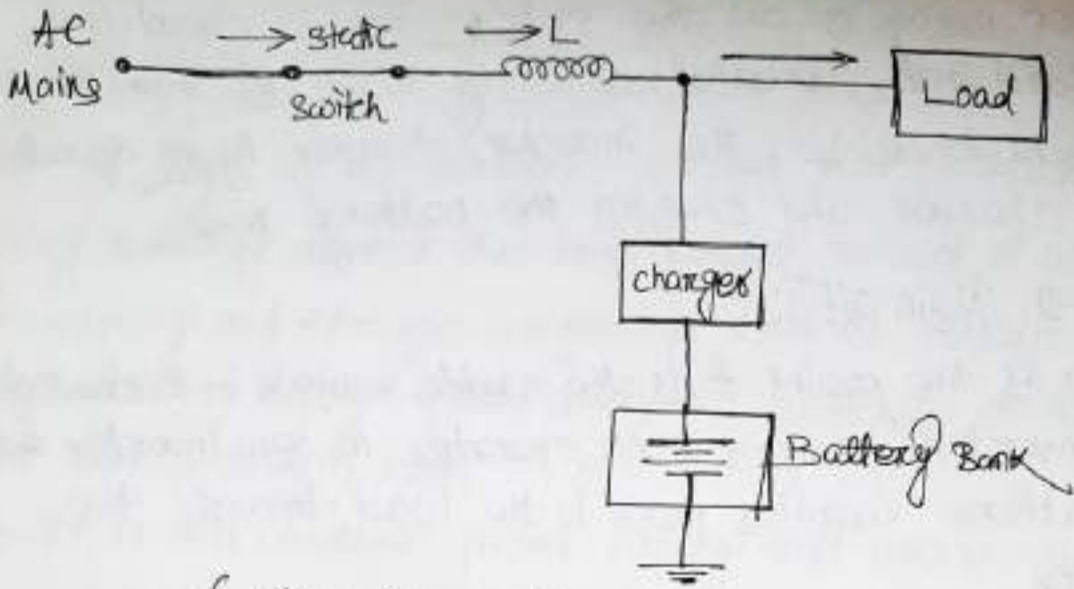
→ The total time taken to sense the power failure and make a changeover from mains to UPS is about 5 ms.

specification

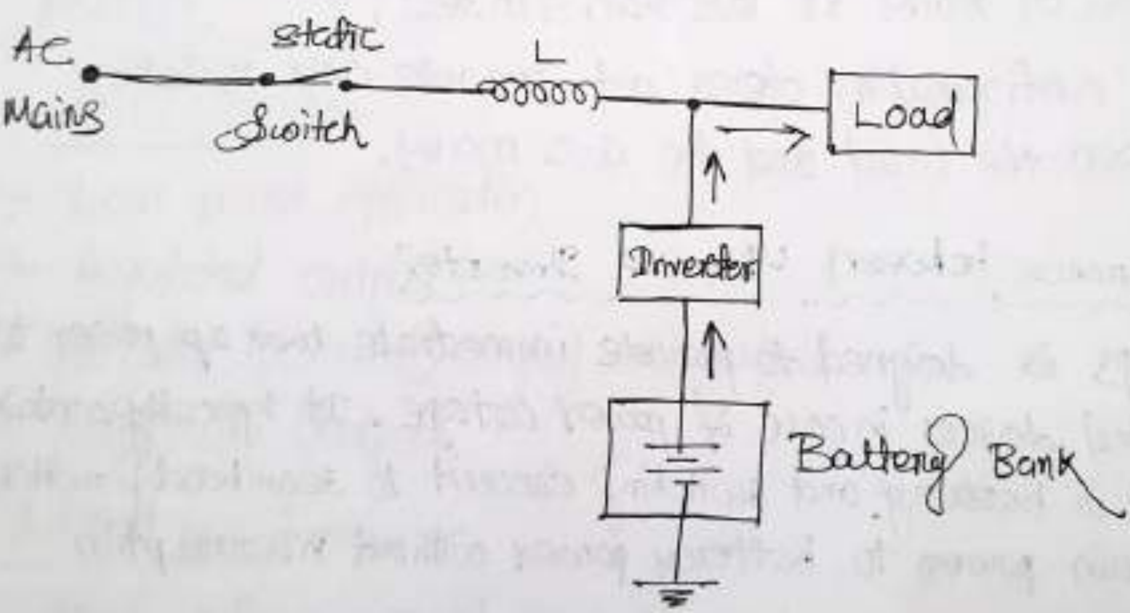
1. power rating ⇒ 500 VA, 1 KVA, 2 KVA etc
2. Input voltage ⇒ Main : 170-270V, 50Hz
   Battery : 24V/6.5AH, 48V/6.5AH etc
3. output voltage ⇒ Main on : 230V ± 5% volts
   ups on : 230V ± 0.5% volts
4. output voltage wave form ⇒ Sinusoidal
5. output frequency ⇒ Main on : 50Hz ± 3%
   ups on : 50Hz ± 2Hz
6. Battery recharge time ⇒ 4 hr
7. Back up time ⇒ 30 minutes or more
8. Transfer time ⇒ 5 ms (typical)
9. Efficiency ⇒ > 85%
10. protections ⇒ (i) output over load
    (ii) Main over voltage
    (iii) Low Battery

(3) Line Interactive UPS :-

→ The heart of this system is the battery charger cum inverter which acts as an inverter. In this system normally the critical load is supplied from the commercial supply through the static switch & an inductance L.


AC
Mains
static
switch
L
Load
charger
Battery Bank

(when Main ON)


AC
Mains
static
Switch
L
Load
Inverter
Battery Bank

Mode-I (Main ON):

→ when mains is ON the static switch is closed and the load gets connected directly to the ac mains through the inductance L. the inverter/charger block operates as a charger and charges the battery bank.

Mode-II (Main off):

As soon as the mains fails the static switch is turned off and inverter/charger block operates as an inverter and the battery supplies power to the load through the inverter.

→ Total time taken for sensing and changeover after the failure of mains is less than 5 msec.

→ this configuration does not provide any isolation between the load and the a.c mains.

Difference between UPS and Inverter?

→ A UPS is designed to provide immediate back up power to connected devices in case of power outage. It typically contains a built in battery and switching circuit to seamlessly switch from main power to battery power without interruption.

→ An inverter on the otherhand converts direct current from batteries or other DC sources into alternating current. Inverter are usually paired with external batteries to provide backup power but do not instantly kick in during power failure.

SMPS

(Switch Mode Power Supply)

→ A SMPS is an electronic circuit that converts power using switching devices that are turned on and off at high frequency and storage components such as inductor or capacitor is supply power when the switching devices is in its non conduction state.

→ It is an electronic power supply that uses a switching regulator to convert electrical power efficiently.

→ The switching device can be a power transistor or MOSFET.

Application :→

→ Low power Application
→ Regulated output
→ Isolation between input and output
→ Multipule output.

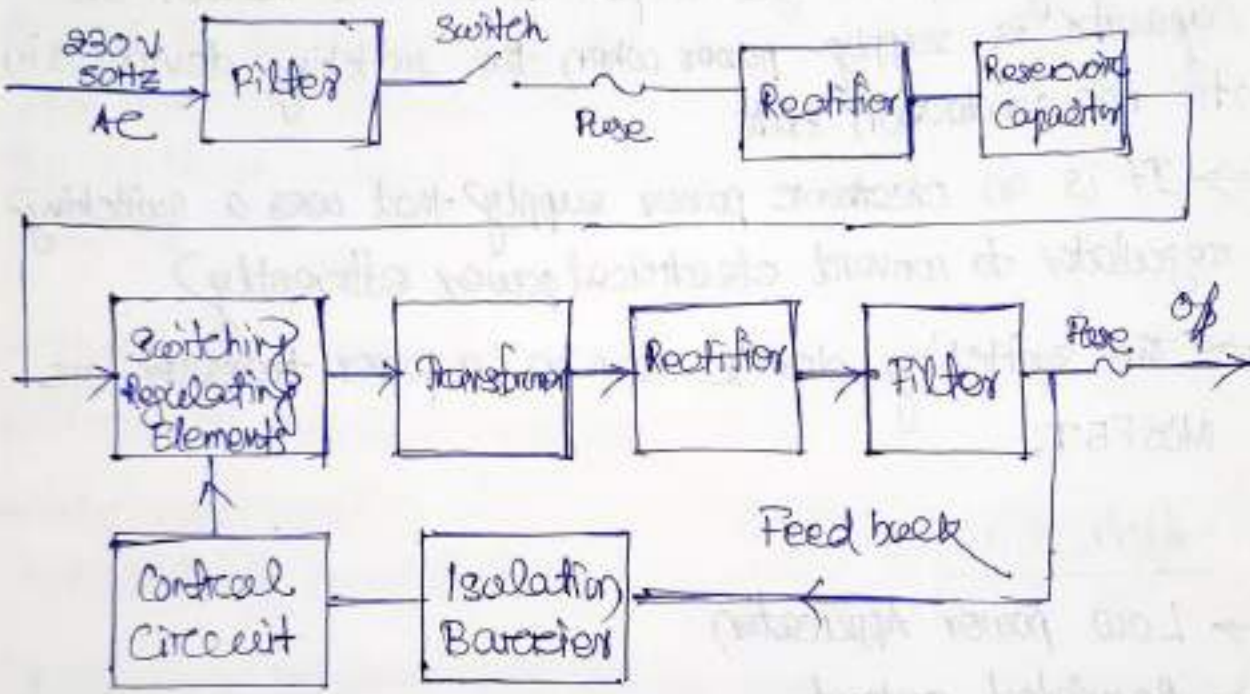
Advantages :→

→ High efficiency of 68% to 90%.
→ Regulated and reliable output regardless of variation in input supply voltage
→ Small size and lighter
→ High power density.

Disadvantges :→

→ Generate electromagnetic interference.
→ Complex circuit design
→ Expensive compared to linear supplies.

Block diagram of SMPS :→



→ Initially the unregulated ac input signal from the source is provided to the input rectifier and filter circuit. Here the ac input signal is rectified to generated a dc signal and further smoothened to remove high frequency noise component from it. The dc output is fed to the power transistor that acts as high frequency switch.

→ Here the dc signal undergoes chopping (switching). This circuit acts as an ideal switch i.e when the power transistor (chopper circuit) is in on state, current passes through it with negligible voltage drop and dc signal is obtained at the output terminal of the transistor. However under the off state of the power transistor no current passes through it and leading to cause maximal voltage drop with in it. Thus at the output side no voltage will be present.

→ Hence according to the switching action of the power transistor dc voltage will be obtained at its output side the chopping frequency plays a crucial role in maintaining the desired dc voltage level.

→ The obtained dc signal at the output of the chopper circuit is then fed to the primary winding of the high frequency power transformer. Here the step down transformer converts the high voltage signal into a low voltage level which is further provided as input to the output rectifier and filter unit. This simply filter out the unwanted residuals from the signal in order to provide a regulated dc signal as the output.

→ The control circuit present here acts as the feedback circuit for the complete unit. This involves a comparator along with a pulse width modulator (PWM). The dc output from the rectifier and filter is fed to the control circuit where the error amplifier which acts as a comparator, compares the obtained dc voltage with the ref. value

→ If the dc output is greater than the chopping frequency is to be decreased. The decrease in chopping frequency will reduce the output power and so the dc output voltage. However if the dc output is less than the reference value than the chopping frequency is increased. When chopping frequency is raised then the dc output voltage will get increased.

→ The pulse width modulator in the above circuit is responsible for generating a fixed frequency pulse width modulated waveform whose duty cycle controls the chopping frequency.

→ Basically the duty ratio is the ratio of on time to the overall cycle time (i.e on + off) time. Hence by making necessary adjustment in the width of the pulses the chopping frequency gets adjusted hence regulated dc output can be obtained.

Types of SMPS →

(1) Non isolated type
- → Buck
- → Boost
- → Buck Boost

(2) Isolated type
- → Fly back Converter
- → Push pull Converter
- → Half bridge Converter
- → Full bridge Converter

(c) The open circuit voltage across each MOSFET is $V_{OC} = V_s$ of all the four configurations of SMPS, full bridge converter operates with minimum voltage and current stress on the power MOSFET. It is therefore very popular for high power application above 750 W.

List of factor affecting speed of a DC Motor :→

Speed of a D.C Motor –

From the voltage equation of a motor

$$E_b = V - I_a R_a \quad \text{——— (1)}$$

$$E_b = \frac{\phi Z N}{60}\left(\frac{P}{A}\right) \quad \text{——— (2)}$$

$$\frac{\phi Z N}{60}\left(\frac{P}{A}\right) = V - I_a R_a$$

$$\Rightarrow N = \frac{V - I_a R_a}{\phi} \times \left(\frac{60A}{ZP}\right) \text{ rpm}$$

$$= \frac{E_b}{\phi} \times \left(\frac{60A}{ZP}\right)$$

$$\Rightarrow N = K \frac{E_b}{\phi}$$

$$\Rightarrow N \propto \frac{E_b}{\phi}$$

factor affecting DC control are
1. The Applied voltage
2. The flux
3. The voltage across an armature

Flux field = increase above normal speed

Armature resistance = below normal speed.

$$N = K\frac{V - I_a R_a}{\phi}$$

It is obvious that speed can be controlled by

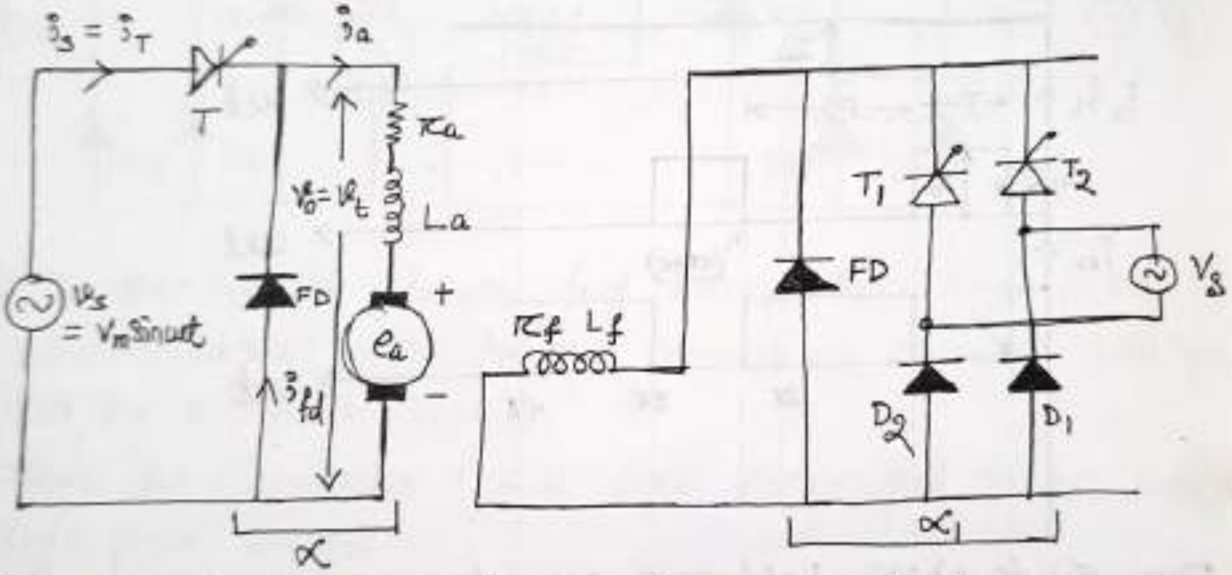
(i) Flux ϕ (Flux control)

(ii) Armature Resistance R_a (Rheostatic control)

(iii) Applied voltage V (voltage control)

Speed Control of DC Motor using Converters :→

① Single phase Half wave Convertor Drives :—

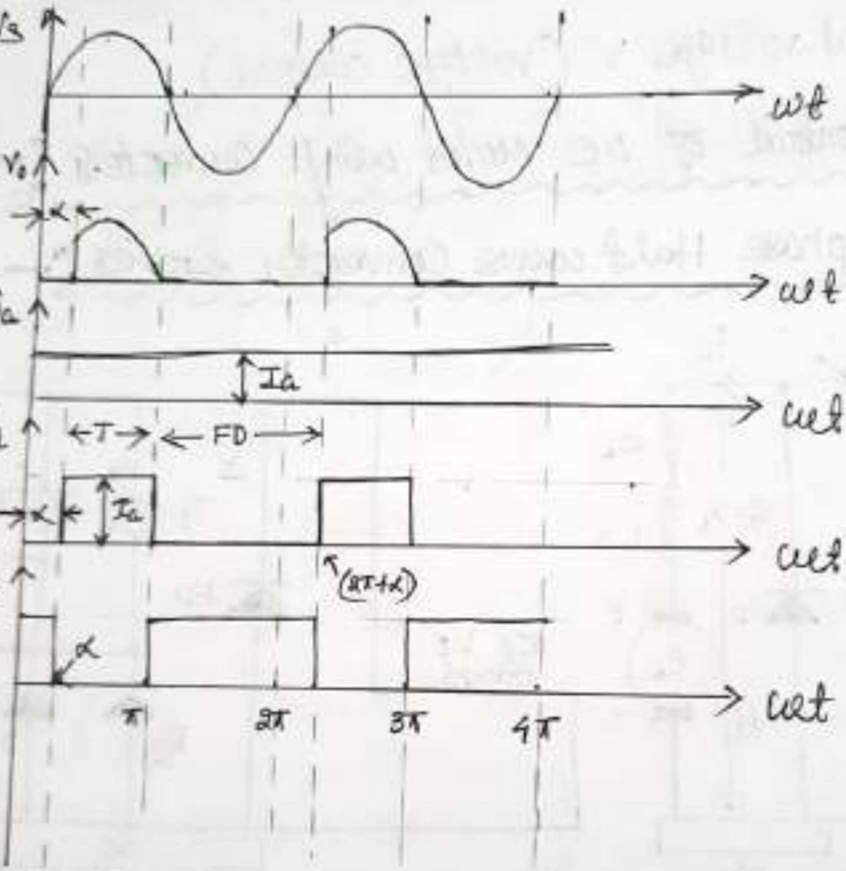


★ The Circuit shows the semi converter feeding a separately excited dc motor.

★ Both armature and field circuits are supplied from single phase ac supply through half wave & semi converter. Because of inductance in the armature and field circuit, freewheeling diodes are required in both the circuit.

★ Freewheeling diodes is connected across the motor terminals to allow for dissipation of energy stored in the motor inductance and to provide for continuity of motor current when the thyristor are blocked.

★ This type of drives used up to about $\frac{1}{2}$ kW dc motors



For single phase half wave converter, average output voltage of converter V_0 = armature terminal voltage V_t

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

single phase semiconverter in the field circuit the average output voltage $V_f = \frac{V_m}{\pi}(1+\cos\alpha_1)$

rms value of armature current $I_{av} = I_a$

rms value of thyristor current $I_{SR} = \sqrt{I_a^2 \frac{\pi-\alpha}{2\pi}} = I_a\left(\frac{\pi-\alpha}{2\pi}\right)^{1/2}$

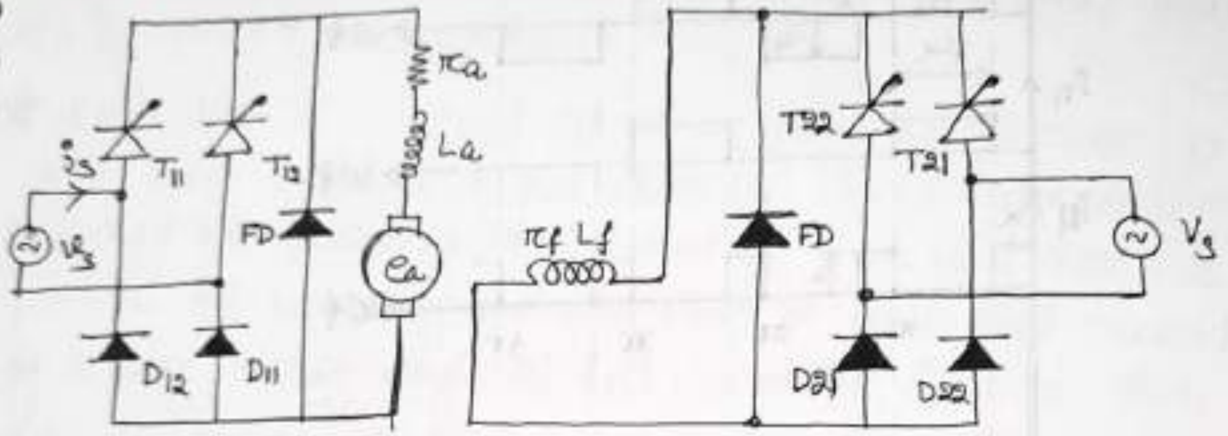
rms value of freewheeling diode current

$$I_{fdr} = \sqrt{I_a^2 \frac{\pi+\alpha}{2\pi}} = I_a\left(\frac{\pi+\alpha}{2\pi}\right)^{1/2}$$

Apparent input power $= V_s I_{sr}$

power delivered to motor $= V_t I_a$

(2) Single phase Semiconverter Drives :-



★ In this type of drives fed through two single phase semiconverters, one for the armature circuit and the other for the field circuit.

★ Both the converter 1 & 2 are connected to the same single phase source.

★ The converter also offers one quadrant drive

★ used upto about 15 kW dc drives.

For single phase semiconverter, average output voltage

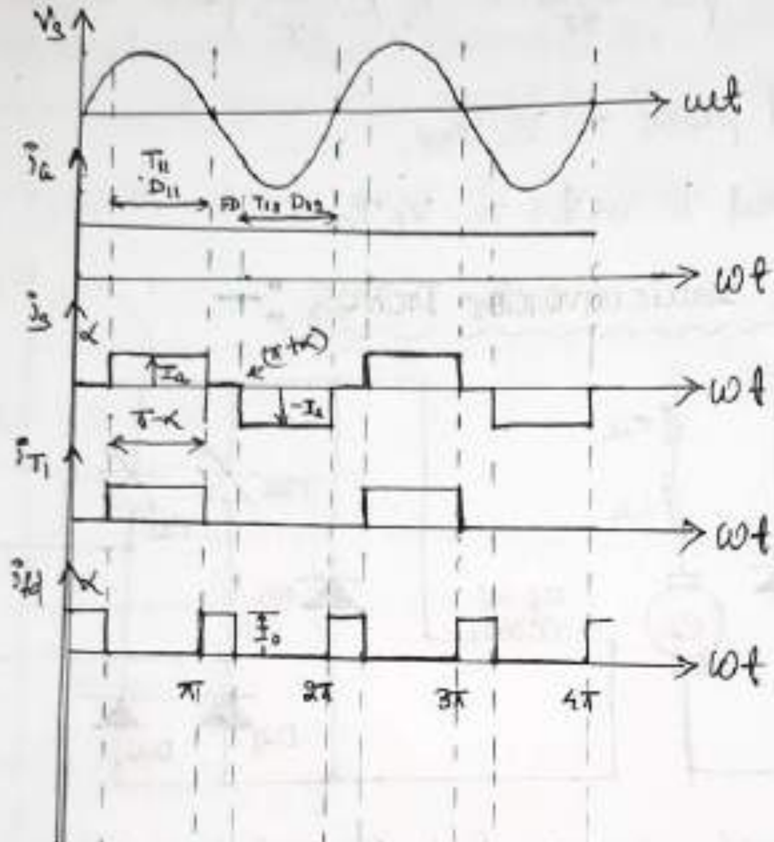
$$V_0 = V_t = \frac{V_m}{\pi}(1+\cos\alpha)$$

For field circuit $V_f = \frac{V_m}{\pi}(1+\cos\alpha_1)$

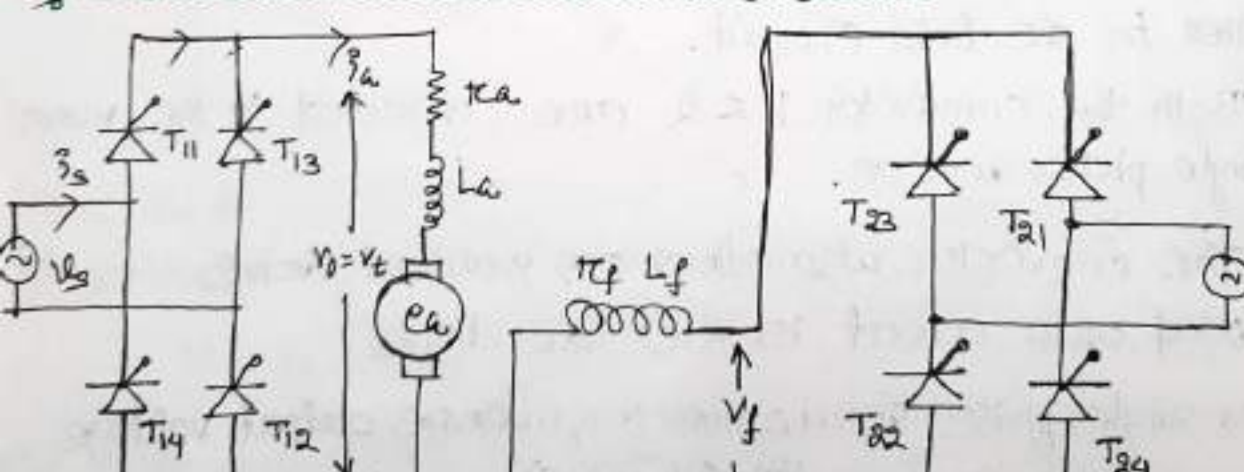
rms value of source current $= I_{sr} = I_a\left[\frac{\pi-\alpha}{\pi}\right]^{1/2}$

rms value of freewheeling diode current $I_{fdr} = I_a\left[\frac{\alpha}{\pi}\right]^{1/2}$

rms value of thyristor current $I_{TR} = I_a\left(\frac{\pi-\alpha}{2\pi}\right)^{\frac{1}{2}}$



(3) Single phase Full converter drives :-

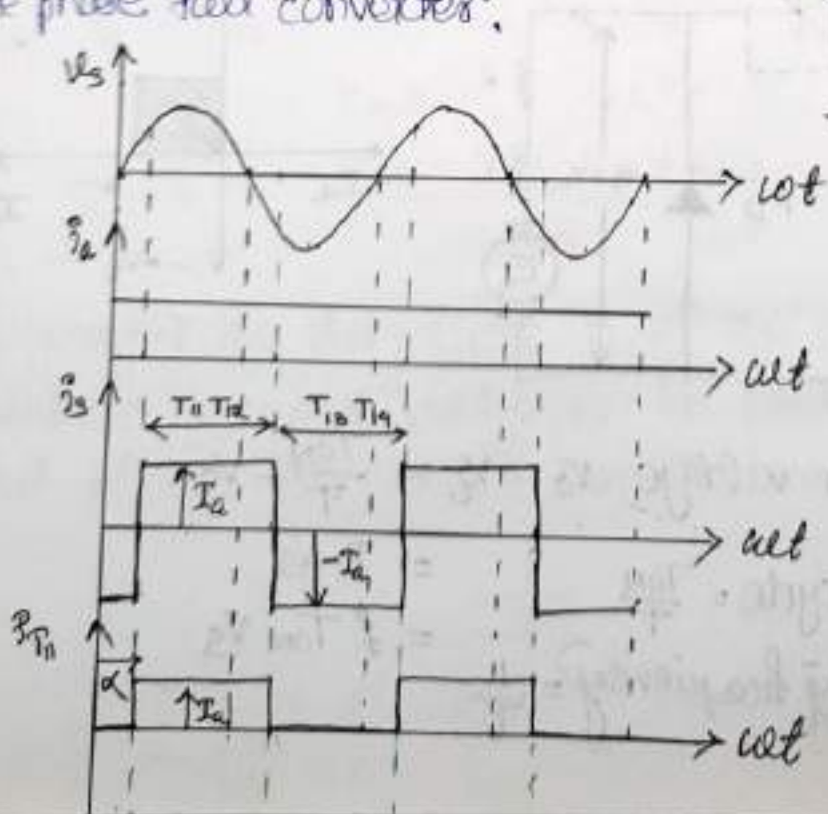


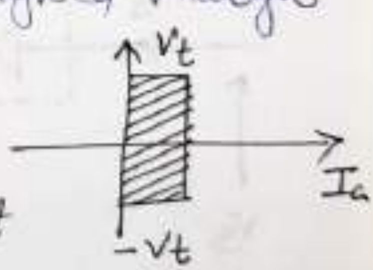
★ Two full converters one feeding the armature circuit and other feeding the field circuit.

★ This offers two quadrant drive, and it use is limited to about 15 kW.

★ For regenerative breaking of the motor the power must flow from motor to the ac source and this is feasible only if motor counter emf is reversed because then $e_a i_a$ would be negative.

★ Direction of current cannot be reversed because as SCR are unidirectional devices. So for regenerative breaking the polarity of e_a must be reversed which is possible by reversing the direction of motor field current by making delay angle of full converter 2 more than 90°. In order that current in field winding can be reversed, the field winding must be energised through single phase full converter.





For the armature converter 1

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

For the field converter 2

$$V_f = \frac{2V_m}{\pi} \cos\alpha_1$$

rms value of source current $I_{sr} = \sqrt{I_0^2 \frac{\pi}{\pi}} = I_a$

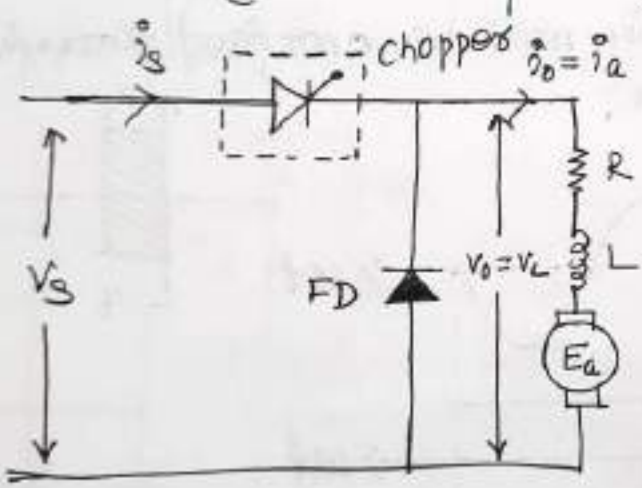
rms value of thyristor current $I_{Tr} = \left[I_0^2 \frac{\pi}{2\pi}\right]^{1/2} = \frac{I_0}{\sqrt{2}}$

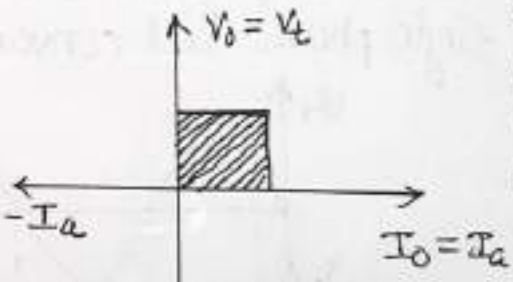
Speed Control of DC Motor using chopper :⇒

(1) Using Type-A chopper

power control or Motoring control :–

first Quadrant Operation





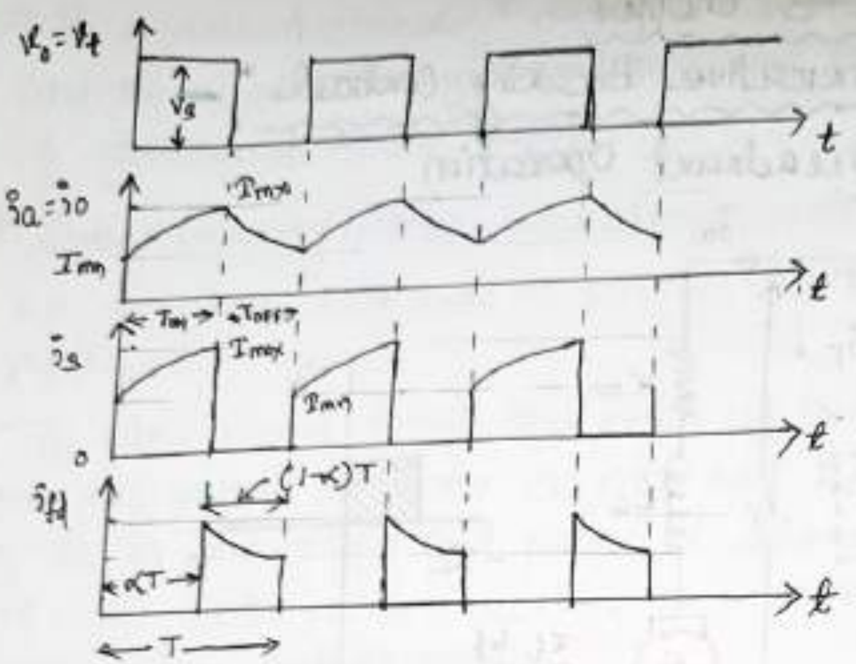
Average motor voltage $V_0 = V_t = \frac{T_{ON}}{T} V_s$

$= D\,V_s$

$= f\,T_{ON} \cdot V_s$

D = Duty cycle $= \frac{T_{ON}}{T}$

f = chopping frequency $= \frac{1}{T}$



power delivered to motor $= V_t I_a = D V_s I_a$

Average source current $= \frac{T_{on}}{T} I_a = D I_a$

Input power to chopper $= V_s D I_a$

For the motor armature circuit

$$V_t = D V_s = E_a + I_a(r_a + r_s)$$

$$= K_m \omega_m + I_a(r_a + r_s)$$

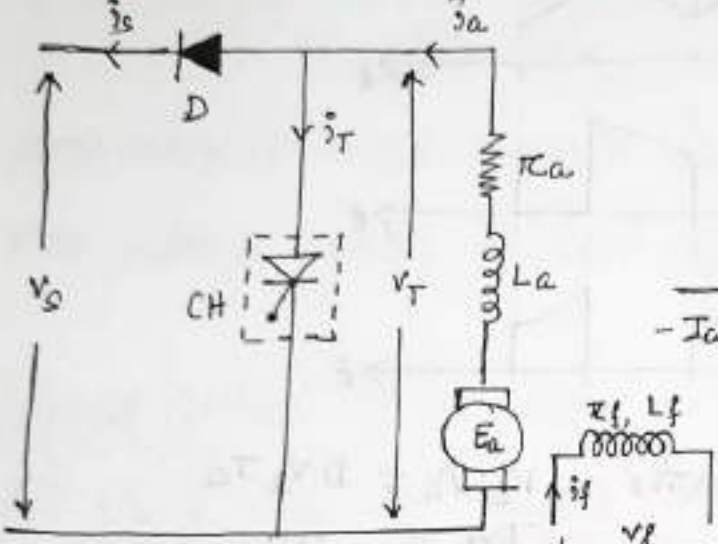
$$\Rightarrow \omega_m = \frac{D V_s - I_a(r_a + r_s)}{K_m}$$

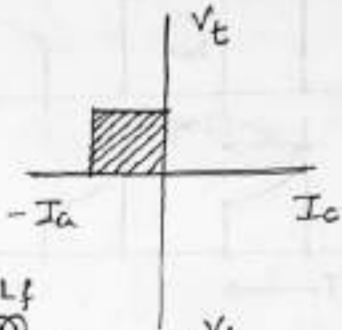
By varying the duty cycle D of the chopper, armature terminal voltage can be controlled and thus speed of the dc motor can be regulated.

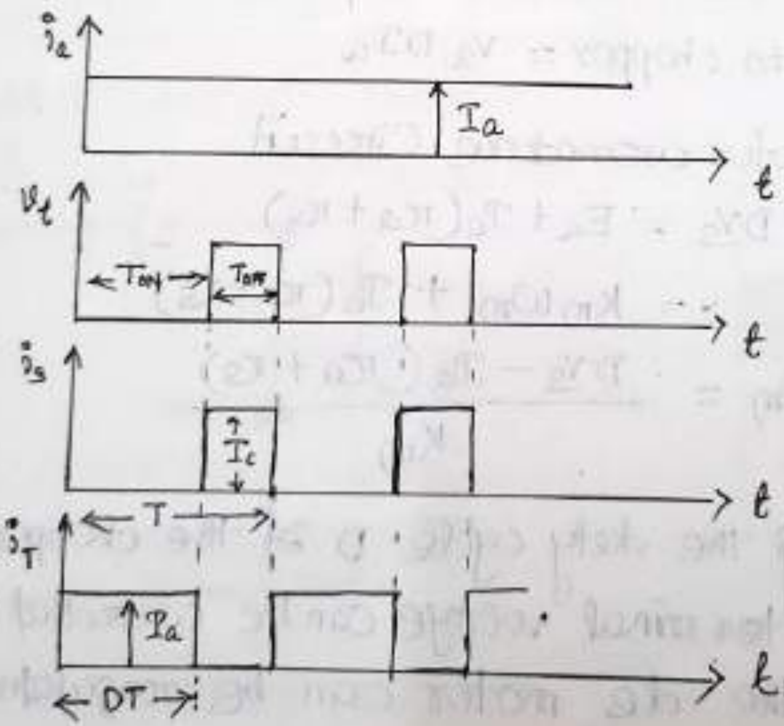
(2) Using Type-B chopper

Regenerative Braking Control :-

Second Quadrant Operation







* In regenerative braking control, the motor acts as generator and the kinetic energy of the motor and connected Load is returned to the supply.

* During motoring mode armature current $I_a = \frac{V_t - E_a}{r_a}$ i.e armature current is positive and the motor consume power.

* In case Load drives the motor at a speed such that average value of motor counter emf $E_a = K_m \omega_m$ exceeds V_t, I_a is reversed and power is delivered to the dc bus. The motor is then working as a generator in the regenerative braking mode.

* when CH ON current through armature inductance La rises as the armature terminals get short circuited through CH. Also $V_t = 0$ during T_{ON}.

* when CH OFF Ea being more than source voltage V_S, diode D conducts and the energy stored in armature inductance is transferred to the source. During T_{OFF} $V_t = V_S$.

* In regenerative braking control offers second Quadrant operation as armature terminal voltage has the same polarity but the direction of armature current is reversed.

The average voltage across chopper or armature terminal $V_t = \frac{T_{OFF}}{T} V_S = (1-D) V_S$

Power generated by the motor

$$= V_t I_a = (1-D) V_s I_a$$

Motor emf generated, $E_a = K_m \omega_m = V_t + I_a r_a$

$$= (1-D) V_s + I_a r_a$$

Motor speed during regenerative braking

$$\omega_m = \frac{(1-D) V_s + I_a r_a}{K_m}$$

when chopper is ON $E_a - I_a r_a - L_a \frac{di_a}{dt} = 0$

$$\Rightarrow (E_a - I_a r_a) = L_a \frac{di_a}{dt}$$

when chopper on L_a must store energy and current must rise i.e $\frac{di_a}{dt}$ must be positive

$$(E_a - I_a r_a) \geq 0$$

when chopper is OFF $E_a - I_a r_a - L_a \frac{di_a}{dt} = V_s$

$$\Rightarrow V_s - (E_a - I_a r_a) = -L_a \frac{di_a}{dt}$$

when chopper OFF $(E_a - I_a r_a)$ must be more than V_s for regeneration purposes and therefore $[V_s - (E_a - I_a r_a)]$ must be negative. This is possible only current decreases during off period i.e $\frac{di_a}{dt}$ in above expression must be negative

$$[V_s - (E_a - I_a r_a)] \leq 0$$

$$\Rightarrow -(E_a - I_a r_a) \leq (-V_s)$$

$$\Rightarrow (E_a - I_a r_a) \geq V_s$$

So the condition for controlling the power during regenerative braking as $0 \leq (E_a - I_a r_a) \geq V_s$

this condition for the two voltages and their polarity for the regenerative braking control.

Minimum braking speed is obtained when $E_a - I_a r_a = 0$

$$\Rightarrow K_m \omega_{mn} = I_a r_a$$

$$\therefore \text{Min}^m \text{ braking speed } \omega_{mn} = \frac{I_a r_a}{K_m}$$

Maximum possible braking speed is obtained when

$$E_a - I_a r_a = V_s$$

$$\therefore \text{Max}^m \text{ braking speed } \omega_{max} = \frac{V_s + I_a r_a}{K_m}$$

Thus regenerative breaking control is effective only when motor speed is less than ω_{mx} and more than ω_{mn}.

$$\omega_{mn} < \omega_m < \omega_{mx}$$

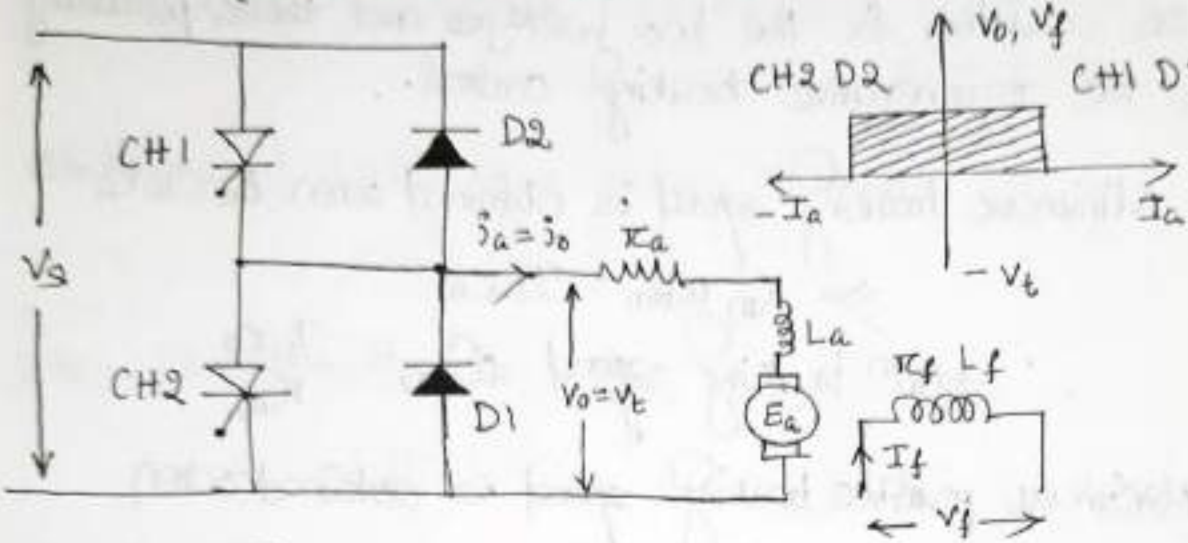
$$\Rightarrow \frac{I_a r_a}{K_m} < \omega_m < \frac{V_s + I_a r_a}{K_m}$$

Therefore the speed range for regenerative braking is

$$\frac{V_s + I_a r_a}{K_m} : \frac{I_a r_a}{K_m}$$

$$\Rightarrow V_s + I_a r_a : I_a r_a$$

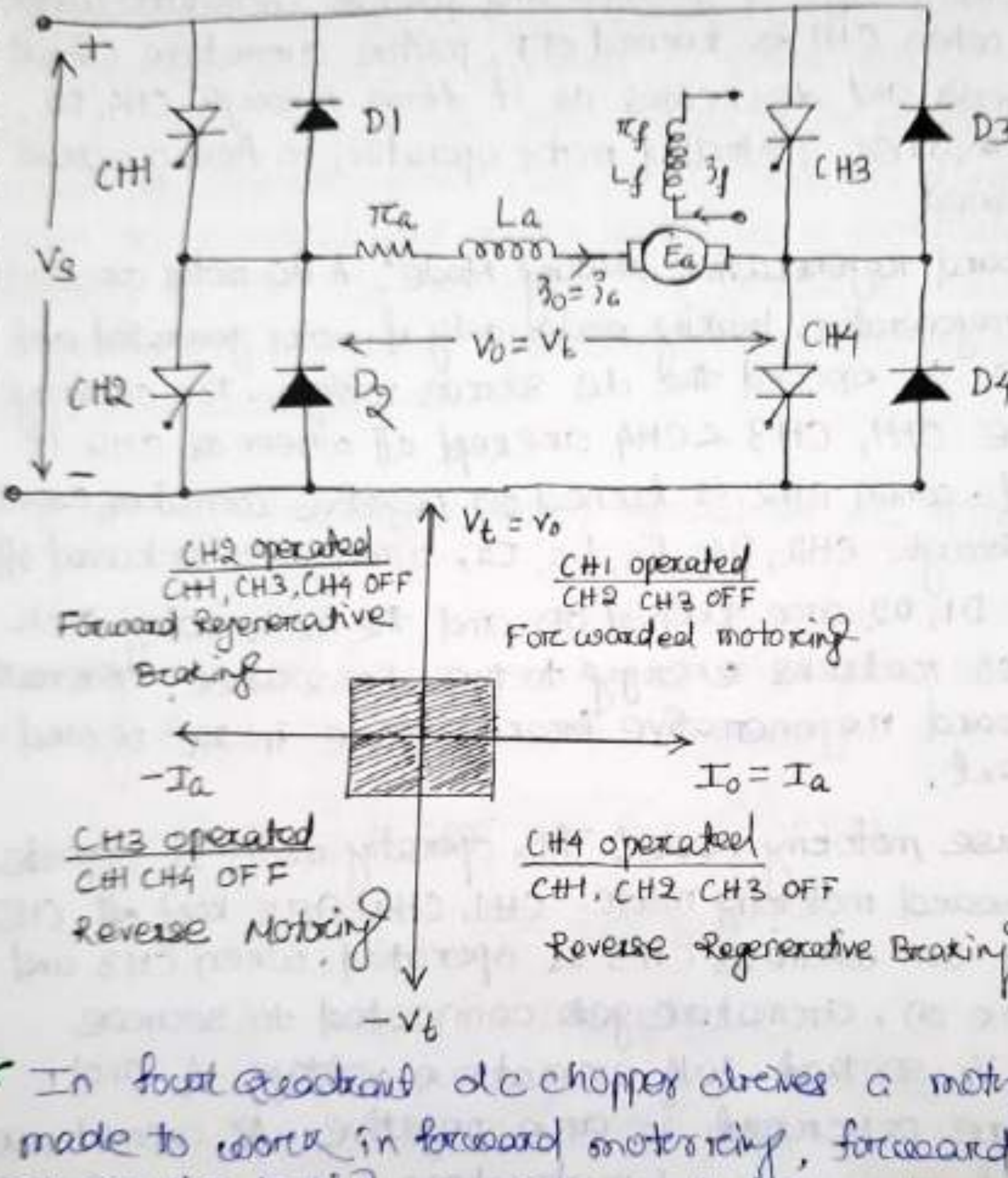
(3) Using Type-C chopper
two quadrant chopper drives :-



★ Motoring Mode: When CH1 ON the supply voltage V_s gets connected to armature terminals and therefore armature current i_a rises. When CH1 is OFF, i_a free wheel through D1 and therefore i_a decays. This shows that with CH1 & D1 motor control in first quadrant is obtained.

★ Regenerative Mode: When CH2 ON the motor acts as a generator and the armature current i_a rises and therefore energy is stored in armature inductance L_a. When CH2 OFF D2 gets turned ON and therefore direction of i_a is reversed. Now the energy stored in L_a is returned to dc source and second quadrant operation is obtained.

(4) Type-E chopper
Four Quadrant Chopper drives :-



★ In four quadrant dc chopper drives a motor can be made to work in forward motoring, forward regenerative braking, reverse motoring and reverse regenerative braking mode.

★ **Forward motoring Mode**: During this mode or first quadrant operation, CH2, CH3 are kept OFF, CH4 is kept ON whereas CH1 is operated. when CH1, CH4 are ON motor voltage is positive and positive armature current rises. when CH1 is turned OFF, positive armature current free wheels and decreases as it flows through CH4, D2. In this manner controlled motor operation in first quadrant is obtained.

★ **Forward regenerative braking Mode**: A dc motor can work in the regenerative braking mode only if motor generated emf is made to exceed the dc source voltage. For obtaining this mode CH1, CH3 & CH4 are kept off whereas CH2 is operated. when CH2 is turned on negative armature current rises through CH2, D4, Ea, La, ra, when CH2 is turned off diodes D1, D2 are turned on and the motor acting as a generator returns energy to the dc source. This result in forward regenerative braking mode in the second quadrant.

★ **Reverse motoring Mode**: This operating mode is opposite to forward motoring mode. CH1, CH4 are kept off CH2 is kept on whereas CH3 is operated. when CH3 and CH2 are on, armature gets connected to source voltage V_s so that both armature voltage V_t and armature current i_a are negative. As armature current is reversed, motor torque is reversed and consequently motoring mode in third quadrant is obtained. When CH3 is turned off negative armature current free wheels through CH2, D4, Ea, La, ra, armature current decreases and thus speed control is obtained in third quadrant. During this mode, polarity of Ea must be opposite to that.

★ Reverse Regenerative braking mode : As in forward braking mode, reverse regenerative braking mode is feasible only if motor generated emf is made to exceed the dc source voltage. For this operating mode CH1, CH2 & CH3 are kept off where as CH4 is operated. When CH4 is turned on positive armature current i_a rises through CH4, D2 r_a, L_a, E_a. This mode also polarity of motor emf E_a must be opposite. When CH4 is turned off, diode D2, D3 begin to conduct and motor acting as a generator returns energy to the dc source. This leads to reverse regenerative braking operation of the dc motor in fourth quadrant.

List of factors effecting speed of AC Motors :→

When 3∅ supply is connected to 3∅ stator winding rotating magnetic field is produced. The speed of this rotating field, called synchronous speed is given by

$$N_s = \frac{120 f_1}{P} \text{ rpm} \quad \text{or} \quad n_s = \frac{2 f_1}{P} \text{ rps}$$

$$\omega_s = \frac{4\pi f_1}{P} = \frac{2\omega_1}{P} \text{ rad/sec}$$

f_1 = supply frequency
ω_1 = supply frequency in rad/sec
P = number of stator poles

otor can not attain synchronous speed It must un at a speed N_r less then N_s

$$N_r = N_s(1-S) \qquad \omega_m = \omega_s(1-S)$$

N_r = rotor speed in rpm
ω_m = rotor speed in rad/sec

$$S = \text{slip} = \frac{N_s - N_r}{N_s} = \frac{\omega_s - \omega_m}{\omega_s}$$

CH = 5

PLC AND ITS APPLICATIONS

Introduction of Programmable Logic Controller :→

* A programmable logic controller (PLC) is an industrial grade computer that is capable of being programmed to perform control functions.

* The programmable controller has eliminated much of the hard wiring associated with conventional relay control circuit.

* The benefits of PLC include fast response, easy programming and installation, high control speed, network compatibility, troubleshooting and testing convenience and high reliability.

* A PLC is an example of a real time system since the output of the system controlled by the PLC depends on the input conditions.

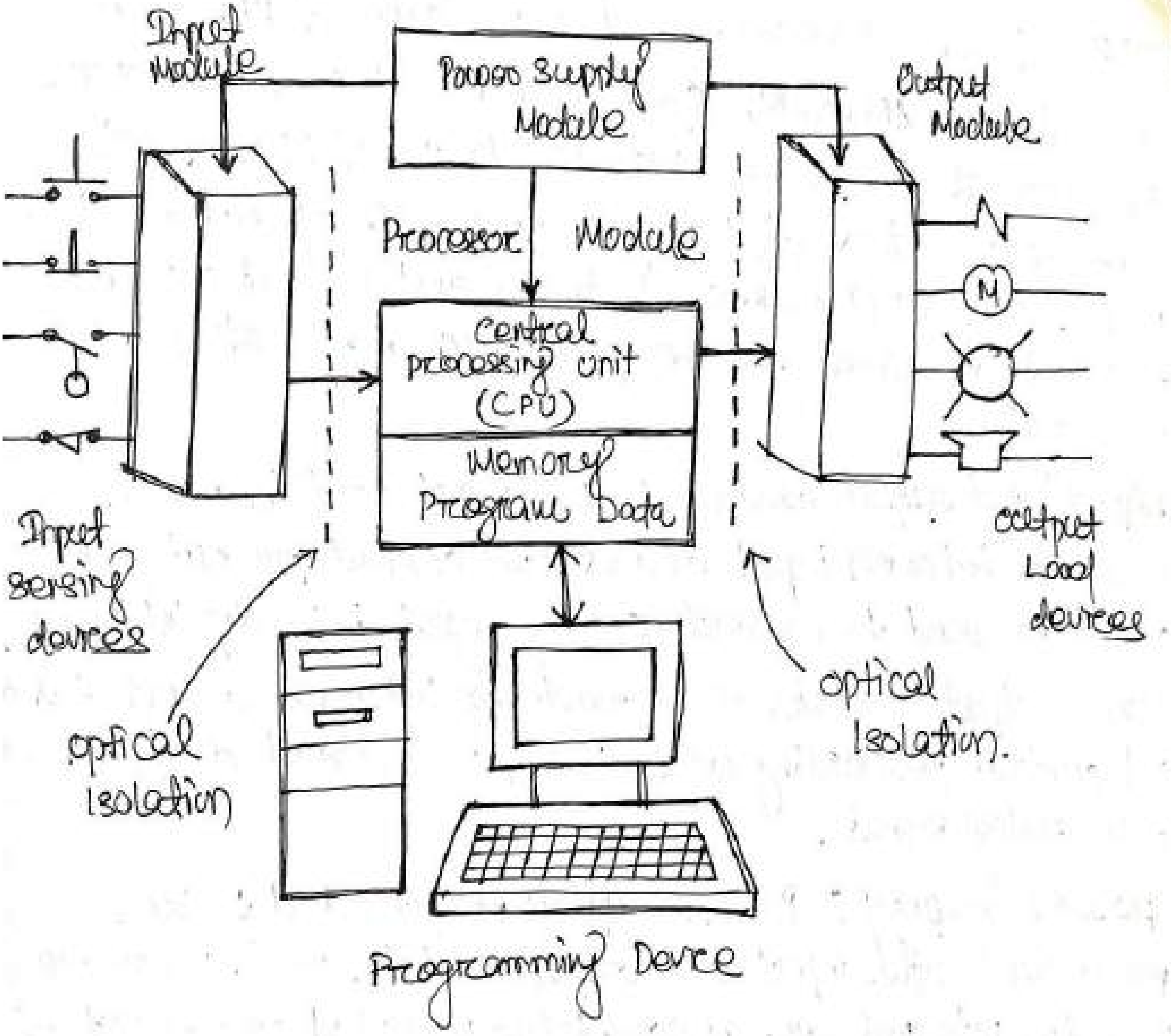
* The PLC is then basically a digital computer designed for use in machine control. Unlike a personal computer it has been designed to operate in the industrial environment and is equipped with special input/output interfaces and a control programming language.

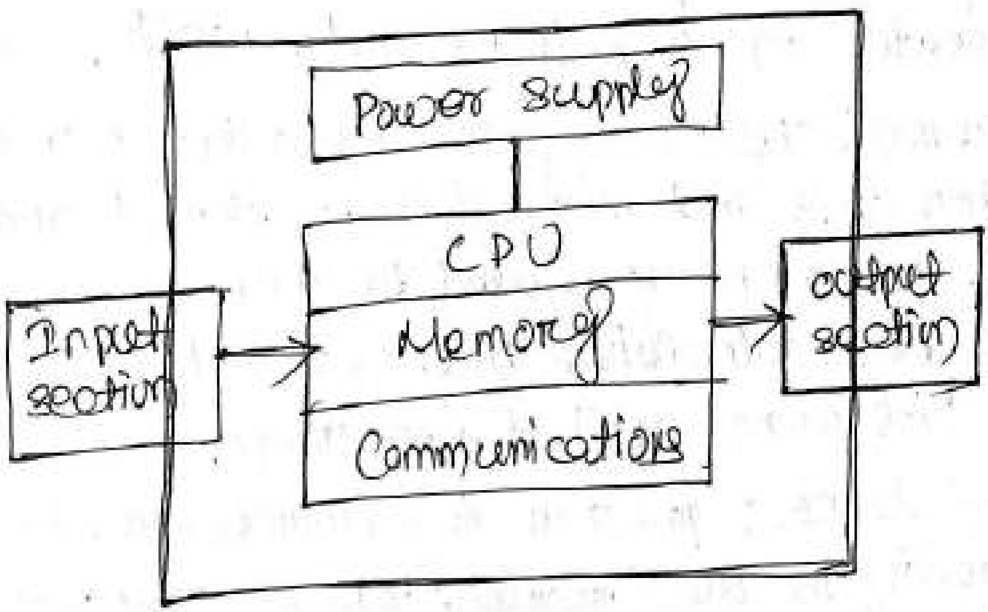
* Programmable controllers offer several advantages over a conventional relay type of control. Relay have to be hardwired to perform a specific function. When the system requirements change, the relay wiring has to be changed or modified. In extreme cases such as in the auto industry complete control panels had to be replaced since it was not economically feasible to rewire the old panels with each model changeover. The programmable
* controller has eliminated much of the hardwiring associated with conventional relay control circuit.

Advantages of PLC :→

1. Increased Reliability
2. More Flexibility
3. Low cost
4. C/B Communications capability
5. Fast Response Time
6. Easier to Troubleshoot
7. Easier to test field devices

Parts of PLC :→


Input Module
Power Supply Module
Output Module
Processor Module
Central processing unit (CPU)
Memory
Program Data
Input sensing devices
Output Load devices
optical Isolation
optical Isolation
Programming Device


Power Supply
CPU
Memory
Communications
Input section
output section

CPU : The processor section is brain of PLC which consists of RAM, ROM, logic solver and user memory. CPU the central processing unit is heart of PLC. . CPU controls, monitors and supervises all operation within PLC. The CPU makes decision and executes control instructions based on the program instruction in memory.

→ Input and output module : The input module is a mediator between input devices and central processing unit which is used to convert analog signal into digital signal. The output module is a mediator between output device and central processing unit which is convert digital signal into analog signal.

C/B power supply : Power supply is provided to the processor unit, input and output module unit. power supply may be integral or separately mounted unit. most of the PLC operates 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 math calculation, bar code data etc. User memory contains user's application program

Programming device : programming devices are dedicated used for loading the user program into program memory or edit it and to monitor the execution of the program of the PLC. It is used to troubleshoot the PLC ladder logic program. Hand held terminal or dedicated terminal or personal computer are programming device commonly used in most of the PLC

Application of PLC :→

(1) Industrial Applications of PLC →

1. Transportation system likes conveyor Belt system
2. Packing and Labeling system in Food & Beverage
3. Automatic Bottle or Liquid Filling system.
4. Packaging and Labelling system in pharma industries
5. Transportation system like Escalator and Elevator
6. Industrial crane control system for operation of overhead Traveling Crane
7. Glass industries for glass production and recording data
8. Paper industries for the production of pages, Books or news papers.
9. cement industries for manufacturing or mixing the right quality and quantities of raw materials and accuracy of data regarding.
10. Automatic Drainage water pump monitoring and controlling system
11. Time and count based control system for an industrial machine.
12. Temperature controller or Humidity by using the sensors input to the PLC system.
13. Fault detection and protection of industrial machines like an induction motor.
14. wind turbine system for maximum efficiency Recording Data and safety purposes.

(15) Conveyor Belt system controls the sequence of conveyors and interlocking procedure.

(16) Energy management system like Boiler, Ball milling coal kiln, shaft kiln etc.

(17) Oil and gas industries for controlling the purging procedure.

② Power system Application →

① PLC uses for the smart grid system to monitor and detect fault conditions.

② It is used in the power generation, Transmission and Distribution system

③ In the power substation PLC can use the Auto Assembly line system

④ Some electrical Equipment like Circuit breaker tripping, capacitor switching can be automatically operated with PLC

⑤ A single phase or three phase sequence detect by using the PLC.

⑥ In oil and gas an Automation power plant, PLC needs for valve switching for changeover of fuels, pilot light ON or OFF, Flame safety checking, oil Filtering procedure and more things.

⑦ Real time PLC uses in underground Coal mine or water level sensing and data survey

(3) Commercial Application →
(1) Smart Traffic control signal system
(2) Smart Elevator control system
(3) Fire Detection and Alarm system
(4) Automatic Machine Handling system
(5) Automatic Vehicle washer system
(6) Automated Guided Vehicle system
(7) In the Roller coasters machine
(8) Automation system for well Drainage system
(9) Luggage Handling system at the Airport
(10) pressure controller in multi Motor pump Applications
(11) sequence or Numerical counting and packing system
(12) Mining Equipment Line detection and Remote control system
(13) wind turbine operation.

(4) Domestic Application of PLC →
(1) water tank level control system
(2) car washing and parking system
(3) Flashing Light controlling system
(4) Automatic door opening/closing system
(5) Remote Monitoring Application like Air compressor, Fan.
(6) ON/OFF switching Application light, Motor, and more daily life application of PLC

(5) Education Application →
Engineering ~~sys~~ students mostly prefer the automation system for doing their academic or research project.

Ladder Diagram :→

* A symbolic depiction of instructions arranged in rungs similar to ladder formatted schematic diagrams.

* A ladder diagram is a type of schematic diagram used in industrial automation that represents logic control circuits.

* Ladder diagrams are composed of two vertical power rails and horizontal logic rungs to form what looks like a ladder.

* The control logic in a ladder diagram is contained within the rungs.

* Ladder diagrams actually looks like a ladder and are commonly known as ladder logic programming.

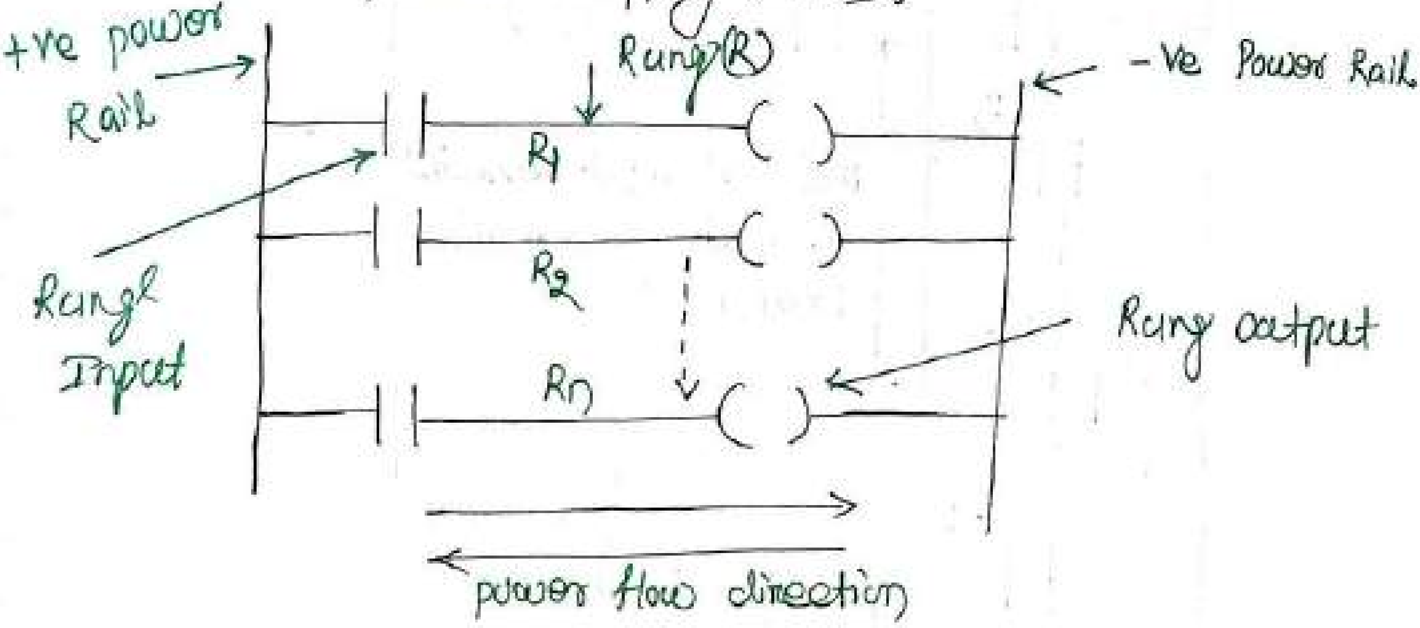
* The ladder diagram is the universal programming language of PLC. It has a short abbreviation as L D and also known as Ladder logic.

* In the ladder diagram the programming language that used to create the program to control the PLC system is known as Ladder diagram Language or ladder logic Language

* Different symbols used in ladder diagram

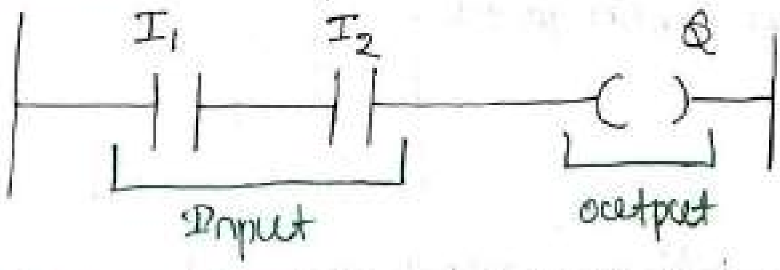
1> Rungs
2> Braches
3> Inputs and outputs for PLC programming
4> Addressing inputs and outputs
5> Instructions.

1> Rungs : In ladder diagram the horizontal lines called Rungs. we can put as many numbers of rungs as per your project requirements, and the vertical lines shows the power supply lines.

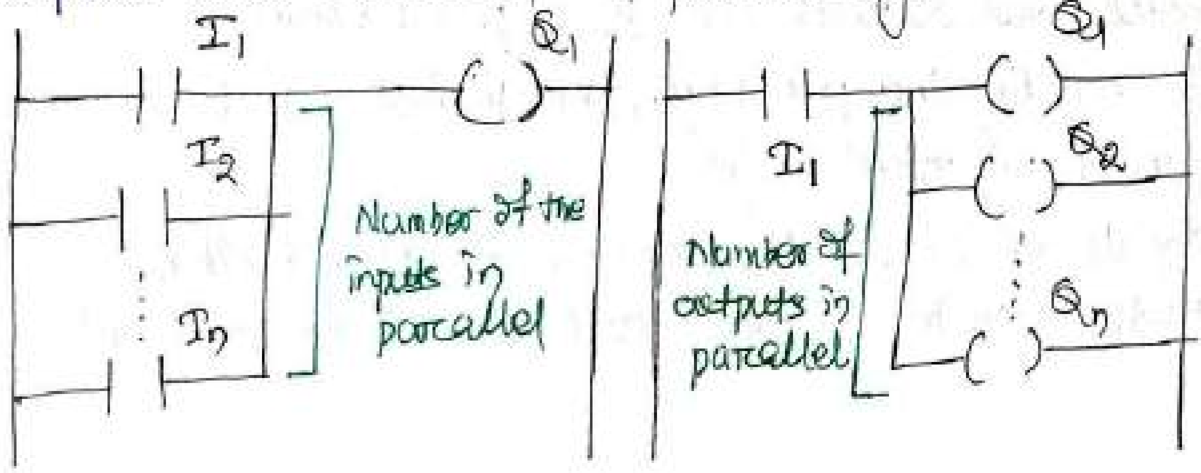


~~2> Branches~~ 2> Branches :

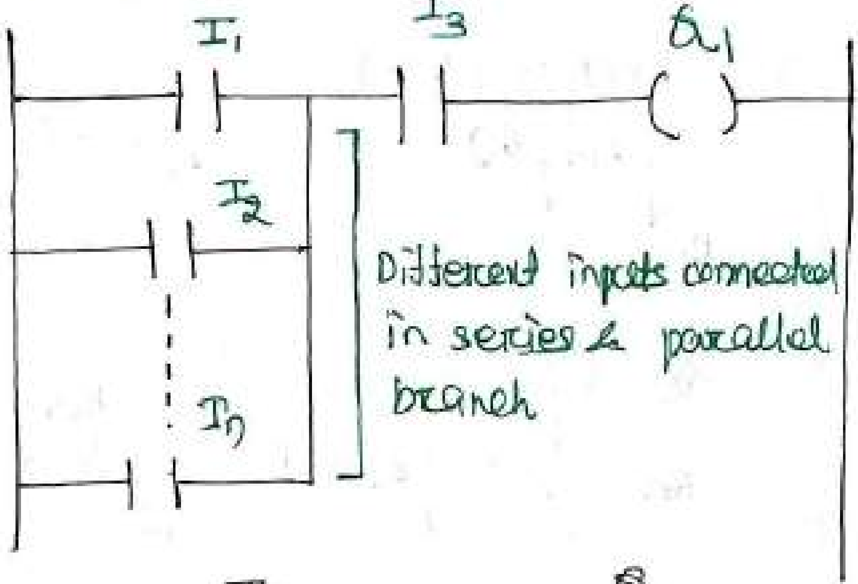
① Series Branch – Inputs and outputs are connected in series

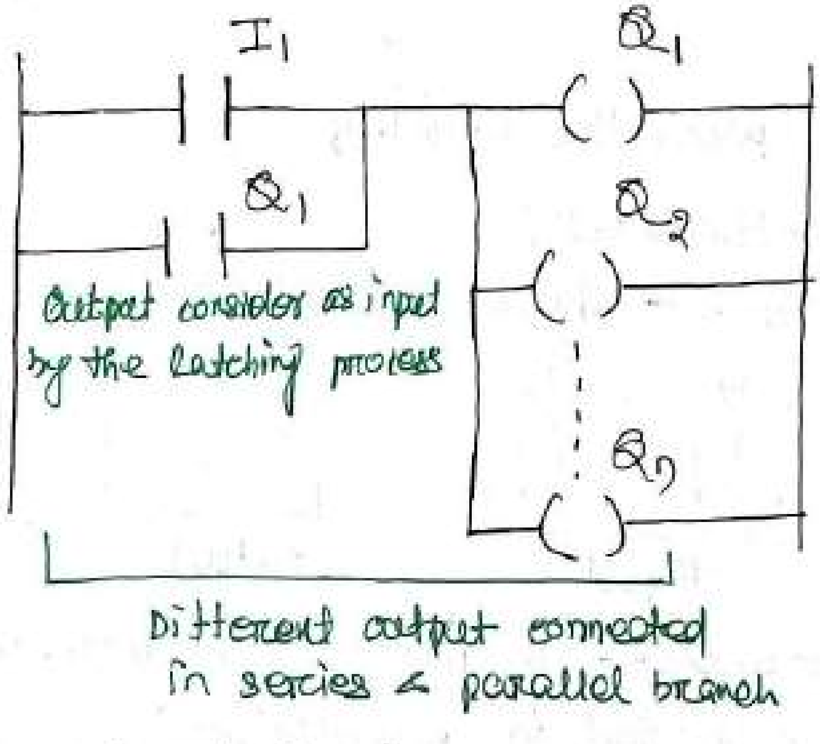


② Parallel Branch – In parallel branch, inputs and outputs are connected in parallelly.



③ Nest Branch — The combination of series and parallel branches in the same or different rungs are called as Nest branch.



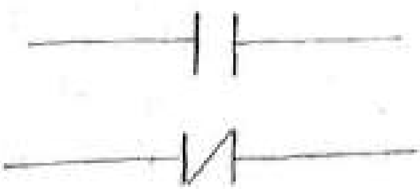


3> Inputs and outputs for PLC programming:

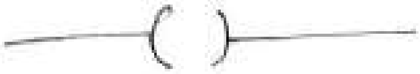
For writing the program, inputs and outputs are playing the most important role

Inputs refer to the switch or push Button

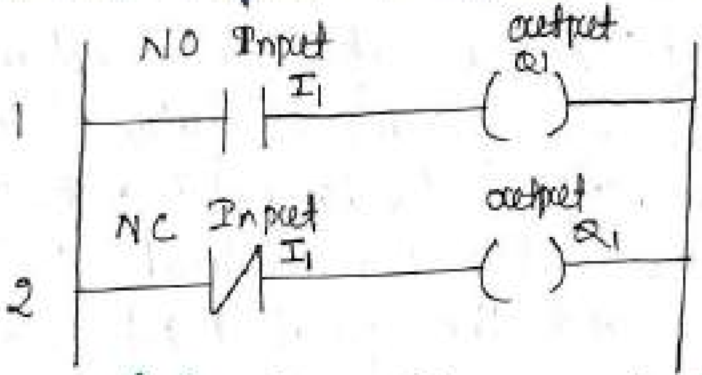
Output refer to the coil or lamp or load

Inputs :  NO → Normally open

NC → Normally closed

output : 

The inputs and outputs looks in LD programming like



Advantages of ladder Diagram in PLC Languages →

→ The ladder diagram is a simple logic construction and more reliable than an electronic circuit controller

→ Easy to learn and read the program

→ Every programming symbol performs specific actions

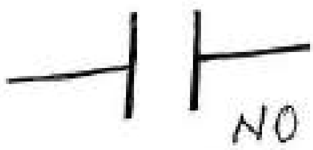
→ LD having good representation for discrete logic

→ Easy to troubleshoot.

→ Shut down the power without the switch.

Description of contacts and coils :→

① Normally Open :→ It is a contact that does not flow current in its normal state. Energizing it and switching it on will close the contact, causing it to allow current flow.



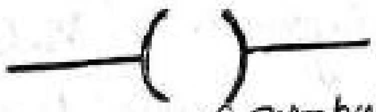
(symbol)

② **Normally closed** :→ It is a contact that flows current in normal state. Energizing it and switching it on will open the contact causing it to not allow current flow.

(symbol)

③ **Energized output** :→ The output Energized instruction (OTE) will energize a single bit of data if the input leading to it is true. It's a fundamental instruction used in PLC. If the same instructions evaluate to false the OTE instruction will set the specified bit to a low state

*



(symbol)

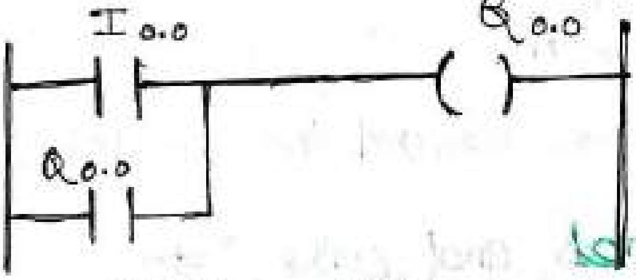
④ **Latched output** :→

C/B

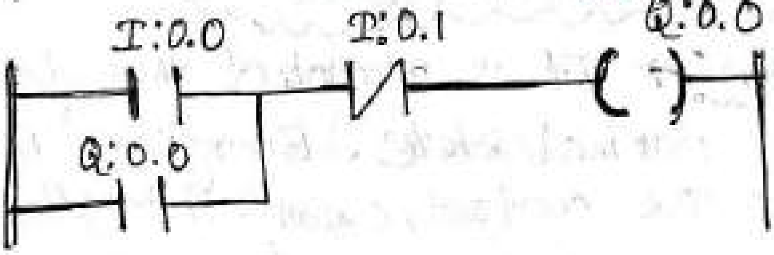
Latch ⇒ Become fixed in a particular state

It is an output instruction used to maintain or latch an output on, even if the input condition changes

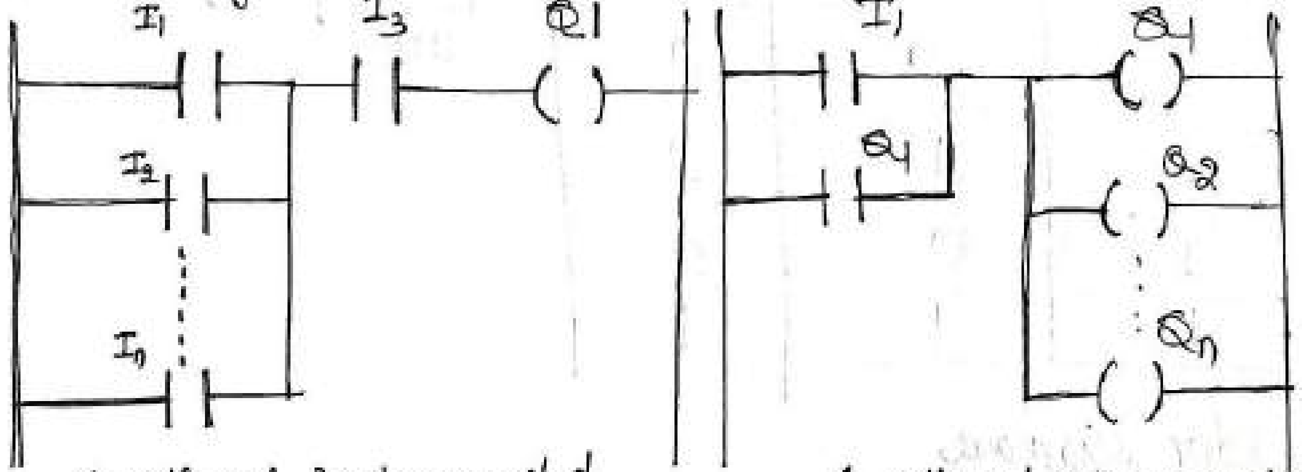
Eg:- ①



②



⑤ **Branching :→** Branching simply means adding more rungs that are associated with the same output or having multiple outputs for the same inputs. we can also have a combination of both like having multiple inputs and multiple outputs for each rung all depending on the logic and how to solve the program.



(Different inputs connected in series & parallel branch)

(Different outputs connected in series & parallel branches)

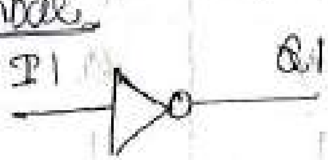
Ladder Diagram for Logic Gates :→

① **NOT Gate :-** NOT gate works as inversion. It takes one inputs and gives one output. when the input is high then the output is low and vice-versa.

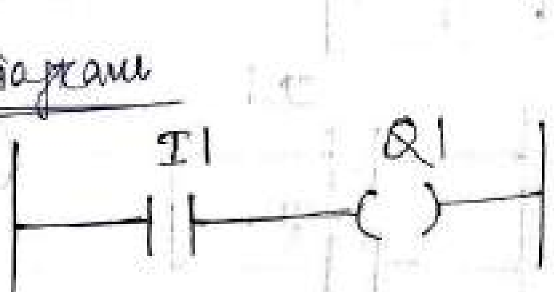
Truth Table

I/p (I1)	O/p (Q1)
0	1
1	0

Symbol



Ladder Diagram

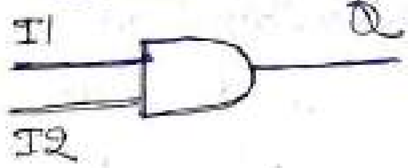


(2) AND Gate :- In AND gate when both inputs are high then the output will be high. for all other inputs will be the low.

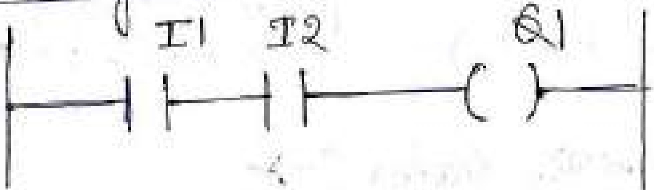
Truth table

I/p (I1)	I/p (I2)	O/p (Q1)
0	0	0
0	1	0
1	0	0
1	1	1

Symbol



Ladder Diagram

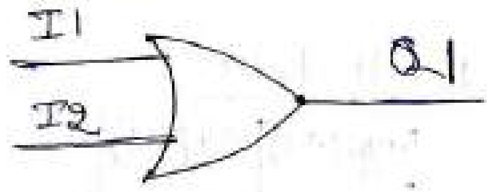


(3) OR Gate :- In OR gate both or any one inputs are closed the coil or output will on.

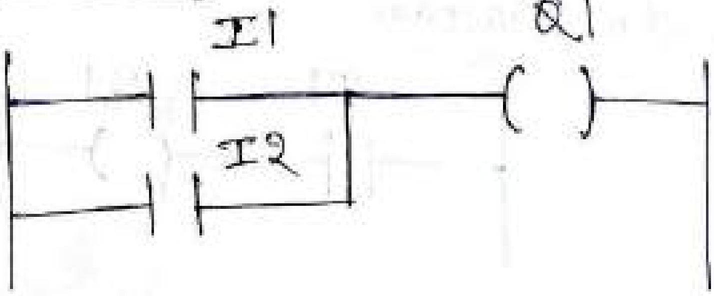
Truth Table

I/p (I1)	I/p (I2)	O/p (Q1)
0	0	0
0	1	1
1	0	1
1	1	1

Symbol



Ladder Diagram

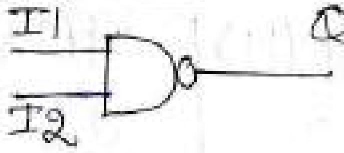


(4) NAND gate :- If both switches or anyone switch are closed the lamp will be glow. In the case both switches are open then the lamp will not be glow.

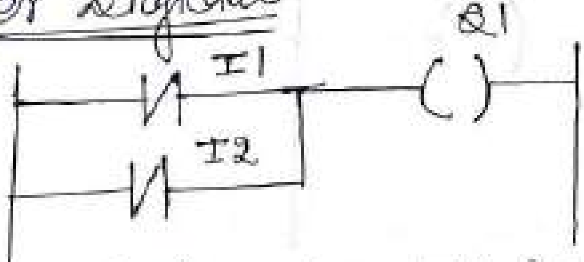
Truth Table

I/p (I1)	I/p (I2)	O/p (Q1)
0	0	1
0	1	1
1	0	1
1	1	0

Symbol



Ladder Diagram

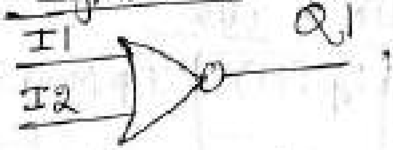


(5) NOR gate :- when both inputs are low then the output will be high. Otherwise the low output will occur if both inputs are high.

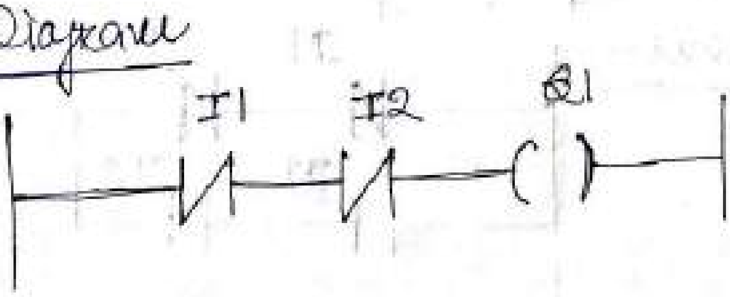
Truth Table

I/p (I1)	I/p (I2)	O/p (Q1)
0	0	1
0	1	0
1	0	0
1	1	0

Symbol



Ladder Diagram



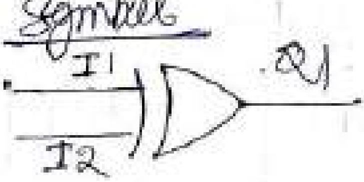
(6) EX OR Gate :-

If both inputs are high or low the output will becomes low. For any other inputs condition, the output will be high.

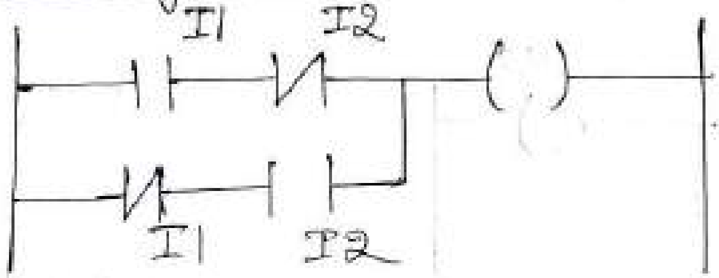
Truth table

I/p (I1)	I/p (I2)	O/p (Q1)
0	0	0
0	1	1
1	0	1
1	1	0

Symbol



Ladder Diagram



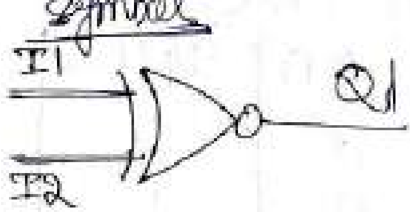
(7) EX NOR gate :-

when both inputs are high or low then the output will high. if any one input is high or low then the output will become low

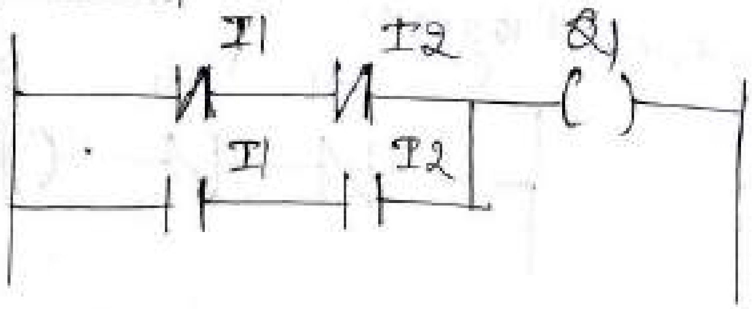
Truth Table

I/p (I1)	I/p (I2)	O/p (Q1)
0	0	1
0	1	0
1	0	0
1	1	1

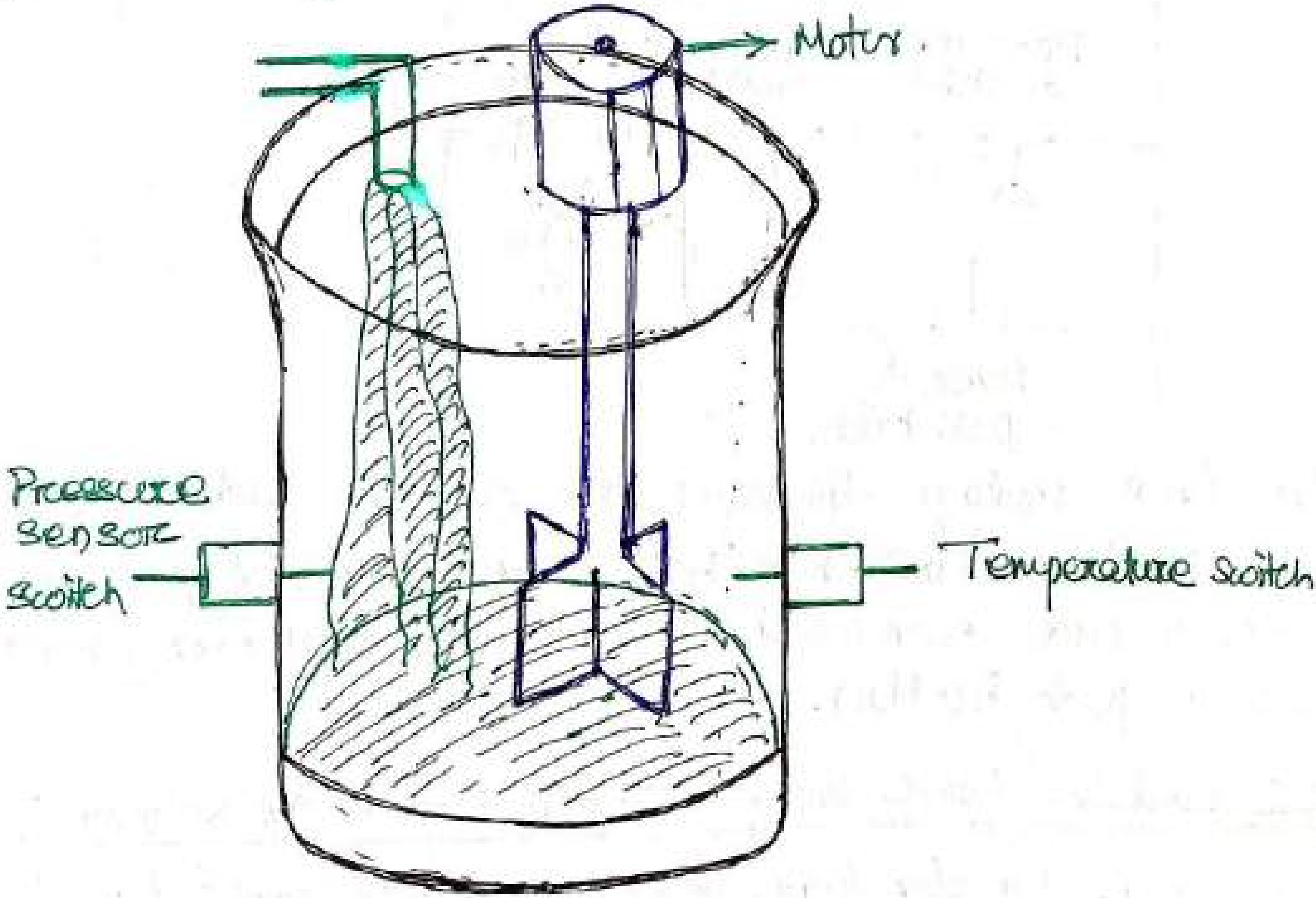
Symbol



Ladder Diagram



PLC Working Principle :→



⇒ To learn about PLC working principle we discuss a simple example in which we study its manual process control, then relay control and finally we can control process by PLC

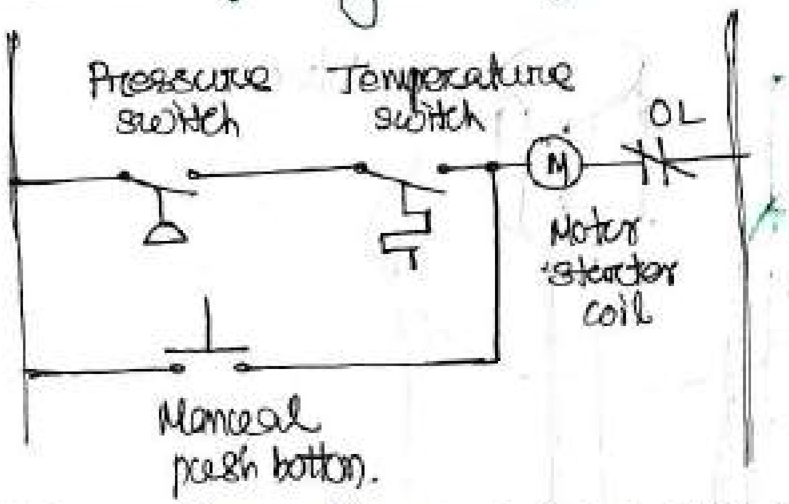
Manual Control :-

⇒ In given diagram we take an example of a motor control mixer. In this process we are using two sensors, the first one is temperature other one is pressure.

⇒ These two sensors are connected with motor and their values have already set.

⇒ when we start a motor with manual push button motor mix the liquid and when set value of temperature and pressure is reached the connected sensor make their contacts closed and tell about process control. By knowing this we can start or stop our motor.

Motor control by using Relay:-



* In given relay diagram we can see that the motor will start working when both temperature and pressure switches are connected or the motor will work when we press a push button.

PLC Ladder Logic Program with Addressing scheme:-

→ The PLC ladder logic program is built and fed in the storage of the central processing unit

C/B ←

→ A distinctive ladder logic program for this procedure is displayed in given diagram.

→ The arrangement used to similar to the arrangement of the wired relay ladder circuit.

→ The discrete symbols is this circuit signify command while the numbering signifies the order position statements

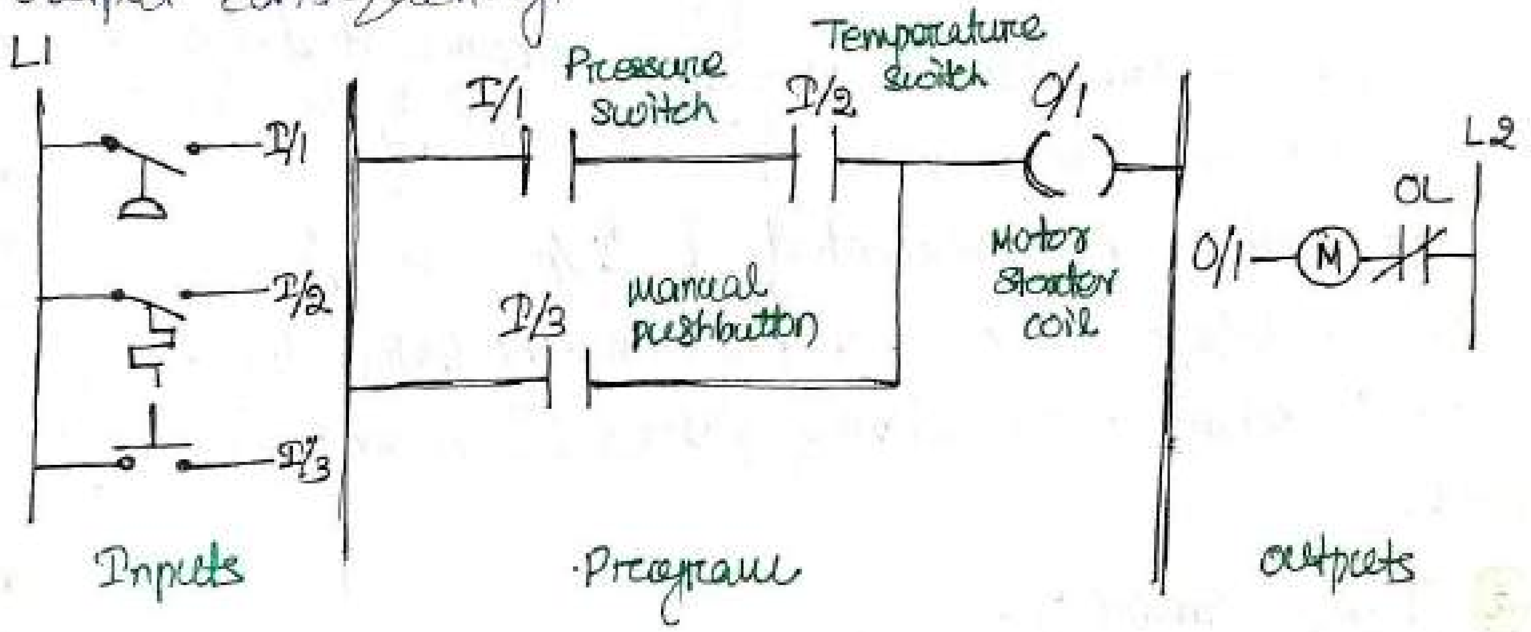
→ To give programming instruction to the controller, you feed these commands one by one in the CPU memory from the programming component.

→ Every input and output component will be assigned a special location address which will allow PLC to know about where it is physically connected.

→ The input and output address will be different for different manufacturing companies.

→ commands are put in the user program part of the CPU storage

→ throughout the program scanning, the controller observes the inputs implements the controller program and vary the output consequently.



(PLC Ladder Logic Program with Addressing scheme)

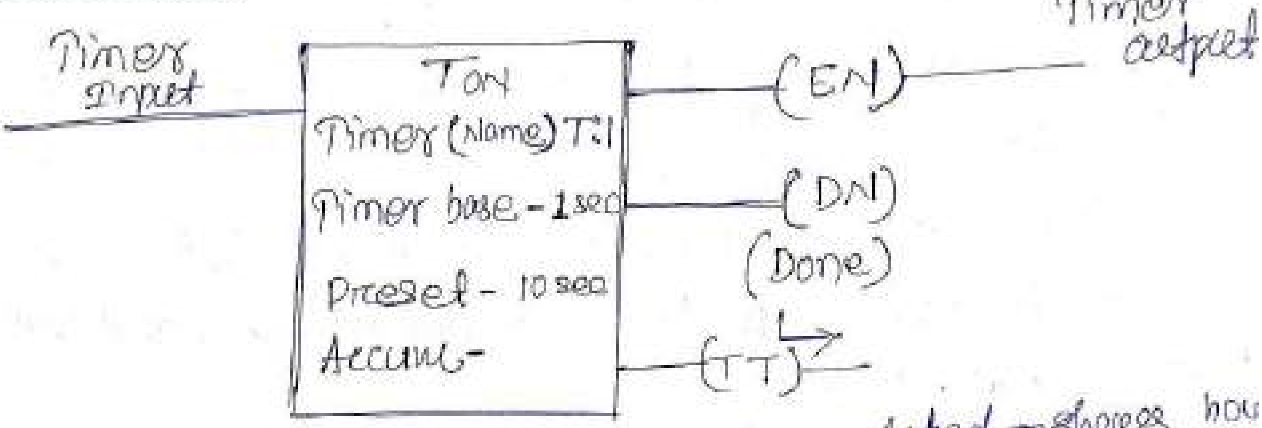
Timer :→

Ton → on delay timer
Toff → off delay timer
Retentive Timer → on/off timer

$I/p \xrightarrow{T_{ON}} O/p$ O/p on after 10 sec T_{ON}

$I/p \xrightarrow{T_{OFF}} O/p$ O/p off after 10 sec T_{OFF}

① TON Timer :-



Accumulated → shows how long the timer has been timing

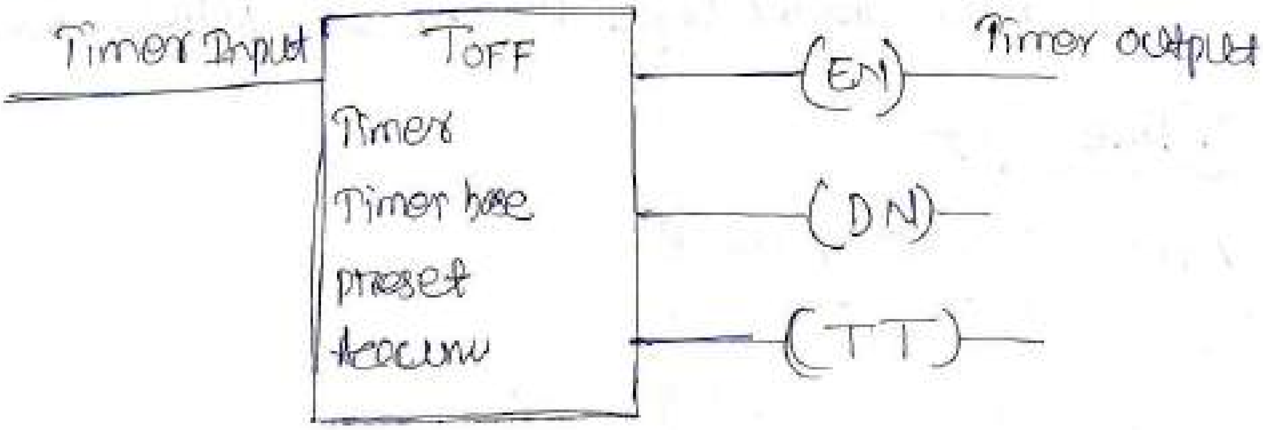
Time = Time base x preset

10 = 1 sec x 10

present = Accumulated   I/p ⟶ O/p

An on delay timer is a programming instruction which used to start momentary pulses for a set period of time

② TOFF Timer :-



An off delay timer is a PLC programming instruction which use to switch off the output or system after a certain amount of time.

EN ⟶ Enable

DN ⟶ Done

TT ⟶ Timer Timing

Timer → File name in PLC tag. This tag is where you can find the timer's preset and accumulated values and the timer enabled, timing and done bits

preset → The timer preset value is the number that shows the delay length of the timer. This number can be changed by just typing it in or you can have the PLC write a number into this value. This number does not change during the timer's normal operation.

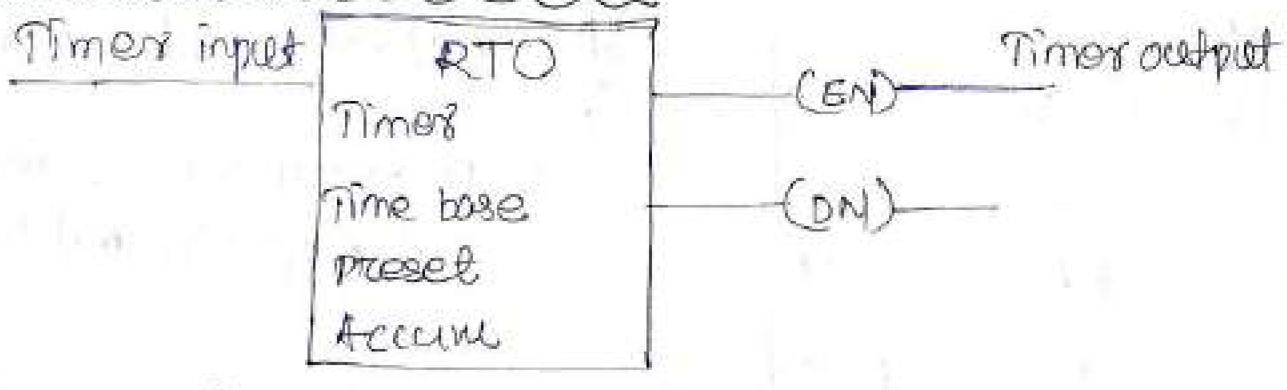
Accumulated → The timer accumulated value is the number that shows how long the timer has been timing

Enabled → The timer enabled bit will be on when the timer is enabled

Timing → The timer timing bit will be on when the timer is timing.

Done → A time done bit is true when the accumulated value is equal to the preset value.

③ Retentive Timer on/off (RTO) :-



→ The main function of the RTO is used to hold or store the set accumulated time.

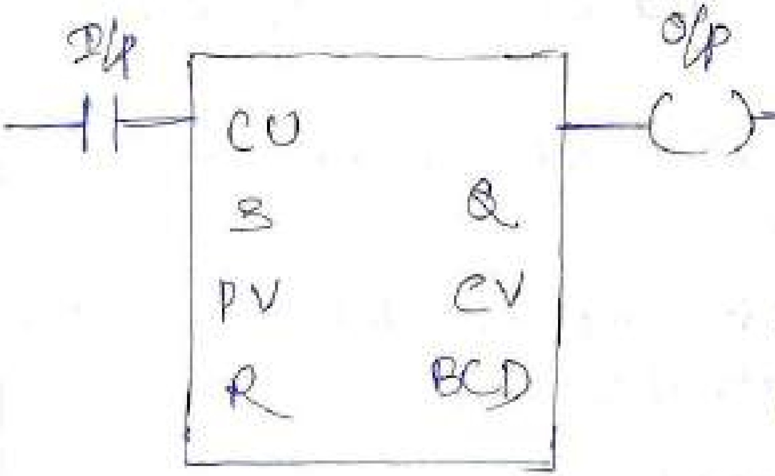
→ RTO is used in the case when there is a change in the rung state, power loss or any interruption in the system.

Counters – CTU, CTD :→

It is define as the counter in PLC programming as an instruction which is useful for sequential counting as digital signal pulse or the number of digits. The instruction is denoted by the C in LD programming

CTU :→ Up counter → counts from zero to the preset value, basically it increases the pulse or number

CTD → Down counter → counts from preset value to zero. It decreases the pulse or number



S → set the value of a counter

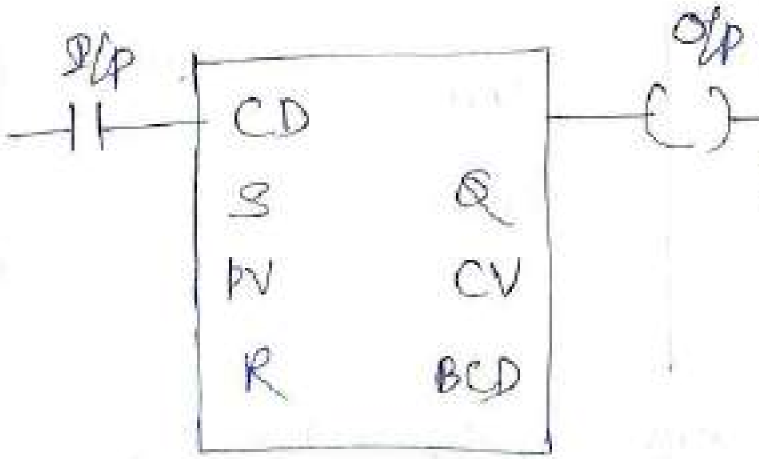
Q → output of the counter

R → Reset value

PV → preset value

CV → count variable

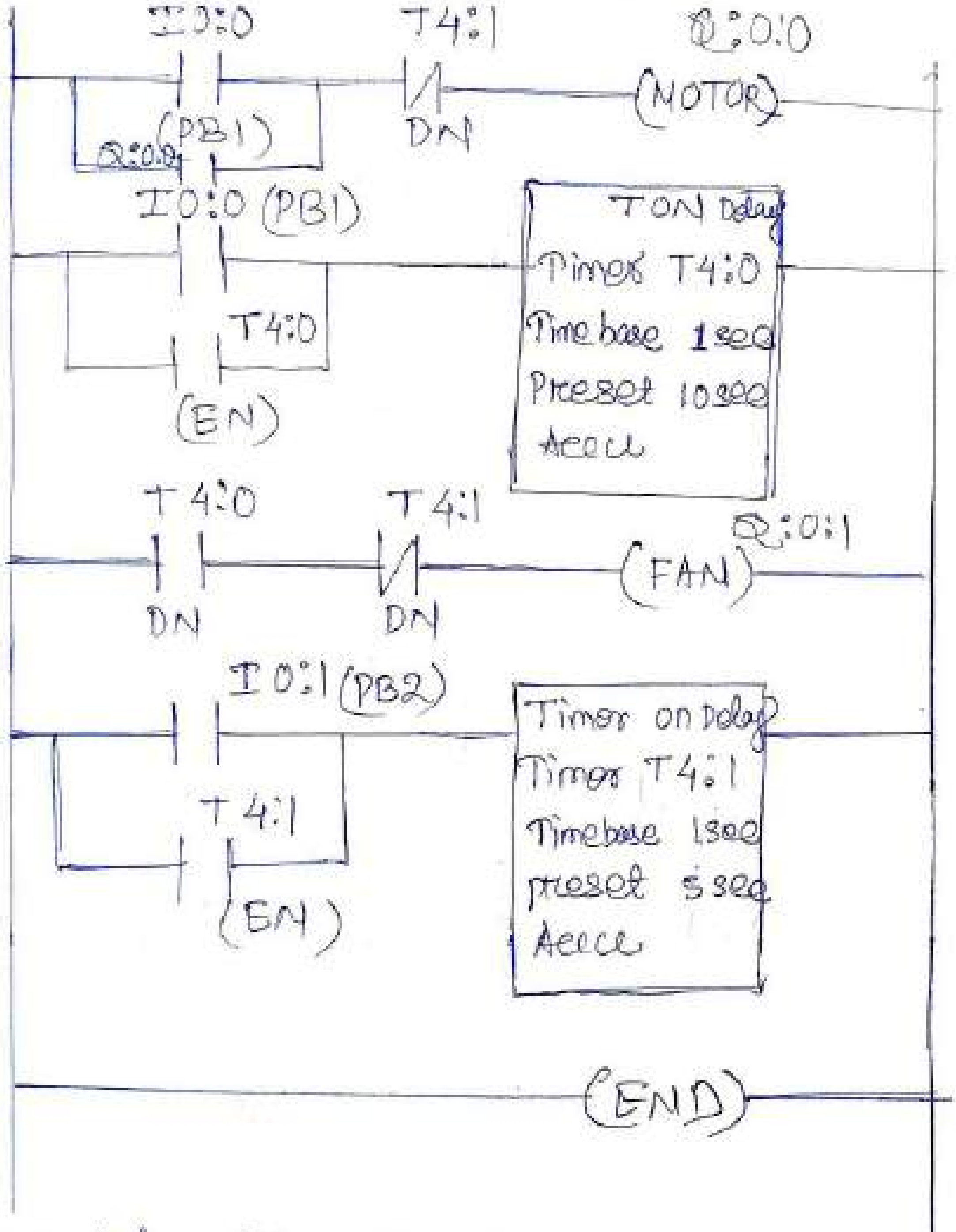
BCD → current count in binary decimal code



Ladder diagram using timer and counters :→

Timer Programming :—

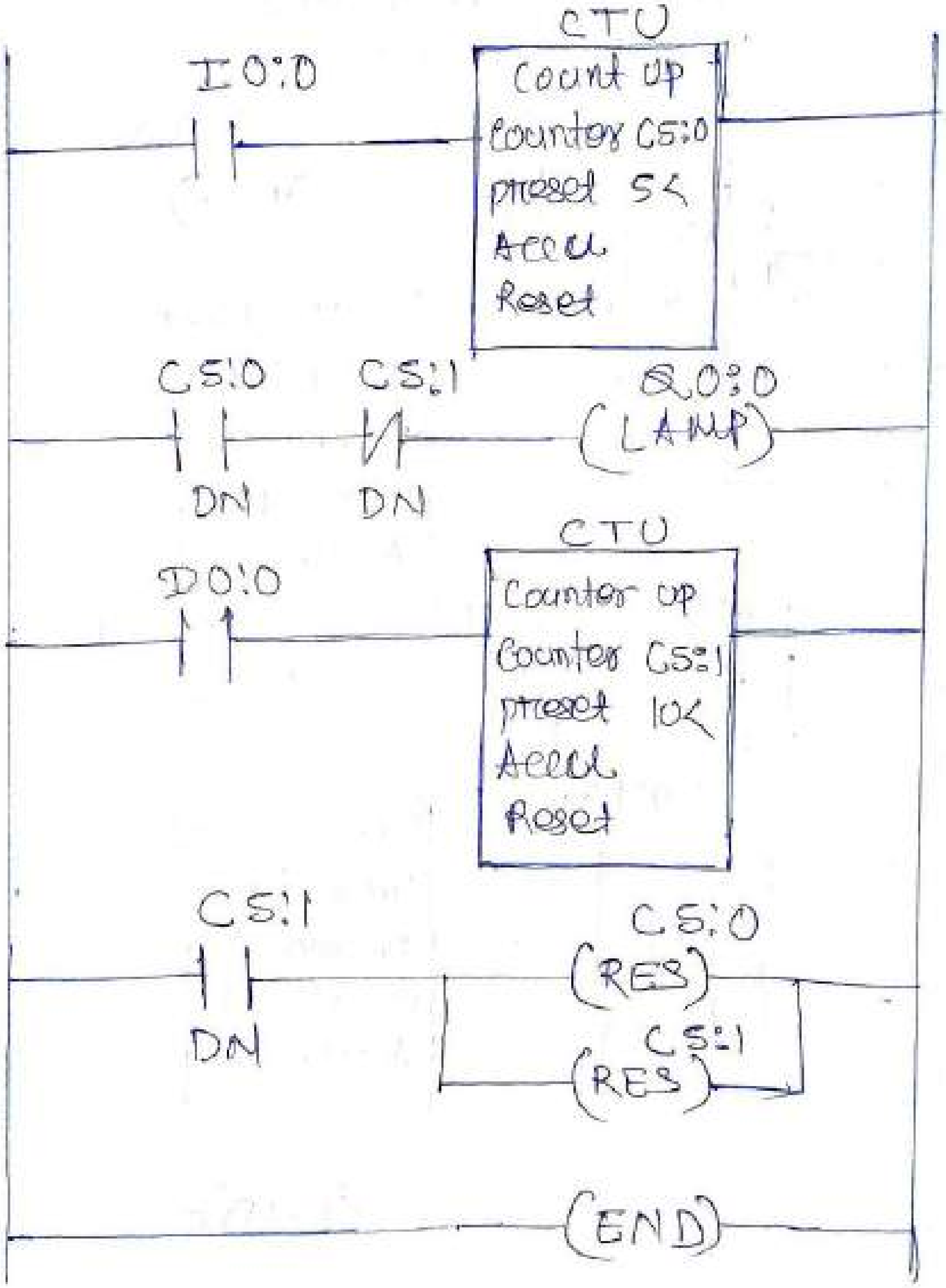
↳ PB1 → ON   Motor ON, FAN ON after 10 sec
PB2 → ON   Both OFF   After 5 sec



EN bit → Timer Energised → EN bit ON
DN bit → preset value = Accumulated value → DN bit on
TT bit → when timer is counting → TT bit will on
(Timer Timing)

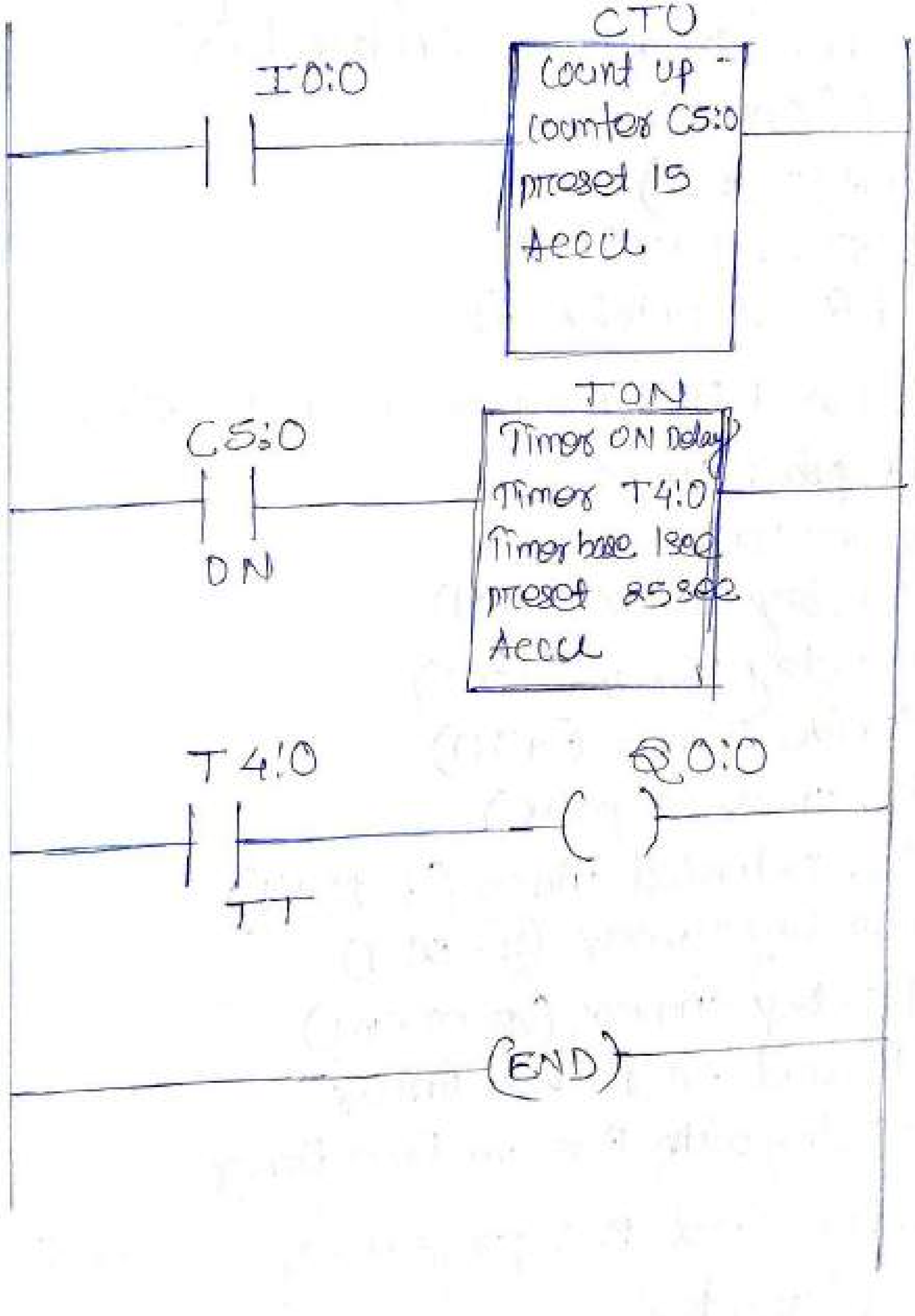
Counter Programming:-

i.e. Lamp goes on at count of 5 & goes OFF at count of 10 and Reset the counter.



Counter & Timer programming:-

Q. After a count of 15 from a sensor. A paint spray machine is to Run for 25 sec



PLC Instruction set :→

The different types of instructions set which are used for the ladder diagram PLC programming

① Basic PLC Programming Instructions :-

1. Input (I or X)
2. Output (O or Q)
3. Set (S) & Reset (R)
4. Latch (L) & Unlatch (U)

② Time Based PLC programming Instructions :-

1. Single pulse Timer
2. Flashing Timer
3. ON Delay Timer (TON)
4. OFF Delay Timer (TOFF)
5. Retentive Timer (RTO)
6. Pulse Timer (S pulse)
7. Pulse Extended Timer (S PEXT)
8. On Delay Timer (S-ODT)
9. Off Delay Timer (S OFFDT)
10. Extended on Delay Timer
11. On Delay with Random time timer

C/B

③ Counting Based PLC programming Instruction :-

1. Up counter
2. Down counter
3. Up down counter

④ Comparison Based PLC programming Instruction :-

① Greater than (GET)
② Lesser than (LET)
③ Equal to (EQU)
④ Not Equal to (NEQ)
⑤ Greater than or equal to (GEQ)
⑥ Lesser than or equal to (LEQ)
⑦ Increment & Decrement
⑧ Limit (LIM)

⑤ Mathematical PLC Programming Instruction :-

① Addition (ADD)
② Substraction (SUB)
③ Multiplication (MUL)
④ Division (DIV)
⑤ Square Root (SQRT)
⑥ Absolute (ABS)
⑦ Sine (SIN)
⑧ Cosine (COS)
⑨ Tangent (TAN)
⑩ Arc Sine (ASN)
⑪ Arc Cosine (ACN)
⑫ Arc tangent (ATN)
⑬ Natural log (LN)
⑭ Log to Base 10 (LOG)

⑥ Data Transfer based PLC programming Instructions :-

1. Fill File (FLL)
2. Move (MOV)
3. Copy (COP)
4. Jump (JMP)
5. Jump Not (JMPN)
6. Conditional jump
7. Jump to subroutine (JSR)
8. Subroutine (SBR)
9. Return (RET)
10. Suspend (SUS)
11. Lable (LBL)
12. Jump and Lable (JMP & LBL)
13. Master Control set (MCS)
14. Master control Reset (MCR)
15. One shot Rising (OSR)
16. One shot falling (OSF)
17. Convert from Integer to BCD (TOD)
18. Convert from BCD to Integer (FRD)
19. Temporary End (TND)
20. Convert Radians to Degree (DEG)
21. Convert Degrees to Radians (RAD)

C/B !

⑦ Logical or Bitwise PLC Programming Instructions :-

1. Bitwise NOT (NOT)
2. Bit wise AND (AND)
3. Bit wise OR (OR)
4. Bitwise Exclusive OR (XOR)
5. Flip flop (RS or SR)
6. Positive H Trigger
7. Negative H Trigger

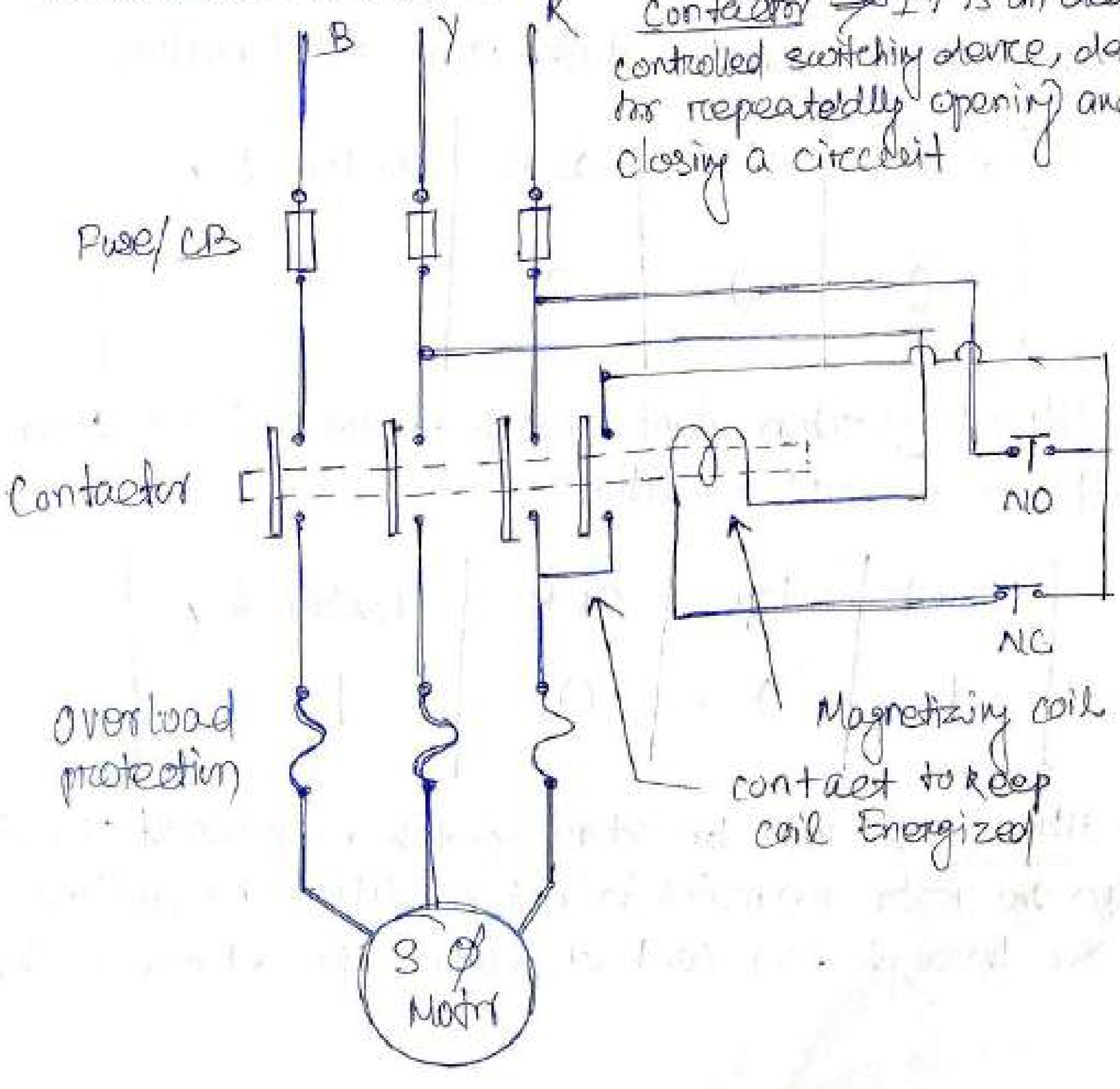
(8) Sequence Based PLC programming Instruction :-

(1) Sequence Input (SQI)
(2) Sequence output (SQO)
(3) Bit shift Left (BSL)
(4) Bit shift Right (BSR)
(5) Sequencer Load (SQL)
(6) Sequencer compare (SQC)

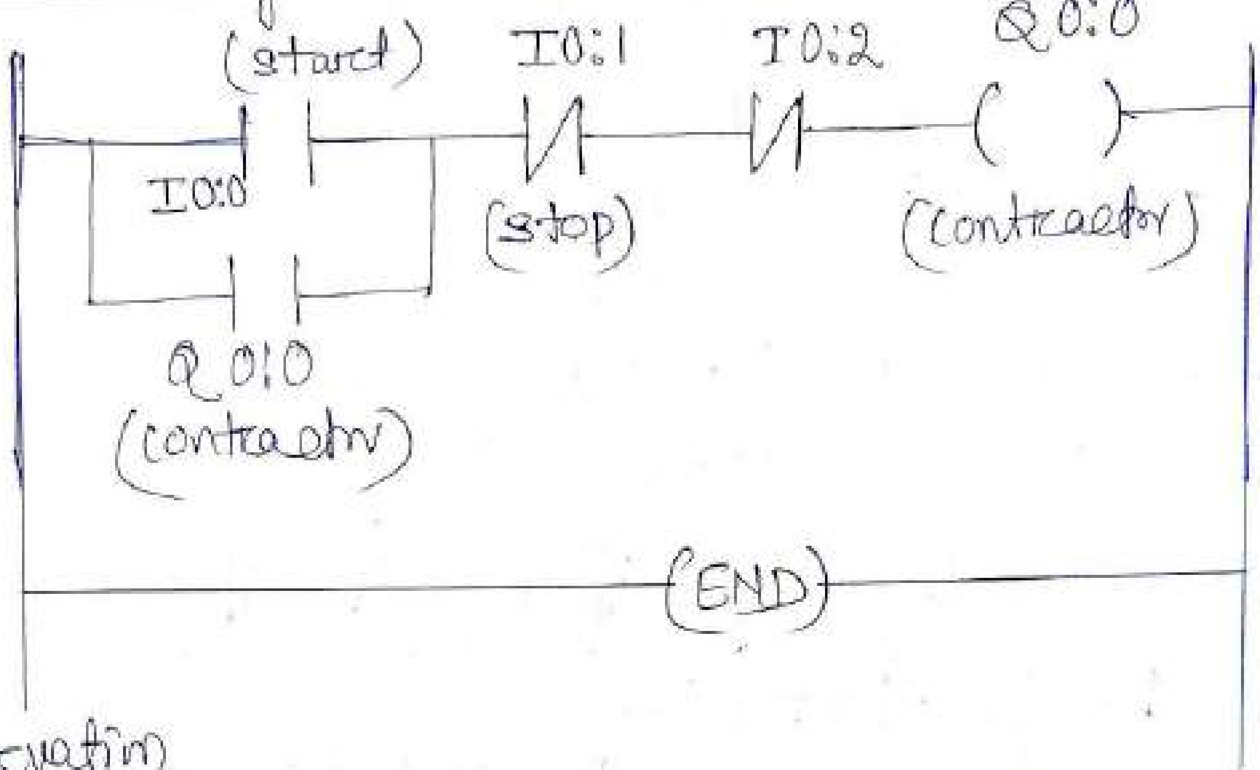
Ladder Diagram of Different Circuit :->

(1) DOL Starter :-

Contactor -> It is an electrically controlled switching device, designed for repeatedly opening and closing a circuit



Ladder Diagram



Observation

Condition 1 → when the Motor is in OFF condition.

start	stop	OLR	contractor
0	0	0.	0

Condition 2 → when start switch is pressed ON then Motor is in ON condition

start	stop	OLR	contractor
1	0	0	1

Condition 3 → when the start switch is pressed OFF then also the motor remains is ON condition by getting power through NO contact across the start switch

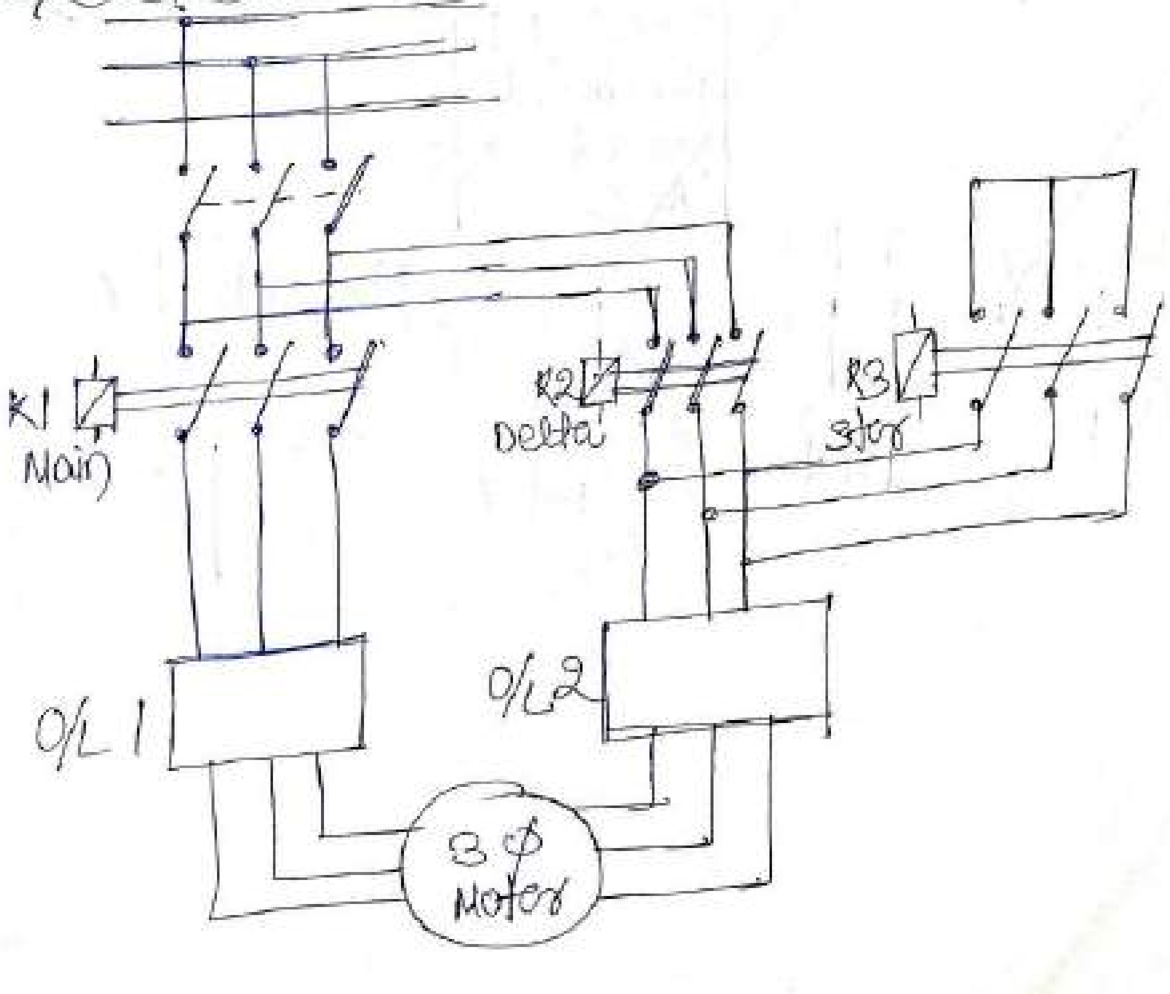
start	stop	OLR	contactor
0	0	0	1

condition-4 → when stop switch is pressed ON then Motor turned off.

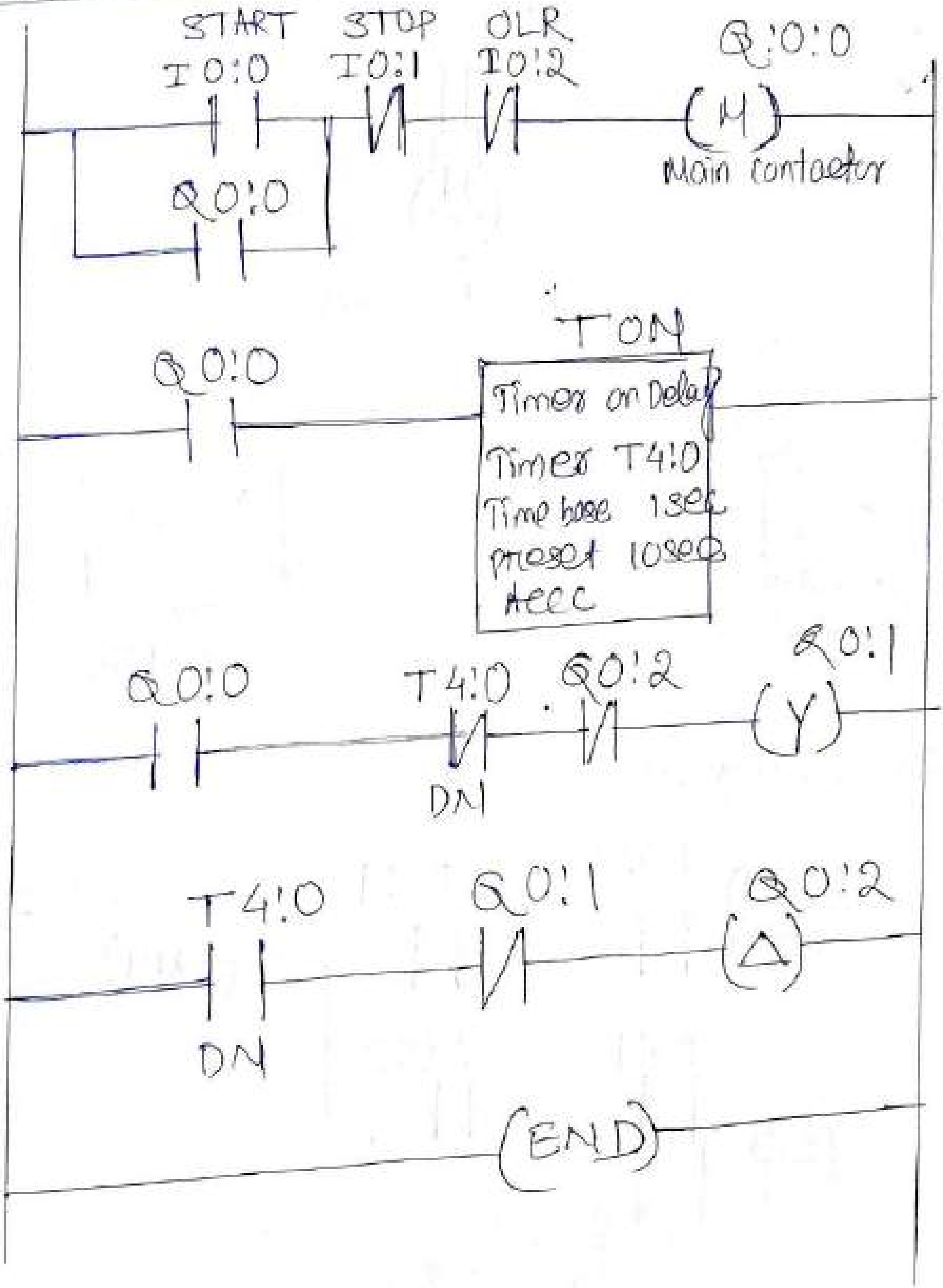
start	stop	OLR	contactor
0	1	0	0

when the STOP switch is pressed OFF the Motor again goes to condition 1. If OLR is activated at ON condition of the Motor then the motor will be OFF.

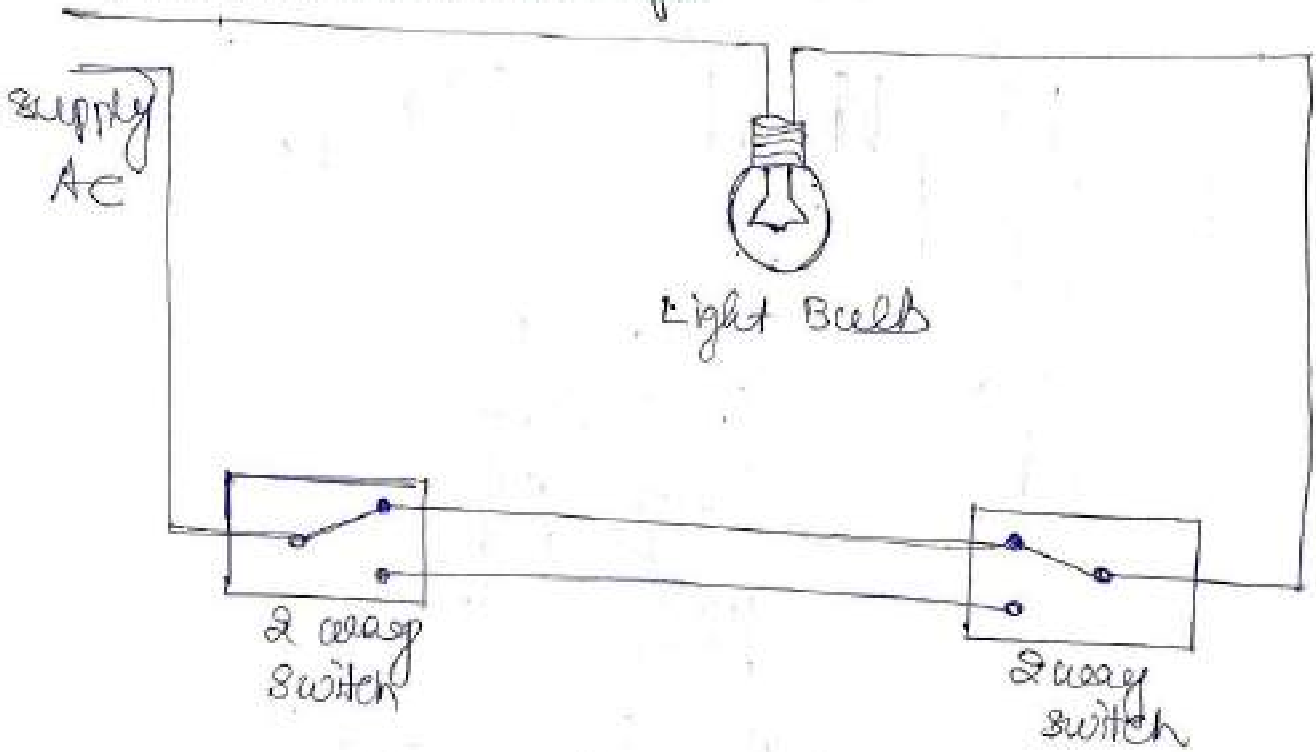
② Star Delta Starter :—



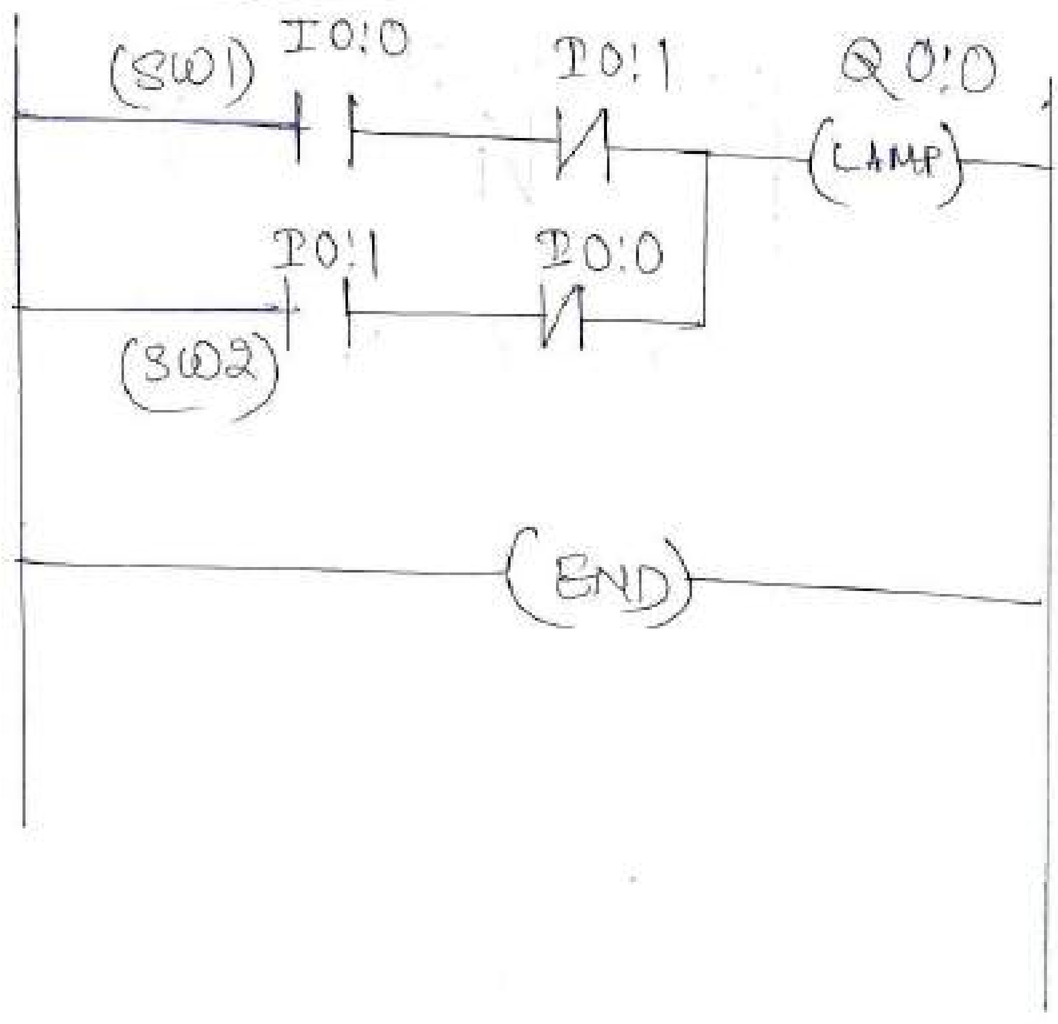
Ladder Diagram



③ Stair Case lighting :-

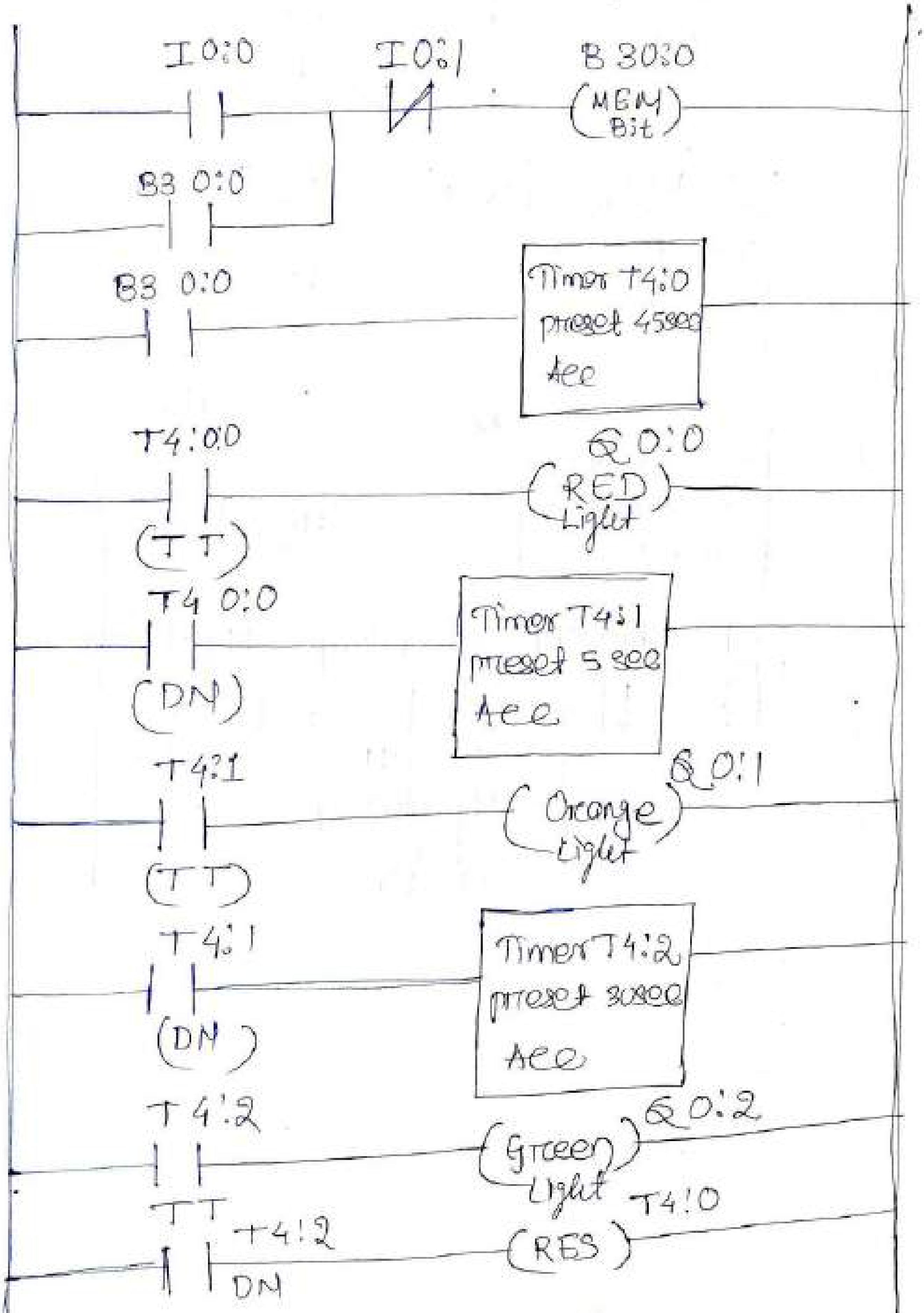


Ladder Diagram

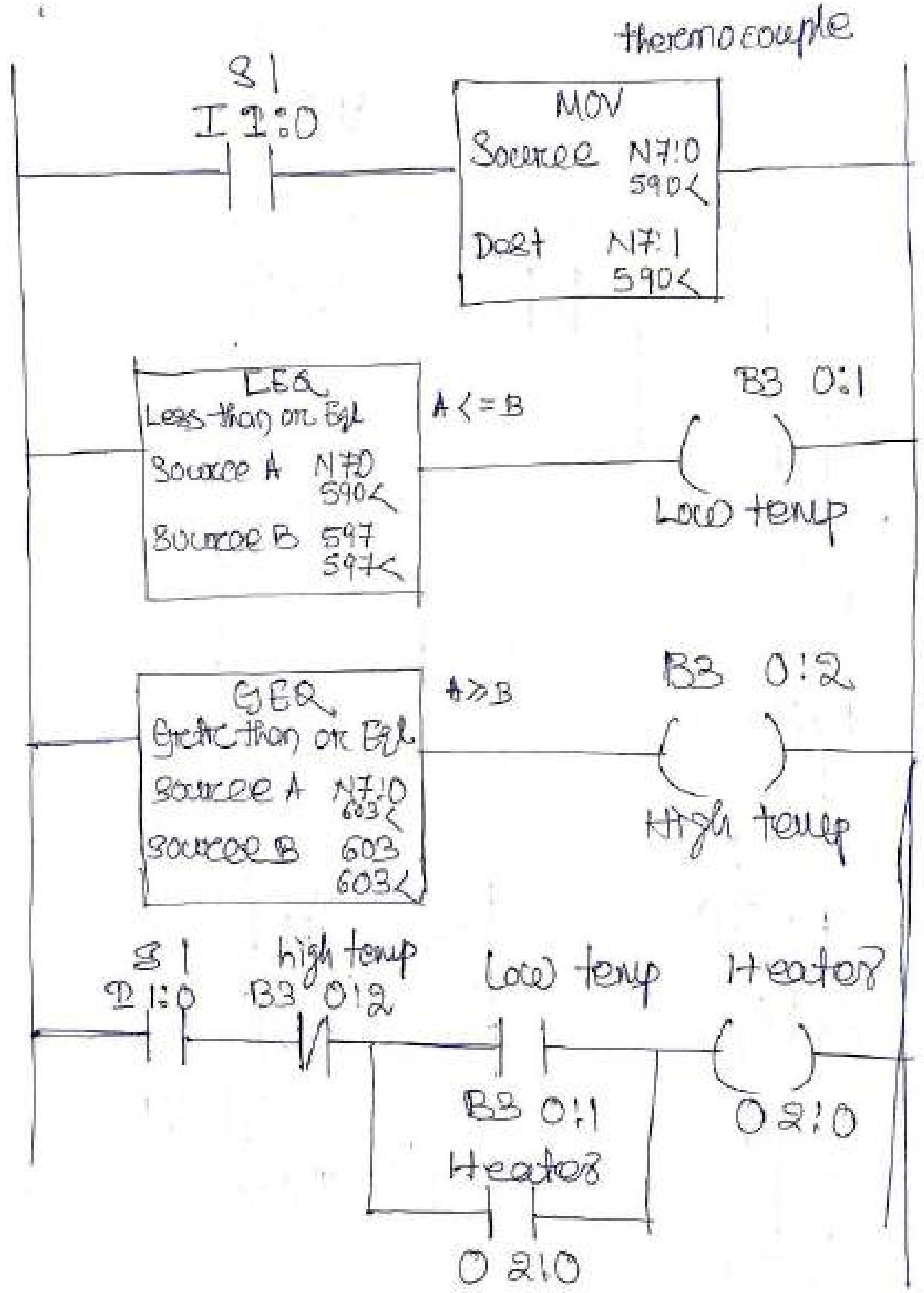


④ Traffic light control :-

Red ⇒ Stop ⇒ 45 sec
Orange ⇒ Ready ⇒ 5 sec
Green ⇒ Go ⇒ 30 sec



(5) Temperature controller :-



Basic DCS & SCADA systems :→

DCS (Distributed Control system) :-

→ A distributed control system is a digital automated industrial control system that uses geographically distributed control loops throughout a factory, machine or control area. The goal of a DCS is to control industrial processes to increase their safety, cost effectiveness and reliability.

→ DCS is a Decentralized control system

→ This DCS architecture around the plant has led to produce more efficient ways to improve reliability of control, process quality and plant efficiency.

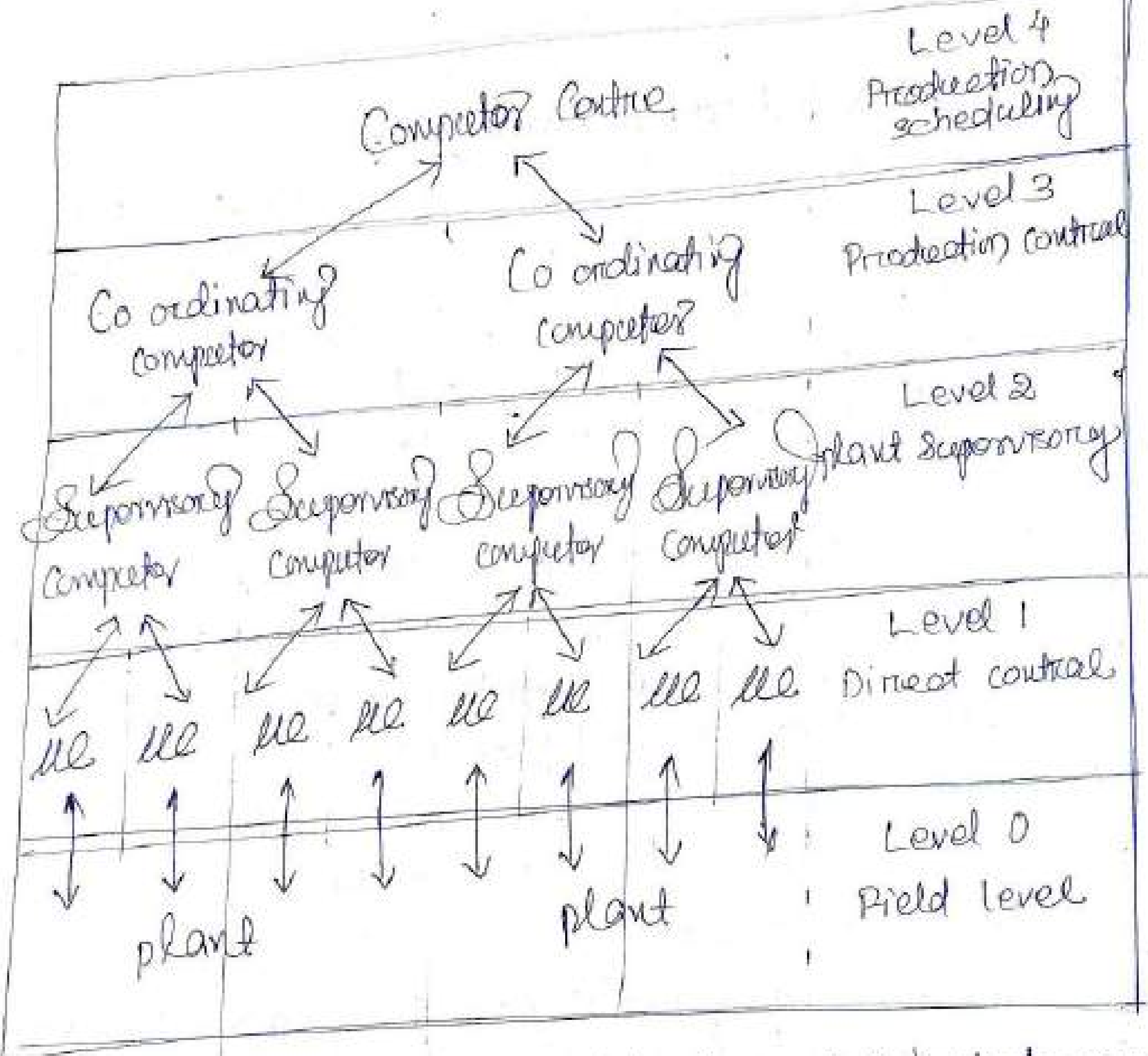
→ DCS also have a claim that when safety is a top priority, it is the most reliable system.

How does a DCS work :→

→ DCS are made up of control elements distributed throughout a plant or factory. These control elements include computers sensors and controllers. Each elements serves a specific purpose such as data collection, data storage or process control.

→ Unlike a centralized control system that operates all machines, a DCS enables each part of a machine to have its own dedicated controller that runs the operation.

→ A DCS has several local controllers throughout the factory. A high speed communication network connects the local controllers, while each controller works autonomously there is central supervisory control running an operation.



→ Having the control system architecture distributed around the factory or plant provides an effective control, efficiency and process quality strategy. Additionally, if a piece of the DCS architecture fails a plant can continue to operate. For these reasons, DCS are commonly found in industrial fields and processing or manufacturing plants.

→ A DCS is commonly used in industrial process industries like agri-culture, chemical plants, petrochemical and refineries, nuclear power plants, water and sewage treatment plants, food processing, Automobile, pharma indus.

How a DCS is structured :-

→ A distributed control system includes both software and hardware elements. The installation of most controllers locally keeps costs low, on site automated control improves the reliability of these systems and human oversight is enabled for central control functions and remote options. Individual processes have their own controllers with separate central processing units so other processes can continue if an individual system fails.

→ The architectural design of a DCS includes the following

An engineering work station → This is a supervisory controller for the DCS as a whole. The station typically includes configuration tools that let the user complete functions such as creating new loops and inputs and outputs points, as well as configuring distributed devices.

An operating station → this station is used for central operation and monitoring.

A process control unit → This microprocessor based controller is designed for automatic and compound loop control

A communication system → This system brings data from station to station and is important in distributed control system. Typical network protocols used include Ethernet, profibus and Device net.

smart devices → These are any smart devices or bus technologies that are used to replace older I/O.

→ In a DCS architecture, sensors gather and process information, which is sent to a nearby I/O module. The data is moved to a process control unit. smart devices if used can also send the data to a process control unit. The data is then further processed and analyzed to to produce an output result.

→ The processed output is based on the control logic used which is the part of a programme that controls programme operations'. This data is sent to a moving actuator device using another bus and then the commissioning process occurs. This is where instruments and control systems are verified and documented and where the control logic and implementation are transferred to an engineering station for the operator to view. The operator sends controls actions to operation stations.

→ The devices in this process can be divided into following five levels.

Level zero → Consists of field devices, like sensors and other control elements.

Level one → The I/O modules and processors.

Level two → The supervisory computers that collect data from processor nodes.

Level three → Focuses on the production control level that monitors production.

Level four → Includes production scheduling.

Advantages :-

① Complex structures → Unlike comparable programmable Logic controllers, a DCS can access Large amounts of information in a complex environment.

② System redundancy → If a processor fails the redundancy provided in the DCS ensures that only one section of ...

③ Scalability → More control or process units can be added wherever needed. Adding more I/O modules to a controller also extends I/Os.

④ Security → Security and cybersecurity capabilities are enabled at the engineer and operator levels.

SCADA (Supervisory Control and Data Acquisition System)

→ It is basically a software or it is a computer graphics install in computer to control any process.

→ SCADA is an industrial computer based control system employed to gather and analyze the real time data to keep track, monitor and control industrial equipments in different types of industries.

→ SCADA systems providing centralized monitoring and control of a plants field sites.

→ It allow remote monitoring and controlling of various plant operations in real time basis.

→ SCADA systems are generally used in automation industries along with PLCs.

→ SCADA systems include hardware and software components the hardware gathers and feeds data into field controller systems which forward the data to other systems that process and present it to a human machine interface in a timely manner. SCADA systems also record and log all events for reporting process states and issues. SCADA SCADA applications warning when conditions become hazardous by sounding alarms

Components of SCADA :-

SCADA systems include components deployed in the field together real time data as well as related systems to enable data collection and enhance industrial automation.

sensors and actuators → A sensor is a feature of a device or systems that detects inputs from industrial processes. An actuator is a feature of the device or systems that controls the mechanism of the process. Both the sensors and actuators are controlled and monitored by SCADA field controllers.

SCADA field controllers → two categories of field controller

1) Remote telemetry units also called remote terminal units interface with sensors to collect telemetry data and forward it to a primary system for further action.

C/B

2) PLC interface with actuators to control industrial processes usually based on current telemetry collected by RTUs and the standards set for the processes.

SCADA supervisory computers → These control all SCADA processes and are used to gather data from field devices and to send commands to those devices to control industrial processes.

HMI software → this provides a system that consolidates and presents data from SCADA field devices and enables operators to understands and if needed modify the states of SCADA controlled

Communication infrastructure → This enables SCADA supervisory systems to communicate with field devices and field controllers. This infrastructure enables SCADA systems to collect data from field devices and to control those devices.

Features of SCADA system:-

① Data acquisition → It is a foundation of SCADA systems; sensors collect data and deliver it to field controllers which is turn feed data to the SCADA computers.

② Remote control → It is achieved through the control of field actuators, based on the data acquired from field sensors.

③ Networked data communication → It enables all SCADA functions. Data collected from sensors must be transmitted to SCADA field controllers which in turn communicate with the SCADA supervisory computers remote control commands are transmitted back to actuators from the SCADA supervisory computers.

④ Data presentation → It is achieved through HMIs which represents current and historical data to the operators running the SCADA systems.

⑤ Real time and historical data ⇒ Both important parts of the SCADA system, as they enable users to track current performance against historical trends

⑥ Alarms → It alert SCADA operators to potentially significant conditions in the system. Alerts can be configured to notify operators when processes are blocked, when systems are failing or when other aspects of SCADA processes need to be stopped, started or adjusted.

(7) Reporting → On SCADA system operations can include reports customized to specific users.

SCADA Architecture :-

(1) Level 0 → The field level includes field devices, such as sensors, used to forward data relating to field process and actuators used to control processes.

(2) Level 1 → The direct control level includes local controllers, such as PLCs and RTUs that interface directly with field devices, including accepting data inputs from sensors and sending commands to field device actuators.

(3) Level 2 → The plant supervisory level includes local supervisory systems that aggregate data from level controllers and issue commands for those controllers to carry out.

(4) Level 3 → The production control level includes systemwide supervisory systems that aggregate data from level 2 systems to produce ongoing reporting to the production scheduling level as well as other site or regionwide functions, like alerts and reporting.

(5) Level 4 → The production scheduling level includes business systems used to manage ongoing processes.

SCADA use cases & Industry :→

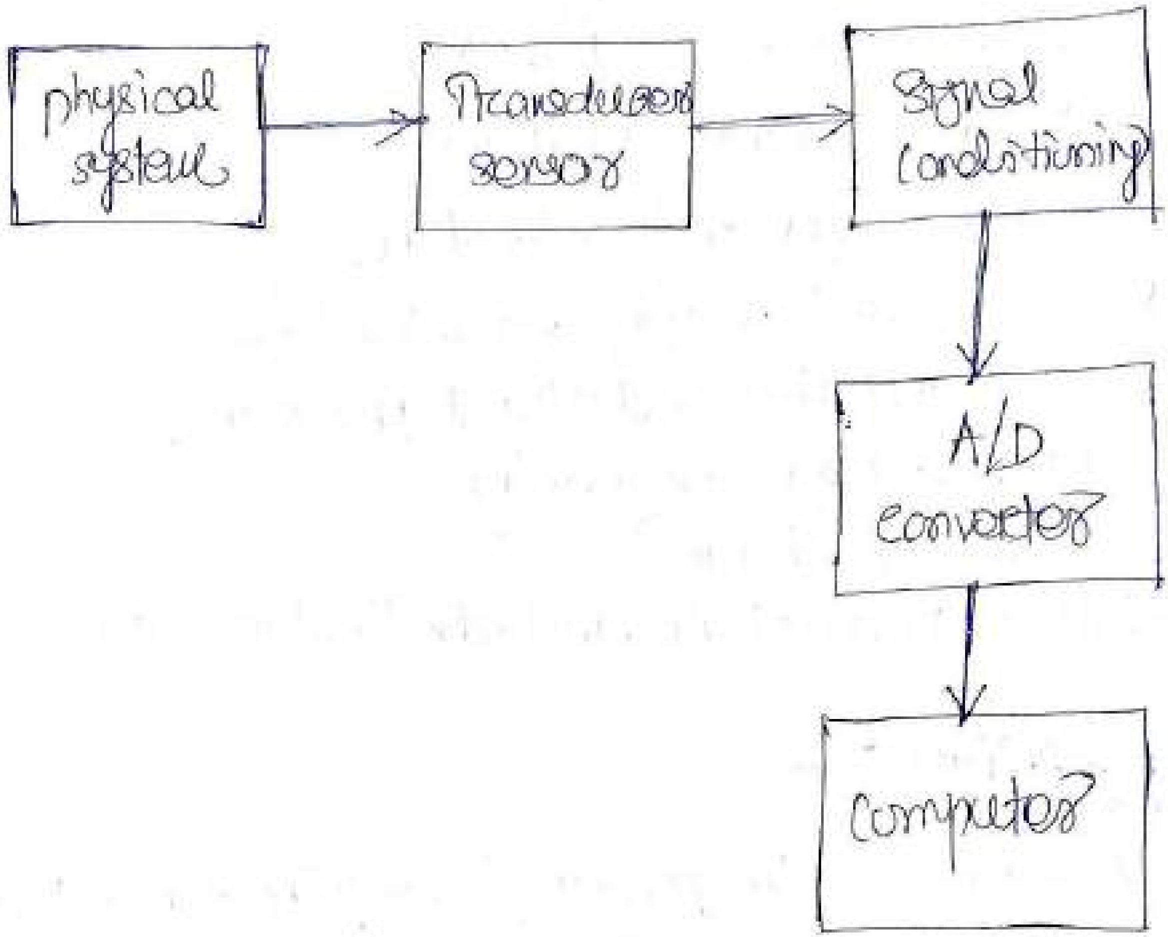
1. Electricity generation & distribution
2. Oil and gas refining operations
3. Telecommunications infrastructure
4. Transportation and shipping infrastructure
5. Fabrication and other industrial processing.
6. Food and beverage processing
7. chemical manufacturing
8. utilities infrastructure, including water & waste control.

Data Acquisition :→

→ Data Acquisition is the process of sampling signals that measure real world physical phenomena and converting them into a digital form that can be manipulated by a computer and software.

→ A data acquisition system is a system that includes measurement devices sensors a computer and data acquisition software. A data acquisition system is used for acquiring, storing, visualizing and processing data. This involves collecting the information required to understand electrical or physical phenomena.

→ components of data acquisition systems are sensors, signal conditioning, Analog to Digital converter, computer with DAQ software for data logging and analysis

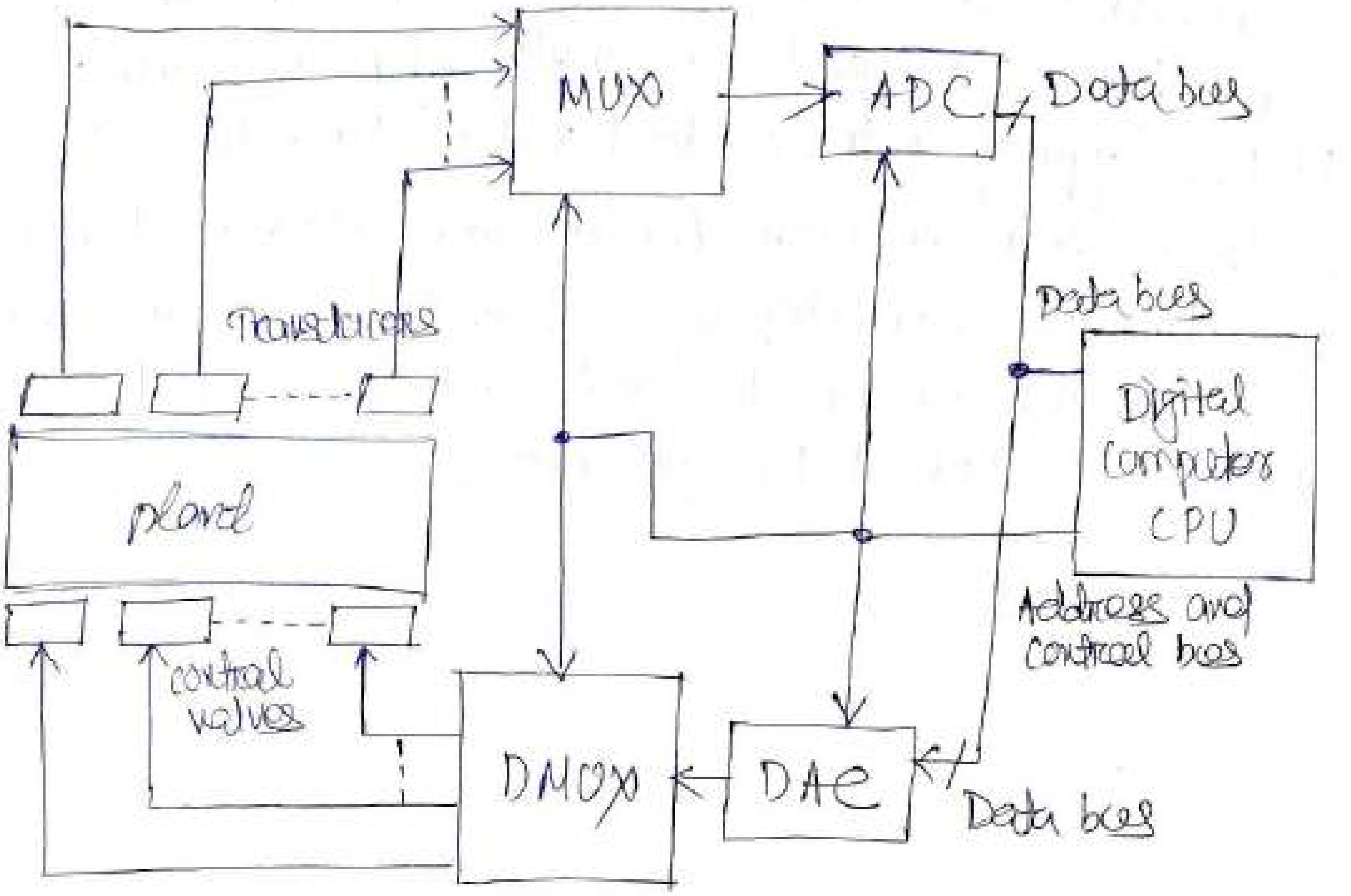


Direct Digital Control system :→

c/p → Direct Digital control is the automated control of a condition or process by a digital device.

→ DDC takes a centralized network oriented approach. All instrumentation is gathered by various analog and digital converters which use the network to transport these signals to the central controller.

→ The centralized computer then follows all of its production rules and causes actions to be sent via the same network to valves, actuators, and other HVAC components that can be adjusted.



→ A basic direct Digital control system is shown in fig. In this system a large number of transducers are sited around the plant each transducer being connected to one input of a mux.

→ A mux can be considered as the electronic equivalent of a switch with a contact or blade which rotates very rapidly so that it moves from one transducer long enough for an ADC to sample and digitise or to quantise the analog signal. The quantised data are then transmitted along the data bus of the system to the CPU.

→ when the CPU has analysed the data from one or more transducers and has compared them with the appropriate set points in the computer program, it sends signals along the data bus to the values controlling the system as follows. The digital signal produced by the CPU is converted into an analog signal by a DAC and the analog signal is transmitted to the appropriate control valve through a demux. As this is being performed, data are displayed on the operator's visual display unit and if necessary he can remotely change the set points associated with various sections of the process.