Power electronic

Electrical power -: It is the amount of electrical energy that can be transferred to some other form (heat, light) per unit time.

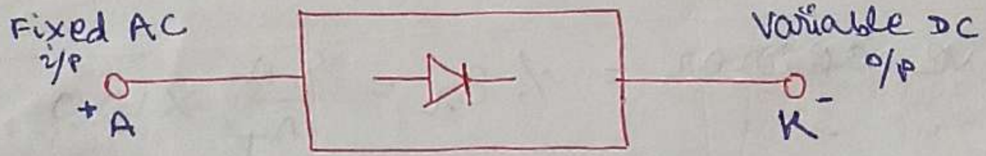
Power -: Power stands for Power engineering. It deals with generation, transmission and distribution of power in high power, high voltage & high current levels.

Electronics -: Electronics stands for electronics engineering. It deals with generation, transmission and distribution of datas & signals in low power, low voltage and low current levels.

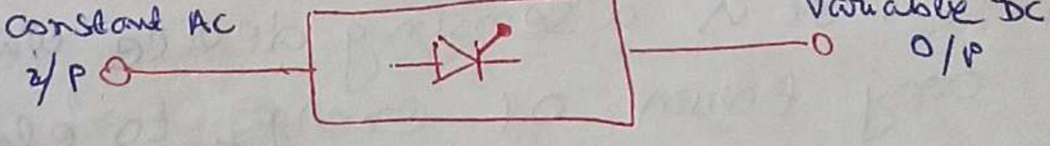
Power electronics -: It may be defined as the application of electronics principles for the control & conversion of electric power in high power levels rather than low power levels.

Application of power Electronics -:

a) uncontrolled Rectifiers -: (Diode) Converts fixed AC voltage to variable DC voltage.



b) controlled Rectifiers -: Convert constant ac voltage to variable dc output voltage.



c) Inverters -: converts fixed DC voltage to variable AC voltage having variable frequency.

d) Chopper -: converts fixed DC voltage to variable DC voltage.

c) AC voltage controller -: converts fixed AC voltage to variable AC voltage.

f) cycloconverter -: converts fixed voltage & fixed frequency A.C to variable voltage & variable frequency A.C in one stage conversion.

Advantages of power electronic converters -:

a) High efficiency. → $\frac{O/P}{I/P}$

b) High reliability.

c) Long life & less maintenance due to absence of any moving parts.

d) Small size & less weight.

e) low cost (converter equipment).

Disadvantage -:

a) generate harmonics in the supply system & in the load circuit.

b) Low power factor. (VI cosϕ)

c) low over load capacity.

d) Regeneration of power is difficult.

CHAPTER - 2 POWER SEMICONDUCTOR DIODES AND TRANSISTORS

→ Low power diode is called signal diode. (Vtg, current, power rating low)

→ High power diode is called power diode. (Vtg, current, power rating high)

→ Power diode operate at lower switching speeds.

→ Signal diode operate at higher switching speeds.

* Uses -: (PD) used as free wheeling diode.

P-N junction -:

→ Basic building block of all power semiconductor devices.

→ P-N junction is formed when P-type semiconductor is in contact with n-type S.C.

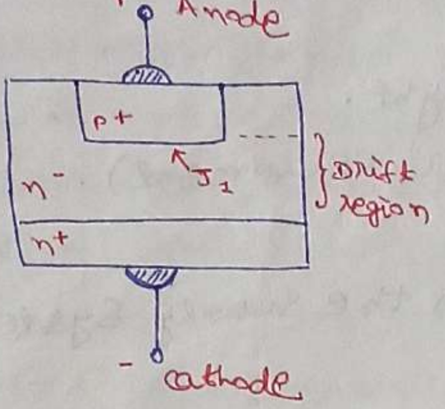
→ P-region has greater concentration of holes where as n-region has more electron-concentration.

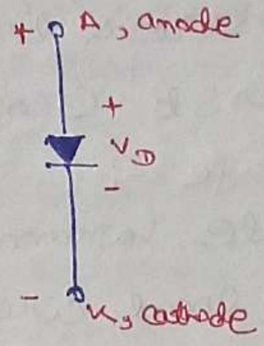
→ P-region -: Majority carriers -: hole   Minority carriers -: free electrons

N-region -: Majority carriers -: free electrons   Minority carriers -: hole

Basic structure of power diodes -:

→ Power diode is needed for high-voltage and high-current applications.

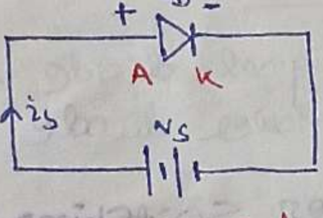




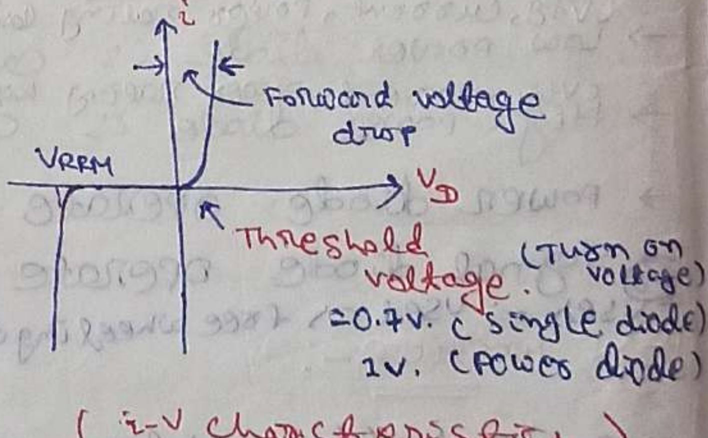
Characteristics -:

* when anode is positive with respect to cathode, diode is said to be forward biased.

* when cathode is positive with respect to anode, the diode is said to be reverse biased.

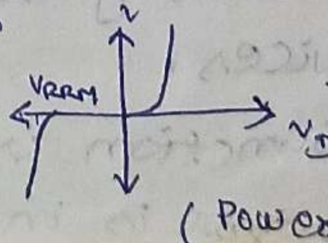


forward-biased power diode.

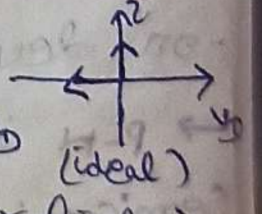


(i-V characteristics)

* V_{RRM} -: peak reverse repetitive voltage.



(Power diode)



(ideal)

Power Transistors-:

→ Power diodes are uncontrolled devices.

→ Turn-on & turn-off characteristics are not under control. But power transistors are controlled devices.

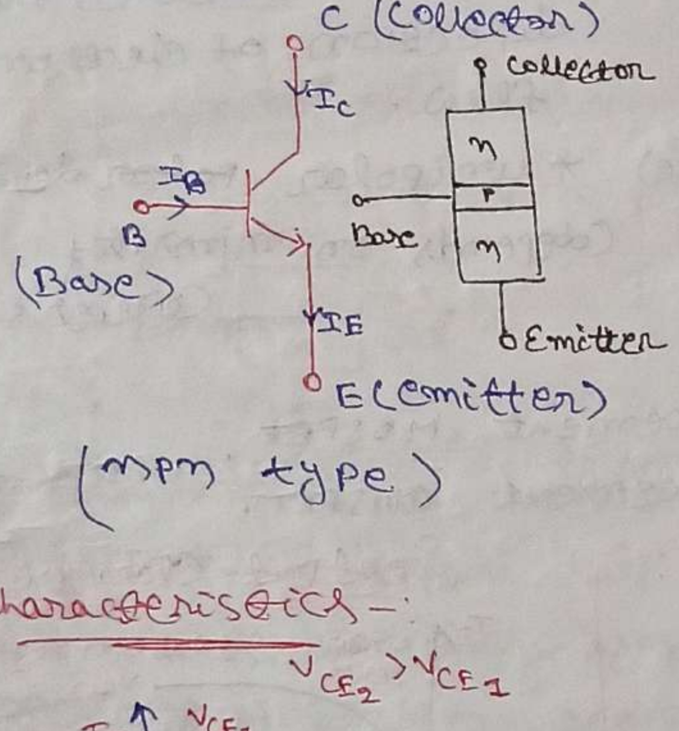
① **Bipolar junction transistors (BJTs)** (Current controlled device)

→ 3 layer, two junction npn or pnp type semi-conductor devices.

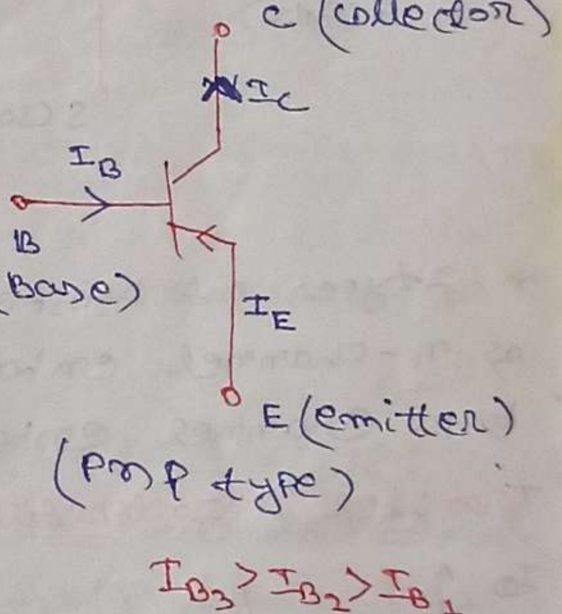
a) npn transistor-: 1 p-region sandwiched by 2 n-regions.

b) pnp transistor-: 1 n-region sandwiched by 2 p-regions.

→ Bipolar-: the current flow in the device is due to the movement of both holes & electrons.

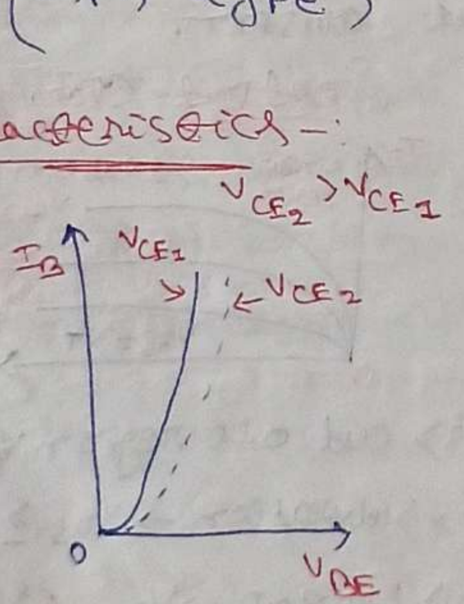


(npn type)

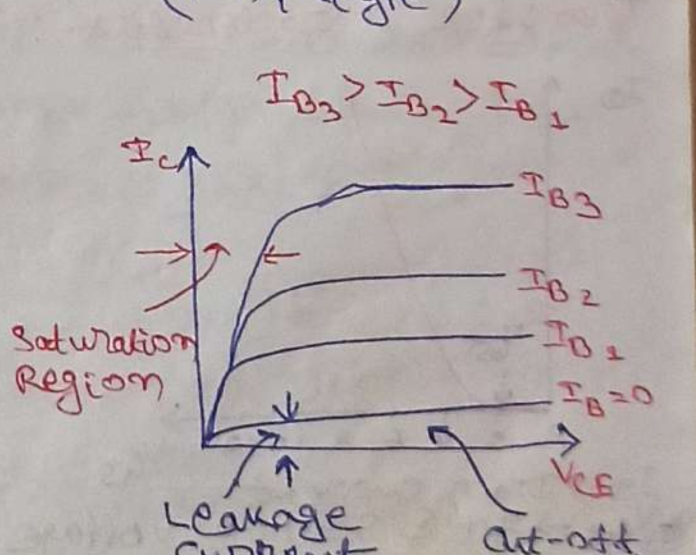


(pnp type)

Characteristics-:



(Input characteristics)



(Output characteristics)

Relationship betn α & β -:

* $\boxed{\alpha = \frac{I_C}{I_E}}$ varies from 0.95 to 0.99

$\alpha \rightarrow$ forward current gain.

* $\boxed{\beta = \frac{I_C}{I_B}}$ $\beta \rightarrow$ current gain.

Divide I_C on both side

* $\boxed{I_E = I_C + I_B}$

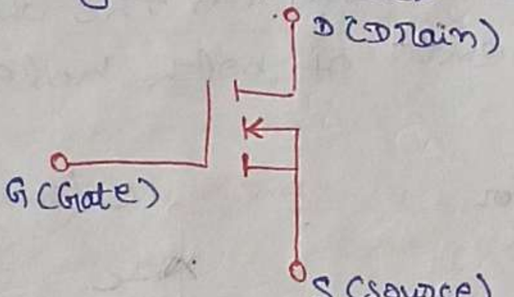
$\frac{I_E}{I_C} = 1 + \frac{I_B}{I_C}$

$\Rightarrow \frac{1}{\alpha} = 1 + \frac{1}{\beta}$

* $\boxed{\alpha = \frac{\beta}{\beta + 1}}$ & $\boxed{\beta = \frac{\alpha}{1-\alpha}}$

MOSFET -: (Metal - oxide - semiconductor field - effect transistor)

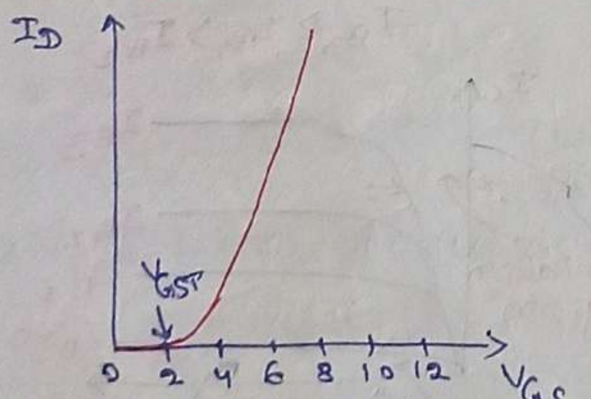
* voltage controlled device.



* arrow indicates the direction of electron flow.
* unipolar ~~polar~~ devices (depends on minority carriers)

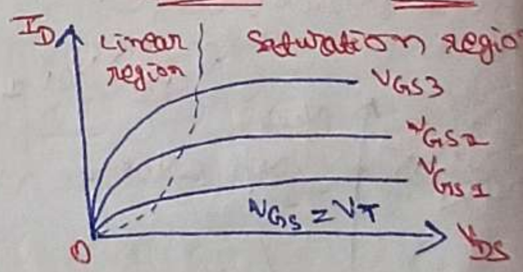
* 2 types of MOSFET
a) n - channel enhancement MOSFET.
b) P - channel enhancement MOSFET.

Transfer Characteristics -:



$I_D \rightarrow$ Drain current
$V_{GS} \rightarrow$ gate source voltage
$V_T, V_{GST} \rightarrow$ Threshold voltage

Output Characteristics



i> cut off region $V_{GS} \leq V_T$
ii> Saturation $\rightarrow V_{DS} \geq V_{GS} - V_T$
iii> Linear $\rightarrow V_{DS} \leq V_{GS} - V_T$

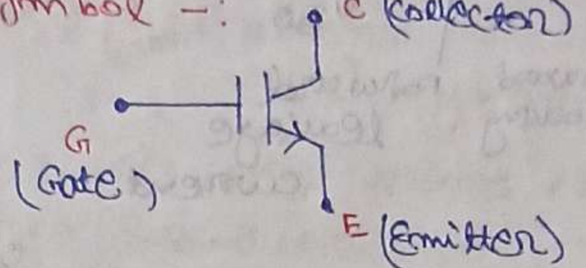
IGBT -: (Insulated Gate Bipolar Transistor)

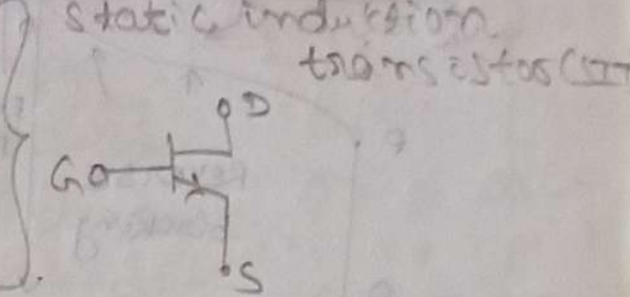
* IGBT has combines advantages over BJTS & MOSFETS.

a) high input impedance like MOSFETS.

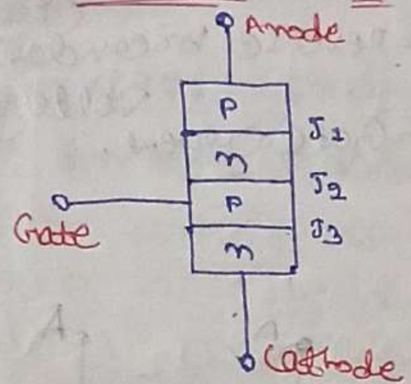
b) low onstate power loss like BJT.

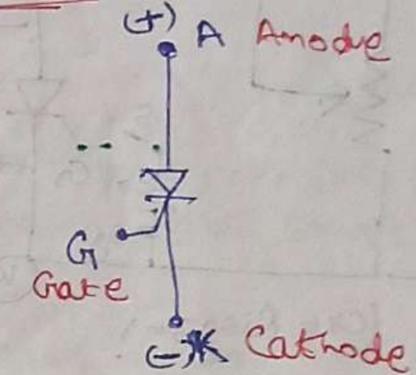
Symbol -:





Construction of SCR (Thyristor)





* 4 layer, 3 junction, 3 terminal semiconductor device.

* The material is silicon doped with p and n type impurities.

* SCR → silicon controlled rectifier.

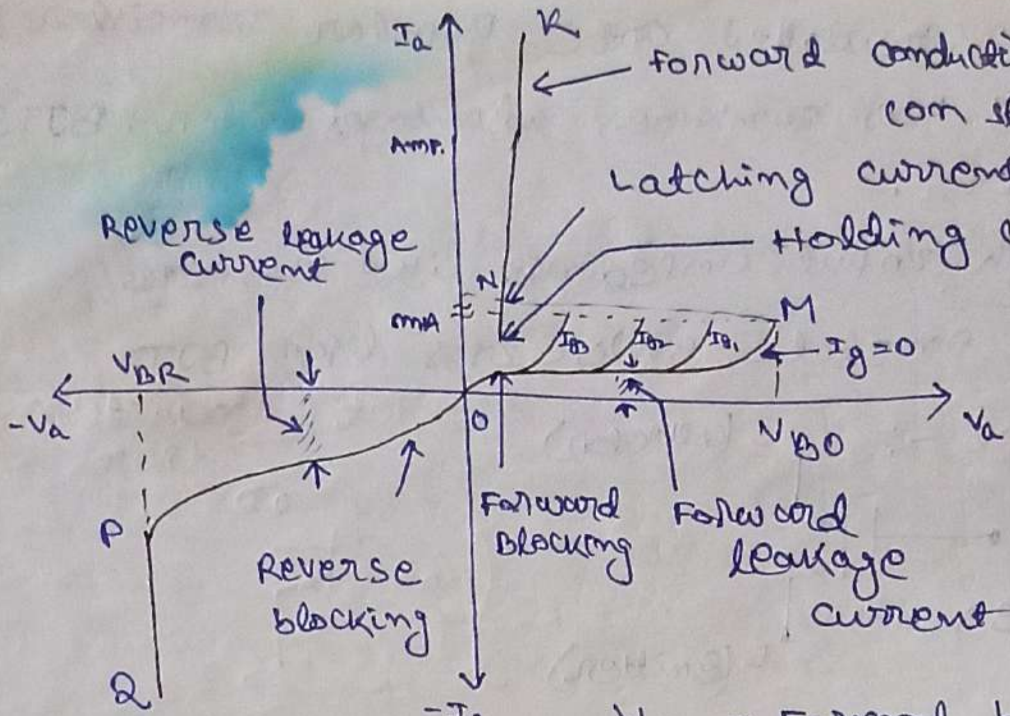
Thyristor is called as SCR because silicon is used for its construction and its operation as a control rectifier.

V-I CHARACTERISTICS OF SCR -:

* V_{BO} = Forward breakover voltage.

* V_{BR} = Reverse break~~over~~ down voltage.

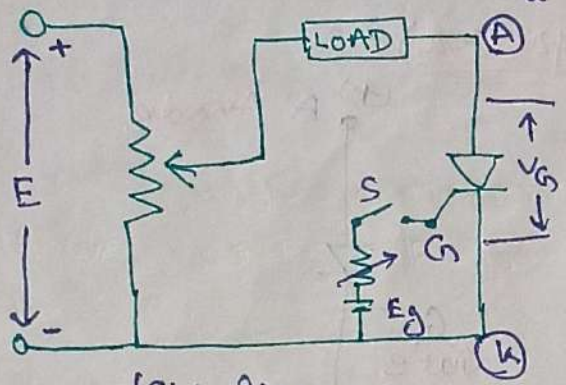
* I_g = Gate current.



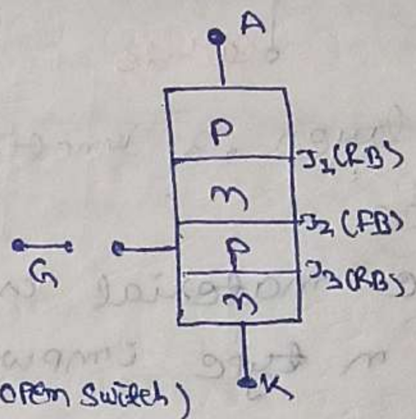
V_{BO} = Forward breakover voltage

V_{BR} = Reverse breakdown voltage

I_g = Gate current.



(Ckt Diagram)

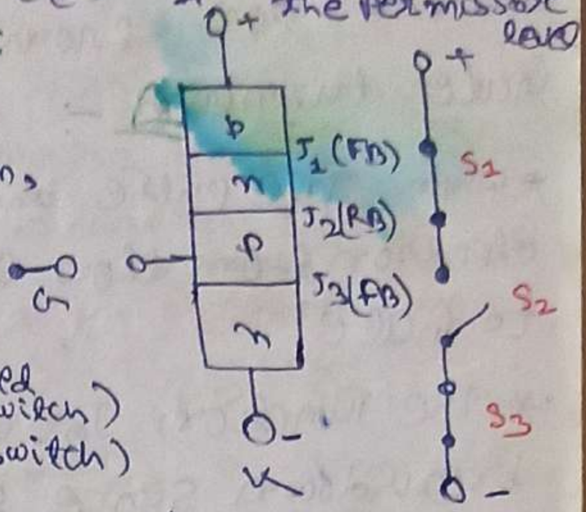


Reverse blocking Mode :-

* when Cathode is +ve w.r.t anode with switch S open, the SCR is reverse biased.
* J_1, J_3 - Reverse biased (open switch)
  J_2 - Forward biased (close switch)
* Current can't flow from cathode to anode.
* SCR ∴ Reverse blocking state.
* Reverse blocking mode = off state
* If the reverse voltage is increased, then at a critical break down level, called reverse break down voltage (V_{BR}) and avalanche occurs at J_1 & J_3 and reverse current increases rapidly.
* A large current associated with V_{BR} give

rise to more losses in the SCR.
* This may lead to SCR damage as the (J) temp. may exceed the permissible level

Forward Blocking Mode -:



* when anode is +ve w.r.t cathode, with gate circuit open, thyristor is said to be forward biased.

* J_1, J_3 = forward biased (closed switch)
  J_2 = Reverse biased (open switch)

* If forward voltage is increased, then (RB Junction J_2) will have an avalanche breakdown occured. This vtg. is also called as forward break over voltage.

Forward Conduction Mode -:

* In this mode, thyristor conducts currents from anode to cathode with a very small voltage drop across it.

→ By exceeding the forward break over voltage or by applying a gate pulse betn gate & cathode, SCR is turned into forward blocking mode to forward conduction mode.

Latching Current -: *voltage drop (1 to 2V)

→ The minimum value of anode current is required to turn on SCR called latching current.

Holding Current -:

→ The minimum value of anode current below which thyristor is turned off.

Turn on Methods of Thyristor (triggering method)

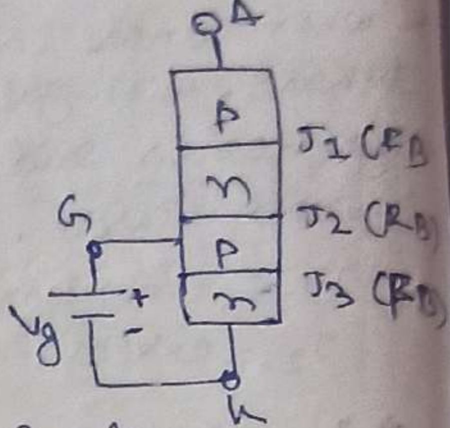
Increasing forward voltage -:

* when SCR is forward biased J_1, J_3 acts as closed switch & J_2 = open switch.
* when applied voltage is increased beyond

break over voltage J_2 breaks down & a through current flow from anode to cathode.

Gate turnon -:

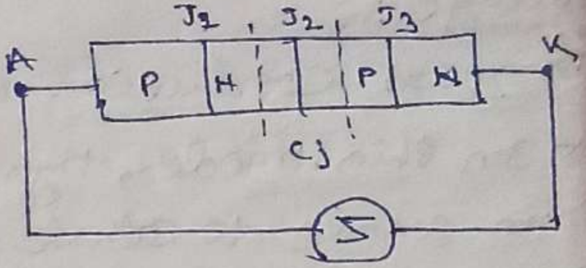
* when gate pulse ~~injected~~ applied, electron flow from cathode to Gate.



* The junction J_2 can easily breakdown since gate pulse supplies large no. of conduction electrons.

* popular method.

dv/dt turn on -:



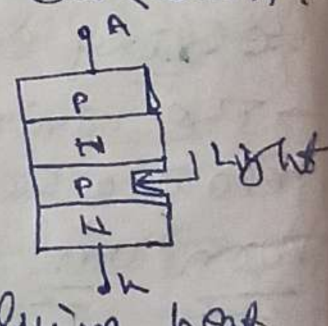
* when anode is +ve w.r.t cathode J_1, J_3 = F.B
J_2 = R.B

* A depletion layer created around J_2 & acts as the dielectric.

* J_1, J_3 = good conductor. & SCR behaves like a capacitor.

* when switch is suddenly closed dv/dt is large. Large charging current ($i_c = C_j \, dv/dt$) flows through the SCR & J_2 = breakdown.

light turn on



* By used of light, co-valent bonds get broken. cause - increase electron-hole.

Thermal turn on -: (By applying heat energy)

> co-valent bond -: sharing of electron pairs betn atoms. (electron pair = share pair, bond pair)

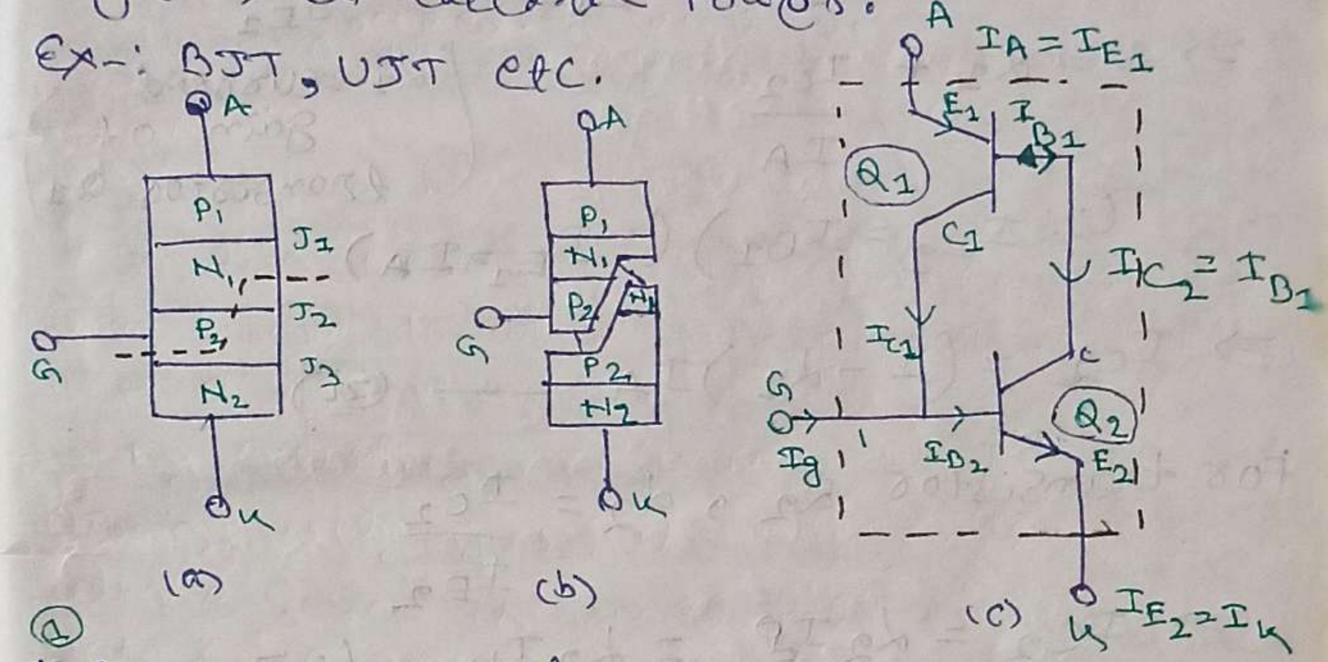
* Light turn on method has been used in high-voltage direct current (HVDC) system.

* The pulse of light wavelength is guided by optical fibres for radiation.
* If the intensity of this light exceeds a certain value, SCR is forward biased & turn on. Such a thyristor is known as light-activated SCR (LASCR).

Two transistor analogy of Thyristor -:

* **Transistor -:** A transistor is a semiconductor device used to amplify & switch electronic signals & electric power.

Ex-: BJT, UJT etc.



① * In this above diagram, A thyristor can be constructed as two complementary transistors.
* (Q_1 = PNP & Q_2 = NPN)

⑤ * When gate is made +ve w.r.t cathode the NPN transistor conducts. & its provide o/p current ($I_K = I_g + I_A$) ~~and this provides~~ ~~as base current for the PNP transistor~~.

② * The output of PNP is the input to the NPN since collector of Q_1 is connected to base of Q_2.

* Even through the gate voltage is removed, the transistor continue to conduct, since they are connected back to back

* ~~Here~~ When the SCR is forward biased & +ve pulse is applied to the gate, it acts as a closed switch.

Mathematical derivation

For transistor Q_1, $I_{E_1} = I_{C_1} + I_{B_1}$ — (i)

Divide I_{E_1} on both side

$$\Rightarrow 1 = \frac{I_{C_1}}{I_{E_1}} + \frac{I_{B_1}}{I_{E_1}} \quad \left(\because \frac{I_{C_1}}{I_{E_1}} = \alpha_1\right)$$

$$\Rightarrow 1 = \alpha_1 + \frac{I_{C_2}}{I_A}$$

(α_1 = current gain of transistor Q_1)

$(\because I_{C_2} = I_{B_1})$ $(\because I_{E_1} = I_A)$

$$\Rightarrow I_{C_2} = (1 - \alpha_1) I_A \quad \text{— (ii)}$$

For transistor Q_2, $\alpha_2 = \frac{I_{C_2}}{I_{E_2}}$

$$\Rightarrow I_{C_2} = \alpha_2 I_{E_2} = \alpha_2 I_K \quad (\because I_{E_2} = I_K) \quad \text{— (iii)}$$

By applying KCL

$(I_A + I_G = I_K)$

$$\Rightarrow I_{C_2} = \alpha_2 (I_A + I_G) \quad \text{— (iv)}$$

Equating eqn (ii) & (iv)

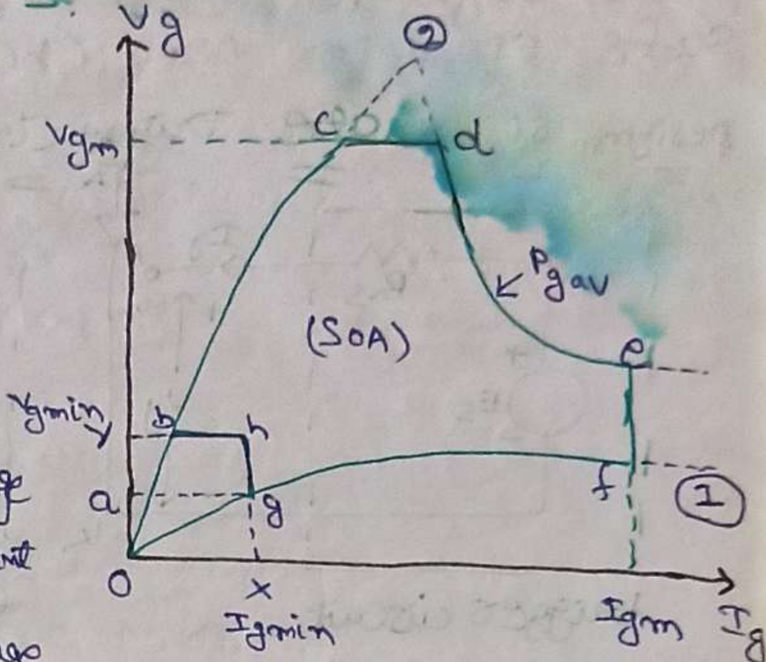
$$(1 - \alpha_1) I_A = \alpha_2 (I_A + I_G)$$

$$\Rightarrow I_A (1 - \alpha_1 - \alpha_2) = \alpha_2 I_G$$

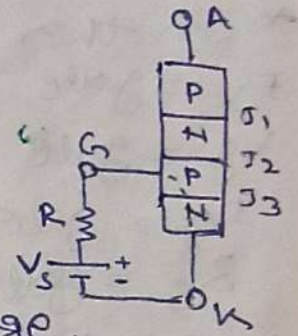
$$\Rightarrow \boxed{I_A = \frac{\alpha_2 I_G}{1 - (\alpha_1 + \alpha_2)}} \quad \text{— (v)}$$

α_1, α_2 = Current gains of transistor Q_1 & Q_2

Thyristor Gate characteristics →



* In this Graph is the representation of forward gate characteristics of a thyristor.
* where Vg = gate voltage
* Ig = gate current
* Vgm = max^m gate voltage
* Igm = max^m gate current
* Vgmin = Min^m gate voltage (OY)
* Igmin = Min^m gate current (OX)



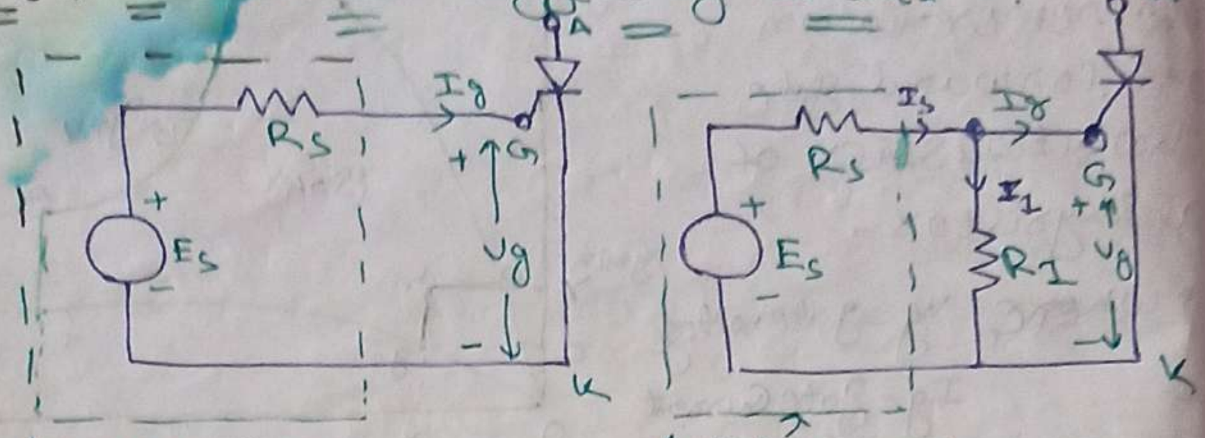
* Oa = Non-triggering gate voltage.
* SOA = Safe operating Area (bcdefgh)
* As gate-cathode circuit of a thyristor is a p-n junction so gate characteristics of the device are similar to that of a diode.
* In this graph curve ① represents the lowest voltage values that must be applied to turn-on the SCR.
* Curve ② gives the highest possible voltage values that can be ~~safe~~ safely applied to the gate circuit.

Notation Pgav = Average gate power dissipation

* This power limits should not be exceeded in order to avoid permanent damage of junction (J_3).
* If Vgm, Igm & Pav are exceeded, then thyristor can be destroyed.

*Thus thyristor must be operate with in safe operation Area (bcdefgh)

Design of Gate Triggering circuit -:

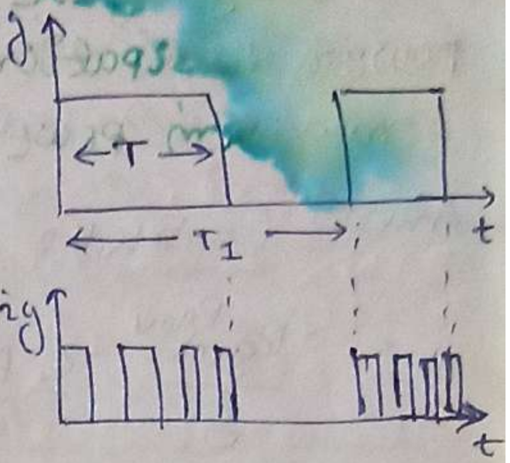


* In this circuit diagram
E_S = gate source voltage
V_g = gate - cathode voltage
I_g = gate current
R_S = gate - source resistance.
* In this figure $\boxed{E_S = V_g + I_g R_S}$
* when SCR is turned on, the current $\left(I_S = \frac{E_S}{R_S}\right)$ is not harmful to the source as well as to the gate circuit.
* In case R_S is low, an external resistance (R_1) is connected in series with R_S.
* Here R_1 provide an easy path to the flow of leakage current between SCR terminals.
* If min gate current (I_{gmin}) & min. gate voltage (V_{gmin}) are applied to turn on the SCR, then $\boxed{E_S = \left(I_{gmin} + \frac{V_{gmin}}{R_1}\right)R_S + V_{gmin}}$

$I_1 =$
* $\left(\frac{V_{gmin}}{R_1}\right)$ is the current flowing through R_1.

* To reduce the gate losses the gate signal is always in the form of a pulse.

* The duration of pulse width (T) should be more than the turn on time of thyristor.



* When pulse triggering is used, the max^m power dissipation (P_{gm}) can be higher.

* If f = frequency.

then $\boxed{T_1 = 1/f}$ $\Rightarrow$ $\boxed{f = \frac{1}{T_1}}$

periodicity

therefore $\frac{P_{gm} T}{T_1} \geq P_{gav}$ (P_{gm}: amplitude, T: pulse width)

$\Rightarrow P_{gm} \cdot T \cdot f \geq P_{gav}$

$\Rightarrow P_{gm} \geq \frac{P_{gav}}{fT} \Rightarrow \boxed{\frac{P_{gav}}{fT} \leq P_{gm}}$ —(i)

In some limiting case $\boxed{\frac{P_{gav}}{fT} = P_{gm}}$

Or $\boxed{f = \frac{P_{gav}}{P_{gm} T}}$ —(ii)

* A Duty cycle is defined as the ratio of pulse on period (T) to periodic time of pulse (T_1).

$\boxed{\text{Duty Cycle } (\delta) = \frac{T}{T_1} = fT}$ —(iii)

∴ Put the value of Eq^n (iii) in Eq^n (i)

$\boxed{\frac{P_{gav}}{\delta} \leq P_{gm}}$

or in some limiting case $\boxed{\frac{P_{gav}}{\delta} = P_{gm}}$

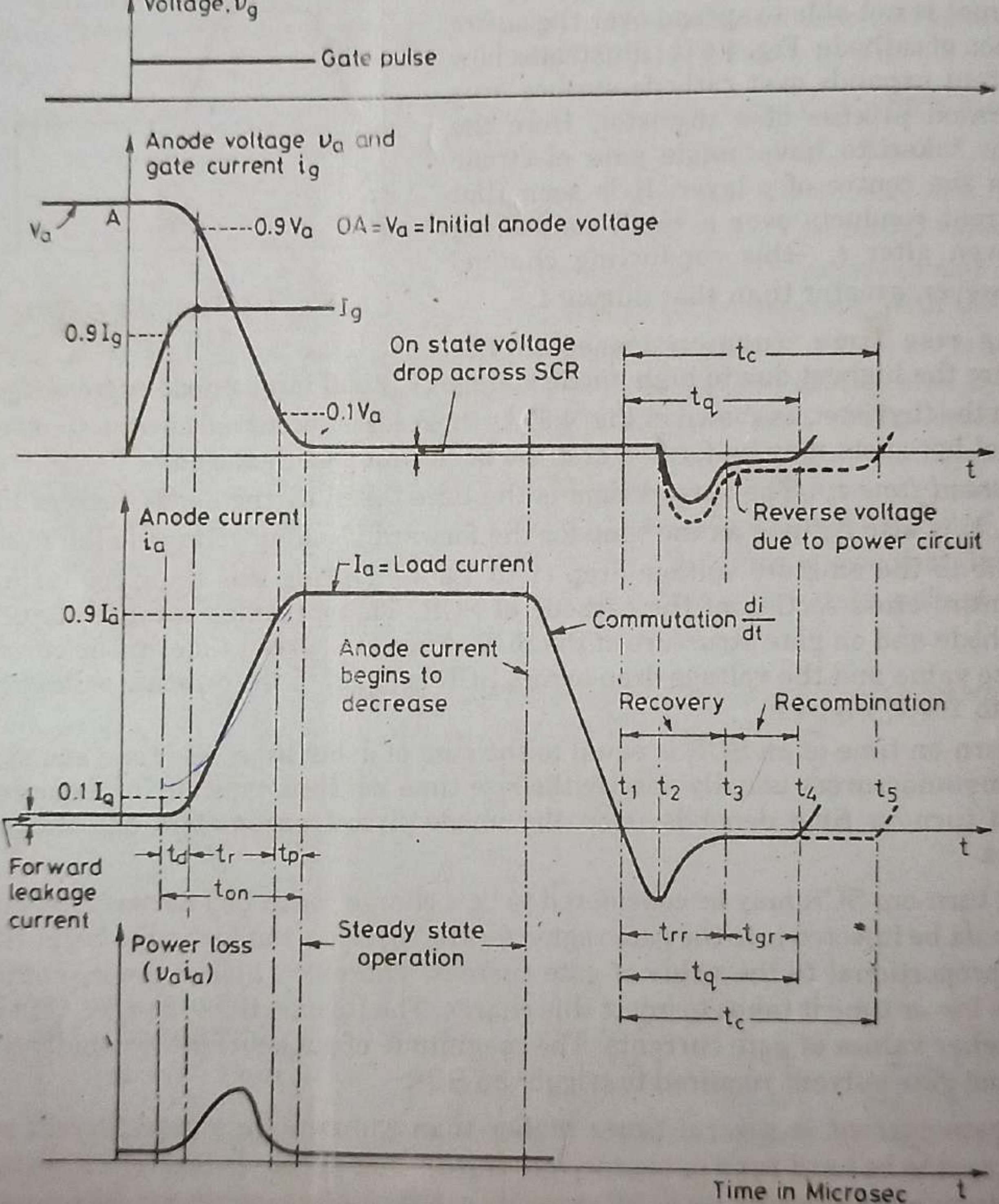


Fig. 4.8. Thyristor voltage and current waveforms during turn-on and turn-off processes.

Switching characteristics of SCR

* During turn on & turn off processes, a thyristor is subjected to different voltages ~~acro~~ across it and different currents through it.
* This time variation of voltage & current across a thyristor during turn-on and turn off process is called as switching characteristics of a thyristor.
* It's otherwise known as dynamic switching characteristics.
* It is of 2 types.

a> Switching characteristics during turn-on
b> Switching characteristics during turn-off

Switching characteristics during turn on -

* The switching characteristics during turn on and turn off processes are shown in the fig below
* Whenever a positive gate voltage is applied betn gate & cathode of a forward biased thyristor, it turned on.
* There is a transistion time from forward off-state (blocking) to forward on-state (conduction). This transition time is called as thyristor turn on time (t_{ON}).
* The total turn on time is divided into three intervals.

a> Delay time (t_d)
b> Rise time (t_r)
c> Spread time (t_p)

Delay time (t_d)

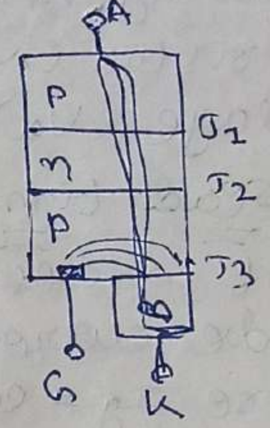
* The delay time may be defined as the time during which anode voltage falls from

V_a to $0.9V_a$, (where V_a = initial value of anode voltage) and anode current rises from forward leakage current to $0.1I_a$.

* Here gate current (I_g) rises instantly from 0.9 I_g to the final ~~the~~ state value.

* Initially the thyristor is in the forward blocking mode : ~~So At that~~ During this time the anode voltage is V_s & anode current is small leakage current.

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



* It's value is much higher near the gate but decreases rapidly as the distance from the gate increases.

* This shows that during delay time (t_d), anode current flows in a narrow region near the gate where the gate current density is higher.

* The delay time can be decreased by applying high gate current and more forward voltage betn anode & cathode.

Rise time (t_r) -:

* It is defined as the time taken by the anode current to rise from $0.1I_A$ to $0.9I_A$.

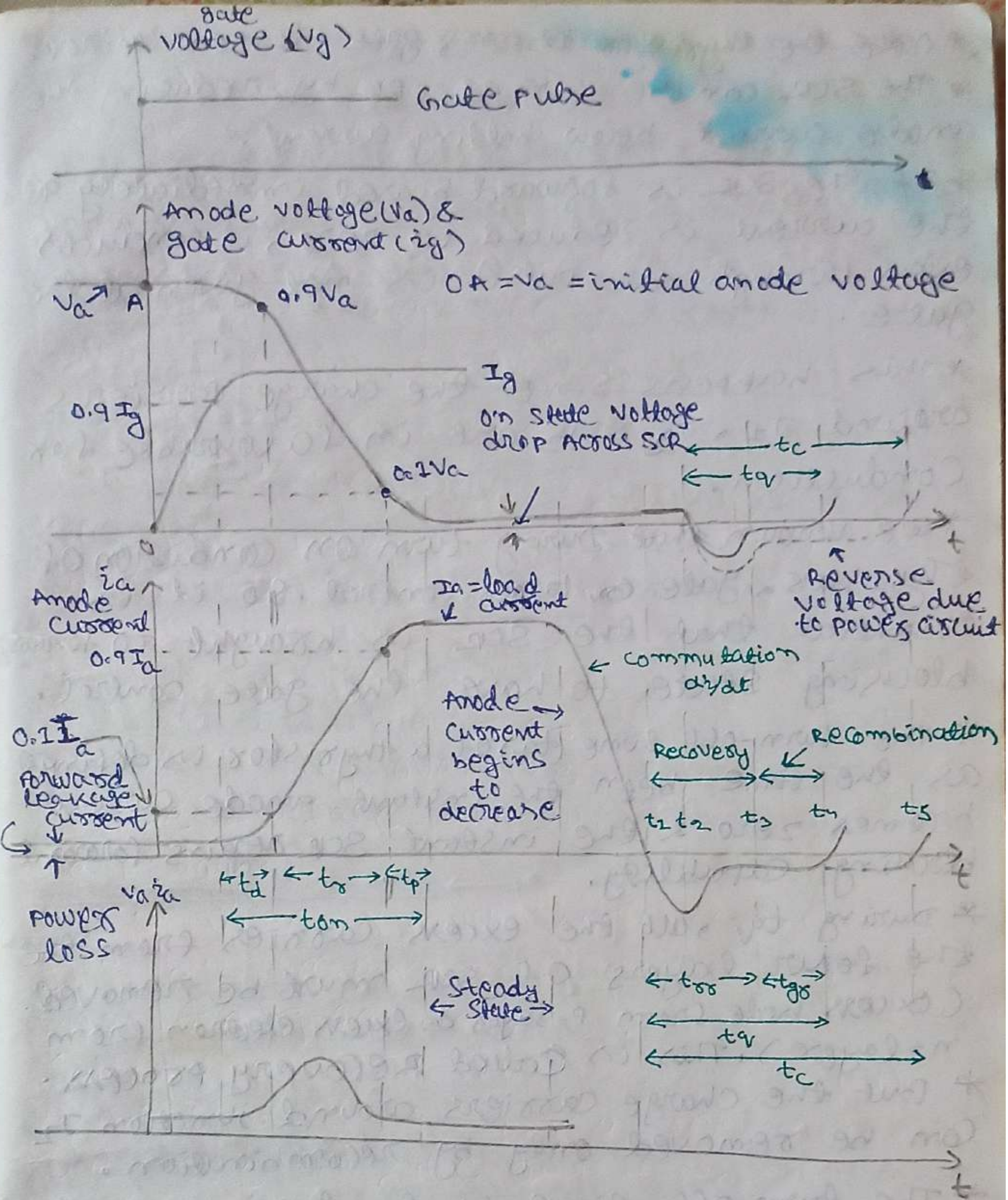
* It can also be defined as the time taken by the forward blocking off state voltage (V_a)

to fall from 0.9_{V_a} to 0.1_{V_a} of its initial value.
* I_g = constant.
* The t_r can be reduced if high & steep current pulses are applied to the gate.
* However the main factor ~~decides the~~ for determin-ing t_r is depends upon the nature of anode current.
ex-: for series R-L circuit the rate of rise of anode current is slow & t_r is more. And for ~~RCL~~ series R-C circuit di/dt is high and t_r is less.
* During the rise time, turn on losses in the thyristor is highest due to high anode voltage (V_a) and high anode current (I_a).

Spread time (t_p) -:
→ It is defined as the time taken by the anode current to rise from $0.9\,I_A$ to I_A. where I_g = constant (steady state condition) & V_a is below $0.1\,V_a$.
* During this time, conduction electrons spreads over the entire cross section of the cathode of SCR. The spreading interval depends on the area of cathode & gate structure of the SCR.
* After the spread time, anode current reaches its steady value (I_A) and voltage drop across SCR is 1 to 1.5 V.
* The total turn-on time of an SCR is equal to the sum of delay time, rise time and spread time.

$$\boxed{t_{on} = t_d + t_r + t_p}$$

~~* The thyristor manufacturers usually~~
* The total turn on time depends on V_a, I_g & I_a.



(Thyristor voltage & current waveforms during turn on & turn off (process)

Switching characteristics during Turn-off -:

→ It is the process by which thyristor changed from on state (conduction) to off state (blocking) is known as commutation process or turn off process.

* The SCR can be turned off by reducing the anode current below holding current.
* If the SCR is forward biased immediately after the current is reduced to zero, it conduces even through +ve pulse is not given at the gate.
* This happens since the charge carriers around J_1, J_2 & J_3 are in favourable for conduction.
* We known that During turn on condition of thyristor, gate losses control. So it is essential that the SCR is brought to forward blocking state to have the gate control.
* The turn-off time (t_q) of a thyristor is defined as the time betn the instant anode current becomes zero & the instant SCR regains forward blocking capability.
* During t_q, all the excess carries from the the four layers of SCR must be removed. (excess hole from p-layer & excess electron from n-layer). This is called Recovery process.
* But the charge carriers around junction J_2 can be removed only by recombination.
* The turn off time is divided into two types

a> Reverse recovery time (t_{rr})

b> gate recovery time (t_{gr})

or $\boxed{t_q = t_{rr} + t_{gr}}$

* Here t_c = circuit turn-off time.

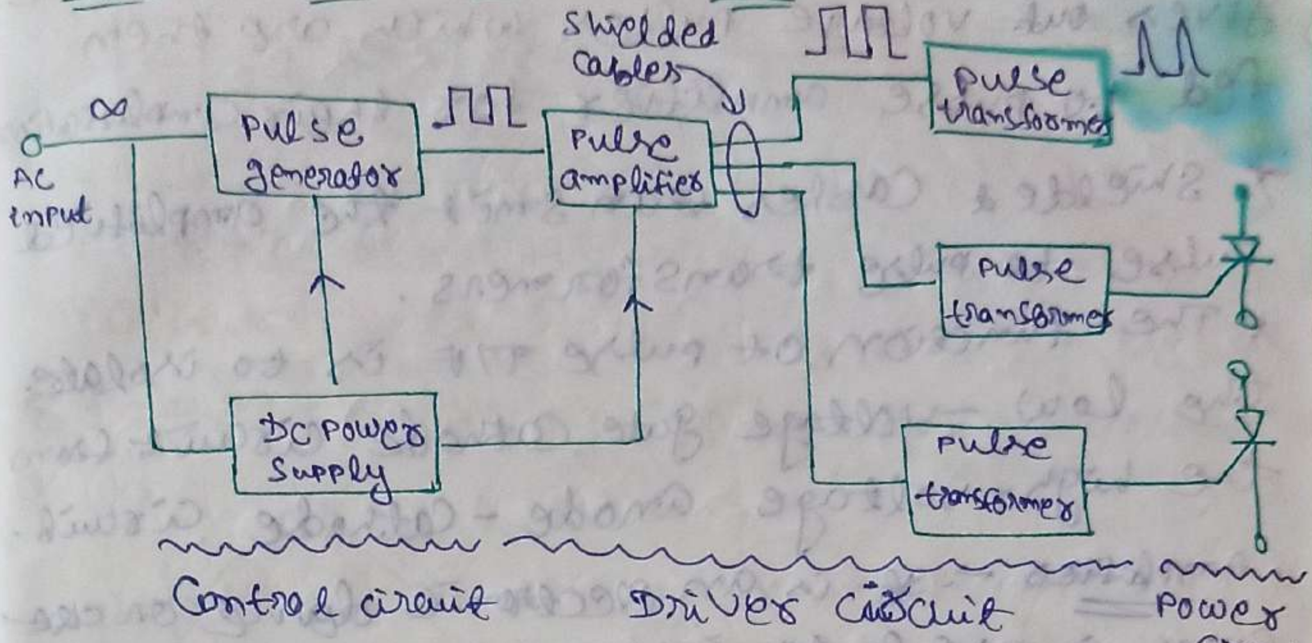
→ It is defined as the time betn the instant anode current becomes zero and the instant reverse voltage reaches zero.

Note -: t_c must be greater than t_q for reliable turn-off, otherwise the device may turn-on at an undesired instant, this is called commutation failure.

* Sh. point -: $t_1 - t_3$	$= J_1$ & J_3 (Recover)
t_4	$= J_2$ (Recover)

* Thyristor with slow turn-off time (50-100 usec) are called converter grade SCR.
* Thyristor with fast turn-off time (3 - 50 usec) are called inverter-grade SCR.

Firing circuits for Thyristors :-

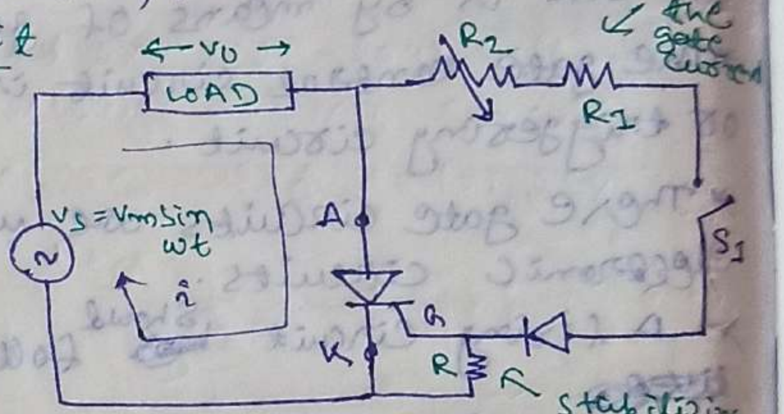


* The most common method for controlling ~~the~~ an SCR is by means of gate voltage control.
* The gate control circuit is also called firing, or triggering circuit.
* These gate circuits are usually low-power electronic circuits.
* A firing circuit should followed some function-~~lities~~
i) If power circuit has more than one SCR, the firing circuit should produce gate pulse for each SCR of the power circuit.
* These pulses must be periodic in nature & the sequence of firing must correspond with the type of ~~power co~~ ~~thyristorised power controller~~ thyristorised power controller.
* Some time, the control signal generated by a firing circuit may not be able to turn-on an SCR. So it required a driver circuit.
* A driver circuit consists of a pulse Amplifier & a pulse transformer.
* In this fig, A regulated dc power supply is obtained from an alternating vtg. source.

* pulse generator, supplied from both ac & dc source, gives out voltage pulses which are then fed to pulse amplifier for their amplification.
* Shielded cables transmit the amplified pulse to pulse transformers.
* The function of pulse T/F is to isolate the low-voltage gate cathode circuit from the high-voltage anode-cathode circuit.

Amplifier :- It is an electronic device or ckt which is used to increase the magnitude of signal applied to its i/p.

for Resistance circuit

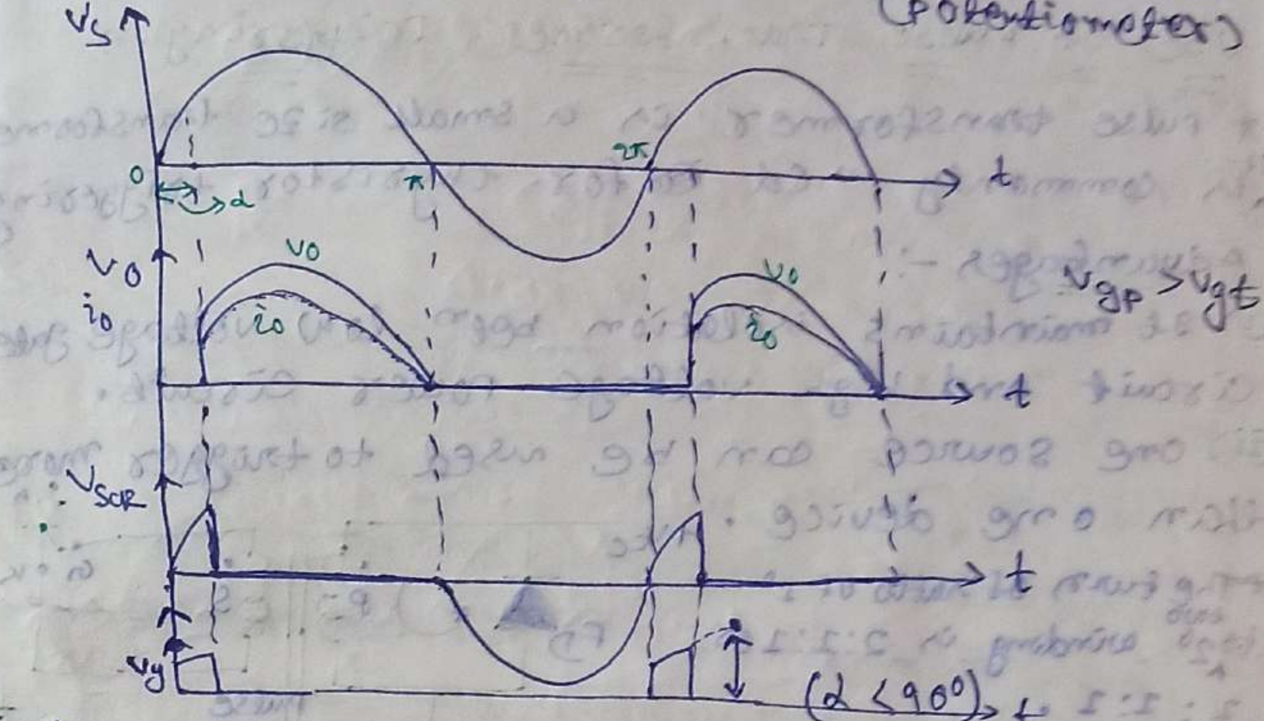


* Here we gave an AC supply to the SCR (V_s).
* During +ve half cycle the SCR will be forward biased (A +ve w.r.t. K) & during -ve half cycle the SCR will be reversed biased (K +ve w.r.t A).
* During forward biased, when we gave gate current to the SCR, then SCR will turn on.
* when SCR is turn on, we can get o/p from the load. But in off condn of SCR, the output will be zero (across load)
* R_1 = Used to limit the gate current then $\boxed{R_1 \geq \frac{V_m}{I_{gm}}}$
* R = Stabilizing gate resistance (used to stabilized the voltage across the gate)

~~terminal to trigger~~

& $\boxed{R \le \frac{R_1 \cdot V_{gm}}{V_m - V_{gm}}}$ where $R_2 = 0$. $\boxed{R \le \frac{(R_1+R_2)\, V_{gm}}{V_m - V_{gm}}}$

* (D) - diode allows the flow of current during +ve half cycle.
* R_2 = used to set gate triggering angle. variable resistor (potentiometer)



* When R_2 large, i = small & voltage across R ~~& $V_g = iR$ is also small & V_{gp} (peak of gate voltage~~ (Draw $\alpha = 90°$)
* If $\alpha < 90°$ V_{gp} (peak of gate voltage) is greater than V_{gt} (gate trigger voltage). (SCR ON)
* If $\alpha = 90°$, $V_{gp} = V_{gt}$ (SCR ON)
* If $\alpha = 0°$, $V_{gp} < V_{gt}$ (SCR OFF) (2°-4°)

relation between V_{gp} & V_{gt}

$$\boxed{V_{gp} \sin\alpha = V_{gt}} \Rightarrow \alpha = \sin^{-1}\left(\frac{V_{gt}}{V_{gp}}\right)$$

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

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

If V_{gt}, R_1, R & V_m are fixed. $\alpha \propto \sin^{-1}(R_2)$

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

H.W (RC firing ck't & wave form)

* If R_2 is more, α = less
* If R_2 is less, α = more
* α = firing angle (0 – 90°)

Use of pulse Transformer Triggering :-

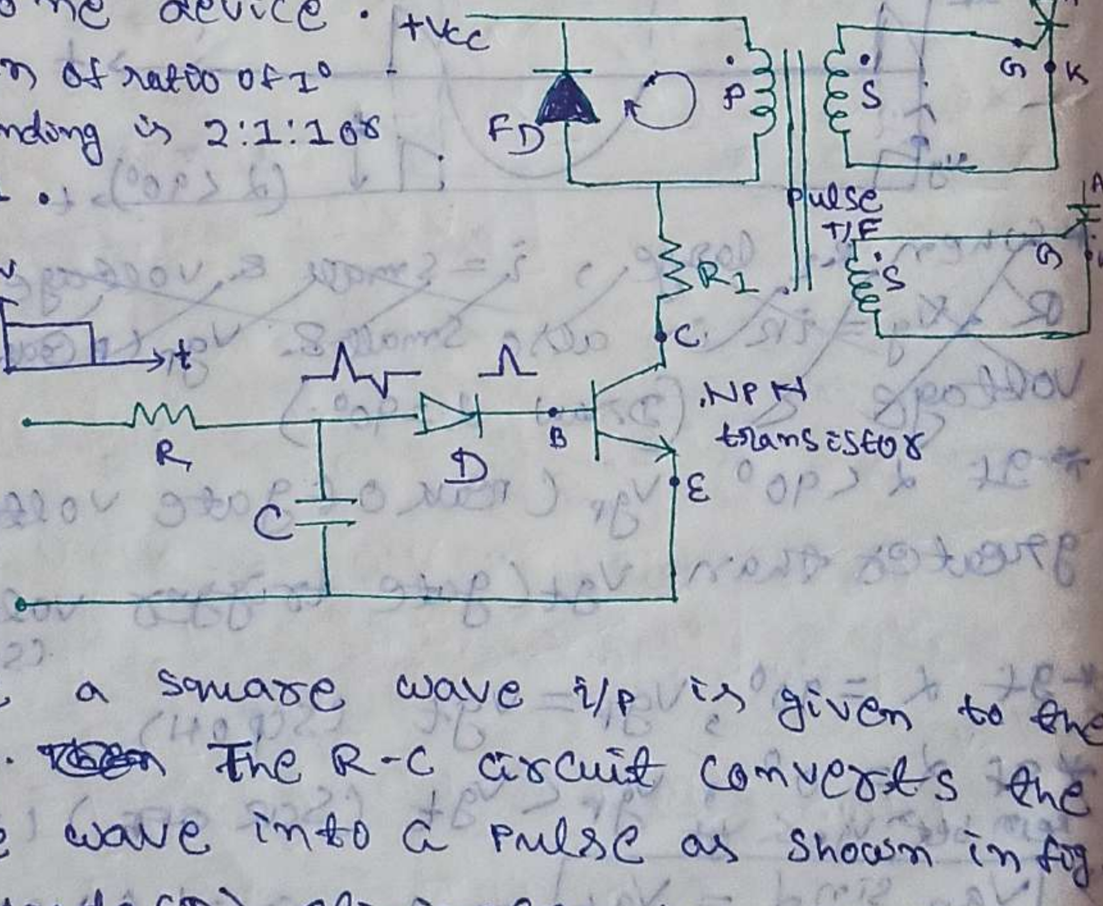
* Pulse transformer is a small size transformer. It is commonly used for thyristor triggering.

Advantages :-

(i) It maintains isolation betn low voltage gate circuit and high voltage power circuit.

(ii) One source can be used to trigger more than one device.

* The turn of ratio of 1° to two 2° winding is 2:1:1 or 1:1:1.



* Here a square wave i/p is given to the circuit. The R-C circuit converts the square wave into a pulse as shown in fig. and diode (D) eliminates the –ve part of the pulse.
* When this pulse is applied to the base of transistor (NPN), the transistor turns on

and the voltage V_{cc} is applied to the primary winding.

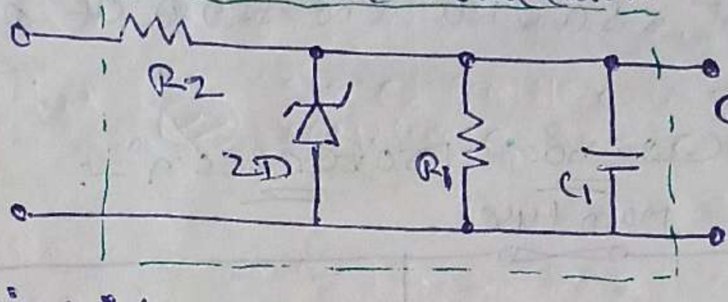
*These voltage is induced to the secondary winding & the secondary voltage acts as a trigger voltage of thyristor.

* When transistor (T) is OFF, the pulse is removed from the pulse transformer.

* At that time, the free wheeling diode (FD) starts conducting and dissipates the stored energy of the primary winding.

Gate protection -:

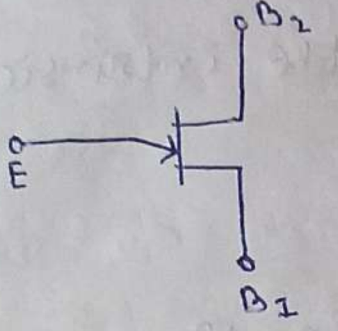
Gate protection



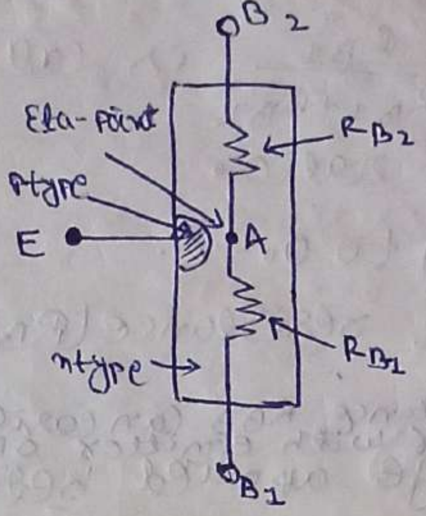
* Gate circuit ~~is used to~~ should be protected ~~the~~ against overvoltages & overcurrents because over-voltages across the gate circuit can cause false triggering of the SCR & over current may raise junction temp. beyond specified limit leading to its damage.
* Protection against over-voltage is achived by connecting a zener diode (ZD) across the gate circuit.
* A Resistor (R2) connected in series with the gate ciruit provides ~~provides~~ protection against over currents.

Zener diode -: It is a particular type of diode that, ~~unlike a normal one~~ allows current to flow not only from its anode to its cathode, but also in the reverse dirn, when the zener voltage is reached.

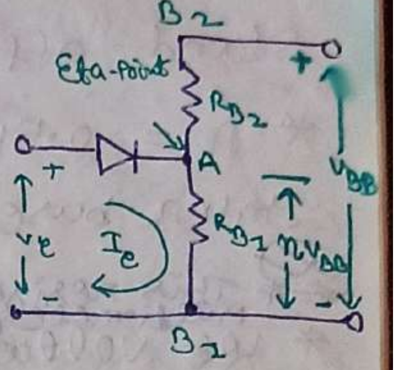
Unijunction Transistor (UJT)



(Symbolic representation)



(Basic structure of UJT)



(equivalent Ckt.)

* UJT is a switching device. It conducts when the applied voltage reaches a critical value.
* It is made up of an n-type silicon base to which ~~and~~ a P-type ~~material~~ emitter is embedded.
* The n-type base is lightly doped whereas P-type is heavily doped.
  ↳ intentional introduction of impurities in S.C.
* An UJT has three terminals, namely the emitter (E), base-one (B_1) and base-two (B_2)
* Resistance R_{B_1} & R_{B_2} are the internal resistance of Base B_1 & B_2 respectively.
* The point betn Base B_1 & B_2 are called as Eta-point (A).
* When a voltage V_{BB} is applied across the two base terminals B_1 & B_2, the potential of point A w.r.t to B_1 is given by

$$V_{AB_1} = \frac{R_{B1}}{R_{B1}+R_{B2}} \cdot V_{BB} = \eta V_{BB}$$

where $\eta = \frac{R_{B1}}{R_{B1}+R_{B2}}$ is called the intrinsic stand-off ratio.

* η = 0.51 to 0.82.

Inter base resistance $(R_{BB}) = R_{B1} + R_{B2}$ (5-10 kΩ)

* This resistance R_{BB} can easily be measured by a multimeter with emitter open.

* Let voltage applied betn E - B_1. When $V_e < \eta V_{BB}$ the E - B_1 unijunction (or p-n junction) is reverse biased & emitter current I_e is -ve. (***)

since emitter is nearer to B_2, resistance $R_{B2} < R_{B1}$

Q// $\eta = 0.72$, $R_{BB} = 8k\Omega$, ...

(***) → At point S, $I_e = 0$, drop across $R_E = 0$ & $V_e = V_{EE}$ (source vtg.)

→ ~~At point~~

(***) When $V_e \geq \eta V_{BB} + V_D$, I_e is +ve, E–B junction begins to conduct.

* The point 'A' is called the peak point and corresponding emitter potential & current are denoted by V_P & I_P respectively. (Peak-point vtg., peak-point current)

* From point A to B, V_e = decreases & I_e increases & the device exhibit a -ve resistance region

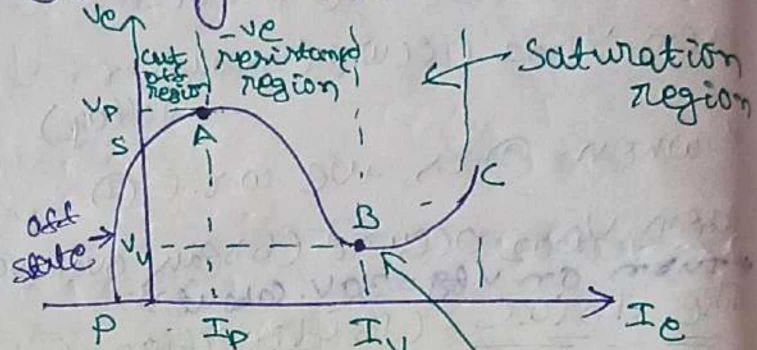
* from point B saturation region start & I_e, V_e are rises.

* Here point 'B' is called valley point &
I_V = Vally point current.
V_V = valley point voltage.

* The -ve resistance region betn peak & vally point gives the UJT switching characteristics for use in triggering ckt.

*(V_{BB} = Biasing vtg.)

(VI char)



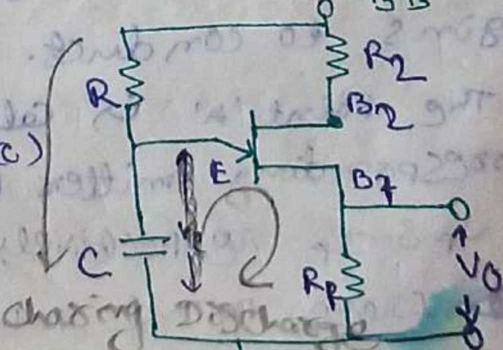
UJT Relaxation oscillator triggering:
* The UJT is a highly ~~effect~~ efficient switch. Its switching time is in the range of nanoseconds.
* It can be used as a relaxation oscillator.

Oscillator: oscillators convert direct current signal from a power supply to an alternating current signal. (periodically).

* Relaxation oscillator process will be occure in the -ve resistance region.

* In this ckt diagram R_1, R_2 are small resistance in comparison with the internal resistance R_{B_1}, R_{B_2} of UJT Base.

~~* Here the capacitor (c)~~
* when source voltage V_{BB} is applied, capacitor(c) begins to charge through Resistor.



* then time const. of the

charge circuit is $\tau_1 = RC$. (Charging)

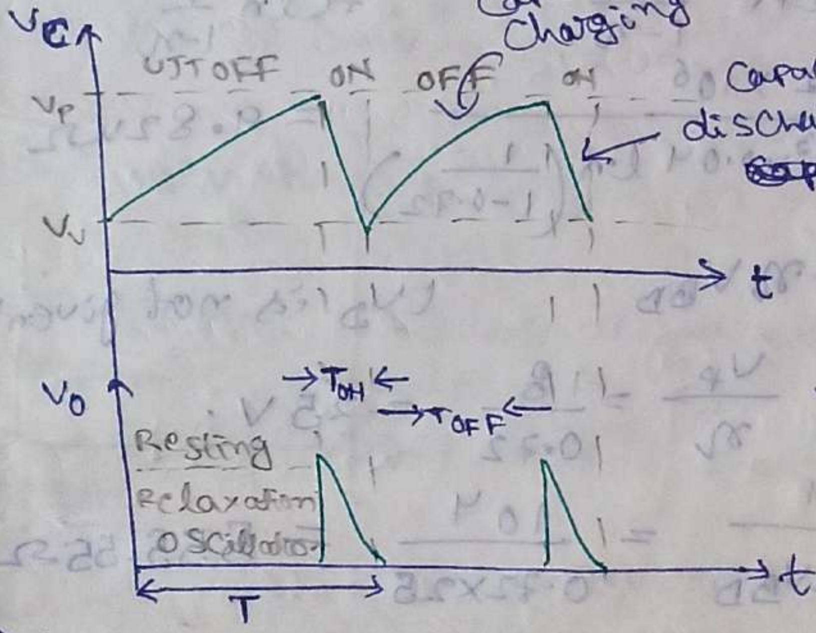
* when the capacitor voltage reaches the peak-point voltage $V_p(\eta V_{BB} + V_D)$, then it will trigger (on) the UJT.

* As a result, UJT will be turn on and capacitor 'C' ~~~~ rapidly discharges through R_1 with a time constant $\tau_2 = R_1 C$.

Note-:

* Charging of the capacitor -: Valley point to peak point.

Discharging of the capacitor -: Peak point to ~~~~ valley point.



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

* when UJT is OFF, the output voltage V_0 = zero.

* when UJT is ON, the output voltage (V_0) is equal to the capacitor discharging voltage.

* Relaxation oscillator -: oscillation rest for some time & generates AC signal.

* T (timeperiod) $= RC \ln\left[\dfrac{1}{1-\eta}\right]$, $f = \dfrac{1}{T}$

* $\boxed{V_P = V_D + \eta V_{BB}}$

* $\boxed{R_{max} = \dfrac{V_{BB} - V_P}{I_P}}$

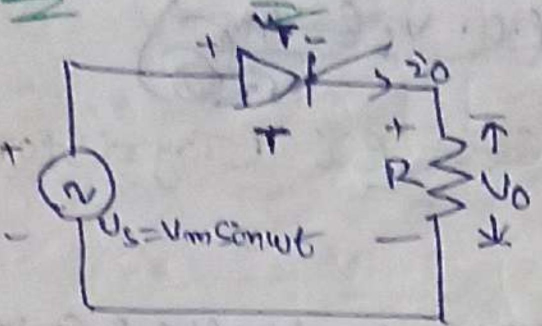
* $\boxed{R_2 = \dfrac{10^4}{\eta V_B}}$

* $\boxed{R_{min} = \dfrac{V_{BB} - V_V}{I_V}}$

Firing angle (α) -: Firing angle is the phase angle of the voltage at which the SCR turns on.

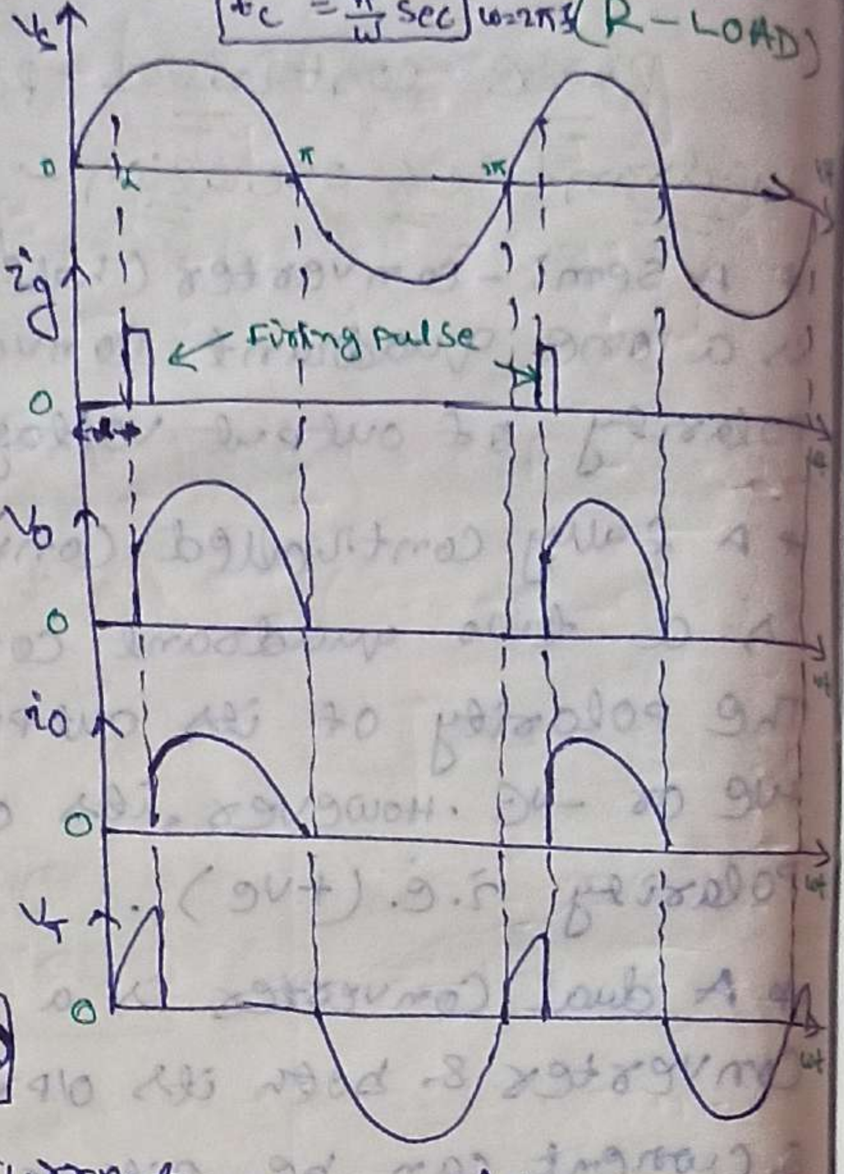
Principle of phase control -: * How SCR conduct
* How O/P will be determine * $\omega t = 0, 2\pi, 4\pi$ ---

Single phase halfwave controlled Rectifier



Cut turn off time =

$\boxed{t_c = \frac{\pi}{\omega} \sec}$ $\omega = 2\pi f$ (R-LOAD)



① **The avg. O/P vtg.**

V_{dc}

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

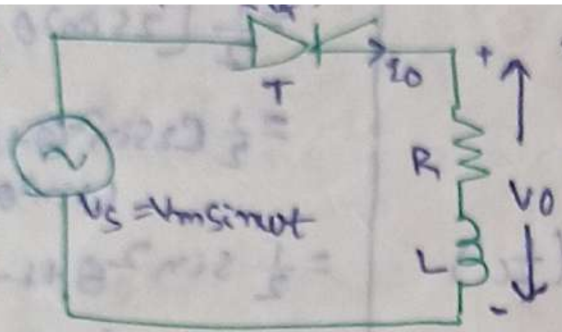
$$= \frac{V_m}{2\pi} \left[-\cos \omega t \right]_{\alpha}^{\pi}$$

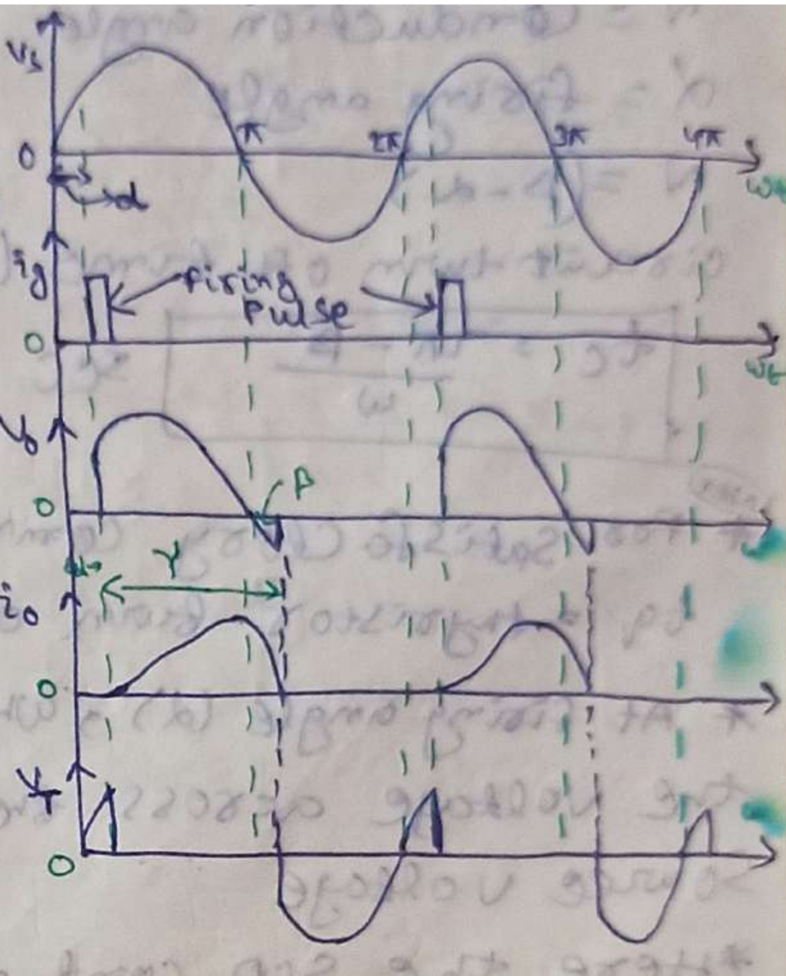
$$= \frac{V_m}{2\pi} \left[\cos \omega t \right]_{\pi}^{\alpha}$$

$$= \frac{V_m}{2\pi} [\cos \alpha - (-1)]$$

$$\Rightarrow \boxed{V_0 = V_{dc} = \frac{V_m}{2\pi} (1 + \cos \alpha)}$$

② **Avg O/P current** $I_{dc} = \frac{V_{dc}}{R}$





① The avg. O/P vtg. :-

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

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

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

$$\boxed{V_0 = \frac{V_m}{2\pi}(\cos\alpha - \cos\beta)}$$

~~O/P current~~ : O/P current $I_0 = \frac{V_0}{R}$

* β = extinction angle
  γ = conduction angle
  α = firing angle
  $\gamma = (\beta - \alpha)$

circuit turn off time (t_c)

$$\boxed{t_c = \frac{2\pi - \beta}{\omega}}$$ sec

$\sin^2\theta = \frac{1}{2} \times 2\sin^2\theta$

$= \frac{1}{2}[2\sin^2\theta + 1 - 1]$

$= \frac{1}{2}(2\sin^2\theta + 1 - (\sin^2\theta + \cos^2\theta))$

$= \frac{1}{2} \sin^2\theta + 1 - \cos^2\theta$

$= \frac{1}{2}[1 - (\cos^2\theta - \sin^2\theta)]$

$= \frac{1}{2}[1 - \cos 2\theta]$

* For satisfactory commutation, $\boxed{t_c > t_q}$
  t_q = thyristor turn off time.
* At firing angle (α), when the SCR is conducting the voltage across the load (R-L) is same as the source voltage
* Here the SCR conducts beyond π since the load inductance (L) forces the output

current to increase gradually to reaches the max^m value & then begins to decrease. (inductor doesn't allow the sudden change of current, so even through the source voltage comes to zero, the current slowly reduced to zero).

* From α to π, v_0 & i_0 are +ve, power is trans-formed from source to load.
* From π to β, i_0 is +ve & v_0 is -ve, power is fed back to the source. This is called Recycling. Recycling continues till the energy in the inductor is given back to the source.
* The avg. o/p voltage gets reduced due to -ve segments. The larger the inductance, the larger the -ve area present or viceversa.
* At $\omega t = 2\pi + \alpha$, SCR is triggered again.

** (($0 < \omega t < \alpha$))

(AC-AC converter) AC voltage controllers

(AC regulator)

* AC voltage controllers are thyristor based devices which convert fixed alternating voltage to variable alternating voltage without a change in the frequency.

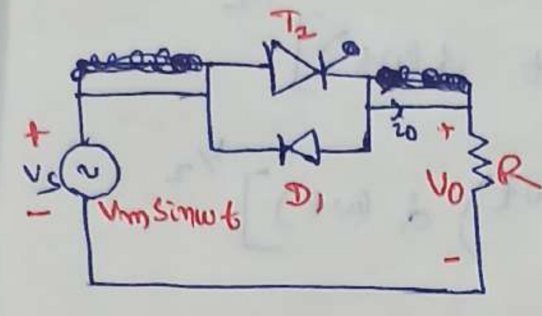
Application -:

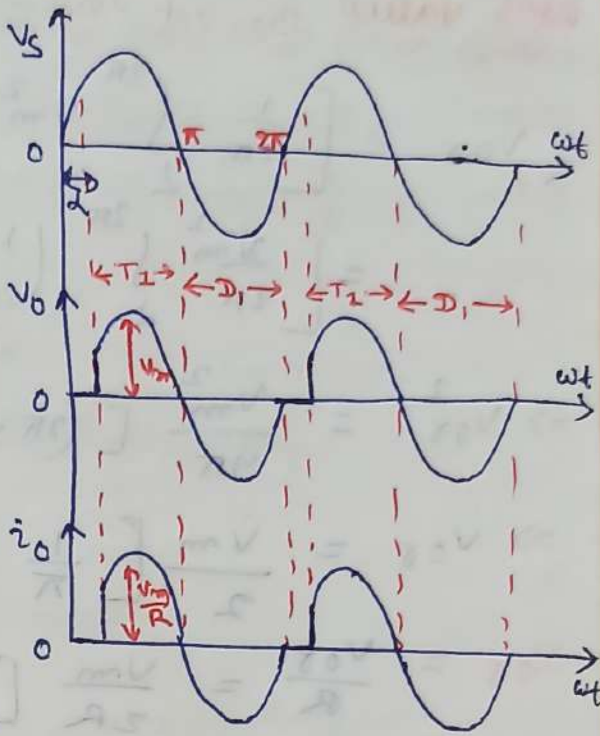
1. Industrial heating.
2. Lighting Control.
3. Speed control of 1-ph & 3-ph AC drives and
(4) Starting of induction motor.
4. Transformer ~~for~~ changing.

Disadvantages -:

* Harmonics generates in the supply current and load voltage waveforms, particularly at reduced output voltage level.
* For regul...

Single-phase half wave voltage controllers with R-load :-





* This circuit consist of a voltage source (V_s), a resistive load (R) and a thyristor (T_1) which is connected in antiparallel direction with a diode (D_1).

Mode (1) -: ($\alpha < \omega t < \pi$)

* During the +ve half cycle, SCR (T_1) is forward biased & on. (provide firing angle α to SCR(T_1)).
* At that time current flows through the path (V_s - $\overset{SCR}{T_1}$ - $\overset{load}{R}$ - V_s) & we can get the output voltage & output current as shown in the fig.

Mode (2) -: ($\pi < \omega t < 2\pi$)

* During the -ve half cycle, Diode (D_1) is forward biased & conduct. So that the current is in the direction of (V_S - R - D_1 - V_s)
* ~~Hence the path~~
* Here we can be controlled only the +ve half cycle but -ve half cycle can't be controlled. Therefore, it is also called as single-phase unidirectional voltage controller.

Avg. O/P voltage :- (V_0) -:

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

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

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

RMS value of o/p vtg :- (V_{or})

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

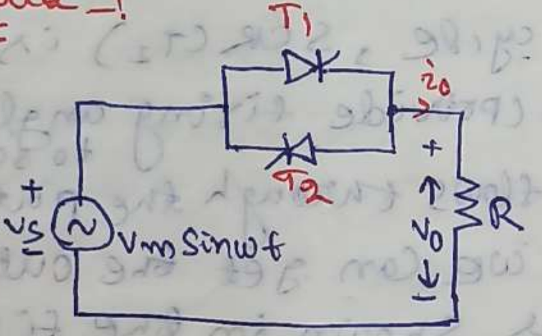
$$= \left[\frac{V_m^2}{2\pi}\int_{\alpha}^{2\pi}\left(\frac{1-\cos 2\omega t}{2}\right) d(\omega t)\right]^{1/2}$$

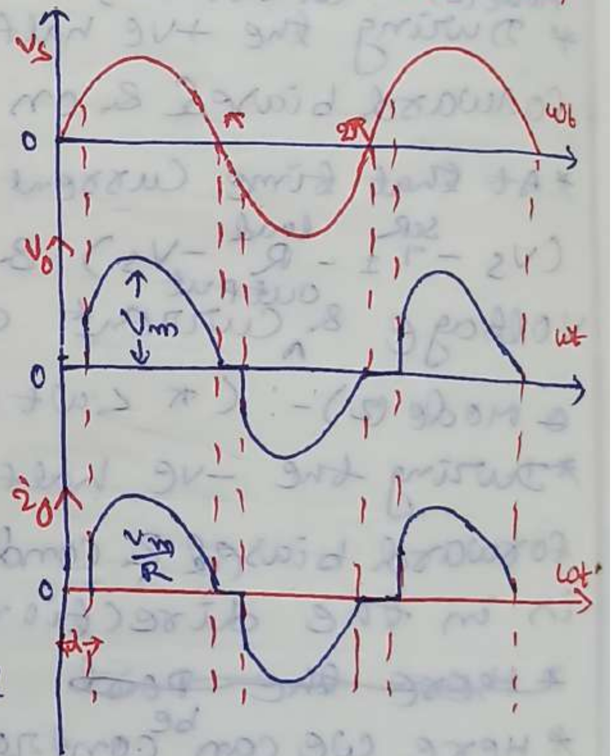
$$\Rightarrow V_{or}^2 = \frac{V_m^2}{4\pi}\left[(2\pi-\alpha) + \frac{\sin 2\alpha}{2}\right]$$

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

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

Single phase full wave voltage controllers with R-load :-





* This circuit consist of a voltage source (V_s), a resistive load (R) and two SCRs (T_1, T_2) which is connected in antiparallel direction.
* Mode(1) = ($\alpha < \omega t < \pi$)
* During +ve half cycle, T_1 is triggered at firing angle (α). So the SCR (T_1) conducts from $\omega t = \alpha$ to π for R load.
* Current flow direction ($V_s - T_1 - R - V_s$)

Mode-(2) = ($\pi+\alpha < \omega t < 2\pi$)

* During -ve half cycle, T_2 is triggered at firing angle (α). So the SCR (T_2) conducts from $\omega t = \pi+\alpha$ to 2π for R-load.
* current flow direction ($V_S - R - T_2 - V_S$)
* Here we can be controlled both the half cycle. Therefore, it is also as single phase bidirectional voltage-controller.

Avg. O/P voltage -:

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

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

$$\Rightarrow \boxed{V_0 = \frac{V_m}{\pi}(\cos\alpha + 1)}, \quad I_0 = \frac{V_0}{R} = \frac{V_m}{\pi R}(\cos\alpha+1)$$

RMS value of O/P Vtg. -: (V_{or})

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

$$\Rightarrow (V_{or})^2 = \frac{V_m^2}{\pi}\int_{\alpha}^{\pi}\left(\frac{1-\cos 2\omega t}{2}\right) . \, d(\omega t)$$

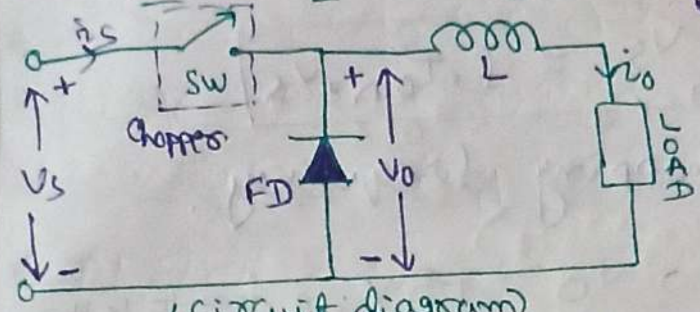
$$\Rightarrow V_{or}^2 = \frac{V_m^2}{2\pi}\left[\omega t - \frac{\sin 2\omega t}{2}\right]_{\alpha}^{\pi}$$

$$\Rightarrow V_{or}^2 = \frac{V_m^2}{2\pi}\left\{(\pi-\alpha) + \frac{\sin 2\alpha}{2}\right\}$$

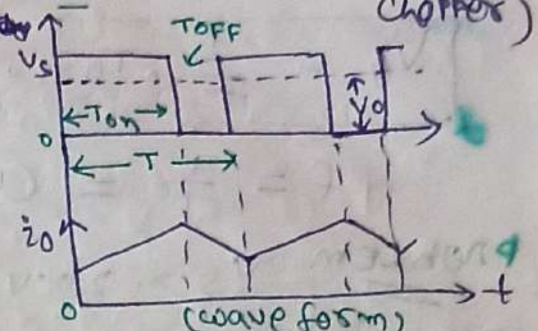
$$\Rightarrow V_{or} = \frac{V_m}{\sqrt{2}}\left[\frac{1}{\pi}\left\{(\pi-\alpha) + \frac{\sin 2\alpha}{2}\right\}\right]^{1/2}$$

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

Principle of Chopper operation (step down Chopper)



(circuit diagram)



(wave form)

* 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.
* Chopper is represented by a switch (SW) inside a dotted ~~rectangle~~, which may be turned-on or turned-off as ~~required~~ desired.
* When Chopper is on (TON), the source current flows through (Chopper – inductor (L) – load) and we can get O/P voltage which is less than I/P voltage. $(V_0 < V_s)$.
* During this period inductor charged by the flow of source current.
* ~~At off condition Chopper~~
* During the off condition of chopper, inductor current free-wheel through (L – Load – FD).
* Note: During (T_{on}) on condn, load current rises whereas in off condition (T_{off}), load current decays.
* Here Avg. load voltage

$$V_0 = \frac{T_{on}}{T_{on}+T_{off}} V_s = \frac{T_{on}}{T} V_s = \alpha V_s$$

T_{on} = On-time $\qquad \alpha = \frac{T_{on}}{T}$ (Duty cycle)

T_{off} = Off-time

$T = T_{on} + T_{off}$ = Chopping period we can also written as.

$$\boxed{V_0 = \frac{1}{T} \cdot T_{on} \cdot V_s = f \cdot T_{on} \cdot V_s}$$

$f = \frac{1}{T}$ = Chopping frequency.

Problem $V_s = 200V$, $V_0 = 75V$, $f = 5kHz$

Find T_{on} & T_{off}, T, α.

$V_0 = f \, T_{on} \, V_s$

$\Rightarrow 75 = 5 \times 10^3 \times 200 \times T_{on}$

$\Rightarrow T_{on} = \frac{75}{5 \times 10^3 \times 200} = 7.5 \times 10^{-5}$ sec.

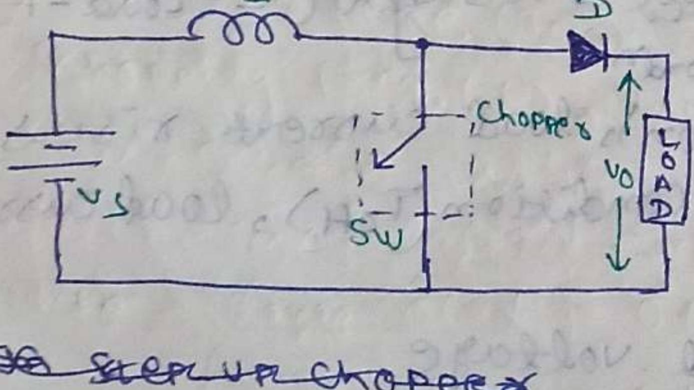
$T_{OFF} = T - T_{on} = \frac{1}{f} - T_{ON} = \underbrace{\frac{1}{5 \times 10^3}}_{2 \times 10^{-4}} - 7.5 \times 10^{-5}$

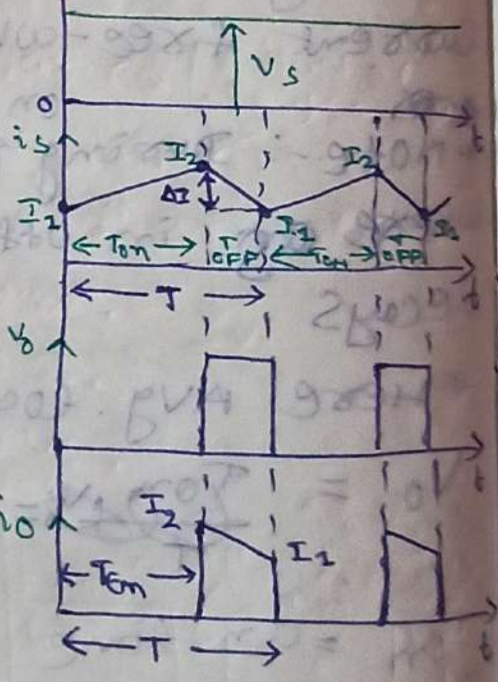
$= 1.25 \times 10^{-4}$ sec.

$T = \frac{1}{f} = \frac{1}{5 \times 10^3} = 2 \times 10^{-4}$ sec.

$\alpha = \frac{T_{on}}{T} = \frac{7.5 \times 10^{-5}}{2 \times 10^{-4}} = 0.375$

Step-Up Chopper :- ($V_0 > V_s$)





~~* Step-up chopper~~

* This circuit consist of a voltage source (Vs), a large inductor (L) which is connected in series with the load, a chopper (step-up chopper), a Diode & a load.

* When chopper is on (T_{on}), current flows through the path (V_S - L - chopper - V_S) & energy will be store in the inductor.
* During Off condition of chopper (T_{off}), current flows through the path (V_S - L - D - load - V_S).
* In on condition current increases gradually whereas in off condition current tends to decrease & polarity of the inductor (L) is reverse.
* So in off condition $\boxed{V_0 = V_S + L\frac{di}{dt}}$
* When CH is on, current through (L) would increase from I_1 to I_2. At Off condition, current would fall from I_2 to I_1.
* At on condition, $\boxed{V_L = V_S}$ & in off condition By applying KVL $V_L - V_0 + V_S = 0$

$$\Rightarrow \boxed{V_L = V_0 - V_S}$$

* Assuming linear variation of output current, the energy i/p to inductor from the source in (T_{on}) period is

$$W_{on} = (\text{voltage across L})(\text{Avg. current through L})T_{on}$$

$$= V_S\left(\frac{I_1 + I_2}{2}\right)T_{on} \quad -(i)$$

For T_{off} condn

$$W_{off} = (\text{Voltage across L})(\text{Avg. Current through L})T_{off}$$

$$= (V_0 - V_S)\left(\frac{I_1 + I_2}{2}\right).T_{off} \quad -(ii)$$

Equating eqn (i) & (ii),

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

$$\Rightarrow V_S \cdot T_{on} = V_0 T_{off} - V_S T_{off}$$

$$\Rightarrow V_0 \cdot T_{off} = V_S (T_{on} + T_{off})$$

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

$$\Rightarrow V_0 = V_S \frac{T}{T - T_{on}} \Rightarrow \boxed{V_0 = V_S \frac{1}{1-\alpha}} \quad \text{—(iii)}$$

Control strategies of chopper -:

* The control strategies for varying duty cycle (α) are . a) Time ratio control (TRC)
  b) Current limit control

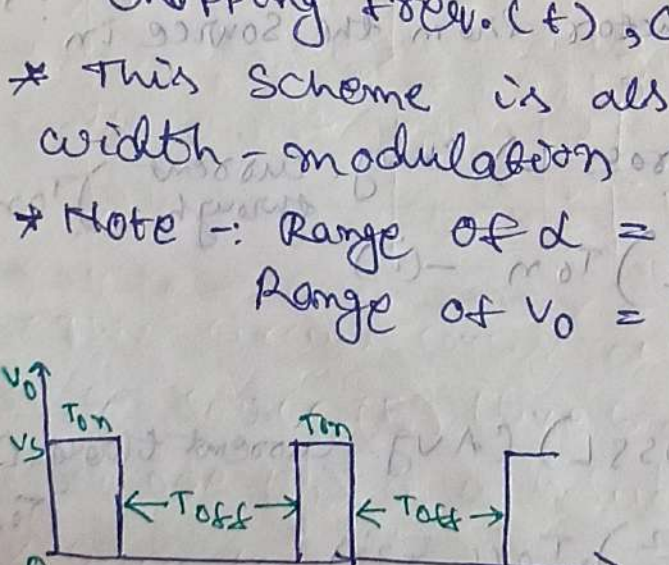
Time ratio control -:

* In this control scheme, we can varies the duty cycle (T_{on}/T).
* It is also of two type.

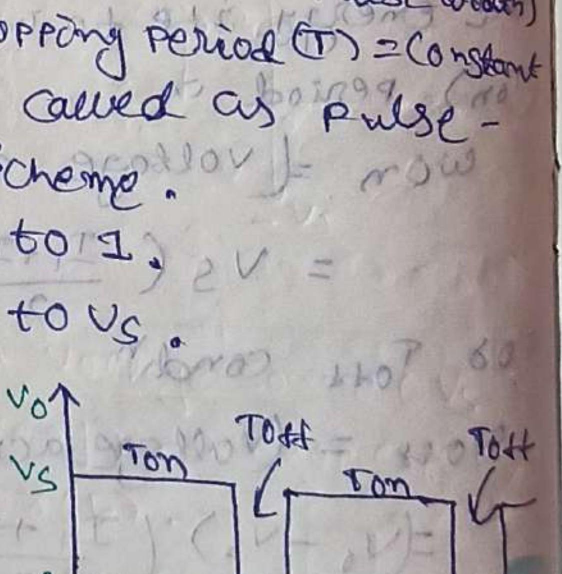
a) Constant frequency system.
b) variable frequency system.

Constant frequency system -:

* The on time (T_{on}) = varied (Adjust of pulse width) Chopping frequ. (f), Chopping period (T) = Constant
* This scheme is also called as pulse-width-modulation Scheme.
* Note -: Range of α = 0 to 1.
  Range of V_0 = 0 to V_S.



$\alpha = 0.25$, $T_{on} = \frac{1}{4}T$



$\alpha = 0.75$, $T_{ON} = \frac{3}{4}T$

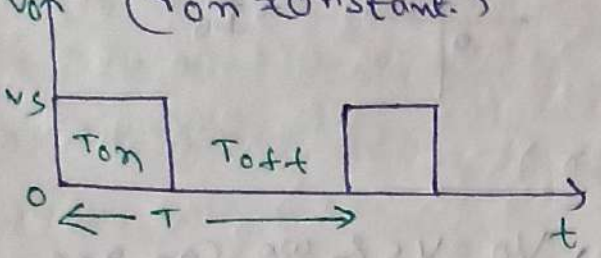
variable frequency system -:

* Chopping frequency (f) or chopping time (T) = varied

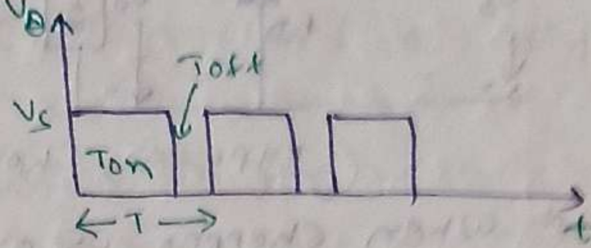
& either (T_{on}) = constant or T_{off} = constant.

* This scheme is also called as frequency-modulation scheme.

(T_{on} = constant.)

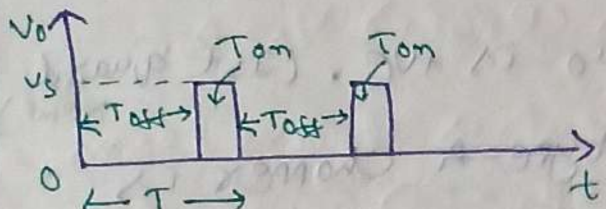


$T_{on} = \frac{1}{4}T$, $\alpha = 0.25$

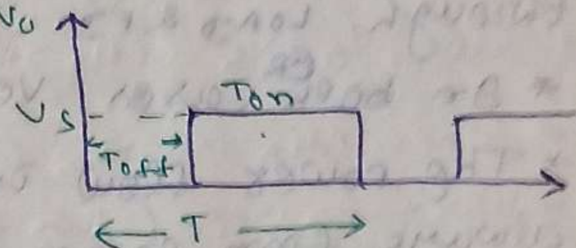


$T_{on} = \frac{3}{4}T$, $\alpha = 0.75$

(T_{off} = constant)



$T_{on} = \frac{1}{4}T$, $\alpha = 0.25$

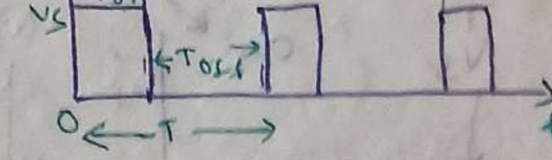


$T_{on} = \frac{3}{4}T$, $\alpha = 0.75$

Current-limit control -:

* I_{omx} = maximum load current.

* I_{omn} = minimum load current.



Note-:

* when load current reaches the upper limit (I_{omx}), chopper is switch off.

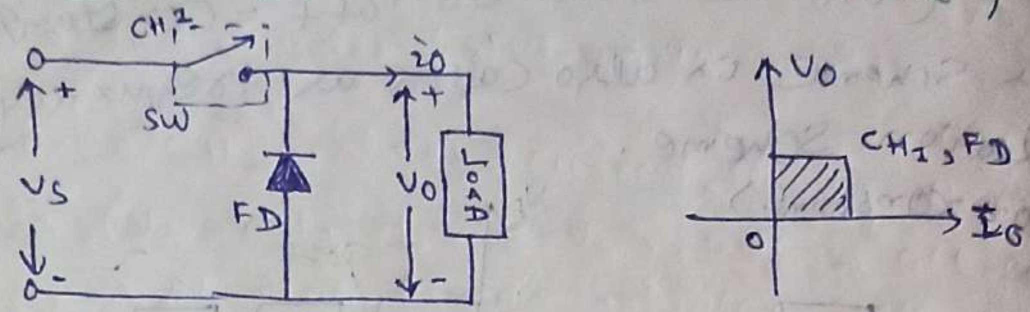
* Now the ~~load~~ current free wheels & begins to decrease. At the ~~~~ lower limit I_{omn}, chopper is switched on. So that the load curr rise again.

* By setting I_{omx} & I_{omn}, we can control the switching freq. of chopper.

$$\boxed{\text{Ripple current} = I_{omax} - I_{omin}}$$

Types of Chopper circuits-:

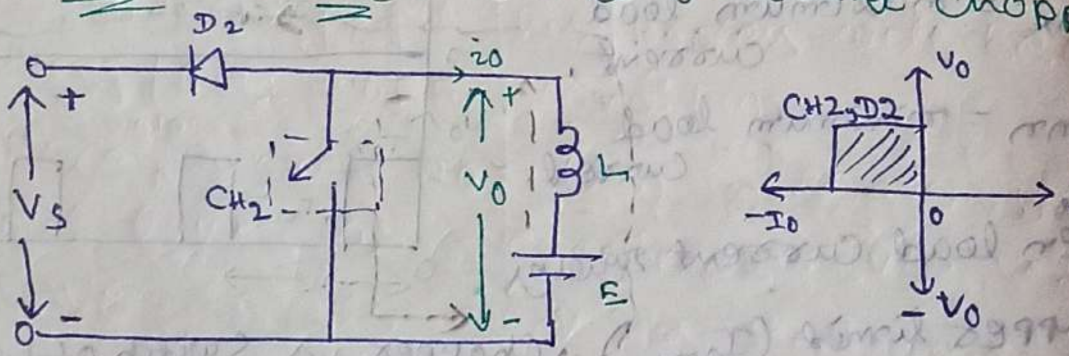
Type-(A) Chopper (First-quadrant)



(Type (A) Chopper)

* When chopper is on, $V_o = V_s$ & we can get O/P current (i_o).
* When chopper is off, $V_o = 0$. current is freewheel through LOAD & FD.
* In both cases V_o & I_o is +ve. (Ist quadrant)
* The power flow in type-A chopper is always from source to load.
* This is also called step-down chopper as ~~where~~ ($V_o < V_s$).

Type (B) Chopper (2nd-quadrant chopper)



* This circuit consist of a voltage source (V_s), a dc source (E) (like battery), a chopper (CH_2) a diode (D_2) & a inductor (L).
* When (CH_2) is on, $V_o = 0$ but load voltage (E) drives current through L & CH_2.

* During this period ($CH_2 = ON$ or T_{on}), inductor stored energy.

* At off condition ($CH_2 = OFF$), $V_0 = \left(E + L\frac{di}{dt}\right)$ exceeds source voltage V_S.

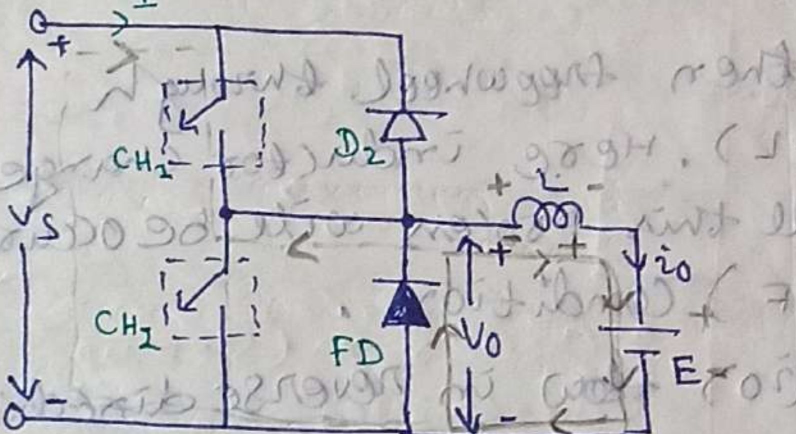
* As a result, Diode D_2 is forward biased & begins to conduct and current flows from load to source. ($E - L - D_2 - V_S - E$)

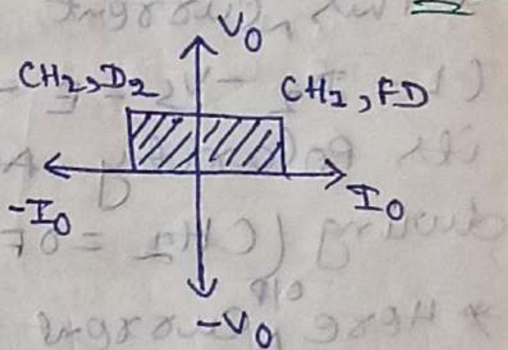
* In both the cases (CH_2 = on/off) o/p current flow from load to source, thus (i_0) is treated as -ve.

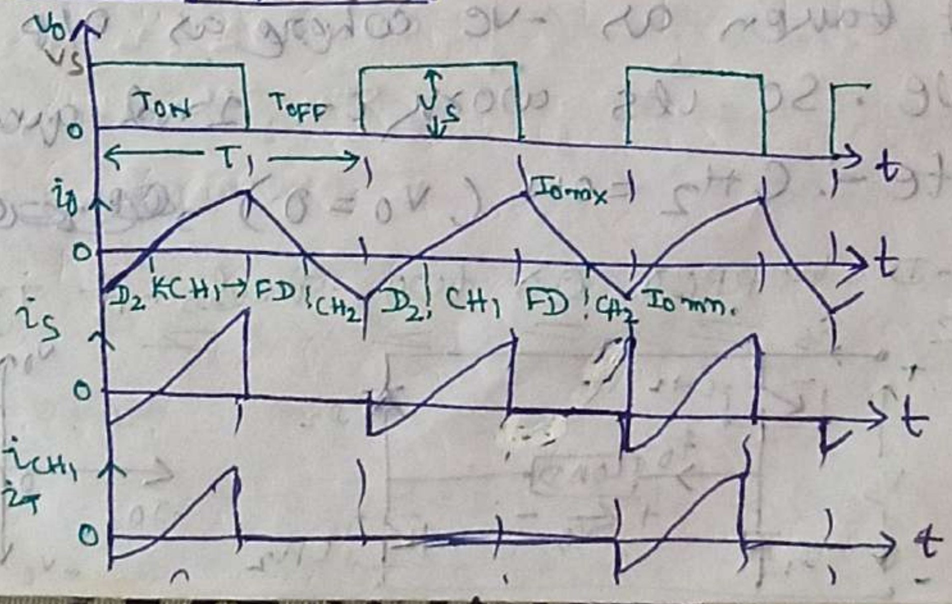
* Note-: The power flow in type-B chopper is always from load to source.

* This is also called step-up chopper as ($V_0 > V_S$).

Type (C) chopper or two-quadrant type-A chopper

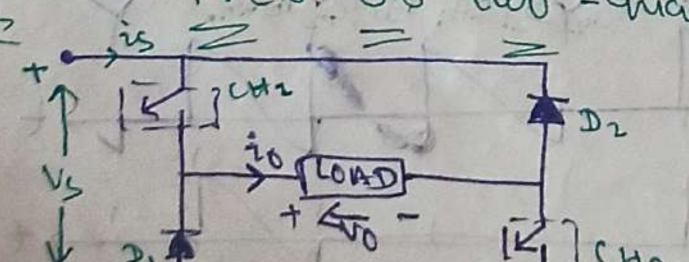


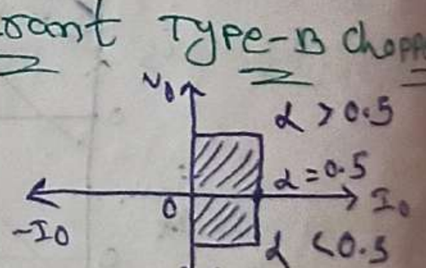


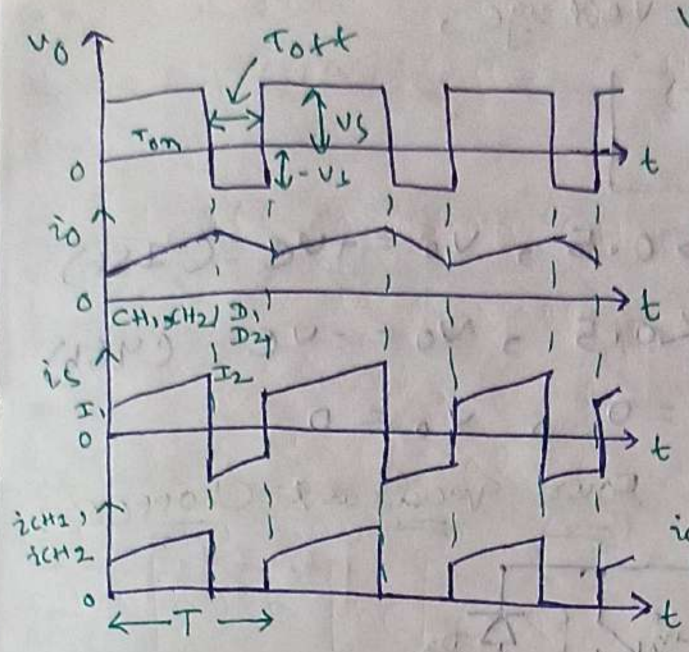


* This type of chopper is the parallel combination of Type-A & Type-B choppers & its works in 1st and 2nd Quadrant.
* In 1st Quadrant, it works as step down chopper (Type-A)
* In 2nd Quadrant, it works as step up chopper (Type-B).
* When CH_1 is ON, current is flowing through the path ($V_s - CH_1 - L - E - V_s$). ~~Battery off condition~~ (~~CH_1 is~~ At that time inductor gets energized
* But in off condition (CH_1 is OFF), the inductor changes its polarity & inductor current free-wheeling through (~~FD~~ L-E-FD-L).
* Here V_0, i_0 are +ve & work in 1st quadrant.
* Note-: $V_0 = V_s$ (CH_1 ON), ~~CH_1(OFF) $V_0 = 0$~~.
* When CH_2 is ON, current is flowing from battery source ($E - L - CH_2 - E$) & inductor gets energized.
* This inductor current then freewheel through ($L - D_2 - V_s - E - L$). Here inductor change its polarity. All this process will be occure during (CH_2 = OFF) condition.
* Here O/P current (i_0) flow in reverse direction so it taken as -ve where as O/P voltage (V_0) is +ve. So its work in 2nd quadrant.
* Note-: CH_2 = ON ($V_0 = 0$), ~~CH_2 = OFF ($V_0 = V_s$)~~

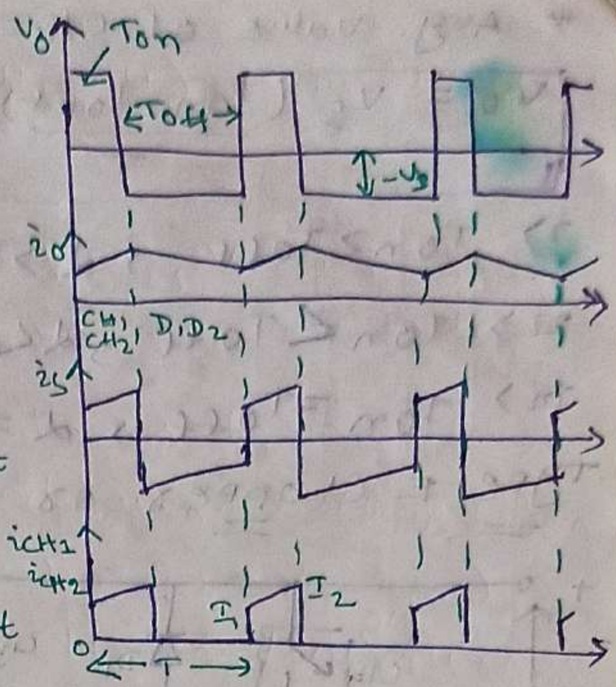
Type-D Chopper. or two-quadrant Type-B chopper







waveforms for $T_{on} > T_{off}$, V_0 is +ve (1st quadrant) ($\alpha > 0.5$)



waveforms for $T_{on} < T_{off}$ V_0 is -ve (2nd quadrant) ($\alpha < 0.5$)

* type 'D' chopper is a combination of two-quadrant type-D chopper & works in quadrant 1 & 4.

* When both the chopper ON (CH_1, CH_2 = ON), the current is flowing through the path (V_S - CH_1 - load - CH_2 - V_S).
* Here output voltage (V_0) = V_S which is +ve & i_0 is also +ve. It's operates in 1st quadrant.
* But in off condition (CH_1, CH_2 = off), the current is flowing from the load to source. (LOAD - D_2 - V_S - D_1 - LOAD)
* Here output voltage $V_0 = -V_S$ which is -ve But i_0 is +ve. (Same direction of current) It's operates in 4th quadrant.
* Note - V_0, I_0 = +ve (Source to load) (1st)
  - V_0, I_0 = load to source (4th)

* Avg. value of o/p voltage,

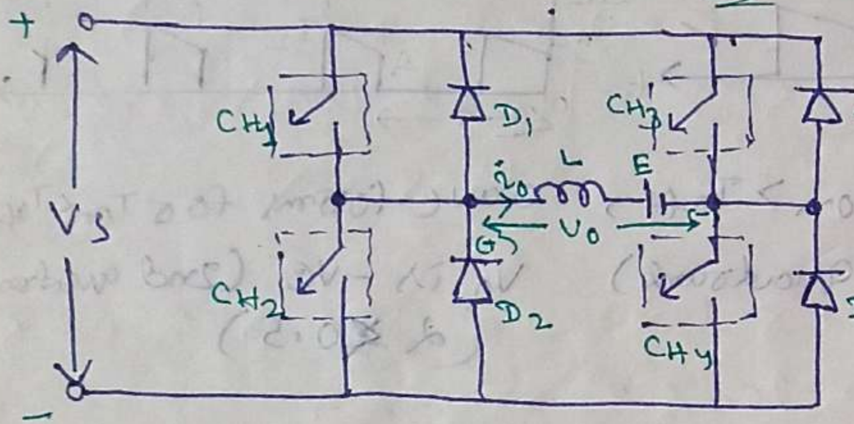
$$\boxed{V_0 = V_S \left(\frac{T_{on}-T_{off}}{T}\right)}$$

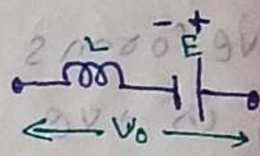
i) $T_{on} > T_{off}$, $\alpha > 0.5$, $V_0 = +ve$ (1st)

ii) $T_{on} < T_{off}$, $\alpha < 0.5$, $V_0 = -ve$ (4th)

iii) $T_{on} = T_{off}$, $\alpha = 0$, $V_0 = 0$

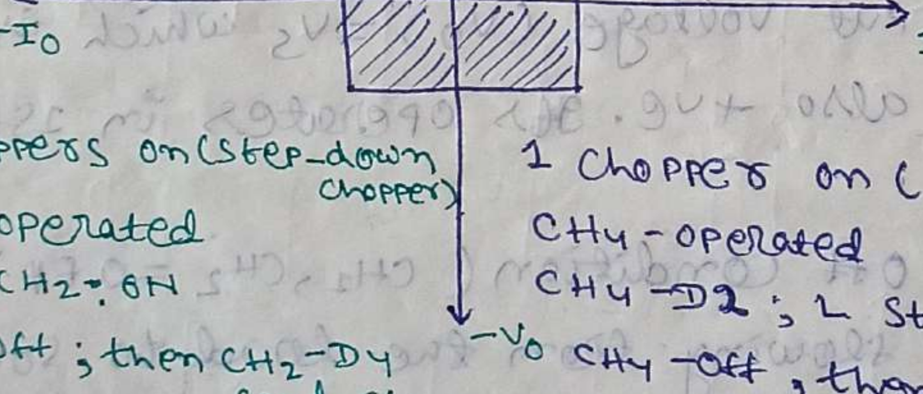
Type-E Chopper or Four-quadrant Chopper:-





(3rd & 4th quadrant)

(Type-E Chopper)
(1st & 2nd quadrant)



1 Chopper on (Step-up Chopper)
CH_2 operated
CH_2-D_4 ; L stores energy.
CH_2-OFF ; then D1-D4 conduct

2 Choppers on (step-down Chopper)
CH_1-operated
CH_1, CH_4 ON
CH_1 - off ; then CH_4-D_2, conduct

2 choppers on (step-down chopper)
CH_3-operated
CH_3 - CH_2 : ON
CH_3-off ; then CH_2-D_4 conduct
E reversed.

1 Chopper on (Step-up chopper)
CH_4 - operated
CH_4 -D2 ; L stores energy
CH_4 -off ; then D_2, D_3 conduct
E reversed.

Inverter

Inverter -: A device that converts dc power into AC power at desired output voltage and frequency is called as inverter.

Industrial Applications of inverters -:

1. Used in variable speed AC motor drives.
2. Inducting heating
3. Uninterruptible power supply (UPS)
4. Stand by aircraft power supplies.
5. HVDC transmission lines.

* Inverters can be classified into two types.

a> voltage source inverters (VSI) or voltage-fed inverter (VFI)

b> current source inverters (CSI) or current-fed inverter (CFI)

(Stiff-: change in shape)

Voltage source inverters (VSI) -:

* VSI is one in which the dc source has small or negligible impedance. In other words, a voltage source inverter has stiff dc voltage source at its i/p terminals.

Current source inverters (CSI) -:

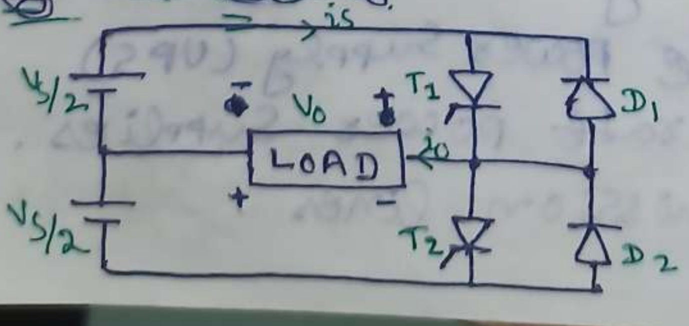
* CSI is one in which the dc source has high impedance. CSI has stiff dc current source & o/p current waves are not affected by the load.

* From the viewpoint of connections of semiconductor device, inverters are classified into 3 types.

a> Bridge inverters b> Series inverters
c> Parallel inverters

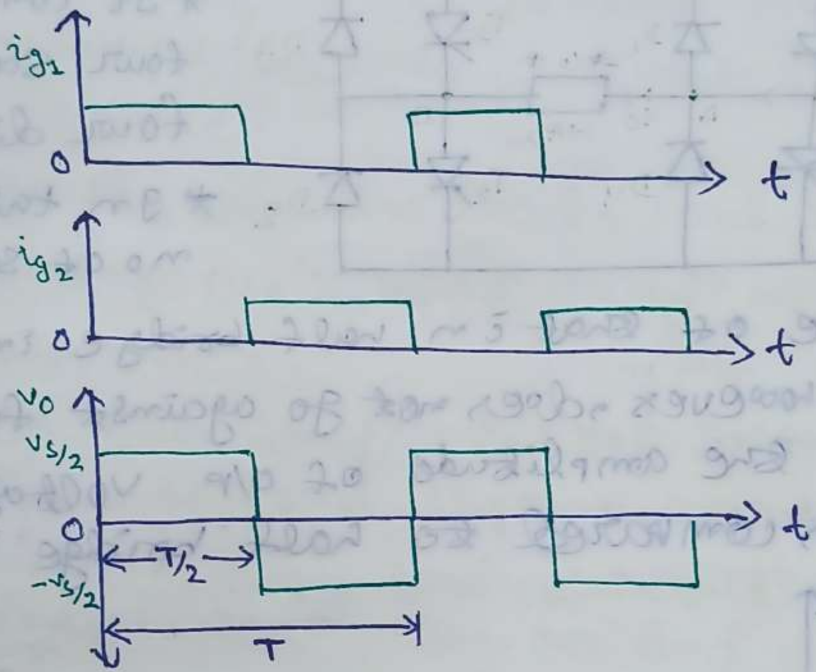
* Bridge inverters method are the more popular method among all the three inverters.

Single phase voltage source half bridge inverter:



* It consists of two SCRs, two diodes and three-wire supply.

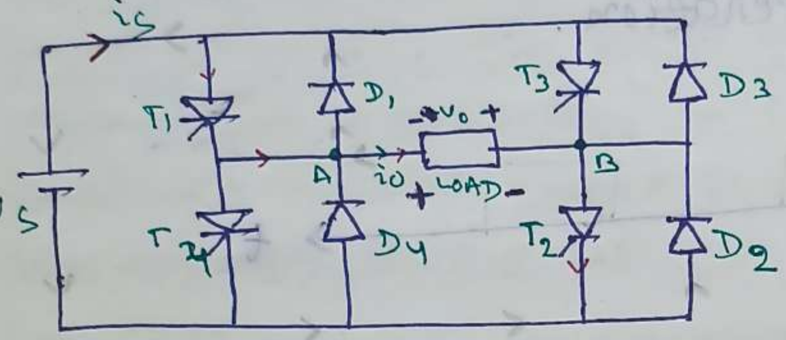
* The load is connected between center tap of the source & center point of SCRs.
* Diodes D_1 & D_2 provide freewheeling operation and are needed only if the load is inductive or capacitive.
* For purely resistive loads D_1 & D_2 don't come into operation.



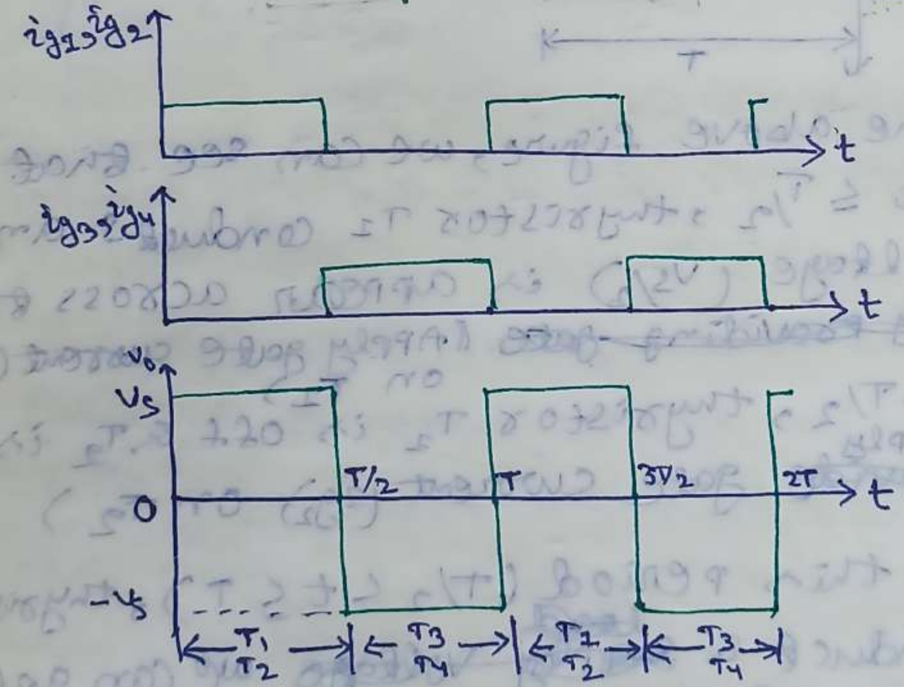
* from the above figure, we can see that for $0 < t \le T/2$, thyristor T_1 conducts and supply voltage ($V_S/2$) is appear across the load. ~~By providing gate~~ (Apply gate current (i_{g1}) on T_1)
* At $t = T/2$, thyristor T_1 is off & T_2 is ON. (~~by Provide~~ Apply gate current (i_{g2}) on T_2)
* During this period ($T/2 < t \le T$), thyristor T_2 is conduct & ~~supply voltage~~ load we can get load voltage ($-V_S/2$).
* At $t = T$, thyristor T_2 is OFF & T_1 is on and so on. ~~this process will be continuous~~.
* Note -: Here the load voltage is an alternating voltage waveform of amplitude $V_S/2$ & freq. $1/T$ Hz.

* The main drawback of half-bridge inverter is that it requires 3-wire dc supply. This difficulty can be overcome by the use of $1\text{-}\phi$ full-bridge inverter.

Single phase full bridge inverter :-



* It consists of four SCRs and four diode.
* In this inverter no of SCRs & diode is twice of that in half bridge inverter.
* This, however, does not go against full inverter because the amplitude of o/p voltage is doubled as compared to half bridge inverter.



* At $(0 < t \leq T/2)$, SCRs T_1 & T_2 are conduct. (apply gate current i_{g1} for T_1 & i_{g2} for T_2) & T_3 & T_4 are off.
* Here the o/p voltage is same as the supply voltage i.e. V_s.

* ~~At~~ ($T/2 \le t \le T$), SCRS T_3 & T_4 are conduct or on (apply gate current i_{g_3} for T_3 & i_{g_4} for T_4) & T_1 & T_2 are off.

* Here the output voltage is ($-V_s$), because current flow from +ve to -ve.

* During inverter operation, two SCRS in the same leg do not conduct simultaneously as this would lead to a direct short circuit of the source.

* Note -: for a resistive load, load current (i_0) & load voltage (v_0) will always be in phase with each other.

* However this condn is not satisfied for other type of load. (Except resistive load)

* For such types of loads, o/p current (i_0) will not be in phase with o/p voltage (v_0) and diodes connected in antiparallel with SCRS, which allow the current to flow, when the main SCRS are turned off.

* As the energy is fed back to the dc source when these diodes conduct, these are called feedback diodes.

Series Inverter -:

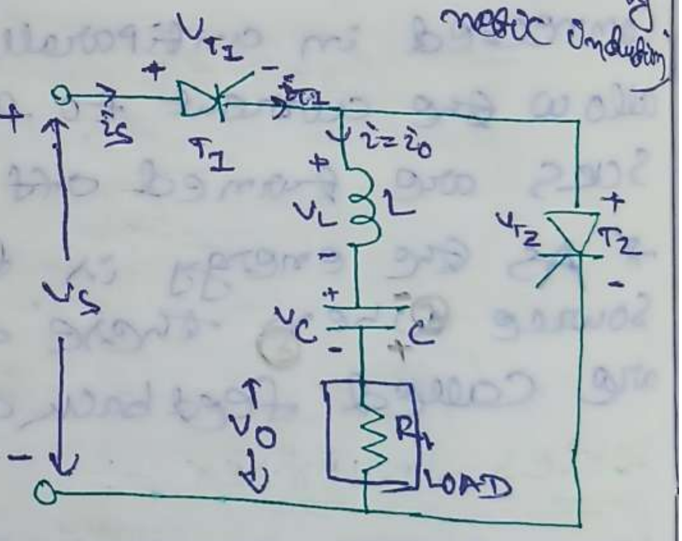
Commutation process -: The process used for turning off a thyristor is called as commutation.

* By the commutation process, the thyristor operating mode is changed from forward conducting mode to forward blocking mode.

* inverters, in which commutating components (L, C) are permanently connected in series with the load are called series inverters.
* The series circuit are underdamped in nature (current ~~approach~~ attains zero value)

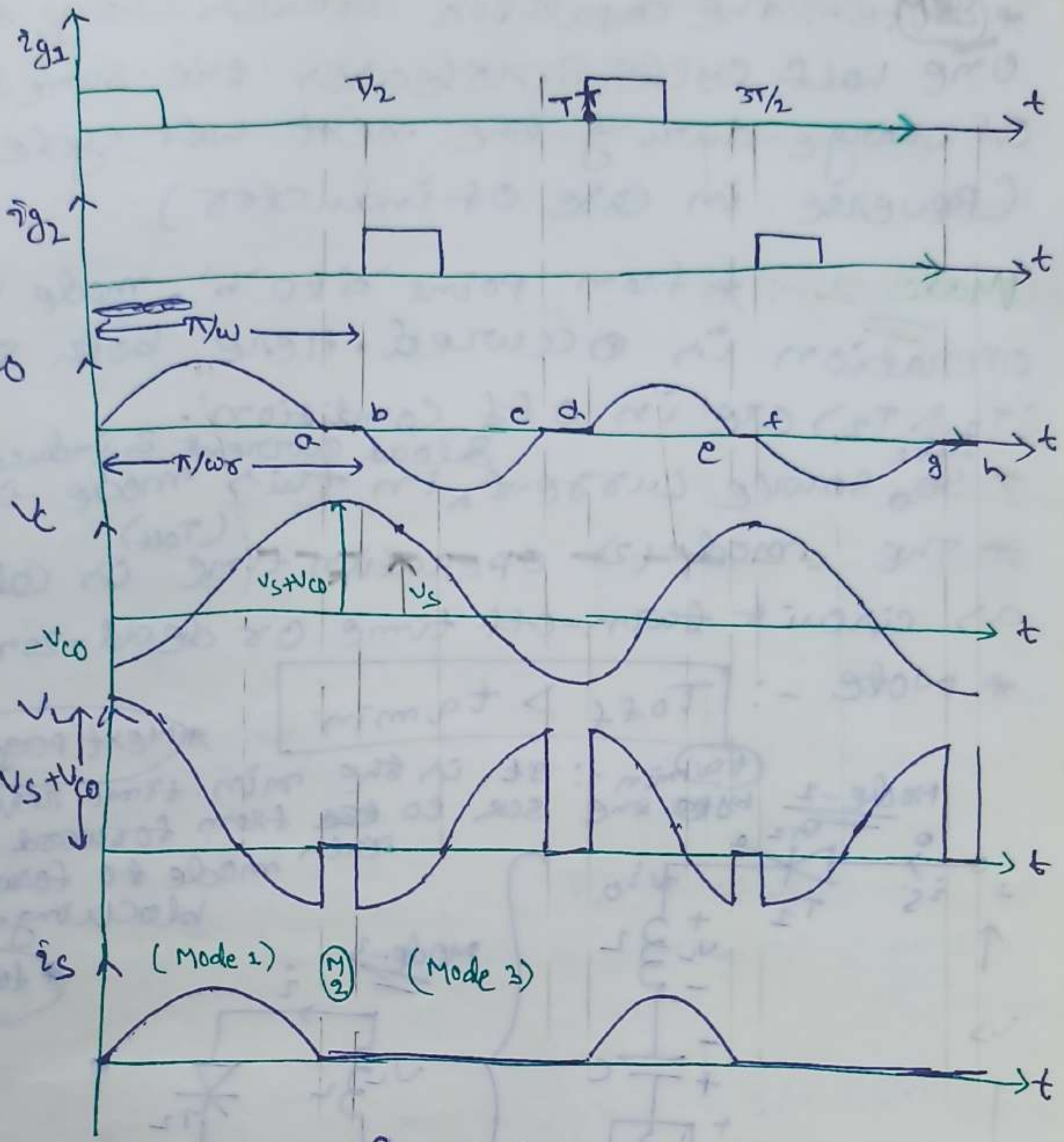
underdamped -: The system oscillates (at reduced freq. compared to the undamped case) with the amplitude gradually decreasing to zero.

* These inverters operate at high freq. (200 Hz to 100 kHz)
* These inverters are used ~~extensively~~ in induction heating, fluoresent lighting. (heating → electrically conducting object by electromagnetic induction)



* It the ckt diagram of a basic series inverter.
* It consists of load resistance (R) connecting in series with the commutating compoments (L & C).
* Two thyristor (T_1, T_2) & a voltage source (V_S) are also used in these circuits.

Mode-1 * When SCR T_1 is tuned on (Apply i_{g1} on T_1) & SCR (T_2) is OFF, current (i) starts building up in the RLC ckt.



(wave form)

* As the circuit is underdamped, the load current(i_0) reached some peak value & then decays to zero at point 'a'.
* At this point T_1 is turned off.

Mode-2

* The ~~minimum time (from a to b) (forward conduction mode to~~ forward blocking mode)

$$t_{q\,min} = \frac{\pi}{\omega} - \frac{\pi}{\omega_r} = \frac{1}{2}\left(\frac{1}{f} - \frac{1}{f_r}\right) \quad (\because \omega = 2\pi f)$$

where ω = O/P freq. (rad/sec)

ω_r = circuit ringing freq. (rad/sec)

* For mode (2) capacitor store charge & its value is $(V_s + V_{co})$ where as inductor discharge the same value.

* Note-: The capacitor stores charge during one half cycle & releases the same amount of charge during the next half cycle. (Reverse in case of inductor)

Mode 2-: * from point 'a' to 'b', mode 2 operation is occured. Here both SCR (T_1 & T_2) are in off condition.

* Here source current & load current & inductor in this mode is zero.

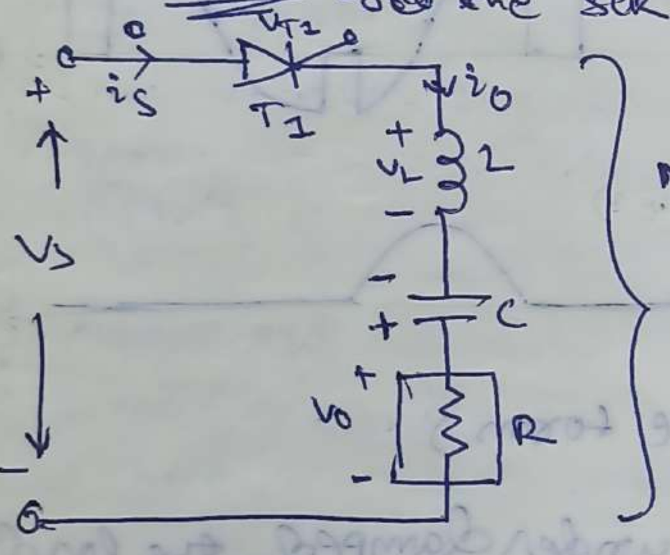
* The mode (2) operation time (T_{off}) is called as circuit turn-off time or dead-zone time

* Note -: $\boxed{T_{off} > t_{q\,min}}$

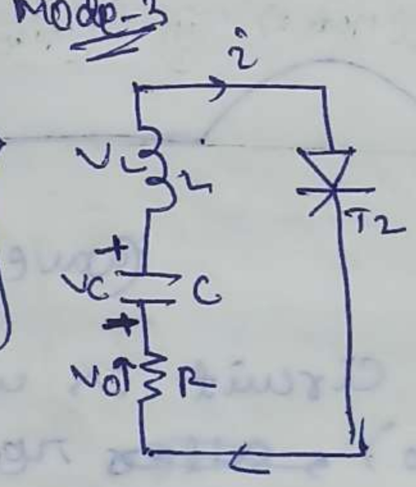
Next page formula

t_q min -: It is the min. time required by the SCR to reach from forward conduction mode to forward blocking mode

Mode-1



Mode-3



Mode-3

At point 'b', SCR (T_2) is ON (Apply gate current i_{g2}) & T_1 is OFF.

* Here capacitor begins to discharge and load current in the reversed direction builds up to some peak negative value & then decays to zero at point c.

* As capaci...

* But the Inductor charged by the same value as Capacitor discharge.
* There is no source voltage is provided to the ckt, thus source current (i_s) is zero.
* At point 'c', T_2 is OFF & ~~Mode (2) operation~~ the process will be continue.

Drawbacks -:

1. For a load power, the load current is taken from the supply during the +ve half cycle only. This has the effect of increasing the peak current rating of the dc source.
2. Since the source current flows during the +ve half cycle only, its harmonic content is much more as compared to other inverter.
3. The maximum operating freq. of the inverter is limited because $\omega < \omega_r$.
4. As $\omega < \omega_r$, the load voltage waveform gets distorted considerably due to the increased duration of the dead zone.
5. This inverter has poor o/p regulation & required high rating commutating components

Single-phase parallel inverter

Cycloconverters

* A device which converts input power at one freq. to output power at a different frequency with one-stage conversion is called as cycloconverter.
* A cycloconverter (it) is also called as one-stage frequency changer.
* It is of two types.

a> Step-down cycloconverters ($f_0 < f_s$)

b> Step-up cycloconverters ($f_0 > f_s$)

(f_0 → o/p freq., f_s → supply freq.)

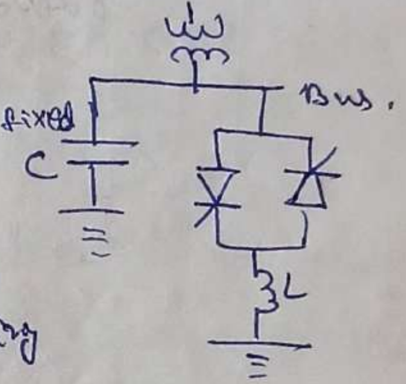
Application of cycloconverters :-

i> Speed control of high-power AC drives.

ii> Induction heating.

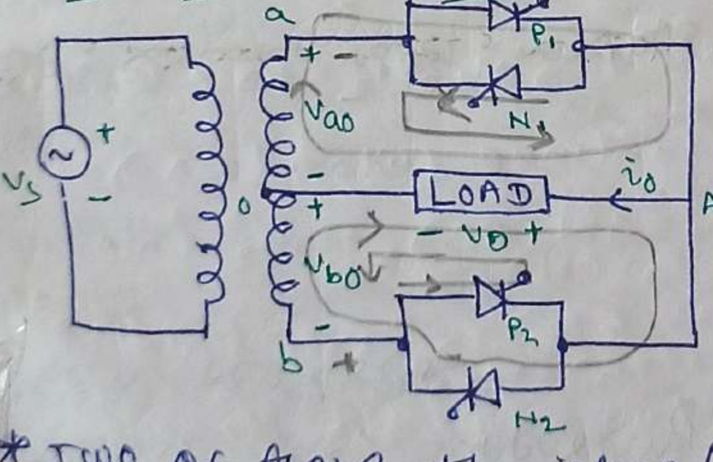
iii> Static VAr compensation etc. (SVC)

* part of Flexible AC transmission system) (FACT). (Used - Regulating voltage, Power factor, harmonics and stabilizing the system).



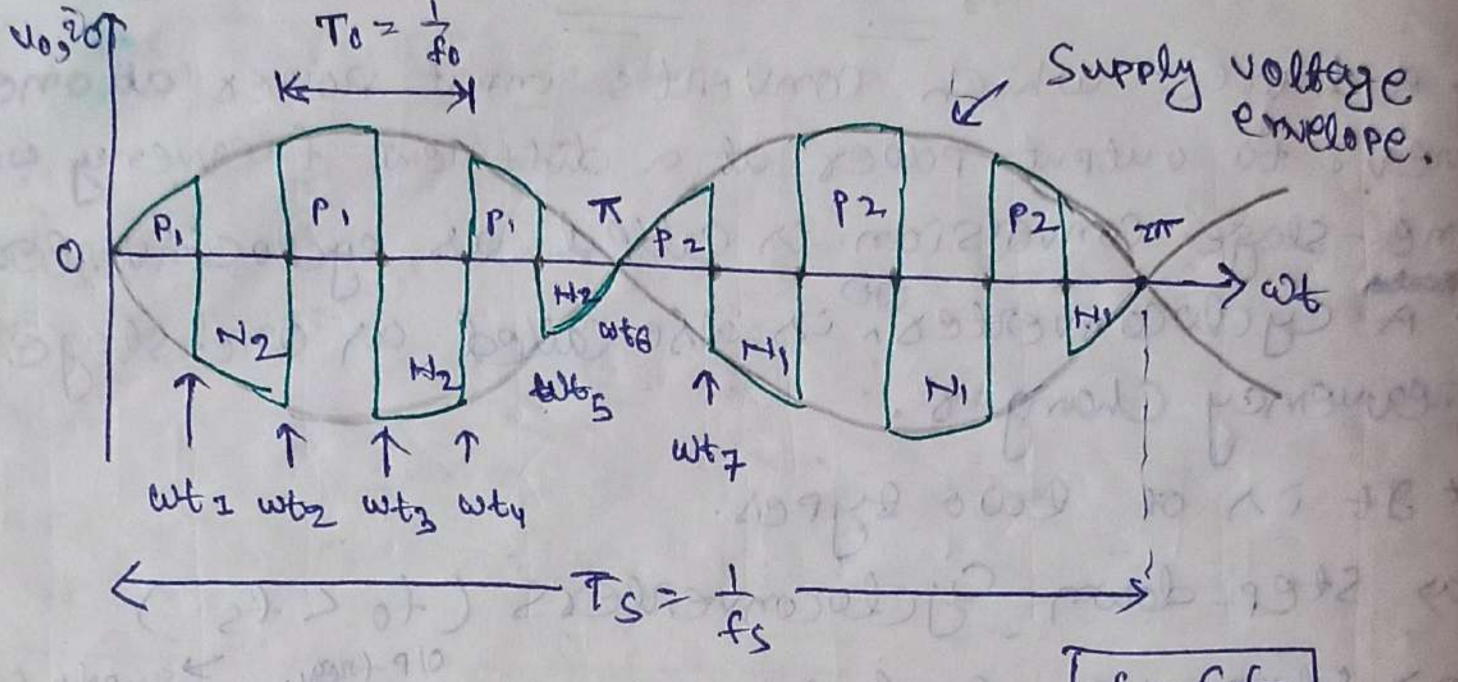
Single-phase to single-phase circuit - step-up cycloconverter

Mid-point cycloconverter :-



* This circuit consists of a single-phase T/F (mid-tap on the secondary winding) and four thyristors.

* Two of these thyristors (P_1, P_2) are for the positive group and thyristors (N_1, N_2) are for the negative group.
* LOAD (R) is connected betn secondary winding mid-point (O) and terminal (A).



v_0, i_0
$T_0 = \frac{1}{f_0}$
Supply voltage envelope.
0
P_1
P_1
P_1
π
P_2
P_2
P_2
2π
ωt
N_2
N_2
N_2
ωt_6
N_1
N_1
N_1
ωt_5
ωt_7
ωt_1 ωt_2 ωt_3 ωt_4
$T_S = \frac{1}{f_S}$

$$\boxed{f_0 = 6 f_S}$$

* During the 1st half cycle of supply voltage, ($\omega t = 0$ to π) (terminal 'a' is +ve w.r.t terminal 'b') & Both the SCRs P_1 and N_2 are forward biased...

* First SCR(P_1) is turned on at $\omega t = 0°$ & load voltage is +ve with terminal A (+ve) & terminal 'O' (-ve). The load voltage now follows the +ve envelope of the supply voltage.

* At instant ωt_1, P_1 is force commutated & N_2 is turned on (F.B). So that load voltage is -ve with terminal 'O' (+ve) & terminal A (-ve). The load voltage now follows the -ve envelope of the supply voltage.

* At ωt_2, N_2 is force commutated and P_1 is turn on. This process will be continue from $\omega t = 0$ to π.

* After $\omega t = \pi$, terminal 'b' is +ve w.r.t terminal a & both the SCRs P_2 & N_1 are forward biased from $\omega t = \pi$ to 2π (-ve half cycle)

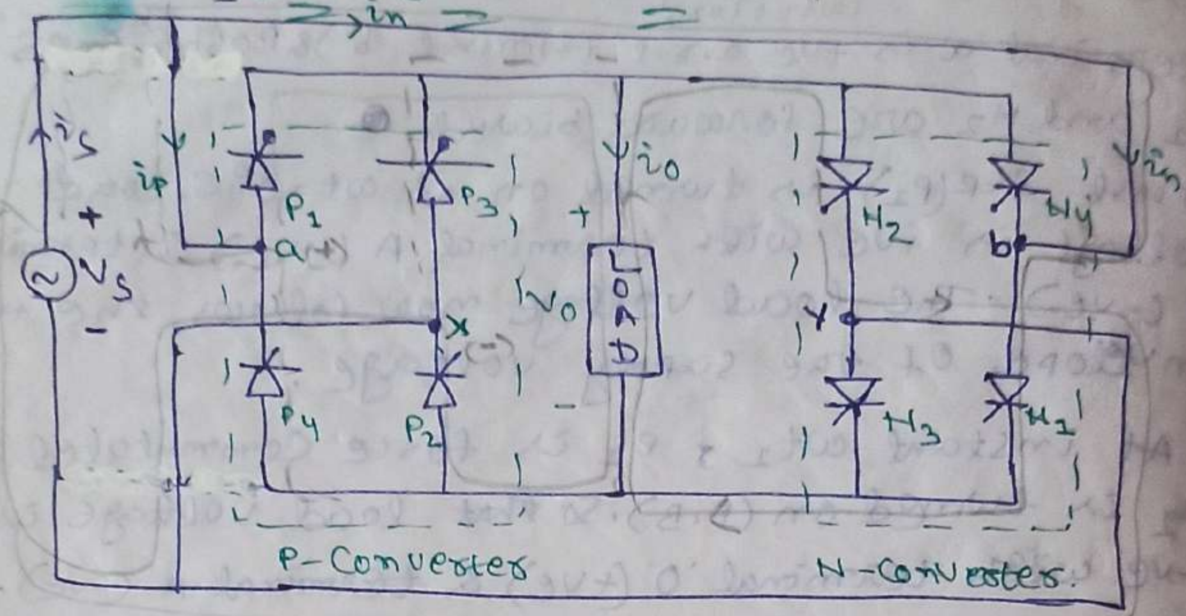
* At $\omega t = \pi$, N_2 is force commutated and SCR P_2 is turned on (F.B).

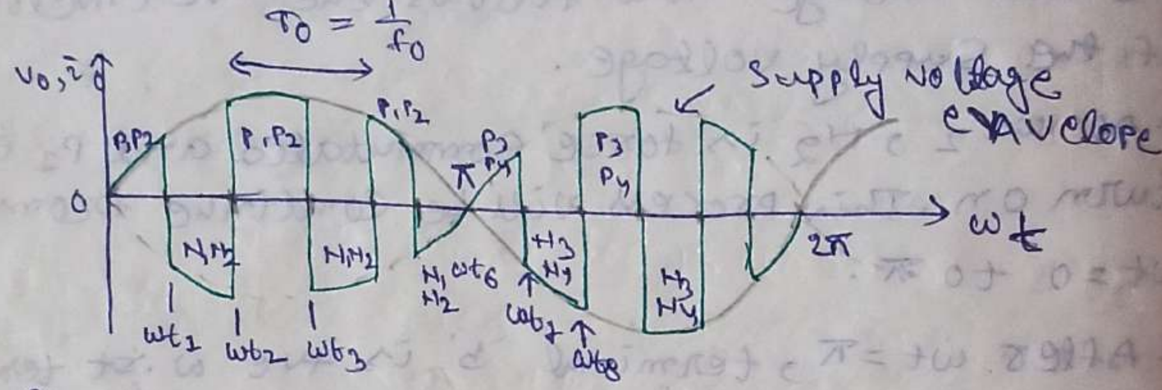
* At ωt_7, P_2 is force commutated and SCR N_1 is turned on (F.B) and so on up to $\omega t = 2\pi$.

* Here $\boxed{f_0 = 6 f_s}$ where f_0 = output frequency
f_s = supply frequency.

* From the wave form, we can observe the SCR P_1 & N_2 are conduct during 1st half cycle & P_2 & N_1 are conduct during 2nd half of the cycle.

Bridge-type cyclo converter -:



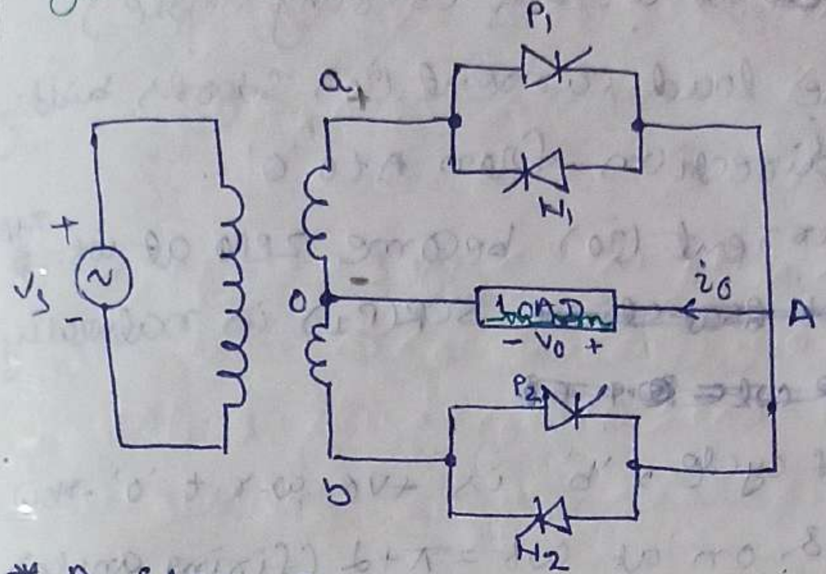


* Consist of 8 SCRs.
* Positive group -: P_1, P_2, P_3, P_4
* -ve group -: N_1, N_2, N_3, N_4
* $\omega t = 0$ (P_1, P_2 = ON Conduct)
* ωt_1 = N_1, N_2 = ON Conduct, P_1, P_2 = force Commutated
* ωt_2 = ~~N_1~~ P_1, P_2 = ON Conduct, N_1, N_2 = force Commuted
* Process will be Continue ($\omega t = 0$ to π)
* At ωt_6 = π, P_3, P_4 = ON (FB), N_1N_2 = force Commuted
* At ωt_7, N_3, N_4 = ON (FB), P_3, P_4 = force Commuted
* At ωt_8, P_3, P_4 = ON (FB), N_3, N_4 = force Commuted
* Process Continue (ωt = π to 2π)
* Here $\boxed{f_0 = 6 f_s}$

current flow dirn -:

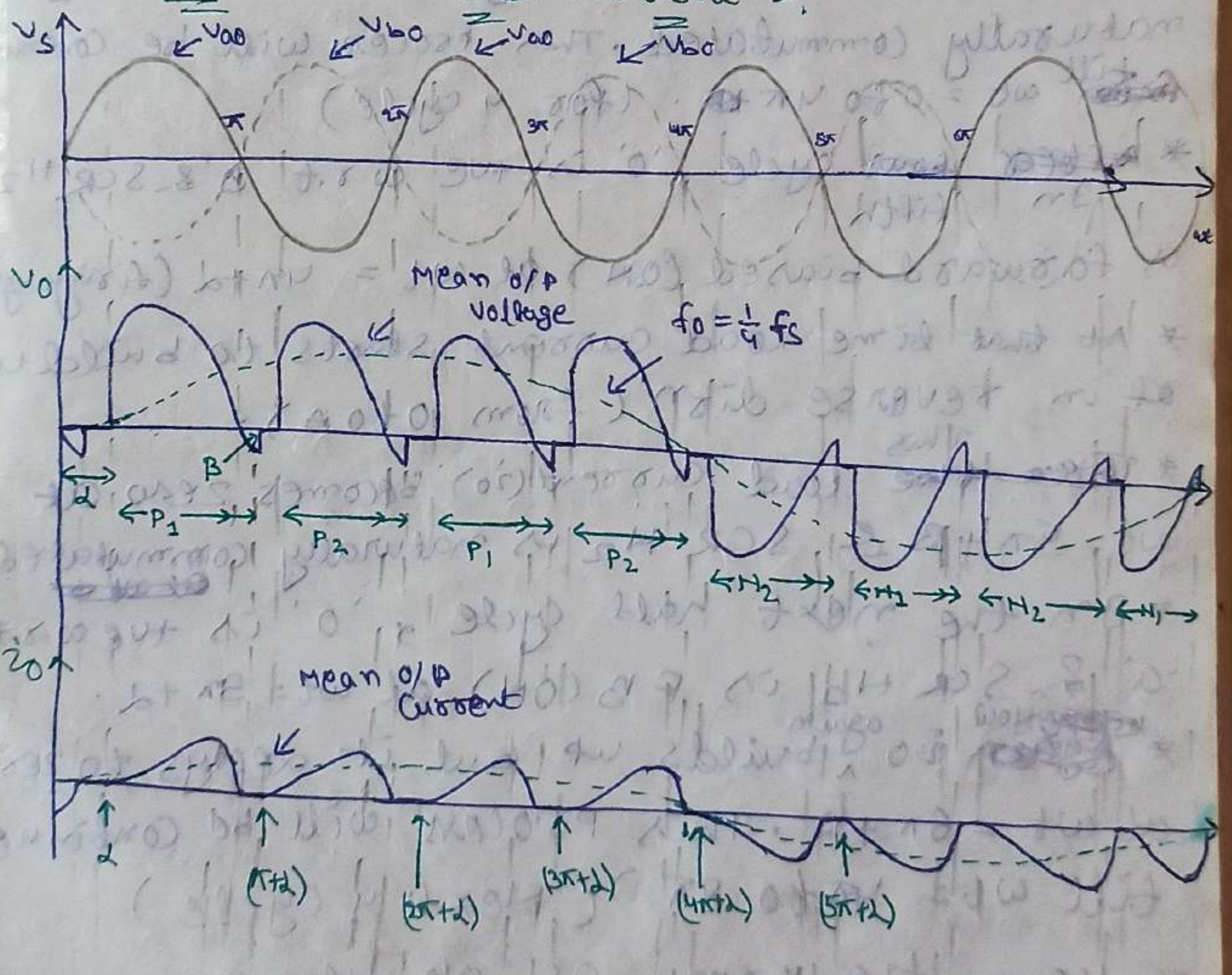
C① -: V_s – 'a' – P_1 – LOAD – P_2 – 'x' – V_s
C② -: V_s – 'b' – N_1 – LOAD – N_2 – 'y' – V_s
C③ -: V_s – 'x' – P_3 – LOAD – P_4 – 'a' – V_s
C④ -: V_s – 'y' – N_3 – LOAD – N_4 – 'b' – V_s

Single-phase to single-phase circuit - step-down cycloconverter -: (Mid-point cycloconverter)



* A step-down cycloconverter does not require forced commutation. These converters need only line or natural commutation which is provided by AC supply.

a) Discontinuous load current -:



$$\boxed{f_0 = \frac{1}{4} f_s}$$

During +ve half cycle,

* 'a' is +ve w.r.t 'O', SCR P_1 is Forward biased and on at $\omega t = \alpha$ (firing angle)

* with this, the load current (i_0) starts building up in +ve direction from A to 'O'.

* The load current (i_0) become zero at $\omega t = \pi+\beta$ ($\pi+\alpha > \pi+\beta > \pi$) & SCR($P_1$) is naturaly commutated.

* During -ve half cycle, 'b' is +ve w.r.t 'O'. Now SCR P_2 is FB & on at $\omega t = \pi+\alpha$ (firing angle)

* Here the load current (i_0) is again flowing from 'A' to 'O'. So load current & voltage is +ve & current starts to build up.

* At $\omega t = 2\pi+\beta$, i_0 decays to zero and P_2 is naturally commutated. This process will be continue till $\omega t = 0$ to 4π. (for 4 cycle)

* In fifth cycle, 'O' is +ve w.r.t 'b' & SCR N_2 is forward biased (ON) at $\omega t = 4\pi+\alpha$ (firing angle)

* At that time load current starts to build up in reverse dirn (from O to A).

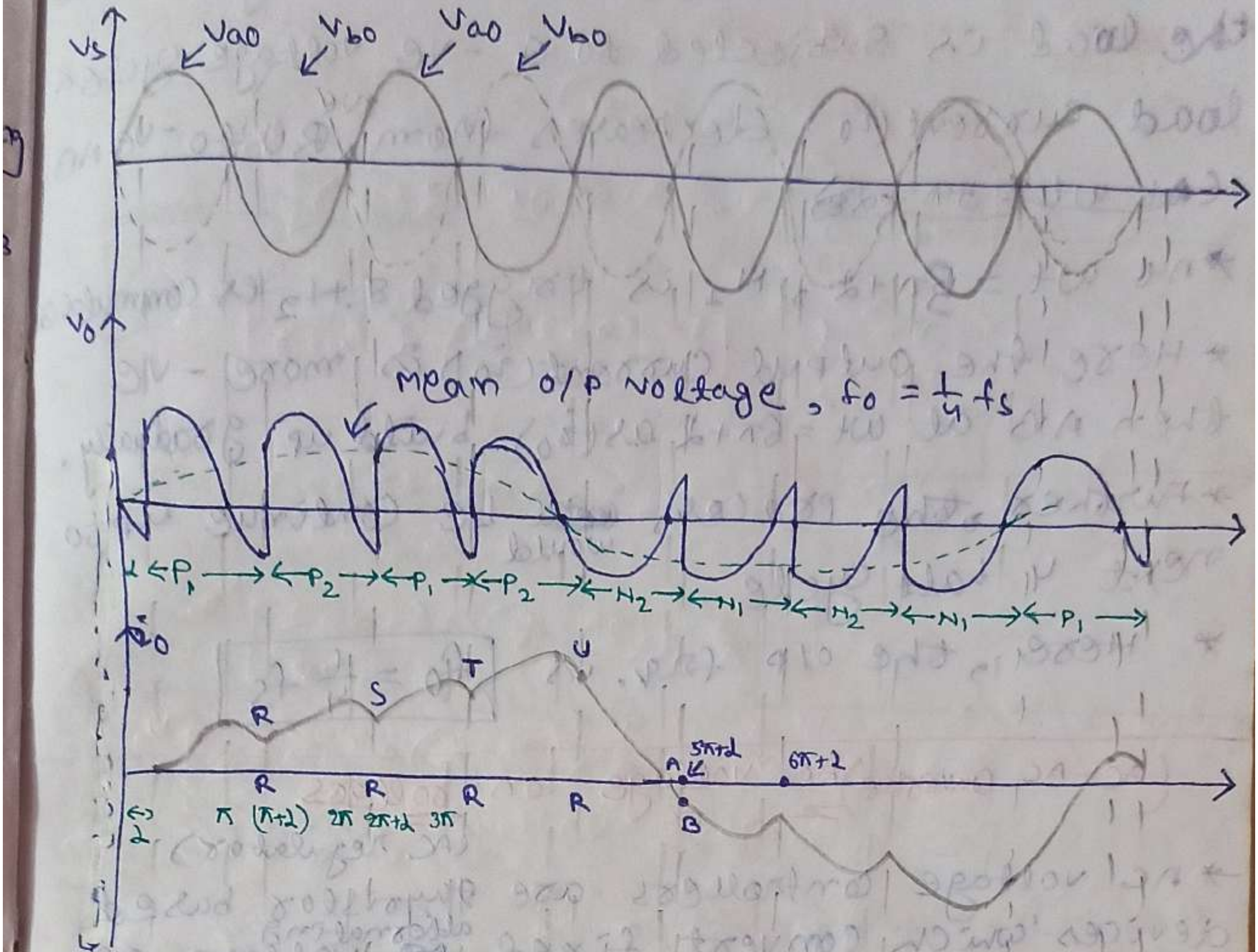
* This load current (i_0) becomes zero at $\omega t = 5\pi+\beta$ & SCR N_2 is naturaly commutated.

* In the next half cycle, 'O' is +ve w.r.t 'a' & SCR N_1 is FB (ON) at $\omega t = 5\pi+\alpha$.

* Now i_0 again builds up but it decays to zero at $\omega t = 6\pi+\beta$. This process will be continues till $\omega t = 4\pi$ to 8π) (Next 4 cycle)

* Here, the freq. of O/P Vtg. & current is $\boxed{f_0 = \frac{1}{4} f_s}$

continous load current -:

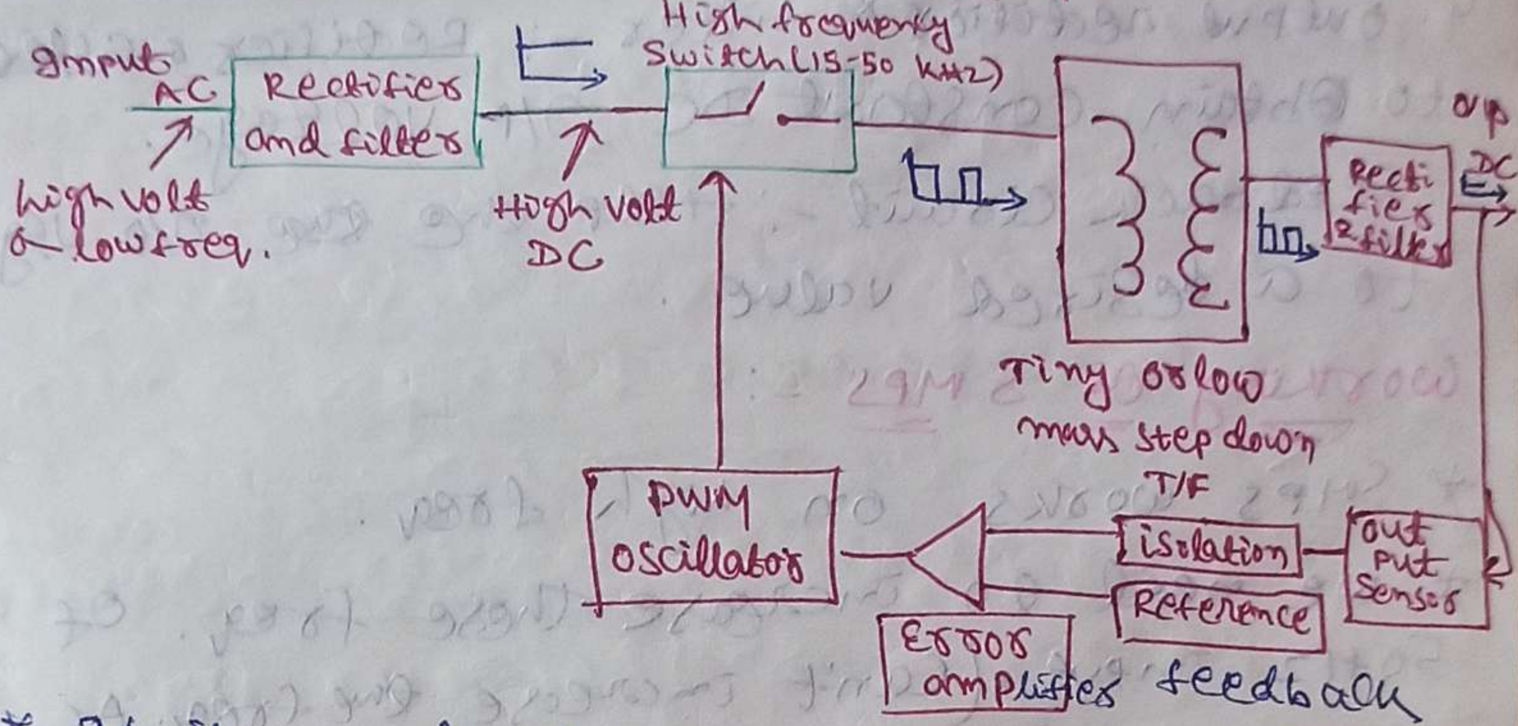


* when 'a' is +ve w.r.t to 'o', P_1 is triggered at $\omega t = \alpha$, positive output voltage appears across load and load current starts building up.
* At $\omega t = \pi$, supply & load voltages are zero.
* After $\omega t = \pi$, P_1 is reverse biased. As the load current is continuous, P_1 is not turned off at $\omega t = \pi$.
* when P_2 is triggered at $\omega t = \pi + \alpha$, a reverse voltage appears across P_1, it is therefore turned off by natural commutation.
* when P_1 is commuted, load current builds up to a value RR.
* with the turning on of P_2 at $(\omega t = \pi + \alpha)$, the o/p voltage is again +ve & load current builds up to a value RS at $(\omega t = 2\pi + \alpha)$.
* At $\omega t = 2\pi + \alpha$, P_2 is naturally commutated & P_1 is turned on.
* At the end of 4 half cycle the o/p current is RU

* when H_2 is triggered, (P_2 = naturally commutated) the load is subjected to a -ve voltage cycle & load current (i_0) decreases from +ve RU to -ve AB.

* At $\omega t = 5\pi + \alpha$, N_1 is trigged & N_2 is commutated
* Here the output current (i_0) is more -ve then AB at $\omega t = 6\pi + \alpha$ as (i_0) build up gradually.
* Further, the process would be continue upto next 4 half cycle...
* Here, the o/p frq. is $\boxed{f_0 = \frac{1}{4} f_s}$

SMPS (Switch Mode power supply)



* It is a device which provides power to any electrical load & involves some kind of switching action.

Why we used SMPS?

* Linear power supplies become very bulky with increase in its current rating. So, we needed something which will allow us to handle large amount of currents without taking a lot of space.

* SMPS works on a very high freq. as compared to linear power supplies & as the size of T/F reduces with increase in freq, the overall size of an SMPS become very small as compared to linear power supply.

* Linear power supply -: low levels of o/p noise and good stabilisation but large size.

Blocks

1. Input rectifier & filter -: I/P AC - DC
2. Chopper -: DC signal to pulsating DC.
3. T/F -: Step down the vtg. to required level.
4. Output rectifier & filter -: Rectifier & filter to obtain constant DC o/p voltage.
5. Feedback circuit -: Help the ~~the~~ o/p vtg. to a desired value.

Working of SMPS -:

* SMPS works on high freq.
* We need to increase these freq. of 50 Hz input. (Can't increase the freq. AC directly)
* So, convert AC - DC and then chop it at high freq. to get pulsating DC output, (Step down by T/F)

* Feedback helps to maintain the level of o/p Vtg.

Adv. * Small size & less weight
* Low noise
* High efficiency (75% - 95%)

Cons * High complexity
* produces EMI (Electromagnetic Interference)
↳ (fast voltage changes) produced EMI

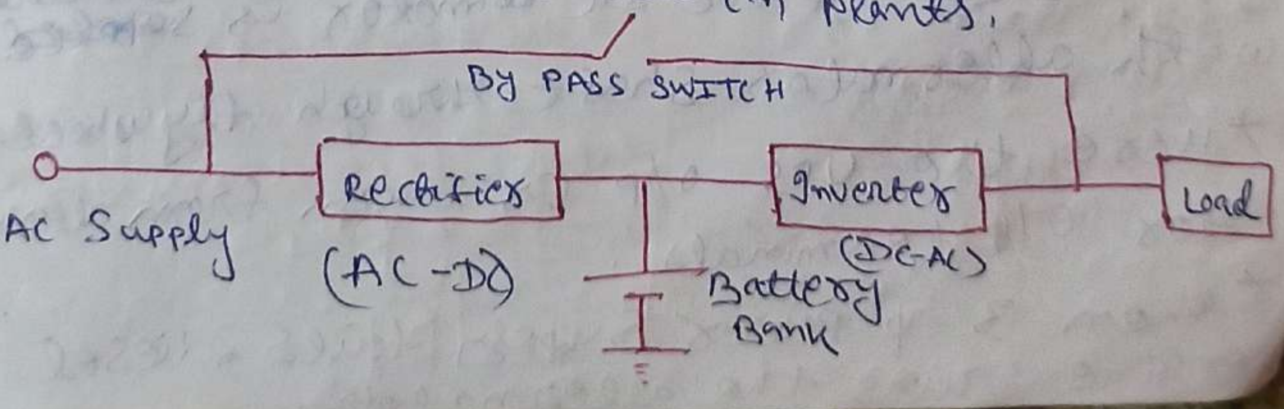
Isolation -: Separate the high current, prevent the primary ckt.

PWM oscillator -: Maintain the chopping freq.

Uninterruptiable Power Supply (UPS)

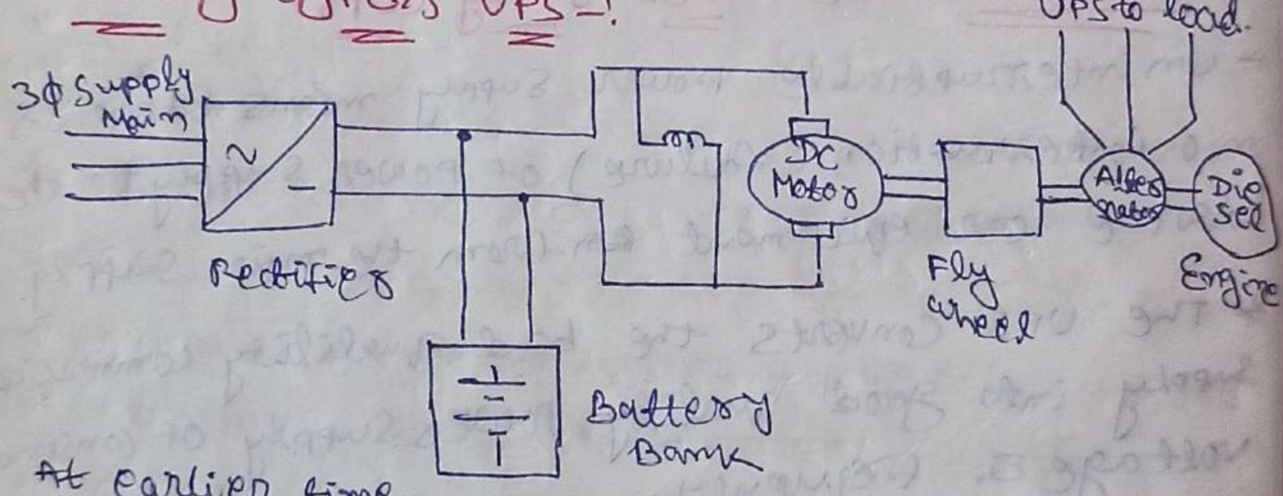
* Uninterruptiable power supply means there is no interruption (failure) of power supply to the device or equipment from the main supply.
* The UPS converts the bad qualility commercial supply into good quality power supply of constant voltage & frequency.

Used -: 1. Hospitals (ICU)
2. Airline & Railway reservation system.
3. Computer system
4. Process control in plants.



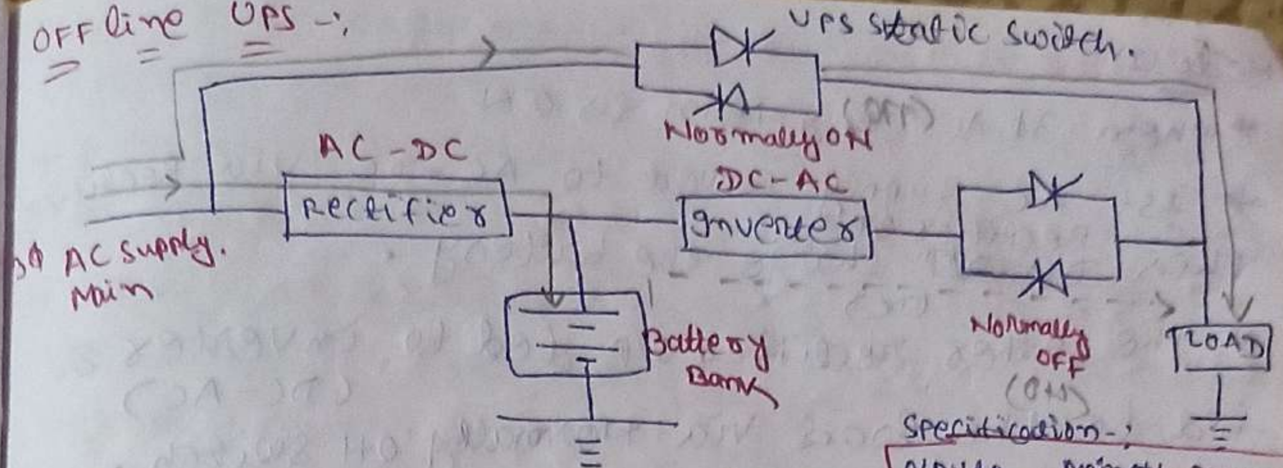
* The Rectifier convert AC to DC. This DC voltage charges the battery bank.
* Here the battery ~~voltage~~ has charged by DC i/p.
* When the AC supply fails, the DC i/p to the inverter is given by the battery & provide supply to the load.
* The bypass switch is closed in case of failure of Rectifier & battery.
* It is of two type.
  a) Rotating type.
  b) Static type — OFF line UPS / ON line UPS

Rotating types UPS :-



At earlier time,
* 3φ AC supply is converted to DC by means of rectifier and charges a battery bank & feeds the DC motor.
* The shaft of the DC motor is connected with alternator shaft through flywheel.
* Here the UPS o/p is taken from alternator o/p terminals.
* When 3-φ power supply fails, diesel engine runs the alternator.

OFF line UPS -:



Specification -:

O/P Vtg -: Main ON - 230V ±5%, UPS ON - 230V ±5%.

O/P freq -: 50 HZ ±3%. 50 HZ ± 2HZ

I/P Vtg. (Battery) - 24, 48, 72 VAH

Power Rating - 1 KVA, 2 KVA

Time to charge battery - 3 to 4 hr

BackUP - 30 min

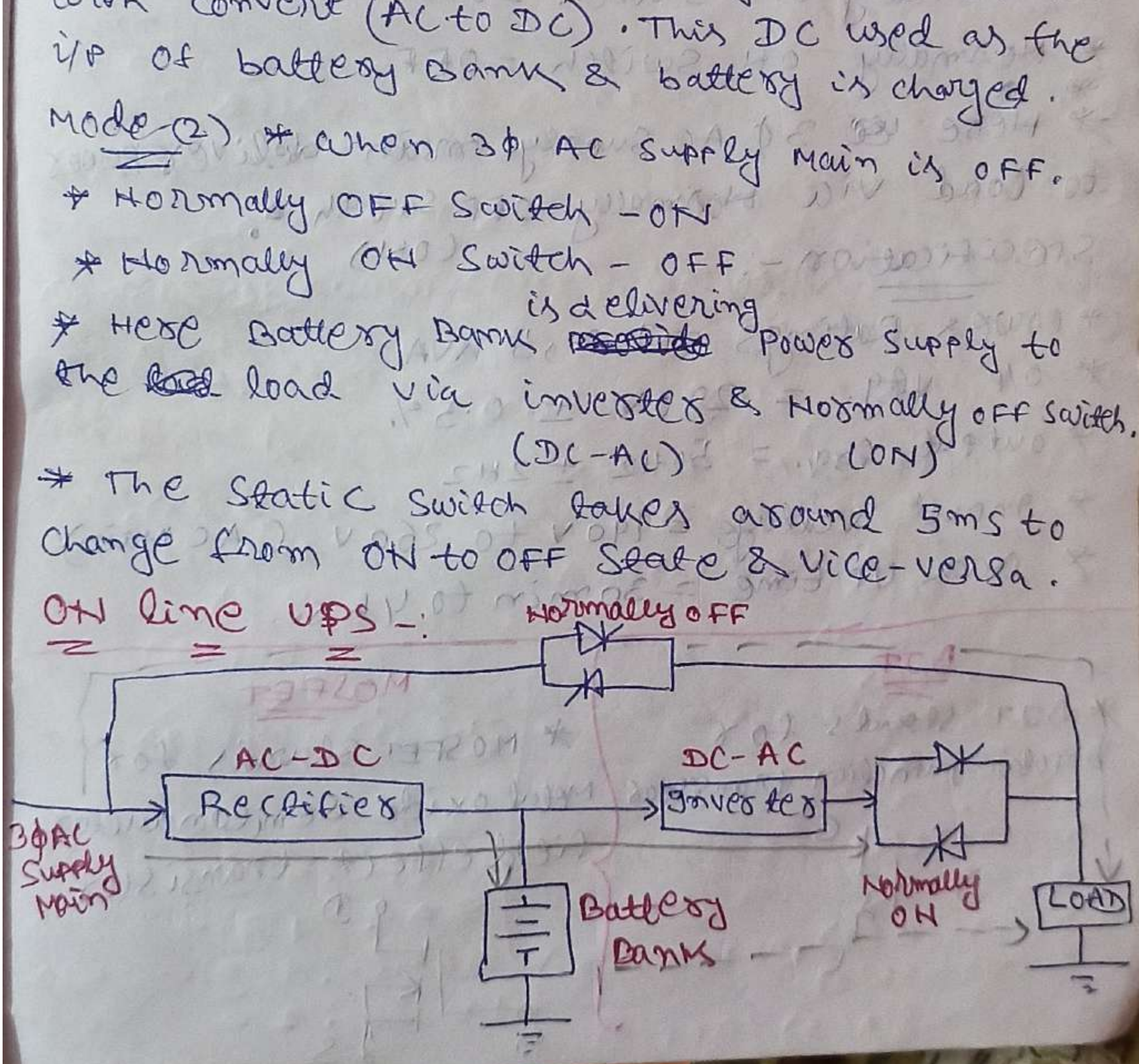
Mode-(1) * When 3ϕ AC Supply Main is ON

* Normally ON switch - ON
* Normally OFF Switch - OFF
* Here AC supply is deliver to the load via Normally ON switch and battery Bank is charged in this mode.
* we give i/p 3ϕ AC supply to the rectifier with convert (AC to DC). This DC used as the i/p of battery Bank & battery is charged.

Mode-(2) * When 3ϕ AC supply Main is OFF.

* Normally OFF Switch - ON
* Normally ON Switch - OFF
* Here Battery Bank is delivering power supply to the load via inverter (DC-AC) & Normally off switch (ON).
* The Static switch takes around 5ms to change from ON to OFF state & vice-versa.

ON line UPS -:



Mode (1)

* When 3ϕ AC Supply Main is ON
* 1st AC Supply convert to AC-DC via Rectifier. This Rectifier O/P (DC) charge the battery.
* The other rectifier O/P fed to inverter (DC-AC) & fed to the load via Normally ON switch.

Mode (2) * When 3ϕ AC supply Main is OFF.

* Battery is provide ~~to~~ back up power to the load via inverter (DC-AC) & Normally ON switch.

~~* Inverter is Mode~~

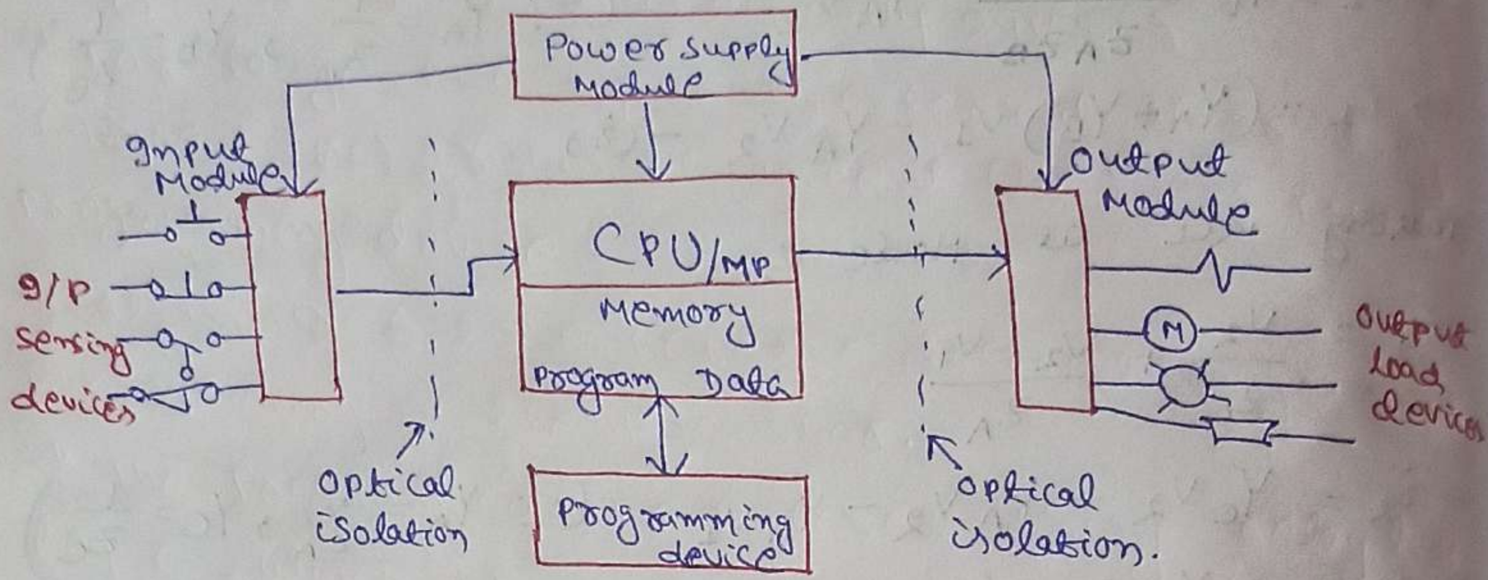
UPS fails * If UPS ckt is fail.

* Normally OFF Switch = ON
* Normally ON Switch = OFF
* Here 3ϕ AC Supply main deliver power to load via Normally OFF switch (ON).

Specification -:

* Power Ratings = 1, 2, 5 KVA
* O/P vtg. = 230V ± 0.5%
* output frq. = 50Hz ± 2Hz
* Input voltage = 190V to 260V (AC Main)
* Back up time = 30min to 4hr.

Components of PLC :-



* The PLC are typically divided into the following parts.
  a) central processing unit (CPU)
  b) Input / output (I/O) section
  c) power supply Module
  d) programming devices
* The term architecture refers to PLC hardware, PLC software or a combination of both PLC hardware & PLC software.
* All though the PLC principal concepts are the same in all methods of programming, there might be slight differences in addressing, memory allocation, retrieval and data handling for different Models.
* PLC programs cannot be interchanged among different

PLC manufacturers.

* Some PLC manufactures are siemens, GE fanuc ABB automation etc.

CPU -:

* The full form of CPU is central processing unit. It is the "brain" of a PLC system.
* A processor (CPU) usually consists of a microprocessor for implementing the logic and controlling the communications among the modules.
* The processor requires memory for storing user program instructions, numerical values, I/O devices status & data.
* The CPU controls all PLC activity and is designed so that the user can enter the desired program in ladder logic.

Input/output (I/O) section -:

* There are two ways of connection for I/O section in PLC.

a) Fixed I/O section b) Modular I/O section

Fixed I/O Section

→ Fixed I/O is typical of small PLCs that come in one package with no separate or removable units.

→ The processor and I/O are packaged together and the I/O terminals will have a fixed number of connections for input & output.

→ Advantage - low cost

→ Disadvantage - lack of flexibility.

* If any part in the unit fails, the whole unit has to be replaced.

Modular I/O Section -:

→ Modular I/O is divided by compartments into which separate modules can be plugged.

* This feature increases your options and the flexibility of unit.
* The basic modular controller consists of a rack, power supply, processor module (CPU) and an operator interface for programming & monitoring.
* Here all the modules are pluged into a rack.

Power supply-:

* we provided DC power supply to the modules that plug into the rack. (Normally 24V DC)
* For large PLC system, external alternating current (AC) or Direct current (DC) are provided.

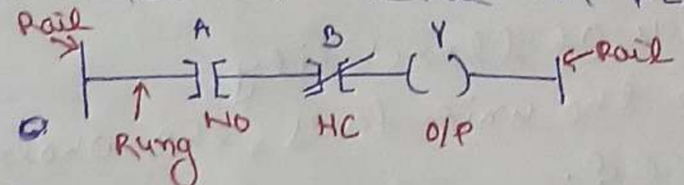
Programming device-:

* It is used to enter the desired program into the memory of the processor.
* The program can be entered using relay ladder logic, which is one of the most popular programming languages.
* It is also used to communicate with the circuits of a PLC.

Ladder diagram-:

* A ladder logic diagram is a graphic programming language developed from the ~~realy~~ relay ladder diagram and is useful in PLC programming.

Ex-:



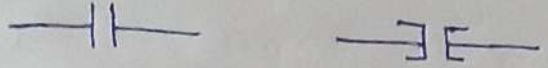
* Rung -: In PLC ladder logic programming, the horizontal line is called Rung.

Rail :- The vertical lines indicates the power supply or ~~flow~~ power flow called Rail.

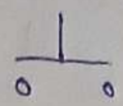
* The main function of the logic ladder diagram is to control outputs based on input conditions.

Ladder Diagram Symbol

Normally open contact (NO)



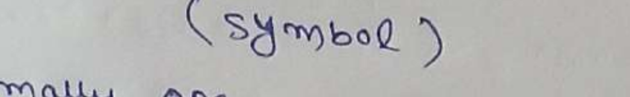
(symbol)



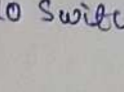
NO switch

* Normally open contact is one that remains open until a specified condition is reached.
* The NO contact stays open until the actuator is pressed.
* when the actuator is pressed, the contact closed & the current begins to flow.
* NO - '0' (NO current flow)(open condition)
* NO - '1' (current flow) (closed condition)

Normally closed contact (NC)



(Symbol)



NC switch

* NC is one that remains closed until a specified condition is reached.

* The NC contact stays closed until the actuator is pressed.

* when the actuator is pressed, the contact open & ~~the~~ NO current will flow.

* NC - '0' (current flow) (closed condition)
* NC - '1' (NO current flow) (open condition)

Energized output

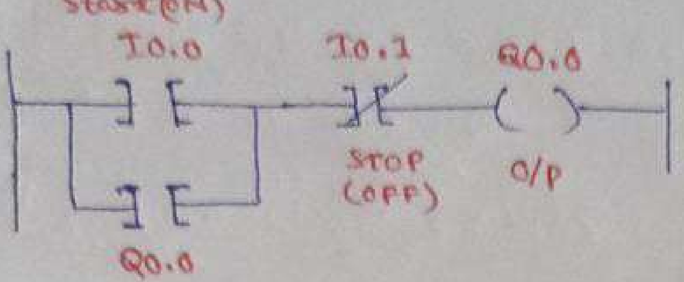
—( )—

Symbol

* This coils are energized, when power flows through them.
* If the output is 1, then the coil is energized
* If the output is 0, then the coil is de-energized.

Latched output -:

* Latched output is used to keep an output Active (high) even when the input is turned off.



I0.0 -: START (ON) PUSH button
I0.1 -: STOP (OFF) PUSH button
Q0.0 -: output energize coil
Q0.0 (contact) -: latch of output coil Q0.0
NO -: Normally open switch
NC -: Normally closed switch

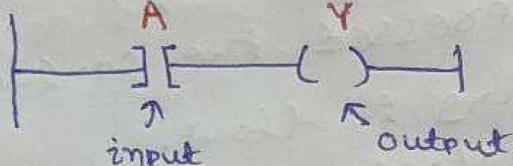
* At first we pressed the Start push button (I0.0) which become NO to NC.
* As the Stop button is already closed (NC), the rung goes true and the coil (bulb) Q0.0 becomes energized.
* Now, if the start push button is released then also the bulb will remain ON (Due to the concept of latching)
* As soon as the coil Q0.0 get energized, the latched contact of this coil which is represented as Q0.0 becomes NO to NC and the logic will pass through this rung and remains the bulb ON even if the start push button is released.
* By pressing the STOP push button, we can de-energized the coil Q0.0. (Turned OFF)
* When we pressed the STOP push button, the push button becomes NC to NO & it disconnected the ~~[illegible]~~ coil.

energized.

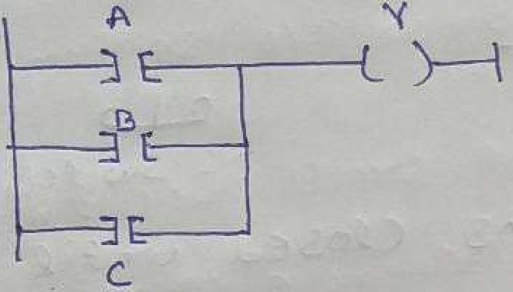
Branching -:

* Branching means adding more rungs that are associated with the same output, or having multiple outputs for the same inputs.

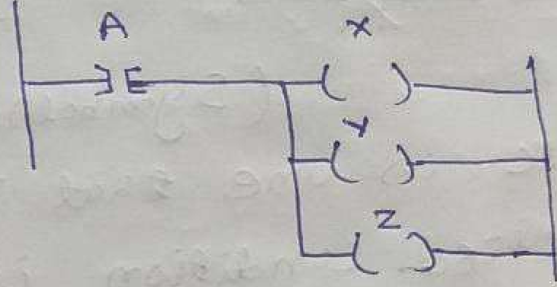
Series branching -: In this branching, the inputs & outputs are connected in series.



Parallel branching -: In this branching, the inputs & outputs are connected in parallel.



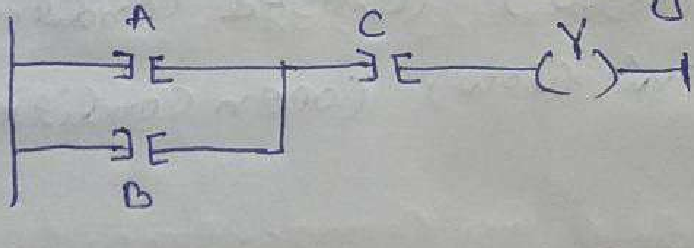
No. of i/P connected in parallel



No. of O/P connected in parallel

Nest Branching -:

* It is the combination of series and parallel branches in the same or different rungs are called as Nest branching.



Timer -: Timers are internal PLC instructions that can be used to delay the input and output signals in the PLC program.

→ During the operation, the timer can also keep track the time of output operation (ON/OFF)

Some important term -:

Enable Bit (EN) -: The enable bit indicates the timing instruction is enabled.

* The EN bit is true when the rung input logic is true or else false when the rung input logic is false.

Done Bit (DN) -: The done bit indicates that accumulated value (ACC) is equal to the preset (PRE) value.

* The DN bit signals the end of the timing process by changing states from false to true or from true to false depending on the type of timer instruction used.

* The DN bit is the most commonly used timer status bit.

Timer timing Bit (TT) -: The timing bit indicates that a timing operation is in process.

* The TT bit is true only when the accumulator is incrementing.

* TT remains true until the Accumulator reaches the preset value.

Note -: True - ON , False - OFF

Accumulator (ACC) -: It specifies the number of transitions the instruction has counted.

* The accumulator value stops changing when

ACC value = PRE value.

Preset (PRE) :- It specifies the value which the accumulated value must reach before the instruction sets the done bit.

* The data type used is Double integer (DINT) to stored the preset value.

→ The time base is always 1msec or 0.001. But in some cases the Time base value is 1 or 0.01 also.

* $\boxed{\text{Delay time} = \text{preset value} * \text{Time Base value}}$

↳ setting time