GOVT. POLYTECHNIC BALASORE

[LECTURE NOTES]

POWER ELECTRONICS & PLC [TH 5]

DIPLOMA
IN
5TH SEMESTER, E&TC ENGINEERING

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Understand the Construction & Working of Power Electronic device.

Power Electronics :-

Power Electronics is a combination of electronic devices & electric power with control operation.

→ Power electronics is the application of electronic devices with high power level & converts one electrical signal to another electrical signal with control operation.

Application :-

(i) It is used in aerospace to provide power supply for aircrafts, satellite etc.

(ii) It is used in commercial sector like AC (Air Conditioner) & central refrigerator, UPS system (Uninterrupted Power Supply), Elevators (lift) etc.

(iii) It is used in domestic purpose like in PC (Personal Computer), Vaccum cleaner, Washing machine.

(iv) It is used in Transportation system like traction control of vehicles & electronic Locomotive (electric vehicle).

Advantages :-

(i) It has high efficiency, due to low loss of power semiconducting device.

(ii) It has high reliability (User friendly) during power conversion.

(iii) It has long life span & high thermal stability. (means it works at high tempᵒ).

(iv) It has fast dynamic response. (Switching (on-off) output) (How much time it takes for ON-off)

(v) It has small size & less weight.

Disadvantages :-

(i) Power electronic devices can't be repairable.

(ii) It can be operated for a certain limit of voltage & current.

(iii) It gets over heated for long time use.

(iv) It is expensive than general electronic devices.

Date: 25/07/2021

Thyristor:

→ Thyristor is a power electronic device that operates as a switch or amplifier with control action.

→ Thyristor is a combination of Thyratron & Transistor.

→ Thyratron is an electronic device, that operates as a switch with controlling of current & power.

Transistor is an electronic device, that operates as a switch or amplifier.

→ There are different members in Thyristor family such as:-

(i) SCR (Silicon Controlled Rectifier).
(ii) DISC (Bi-direction diode Thyristor)
(iii) TRIAC (-direction Triode)
(iv) GTO (Gate Turn off Thyristor)
(v) RCD (Reverse Conducting Thyristor).
(vi) MCT (MOS Controlled Thyristor).
(vii) IGBT (Insulated Gate Bipolar transistor).

From the above member SCR is mostly used in power electronics industries, So SCR is generally called Thyristor.

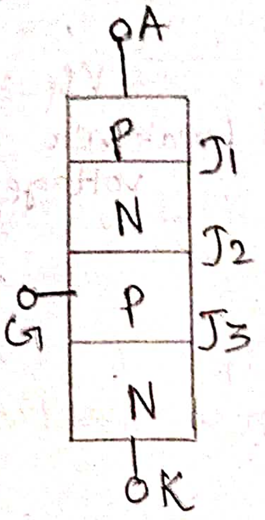
SCR:-

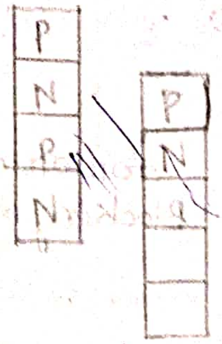
SCR stands for Silicon Controlled Rectifier.

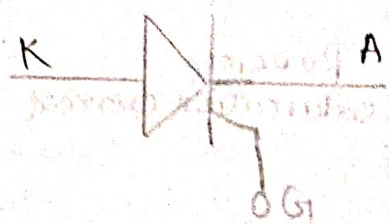
The name is so because, silicon material is used & it operates as a controlled rectifier.

[Why silicon used:- → (i) Easily available (cost low)
→ (ii) Thermal stability very high.

Construction:-





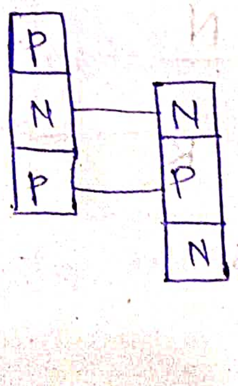


(Symbol)

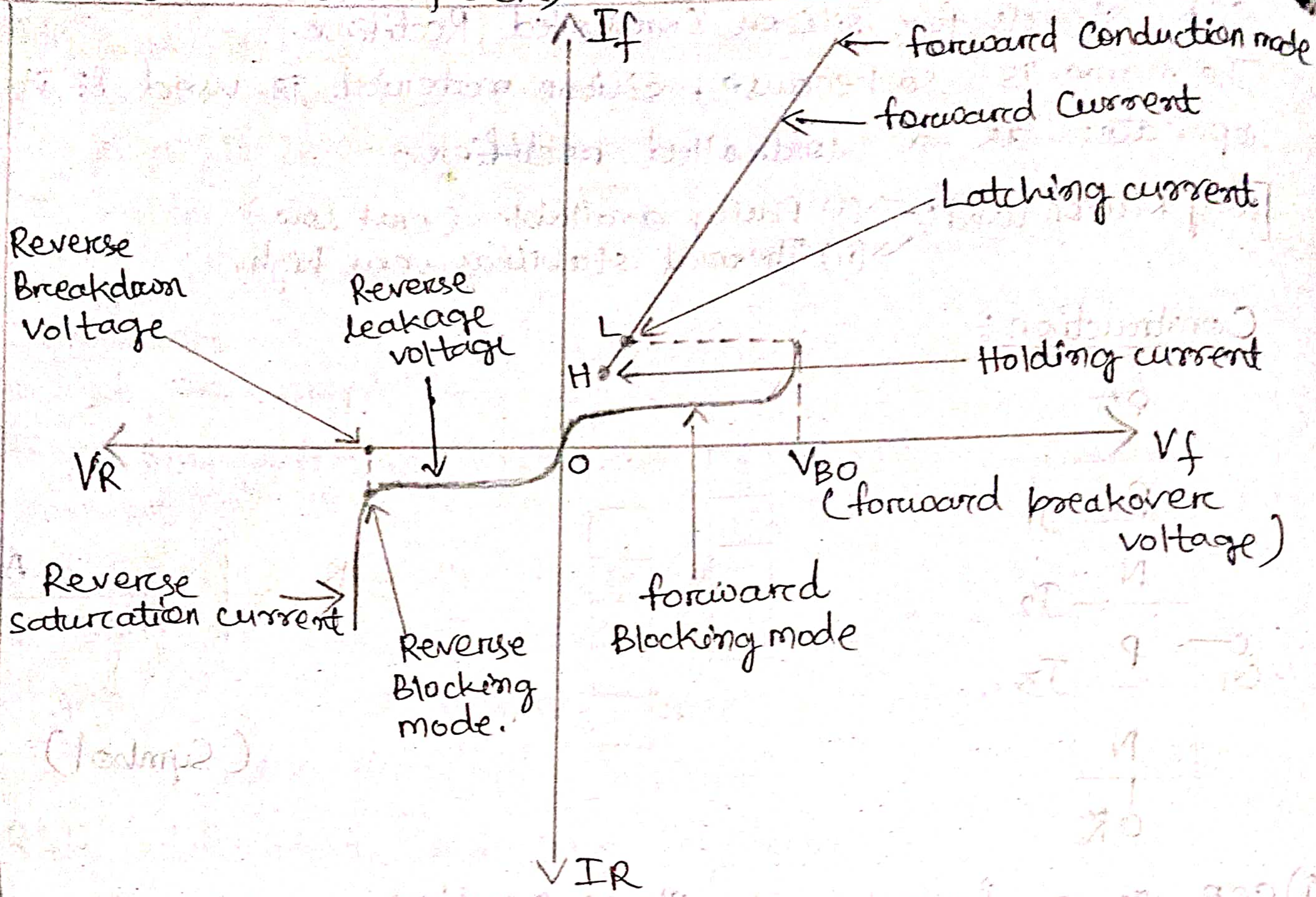
(i) SCR is a four layers, three junction semiconducting switching device.
There are three terminal named as Anode, Cathode & Gate.

(ii) The Gate terminal is connected near the Cathode terminal to provide control system betn Gate & Cathode.

(iii) The operation of SCR is obtained from V-I characteristics.

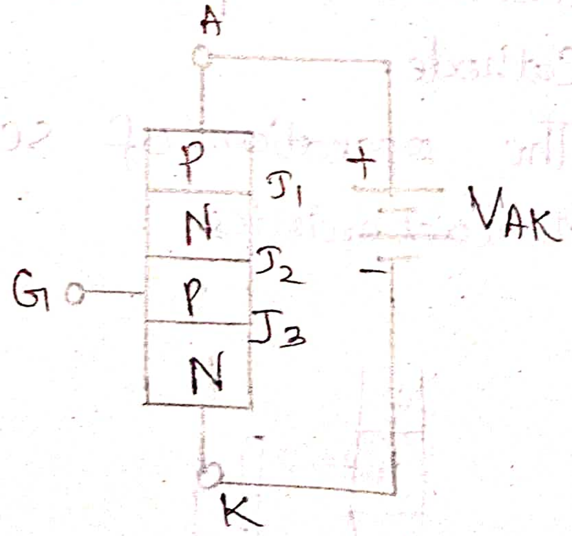


(V-I characteristics of SCR)



→ figure shows V-I characteristics of SCR.
The operation of SCR have 3 modes, such as

(i) forward Blocking mode.
(ii) forward Conduction mode.
(iii) Reverse Blocking mode.



Forward Blocking mode :-

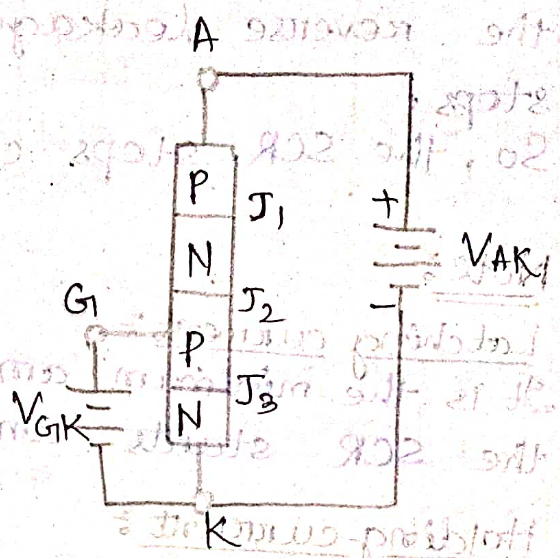
→ In this mode of operation the anode terminal is made positive w.r.to Cathode terminal & Gate terminal is opened.

→ In this mode the junction 'J_1' & 'J_3' become forward biased & the junction 'J_2' becomes reversed biased.

→ Due to reversed biasing normal current can not flow through the SCR, but a leakage current flows through SCR due to minority charge carrier.
→ This mode is obtained upto forward break over voltage (VBO).

__forward Conduction mode :-__

→ The forward conduction mode of SCR can be obtained by 2 ways i.e,
(a) By increasing forward voltage above 'VBO'.
(b) By suppling positive Gate voltage w.r.t Cathode.

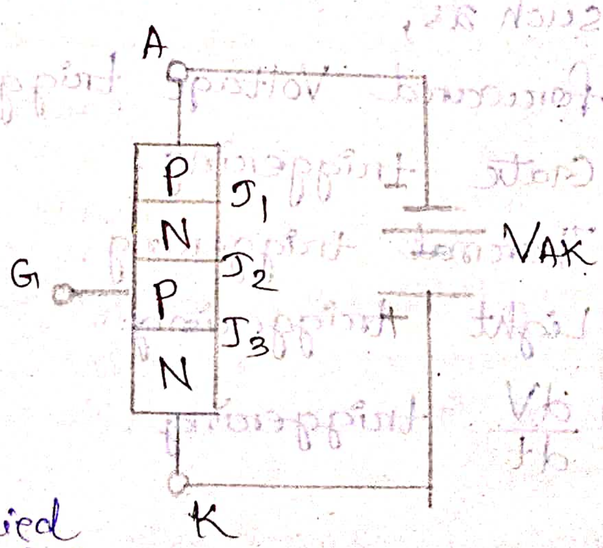


→ When VAK exceeds VBO then the junction 'J2' breaks down due to reverse breakdown voltage & the normal flows through SCR & operated in conduction mode.
→ When Gate supply is given then the junction 'J2' is becomes forward biased
The junction J1 & J3 becomes forward biased due to VAK, so the normal current flows through the SCR & SCR acts as a closed switching.

__Date :- 28/09/2021__

__Reverse Blocking mode :-__

→ In this mode of operation the anode terminal is made negative w.r.to cathode.
The Gate terminal is made open.



→ When reversed voltage is applied to SCR then the junction 'J1' & 'J3' become reversed biased

& the junction 'J_2' become forward biased.
So, the normal current can not flow through the SCR ; but a leakage current flows due to minority charge carrier.

→ In this mode of operation, when the reverse voltage exceeds the reverse breakdown voltage (V_{BR}), then the reverse leakage current suddently raises & stops.
So, the SCR stops conducting & acts as an open switch.

Note :

- **Latching current :**
It is the minimum amount of anode current at which the SCR starts conducting or turn **ON**.

- **Holding current :**
It is the minimum amount of anode current below which the SCR stops conducting.

☆ The Latching current generally two or three times of holding current.
i.e
L·C = 2 or 3 H·C

$\boxed{L \cdot C = 2/3\ H \cdot C}$

Long question

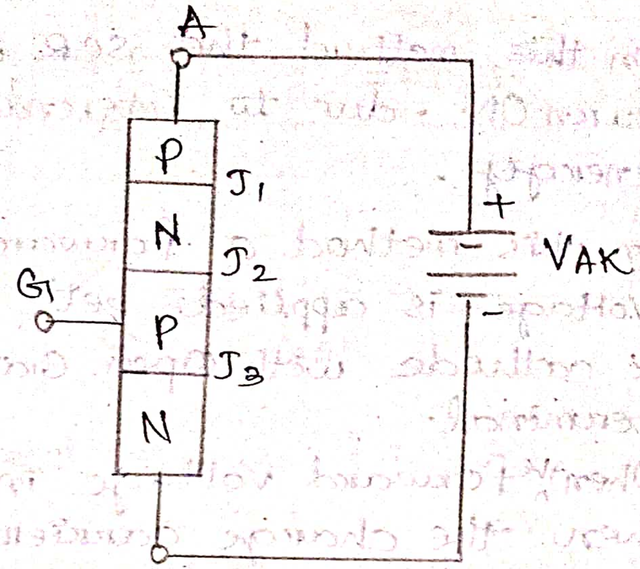
Turn ON method : (Triggering Method)

There are different methods of triggering SCR, such as,
(a) forward Voltage triggering.
(b) Gate triggering.
(c) Thermal triggering.
(d) Light triggering
(e) $\frac{dV}{dt}$ triggering

(a) Forward voltage Triggering Method:

(i) In this triggering method the forward voltage is used to turn ON the SCR.

(ii) The anode is made positive w.r.t cathode & the Gate terminal remain open. So, the junction 'J_1' & 'J_3' become forward biased & the junction 'J_2' become reversed biased.

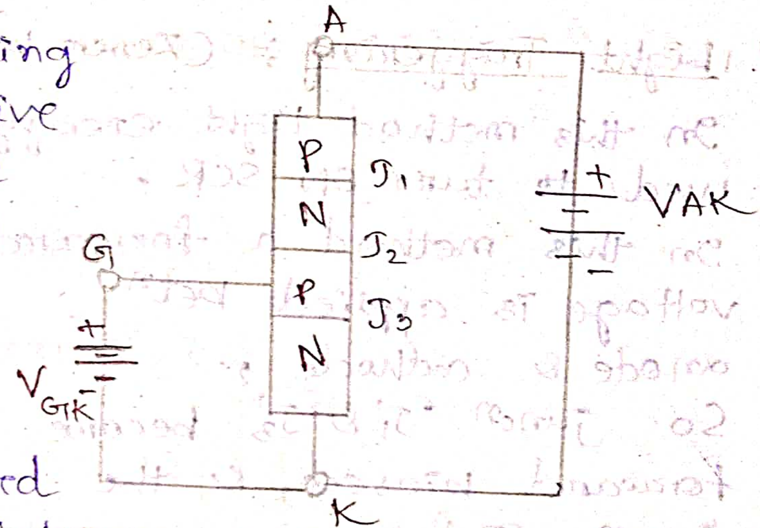


(iii) When the forward voltage (V_{AK}) exceeds forward breakover voltage (V_{BO}), then the junction 'J_2' breaks down & normal current flows through the SCR.

(iv) So, the SCR will turn ON & acts as a closed switch.

(b) Gate Triggering method:

(i) In this method of triggering the anode is made positive w.r.t cathode & a Gate supply is given i.e the Gate is made positive w.r.t cathode.

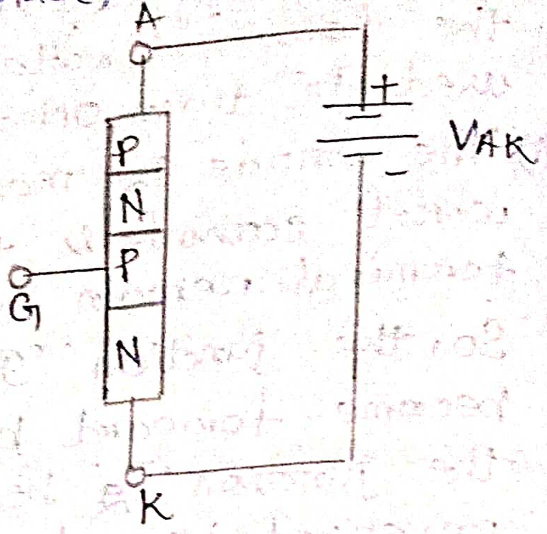


(ii) When Gate supply is absent then the junc^n 'J_1' & 'J_3' become forward biased & the junc^n 'J_2' become reversed biased. So, normal current can not flow.

(iii) When positive Gate supply is given, then the junc^n 'J_2' become forward biased, so normally current can flow through the SCR & the SCR will turn ON.

(iv) After conduction of SCR the Gate supply is removed to avoid excess power loss.

(c) Thermal triggering method :-
(Here avalanche breakdown takes place)



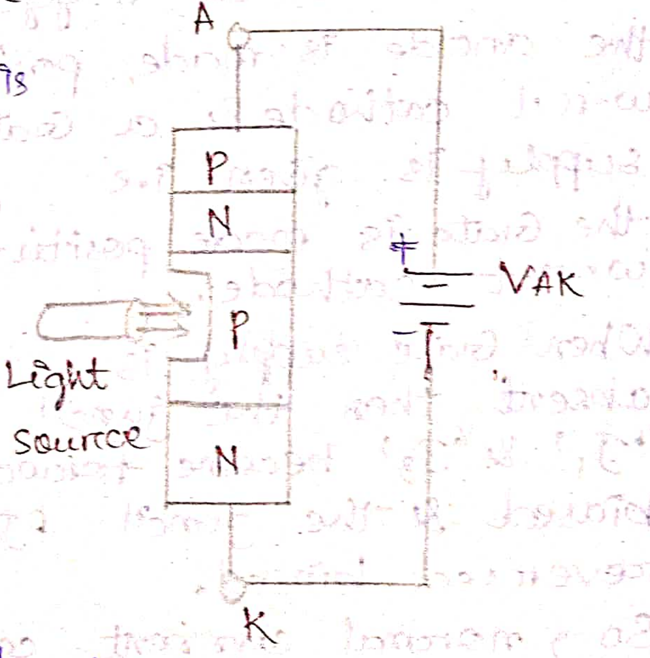
(i) In this method the SCR will turn ON, due to internal heat energy.

(ii) In this method a forward voltage is applied betⁿ anode & cathode with open Gate terminal.

(iii) When the forward voltage increases, then the charge carriers near the junction 'J_2' provides avalanche breakdown due to developement of thermal energy.

(iv) Therefore the junc^n 'J_2' breaks down & the SCR starts conducting.

(d) Light Triggering :- (Zener breakdown takes place)



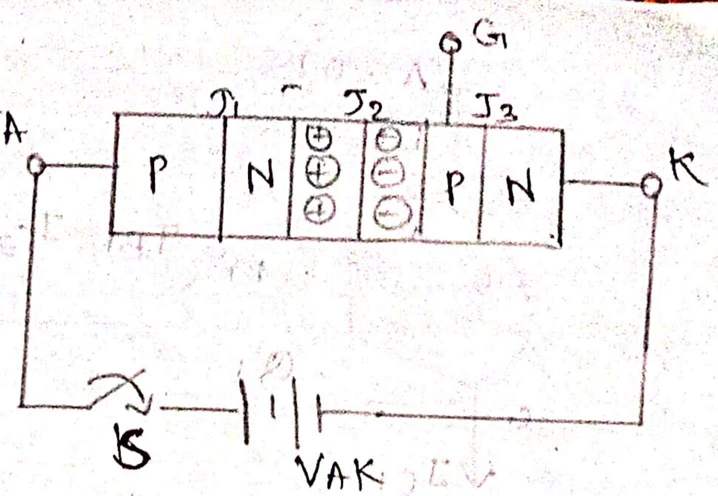
(i) In this method Light energy is used to turn ON SCR.

(ii) In this method a forward voltage is applied betⁿ anode & cathode,
So junc^n 'J_1' & 'J_3' become forward biased, & the junc^n 'J_2' become reversed biased.

(iii) When light energy is applied at Gate region, then the electrons near the junc^n 'J_2' are energised & breakes the junction 'J_2'.
So the SCR starts conducting.

(iv) This method is used for special type of SCR i.e Light Activated SCR (LASCR).

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



(i) In this method the forward voltage is applied betn anode & cathode with open Gate, So, the juncn 'J1' & 'J3' become forward biased & 'J2' become reversed biased.

(ii) Due to reversed biased junction, a junction capacitance is formed at 'J2'.

(iii) The current produced by the capacitor is given by

$$i_c = C \frac{dv}{dt}$$

(iv) When the supply voltage is changed by the help of switch (S), So $\frac{dv}{dt}$ value increases.

(v) Hence the current value increases at 'J2' & the juncn breaks down.

(v) Therefore the SCR will turn ON & acts as a closed switch.

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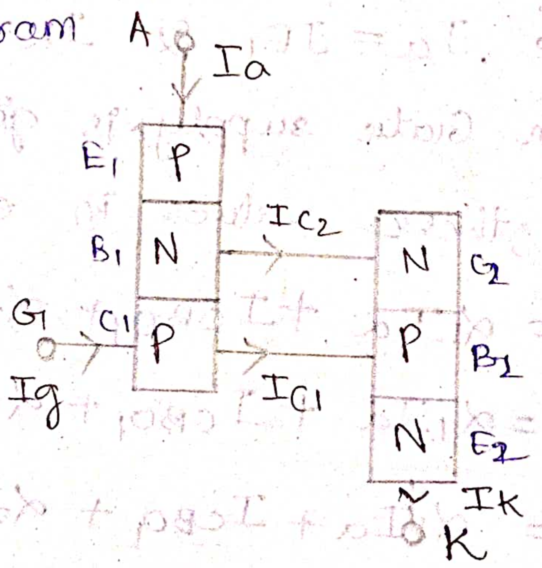
Two Transistor Analogy of SCR :-



→ The fig. shows the ckt diagram of SCR with two transistor analogy

→ In off state the transistor, the collector current is related to emitter current in common ~~emitter~~ base configuration is given by

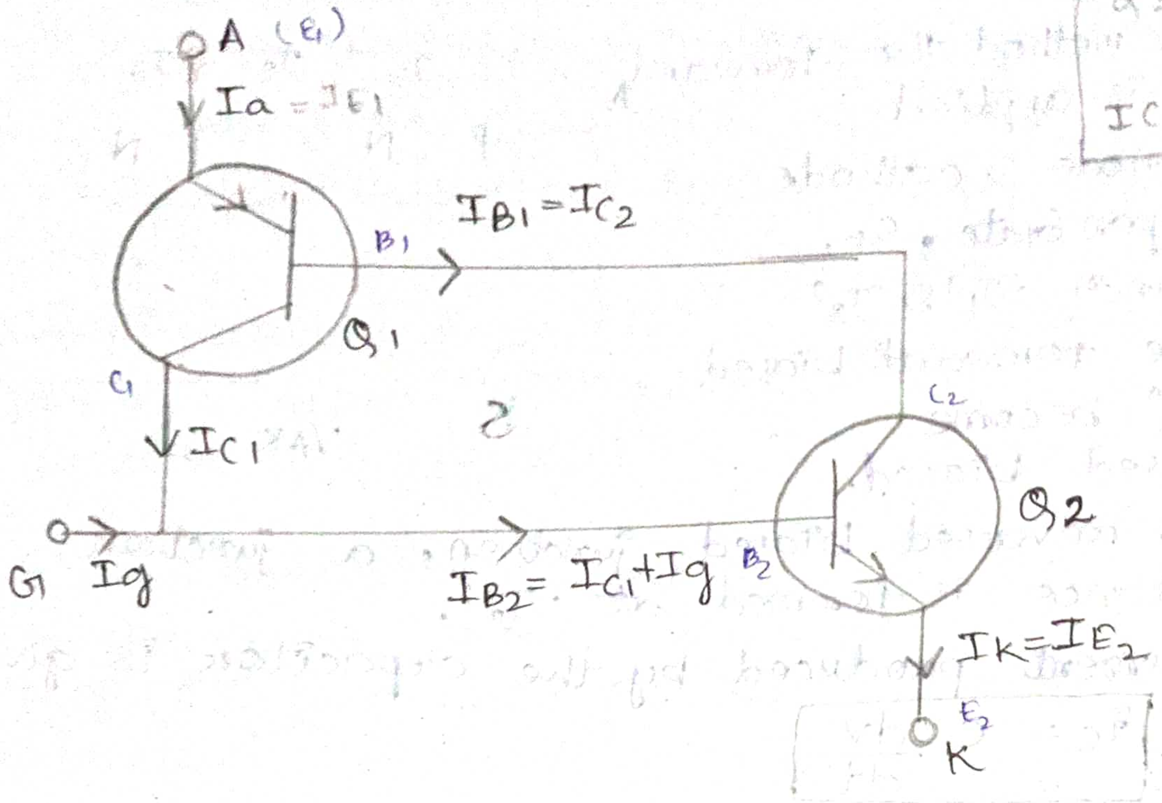
$$I_C = \alpha I_E + I_{CBO}$$

Where α is current gain of CB configuration.

I_{CBO} is Collector to Base leakage current with open ammeter.

$\alpha = \frac{I_C}{I_E} < 1$

$I_C = \alpha I_E$



for transistor Q_1 & Q_2, the output current is given by,

$I_{C1} = \alpha_1 I_{E1} + I_{CBO1}$

$I_{C2} = \alpha_2 I_{E2} + I_{CBO2}$

→ for SCR the total anode current is given by

$I_a = I_{C1} + I_{C2}$

$I_a = (\alpha_1 I_{E1} + I_{CBO1}) + (\alpha_2 I_{E2} + I_{CBO2}) \longrightarrow (i)$

Here $I_a = I_{E1}$ & $I_K = I_{E2}$

When Gate supply is given, $I_K = I_a + I_g$

Put these values in eqn (i)

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

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

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

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

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

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

$I_a - I_a\alpha_1 - I_a\alpha_2 = I_{CBO_1} + I_{CBO_2} + \alpha_2 I_g$

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

$$\boxed{I_a = \frac{I_{CBO_1} + I_{CBO_2} + \alpha_2 I_g}{1-(\alpha_1+\alpha_2)}}$$

→ If $(\alpha_1+\alpha_2)$ becomes unity, then the anode current will be infinity. It indicates that a small amount of Gate current is required to turn ON the SCR.

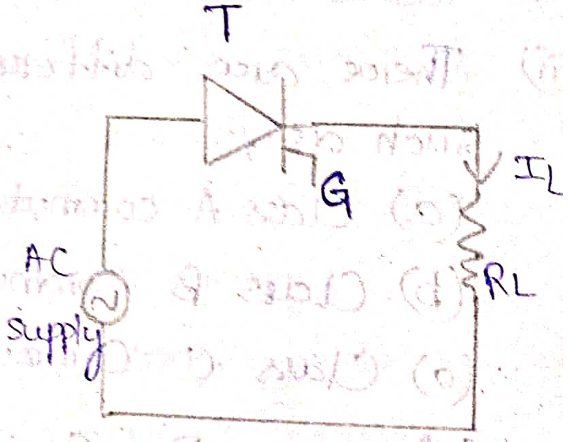
Turn Off method (Commutation method of SCR):

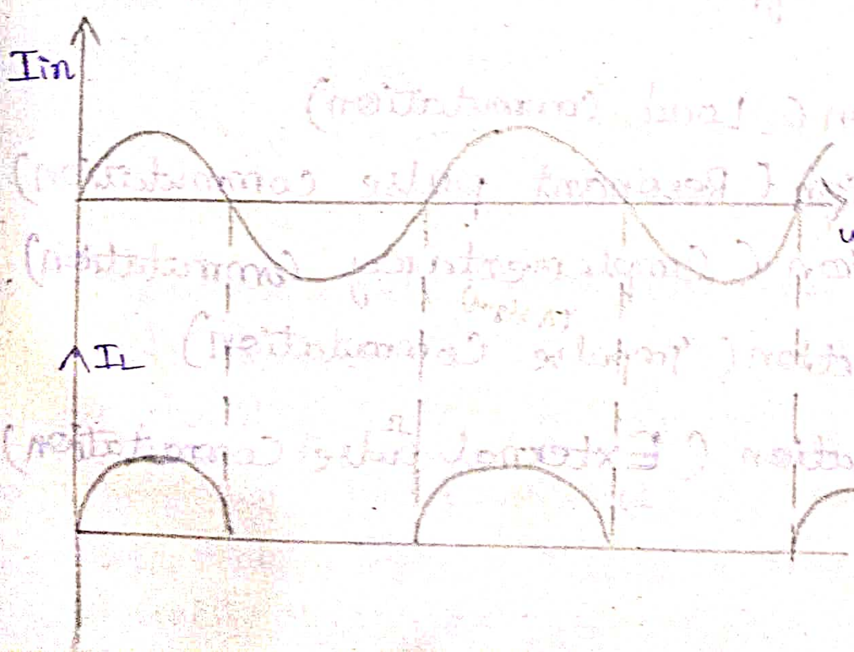
There are basically 2 types of commutation method, such as,

(a) Line Commutation (Natural Commutation).
(b) Forced Commutation.

Line Commutation:

(i) This type of commutation is also called "Natural - Commutation" & it can be obtained for AC signal only.





(i) fig. shows a half wave controlled rectifier by using SCR.
Here output is obtained at Load resistor {"RL"}.

(ii) When AC supply is given to the SCR, then it will in forward blocking mode.
When Gate supply is given the SCR will turn ON & current flows towards load resistor.

(iii) When the anode current reaches the natural zero position of an ac cycle then the SCR will be in reverse blocking mode & stops conducting. i.e commutation occures.

(iv) This methode is called Natural commutation because no external circuit is used for commutation.

(v) This method is used in Phase Controlled Converters, Line Commutated inverters, AC Voltage Controllers, Stepdown Cycloconverter etc.

Date:- 04/10/2021

competitive

Forced Commutation:-

(i) In this commutation process an external circuit is used to turn Off the SCR during operation.

(ii) The external ckt is also called "Commutating Circuit".

(iii) There are different types of forced Commutation, such as,

(a) Class A commutation (Load Commutation)

(b) Class B Commutation (Resonant pulse commutation)

(c) Class C Commutation (Complementary Commutation).

(d) Class D Commutation (Impulse (Λ signal) Commutation)

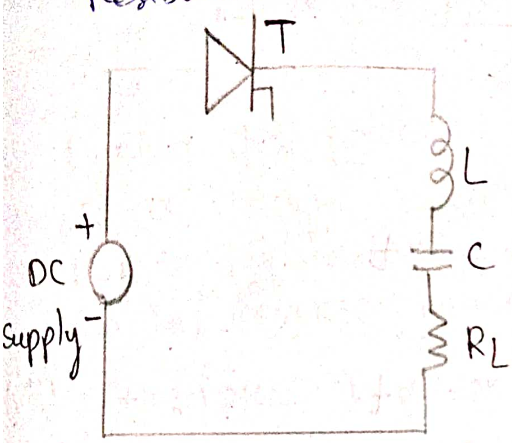
(e) Class E Commutation (External pulse Commutation)

1) Load Commutation :-

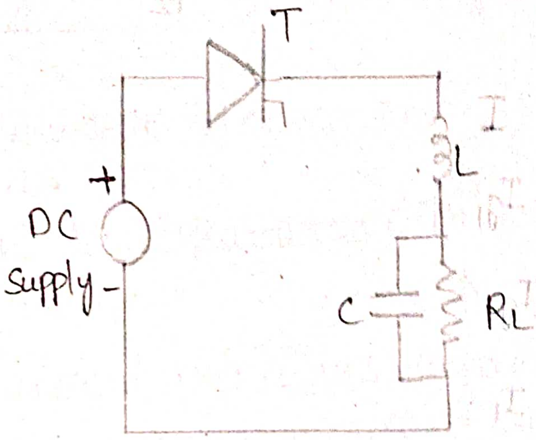
i) In this commutation an inductor & capacitor are connected with the load resistor to provide commutation.

ii) If the load resistor has low value then the inductor & capacitor are connected in series with the load resistor.

iii) If the load resistor have high value, then the inductor is connected in series & the capacitor is connected in parallel with the load resistor.



(Low value Resistor



(High value Resistor)

→ fig shows the ckt diagram of Load Commutation, that consists of a Thyristor, load resistor (RL) & LC Circuit.

→ The LC ckt is an underdamped circuit, that produces an underdampped signal when current flows through it.

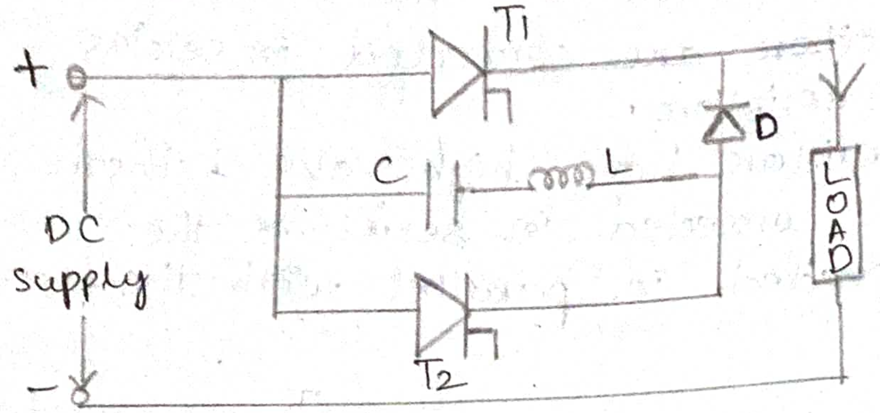
→ When the supply voltage is given to the SCR, then the SCR will turn ON with Gate triggering.

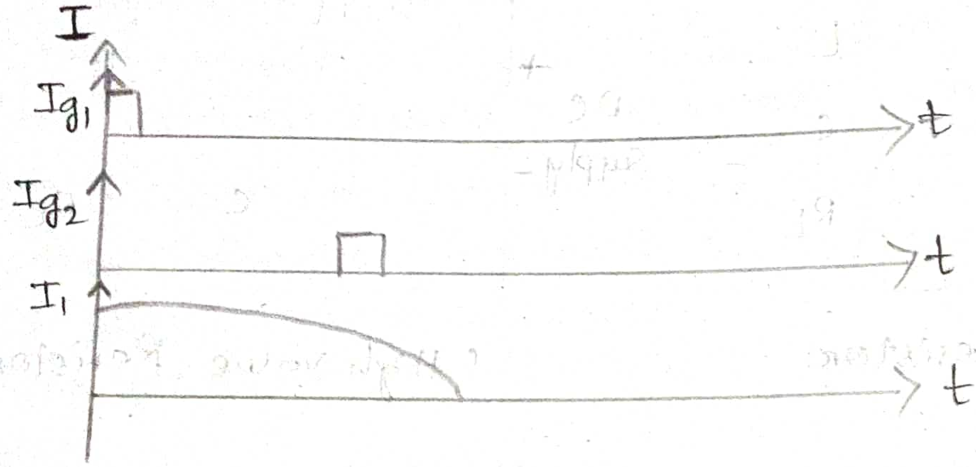
→ When normal anode current flows through the load resistor, then the load voltage increases gradually due to damping circuit.

→ When the load voltage exceeds the supply voltage, then the SCR will be in reverse blocking mode & will turn off.

→ As the Commutation of SCR is obtained by external ckt, So it is called forced commutation.

(b) Resonant Pulse Commutation:-





(i) fig. shows the ckt diagram of Resonant Pulse Commutation of SCR.

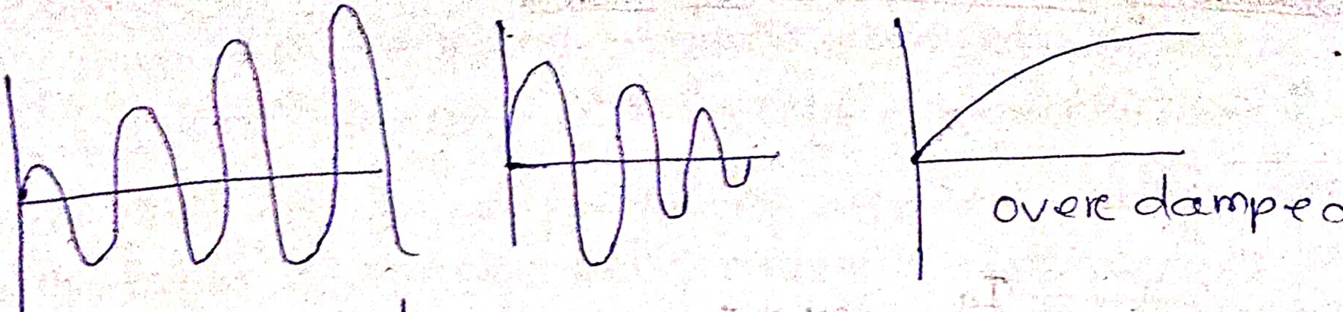
(ii) It consists of an external ckt, which involves L, C & an auxilary (extra) thyristor (T_2).

(iii) When supply voltage is given the thyristor 'T_1' will be in forward blocking mode & the capacitor is charged upto maximum value.

(iv) When the Gate supply is given to 'T_1', then it will turn ON & the load current is obtained.

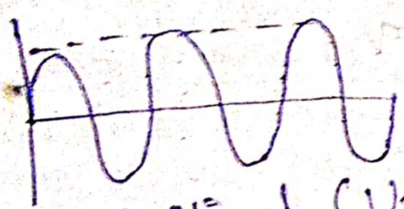
(v) When the SCR 'T_1' is to be off, then the auxilary thyristor (T_2) is triggered.

(vi) The capacitor discharges through 'T_2' & provides a current in the path $C \rightarrow T_2 \rightarrow L \rightarrow C$.



over damped

Underdampped



Critical (Undampped)

During this process the inductor stores energy & a voltage is developed.
Due to this inductive voltage the thyristor (T_2) will go to reverse blocking mode.

(vii) Therefore a resonant current flows towards 'T_1' which is opposite to the anode current of 'T_1'.
This resonant current is obtained by 'LC' ckt.
Hence the net current of anode current of 'T_1' & resonant current decreases gradually.

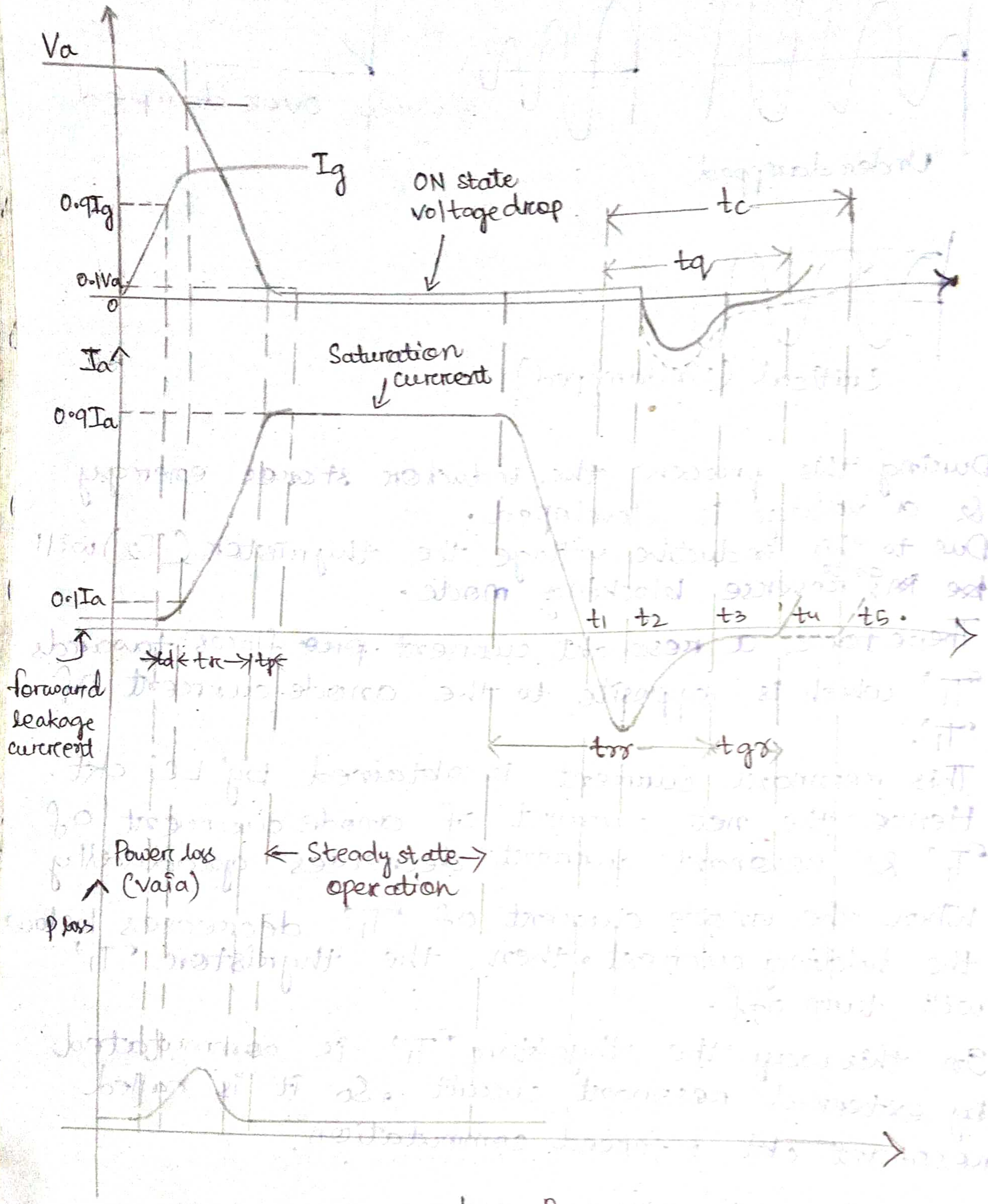
(viii) When the anode current of 'T_1' decreases below the holding current, then the thyristor 'T_1' will turn off.

(ix) In this way the thyristor 'T_1' is commutated by external resonant circuit, So it is called resonant ckt, forced commutation.

Note :
The diode 'D' provides unidirectional current, that flows from resonant ckt & blocks the main current flowing through 'T_1'.

Date 05/10/2

Switching Characteristics of SCR :



trr = Reverse recovery time

tgr = Gate recovery time

td = delay time

tr = rise time

tp = peak time

tc = commutation time.

(i) fig shows the switching characteristics of SCR. It indicates 'Turn ON' & 'Turn Off' characteristics.

(ii) When the SCR is triggered by applying Gate voltage with forward voltage betn anode & cathode, then the SCR change its state from Off state to ON state.

(iii) The turn ON characteristics has three parts, such as
(a) Delay time (td)
(b) Rise time (tr)
(c) Peak time (tp)

(a) Delay time:-

→ It is the time interval at which the gate current is 90% & the anode current is 10% of maximum value.

→ It is also defined as the time interval at which the anode voltage decreases from 100% to 90% of maxm value.

(b) Rise time:-

→ It is the time interval taken by the anode current to rise from 10% to 90% of maxm value. (Ia = maxm value) (i.e 0.1 Ia to 0.9 Ia)

→ It is also defined as the time taken by anode voltage to fall from 90% to 10% of maxm value. (i.e 0.9 Va to 0.1 Va)

(C) Peak time:-

→ It is the time interval taken by the anode current to rise from 90% to 100% of maxm value (i.e, 0.9 Ia to Ia)

→ It is also defined as the time taken by the anode voltage to fall from 100% to ~~90% of maxm value~~ to on state voltage.

☆ The ON state voltage of SCR is 1V to 1.5V.

Turn Off Characteristics :-

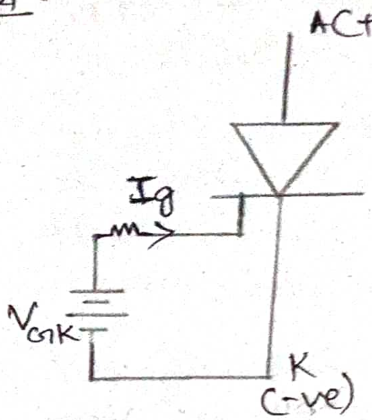
→ It is the time required to Turn 'Off' the SCR.
→ It indicates the transistion (state change) the SCR from ON state to Off state.

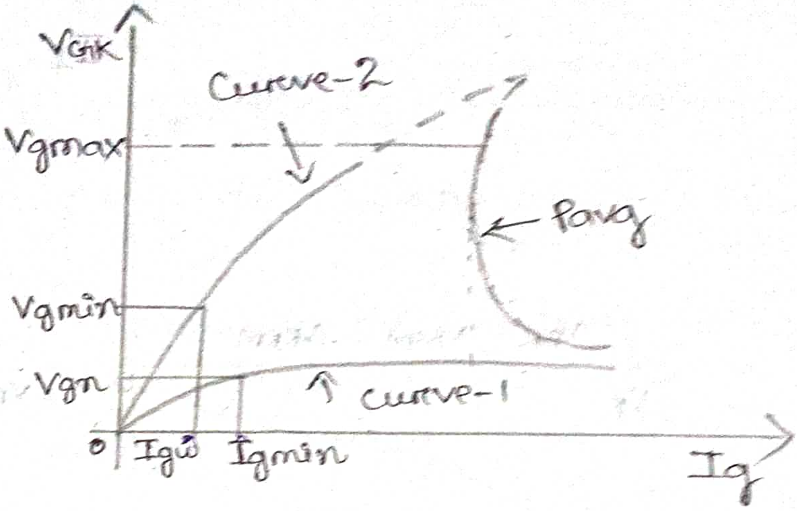
→ It has two parts, such as
(a) Reverse Recovery time (t_{rr})
(b) Gate Recovery time (t_{gr})

(a) **Reverse Recovery Time :-**
→ It is the time required to remove excess charge carriers from junction 'J_1' & 'J_3'.
→ In this time the current flows due to sweeping out of holes from P layer & e⁻s from N layer.
→ This time period is indicated by the betⁿ 't_1' & 't_3'. In this time the forward junction tends to be in reverse mode.

(b) **Gate Recovery time :-**
→ In this the time required from the combination of charge carriers through which the SCR changes its state from forward blocking mode to reverse blocking mode.
→ This time is indicated by 't_3' & 't_4'.
In this time the juncⁿ 'J_2' recovers its reverse biasing property.
The forward voltage can be reapplied betⁿ anode & cathode to 'Turn ON' the SCR again.

Gate Characteristics :-





(i) fig shows the Gate characteristics of SCR. It indicates the relationship betn Gate voltage & Gate current of SCR at constant "VAK".

(ii) The Gate characteristics provides the safe limits for applying Gate voltage.

(iii) In the above characteristics Igmin & Vgmin are the minimum Gate current & voltage required to Turn-ON the SCR.

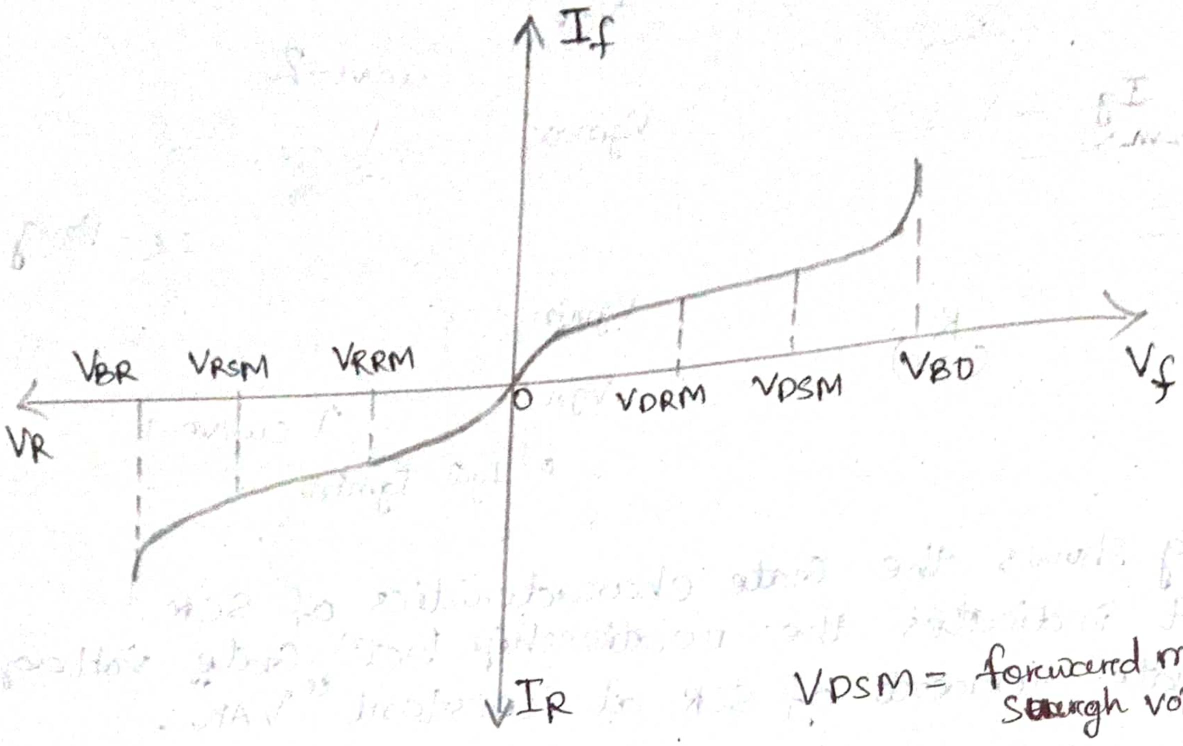
(iv) Vgmax is the maximum Gate voltage that can be applied to the SCR above which the SCR will be damaged.

(v) The curve(1) represents the minimum Gate voltage & Gate current, that can be applied to the SCR.

(vi) The curve(2) represents the maximum Gate voltage at the Gate terminal of SCR.

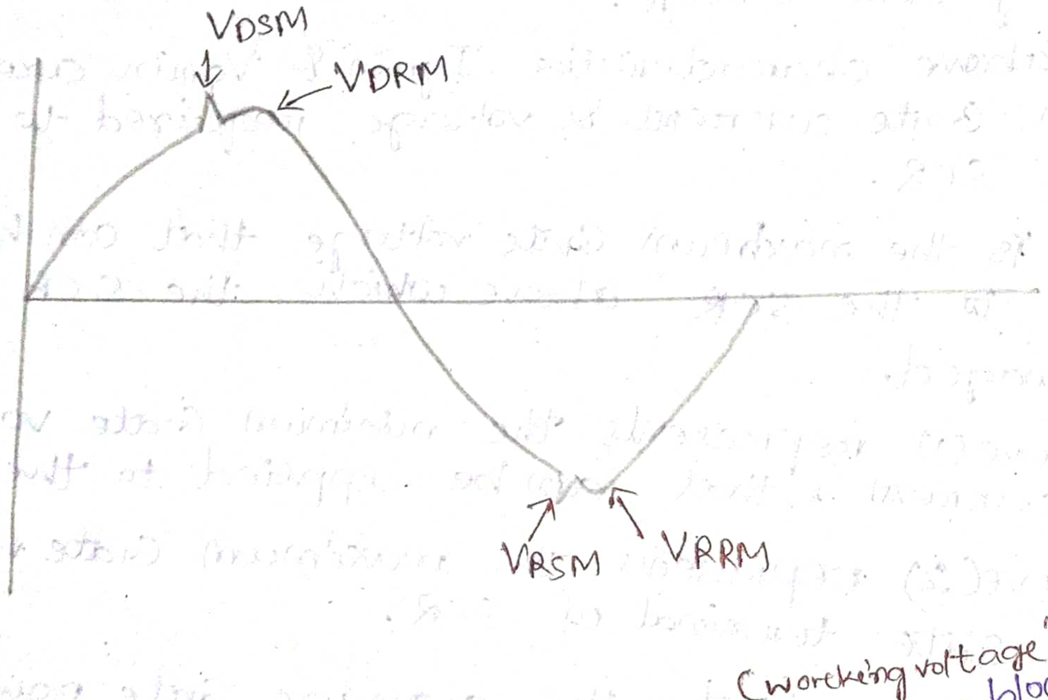
(vii) Pavg graph indicates the average Gate power dissipation during Turn ON of SCR.

Voltage Rating of Thyristor :-



V_{DSM} = forward max^m surgh voltage

V_{DRM} = forward max m recovery



(i) V_{BO} / V_{DWM} it is the max^m forward blocking voltage (working voltage) at which the SCR can withstand in forward blocking mode.

(ii) V_{DRM}: it the max^m repetative forward blocking voltage at which the peak transient voltage occures periodically in a thyristor.
This rating is specified at a max^m allowable junction voltage with open Gate terminal.

(iii) VDRM is encountered ('required') when the thyristor is commutated.

(iv) VDSM : It is the max^m surge forward blocking voltage at which repeatation can not occur.

→ It's value is about 130% of VDRM, but less than VBO.

(v) VBR/VRWD :- It is the max^m reverse working voltage or breakdown voltage below which the SCR operated safely in reverse blocking mode.

(vi) VRRM : It is the max^m reverse repeatative voltage, which specifies the peak reverse transient voltage that can occures repeatatly in reverse blocking mode.

(vii) VRSM : It is the max^m reverse surge voltage at which max^m peak value occures that can not be repeatate.

→ It's value is about 130% of VRRM, but less than VBR.

2 marks **ON State Voltage drop : (V_T)**

(i) It is the max^m voltage drop bet^n anode & cathode of a thyristor during Turn ON time.

(ii) It's value is about 1V to 1.5V.

Fingere Voltage :

It is the min^m forward voltage bet^n anode & cathode of a thyristore at which the thyristore will turn ON with Gate triggering.

forward $\frac{dv}{dt}$ rating :

It indicates the rate of rise of forward voltage bet^n anode & cathode to Turn ON the SCR without Gate triggereing.

Voltage Safety factor : (VSF)

(i) It is defined as the ratio of peak repeatative reverse voltage (V_{RRM}) to the max^m input voltage.

(ii) It is given by,

$$V_{SF} = \frac{V_{RRM}}{V_M}$$

$$= \frac{V_{RRM}}{\sqrt{2} \times V_{RMS}}$$

Date
08/10/21

Current Rating Of SCR :

"Average ON State Current":

→ It is the rated average current that flows through the SCR, during conduction mode.

It is the ratio of RMS of value of current to the formfactor.

→ It is given by

$$I_{Tav} = \frac{\text{RMS value}}{\text{f.f.}}$$

I_T = Thyristor current

av = average value

RMS ON State Current :

It is the max^m rated rms value of current, that flows through the SCR, during conduction mode.

It is same for all conduction angles.

Surge Current Rating :

It is the max^m non repeatating onstate current that flows through the SCR.

It indicates the max^m possible current for the operation of SCR in safe limit.

I^2t Rating :

This rating is used for ~~fews~~ fuse & other protective equipement associated with the thyristor.

It specifies the max^m energy that the device can absorb for a short time before fault is cleared.

$\frac{di}{dt}$ Rating :

This rating indicates the max^m rate of rise of current that flows through the SCR, during conduction mode without damaged.
It's value is about 20A ~~due~~ to 500 A ~~for~~ per microsecond.

Protection Of Thyristor :

There are 3 types of protection for the ~~thyristor~~ thyristor, such as,
(a) Over Voltage Protection.
(b) Over Current Protection.
(c) Gate Protection.

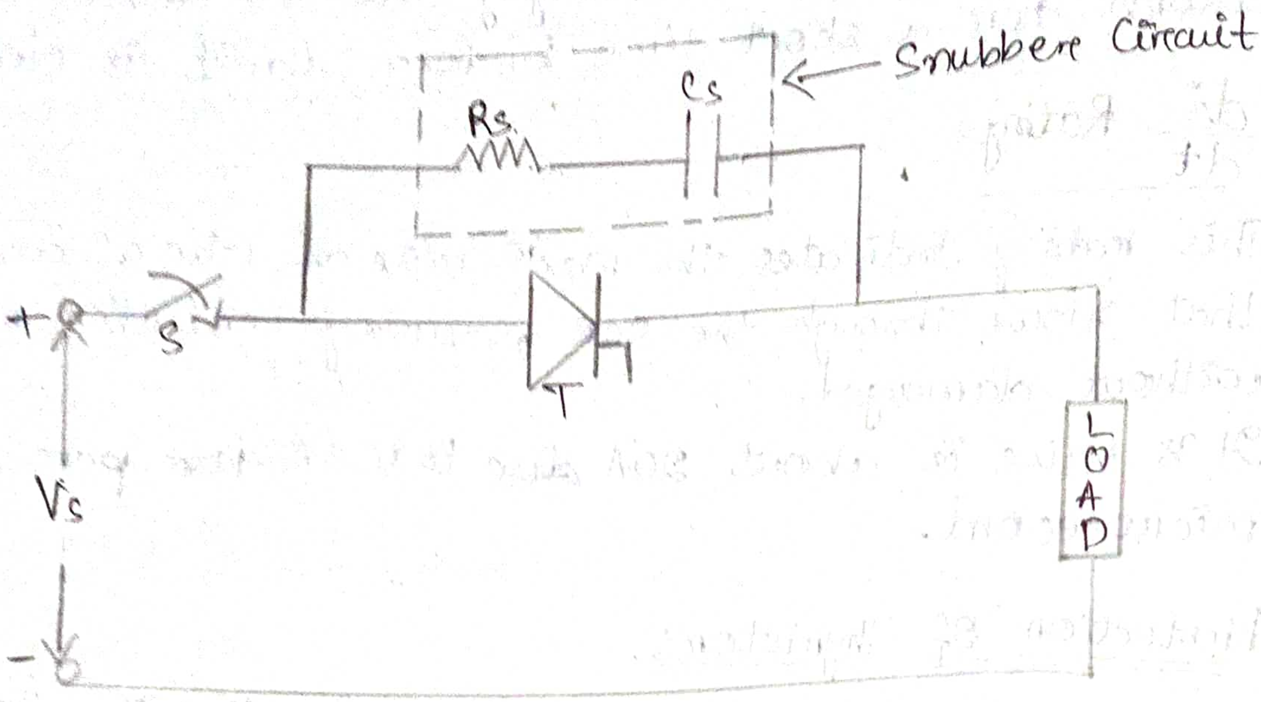
(a) Over Voltage Protection :

(i) There are 2 ways to protect the SCR from over voltage i.e, internal protection & external protection.

(ii) The internal over voltage is produced, during commutation period & the external over voltage is produced due to interruption of current flow through SCR with inductive load. & also due to lighting stroke.

(iii) The damage due to over voltage can be protected by 2 ways, i.e
(I) By fusing snubber circuit.
(II) By using voltage clamping device (Varistor)

Snubber Circuit :



(i) fig. shows the basic ckt diagram for over voltage protection by using Snubber Circuit.

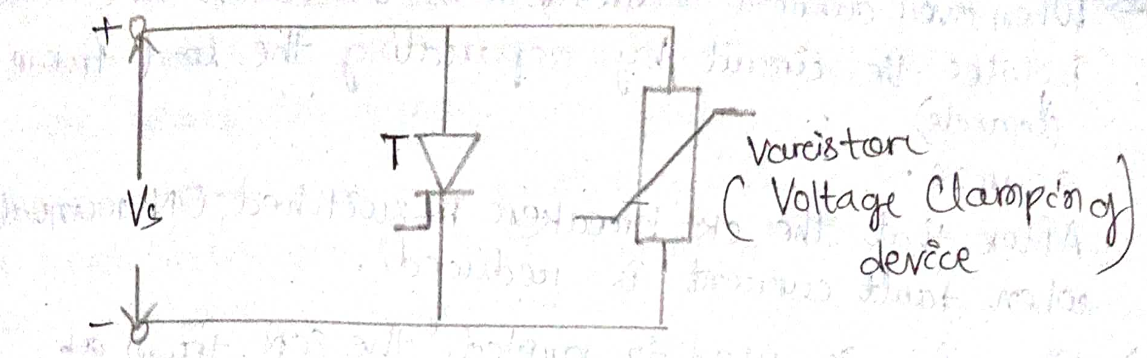
(ii) Snubber ckt is a series combination of resistor & capacitor.

(iii) When sudden change in voltage is often, then a high amount of current is produced, which may damage the thyristor.
The Capacitor act as short ckt due to sudden change voltage & charged upto max^m value.

(iv) With the passages of time the voltage across capacitor build up that protects the SCR from over voltage.

(v) When the capacitor discharges then the discharging current may damage the SCR; due to same direction.
To protect the SCR, a limiting resistance (Rs) is used to reduce discharging current.

Voltage Clampping Device :-



[Varistor : falling resistance with rise in voltage]

(i) fig. shows the basic arrangement of SCR protection by using voltage clamping device.

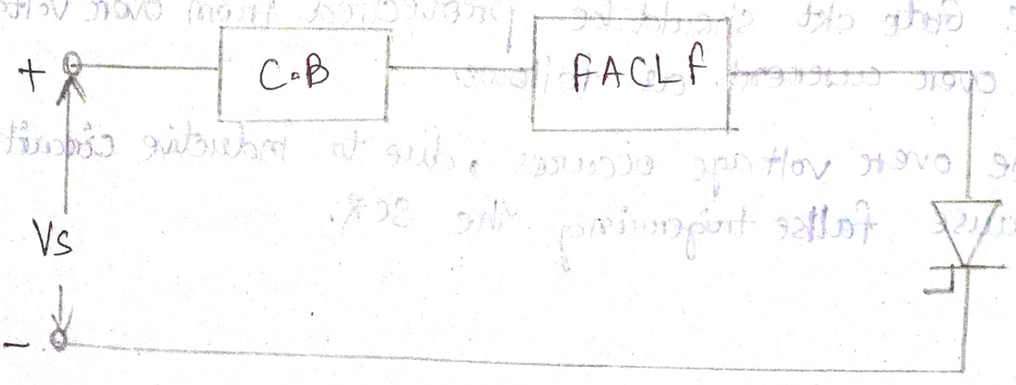
(ii) Voltage clamping ckt is a non-lineare varistore, which has falling resistance characteristics with voltage.

(iii) When high current is ~~A~~ produced due to over voltage, then the varistor changes it's resistance accordingly & excess current flows through the varistore & the SCR is protected.

(b) Over Current Protection :-

(i) The over current is obtained, due to faults in the ckt are due to short ckt.
Due to this over current, the temp. of thyristore increases suddently & it is damaged.

(ii) To protect the SCR from over current, two devices are used i.e,
Circuit Breaker & fast acting current limiting fuse (FACLF).



→ When over current occures, then the circuit breaker isolates (separate) the circuit by separating the load from the source.

After that the ckt breaker is switched ON manually, when fault current is reduced.

→ When fuse is used to protect the SCR from over current, then it melts due to excess heat & isolates the load from the source.

After that the fuse wire is replaced by a new one.

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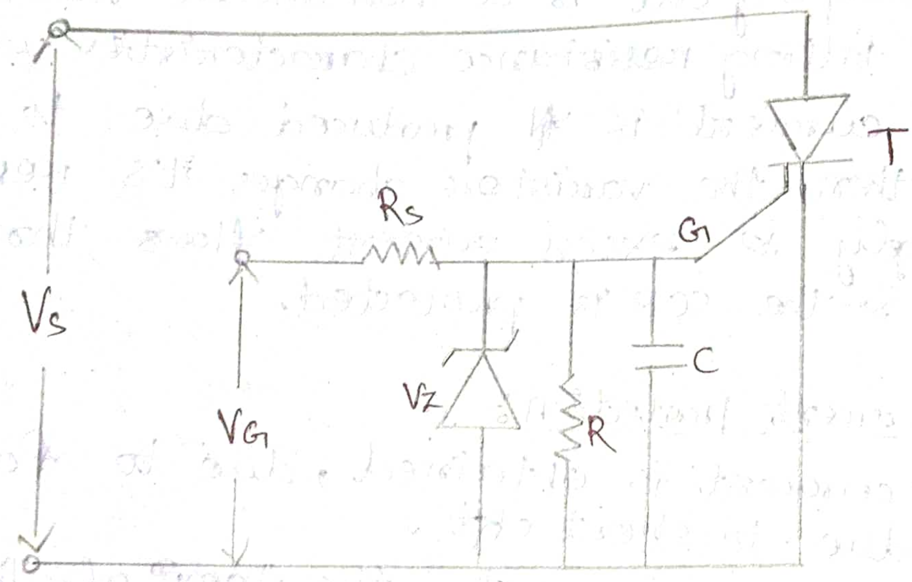
(C) Gate Protection:-



V_S = Supply voltage

R_S = Series resistance

V_G = Gate voltage

V_Z = Zener diode voltage

→ The Gate ckt should be protected from over voltage & over current as follows.

→ The over voltage occures, due to inductive circuit that cause false triggering the SCR.

→ The over current occures due to short ckt that causes rise in junc^n temperature beyond the limit, which leads to damage the SCR.

→ Over voltage can be protected by using a zener diode across Gate terminal, which maintanes a constant voltage even if input voltage is high.

Over current can be reduced by using series resistor (Rs) at the Gate terminal.

→ Sometimes unwanted signal (noise) can cause trigerring of SCR.

Prevent this noise RC filter ckt is used.

[

firing Circuit :-

→ firing means trigerring of SCR by applying Gate voltage.

The application of required Gate voltage at Gate to Cathode terminal is called "firing".

→ The external ckt i.e used to provide Gate voltage for SCR is called firing Circuit.

→ The firing ckt has 2 conditions, such as

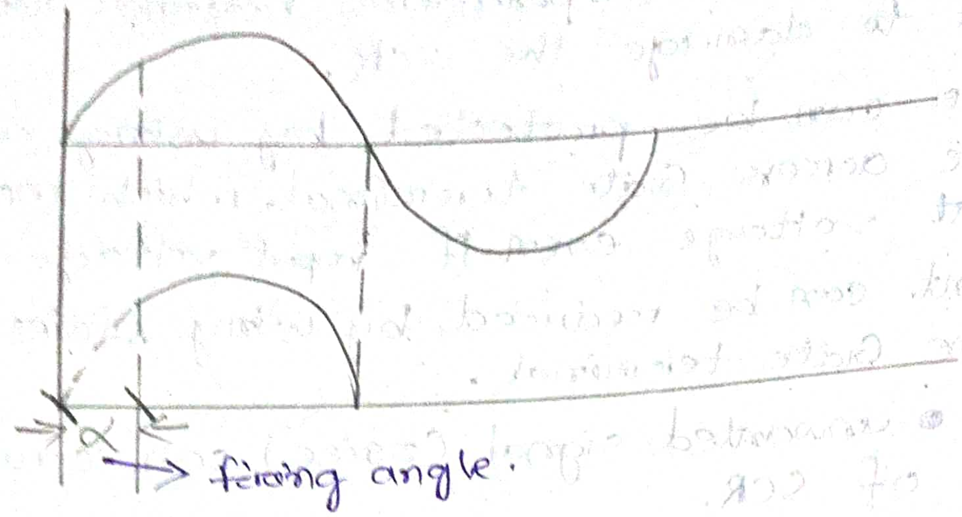
(i) If the power circuit has more than one SCR, then the firing ckt should produce required Gate voltage for each SCR.

(ii) The control signal (Gate signal) generated by the firing ckt should be applicable for the Gate terminal of SCR.

(2 marks) **firing angle :-**

It is the angle bet^n the instant (time), when the SCR starts conducting & the instant, when the SCR Turns ON like a diode.

→ It is denoted by 'α'.

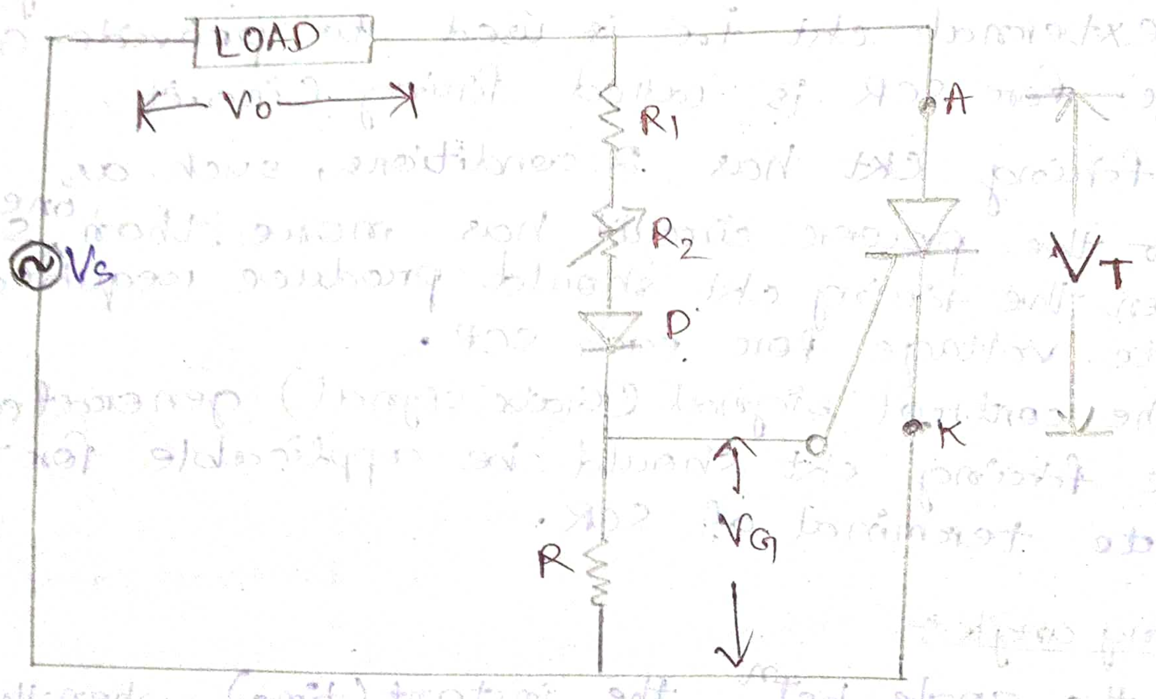


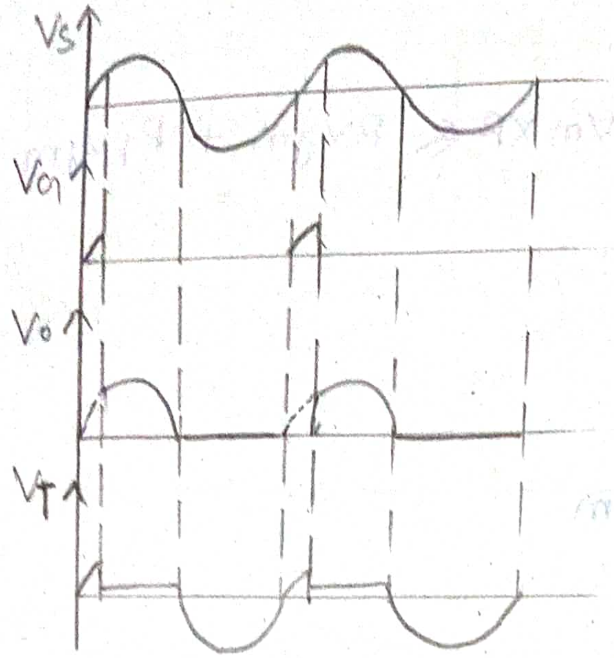
imp **Types of firing or Trigerring Circuit :-**

There are 3 types of firing circuit, such as

(a) R Trigerring.
(b) RC Trigerring.
(c) UJT Trigerring.

(a) **R Trigerring :-**





→ fig shows the basic circuit diagram & wave form of R Triggering or Resistance Triggering.

→ It consists of a variable resistor R_2 that controls the current flows through it & a stabiling resistor R.
R_1 is used for over current protection.

→ If R_2 becomes '0', then the Gate current flows in the path Vs → Load → R1 → D → Gate → Cathode
Therefore this current should not exceed from maximum Gate current i.e Igm.

So, $I_{gm} \geq \frac{V_m}{R_1}$

$\Rightarrow R_1 \geq \frac{V_m}{I_{gm}} \quad \Rightarrow R_1 \geq \frac{V_m}{I_{gm}}$

Here the funcⁿ of R_1 is to limit the Gate current in a ~~shape~~ safe value.

→ During ~~a output 0~~' $R_2 = 0$, the voltage across R should be such that the maxᵐ voltage drop does not ~~exis~~' exceed the maxᵐ gate voltage.

i.e $\frac{V_m \times R}{R + R_1} \leq V_{gm}$ (voltage division rule)

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

$\Rightarrow$ $V_m \times R \leq (R+R_1)V_{gm} \Rightarrow V_m \times R \leq RV_{gm} + R_1 V_{gm}$

$$R \leq \frac{(R+R_1)V_{gm}}{V_m}$$

$\Rightarrow$ $V_m R - V_{gm} R \leq R_1 V_{gm}$

$\Rightarrow$ $R(V_m - V_{gm}) \leq R_1 V_{gm}$

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

→ During positive half cycle of input voltage, the diode become forward biased, so the current flows in the path $V_s \to Load \to R_1 \to R_2 \to D \to R \to V_s$.

→ Here the voltage drop across 'R' will provide necessary Gate voltage for SCR.

So, SCR will turn ON & the current will flow in the path $V_s \to Load \to T \to V_s$.

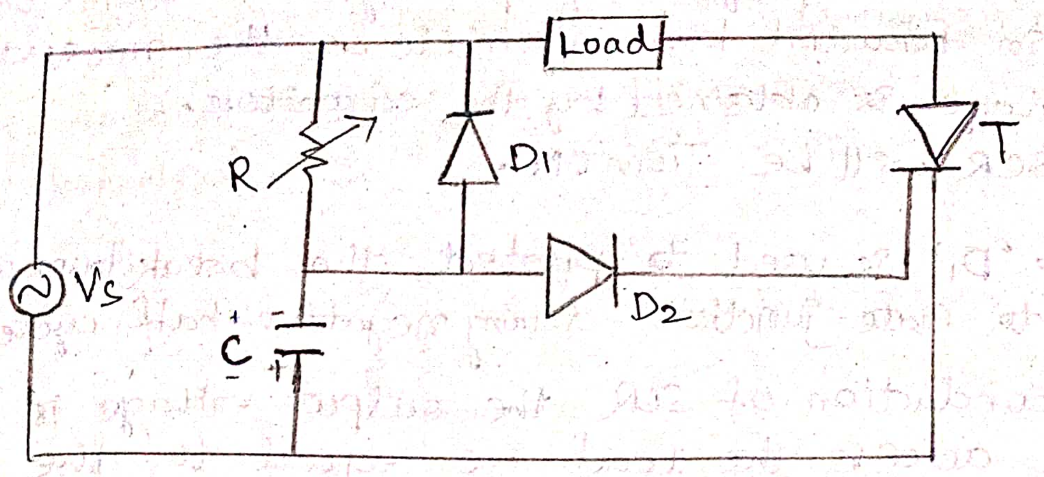
→ During negative half cycle of input signal, the diode becomes reversed biased & the SCR will be in reverse blocking mode. So, SCR acts like an open circuit.

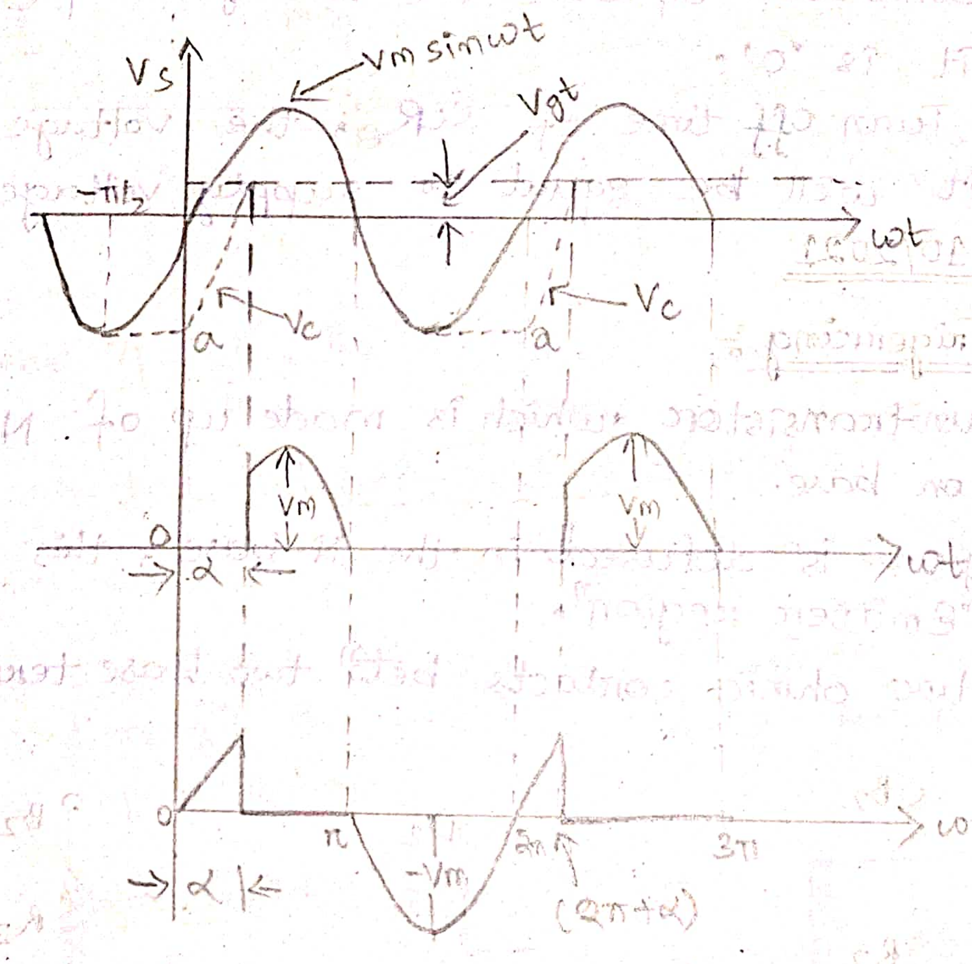
So, The voltage across load will be '0'.

→ The voltage across thyristor becomes '0', during conduction time & the voltage across SCR will same as input voltage during Turn OFF time.

→ In 'R' triggering the firing angle can be varied betn 0° to 90°.

(b) RC Triggering :





→ fig shows the ckt diagram & wave form of R-C triggering.
Here the firing angle can be varied from 0° to 180°.

→ In negative half cycle of input signal, the capacitor is being charged upto max^{m} value.
So, the diode After that the capacitor starts discharging through the diode 'D2'.

→ During positive half cycle of input signal ; Thyristor will be in forward blocking mode & the necessary Gate voltage is obtained by the capacitor.
So, the SCR will be Turn ON.

→ The diode 'D₁' is used to protect the breakdown of Cathode to Gate junction during negative half cycle.

→ During conduction of SCR the output voltage is obtained across the Load i.e equal to the supply voltage.

→ During conduction of SCR the voltage drop (V_T) across it is '0'.
During Turn off time of SCR, the voltage drop across it will be equal to supply voltage.

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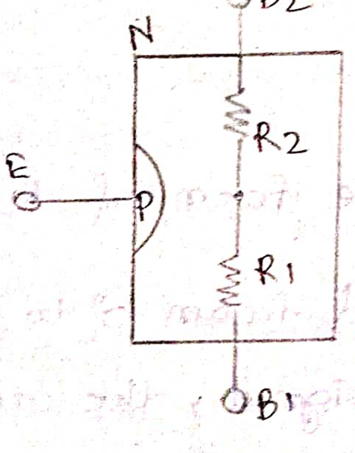
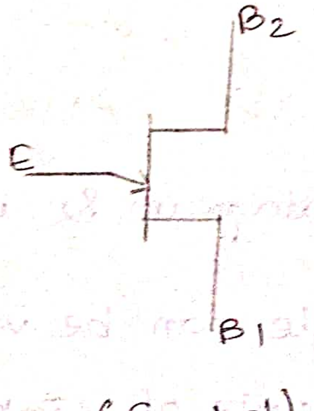
(c) UJT Triggering :-

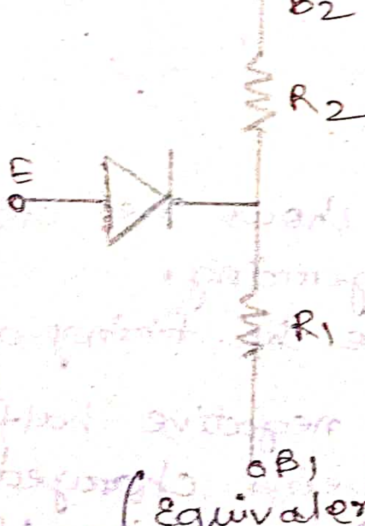
→ It is a unitransistor which is made up of N-type semi silicon base.
The P-region is defused in the N-base, this P-region is called "Emitter region".

→ There is two ohmic contacts betⁿ two base terminals.





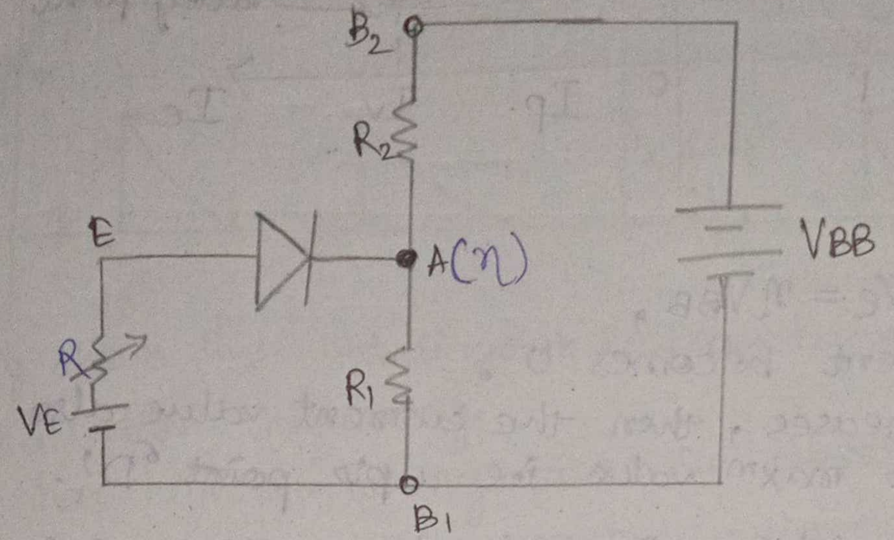
(Symbol)



(Equivalent Circuit)

→ During operation of UJT a voltage V_{BB} is applied betn two base terminal with B_2 higher potential.

→ The emitter terminal is made positive with respect to B_1 terminal for the another supply.



(i) The voltage across R_1 is given by, $V_{R_1} = \frac{V_{BB} \times R_1}{R_1 + R_2}$

$= V_{BB} \cdot \eta$

Where $\eta = \frac{R_1}{R_1 + R_2}$ &

is called intrinsic stand of ratio. → 2mark

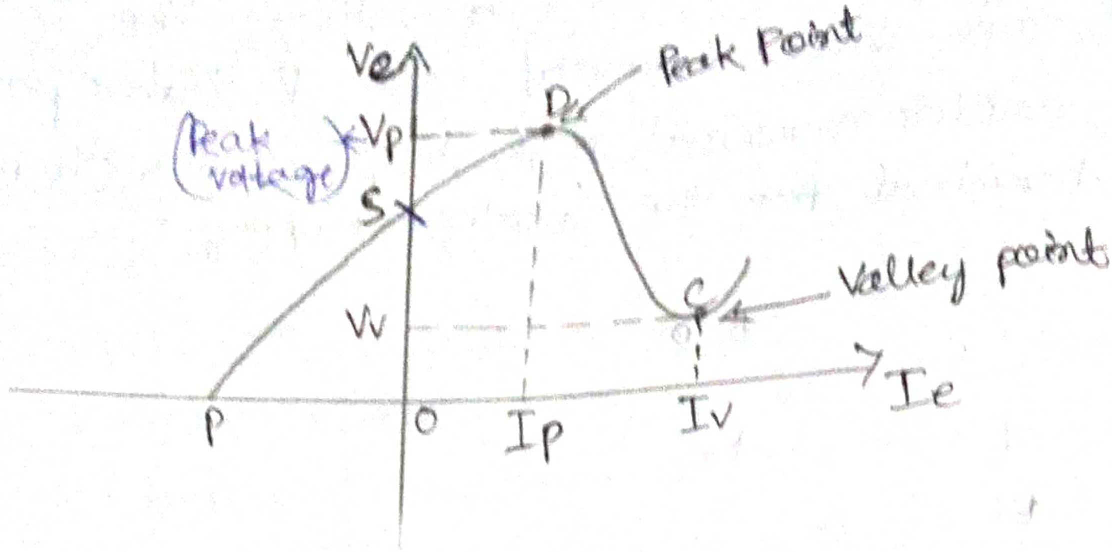
The value of η lies betn 0.51 to 0.82.

(ii) When the input voltage V_E is given, then current flows through the juncn & voltage drop is obtain across R_1 resistor.

V.I characteristics of UJT:-

(i) fig. shows the input characteristics of UJT. The voltage V_e is varied by regulating the external resistance 'R'.

(ii) When $V_e < \eta V_{BB}$ then the emitter & B_1 junction become reversed biased, So negative current (reverse leakage current) flows through the juncn, i.e indicated by 'p' to 's' region.



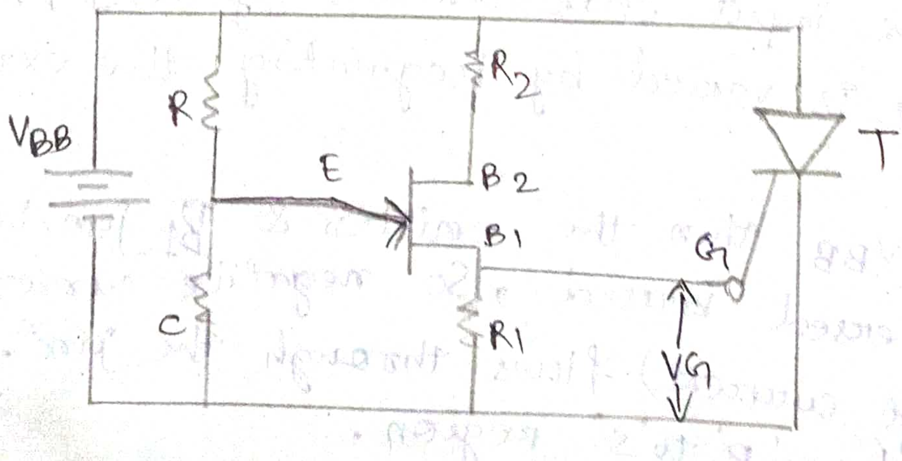
(iii) At point 'S' $Ve = \eta V_{BB}$,
So the current becomes '0'.
When Ve increases, then the current value also increases upto max^m value i.e upto point 'D'.

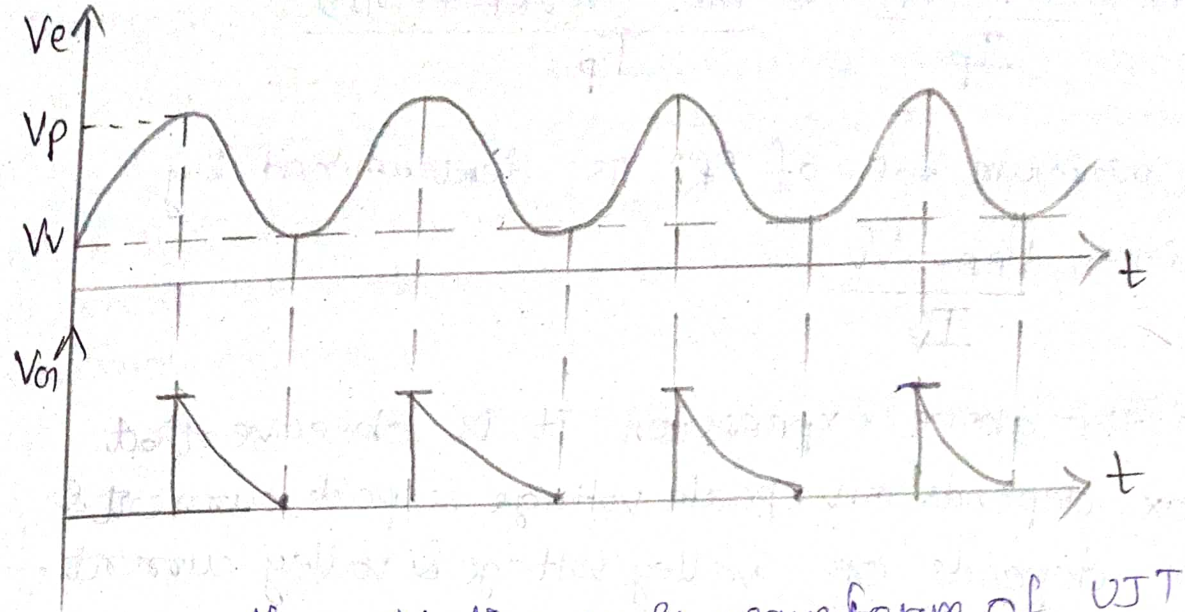
(iv) At this peak point (max^m point) the emitter region injects holes towards B_1 terminal.
So, the resistance of EB_1 terminal decreases & voltage drop across 'R_1' also decreases with increase in current.
This shows negative resistance region.

(v) At point 'C' the value of voltage & current is minimum & is called "Valley voltage" & "Valley current".

(vi) After valley point the current value increases lightely with increase in voltage & cut-off region occures.

<u>UJT Oscillation trigerring</u> :-





→ fig shows the ckt diagram & waveform of UJT oscillation triggering.
It has high switching time, i.e about in nanosecond(10^{-9})
→ Since UJT exhibites negative resistance characteristics, so it is used as a relaxation oscillator by using R & C.
→ In the ckt external resistances R_1 & R_2 are small as compare to Internal resistances of UJT.
→ When V_{BB} is applied, the capacitor begins to charge through resistance 'R' exponentially.
During charging period, the emitter ckt of UJT remain open due to ηV_{BB}.
The capacitor charges upto max^m voltage i.e equal to emitter voltage.

$V_C = V_E = V_{BB}\left(1 - e^{-\frac{t}{RC}}\right)$ (RC = time constant)

→ When the emitter voltage reaches to peak point, then the junc^n EB_1 breaks down & UJT will turn ON.
So, the capacitor discharges through UJT suddently.
Therefore a voltage drop is obtain across resistance 'R_1'.
→ When the voltage drop at R_1 is equal to Gate voltage of SCR, then the SCR will turn ON.
→ The max^m value of 'R' is determined by

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

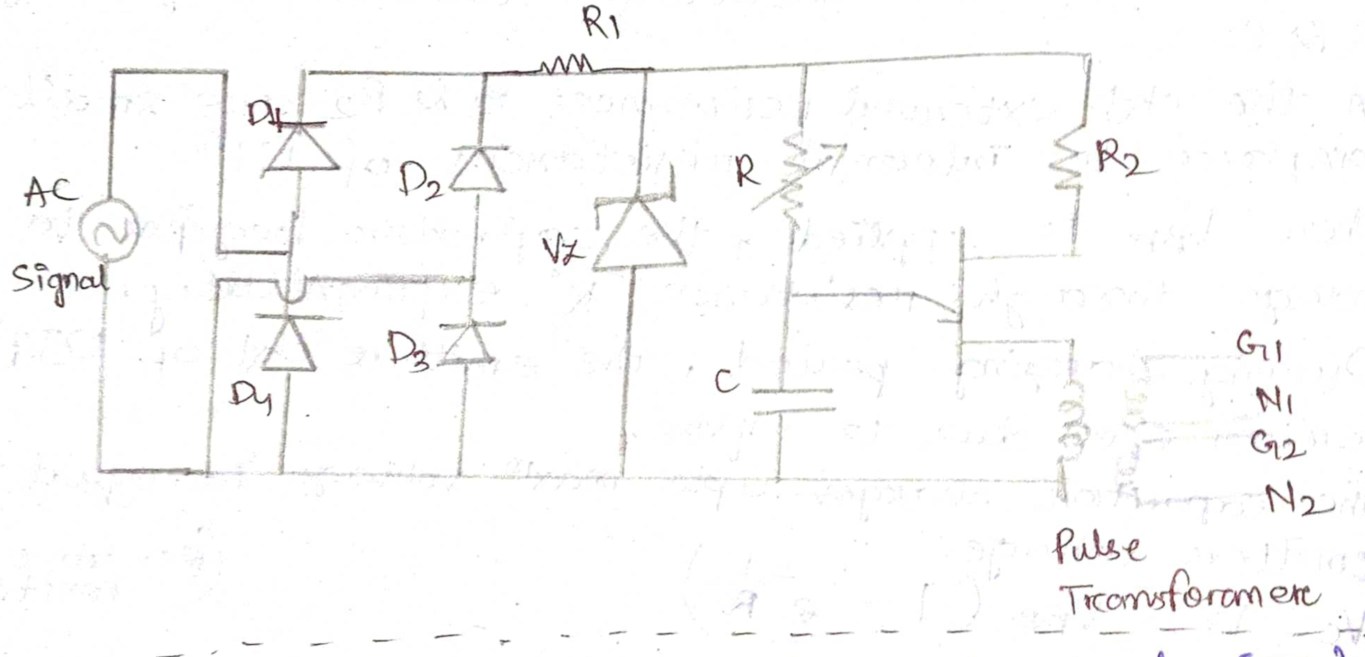
The minimum value of 'R' is determined by

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

→ from the above expression it is observe that R_{max} depends on peak voltage & peak current & R_{min} depends on valley voltage & valley current.

Date :- 28/10/2021

Ramp triggering :-



Pulse Transformer - in output it creates pulse signal. (⎍)
- It has more than one winding in secondary.

(i) fig shows the basic circuit diagram of ramp triggering for SCR.
It consists of a bridge rectifier circuit, a current limiting resistance (R_1), zener diode, capacitor & UJT & pulse transformer.

(ii) The input ac signal is given to the bridge circuit & a dc signal is obtained across the zener diode.

The zenere diode maintaines a constant voltage (V_Z).

(iii) The zener voltage (V_Z) is applied to the RC circuit. So, the capacitor starts charging upto maximum value.

(iv) When the capacitore discharges, then the discharging current flows thowards UJT & the EB_1 juncn becomes forward biased

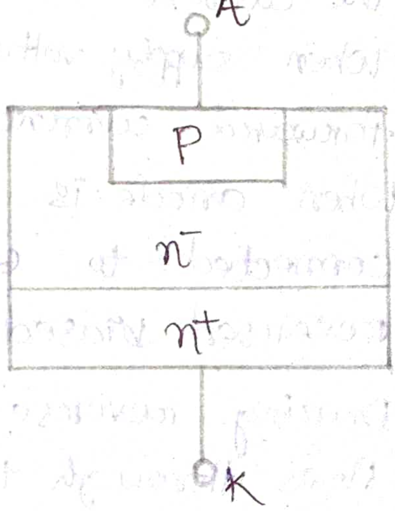
(v) The UJT provide necessary primary voltage for the pulse transformer.
The output of pulse transformer is obtained across secondary windings due to mutual induction.

(vi) As the secondary windings of pulse transformer have different turn, So different output voltages are obtained
The output of secondary windings are given to differen Gate terminal of SCRs & the SCRs will be trigerered.

(vii) Here the rate of rise of capacitive voltage depends on resistor (R).
The firing angle can be controlled upto $150°$

Power diode :-

(i) Power diodes are suitable for high voltage & high current appliances.



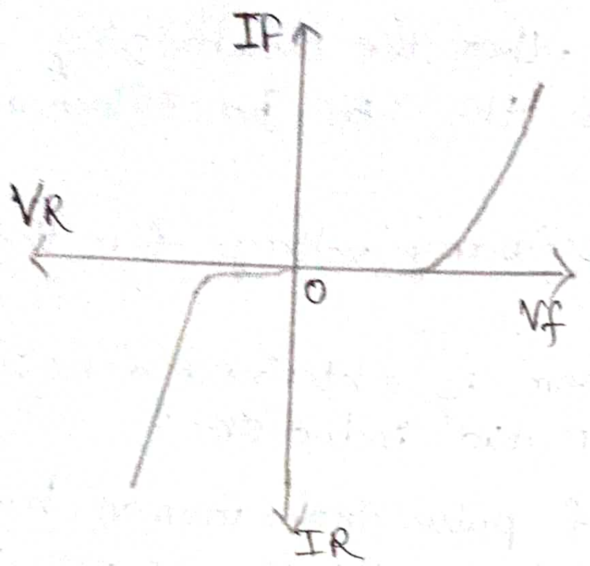
(ii) It consists of heavily doped n^+ substrate (Base).
On this substrate a ligthly doped n^- layer is epitaxially grown.

(iii) The function of n^- layer is to absorbs the depletion layer, during reversed biased condition.

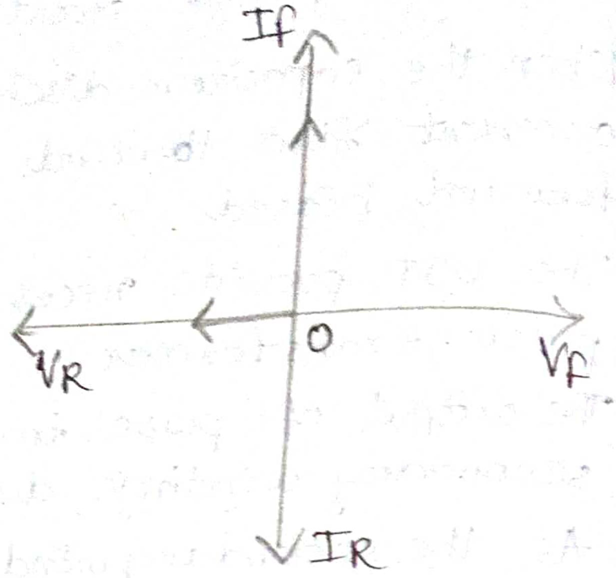
(iv) The drawback of n^- layer is to add ohmic resistance to the diode during forward biased.
It leads to large power dissipation (radiation).
So, proper cooling arrangement is given to protect from

thermal runaway.

V-I Characteristics :-



(for practical diode)



(for ideal diode)

(i) fig shows the V-I characteristics of practical & ideal power diode.

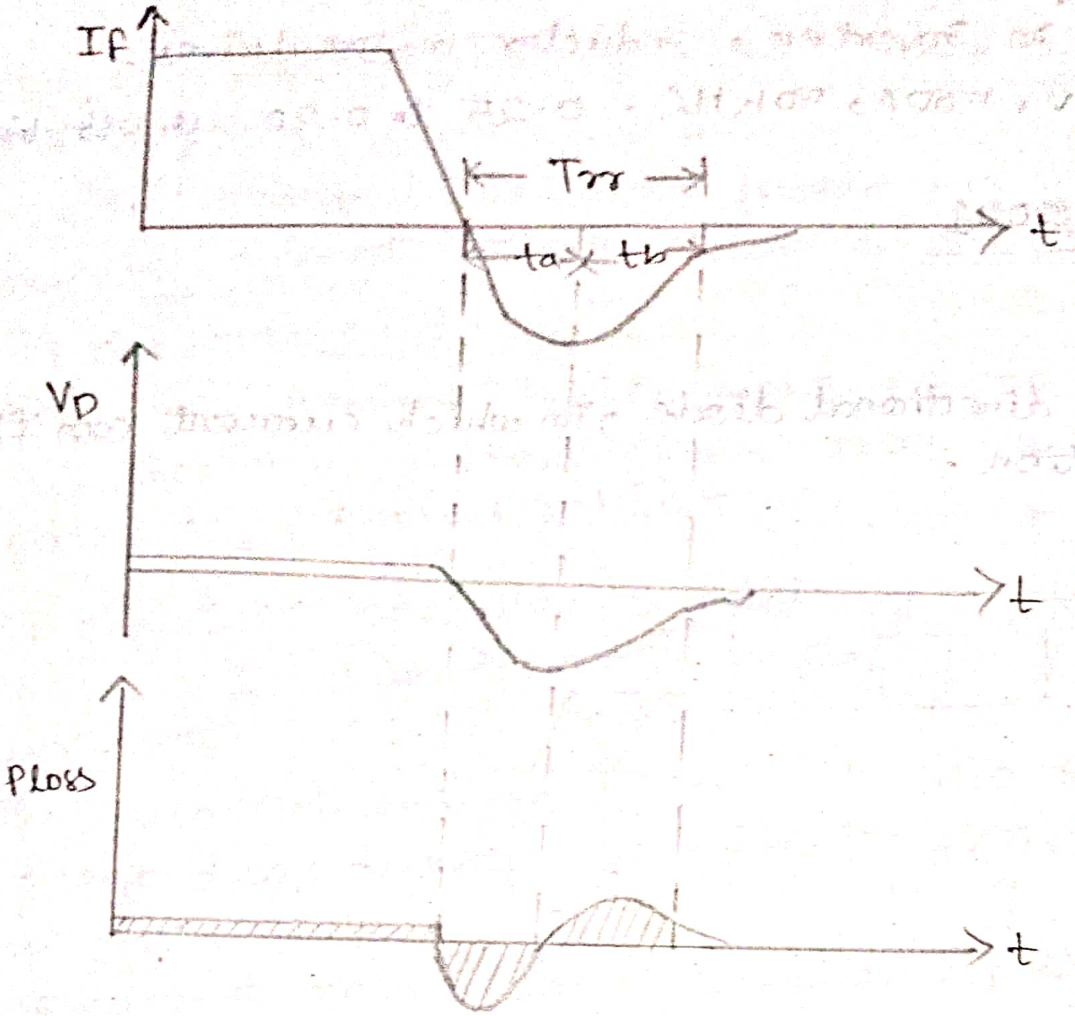
(ii) When the diode is forward biased i.e anode is connected to (+)ve & ~~pos~~ cathode is connected to negative then the current will flow after barriere voltage.

(iii) When the source voltage remains below the knee voltage, the current remains '0'.
When supply voltage exceeds threshold voltage, then forward current flows through the diode.

(iv) When anode is connected to negative & cathode is connected to ~~cat~~ positive, then the diode becomes reversed biased.

(v) During reverse biasing, a reverse leakage current flows through the junc^n due minority charge carrier. The range of reverse current is in microampere.

Diode reverse recovery characteristics :-



→ fig shows the waveform of switching characteristics after the forward current decays to '0', the diode conducts in reverse direction.
The reverse current flows for a time period called as reverse recovery time 'Trr'.

→ The Reverse recovery time is defined as the time betn the instant forward current becomes '0' & the instant reverse recovery current delays to 25% of its reverse phase value.

→ 'Trr' consists of 'ta' & 'tb'. The ratio of ta & tb is called softness factor or s-factor i.e

$$S\text{-factor} = \frac{t_a}{t_b}$$

→ It is used in UPS system, power supplies & devices for relays & contractors.

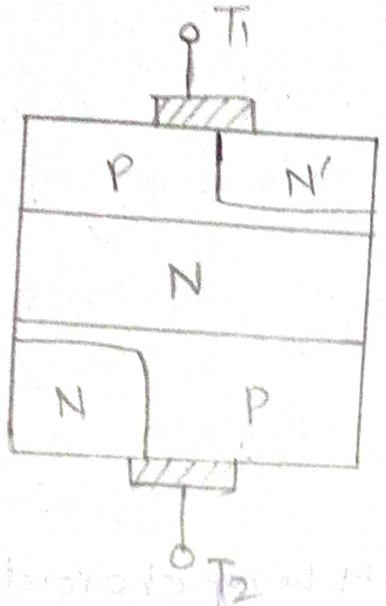
→ It is used in inverter, inductor motor drives.

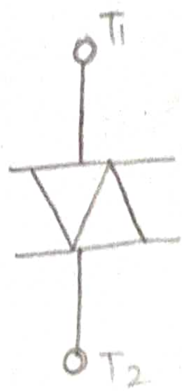
Rating : 1200V, 500A, 50KHZ, 0.25 to 0.20 μs off time.

Date :- 30/10/2021

DIAC

→ It is a bi-directional diode, in which current can flow in both direction.





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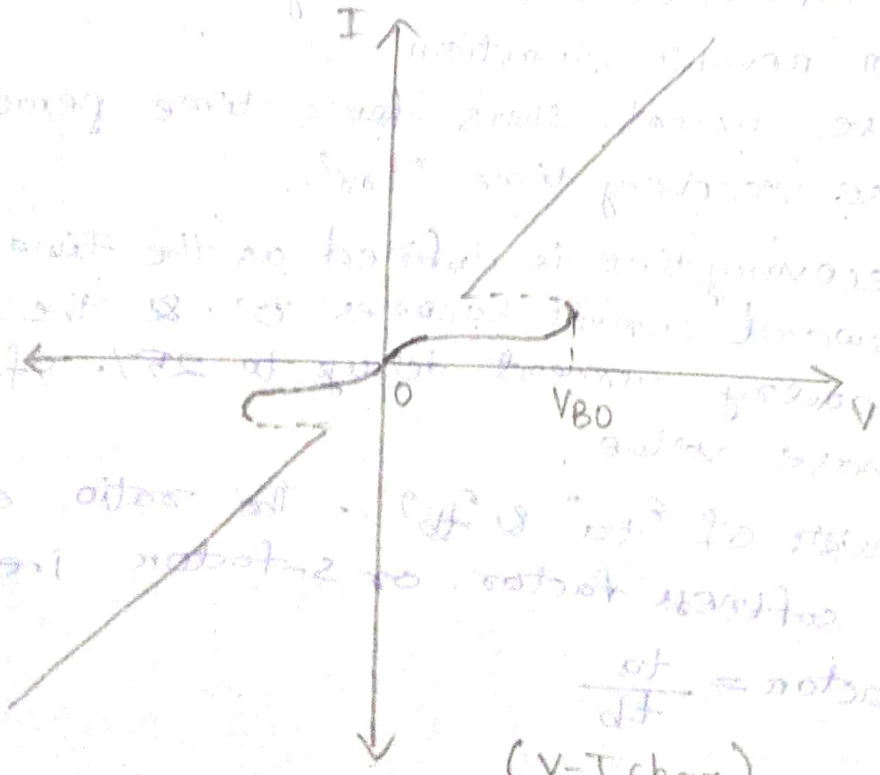


(V-I char)

(i) fig shows the cross- sectional view, symbol, V·I- characteristics of DIAC.

DIAC is a electronic device which works on AC supply in both direction.

(ii) When the terminal 'T1' is made positive w.r.t terminal 'T2' then the current flows from T1 to T2 in the path.

T1 → P → N → P → N → T2.

(iii) When the terminal 'T2' is more positive than terminal T1, then the current flows from T2 to T1 in the path, T2 → P → N → P → N' → T1.

(iv) As the DIAC operates symmetrically in both direction, So the V·I characteristics is similar in 1st & 3rd quadrant.

(v) The turn ON voltage of DIAC is about 40V & the voltage drop during conduction is about 3V, due to low resistance.

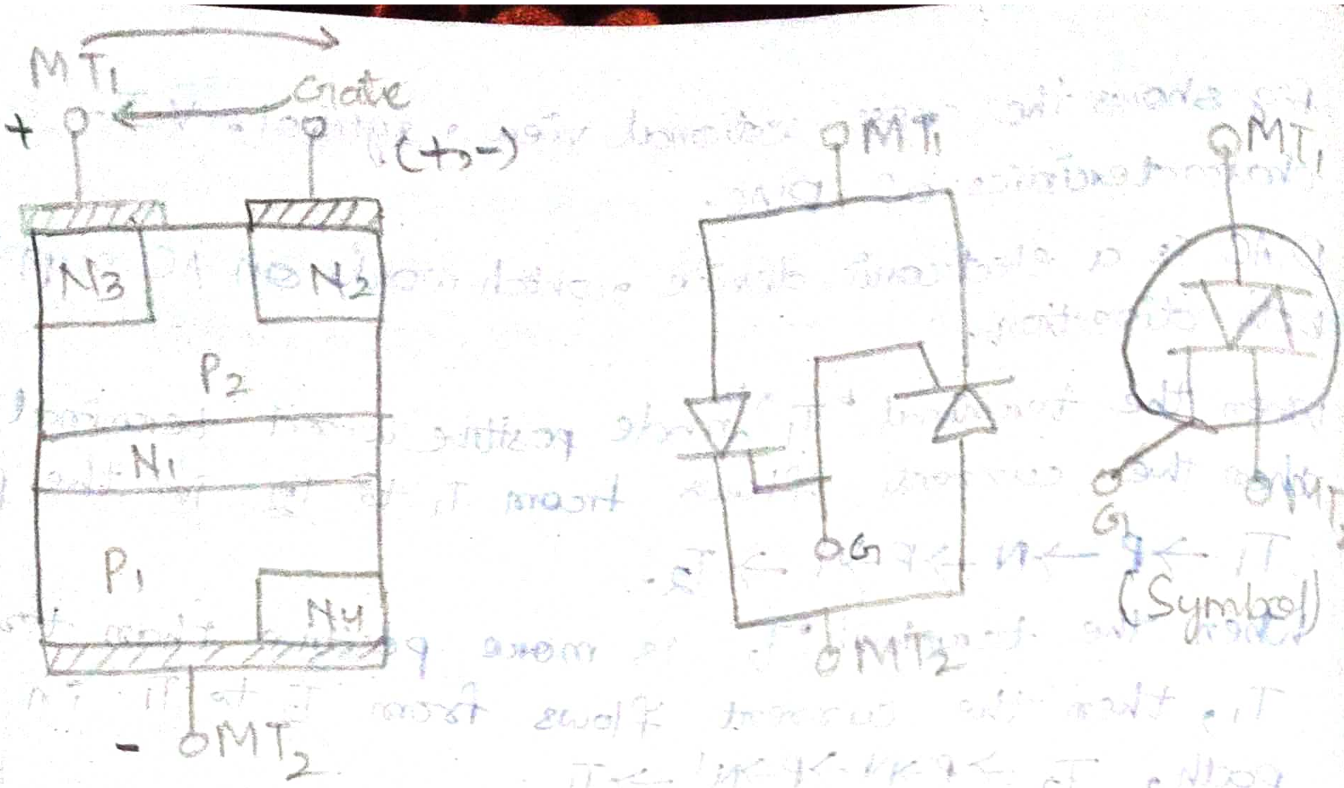
(vi) The current rating during breakover point is about 50 to 200 μA.

(vii) It acts like a close switch, during turn ON & an open switch during turn OFF.

(viii) It is used to trigerred the TRIAC basically, to reduce harmonic signal during switching operatio

TRIAC:-

(i) TRIAC is an electronic device i.e operated as a TRIODE = triode is AC.



(i) figure shows basic cross-sectional view, two SCR-analogy & symbol of TRIAC.

(ii) It has 3 terminals named as MT_1 & MT_2 & Gate.

(iii) It is used for the control of power in AC circuit & can be used as a switch.

Operation :- (Long question - 10 mark)

(1) The operation of TRIAC is divided into 4 catagorey

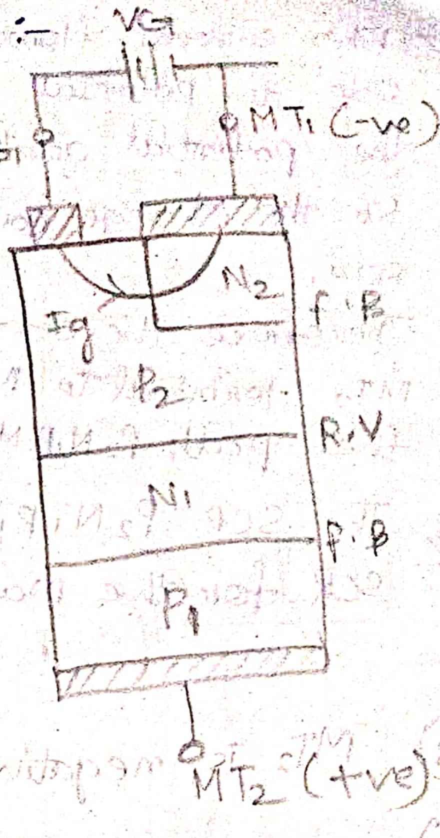
Such as :- (a) MT_2 is positive, MT_1 is negative, Gate is positive

(b) MT_2 is positive, MT_1 is negative & Gate is negative.

(c) MT_1 positive, MT_2 negative & Gate negative

(d) MT_1 ~~negative~~ positive, MT_2 ~~positive~~ neg & Gate positive

(a) MT_2 (+)ve, MT_1 is (-)ve & Gate is (+)ve :-



(i) In this mode of operation MT_2 terminal is made (+)ve w.r.t MT_1 & (+)ve Gate supply is given w.r.t MT_1.

(ii) When Gate supply is absent, then the junc^n P_1N_1 & P_2N_2 are forward biased.
The junction P_2N_1 becomes reverse biased.
So, the main current can't flow bet^n main terminals.

(iii) When (+)ve Gate voltage is given, then the electrons present in N_2 region are repeled by negative terminal & move towards Gate terminal.
So, a Gate current (I_g) flows bet^n Gate & MT_1 terminal.

(iv) When Gate voltage increases, then the e⁻s present in N_2 layer are injected towards P_2N_1 junction.
So, junction breakdown occures.

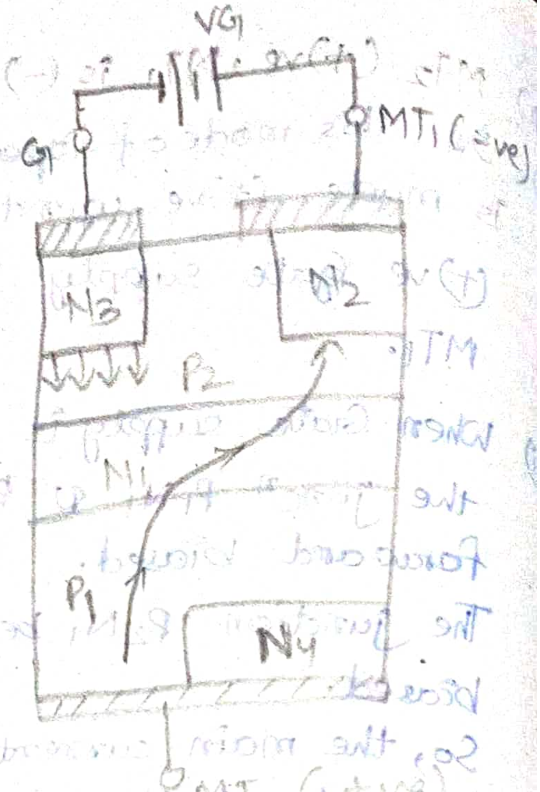
(v) Therefore, the main current will flow from M_2 to M_1 in the path $MT_2 \to P_1 \to N_1 \to P_2 \to N_2 \to MT_1$.

(b) MT_2 is (+)ve, MT_1 is (-)ve & Gate is (-)ve :-

(i) Here MT_2 is positive with respect to MT_1 & Gate is negative with respect to MT_1.

(ii) Due to -ve gate voltage P_1N_3 junction becomes forward biased.
So, this junc^n breaks down & the e⁻s move towards MT_2 terminal.
Therefore the current which flow from MT_2 to gate terminal through the path $P_2N_1P_1N_3$.

→ When current flows in left half side. Its potential decreases; so the potential gradient is obtained. So the charge carrier present in side.

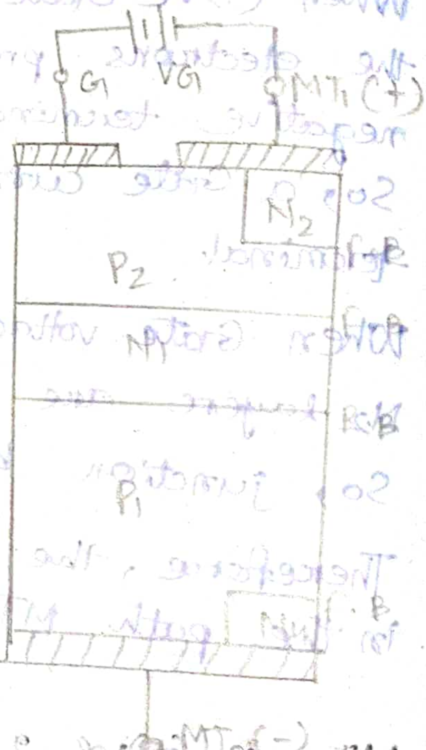


Therefore the current will flow from MT_2 terminal to MT_1 terminal in the path $P_2N_1P_1N_2$ → ($P_1N_1P_2N_2$).

→ The SCR $P_2N_1P_1N_3$ acts as a pilot SCR for the main SCR $P_2N_1P_1N_2$ → ($P_1N_1P_2N_3$) ($P_1N_1P_2N_2$)

(3) MT_2 is negative & gate current is (+)ve.

(i) In this condition MT_1 is positive w.r.t MT_2 & gate terminal is positive w.r.t MT_1.



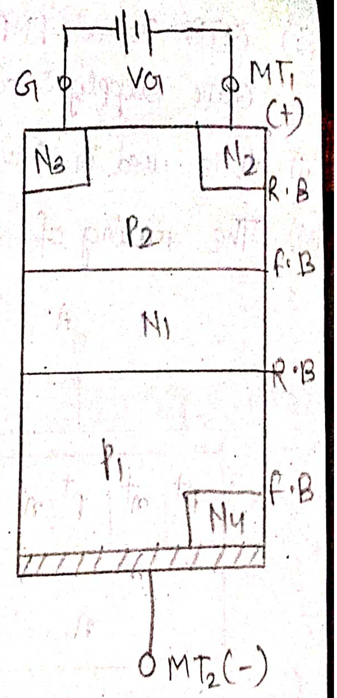
(ii) When gate supply is absent then the junc^n (P_1N_1) is reversed biased & othere junc^{n}s are forward biased. So, normal current can not flow bet^n (MT_1 & MT_2).

(iii) When +ve gate supply is given then the junc^n (P_2N_2) becomes forward biased. So, the e⁻s present in N_2 are repelled by the -ve terminal of gate voltage. So, a gate current flows bet^n (MT_1) & (G) terminal. After sometime e⁻s present in 'N_2' layer are injected towards (P_1N_1) junc^n & this junc^n breakdown.

(iv) Therefore, the normal current flows bet^n MT_1 & MT_2 in the path ($P_2N_1P_1N_4$)

4. MT_2 is negative & gate is negative:-

(i) In this condition MT_1 is (+)ve w.r.t MT_2 & gate terminal is (-)ve w.r.t MT_1.



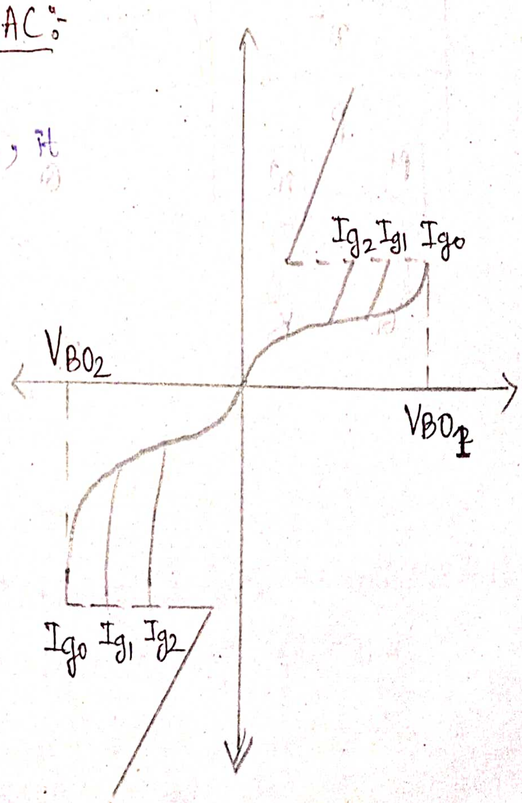
(ii) When gate supply is absent then the junc^n (P_1N_1) is reverse biased & other junctions are forward biased. So, normal current can't flow bet^n (MT_1 & MT_2).

(iii) When (-)ve gate supply is given then the junc^n (P_2N_3) becomes forward biased. So, the e⁻s present in N_3 are repelled by the (-)ve terminal of gate voltage. So, a gate current flows bet^n (MT_1 & G) terminal. After sometime e⁻s present in 'N_3' layer are injected towards (P_1N_1) junc^n & this junc^n breakdowns.

(iv) Therefore the normal current flows bet^n MT_1 & MT_2 in the path ($P_2N_1P_1N_4$).

V.I characteristics of TRIAC:-

(i) During operation of TRIAC, it is more sensitive in 1st & 3rd quadrant. So, the V-I characteristics is obtained in these quadrant.



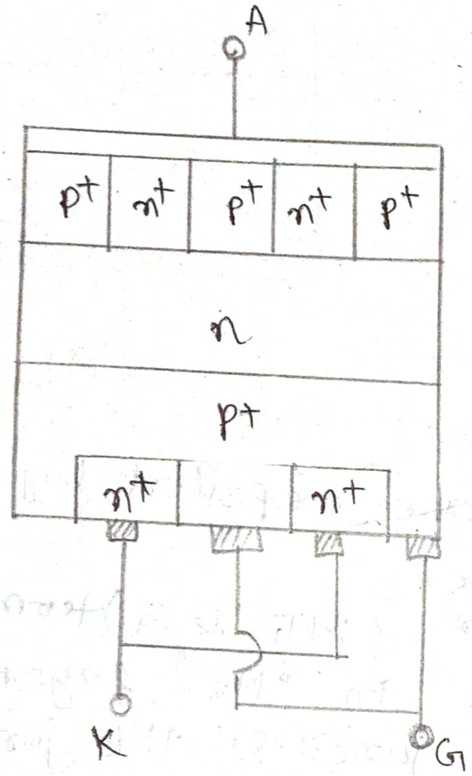
GTO (Gate Turn Off Thyristor)

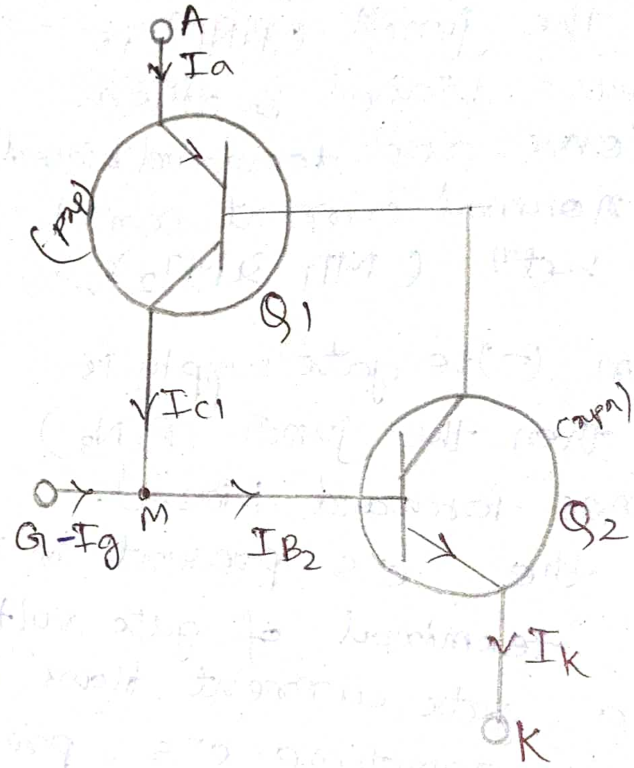
Date:- 02/11/2021

(i) GTO is a PNPN device, that can be turn ON by (+)ve Gate supply & can be turn off by (-)ve Gate supply.

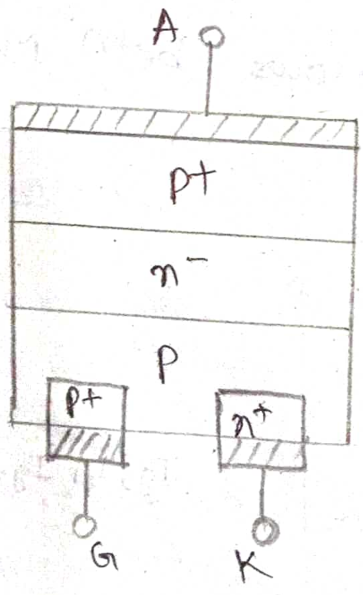
(ii) It is used in inverter, inductor, motor drives.

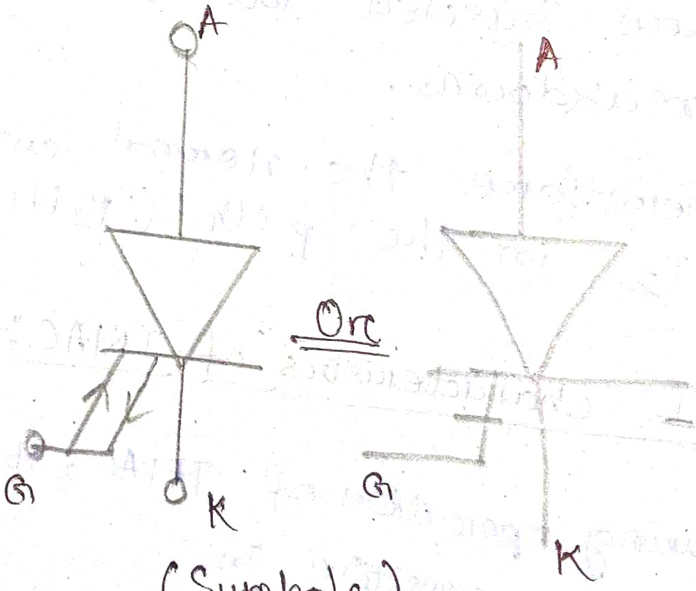
(iii) The rating of GTO is 1200V, 200Ampere.





Or





(Symbole)

Turn ON Process:-

(*) GTO is turned on by applying (+)ve Gate supply in reference direction.
When GTO is forward biased, then current flows through it like SCR.

Turn Off Process:-

→ When negative Gate supply is given at Gate terminal w.r.t cathode, then the SCR will turned Off.

→ In common Base configuration,

$I_{C1} = \alpha_1 I_{E1}$

$I_{C2} = \alpha_2 I_{E2}$

Applying KCL at node 'M', we get $I_{C1} - I_g - I_{B2} = 0$

$I_{B2} = I_{C1} - I_g$

$I_{B2} = \alpha_1 I_{E1} - \alpha_2 I_{E2}$

$$\boxed{I_{B2} = \alpha_1 I_a - I_g}$$

$I_{E1} = I_a$ = Anode current

We know that $I_a = I_{C1} + I_{C2}$

$I_{C2} = I_a - I_{C1}$

$I_{C2} = I_a - \alpha_1 I_{E1}$

$I_{C2} = I_a - \alpha_1 I_a$

$$\boxed{I_{C2} = I_a(1-\alpha_1)}$$

$I_K = I_{B2} + I_{C2}$

$I_K = \alpha_1 I_a - I_g + I_a(1-\alpha_1)$

$I_K = I_a(\alpha_1 + 1 - \alpha_1) - I_g$

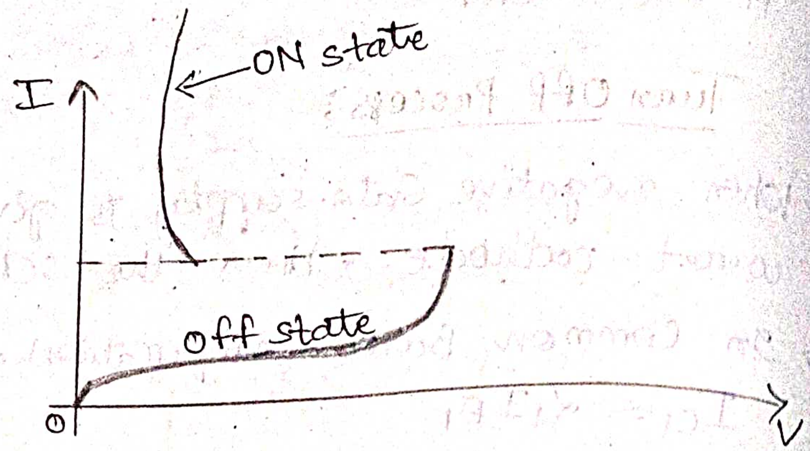
$$\boxed{I_K = I_a - I_g}$$

→ When negative Gate current flows at Gate terminal, then it will reduce the resultant Base current for the transistor Q_2.

Thereforce the transistore 'Q_2' moves towards cut-off region.

→ In this way GTO is turned off by applying negative Gate supply.

V.I characteristics :-



Advantages:-

(i) It has high switching characteristics.

(ii) It has less weight & size.

(iii) Here commutation is not required, so the ckt is simple.

(iv) It has less maintainance.

(v) The blocking voltage capacity is high as compare to SCR.

(vi) $\frac{di}{dt}$ rating is high at turn ON.

(vii) Efficiency is high.

Disadvantages:-

(i) It has more ON state voltage drop, so more loss occures.

(ii) The Gate trigerring current has high value as compare to SCR.

(iii) The Latching & holding current value is high as compare to SCR.

The Latching current is about 2A, but in SCR current is is 100mA to 500mA.

Application :-

(i) It is used in inverters, choppers, AC drives, dc drives, dc ckt breaker, static VAR compensation.

Date :- 09/11/2021

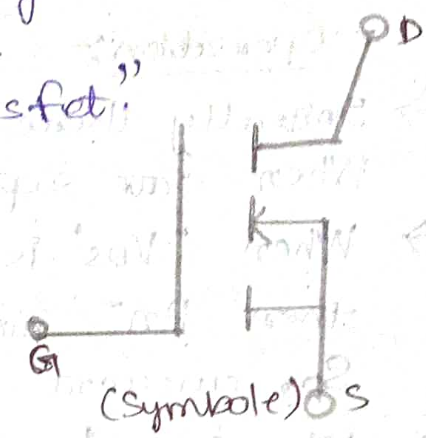
Power Mosfet :

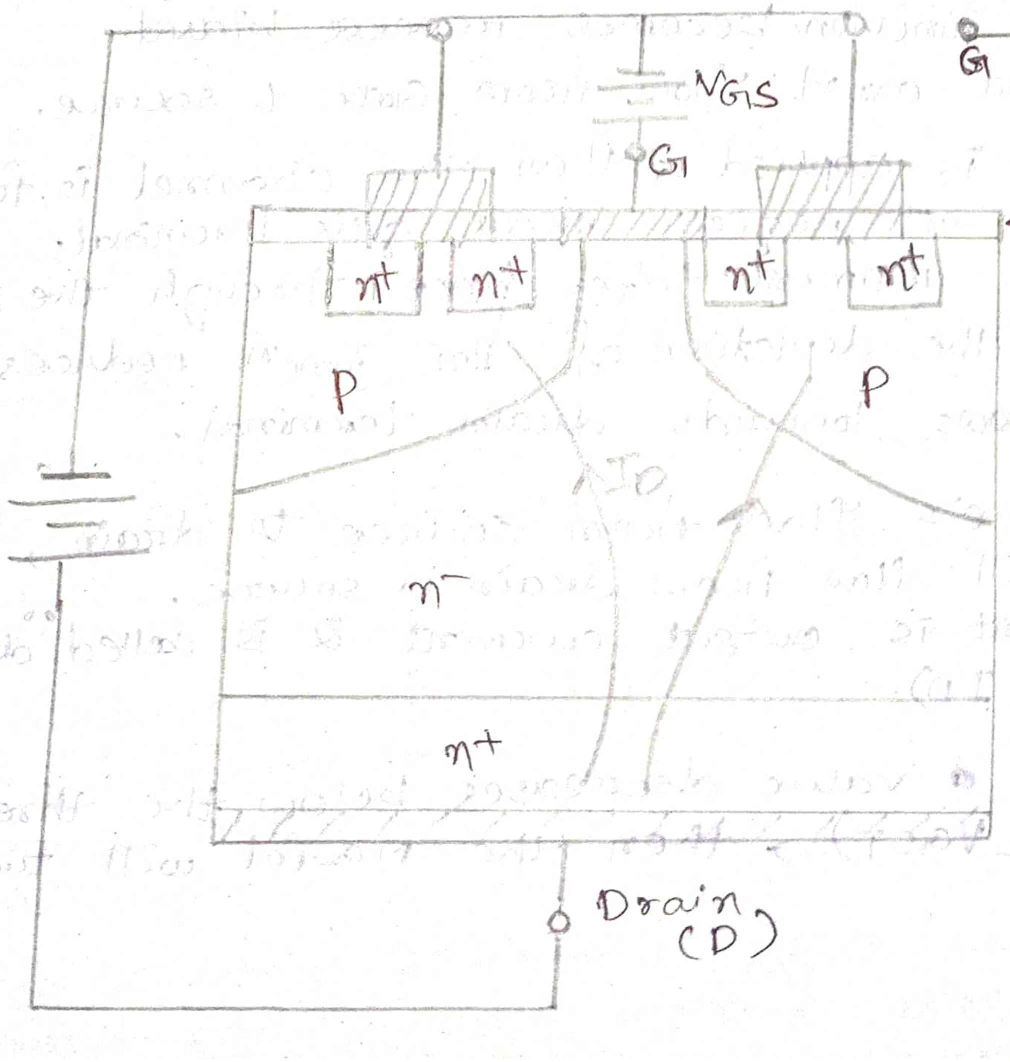
→ A Power Mosfet has 3 terminals i.e Drain (D), Source (S) & Gate (G).

→ It is a voltage controlled device that means the output current depends on input voltage.

→ It is also a unipolar device that means current conduction occurs due to one charge carrier. (i.e either e⁻s or holes).

→ Power Mosfet is of 2 types according to channel formation, such as "p channel Mosfet" & "N channel Mosfet."





Construction :-

→ figure shows the basic structure of N-channel Mosfet. Here 'n^+' substrate is taken & n^- layer is epitaxially. The thickness of n^- layer determines the voltage blocking capability of the device.

→ A metal layer is connected to n^+ substrate to form the drain terminal.

→ P region is defused to n^- layer & then n^+ layer is defused to P layer.

→ An insulating layer of SiO_2 is provided on the surface at which metal contacts are given & source terminal & Gate terminal is formed.

Operation :-

→ Initially there was no channel betn source & drain. When gate supply is given then the channel is formed.

→ When 'V_{DS}' is applied in absence of gate voltage, then Pn^- junction becomes reverse biased. So, current can't flow from Gate to source.

→ When 'V_{GS}' is applied, then the channel is formed betn two n^+ region near gate terminal. So, electron moment takes place through the channel. Therefore, the depletion of Pn^- juncn reduces. & electron flows towards drain terminal.

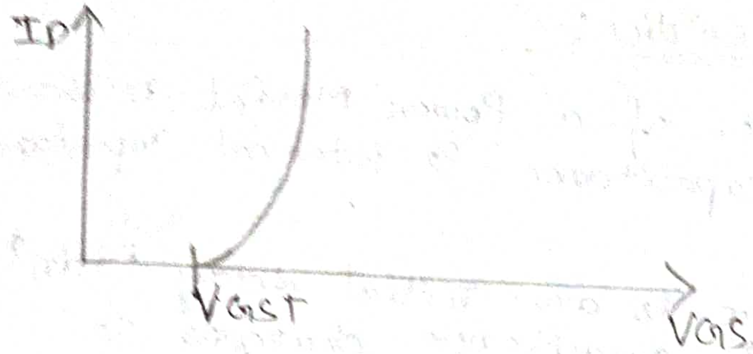
→ When the e^-s flows from source to drain, then the current will flow from drain to source. This current is output current & is called "drain-current" (I_D).

→ When V_{GS} value decreases below the threshold voltage (V_{GST}), then the Mosfet will turn off.

Mosfet Characteristics :-

The characteristics has 2 categories,
Such as → (I) Transfer characteristics (Input characteristics)
(II) Drain characteristics (Output characteristics)

Transfer characteristics :-

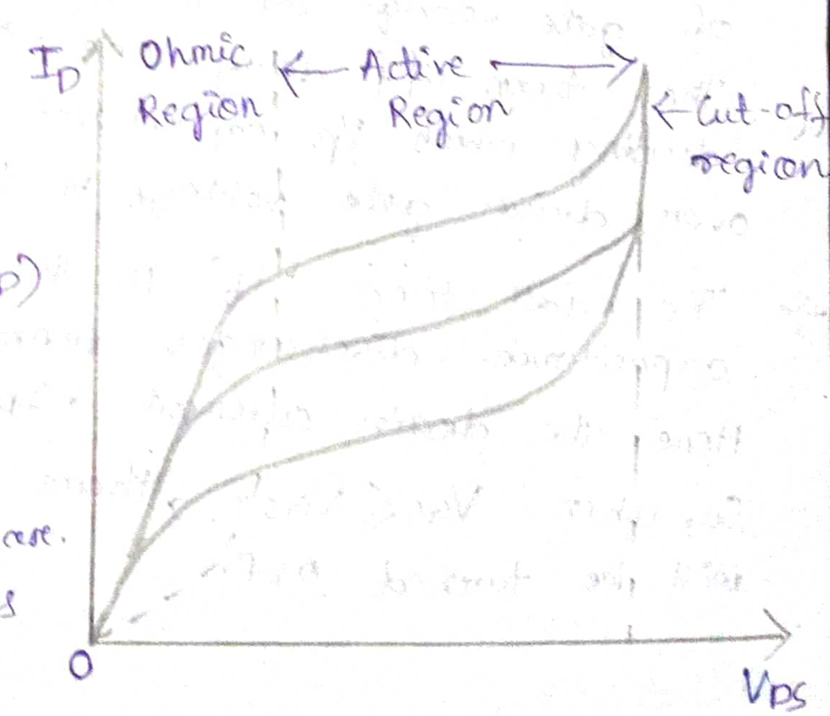


→ This characteristics has the relationship betn Gate to source voltage (V_{GS}) & Drain current (I_D).

→ When V_{GS} reaches threshold voltage (V_{GST}), then current flow starts in Mosfet.

→ The current value increases upto maximum value for a particular V_{GS} after that, juncn breakdown occures & current conduction stops.

Drain Characteristics :-



→ The output characteristics is drawn Drain to source voltage & Drain current (I_D)

at constant V_{GS}.

→ for low value of V_{DS} the graph remains linear. that means it operates in ohmic region.

→ When high voltage is given at drain terminal, then the mosfet goes to active region & operates as an amplifier. In this region maxm current will flow through the Mosfet & it's called saturation region.

→ When the drain to source voltage (V_{DS}) exceeds forward breakover voltage, then the Mosfet goes to cut-off region.

Switching Characteristics :-

→ The switching charac. of a Power Mosfet is obtained due to internal capacitance & internal impedance of Gate drive ckt.

→ At turn-'ON' there is an initial delay 't_{dn}' during which input capacitance charges to threshold voltage 'V_{GST}'.

→ There is further delay 't_r' called rise time, during which gate voltage rises to 'V_{GST}' a voltage sufficient to drive the Mosfet.

During 't_r' drain current rises from zero to full-on current 'I_D'.

So total turn-ON time is $t_{ON} = t_{dn} + t_r$

→ The MOSFET can be turned off after removal of gate voltage after time 't_1'.

The turn-off delay time, 't_{df}' is the time during which i/p capacitance discharges from over drive gate voltage V_1 to V_{GSP}.

→ The fall time 't_f' is the time during which i/p capacitance discharges from V_{GSP} to V_{GST}.

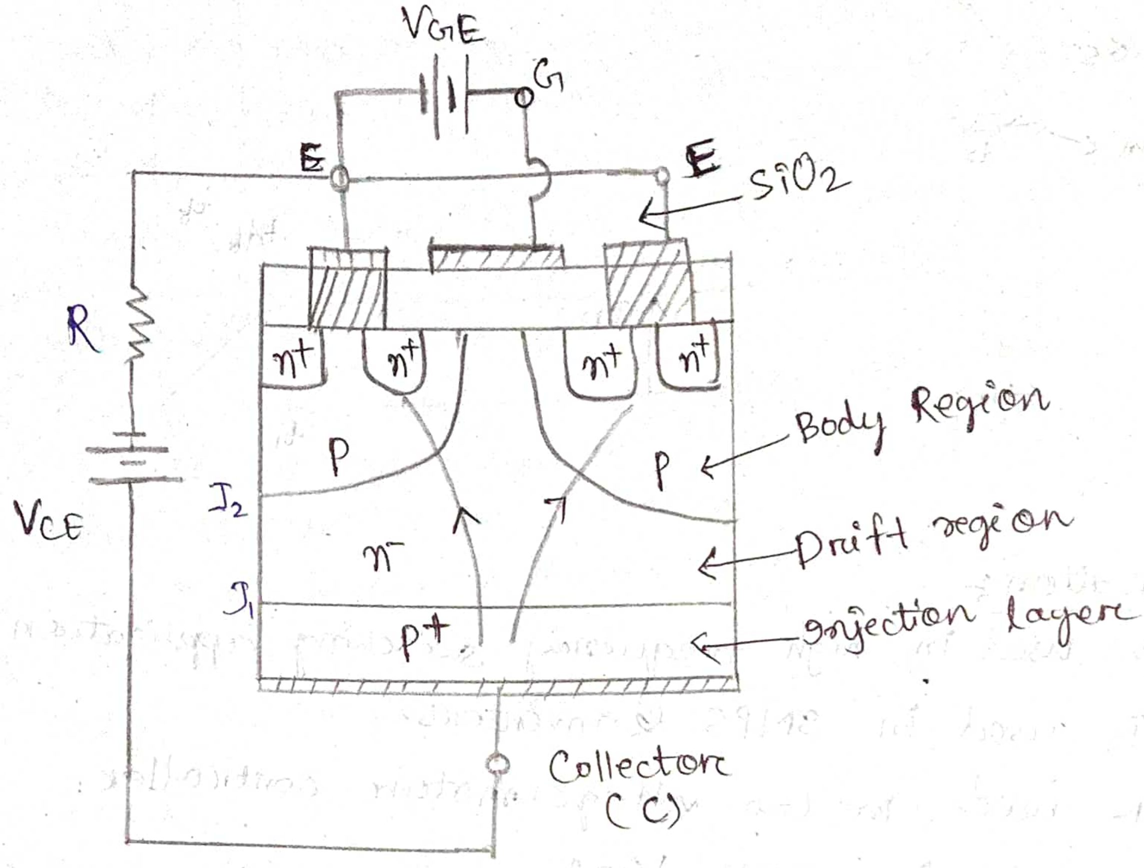
Here the drain current 'I_D' fall to Zero.

So, when $V_{GS} \leq V_{GST}$, there the power MOSFET will be turned off.

Date: 16/11/2021

IGBT:

It is Insulated Gate Bipolar transistor.
It is a combination of BJT & P-MOSFET.
So, it possess high input impedance like P-MOSFET & low onstate power loss like BJT.



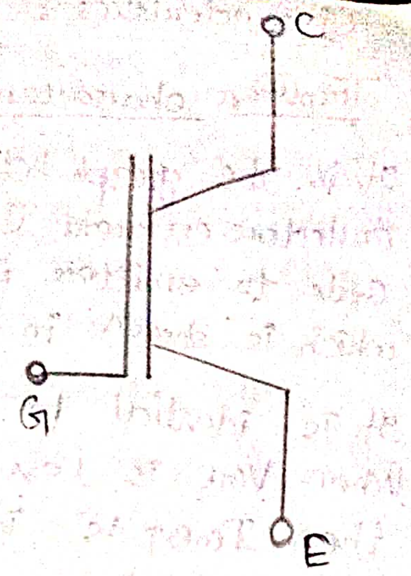
(i) fig. shows the basic structure of an IGBT. This structure is same as Mosfet except that the substrate is p+ layer.
The p+ substrate is called collector layer & the terminal is called collector terminal.

(ii) The p+ layer is also called injection layer, because it injects holes towards n- layer.

(iii) The n- layer is called Drift region & it determined voltage blocking capacity of IGBT.

(iv) The P layer is called Body of the IGBT.
The n- layer betn P & p+ region, ~~solves~~ serves

the depletion layer of pn^- junc^n.



(Symbole)

Working :-

(i) When the Gate terminal is opened the junc^n pn^- becomes reversed biased due to voltage V_{CE}.
So, current can't flow from collector to emitter.

(ii) When Gate is made (+)ve w.r.t ~~Gate~~ emitter, ~~the~~ then a channel is formed near the Gate terminal & bet^n n^+ regions.
This 'n' channel is formed bet^n n^- region & n^+ region
So, e⁻s stars flowing from n^+ to n^- layer.

(iii) The IGBT is said to be in forward biased condition, when the collector is made (+)ve w.r.t emitter & Gate is also made (+)ve w.r.t emitter.
So, the collector region injects holes towards n^- layer & the charge density increases near the channel or drift region.
As a result conductivity ~~X~~ increases & collector current flows bet^n collector terminal & emitter terminal.

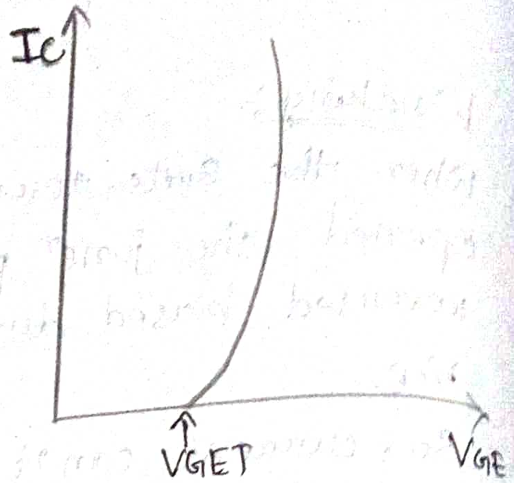
(iv) The collector current (I_c) consists of two component i.e hole current, due to injection from p^+ layer & electron current (I_e), due to injection of e⁻s from n^+ layer.
So, the total current is given by, $I_c = I_h + I_e$

Application :-

→ It is used in UPS system, power supplies & drives for relays & contacts.
→ It is used in inverter, Inductor motor drives.
Rating :- 1200V, 500A, 50kHz, 0.25 to 0.20 μs off time.

Characteristics :-

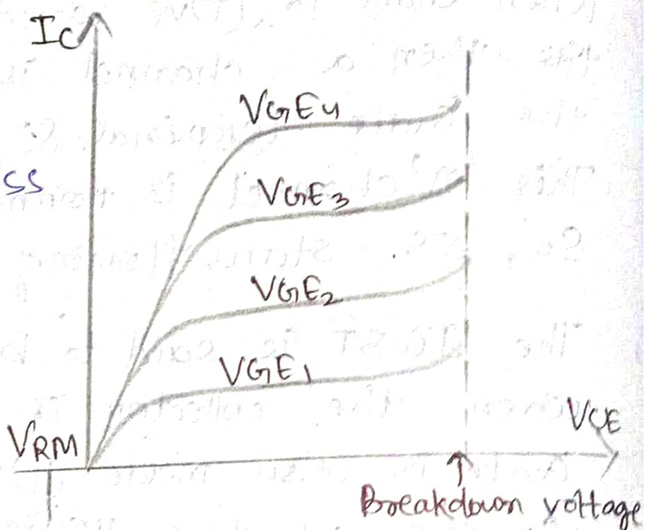
(i) Transfer characteristics :-



→ It is the graph betn collector current (I_c) & Gate to emitter voltage (V_{GE}), which is shown in the fig.

→ It is identical to PMOSFET. When V_{GE} is less than V_{GET}, then IGBT is in off state. When $V_{GE} > V_{GET}$ then the IGBT will be in ON-state.

(ii) V-I characteristics :-



→ fig. shows the V-I characteristics of IGBT, which is drawn betn collector current (I_c) & collector to emitter voltage (V_{CE}) with constant gate to emitter voltage (V_{GE}).

→ In the forward direction the graph is same as BJT but here the controlling parameter is V_{GE} as IGBT is a voltage controlled device.

→ When the device is off, the juncn 'J_2' blocks forward voltage & in case reverse voltage appears across collector & emitter juncn 'J_1' blocks the forward voltage. The maxm reverse breakdown voltage is V_{RM}.

Switching characteristics :-

→ fig. shows the switching characteristics of IGBT during turn ON & turn Off.

→ The turned- ON time is defined as the time betn the instants of forward blocking to forward ON-state. Turn-ON time is composed of delay time (t_{dn}) & rise time (t_r) i.e ($t_{ON} = t_{dn} + t_r$).

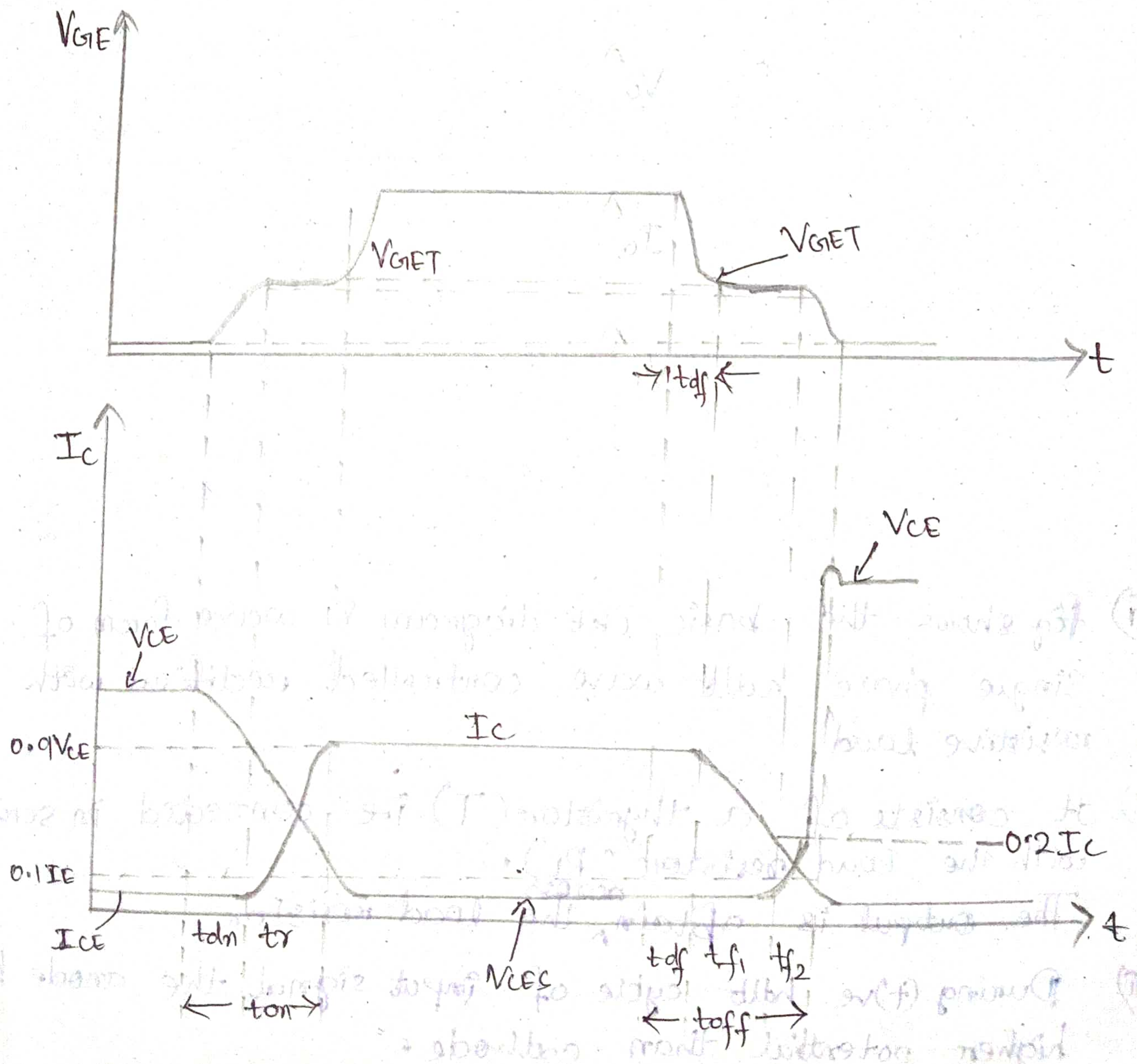
→ The delay time is defined as the time of the V_{CE} falling from 100% to 90%. It is also defined as the time for the collectore current to rise from initial leakage current I_{CE} to $0.1 I_C$.

→ The rise time (t_r) is the time during which V_{CE} falls from 90% to 10%. It is also defined as the time for the collectore current to rise from ($0.1 I_C$) to it's final value (I_C).

→ The turn off time consists of 3 intervals i.e ($t_{off} = t_{df} + t_{f1} + t_{f2}$) from V_{GE} to V_{GET} & the collectore current falls from (I_C to $0.9 I_C$)

→ The first fall time (t_{f1}) is defined as the time during which collectore current falls from ($0.9 I_C$) to ($0.2 I_C$) & V_{CE} rises from (V_{CE} to $0.1 V_{CE}$).

→ The final fall time (t_{f2}) is the time during which I_C falls from ($0.2 I_C$) to ($0.1 I_C$) & V_{CE} rises from $0.1 V_{CE}$ to final value V_{CE}.



Date
20/11/21

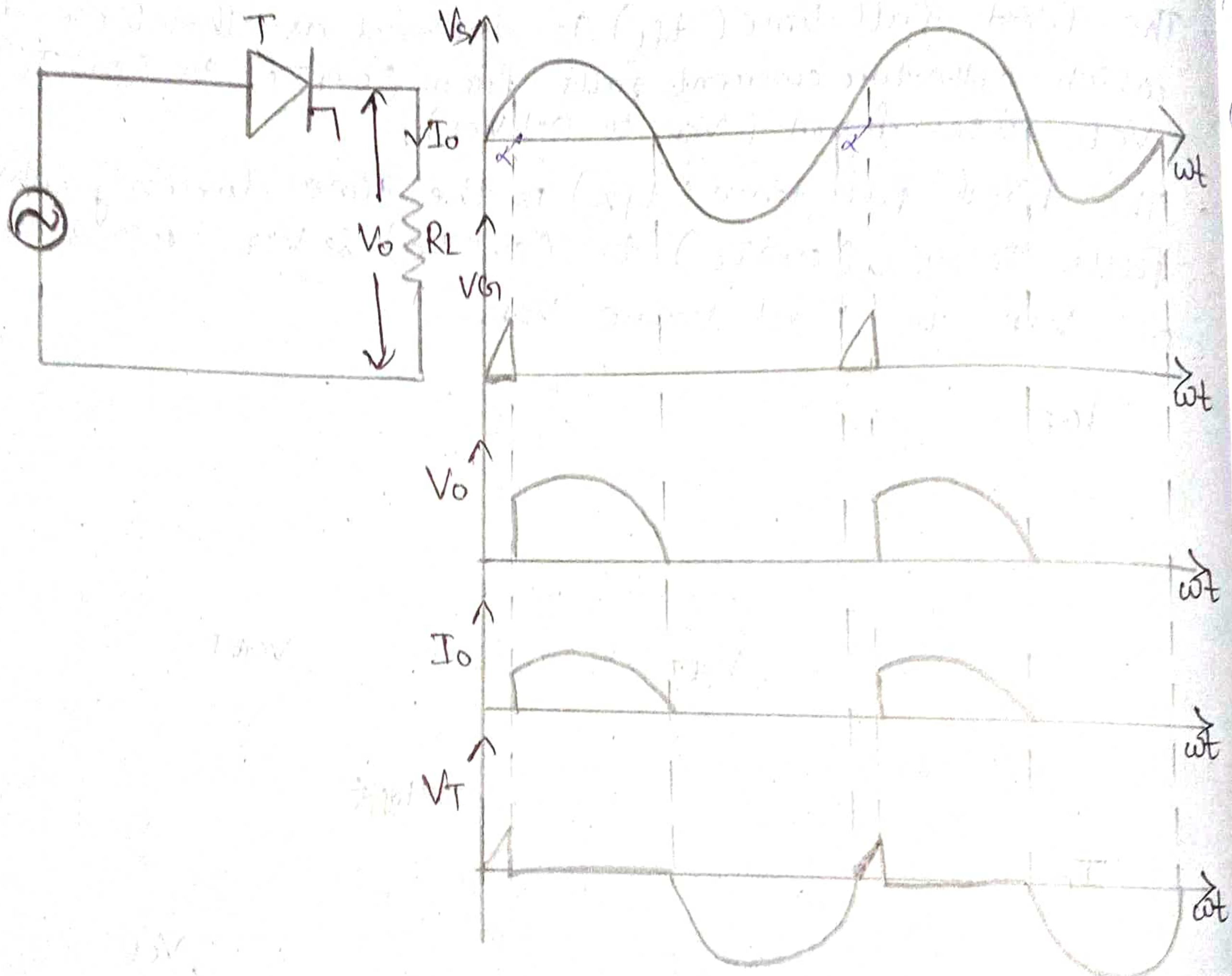
UNDERSTAND THE WORKING OF CONVERTERS, AC Regulators & Choppers — CHAPTER:2

Phase Controlled Rectifier:-

(i) It is an electronic circuit, that converts AC signal into pulsating dc signal with controlled output level.

(ii) The basic component of phase controlled rectifier is SCR or thyristor.

Single Phase Half wave rectifier with R-load:-



(i) fig shows the basic ckt diagram & wave form of single phase half wave controlled rectifier with resistive load.

(ii) It consists of a thyristor (T) i.e connected in series with the load resistor (R_L).
The output is obtain across the load resistor.

(iii) During (+)ve half cycle of input signal the anode has higher potential than cathode.

So, thyristor is in forward blocking mode.
When Gate supply is given after firing angle (α), then the thyristor is starts conducting & the output is obtained.

(iv) During (-)ve half cycle of input signal the anode has lower potential than cathode.
So, the thyristor is in reverse blocking mode & output is not obtained.

(v) Due to resistive load, the current & voltage across the load will be in same phase.

(vi) The voltage across thyristor will be zero, during conduction time period & the voltage will be same as input signal voltage during turn off time period.

Average value :-

Let, the instantaneous value of supply voltage is

$$v = V_m \sin\omega t$$

The average value is given by,

$$V_{avg} = \frac{1}{2\pi}\int_{\alpha}^{\pi} v \, d\omega t$$

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

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

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

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

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

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

RMS value:

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\pi} v^2 \, d\omega t}.$$

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

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

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

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

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

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

$$V_{rms} = \sqrt{\frac{V_m^2}{2\pi \times 2}\int_{\alpha}^{\pi} \left(\frac{1 - \cos 2\omega t}{2}\right) d\omega t}$$

$$V_{rms} = \sqrt{\frac{V_m^2}{4\pi}\int_{\alpha}^{\pi} (1 - \cos 2\omega t) \, d\omega t}$$

$$V_{rms} = \sqrt{\frac{V_m^2}{4\pi}\int_{\alpha}^{\pi} 1 \, d\omega t - \int_{\alpha}^{\pi} \cos 2\omega t \, d\omega t}$$

$$V_{rms} = \sqrt{\frac{V_m^2}{4\pi}\left\{\left[\omega t\right]_{\alpha}^{\pi} - \left[\frac{\sin 2\omega t}{2}\right]_{\alpha}^{\pi}\right\}}$$

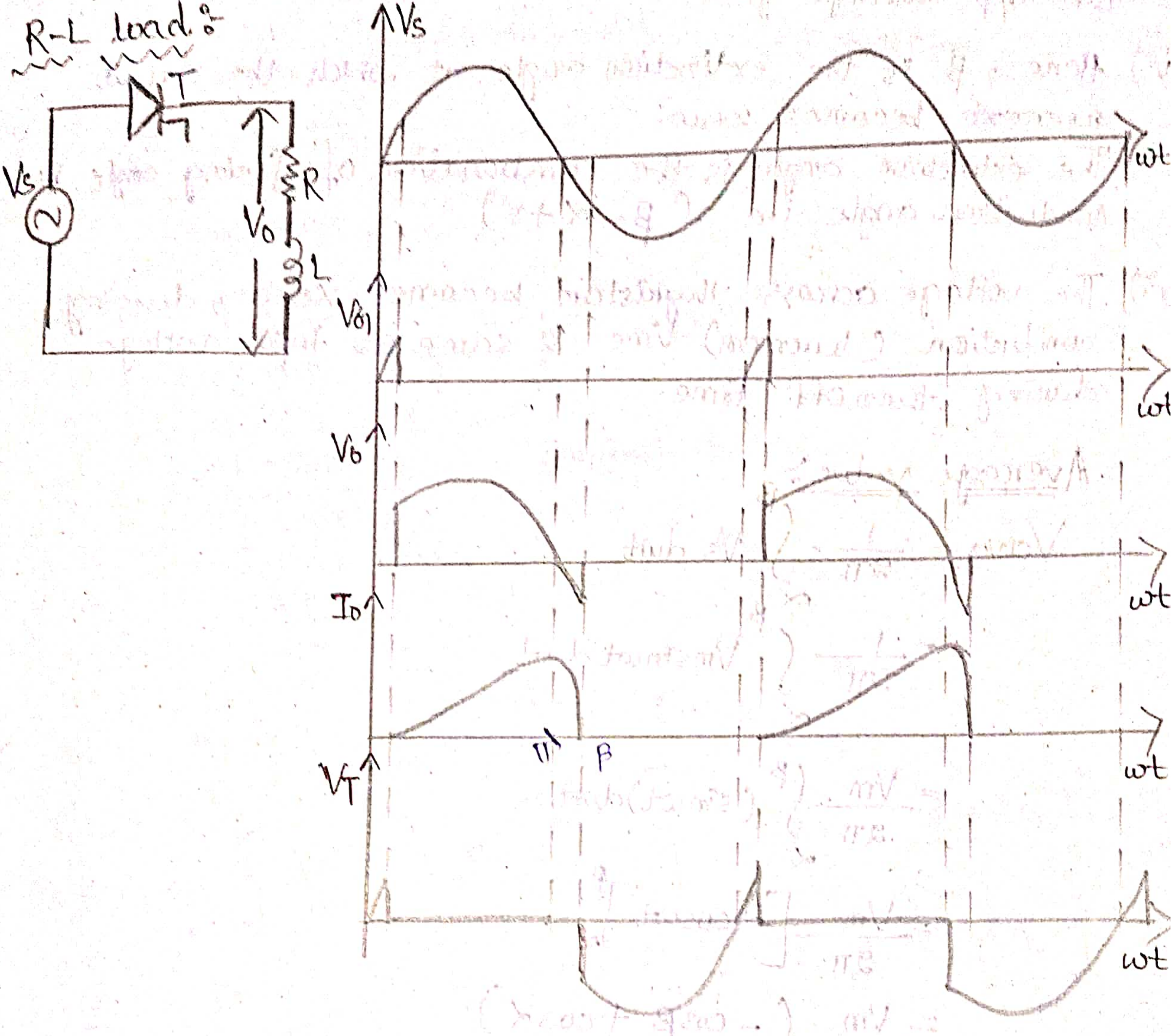
$$V_{rms} = \sqrt{\frac{V_m^2}{4\pi}\left\{(\pi - \alpha) - \left(\frac{\sin 2\pi}{2} - \frac{\sin 2\alpha}{2}\right)\right\}}$$

($\sin 2\pi \to 0$)

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

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

Single phase (1-ϕ) Half wave Controlled Rectifier with R-L load :-



(i) fig. shows the basic ckt diagram & wave form of Single phase half wave controlled rectifier with R-L load.

(ii) During (+)ve half cycle of input signal the thyristore is in forward blocking mode.

(iii) When Gate supply is given after firing angle 'α' then the thyristor conducts & current will flow towards load in the path ($V_s \rightarrow T \rightarrow R \rightarrow L \rightarrow V_s$)

(iv) At ($\omega t = \pi$) the output voltage becomes zero, but the output current will be max^m due to lagging nature of inductor.

(v) After ($\omega t = \pi$) the output current decreases towards zero. As the output current flows betn ($\omega t = \pi$ & $\omega t = \beta$), so the o/p voltage goes -ve.

(vi) Here, β is the extinction angle at which the output current becomes zero.
The extinction angle is the combination of firing angle & conduction angle i.e ($\beta = \alpha + \gamma$)

(vii) The voltage across thyristor becomes zero, during conduction (turn on) time & same as input voltage during turn off time.

Average value :-

$$V_{avg} = \frac{1}{2\pi}\int_{\alpha}^{\beta} V_s \, d\omega t$$

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

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

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

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

$$\boxed{V_{avg} = \frac{V_m}{2\pi}\left[\cos\alpha - \cos\beta\right]}$$

Similarly,

$$\boxed{I_{avg} = \frac{I_m}{2\pi}(\cos\alpha - \cos\beta)}$$

RMS value :

$$V_{rms} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\beta} v^2 \, d\omega t}$$

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

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

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

$$= \sqrt{\frac{V_m^2}{2\pi \times 2}\int_{\alpha}^{\beta} 1-\cos 2\omega t \, d\omega t}$$

$$= \sqrt{\frac{V_m^2}{4\pi}\int_{\alpha}^{\beta} 1 \, d\omega t - \int_{\alpha}^{\beta} \cos 2\omega t \, d\omega t}$$

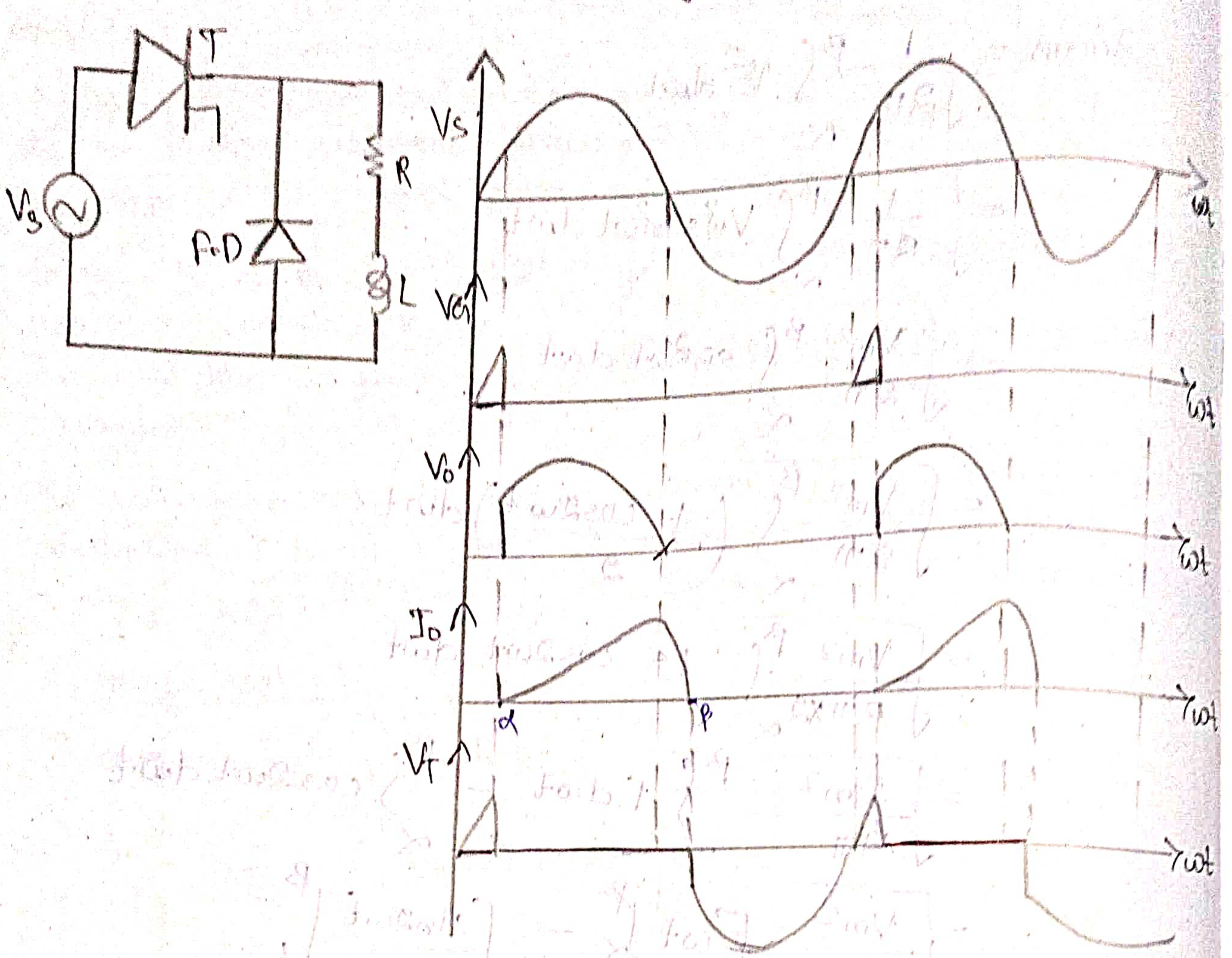
$$= \sqrt{\frac{V_m^2}{4\pi} \left[\omega t\right]_{\alpha}^{\beta} - \left[\frac{\sin 2\omega t}{2}\right]_{\alpha}^{\beta}}$$

$$= \sqrt{\frac{V_m^2}{4\pi}\left[\beta - \alpha\right] - \left[\frac{\sin 2\beta}{2} - \frac{\sin 2\alpha}{2}\right]}$$

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

$$= \frac{V_m}{2\sqrt{\pi}}\left[\beta - \alpha - \frac{\sin 2\beta}{2} + \frac{\sin 2\alpha}{2}\right]$$

Single phase (1φ) Half wave Controlled Rectifier with R-L load with free wheeling Diode :-



→ fig shows ckt diagram & wave form of single phase half wave controlled Rectifier with R-L load with free wheeling Diode.

→ It consists thyristor & R-L load. The free wheeling diode (F.D) is connected in parallel across the load.

→ During (+)ve half cycle of input signal thyristor is in forward blocking mode. When gate voltage is given, then the thyristor will be turn ON after firing angle α.

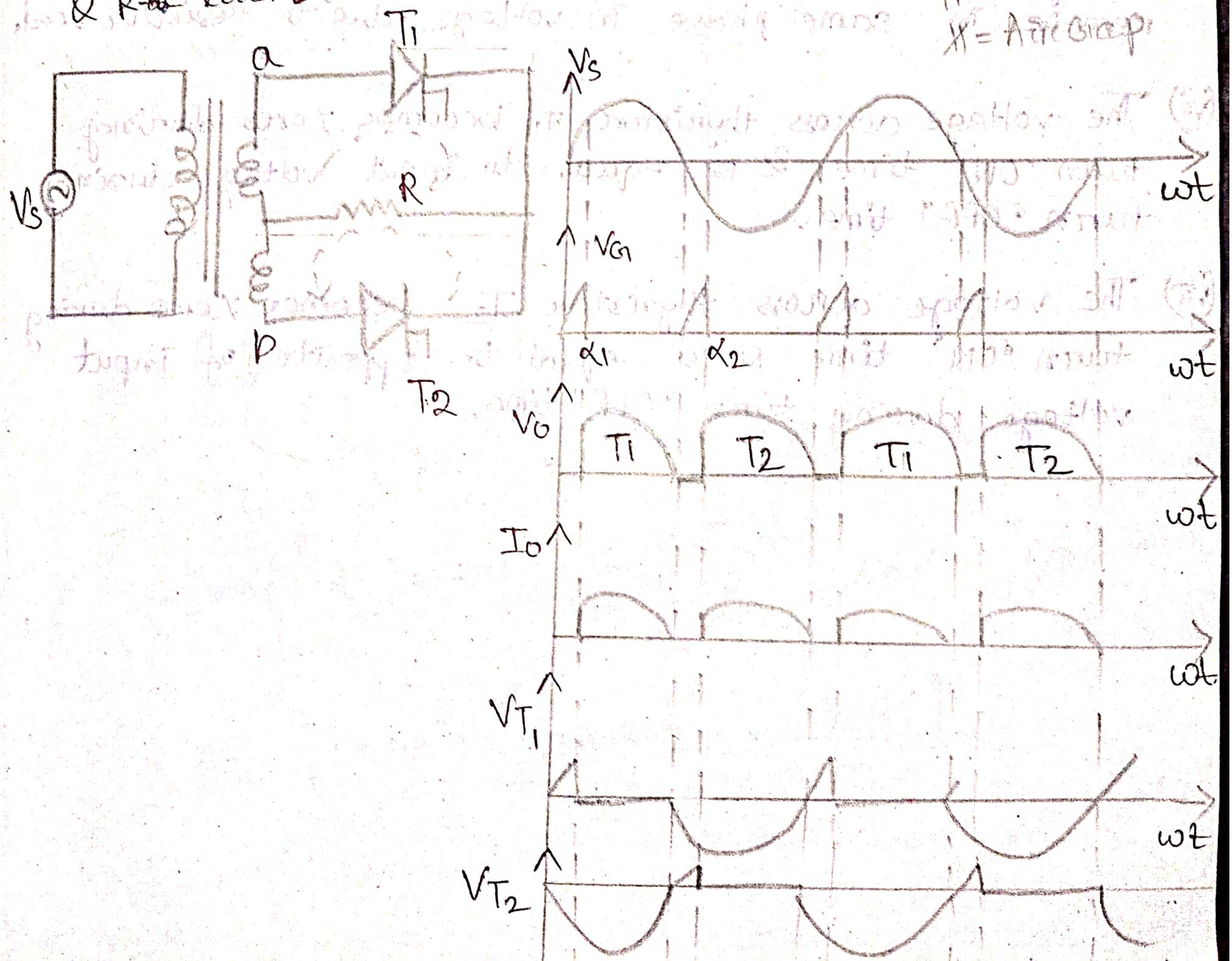
→ During conduction of SCR, the output current flows from source to load in the path Vs→T→R-L→Vs.

The inductor stores energy.

- At $\omega t = \pi$ the voltage becomes '0', but the current is maximum, due to lagging nature of inductor.
- After $\omega t = \pi$, the inductor releases its energy through free wheeling diode, because the diode becomes forward biased after $\omega t = \pi$.
So, diode acts as a short-ckt & output voltage becomes zero, during the half cycle, but the output current will not be '0' at $\omega t = \pi$.
The output current decreases to '0' at $\omega t = (\pi + \beta)$
- The voltage across thyristor remains '0' during conduction time period & will be equal to supply voltage, during turn off time period.

1φ ~~Half~~ full wave controlled Rectifier with ~~Lead~~ mid point & R-~~L~~ load :-

|| = Iron Core
X = Air Gap



(i) fig. shows the ckt diagram & wave form of single phase full wave mid point converter.

(ii) It consists of a centre tap transformer, 2 thyristors T_1 & T_2 & the load resistance 'R' as shown in fig.

(iii) During (+)ve half cycle of i/p signal the thyristor T_1 is in forward blocking mode & thyristor T_2 is in reverse blocking mode.
When T_1 is trigered after firing angle α_1, then the current flowing through the load & output will come.

(iv) During (-)ve half cycle of i/p signal the thyristor T_2 is in forward blocking mode & the thyristor T_1 is in reverse blocking mode.
When T_2 is trigered after firing angle α_2, then the current flows through the load & output is obtained.

(v) During both +ve & -ve half cycle of i/p signal the voltage across load have same polarity & the current remain in same phase in voltage, due to resistive load.

(vi) The voltage across thyristor T_1 becomes zero during turn 'ON' time & is equal to input voltage during turn 'Off' time.

(vii) The voltage across thyristor T_2 becomes zero during turn 'ON' time & is equal to opposite of input voltage during turn 'Off' time.

Average value

$$V_{avg} = \frac{1}{\pi}\int_{\alpha}^{\pi} v_0 \, d\omega t$$

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

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

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

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

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

$\cos\pi = -1$

$$V_{avg} = \frac{V_m}{\pi}\left[\cos\alpha - \cos\pi\right]$$

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

Similarly,

$$\boxed{I_{avg} = \frac{I_m}{\pi}\left[\cos\alpha + 1\right]}$$

RMS value :

$$V_{avg} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} v^2 d\omega t}$$

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

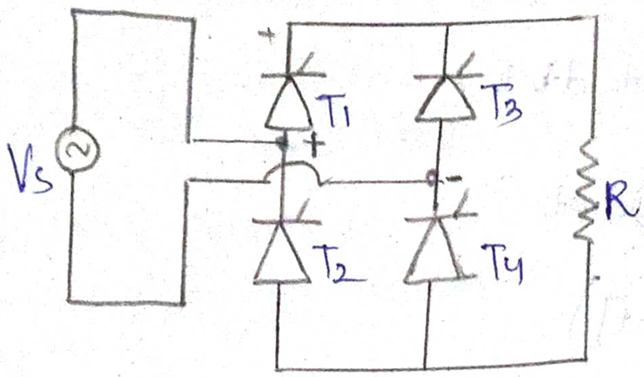
$$= \sqrt{\frac{V_m^2}{\pi}\int_{\alpha}^{\pi}\left(\frac{1-\cos 2\omega t}{2}\right) d\omega t} = \sqrt{\frac{V_m^2}{2\pi}\int_{\alpha}^{\pi} 1 \, d\omega t - \int_{\alpha}^{\beta} \cos 2\omega t \, dt}$$

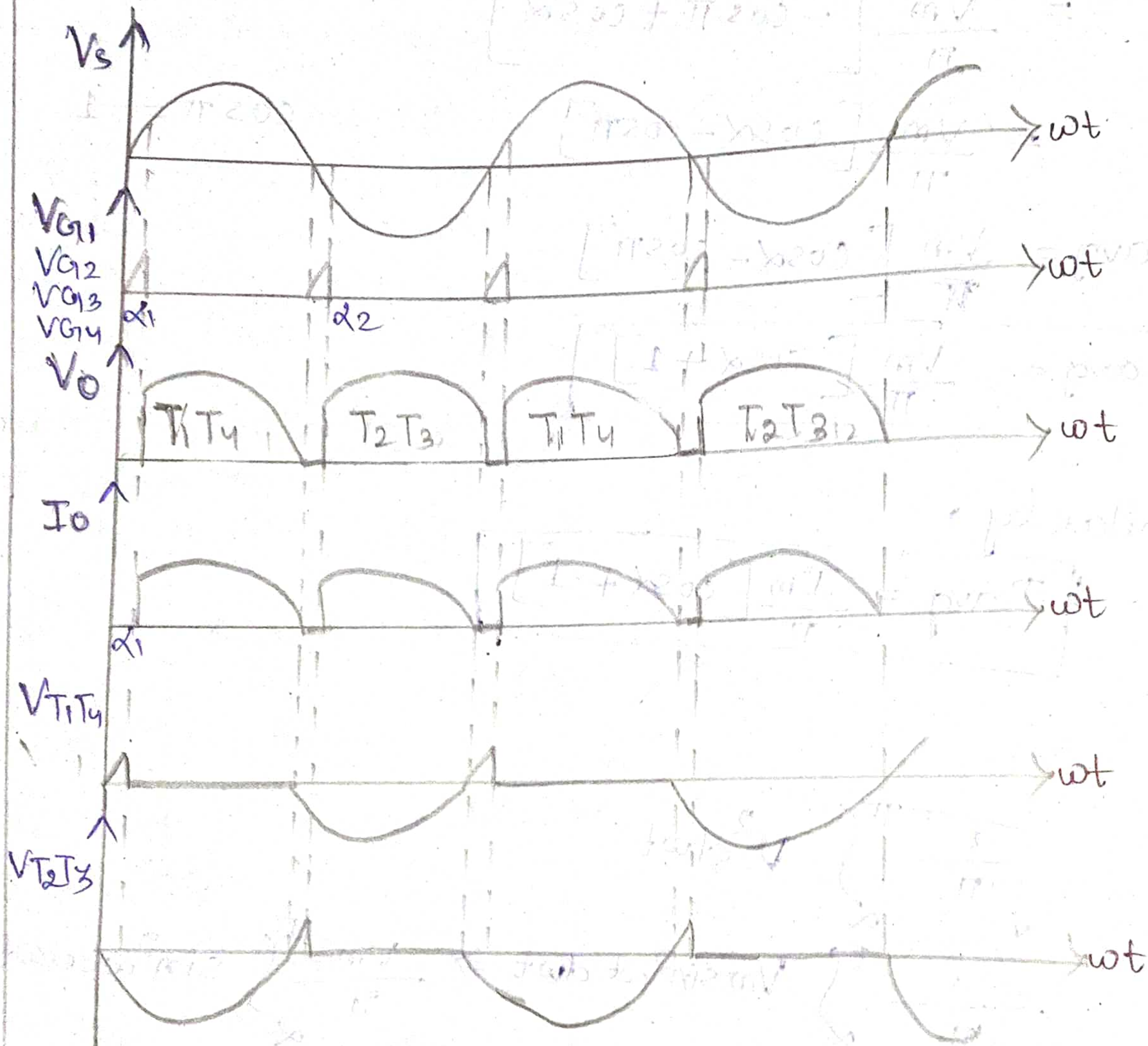
$$= \frac{V_m^2}{2\pi}\left[\pi - \alpha\right] - \left[\frac{\sin 2\pi}{2} - \frac{\sin 2\alpha}{2}\right]$$

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

(1-ϕ) full wave Bridge Controlled Rectifier with R load

C+A C-A → Supply
A-A C-C → Load





(i) fig shows the circuit diagram & wave form of 1-ϕ full wave Bridge controlled Rectifier (FWBCR) with R-load.

(ii) It consists of 4 thyristors i.e (T1, T2, T3, T4) which are connected to form a bridge circuit.

(iii) The supply voltage & load resistore are connected as shown in fig.

(iv) During (+)ve half cycle of input signal the thyristore (T_1, T_4) are in forward blocking mode & the thyristors (T_2, T_3) are in reverse blocking mode.

(v) When gate supply is given to the thyristore (T_1, T_4) after firing angle 'α_1' then they conduct & the current flows towards load in the path
$(V_s \rightarrow T_1 \rightarrow R \rightarrow T_4 \rightarrow V_s)$.
The output voltage will come.

(vi) During (−)ve half cycle of input signal the thyristore (T_2, T_3) are in forward blocking mode & the thyristor (T_1, T_4) are in reverse blocking mode.

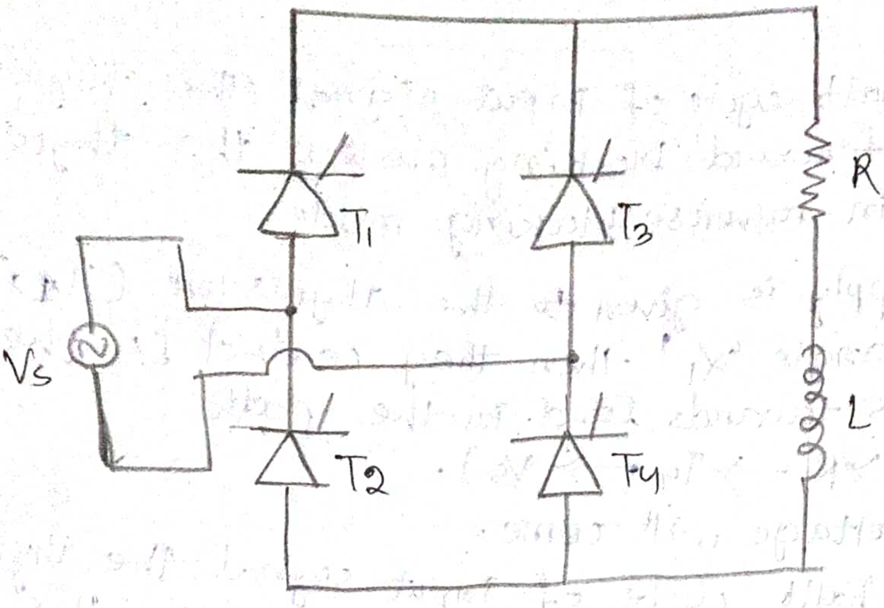
(vii) When gate supply is given to the thyristor (T_2, T_3) after firing angle 'α_2' then they conduct & the current flows towards load in the path
$(V_s \rightarrow T_3 \rightarrow R \rightarrow T_2 \rightarrow V_s)$.
The output voltage will come.

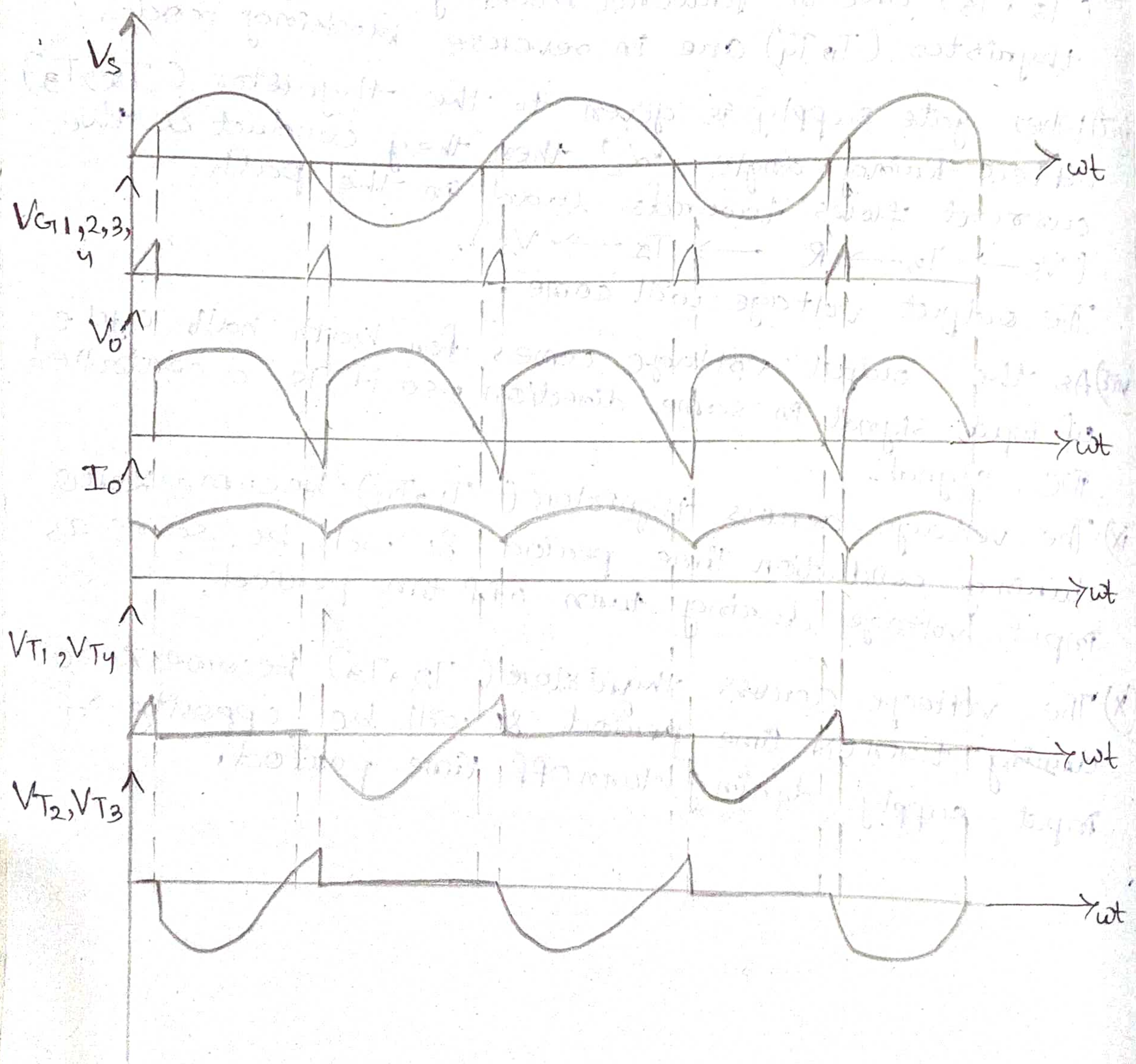
(viii) As the output voltage comes for both half cycle of input signal in same direction, so it is a controlled DC signal.

(ix) The voltage across thyristore (T_1, T_4) become zero during conduction time period & will be same as input voltage during turn off time period.

(x) The voltage across thyristore (T_2, T_3) become zero during turn ON time period & will be opposite of input supply during turn off time period.

(1-ϕ) full wave Bridge Controlled Rectifier with R-L Load :-





→ fig shows the ckt diagram & waveform of single phase fullwave bridge controlled rectifier.
It consists of 4 thyristors. i.e T_1, T_2, T_3, T_4 connected to form a bridge ckt & the voltage supply is given & R-L load is shown in fig.

→ During the (+)ve half cycle of input signal the thyristor T_1 & T_4 are in forward blocking mode & T_2 & T_3 are in reverse blocking mode;
When the thyristor T_1 & T_4 are triggered by applying gate supply with firing angle 'α_1' then they start conducting & the current flows through the load in the path $V_s \to T_1 \to R \to L \to T_4 \to V_s$

→ Due to inductive load the current lags behind the voltage. So, at $\omega t = \pi$, the output voltage becomes zero but the output current becomes maximum.
After that the output current decreases & the output voltage is in negative polarity.

→ During negative half cycle of input signal the thyristor T_1 & T_4 are in reverse blocking mode & the thyristor T_2 & T_3 are in forward blocking mode.

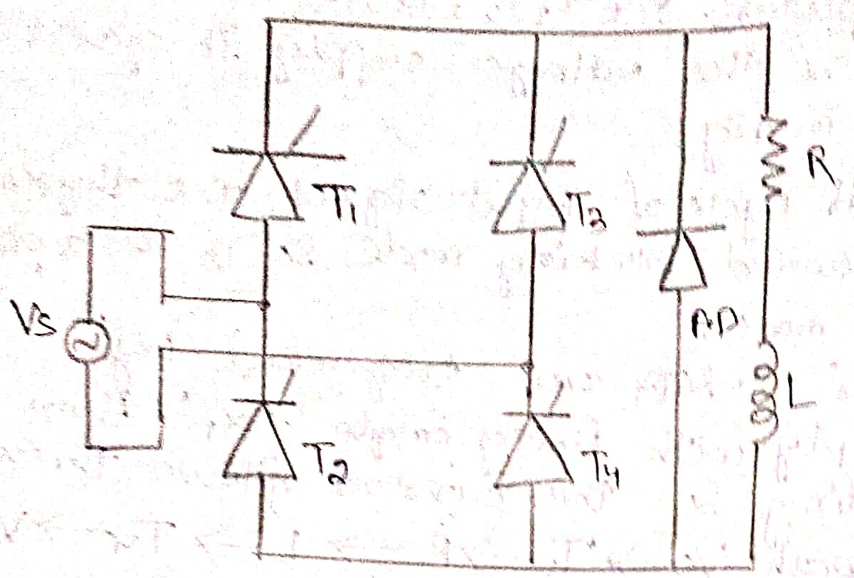
→ When the gate supply is given to the thyristor T_3 & T_2 then, they start conducting.
The output current will flow through the load in the path $V_s \to T_3 \to R - L \to T_2 - V_s$.

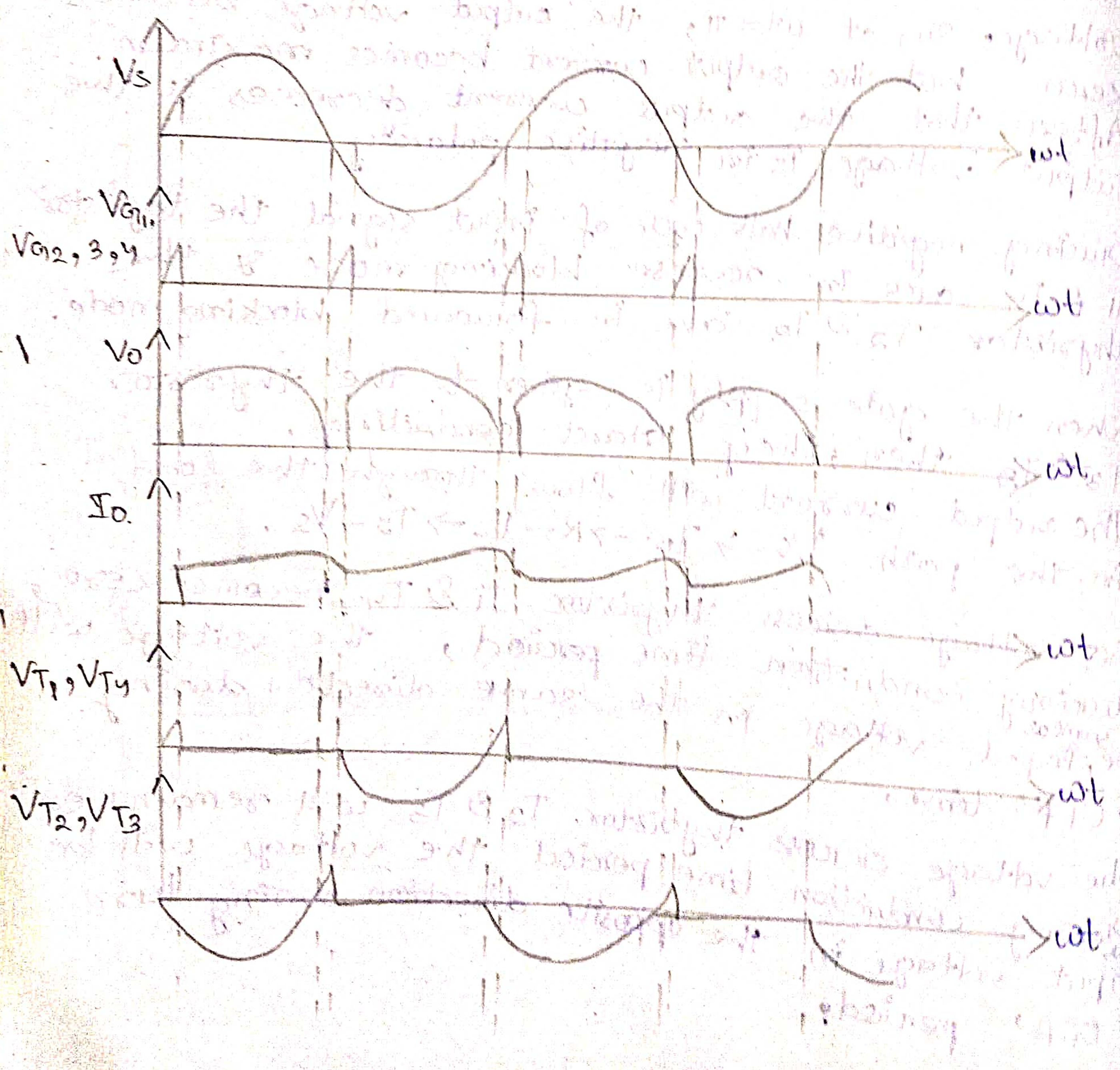
→ The voltage across thyristor T_1 & T_4 becomes zero, during conduction time period, the voltage will be same as input voltage in the same direction during 'off' time.

→ The voltage across thyristor T_2 & T_3 will remain zero. During conduction time period. the voltage will be same as input voltage in the opposite direction during turn 'off' period.

Date
25/11/21

Single phase full controlled Rectifier with R-L load & free wheeling diode :-





→ fig shows ckt diagram & wave form of single phase full wave controlled rectifier with R-L load & free wheeling diode.

→ During (+)ve half cycle of input signal, the thyristore T_1 & T_4 are in forward blocking mode & T_2 & T_3 are in reverse blocking mode.

→ When gate supply is given to thyristore T_1 & T_4 after firing angle 'α_1', then they start conducting & the current flows from source to load in the path
$V_s \rightarrow T_1 \rightarrow R \rightarrow L \rightarrow T_4 \rightarrow V_s$.

→ Due to inductive nature of load, the output current lags behind output voltage.
At $\omega t = \pi$, the output voltage becomes zero & the output current becomes maximum. & then the output current decreases ~~to zero~~.
output current

→ During negative half cycle of input signal, the thyristore T_2 & T_3 are in forward blocking mode & thyristor T_1 & T_4 are in Reverse blocking mode.

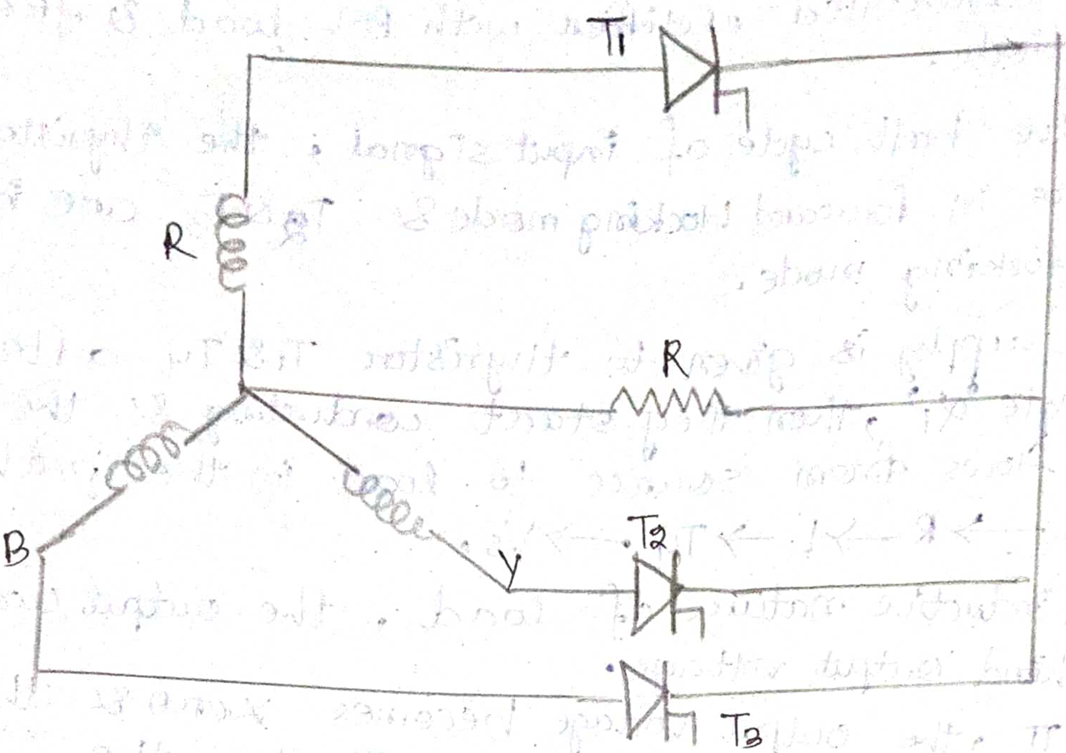
→ When Gate is given to thyristor T_2 & T_3, after the firing angle 'α_2', then they start conducting & the current flows from source to load in the path
$V_s \rightarrow T_3 \rightarrow R \rightarrow L \rightarrow T_2 \rightarrow V_s$.

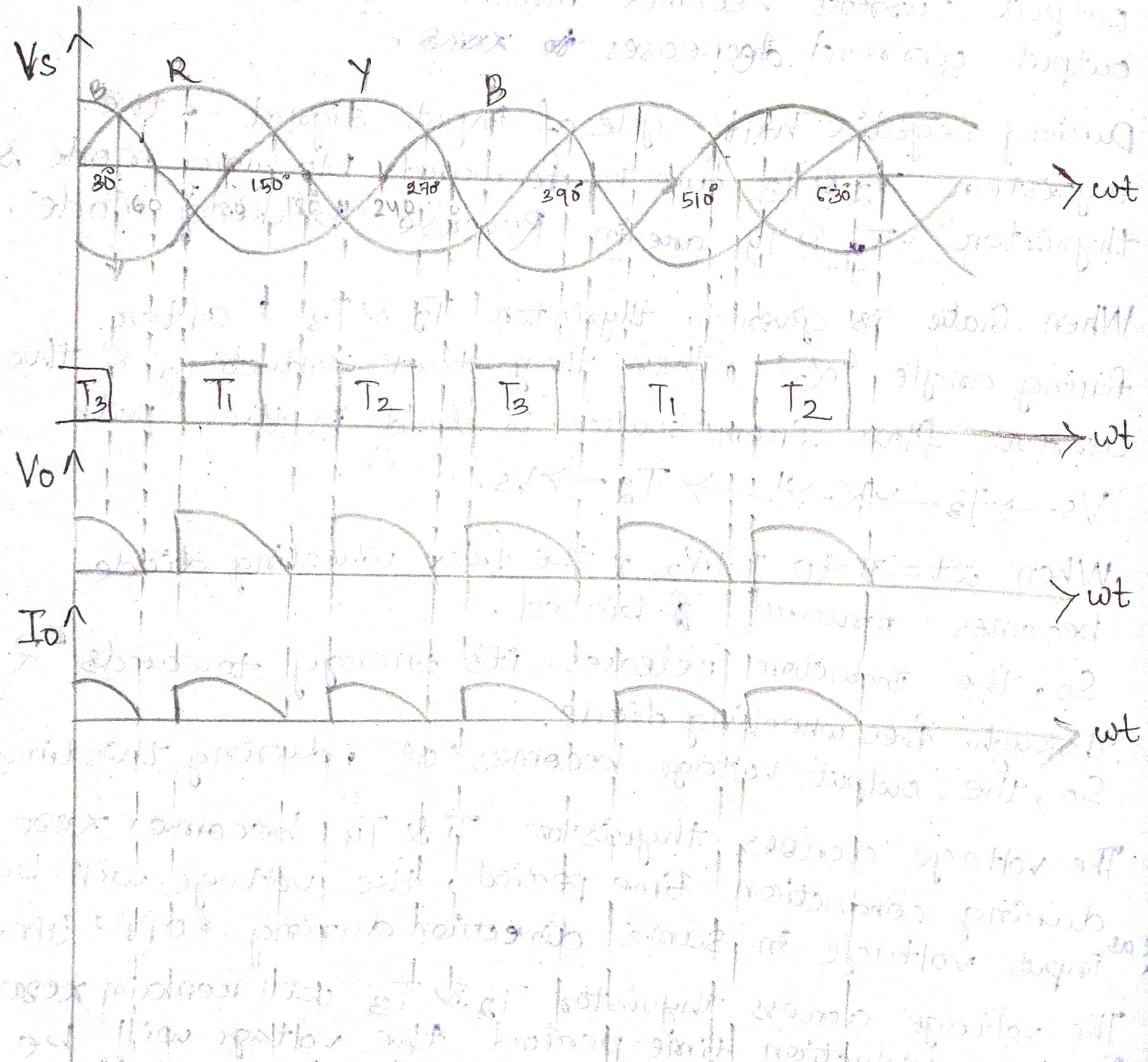
→ When $\omega t = \pi$ to $\pi + \alpha_2$, the free wheeling diode becomes forward biased.
So, the inductore releases it's energy towards 'R' through free wheeling diode.
So, the output voltage becomes '0', during this time.

→ The voltage across thyristor T_1 & T_4 becomes zero, during conduction time period, the voltage will be same as input voltage in same direction during 'off' time.

→ The voltage across thyristor T_2 & T_3 will remain zero. During conduction time period the voltage will be same as input voltage in the opposite direcn during "turn off" period

(3-ϕ) Half Controlled Rectifiere with R-load :





Date :- 28/11/2021

(i) fig shows the basic ckt diagram & wave form of 3-ϕ half controlled rectifiere.
It consist of 3 thyristore T_1, T_2 & T_3 which are connected with the 3-ϕ supply.

(ii) T_1 is in forwared blocking mode for the time interval 30° to 150° & 390° to 510°.
When (+)ve gate supply is given to the thyristore 'T_1', then it's starts conducting & output voltage is obtained during conduction time period.

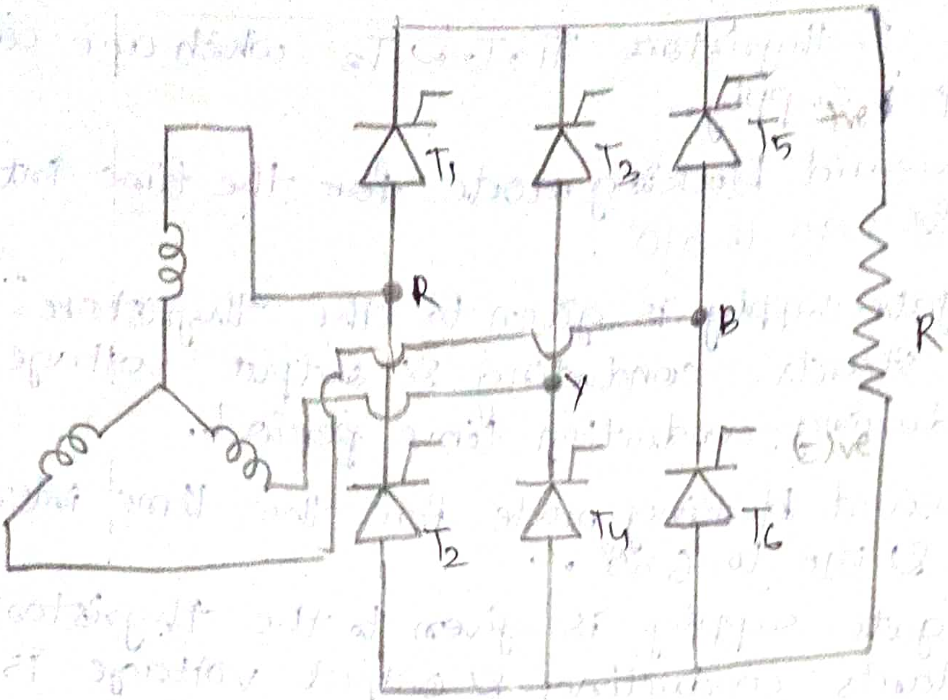
(iii) T_2 is in forwared blocking mode for the time interval 150° to 270° & 510° to 630°.
When (+)ve gate supply is given to the thyristor 'T_2', then it starts conducting & output voltage is obtained during conduction time period.

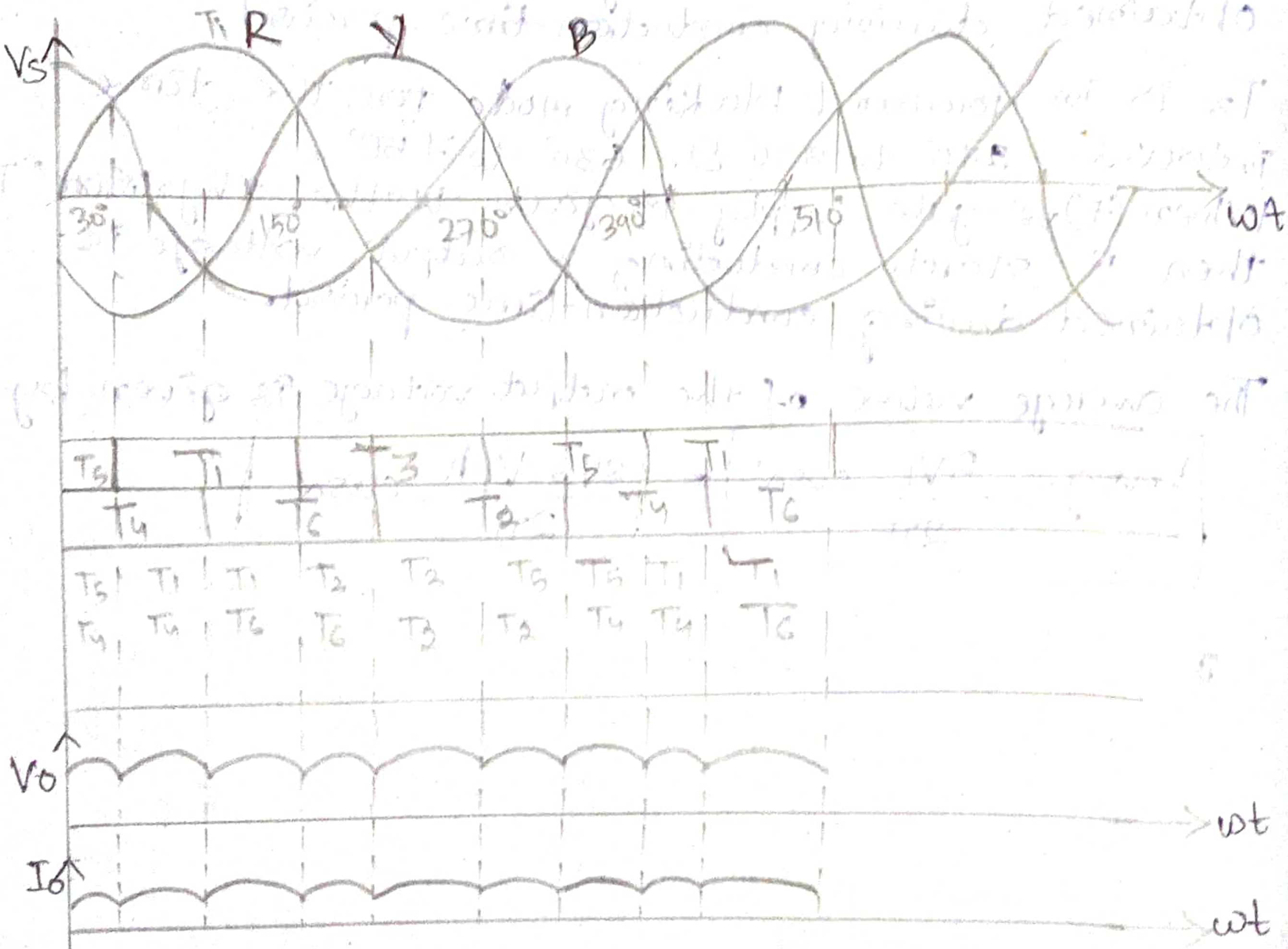
(iv) T_3 is in forwarcd blocking mode for the time interval 270° to 390° & 630° to 750°.
When (+)ve gate supply is given to the thyristore 'T_3' then it starts conducting & output voltage is obtained during conduction time period.

(v) The average value of the output voltage is given by

$$V_{avg} = \frac{3V_L}{2\pi}\cos\alpha = \frac{3\sqrt{3}\,V_{ph}}{2\pi}\cos\alpha$$

3-ϕ full controlled Rectifier with R-Load :-





*NOTE

I ←120°→ f |←240°→| I ←120°→ f

I = Initial point
f = final point

(i) fig shows the ckt diagram & waveform of 3-ϕ full controlled rectifier.
It consists of 6 ~~to~~ thyristor i.e T_1, T_2, T_3, T_4, T_5 & T_6. with resistive load 'R'.

(ii) for (+)ve half cycle of 3-phase supply, the thyristors T_1, T_3 & T_5 are in forward blocking mode. for (-)ve half cycle of 3-phase supply, the thyristors T_2, T_4 & T_6 are in forward blocking mode.

(iii) At $\omega t = 30°$ to $150°$ & $390°$ to $510°$, The thyristor T_1 is in forward blocking mode.

(iv) The thyristor 'T_3' will be in forward blocking mode during the time $\omega t = 150°$ to $270°$ & $510°$ to $630°$.

(v) The thyristor 'T_5' will be in forward blocking mode during the time interval $\omega t = 270°$ to $390°$ & $630°$ & ~~so on.~~ $750°$ and so on.

(vi) The thyristor 'T_2' will be forward blocking mode during the time $\omega t = 210°$ to $330°$ & $570°$ to $690°$ & so on.

(vii) The thyristor 'T_4' will be in forward blocking mode during the time $\omega t = 330°$ to $450°$ & ~~570°~~ $690°$ to $810°$ & so on.

(viii) The thyristor 'T_6' will be in forward blocking mode during the time interval $\omega t = 450°$ to $570°$ & $810°$ to $930°$ & so on.

I ←→ f (120°) ← 240° → I ←→ f (120°)

(ix) A pair of thyristors will be conducted, when gate voltage is applied.
If the firing angle 'α' is 30°, then the output voltage will be obtained for the phase difference of 60° for ~~half the time interval two~~ one pair of conducting thyristor.

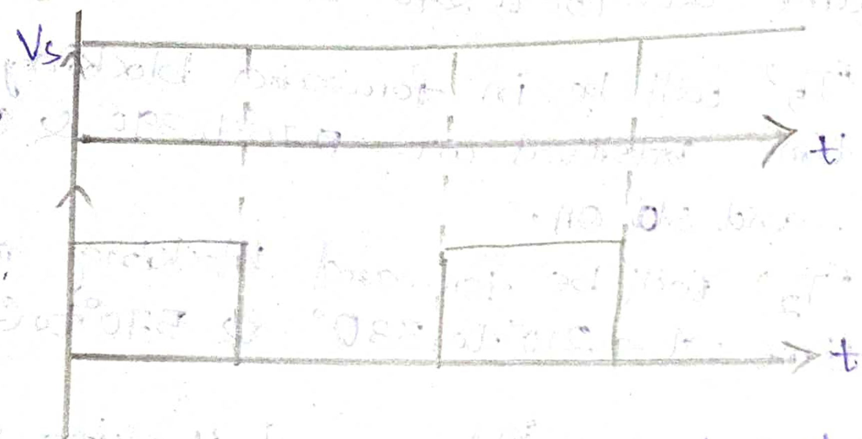
(X) The average value of the output voltage is given by

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

Date :- 04/12/2021

CHOPPER :-

Chopper is an electronic device that converts fixed dc to variable dc.
This conversion can be obtained by using switching devices like thyristor, MOSFET, IGBT etc.
The switching device operates periodically.



→ The choppers are used in speed control of dc motor, battery driven car, dc toys etc.

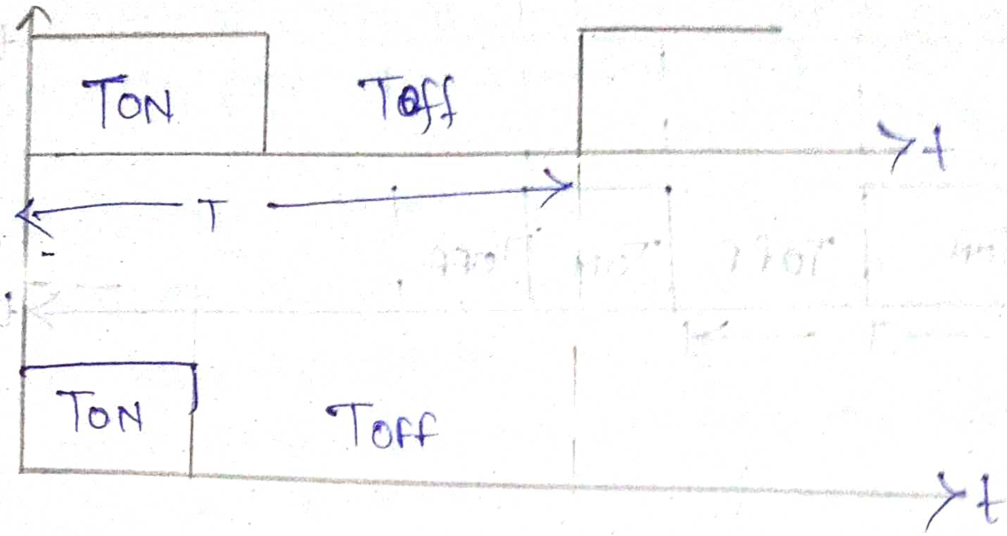
long Control ~~stra~~ strategy :-

→ There are 2 control strategy used for choppers, i.e
(a) Time Ratio Control (TRC)
(b) Current Limit Control (CLC)

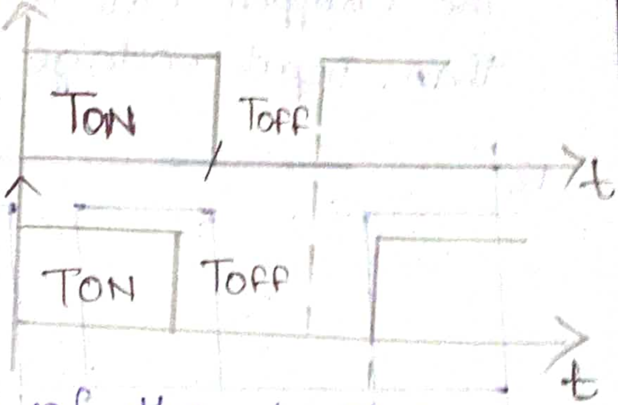
Time Ratio Control :- (TRC)

→ In this control scheme, the time ratio $\left(\frac{T_{ON}}{T}\right)$ is varied.
In this method 2 types of operation ~~are~~ is obtained i.e constant frequency method & variable frequency method.

→ In constant frequency method, the ON time (TON) is varied, but the chopper frequency remain constant. In this method, the width of ON time is varied, so it is also called "pulse with modulation scheme".



→ In variable frequency scheme, the chopper frequency is varied, but the ON time (TON) remain constant. This method is also called frequency modulation scheme.



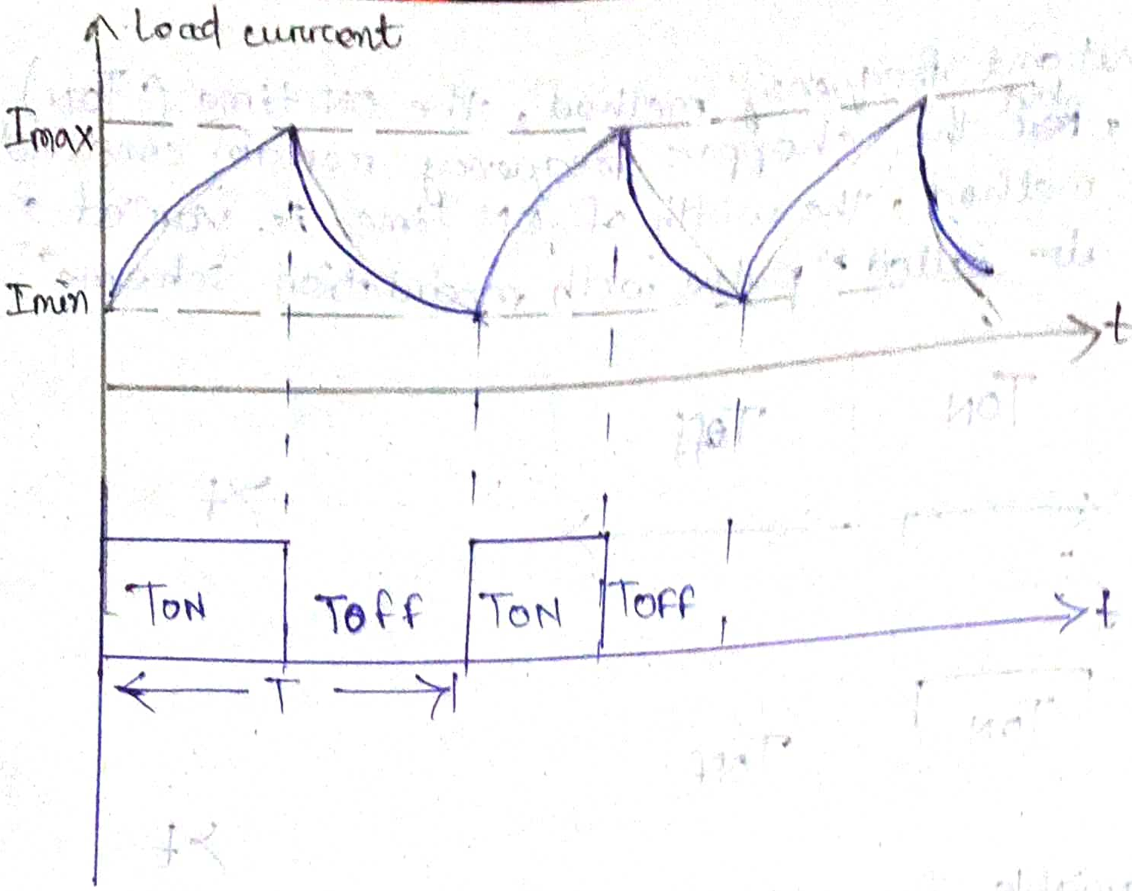
Current limit Control :- (CLC)

→ In this stratergy, the frequency of the chopper is guided by previous set value of load current i.e (I_{max} & I_{min})

→ When the load current reaches to I_{max}, then the chopper is switched off, & the current value decreases exponentially.

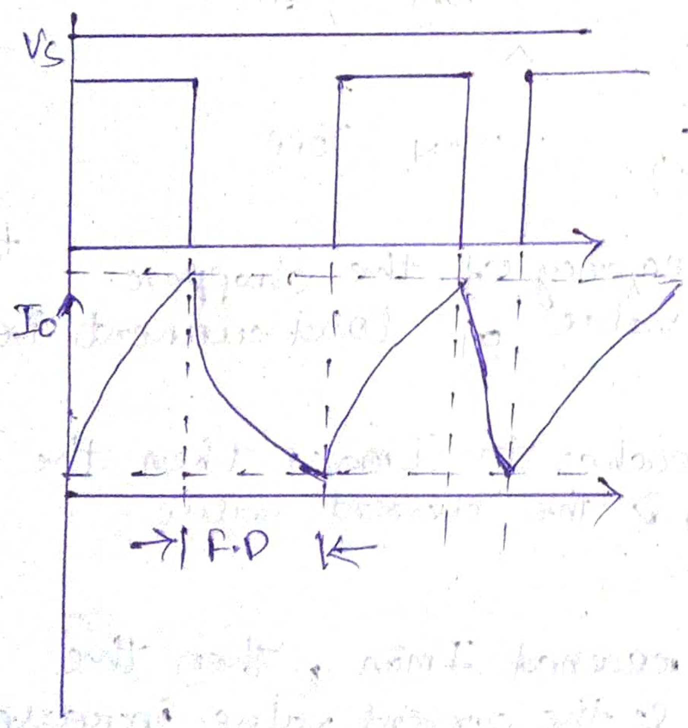
→ When the load current reached I_{min}, then the chopper is switched ON, & the current value increases exponentially.

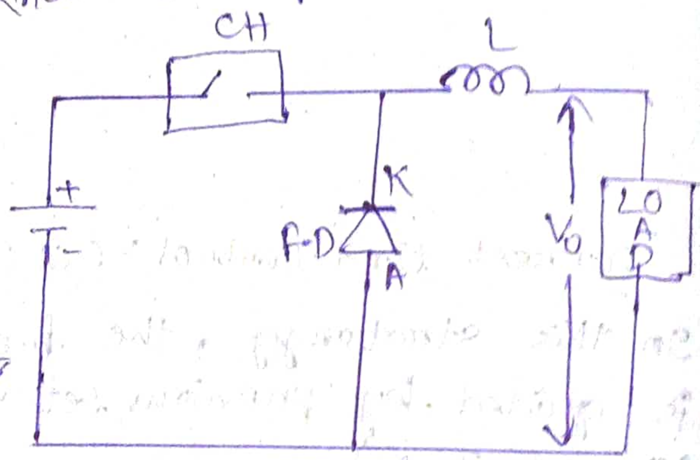
→ The chopper frequency can be varied by setting different values of I_{max} & I_{min}.



Step down CHopper (BUCK converter) :-

The Chopper ckt in which, the output voltage is less than input voltage is known as Stepdown Chopper.





→ fig shows the basic ckt diagram & wave form of stepdown chopper.
It consists of a switching device ('CH', a free wheeling diode, a large inductor 'L' & a load).

→ When 'CH' is on, then the current flows from source to load in the path Vs → CH → L → Load → Vs. During this time the output voltage is obtained & is given by :-
$V_0 - V_s - V_L$ (by KVL method).

→ When CH is off then the lagging current flows through the free wheeling diode.

→ During this time the inductor releases the energy so the current value decreases.

→ In this way the output voltage becomes less than the input voltage by using chopper switch.

→ A average output voltage is given by :-

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

$$= \alpha \cdot V_s$$

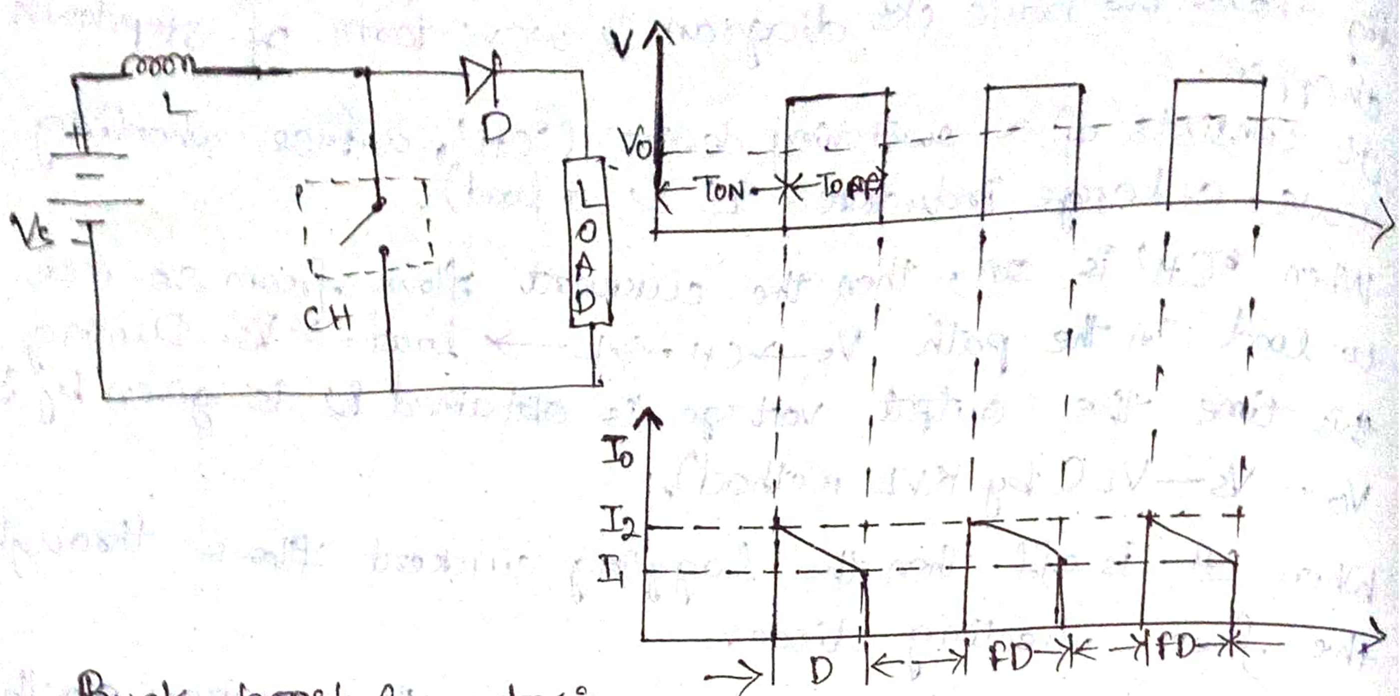
Where, α = duty cycle.

→ Duty cycle is defined as the ratio of on time to the total time.

→ By varying the duty cycle, the output voltage can be varied.

Step up Chopper (Boost Converter) :-

→ The chopper ckt, in which the output voltage is greater than input voltage is known as step up chopper.



Buck-boost Converter:

→ fig shows the ckt diagram of buck boost converter. It consists of a supply voltage (Vs) chopper switch (CH) & an inductor (L), a diode (D) & a load.

→ When switch is on then the current flows through the inductor in the path: Vs → CH → L → Vs.
During this time the inductor stores the energy than energy is given by:

$$E_{ON} = V_s \times \frac{I_1 + I_2}{2} \times T_{ON}$$

→ When switch is off then the current flows through the inductor releases its energy through load & the current flows in the path: L → Load → D → L.

→ The energy released by inductor is given by:

$$E_{off} = V_0 \times \frac{I_1 + I_2}{2} \times T_{off}$$

→ for ~~loss~~ loss less system the storing energy is equal to releasing energy in inductor i.e

$$E_{ON} = E_{off}$$

→ $V_s \times \frac{I_1+I_2}{2} \times T_{ON} = V_0 \times \frac{I_1 I_2}{2} \times T_{off}$

→ $V_s \times T_{ON} = V_0 \times T_{off}$

→ $V_0 = V_s \times \frac{T_{ON}}{T_{off}}$ → $V_s \times \frac{T_{ON}/T}{T - T_{ON}/T}$

→ $\boxed{V_0 = V_s \times \frac{\alpha}{1-\alpha}}$ ∴ $(T = T_{ON} + T_{off})$

→ If CH is continuously "ON" time then $T_{ON} = T$

→ $\alpha = \frac{T_{ON}}{T} = 1$

→ Therefore $V_0 = \frac{1}{0} \times V_s = \infty$. Here $V_0 > V_s$ —— (1)

→ If CH is continuously off then, $T_{ON} = 0$

$\alpha = \frac{T_{ON}}{T} = 0$

→ Therefore, $V_0 = \frac{0}{1} \times V_s = 0$. Here V_0 is less than V_s.

$V_0 < V_s$ —— (2)

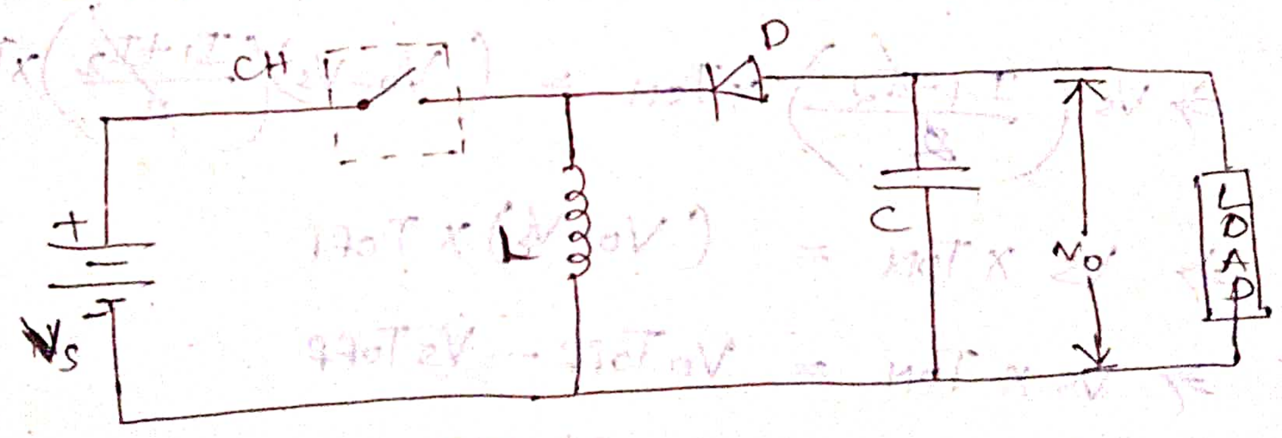
→ If $T_{ON} = T_{off}$, then $\alpha = 0.5$

→ Therefore, $V_0 = V_s$ —— (3)

from eqn (1), (2) & (3) it is cleared that :-

$0 < \alpha < 0.5$ (back converter or stepdown chopper)

$0.5 < \alpha < 1$ (boost converter or step up chopper)



Step up Chopper:

→ fig. shows the basic ckt diagram & wave form of step up chopper.

→ When 'CH' is ON, the current flows through the Inductor in the path $V_s \to L \to CH \to V_s$. During this time the inductor stores energy & the current value increases through inductor.

→ When 'CH' is off, then the inductor releases its energy towards load & the current flows in the path : $V_s \to L \to D \to Load \to V_s$.

→ The output voltage is given by $V_0 = V_s + V_L$. It Indicates the output voltage is greater than the input voltage.
The energy stored in the inductor during 'ON' time is given by

$$\therefore E_{ON} = V_s \left(\frac{I_1 + I_2}{2}\right) \times T_{ON}$$

→ The energy released by the inductor in 'off' time is given by

$$\therefore E_{off} = (V_0 - V_s)\left(\frac{I_1 + I_2}{2}\right) \times T_{off}$$

→ for loss less system:

$$E_{ON} = E_{off}$$

$$\Rightarrow V_s \left(\frac{I_1 + I_2}{2}\right) \times T_{ON} = (V_0 - V_s)\left(\frac{I_1 + I_2}{2}\right) \times T_{off}$$

$$\Rightarrow V_s \times T_{ON} = (V_0 - V_s) \times T_{off}$$

$$\Rightarrow V_s \times T_{ON} = V_0 T_{off} - V_s T_{off}$$

$$\Rightarrow V_s T_{ON} + V_s T_{off} = V_0 \cdot T_{off}$$

$$\Rightarrow V_s (T_{ON} + T_{off}) = V_0 T_{off}$$

$$\Rightarrow V_s \times T = V_0 \cdot T_{off}$$

$$\Rightarrow V_o = V_s \frac{T}{T_{off}}$$

$$\Rightarrow V_o = V_s \times \frac{T/T}{T_{off}/T}$$

$$\Rightarrow V_o = V_s \times \frac{T/T}{(T - T_{ON})/T}$$

$$\Rightarrow V_o = V_s \times \frac{1}{\left(1 - \frac{T_{ON}}{T}\right)}$$

$$\Rightarrow V_o = V_s \left(\frac{1}{1-\alpha}\right)$$

→ When 'CH' is always 'ON', $\alpha = 1$

$\Rightarrow V_o = \infty$

→ When 'CH' is always 'off', then $\alpha = 0$

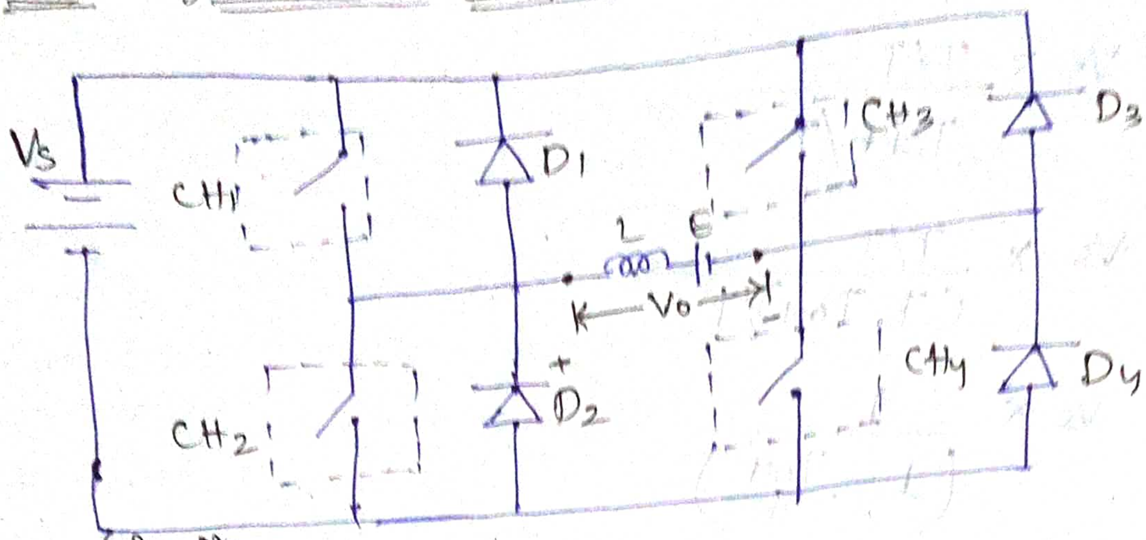
$\Rightarrow V_o = V_s$

So, the output voltage can be varied by varying the duty cycle from $0 < \alpha < 1$.

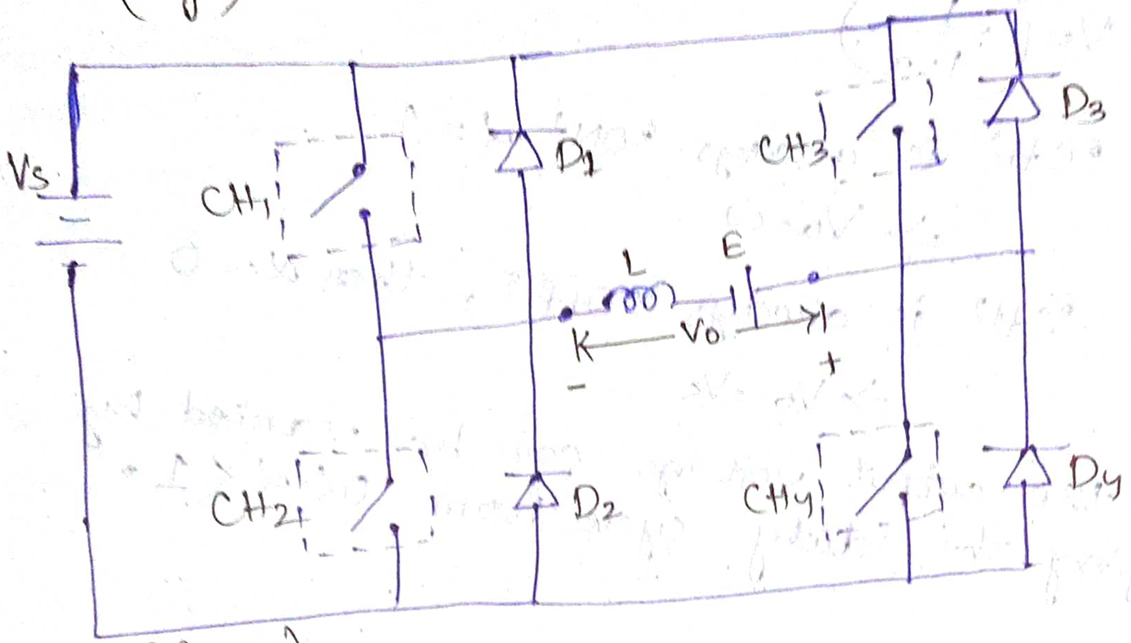
Date: 07/11/2021

10 mark imp

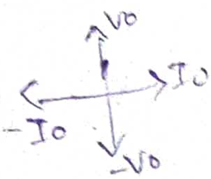
Four Quadrant Chopper: (Type E)

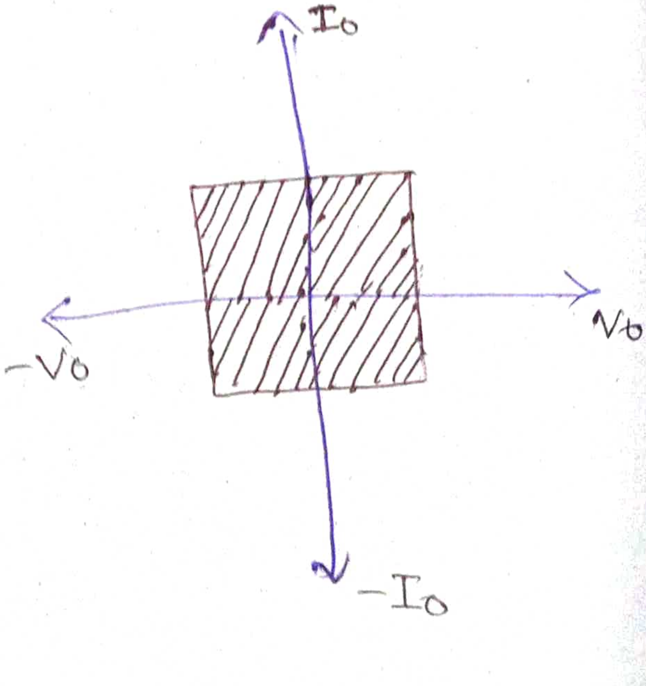


(fig i)



(fig ii)





→ fig. shows the ckt diagram of type E chopper. It consists of 4 chopper switches (CH_1, CH_2, CH_3, CH_4), 4 diodes (D_1, D_2, D_3, D_4) & a supply voltage (V_s) with inductive load & source voltage (E). All the components are are arranged as per the ckt diagram.

→ fig (i) indicates the 1st quadrant & 2nd quadrant operation that means the o/p voltage is positive but the o/p current may be positive or negative.

→ fig (ii) indicates the 3rd quadrant & 4th quadrant operation that means the o/p voltage is positive negative but the o/p current maybe positive or negative.

1st quadrant operation :-

→ In this quadrant operation CH_1 is operated, CH_4 is 'ON' & CH_2, CH_3 remain 'off'.

→ When CH_1 is 'ON' then the current flows due to source voltage towards load in the path :-

$V_s \rightarrow CH_1 \rightarrow L \rightarrow E \rightarrow CH_4 \rightarrow V_s$.

During this the induction stores energy. Here the current & voltage remain positive.

→ When CH_1 is 'off' then the inductor releases its energy by supplying a current in the path :-

$L \rightarrow E \rightarrow CH_4 \rightarrow D_2 \rightarrow L$. Here the voltage & current remain positive.

→ In both cases (i.e 'ON' & 'off' of CH_1) the o/p voltage & o/p current remain positive. So, it indicates 1st quadrant operation.

2nd quadrant operation:-

→ In this quadrant operation CH_2 is operated & CH_1, CH_3, CH_4 remain 'OFF'.

→ When CH_2 is 'ON', then the current flows due to the source 'E' in the path :- $E \rightarrow L \rightarrow CH_2 \rightarrow D_4 \rightarrow E$
Here the current is negative & voltage is positive & the inductor stores energy.

→ When CH_2 is 'off', then the inductor releases its energy by supplying a current in the path :-
$L \rightarrow D_1 \rightarrow V_s \rightarrow D_4 \rightarrow E \rightarrow L$.
Here current is negative & voltage is positive.

→ In both cases (i.e 'ON' & 'off' of CH_2) the o/p voltage is (+)ve & o/p current is (−)ve. So, it indicates 2nd quadrant operation.

3rd quadrant operation:-

→ In this quadrant operation CH_3 is operated & CH_2 remains 'ON' & CH_1, CH_4 remain 'off'.

→ When CH_3 is 'ON' then the current flows due to source voltage V_s towards the load in the path:-
$V_s \rightarrow CH_3 \rightarrow E \rightarrow L \rightarrow CH_2 \rightarrow V_s$.
During this time inductor stores energy.
Here the voltage & current remain negative.

→ When CH_3 is 'off', then the inductor releases its energy by supplying a current in the path:-
$L \rightarrow CH_2 \rightarrow D_4 \rightarrow E \rightarrow L$.
Here the current & voltage negative.

→ In both cases (i.e 'ON' & 'off' of CH_3) the o/p voltage & o/p current remain negative. So, it indicates the 3rd quadrant.

4th quadrant operation:-

→ In this quadrant operation CH_4 is operated & CH_1, CH_2, CH_3 remain 'OFF'.

→ When CH_4 is 'ON', then the current flows due to the source 'E' in the path :- $E \rightarrow CH_4 \rightarrow D_2 \rightarrow L \rightarrow E$.
Here the current is positive & voltage is negative & the inductor stores energy.

→ When CH_4 is 'OFF', then the inductor releases its energy by supplying a current in the path - $E \rightarrow D_3 \rightarrow V_s \rightarrow D_2 \rightarrow L \rightarrow E$.
Here current is positive & voltage is negative.

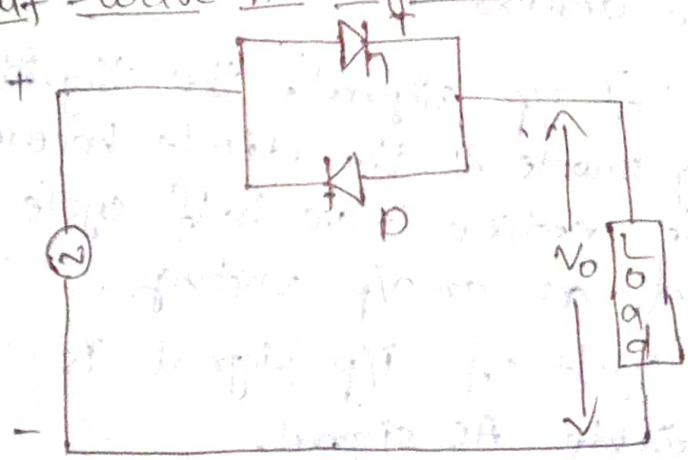
→ In both cases (i.e 'ON' & 'OFF' of CH_4) the o/p voltage is negative & o/p current is positive. So, it indicates 4th quadrant operation.

AC - Voltage Regulator:-

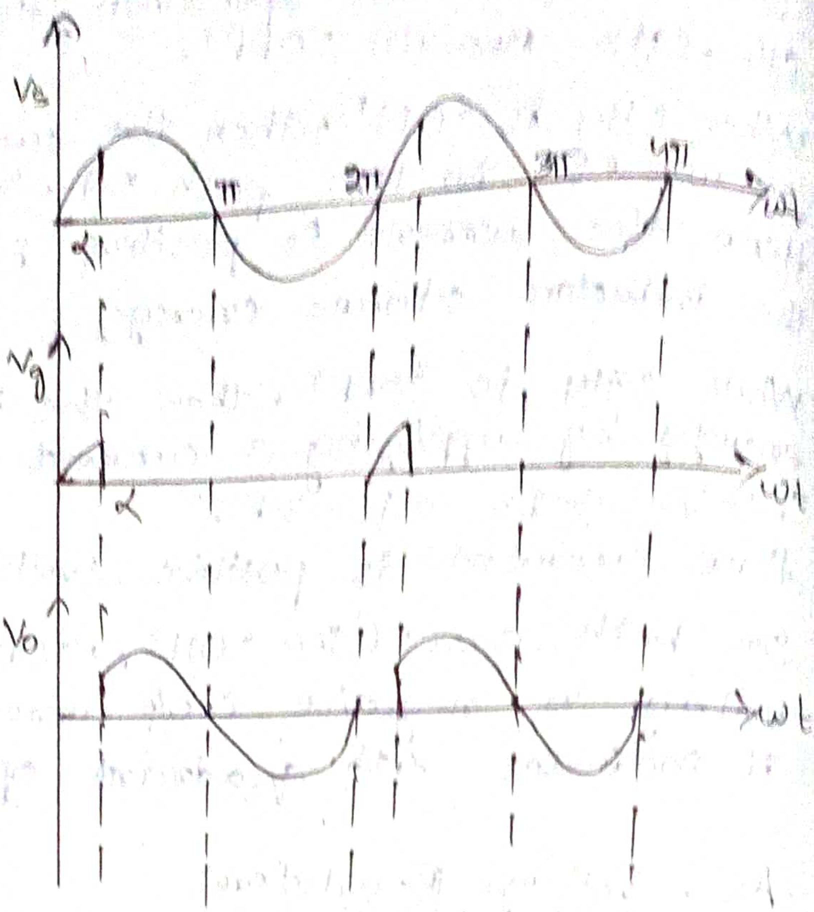
→ It is an electronic device, which converts a fixed AC signal into variable AC signal.
That means the amplitude of the i/p AC signal can be varied.

→ It is of 2 types:- that is
(i) Half-wave AC regulator.
(ii) Full-wave AC regulator.

(i) Half-wave AC regulator:-



→ The AC regulator in which the o/p voltage is controlled by only 1 half cycle of i/p signal, then it is called Half-wave AC regulator.



→ fig. shows the circuit diagram & wave form of half-wave AC regulator.
It consists of a thyristor & a diode connected in anti parallel connection.
A supply voltage & load is connected as shown in fig.

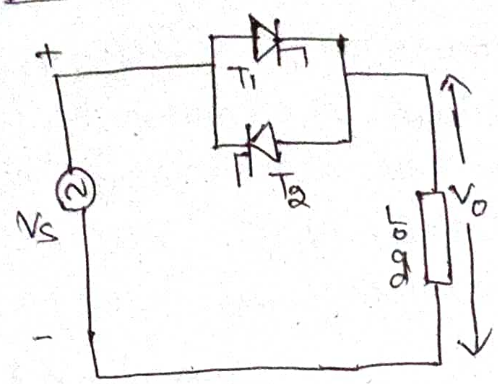
→ During (+)ve half cycle of i/p signal the thyristor is in forward-blocking mode & the diode is in reverse biased condition.

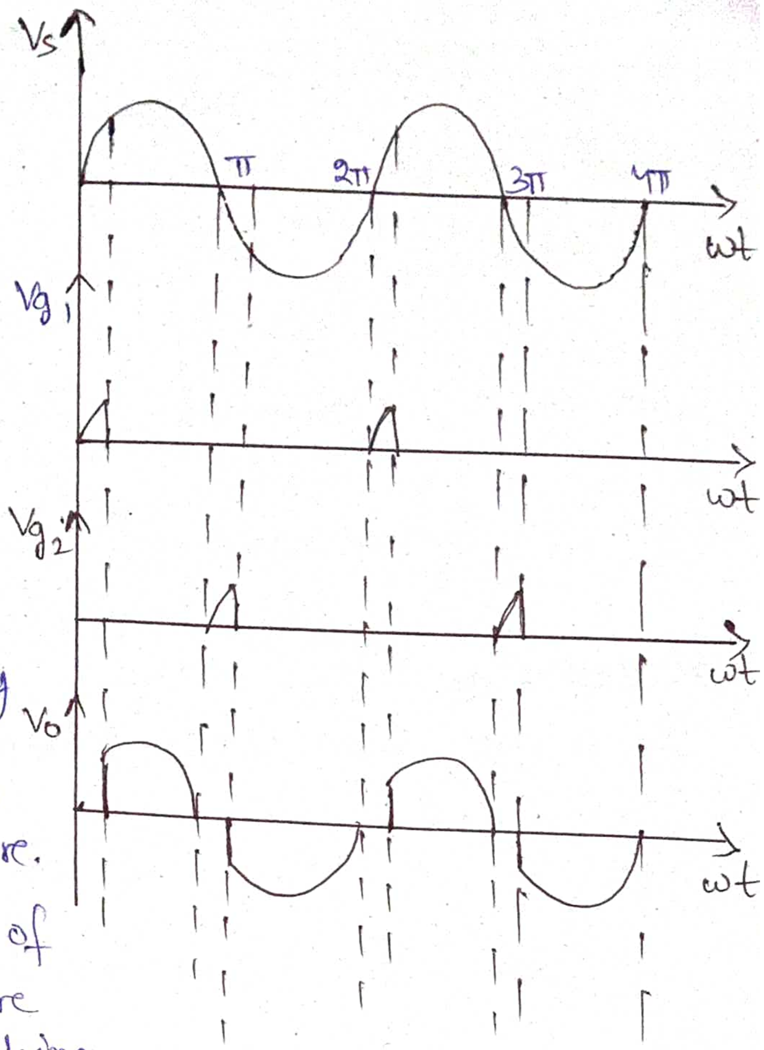
→ When the thyristor is triggered after firing angle 'α' then it is turned 'ON' & the current flows towards the load.
So, o/p voltage will come across the load.

→ During (−)ve half-cycle of i/p signal, the thyristor is in reverse blocking mode & the diode becomes forward biased. So, the entire (−)ve half cycle comes across the load as an o/p voltage.

→ In this way 1 half cycle of i/p signal is controlled to get variable AC signal.

(ii) Full-wave AC Regulator :-





→ The AC regulator in which the o/p voltage is controlled by controlling both half-cycles of i/p signal is known as full-wave AC regulator.

→ During (+)ve half cycle of i/p signal the thyristor 'T_1' is in forward blocking mode & thyristor 'T_2' is in reverse blocking mode.

→ When gate supply is given to the thyristor 'T_1' after firing angle 'α_1', then it conducts & the current flows towards load & o/p voltage will come across load.

→ During -ve half cycle of i/p signal, the thyristor 'T_1' is in reverse blocking mode & thyristor 'T_2' is in forward blocking mode.

→ When gate supply is given to the thyristor 'T_2' after firing angle 'α_2', then it conducts & the current flows towards load & o/p voltage ~~'α_2' then it cond~~ will come across load.

→ In this way the o/p voltage can be controlled by controlling both half cycles of i/p signal.

Date 14/12/21 CHAPTER: 3 Understand The Inverts & CycloConverters.

Defination:- CycloConverter:-

It is an electronic device that converts AC signal in one frequency into AC signal in another frequency. So, the cyclo converter is also called AC to AC converter or frequency changer.

Advantages:-

→ It provides direct frequency conversion without any intermmediate stage.
→ It can transfer the power bi-directionally.
→ It can operate at any power factor.
→ It can be useful for very low speed application.
→ It provides high quality sinosoidal signal at low frequency.

Disadvantages:-

→ It's control circuit is complex due to use of more SCR.
→ The power factor becomes low for low voltage.
→ The supply ~~gets~~ gets short circuited, due to failure of commutation.
→ The output frequency is limited upto 1/3rd of i/p frequency.

Application:-

It is used in speed control of high speed AC drives, Induction heating, Static VAR compensation, Air craft, Ship Control mode.

Types of Cycloconverter:-

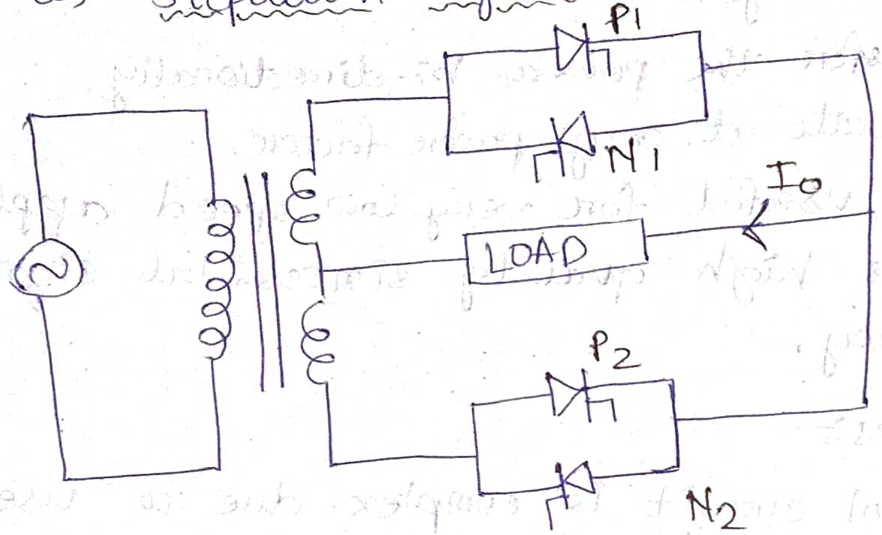
It is of 2 types such as :-

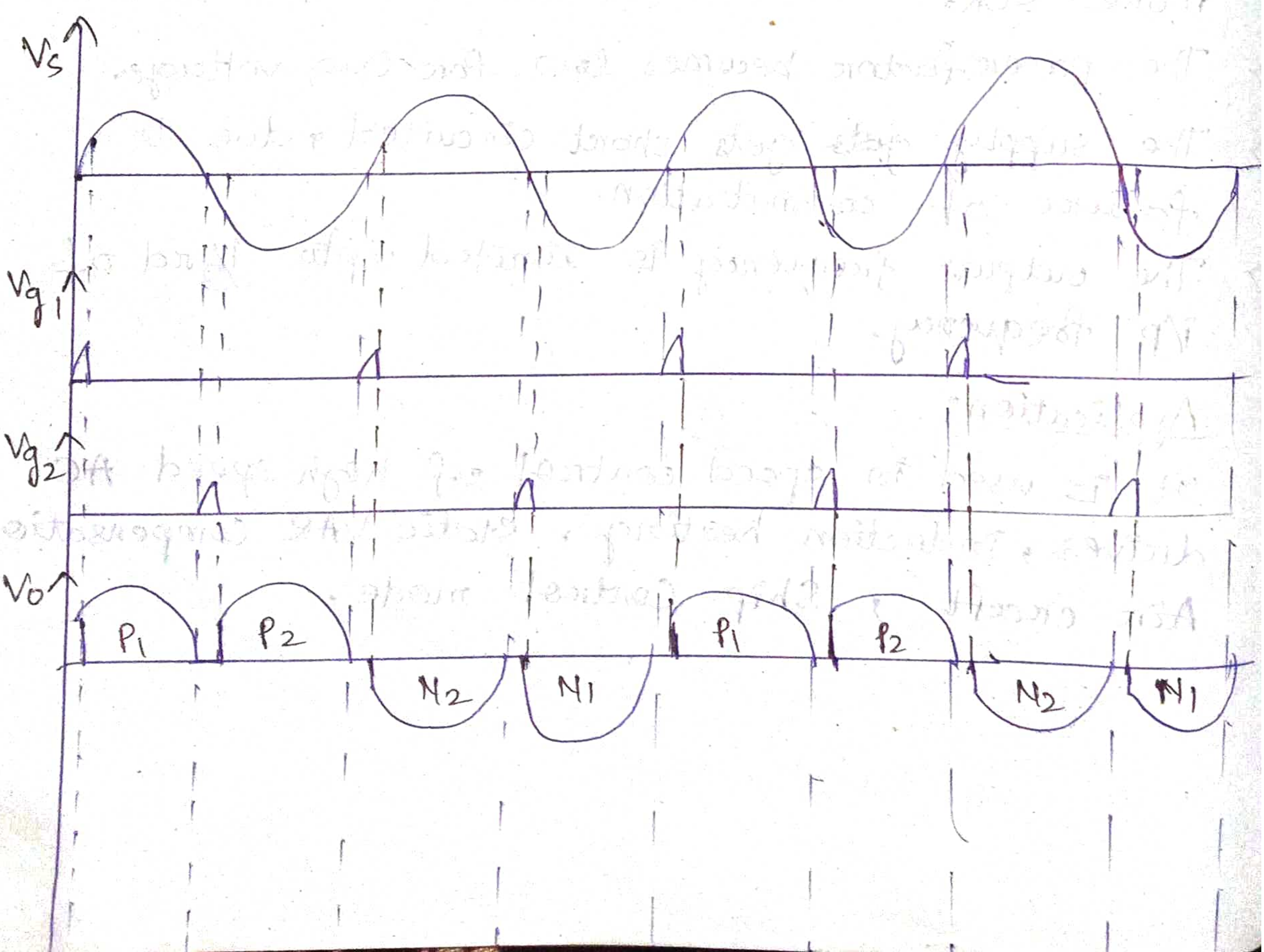
(i) Step up cycloconverter

(ii) Step down cycloconverter.

Stepdown Cycloconverter:-

→ The cycloconverter in which, the output frequency is less than input frequency (i.e $f_o < f_s$) is known as "Stepdown Cycloconverter".





→ The cyclo-converter in which the o/p frequency is smaller than i/p frequency is known as stepdown cyclo-converter.

→ fig. shows the ckt diagram & waveform of stepdown cyclo-converter.
It consists of a centre tapped transformer, 4SCR, i.e (P_1, P_2, N_1, N_2) & a load.

→ P_1–N_1 & P_2–N_2 are connected in anti-parallel connection.

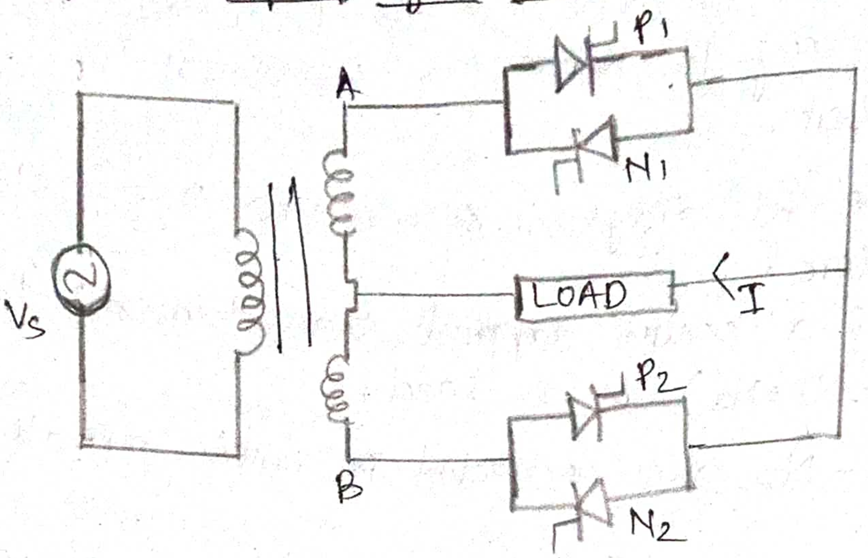
→ During (+)ve half cycle of i/p signal (i.e $\omega t = 0-\pi$) the SCR- P_1 & N_2 are in forward blocking mode. If P_1 is triggered after firing angle 'α_1' then the o/p will come as +ve half cycle.

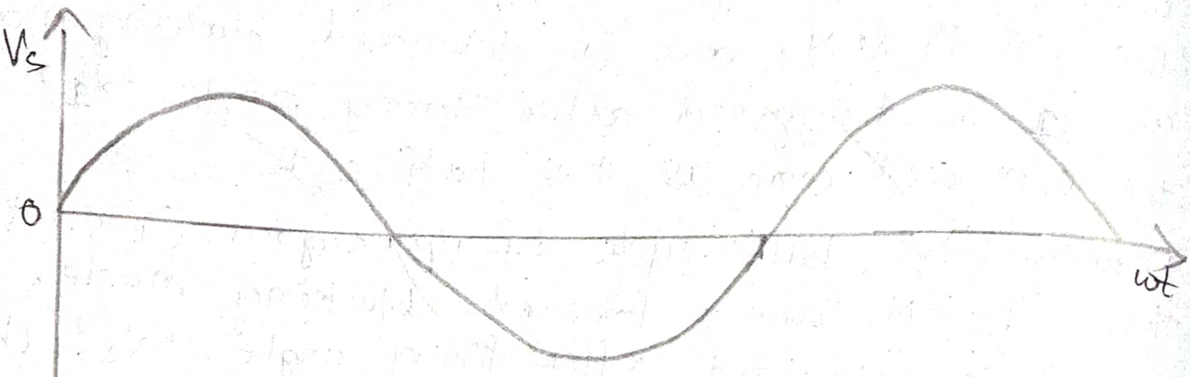
→ During (−)ve half cycle of i/p signal (i.e $\omega t = \pi - 2\pi$) the P_2 & N_1 are in forward blocking mode. If P_2 is triggered after firing angle 'α_2' then the o/p will come as (+)ve half cycle.

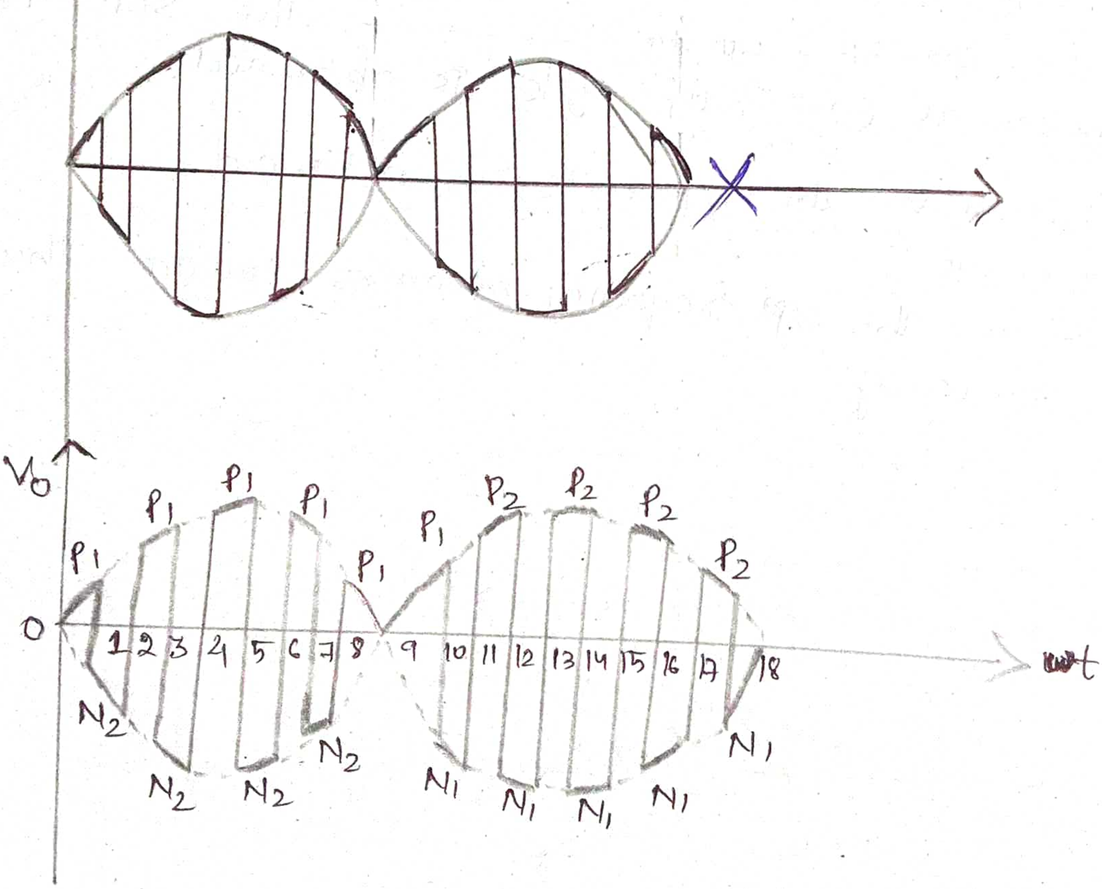
→ At $\omega t = 2\pi - 3\pi$, $6\pi - 7\pi$ -------- the SCR N_2 is triggered as (−)ve half cycle is obtained.

→ In this wave the o/p cycle is obtained $\omega t = 0$ to 4π.
Therefore the o/p frequency becomes lower than the i/p frequency.

Single phase step-up cyclo converter:







→ The cyclo converter in which the o/p frequency is greater than i/p frequency is known as step-up cyclo converter.

→ fig. shows the ckt diagram & wave form of step up cyclo converter.
It consists of a centre tapped transformer, 4 SCR, i.e (P_1, P_2, N_1, N_2) & a load.

→ P_1 – N_1 & P_2 – N_2 are connected in anti parallel connection as shown in fig.

→ During (+)ve half of i/p signal the terminal 'A' has higher potential than terminal 'B'. So, the SCR P_1 & N_2 are in forward blocking mode.

→ SCR P_1 is triggered at ωt=0, t_2, t_4, t_6, So the P_1 acts as close switch & current flows towards the load at o/p is obtained as the (+)ve cycle.

→ At ωt= t_1, t_3, t_5 ---- the SCR P_1 is forced commutated & SCR N_2 is triggered.
So, the N_2 acts as closed switch & the current flows through load & o/p is obtained as -ve half cycle.

→ During (-)ve half cycle of i/p signal the SCR P_2 & N_1 are in forward blocking mode.

→ At ωt = t_9, t_{11}, t_{13} ------ the SCR P_2 is forced commutated & SCR N_1 is triggered.
So, current flows through load & o/p is obtained as (-)ve half cycle.

→ In this way more no. of cycles are created for one cycle of i/p signal.
So, the o/p frequency is greater than i/p frequency which indicate step up cyclo converter.

Date: 16/11/2021

Inverter:

(i) It is an electronic device, which converts DC power into AC power with desired voltage & frequency.

(ii) Inverters are used in air craft for power supply, UPS, Induction heating, adjustable speed AC drives, HVDC transmission line etc.

(iii) The DC power is obtained from alternator with rectifier, battery, solar pannel, magneto-hydro dynamic generator. (MHD).

(iv) According to source of i/p supply, inverter is of 2 types (i.e).
(a) Voltage source inverter (VSI)
(b) Current source inverter (CSI)

(v) According to the connection of semi-conducting component inverter is of 3 types (i.e)
(a) Bridge inverter.
(b) Series inverter.
(c) Parallel inverter.

(a) Bridge type inverter:-

→ The inverter in which bridge circuit are used, is known as bridge inverter.

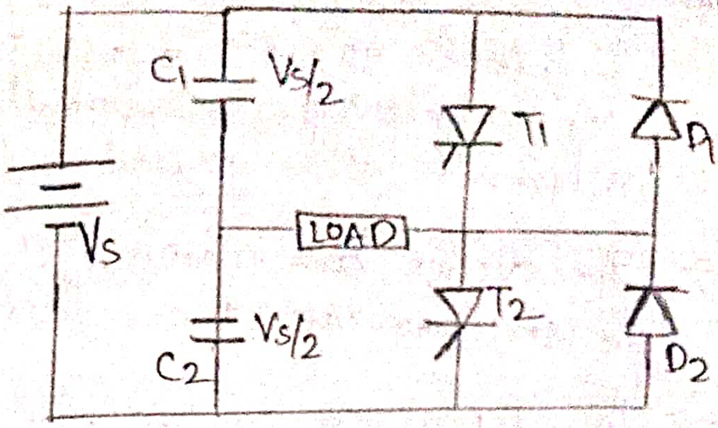
→ It is of 2 types:- (i) Half-bridge inverter.
(ii) Full-bridge inverter.

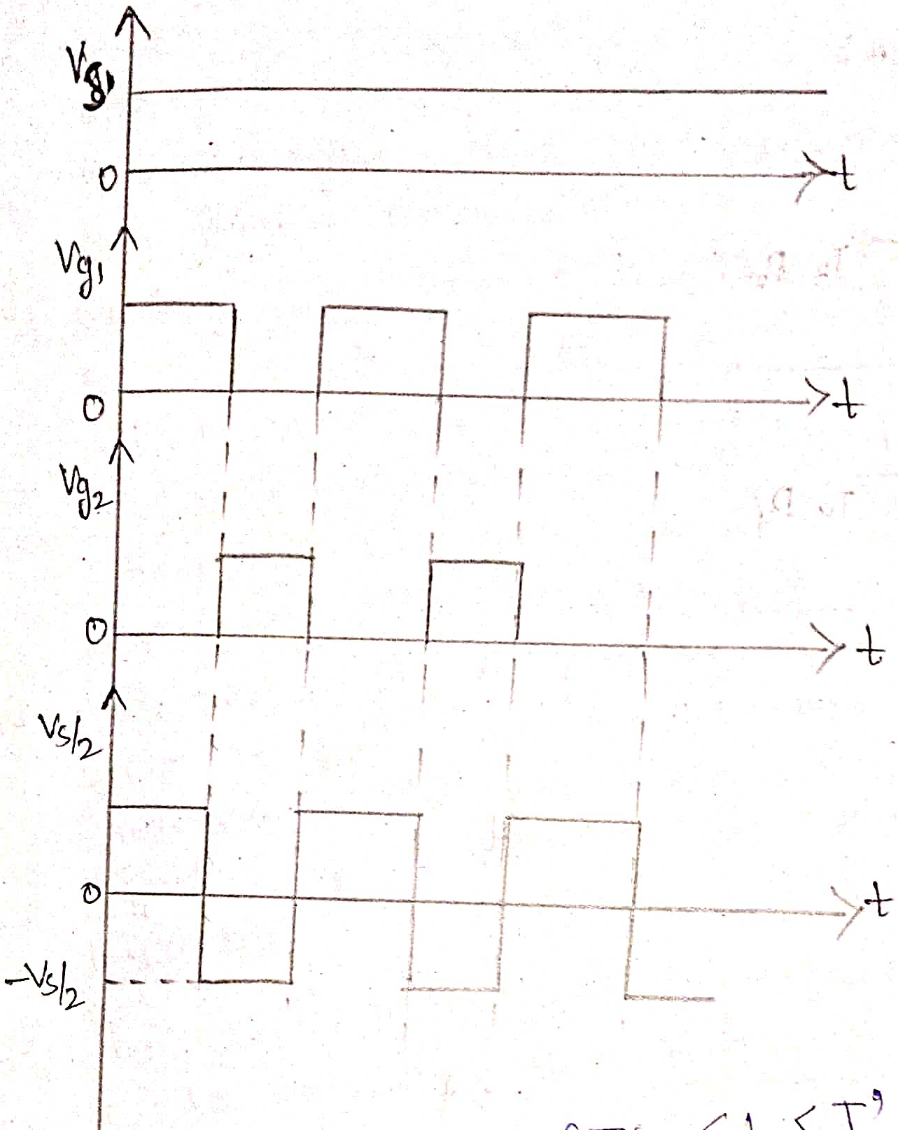
(i) Half-Bridge inverter:

→ The voltage across each capacitor is equal to the half of the supply voltage (i.e $V_C = V_S/2$).

→ During ('$0 \leq t \leq T/2$') the thyristor 'T_1' is trigerred & turn ON by applying gate supply. So, the current flows towards the load in direction '$C_1 \rightarrow T_1 \rightarrow$ load $\rightarrow C_1$'.

→ After the time 't = T/2' the thyristor 'T1' is forced commutated, so the o/p is obtained as Vs/2.





→ During the time 'T/2 ≤ t ≤ T' the thyristor 'T2' is turned ON applying gate supply at the time t = T/2. So, the current flows towards the load in the direction :- $C_2 \to$ load $\to T_2 \to C_2$.

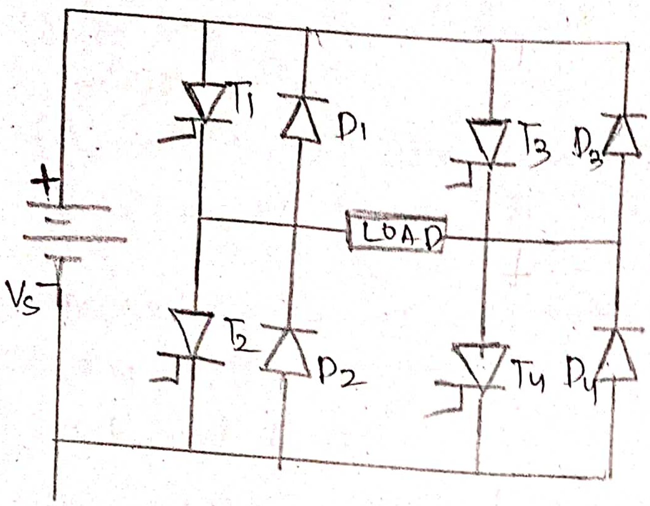
After that the thyristor 'T2' is forced commutated.

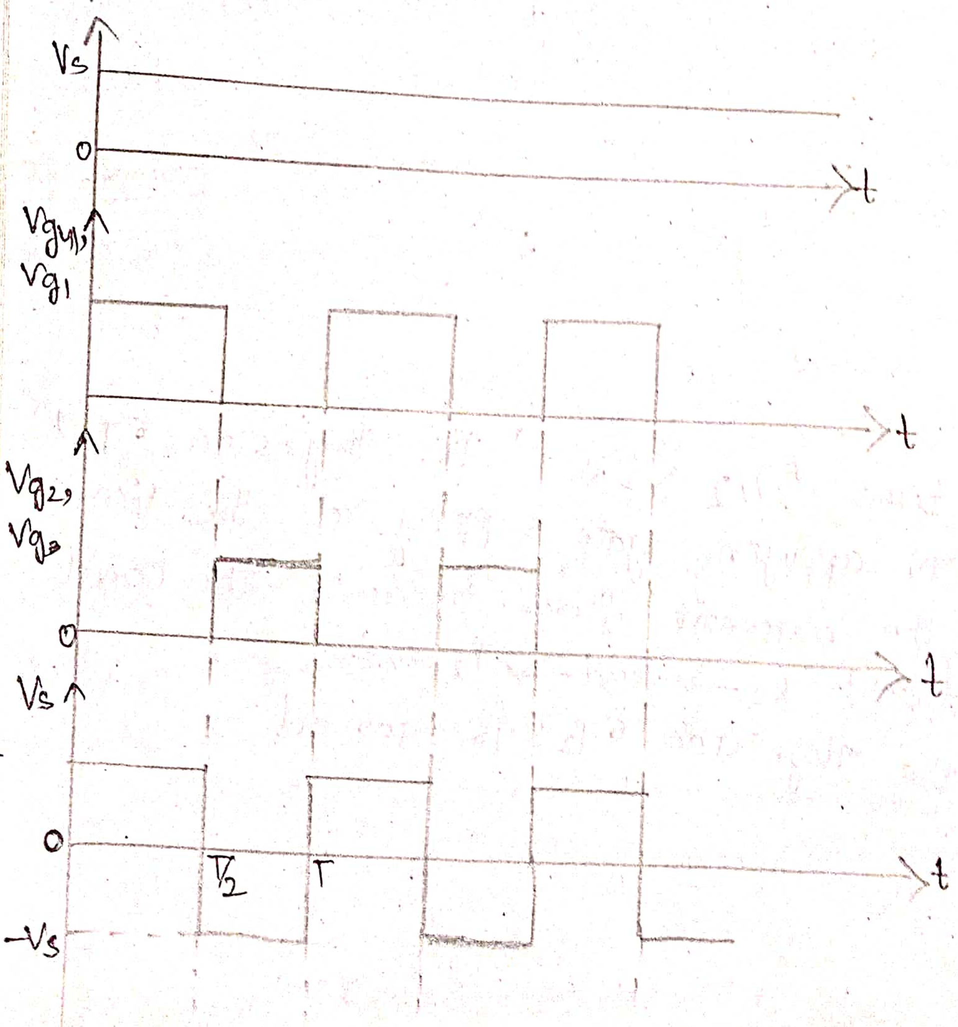
→ In this way, a (+)ve half cycle & -ve half cycle is obtained across the load.
Therefore the DC signal is converted to AC signal by triggering & commutating the thyristors in different time period.

→ The diodes are used for protection of thyristor & to provide the feedback path.

→ The frequency of o/p signal is given by :- $f = \frac{1}{T}$.

(ii) Full-Bridge Inverter:





→ fig. shows the diagram & waveform of full bridge inverter.
It consists of 4 thyristors, i.e (T_1, T_2, T_3 & T_4), 4 diodes (D_1, D_2, D_3, D_4) & a resistive load.

→ During the time '$0 \leq t \leq T/2$' the thyristor 'T_1 & T_4' are turned 'ON' by applying the gate supply. So, the current flows towards the load in the path :- $V_s \rightarrow T_1 \rightarrow$ load $\rightarrow T_4 \rightarrow V_s$.

→ Therefore the o/p voltage is obtained in positive direction, which is equal to the supply voltage.

→ Then at the time $t = T/2$ the thyristor 'T_1 & T_4' are forced commutated.

→ During the time '$T/2 \leq t \leq T$' the thyristor 'T_2 & T_3' are triggered at $t = T/2$. So, the current flows towards load in the path :-
$V_s \rightarrow T_3 \rightarrow$ load $\rightarrow T_2 \rightarrow V_s$.
Therefore the o/p voltage is obtained in (-)ve direction which is equal to supply voltage.

→ In this way, a positive & a negative half cycle is obtained across the load.
Therefore the DC signal is converted to AC signal by triggering & commutating the thyristor at different time period.

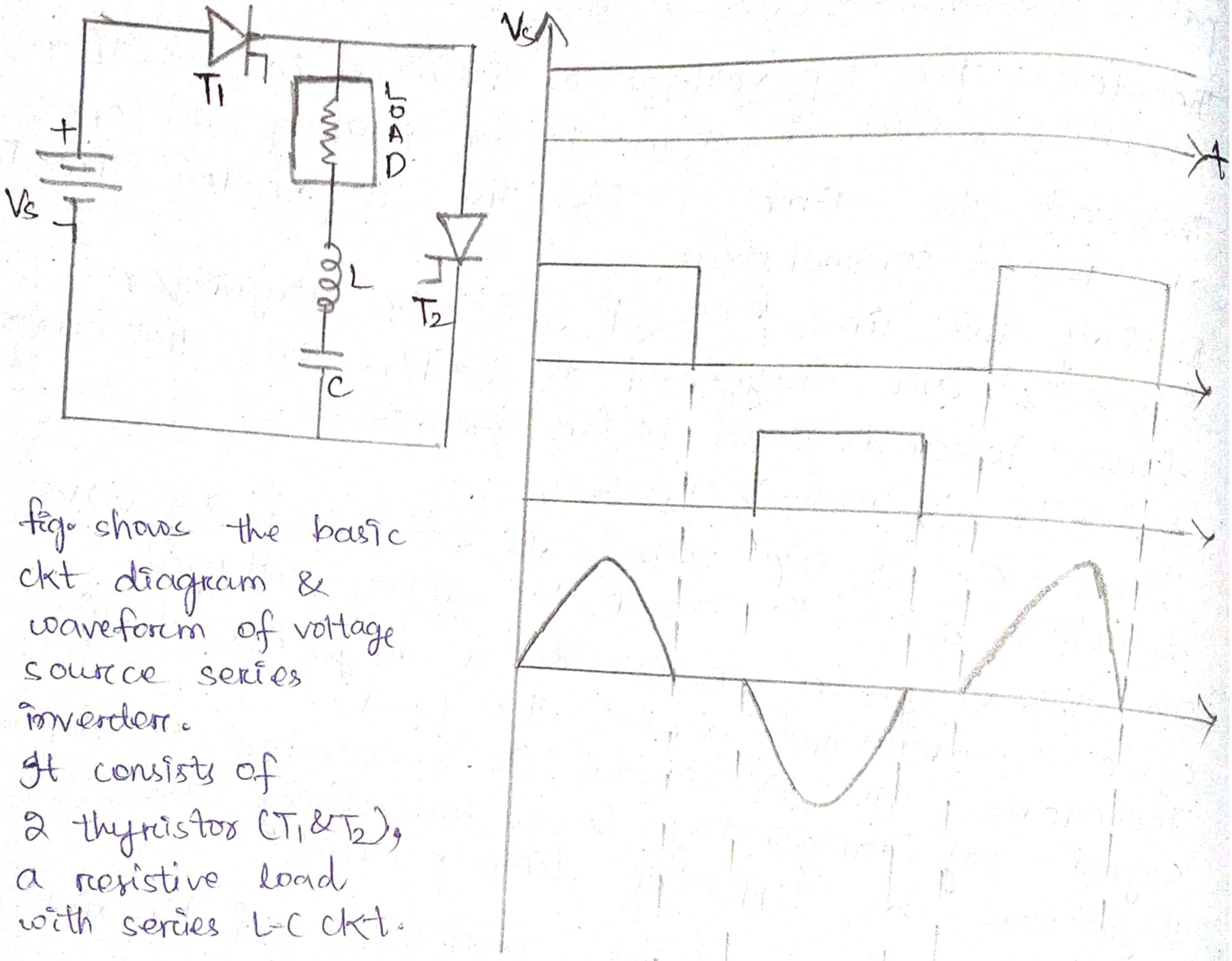
→ The diodes are used for protection of thyristor & to provide the feedback path.

→ The frequency of o/p signal is given by :-
$f = \frac{1}{T}$.

(ii) Series Inverter:

→ The inverter in which the commutating components are permanently connected in series with load, is known as Series Inverter.

It is also called self commutated inverter or load commutated inverter.

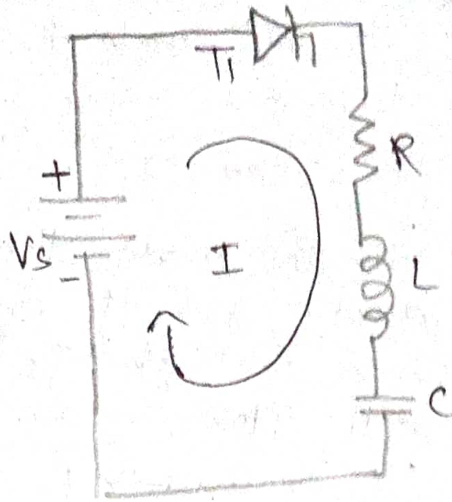


→ fig. shows the basic ckt diagram & waveform of voltage source series inverter.

It consists of 2 thyristor (T_1 & T_2), a resistive load with series L-C ckt.

→ The operation of this inverter has three modes i.e mode 1, mode 2 & mode 3.

Mode 1 :-

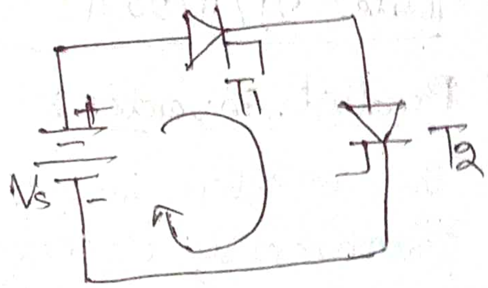


→ In this mode the main thyristor 'T_1' is triggered by applying gate voltage. So, the current will flow towards the load through the path :- 'V_s → T_1 → load → L → C → V_s'

→ When the load current reaches max^m value, then the voltage across capacitor will be greater than the supply voltage. Therefore the thyristor 'T_1' is forced commutated by capacitive voltage, then the current value decreases.

→ During this mode the (+)ve half cycle of current is obtained at the load.

Mode 2 :-



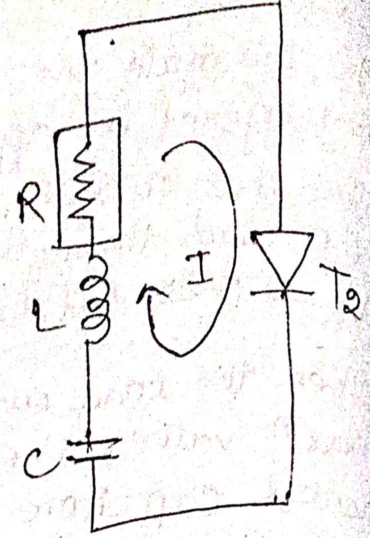
→ In this mode both thyristors are triggered by applying Gate voltage. So, the current will flow in the path :- 'V_s → T_1 → T_2 → V_s'

→ Here a short circuit path is obtained across the supply voltage. So, the o/p voltage will be zero. This situation is called dead zone of operation.

→ Due to short ckt of voltage source there will be a chance of damage. So, both thyristors can not be turned 'ON' simultaneously.

Mode 3:-

→ In this mode the thyristor 'T2' is triggered after turned 'off' of thyristor 'T1'.



→ In this mode the capacitor discharges its energy towards load through 'T2' & the current will flow in the path:-
'C → load → R → T2 → C'.
Here the current is in opposite direction of 'mode 1'. So, it is treated as -ve half cycle.

→ In this way the DC supply is converted to AC supply by using series inverter.

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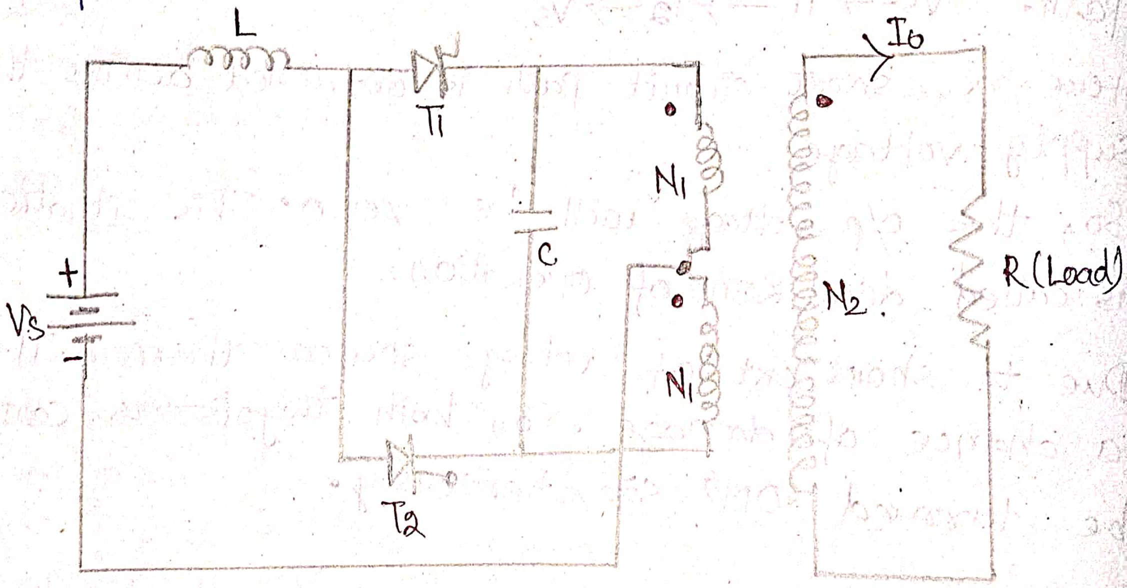
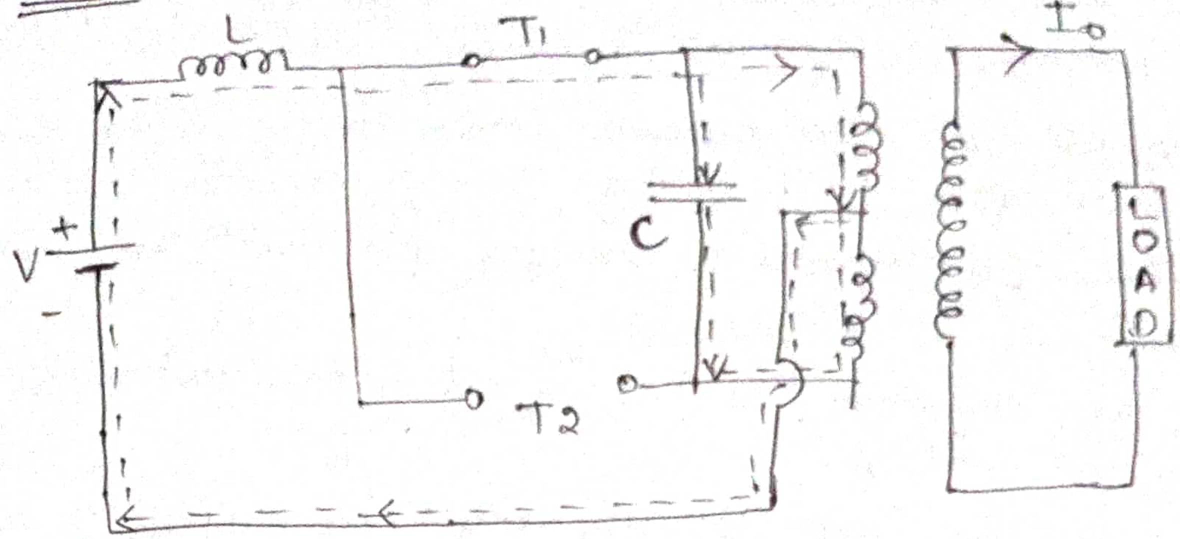
(iii) Parallel inverter:-

→ The inverter in which the commutating components are permanently connected in parallel with load, is known as parallel inverter.



☆ Operation of parallel inverter can be explained in 2 modes:-

Mode:-1



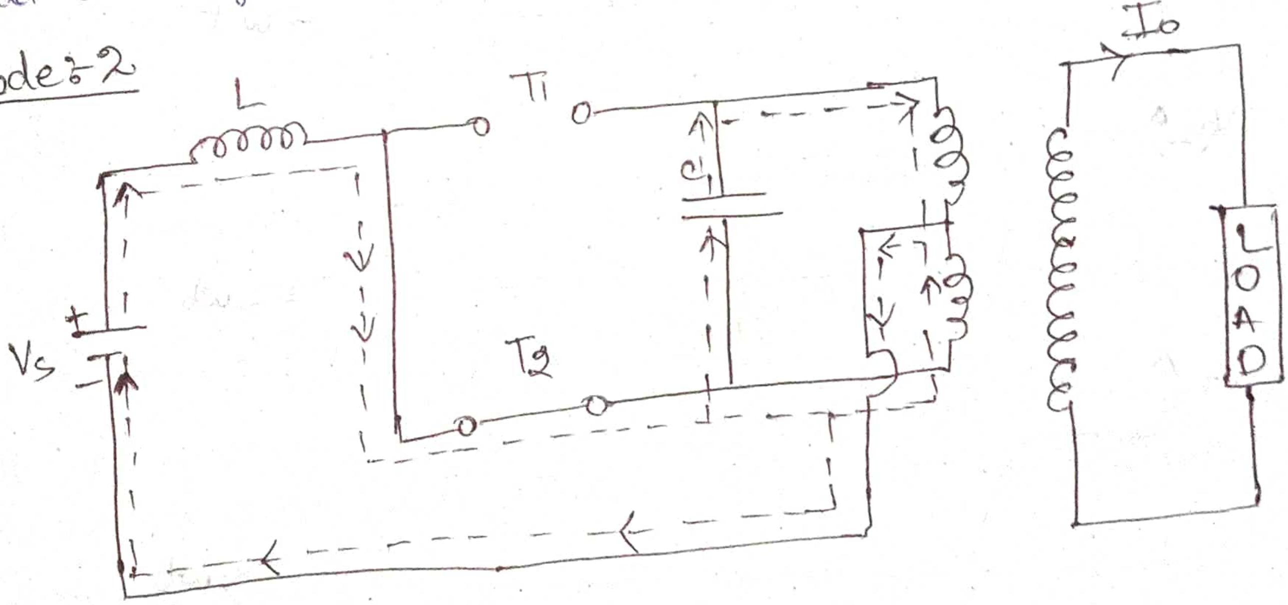
- **mode-1:**

→ In this mode thyristore 'T1' is triggerred by applying Gate voltage & thyristore 'T2' remain 'off'.

→ During this time the currecent flows in the upper half of winding & lower half of winding through capacitore. Therefore the capacitore charges upto maxm value (2Vs).

→ When the capacitore is fully charged, then the thyristore 'T1' is forced commutated due to capacitive voltage.
At this time the capacitore discharges through the load winding & (+)ve half cycle is obtained.

Mode:-2



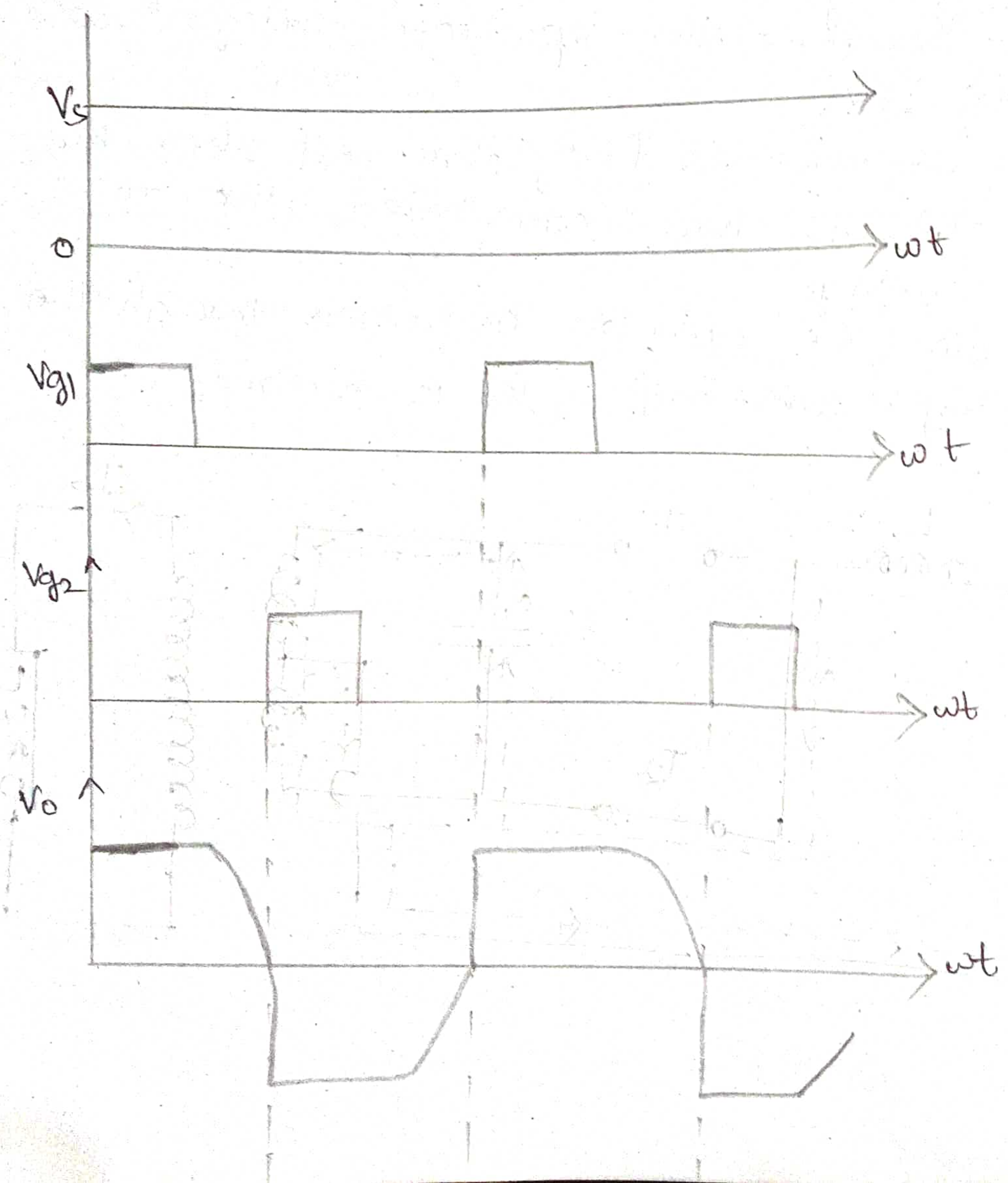
→ In this mode, the thyristore 'T2' is triggerred by applying Gate voltage & thyristore T1 remain 'off'.

→ During this time the currrent flows in the lowere half winding & upper half winding through capacitore. Therefore the capacitore charrges upto maxm -ve voltage (-2Vs).

→ Then the thyristore 'T2' is forced commutated due to capacitive voltage.

→ After that the capacitore discharrges by supplying a current towards the transformere & -ve half cycle is obtained.

→ In this way the fixed DC voltage is converted to AC voltage by using parrallel inverter.



Date 21/12/21 Chapter:-4 APPLICATIONS OF POWER ELECTRONICS CIRCUIT

UPS (Uninterrupted Power Supply)

→ It is a static device, which provides a continuous power supply towards the load without any interruption.

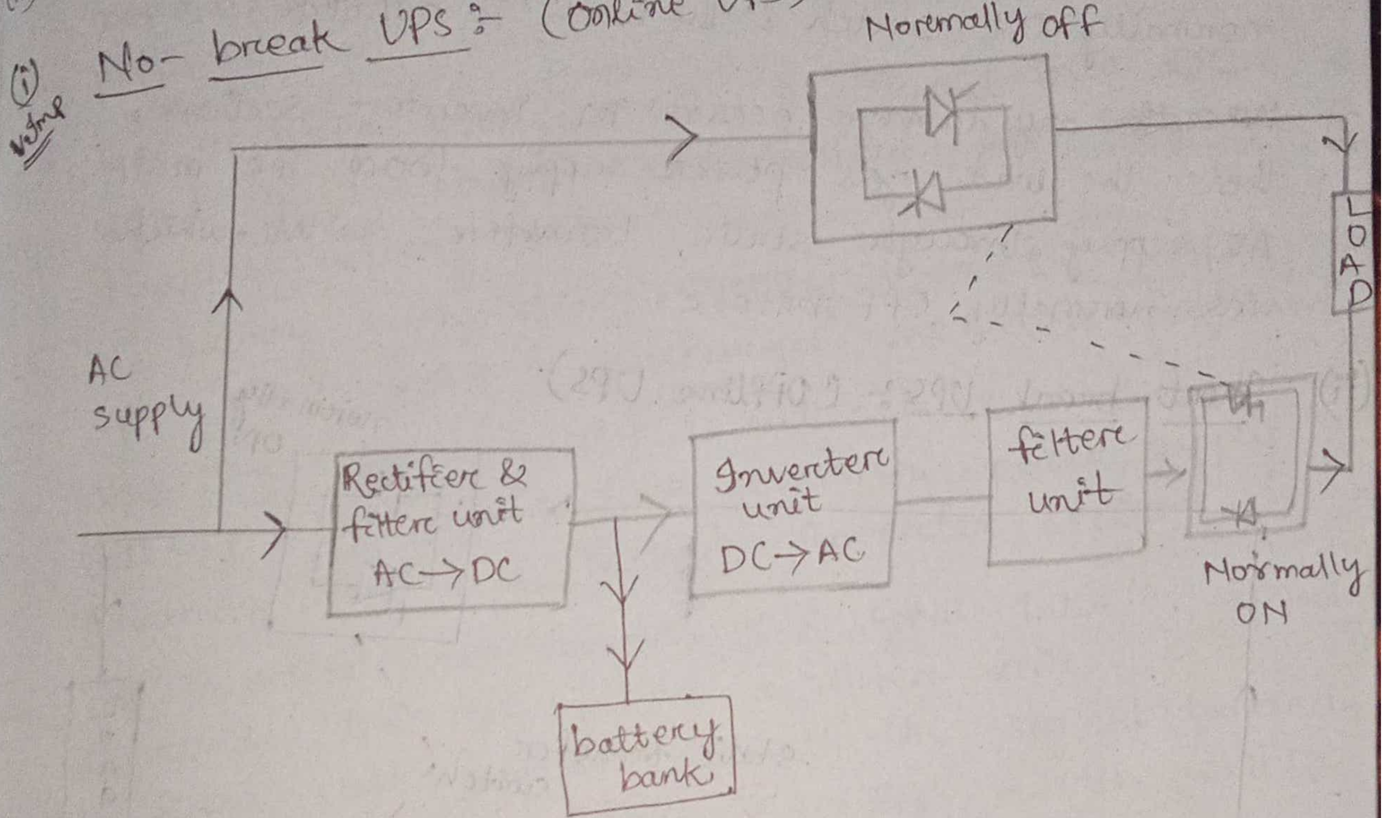
→ It is used in critical loads which are present in computer, process control in chemical plant, communication system, ICU in hospital etc.

→ It is of 2 types such as:-

(i) No-break UPS (Online UPS)

(ii) Short-break UPS (Offline UPS)

(i) No- break UPS :- (Online UPS)



→ fig. shows the basic block diagram of online UPS. It consists of rectifier & filter unit, battery bank, inverter unit, filter unit, static transfer switch at load.

→ This UPS is called online UPS because the load gets continuous power ~~form~~ from the inverter unit without any interruption.

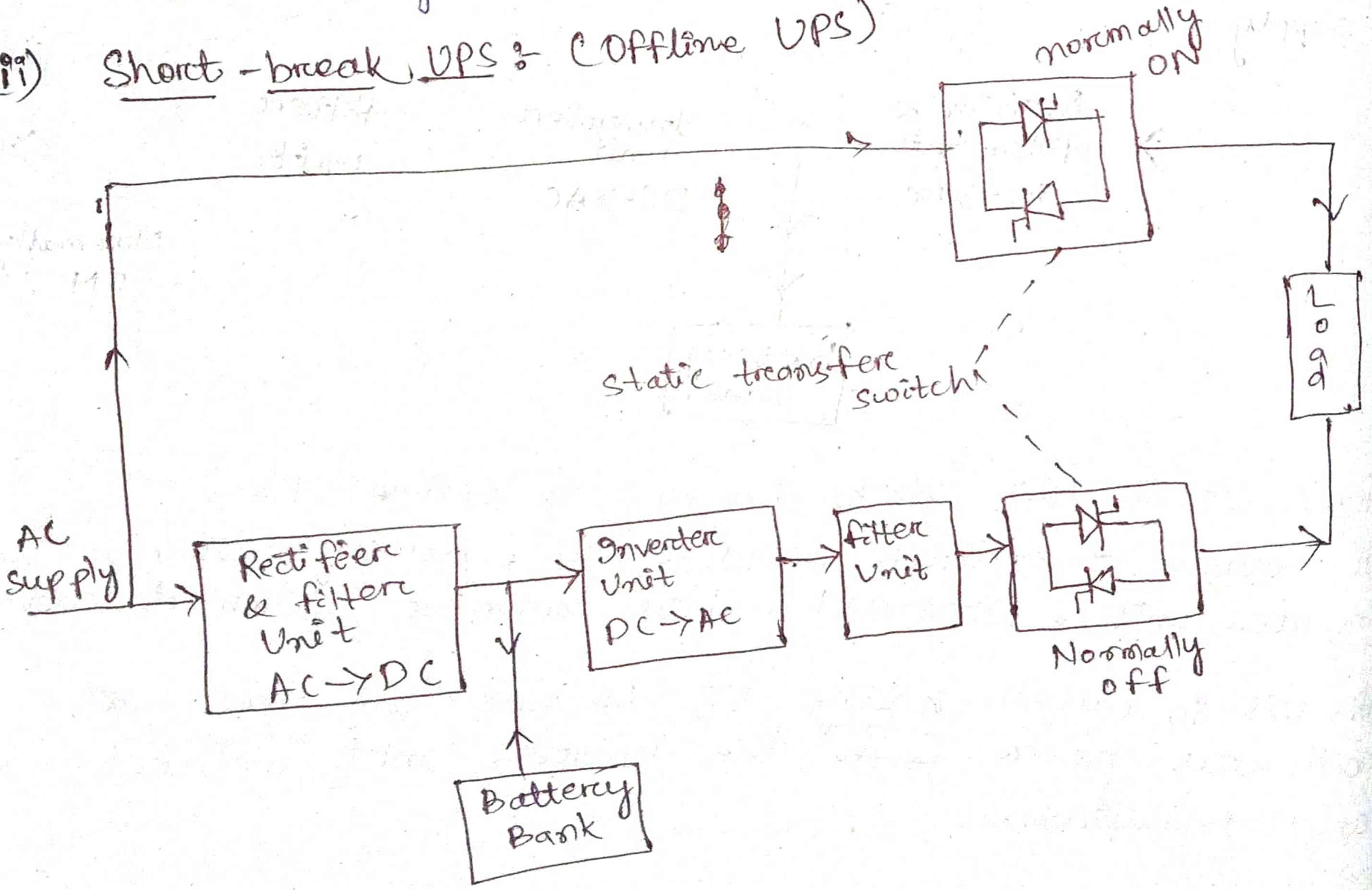
→ The AC supply is given towards rectifier & filter unit which converts AC supply into DC supply.

→ The DC supply is given towards battery bank & inverter unit.
The battery bank stores energy upto max^m value & discharges its energy whenever required.

→ The inverter unit converts DC supply into AC supply. This AC supply is given towards filter unit. The filter unit provides a smooth AC supply. Then AC signal is given towards load through normally ON switch & the load is activated.

→ When ~~the~~ any damage occurs in inverter section, then the load gets power supply from the main AC supply through static transfer switch, which was normally OFF before.

(ii) <u>Short-break UPS</u> :- (Offline UPS)



→ fig. shows the basic block diagram of offline UPS. It consists of rectifier & filter unit, battery bank, inverter unit, filter unit, static transfer switch & load.

→ This UPS is called offline UPS because the load is directly connected to the AC main supply through static transfer switch, when the main supply cuts off, then there is some interruption for very few seconds.

→ The AC supply is given towards the load through the normally ON switch as well as towards the rectifier unit.

→ The rectifier unit converts AC signal into DC signal & the output of rectifier unit is given towards battery bank.

→ The battery bank stores energy from DC supply upto max^m value & discharges whenever required.

→ When the main AC supply is cut off then the battery bank provides the necessary power supply towards the load through inverter section.

→ The inverter unit converts DC signal into AC signal & provides the its output in filter unit. The filter unit provides smooth AC signal towards the load through static transfer switch which was normally off before.

→ In this way the load gets uninterruptable power supply by the help of UPS.

List of application of power electronic circuit:

→ There are different applications of power electronics devices in different areas, which are given below.

(i) In areospace sector, power electronics devices are used in:

→ space shuttle power supplies.
→ satellite power supplies.
→ aircraft power system.

(ii) In commercial sector power electronic devices are used in:

→ advertising, heating.
→ Air conditioning power supplies.
→ Computers.
→ Office equipment.
→ elevators.
→ light dimmer
→ UPS
→ Central refrigeneration.

(iii) In industrial sector power electronic circuit are used in:

→ Arc & industrial furnance.
→ blowers & fans
→ pumps & compressors.
→ industrial lasers.
→ transformer top changers.
→ rolling mills.
→ textile mills.
→ excavators.
→ cement mills.
→ welding.

(iv) In residential sectors power electronic devices are used in:

- air-conditioning.
- cooking
- lighting
- refrigerators.
- electric door openers.
- dryers
- fans
- computers
- Vaccum cleaners.
- Washing machine.
- food mixtures.

(v) In telecommunication sectors the power electronics are used in:

- battery charges.
- power supplies for communication instruments.

(vi) In transportation sector the power electronics circuits are used:

- Traction control of electric vehicles.
- electric locomotives.
- street cars
- Trolley buses
- Sub-ways
- automotive electronics.

(vii) In utility system power electronic circuits are used in:

- HVDC
- VAR compensation.
- Static circuit breakers.
- Fans & boilers feed pump.
- Solar or wind energy system.

★ List of the factor affecting the speed of DC motors:-

Motor performance depends on 3 elements, such as:- terminal voltage, terminal resistance, magnetic force.

→ There are various factors that affects the parameters, So the performance of motor changes:-

These factors are:-

(i) Voltage of power supply.
(ii) Types of power supply.
(iii) Types of winding material.
(iv) Environmental temperature.
(v) Types of magnet.
(vi) Structure of yoke & flux linkage with yoke.
(vii) frequency of power supply.

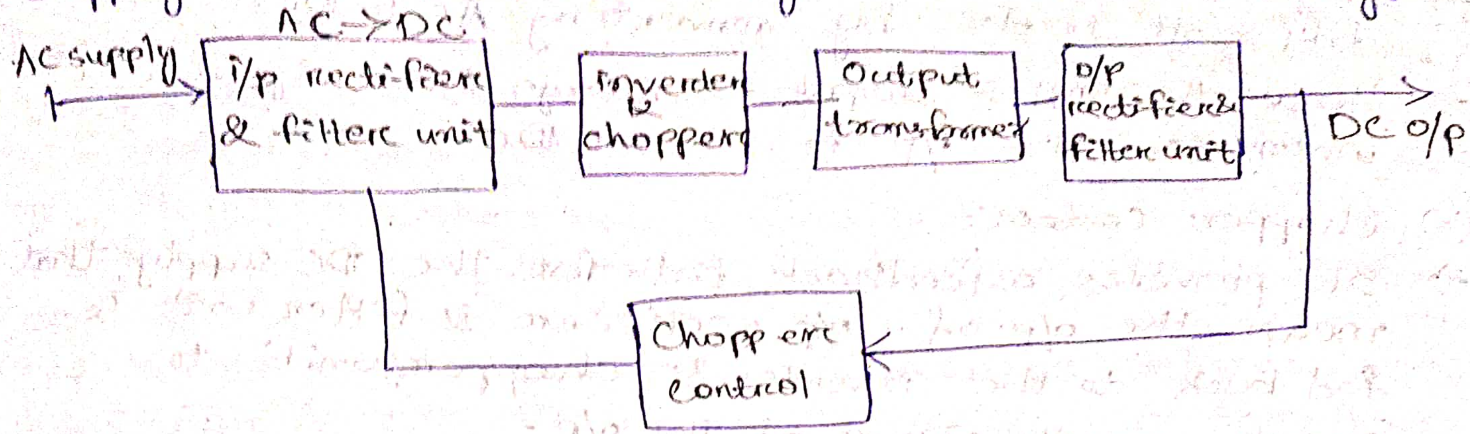
→ The speed of the DC motor can be controlled by 3 methods, i.e

(i) flux control method.
(ii) Voltage control method.
(iii) Rheostatic control method.

Date: 23/12/21

* SMPS :-

→ SMPS stands for "Switched mode power supply". It is an electronic device, which produces a regulated supply with different magnitudes simultaneously.



→ fig shows the basic block diagram of SMPS. It consists of different blocks which converts AC supply or DC supply to DC supply. The different blocks are explained below.

(i) i/p rectifier & filter unit :-

→ If the SMPS has an AC input, then the signal is converted to DC with the help of rectifier & filter unit.

→ If the SMPS has DC input, then this block is not necessary & the DC input is directly given to the inverter & chopper unit.

(ii) Inverter & Chopper unit :-

→ This unit provides AC signal to the o/p transformer by taking DC signal from the rectifier unit.

(iii) Output T/f :-

→ It has a small & few winding & operates with a frequency of 10KHz - 100KHz. It provides different o/p voltage according to requirement of load.

→ It also isolates the load from the control circuits. Then o/p of output T/f is given towards o/p rectifier

& filter unit.

(iv) o/p rectifier & filter unit :-

→ It provides a constant desired DC output to the different loads by converting AC to DC.

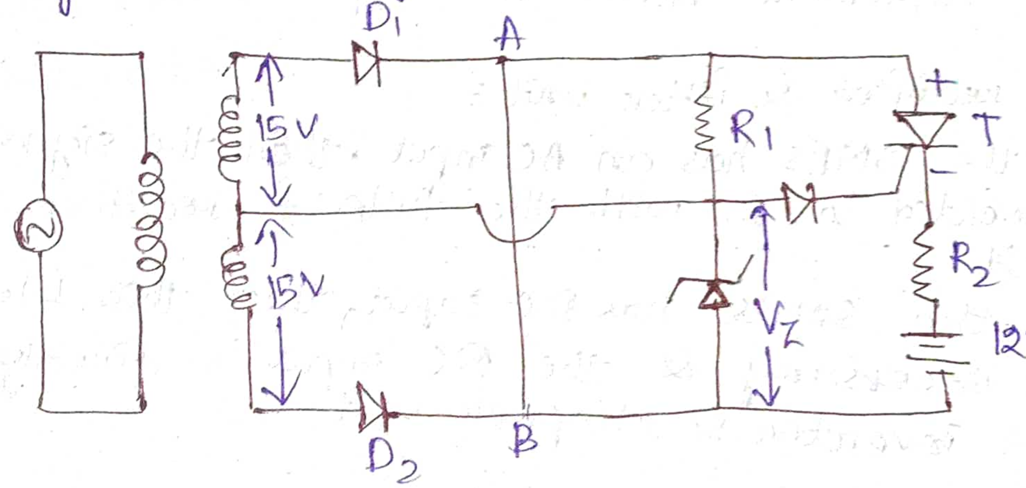
→ Hence the SMPS output is always DC signal whenever the i/p is AC or DC.

(v) Chopper Control :-

→ It provides a feedback path for the DC supply that means the o/p of o/p rectifier & filter unit is fed back to the inverter & chopper unit to create smooth signal at the o/p.

★ Battery Charger :-

→ It is an electronic device which is used for charging the battery from the AC supply.



→ fig shows the basic circuit diagram of automatic battery charger.

It consists of a ~~contire~~ centred tap step down transformer, 2 diodes used for rectification purpose, 1 diode used for supplying gate current in one direction, 2 resistors (R_1 & R_2) are used for limiting the current, Zener diode to provide constant supply for the gate terminal, thyristor (T) used for controlling the charging & discharging of battery.

- Working :-

→ When an AC supply is given to the primary winding of the T/f, then equal output voltage is obtained at the upper & lower half of the secondary winding.

→ During the (-)ve & (+)ve half cycle of the AC signal, the terminal (A) will be higher potential than the referenced line through the diode (D_1 & D_2)

→ The thyristor remains in forward biasing mode because the anode is at higher potential than cathode.

→ The zener diode remains in reversed biased condition & acts as a voltage regulator for the gate terminal of the thyristor.

→ When the required gate voltage is obtained, then the thyristor will be turned 'ON' & the battery gets the power supply for charging.

→ When the battery is fully charged then the cathode of the thyristor will be higher than the anode terminal.
So, the thyristor will be reversed blocking mode & cuts 'off' the supply towards battery.

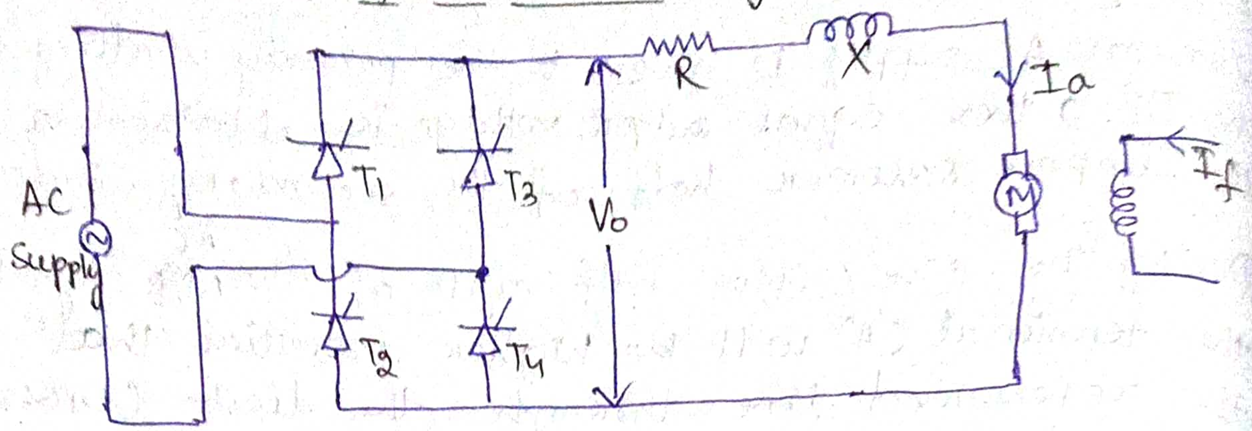
→ When the battery discharges through the load, then the cathode terminal of the thyristor becomes lower potential than anode terminal.
So, the thyristor will be turn 'ON' & the battery is being charged again.

→ In this way the thyristor controls the charging of battery automatically from the power supply.

- Application:-

→ The battery charger circuit is used in starting of vehicles, UPS, Charging adaptor, ~~telephony~~ telephony system.

✯ Speed Control of DC motor using converter :-



→ fig. shows the ckt diagram of full bridge converter with a separately excited DC motore. It consists of 4 thyristores (T_1, T_2, T_3 & T_4) & a DC motore.

→ Here 'R' & 'X' are resistance & reactance of armature winding, 'If' is the field current & 'Ia' is a armature current.

- Working :-

→ When AC supply is given to the full converter, then a controlled DC output supply is obtained & this output is given to the armature winding of the motore.

→ The thyristors are triggered, when a gate voltage is applied after firing angle alpha (α).
That means by varying the firing angle the output voltage can be varied at the output terminal of converter

→ When a change in supply is given to the armature winding of DC motor, then the speed of the DC motor changes.

→ The output voltage of the converter is given by:-

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

If 'α' varies, then the o/p voltage varies. So, the current flows towards the armature winding also varies.

→ Therefore the speed of the motore can be varried by varying 'α'.

→ In this way the speed of DC motore can be varried by using converter circuit.

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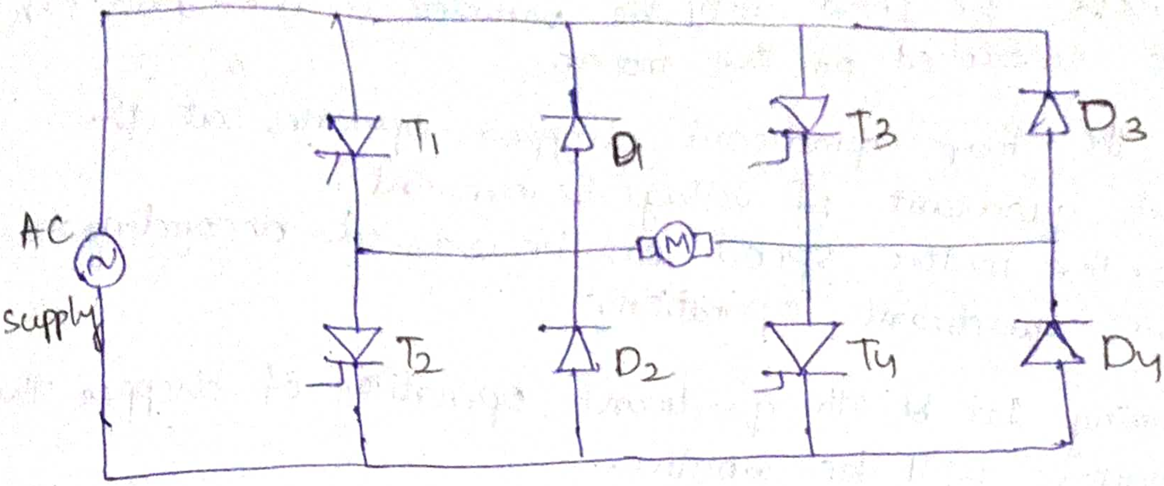
Speed Control of DC motor using chopper:



→ fig. shows the ckt diagram of 4th quadrant chopper. Here thyristor is used as a chopper switch. It consists of four thyristors i.e T1, T2, T3, T4, four diodes D1, D2, D3, D4 & a DC motor as a load.

→ The diodes are used for protection of thyristor from over current.
An AC supply is given to the chopper circuit.

→ During ~~position~~ positive half cycle of input signal the thyristor T1 & T4 are in forward blocking mode. When a necessary gate voltage is given to the thyristors, then thyristor will turn 'ON' & current flows from source to load.
So, the motor will start.

→ During (-)ve half cycle of input signal, thyristors T2 & T3 are in forward blocking mode. When a necessary gate supply is applied to the thyristors, then the thyristors will turn 'ON'. So, the current flows towards load from source in opposite direction across the load.

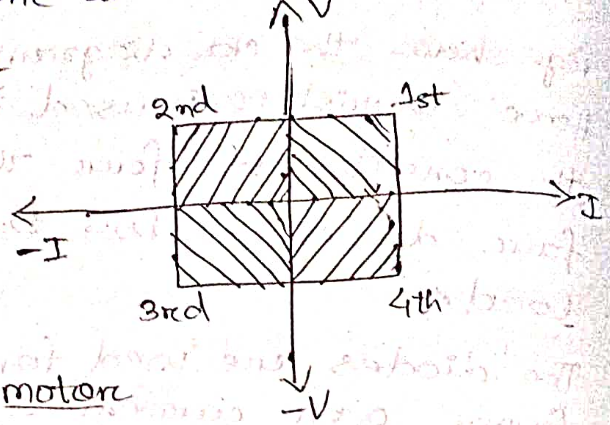
→ If the polarity of the chopper switch are changed then the current will flow towards load, during (-)ve half cycle of i/p signal & motor will rotate or start

→ When the firing angle is changed, then the voltage across the load will be varied & the speed can be controlled of the motor.

→ As the four quadrant chopper operates at the four quadrant of voltage & current. So, the motor speed can be varied according to the quadrant operation.

→ During 1st & 4th quadrant operation of chopper the current will be positive. So, the motor will run in one direction.

→ During 2nd & 3rd quadrant operation of chopper the current will be negative. So, the motor will in another direction.



☆ **Speed Control of Induction motor by using AC voltage regulation:-**

→ Induction motor operates by mutual Induction principle. Induction motor has 2 parts that is stator & rotors.

→ The supply voltage is applied to the stator winding which produces stator magnetic field around the stator winding, due to flow of current. The magnetic field in the stator revolves around the rotor winding. So, the rotor starts rotating due to mutual induction.

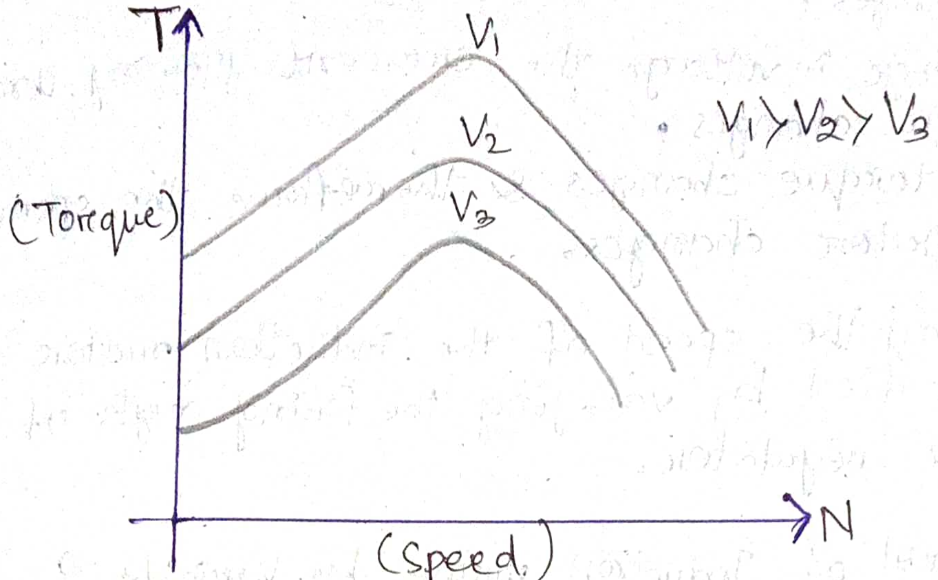
→ The applied voltage can be controlled by following methods:-

(i) by connecting an external resistor with the stator ckt.

(ii) by using auto transformer.

(iii) by using thyristor voltage controller.

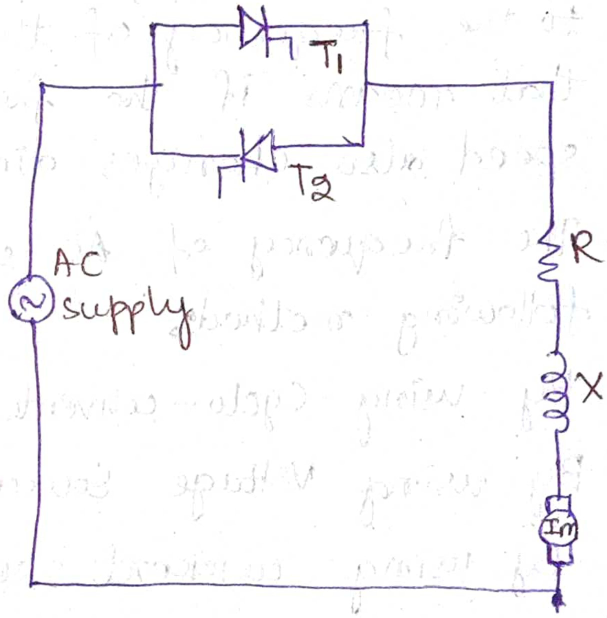
(iv) by using TRIAC controller.



→ The torque can be produced due to repulsive magnetic force or rotating magnetic field. When torque produced in the motor, then the rotor starts rotating in a speed 'N'.

→ The speed can be varied by varying the applied voltage by using AC voltage regulator.

→ The fig. shows the basic circuit diagram of AC voltage regulator with induction motor.
It consists of 2 thyristors (T_1 & T_2) connected in anti-parallel, & an induction motor with resistance (R) & reactance (X) respectively.



→ During (+)ve half cycle of AC signal the thyristor (T_1) operates & during (−)ve half cycle of AC signal the thyristor (T_2) operates.

→ When the firing angle of thyristor (T_1 & T_2) changes, then the voltage developed across the induction motor changes.

→ Due to change in voltage the current flowing through the motor changes,
So, the torque changes & therefore the speed of the motor changes.

→ In this way the speed of the induction motor can be varied by varying the firing angle of the AC voltage regulator.

★ <u>Speed control of Induction motor by Variable frequency</u>:

→ The speed of the motor is given by $N_s = \frac{120 f}{P}$

Where, N_s = Synchronous Speed.
f = frequency of supply.
P = No. of poles of motor.

→ Here the speed of the motor is directly proportional to the frequency of the supply,
that means if the frequency changes, then the speed also changes directly.

→ The frequency of AC supply can be varied by following methods:-

(i) By using Cyclo-converter.
(ii) By using Voltage Source inverter.
(iii) By using current source inverter.

→ Cyclo-converter produces variable frequency signal on a fixed frequency signal.
So, when the motor is connected to the supply through cyclo-converter., then the frequency of the supply can be varied & hence the speed can be varied.

→ The inverter converts DC signal into AC signal with desired frequency.
So, when the frequency of an AC signal is to be changed then the AC signal is converted to DC signal, first by using controlled rectifier & then DC signal is converted to AC signal with desired frequency by using inverter.
When the motor is connected to main supply through controlled rectifier & inverter unit, then a variable frequency is obtained & the speed can be varied.

Date 04/01/2022 Chapter :- 5

PLC & It's Application

PLC

Introduction :-

A programmable logic controllere is a specialized computer used to to control different machines & processes.

→ It uses a programmable memory to store instructions & execute specific functions that include ON/Off control, timing, counting, sequencing, arithmatic & data handling.

→ PLC is an assembly of solid state digital logic elements designed to make logical decissions & provide outputs.

PLC are used for the control & operation of manufacturing process equipment & machinery.

Advantages of PLC :-

→ Increased Realiability.

→ More flexibility.

→ Lower cost.

→ faster response time.

→ Easier to Troubleshoot. (fault finding)

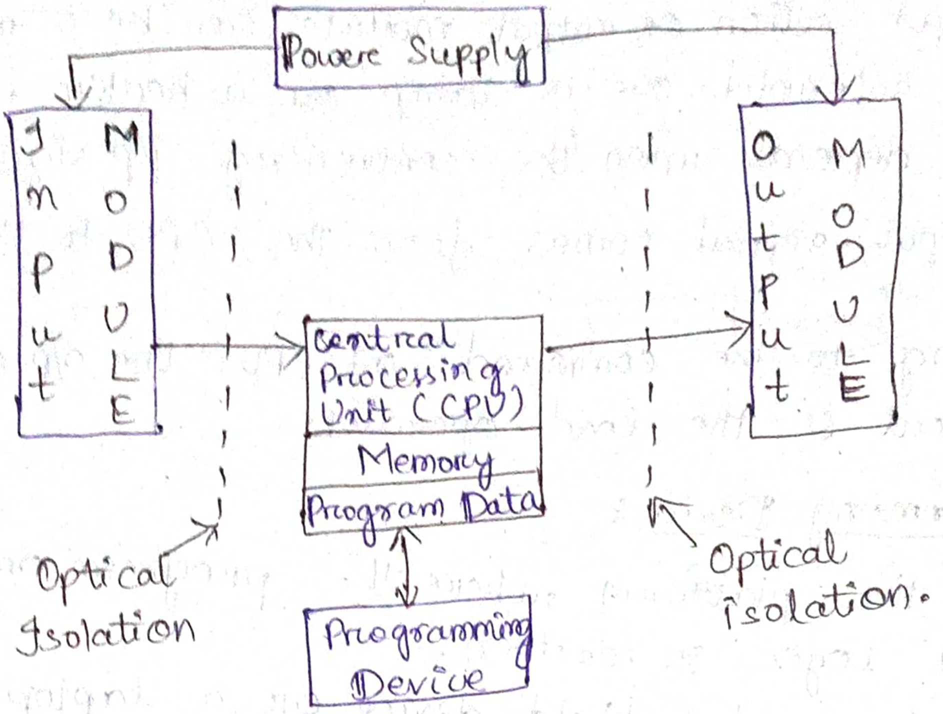


fig. shows the basic architecture of PLC, which consists of different blocks, such as

(i) Power supply.
(ii) Input Module.
(iii) Output Module
(iv) CPU & Memory
(v) Programming Device.

Power Supply :-

PLC system generally works on a power supply of about 24 V, which is given to input & output devices.

Input Module :-

The i/p section or i/p module consists of devices like sensors, switches & many other real world i/p sources.

→ The i/p from the sources is connected to the PLC through the i/p connector rails.

→ The i/p signal may be in the form of analog or discrete signal.

Output Module :-

The output section or output module can be a motor or a solenoid or a lamp or a heater, where function depends upon the controlling i/p signal.

→ The output signal comes from the CPU to the o/p module.

According to the command of CPU, the o/p signal comes out & the load operates:

Programming Device :-

It is the platform, where the program or the control logic is written.

It can be a handheld device or a laptop or a computer itself.

CPU :-

It is the brain of the PLC.

It can be a hexagonal or an octal microprocessor.

It carries out all the processing related to the i/p signals in order to control the output signals based on the control program.

Memory :-

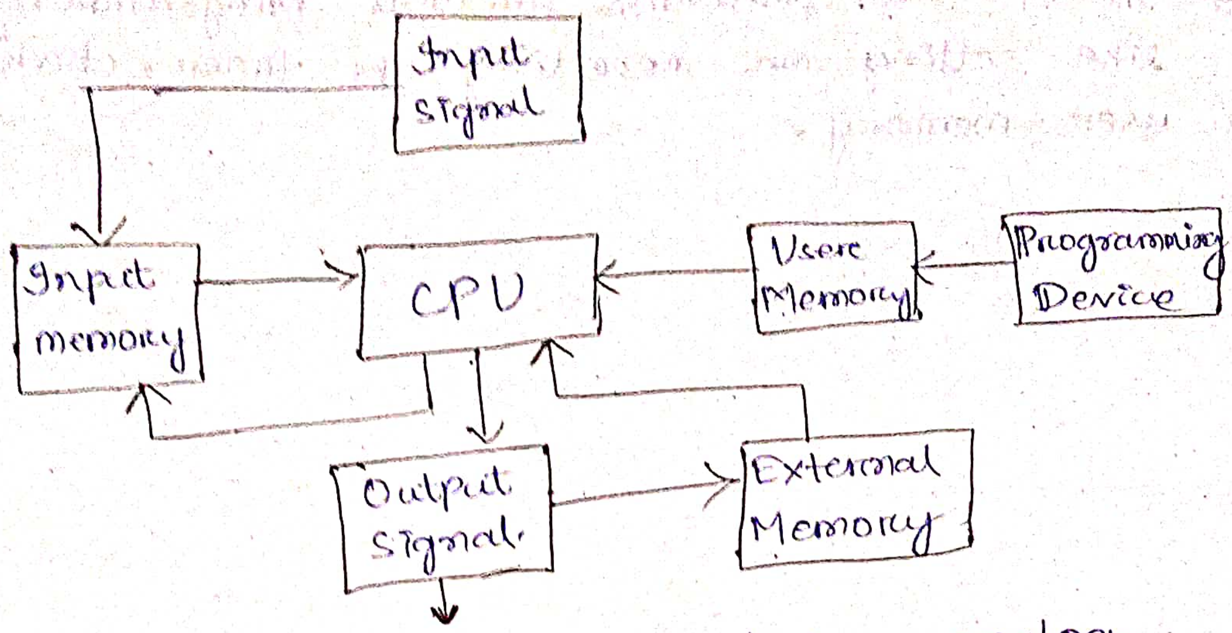
Memory is like a blank page of a notebook.

The memory is divided into two parts i.e data memory & program memory.

→ The i/p, o/p signals & the timer & counter signals are stored in the input & output signals are stored in the input & output external memory.

→ The program information or the control logic is stored in the user memory or the program memory from, where the CPU fetches the program instructions.

Working of PLC :-



→ The i/p sources convert the real time analog electric signals to suitable digital electric signals & these signals are applied to the PLC through the connector rails.

→ These input signals are stored in the PLC external image memory in locations known as bits. This is done by CPU.

→ The control logic or the program instructions are written on to the programming device through symbols or through mnemonics & stored in the user memory.

→ The CPU fetches these instructions from the user memory & executes the i/p signals by manipulating, computing, processing them to control the o/p device.

→ The execution results are then stored in the external image memory which controls the output drives.

→ The CPU also keeps a check on the o/p signals & keeps updating the contents of the input image memory according to the changes in the o/p memory.

→ The CPU also performs internal programming function, like setting or resetting the timer, checking the user memory.