LEARNING MATERIAL

OF

POWER ELECTRONICS & PLC

(5TH SEM)

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Chapter-1 PE & PLC

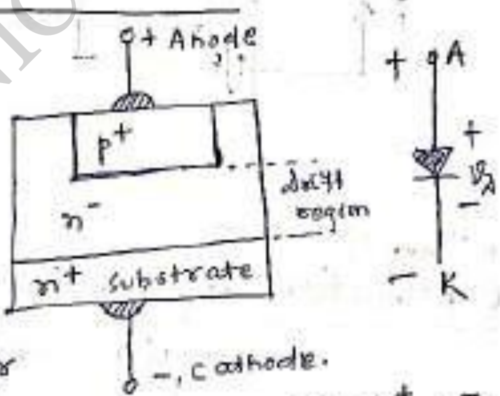
Imp Semester Qn.

Construction & operation of power diode

Imp answers (difference bet^n power diode & signal diode)

Imp - power diodes differ in structure from signal diode in construction. Signal diode constitutes a simple p-n junction. But the difference in power diode is that, power diodes are designed for high voltage & high current applications. So a power diode should be so designed to handle high forward current & a large reverse breakdown voltage.

Construction & operation of power Diodes:-



- power diode consists of heavily doped n+ substrate. On this substrate, a lightly doped n- layer is there.
- The function of this n- layer is to increase the breakdown voltage, while junction p+, n- is reversed biased.
- The drawbacks of n- layer that it is adding the significant ohmic resistance to the diode, when it is conducting the forward current.
- when anode is +ve w.r.t cathode, diode is said to be forward biased.

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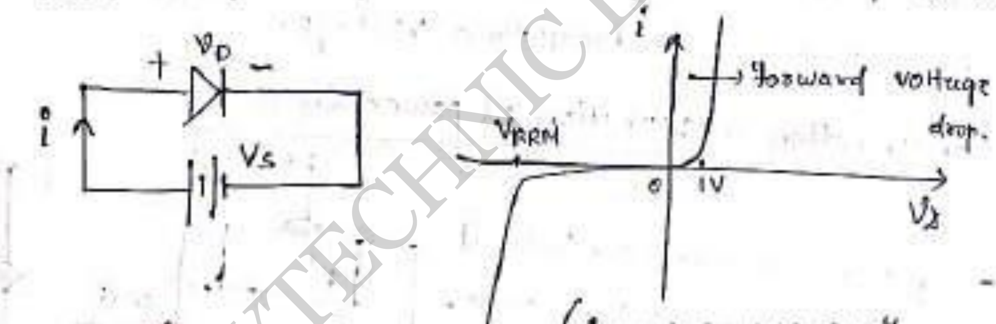
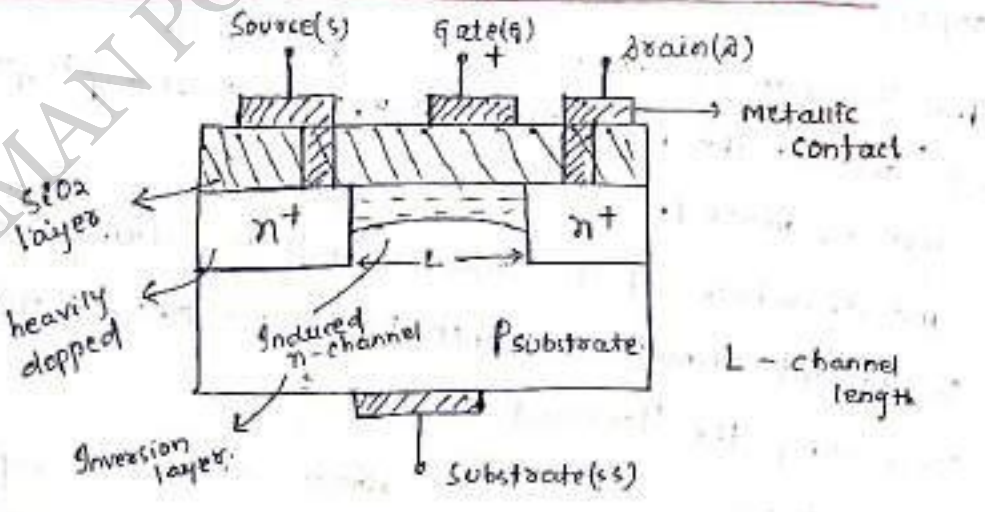
- With increase in forward voltage(V_s) the diode current rises quickly beyond the threshold voltage.
- When diode is reversed biased then small leakage current flows. The leakage current is almost independent of the magnitude of the reverse voltage until it reaches breakdown voltage. At reverse breakdown large reverse current flows that may destroy the diode so diode must be operated below the specific peak reverse repetitive voltage (V_{RRM})



(i-v characteristics of power diode)

2019 Imp 5 marks

Construction & working principle of MOSFET :-



(n-channel MOSFET)

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- The metal oxide semiconductor FET i.e MOSFET has a source, gate and drain like JFET. Here the gate is insulated from the channel so for this reason the input impedance of MOSFET is very high of the order of $10^4 - 10^9$ MΩ.
- The MOSFET can be n-channel and p-channel.
- Looking into the construction details of the n-channel MOSFET -
- It consists of a lightly doped p-type semi-conductor substrate into which two heavily dopped n-regions (denoted by n^+) are formed. These n^+ regions can act as source & drain.
- A thin layer of insulation SiO_2 is grown on the surface of the structure so that the gate remains insulated from the n-channel.
- If the gate potential is such that it creates electrons in the n-channel MOSFET & holes in the p-channel MOSFET, to fill the space between source & drain and if the increase in the gate potential increases the drain current (I_D), then this type of operation called the enhancement mode & if by increasing gate potential the drain current is reduced then it is called depletion mode. So two types of MOSFETs are there -

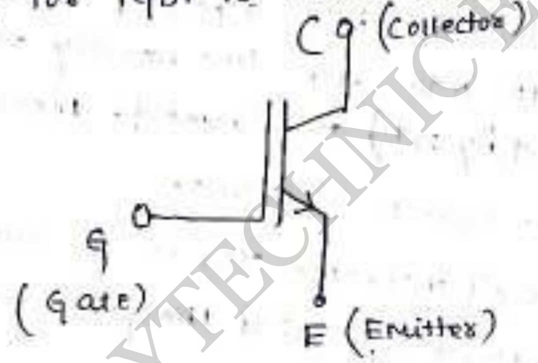
(1) E - MOSFET.

(2) D - MOSFET.

page-4 (Working not required) only.

Construction & working principle of IGBT :–

- IGBT (Insulated Gate Bipolar Transistor) is a three terminal power switch having high input impedance like PMOSFET and low on-state power loss as in BJT.
- IGBT has three terminals. The three terminals are Gate (G), Emitter (E) & Collector (C). The circuit symbol for IGBT is shown below.



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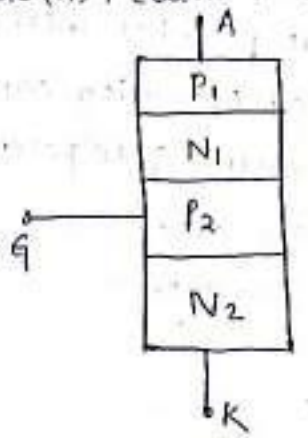
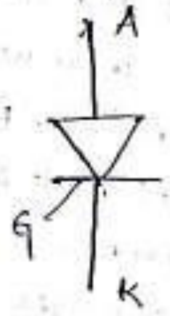
SCR (Silicon Controlled Rectifier)

It has 4 layer, 3 - terminals, 3 Junction. Anode (A), cathode (K) & gate (G).





(Thyristor)

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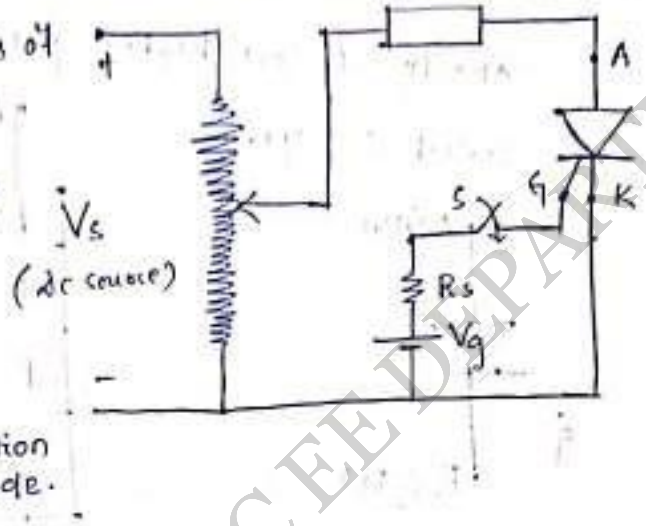
- The VI Charactristics is also called the static characteristics because here, time is not considered.

- It has 3 - modes of operation -

(1) Reverse Blocking mode

(2) Forward Blocking mode

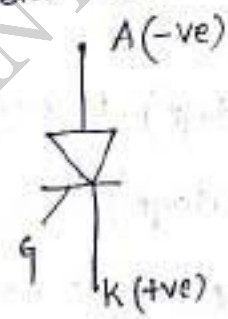
(3) Forward conduction mode.

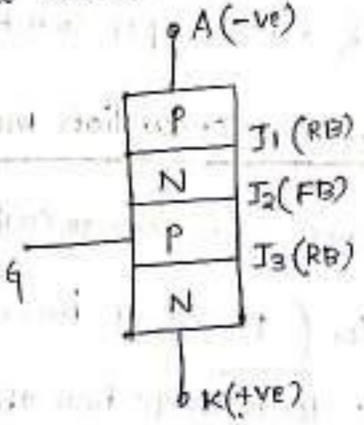


(1) Reverse Blocking mode:—

- Anode is at lower potential & cathode is at higher potential with gate switch open.

- so when a reverse voltage is applied the small leakage current called reverse leakage current flows.





if V_{AB} increased & reached more than reverse breakdown voltage then breakdown occurs at Junctions J_1 & J_3 & heavy current flows.

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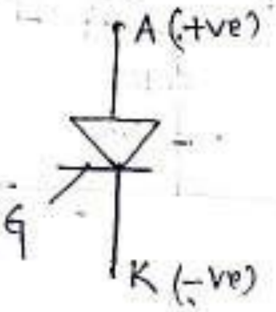
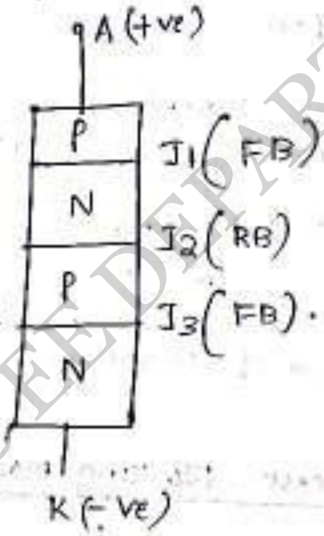
(a) Forward Blocking Mode :-

Anode is at higher potential than cathode.

The switch is open.





- When V_{AK} increased & reached beyond forward Breakover voltage (V_{BO}) then breakdown of junction J_2 occurs but before that the SCR was in blocking mode & acts as open switch.

(b). Forward Conduction Mode :-

- When V_{AK} (Anode cathode voltage) is more than the V_{BO} (Forward breakover voltage) then the J_2 breaks down thats how the SCR conducts means it will act like a closed switch.

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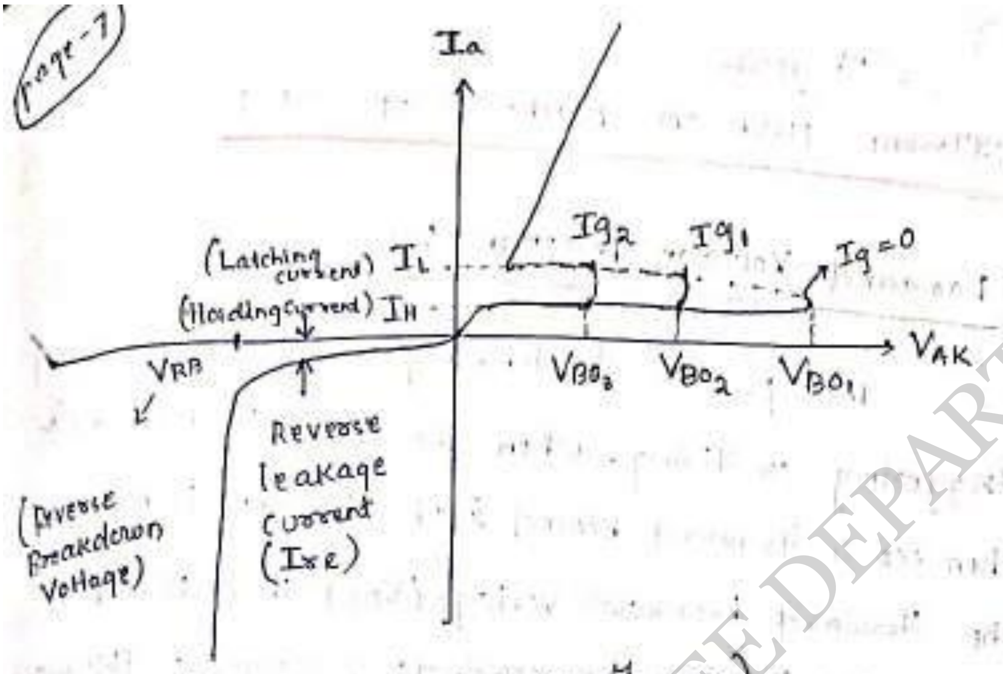

(VI - characteristics of SCR)

- when gate current is zero, VBO was more, but when gate current gradually increases like $i_{g_2} > i_{g_1} > i_g$ then thyristor turned on at lesser breakover voltages $V_{BO_3} < V_{BO_2} < V_{BO_1}$.

Imp
Latching current (I_L):—
Latching current is the minimum value of Anode current during turn on process, such that if anode current reaches this value then SCR continues to conduct even if gate is removed.

Imp
Holding current (I_H):— For an SCR, once it is turned on, the gate looses its control. The holding current is that value of anode current, during turn off process such that if anode current falls below holding current, then the SCR is turned off.

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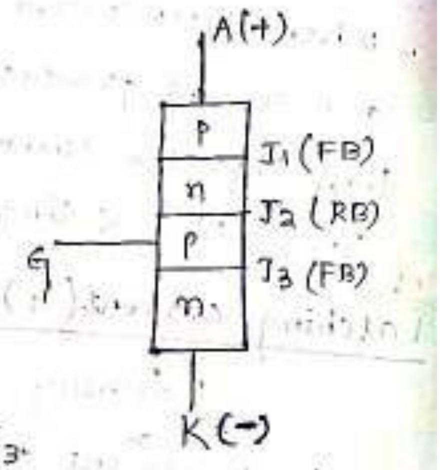
v v Imp long

Different Turn-on Methods OF SCR :—

① Forward Voltage Triggering :—

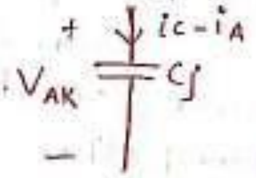
The process of turning on of SCR is called triggering or firing. When the Anode is +ve w.r.t K then SCR is forward biased & if the V_{AK} is more than the forward breakover voltage (V_{BO}) then the inner Junction (J_2) breaks & SCR conducts generally as this method involves breakdown of one junction, so generally this is not prefered.

② $\frac{dv}{dt}$ Triggering :—



Here when SCR is in the forward blocking state, the Junctions J_1 & J_2 are forward biased (FB) but the Junction (J_2) is reversed Biased. so betn J_1 & J_3 one capacitance is formed so,

$i_c = c\frac{dV_{AK}}{dt}$ if $\frac{dv}{dt}$ is more then there is a chance that SCR might turned on, but it needs for the rate of change of V_{AB}.



$i_c = C_j\frac{dV_{AK}}{dt}$

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(3) Temperature Triggering :—
(Radiation Triggering)

– Here a process is made in the inner 'P' layer which is irradiated by a light wave of appropriate wave length & intensity, through a optical fibre cable from an optical source. It is more efficient for triggering of multiple SCRs simultaneously. Due to this electron-hole pairs are generated near inner Junction (J_2) which helps to breakdown Junction (J_2). Therefore the SCR turns ON. This is known as light Triggering. This SCRs are known as Light activated SCR (LASCR) for HVDC application.

(4) Gate Triggering :—

In gate triggering, due to the gate signal given to the gate cathode Junction, the SCR turned on. The gate Triggering can be of the following types -

(a) DC Gate Triggering
(b) AC gate Triggering
(c) pulse gate Triggering

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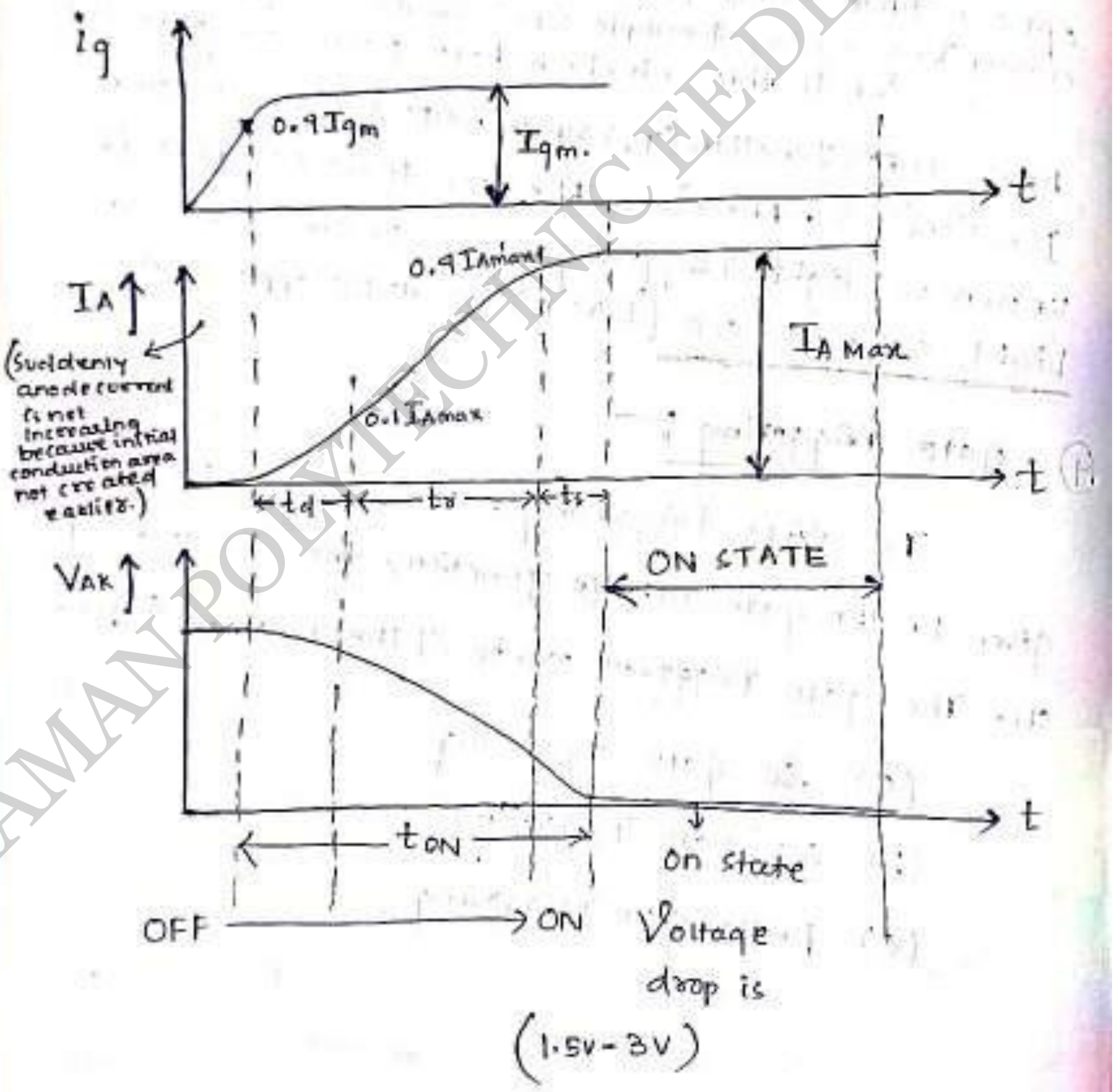
Switching characteristics / Turn-on / Turn OFF characteristics:

↳ Also called dynamic characteristics.

Turn ON characteristics:

It is the switching behaviour of SCR from OFF state to ON state.



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Delay time (td) :–

The time taken by the anode current to reach or rise from 0 to 10% of $I_{A max}$ is called delay time (td).

Rise time (tr) :–

The time taken by the anode current to rise from 0.1 to 0.9 of $I_{A max}$. If inductor is there in the load then it will oppose sudden rise of anode current so in that case tr is more & it will take more time for turn ON.

Spread Time (ts) :–

Spread time depends on the geometrical structure of the device.

Total turn on time (tON) = td + tr + ts

So the turn on time of the SCR depends on the gate signal magnitude & the gate parameters.

Turn-OFF characteristics :–

It is the switching behaviour of the SCR from ON state to OFF state.

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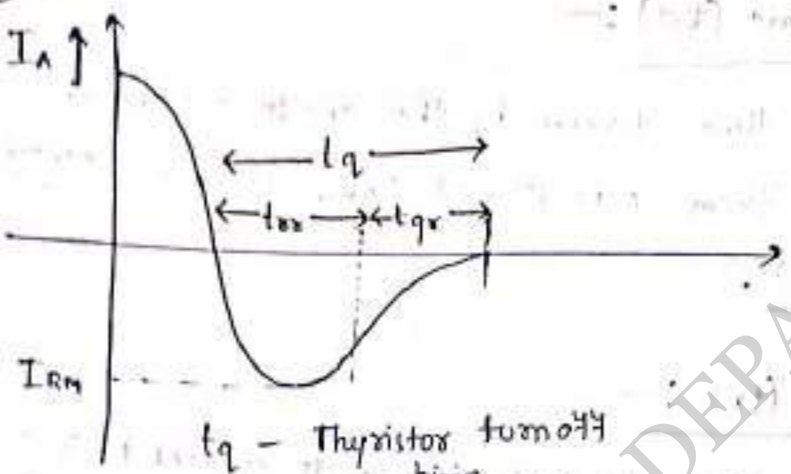

t_q – Thyristor turn off time

t_{rr} – Reverse Recovery time

t_{gr} – Gate Recovery time.

– When SCR is conducting, in the forward direction, some extra charge carriers are stored in the device. These excess charge carriers are mainly due to minority charge carriers.

– When SCR is switching from ON state to OFF state, these charge carriers are still present in the SCR even after anode current becomes zero.

– In order to remove these charge carriers, & to regain its normal blocking state recombination process begins & hence reverse current flows through the diode until all the charge carriers are completely removed. This process is known as reverse recovery process & transition time during this process is known as reverse recovery time (t_{rr}).

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t_{rr} - During this period the excess charge carriers present in the outer layer is removed.

t_{gr} - During this period the excess charge carriers present near the gate Junction is removed.

The circuit turn off time (t_c) must be greater than thyristor turn off time (t_q) for successful commutation.

Thyristor Commutation Technique :-

The process of turning off of the thyristor is called commutation. There are two types of commutation

(1) Natural commutation or Line commutation :-

If the nature of the supply supports the commutation process then it is known as Natural commutation.

(2) Forced commutation :-

- Dc supply cannot support the commutation. Therefore we must use a forced commutation circuit to turn off the SCR if Line/load commutation is not possible.

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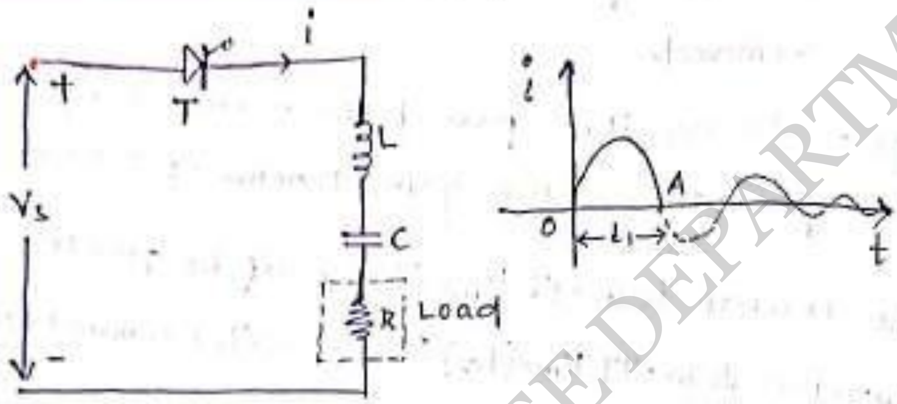
Load commutation :-



- For achieving load commutation of a thyristor, the commutating L & C are connected as shown in the above figure.

- For this circuit, the overall circuit must be under-damped. When these circuits are energized from dc, current waveforms are shown in the figure. It is seen that current i first rises to maximum value & then begins to fall. When current decays to zero, and tends to reverse, thyristor T is turned off on its own at instant A.

- Load commutation is possible in dc circuits & not in ac circuits. Class A or load commutation is also called resonant commutation or self-commutation.

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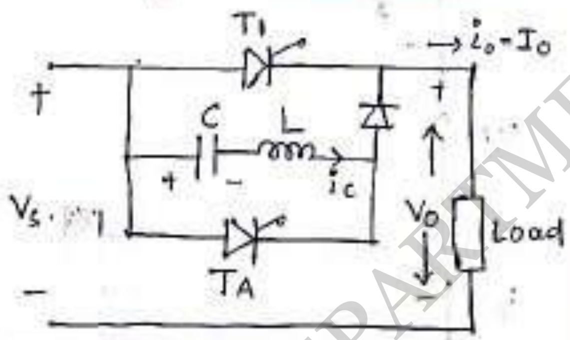
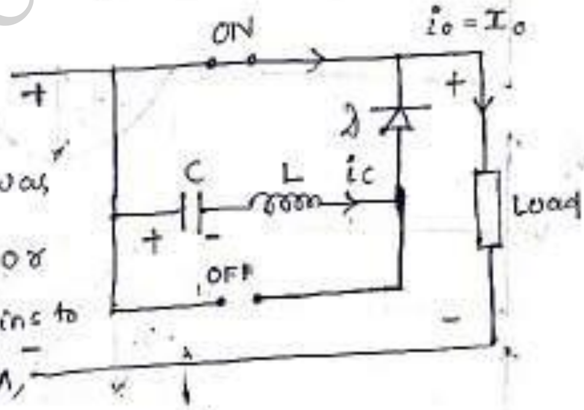
Resonant - pulse commutation / class - B commutation



- Initially capacitor C is fully charged with V_s, as shown in polarity main thyristor as well as auxiliary thyristor are off.

- At $t = 0$; the thyristor T_1 turned on for which a constant current flows through load, diode 'D' was reversed biased & off.



- Then at $t = t_1$ the auxiliary thyristor T_A was ON so capacitor current or resonant current i_c begins to flow from C through T_A, L, and back to 'C'.

After a half-cycle, i_c from instant t_1, $i_c = 0$, After π radian from instant t_1, $V_c = -V_s$ and $i_{T1} = I_o$. After π radian from instant t_1, as i_c tends to reverse, T_A i.e. just after instant t_2, is turned off at t_2. With $V_c = -V_s$ right hand plate has positive polarity.

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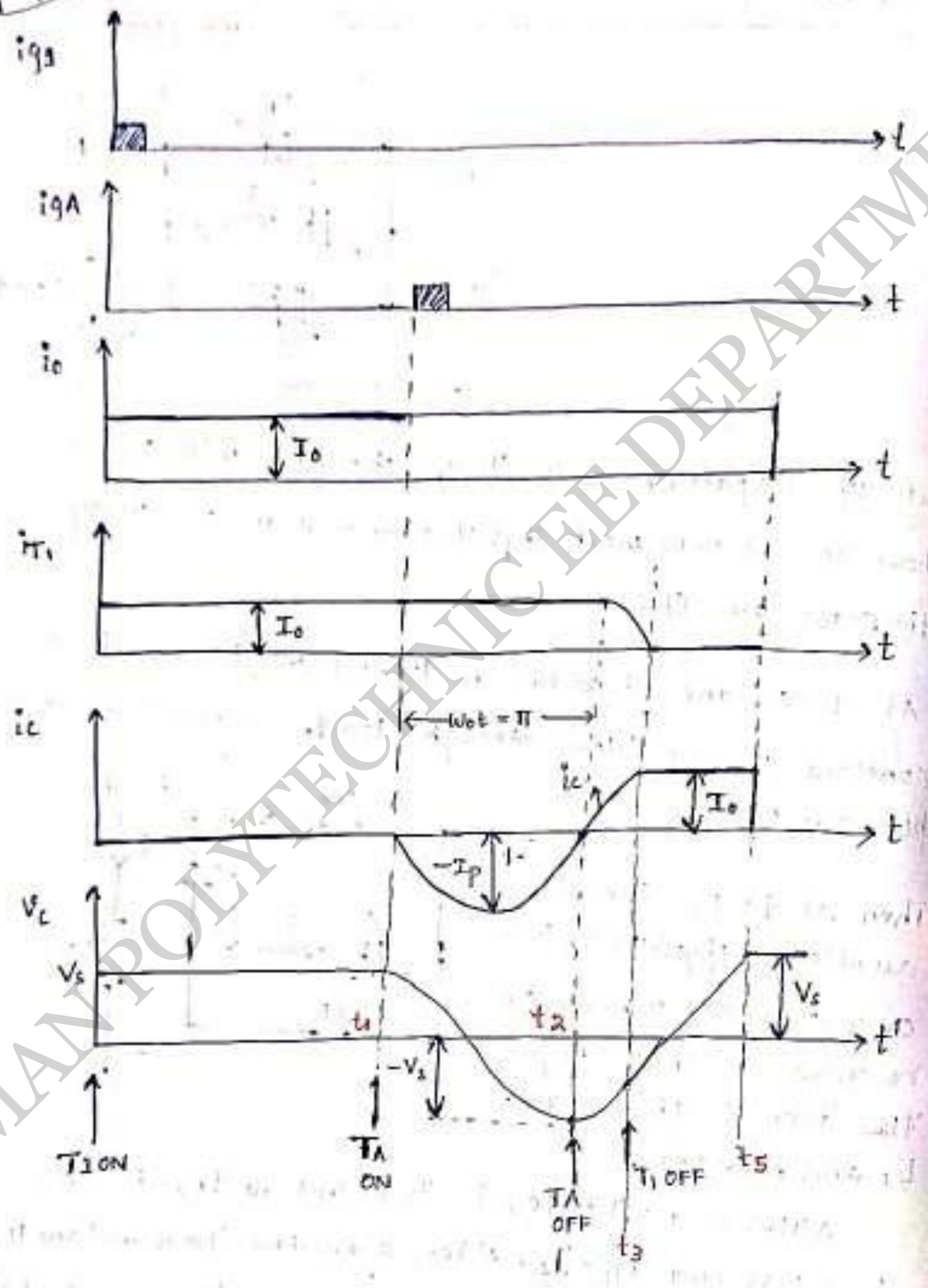


- Resonant current i_c now builds up through C, L, D, and T_1. As this current i_c grows opposite to forward thyristor current of T_1; net forward page 17

current in T_1 decreases $i_{T_1} = I_0 - i_c$ & finally at t_3, T_1 is turned off.

As thyristor is commutated by the gradual build up of resonant current in the reverse direction. this method of commutation is called current commutation (or) class B commutation (or) resonant pulse commutation.

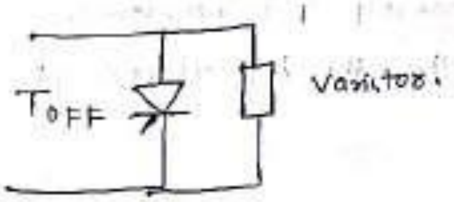
Imp
protection OF Thyristor :-

There are different protection scheme for thyristor -

① over current protection :- we must connect the fuse or circuit breaker for the over current protection of thyristor.

② Over Voltage protection :- we must connect varistor across SCR for over voltage protection.

- varistor is a non linear resistance. All metal oxide resistor behaves as non-linear resistor eg - Zinc oxide. This is called Varistor.



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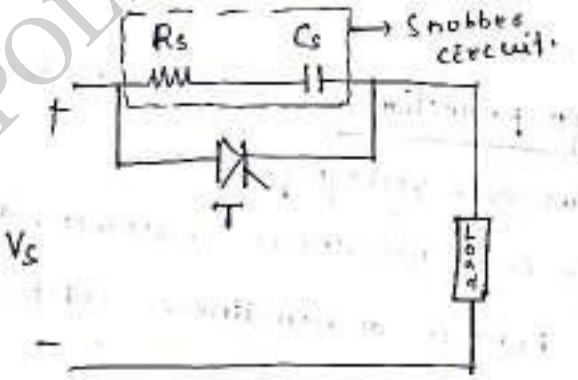
(3) $\frac{dv}{dt}$ protection :-

$$\uparrow i_c = C_J \frac{dv}{dt} \uparrow$$

- At high $\frac{dv}{dt}$ SCR will turn on before the gate pulse is given. It is an accidental turn on. This unwanted turn on is also known as false turn on.
- $\frac{dv}{dt}$ protection is needed to avoid this false turn on.
- We must connect a snubber circuit across SCR for $\frac{dv}{dt}$ protection.

Snubber circuit :-



- C_s acts as S.C path.
- When C_s fully charged T is Triggered.
- R_s is used to limit the high discharge current of C_s.

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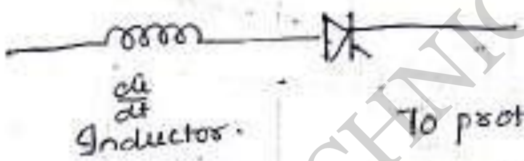
(4) $\frac{di}{dt}$ protection:-

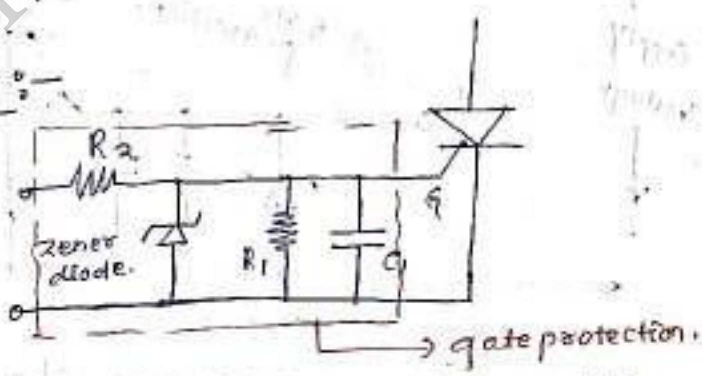
- When the thyristor is Forward biased & turned on, the anode current starts to rise.

- If the rate of rise of anode current is much more than the spread velocity of charge carriers, the local hotspots are created near gate junction due to increased current density which may damage the SCR. protection against this is called as $\frac{di}{dt}$ protection.



To protect against $\frac{di}{dt}$ the inductor called $\frac{di}{dt}$ inductor is connected in series with the SCR.

(5). Gate protection:-



- Gate circuit should also be protected against over-voltages & overcurrents.

- Over voltages across the gate circuit can cause false triggering of the SCR. protection against over-voltages is achieved by connecting a zener diode across the gate circuit.

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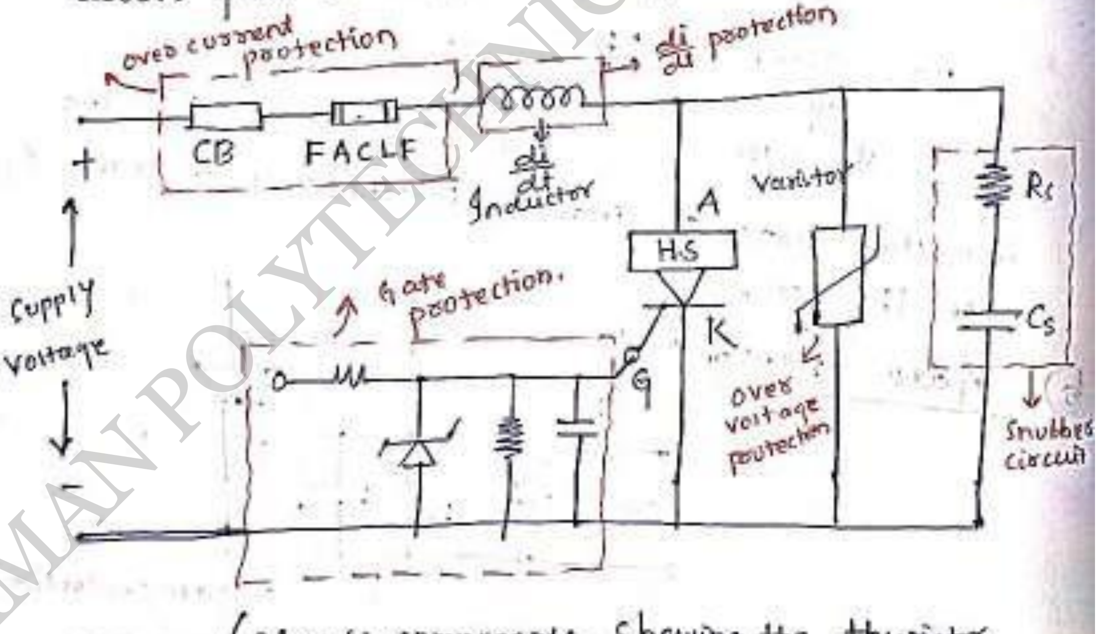
- A Resistor R_2 connected in series with the gate circuit provides protection against overcurrents.

- Some undesirable trigger pulses may turn on the SCR leading to false operation of the main SCR. Gate protection against such firing is obtained by using shielded cables or twisted gate leads.

- The capacitor C_1 & resistor (R_1) are also connected across gate to cathode to bypass the noise signals.



(Circuit components showing the thyristor protection)

C.B - Circuit Breaker

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

H.S - Heat sink

Z.D - zener diode.

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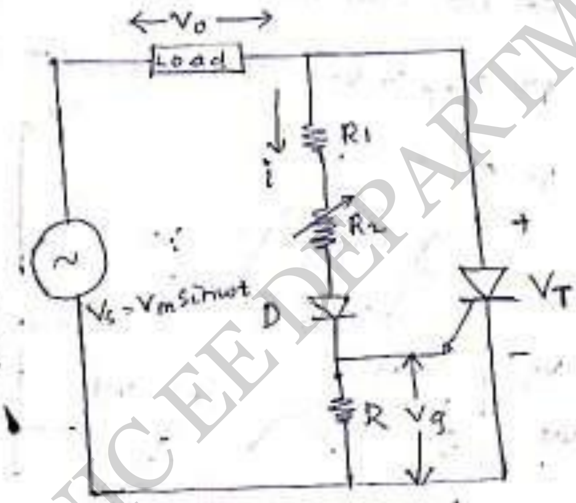
Firing circuit :-

Resistance Firing circuit :-



R - stabilizing Resistance

R_2 - controlling Resistance ↓ used to control the firing angle

R_1 - control the magnitude of gate current

Let, I_{gm} - max permissible value of gate current

V_{gm} - max permissible value of gate voltage

$I_g < I_{gm}$, $V_g < V_{gm}$ } (for safe operation)

$I_g = \frac{V_m}{R_1 + R_2}$, so when $R_2 = 0$, $\frac{V_m}{R_1} \leq I_{gm}$

so $\boxed{R_1 \geq \frac{V_m}{I_{gm}}}$ → (R_1 should be designed such that I_g should be less than max^m permissible value of gate current)

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

→ $\boxed{(R_1 + R) \geq \frac{V_m R}{V_{gm}}}$

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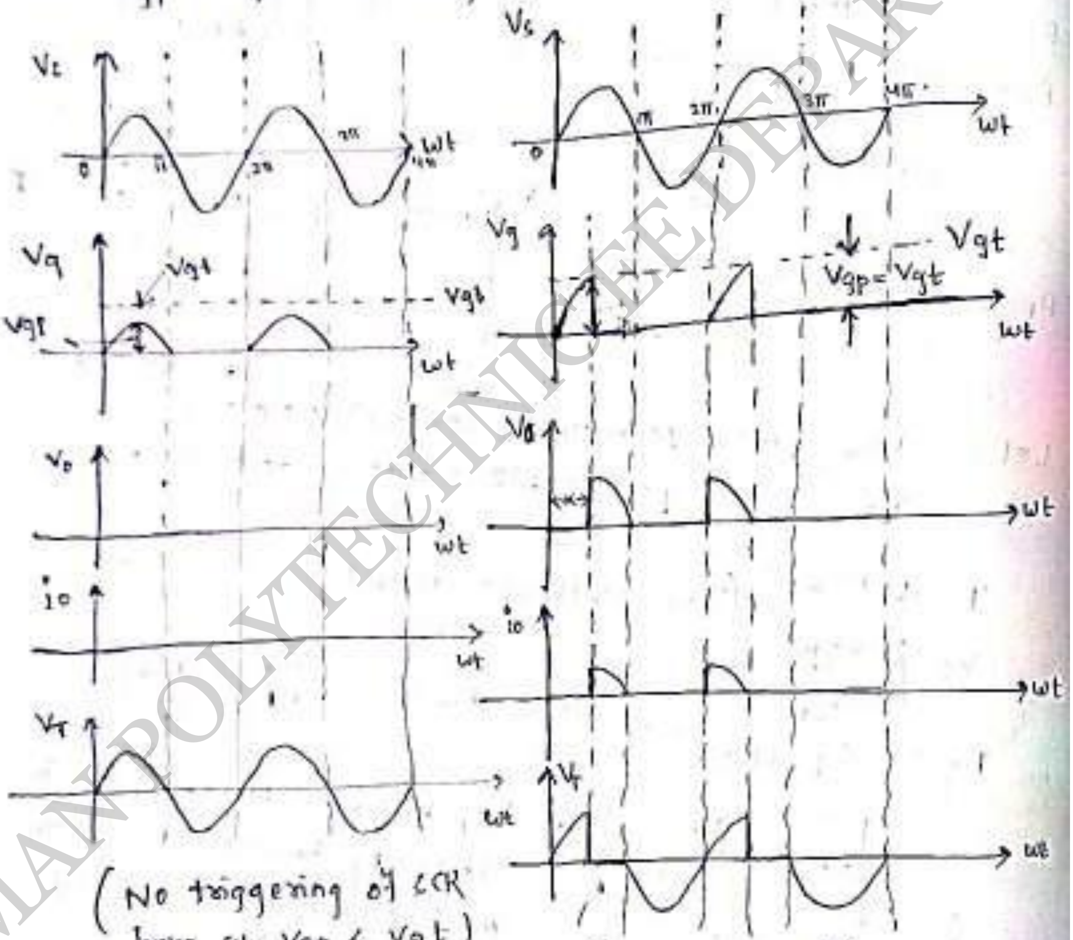
$$V_g = \frac{V_m R}{R_1 + R_2 + R}$$

So we can vary the V_{gp} by varying R_2 value.

If $V_{gp} \geq V_{gt}$ then only SCR triggers.



(No triggering of SCR here as $V_{gp} < V_{gt}$)

(here $\alpha = 90°$)

- The drawback of R triggering is that here α can be varied max^m upto 90°.

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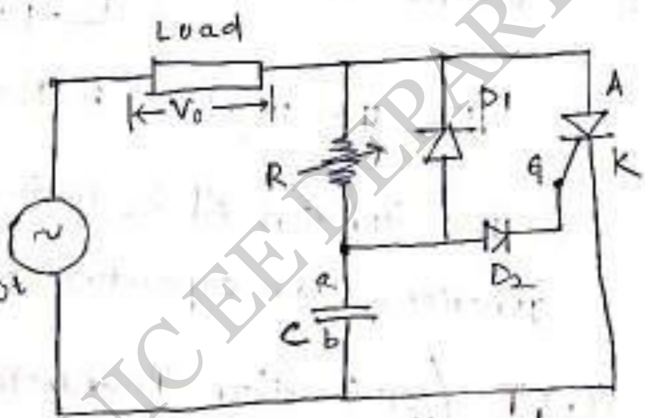
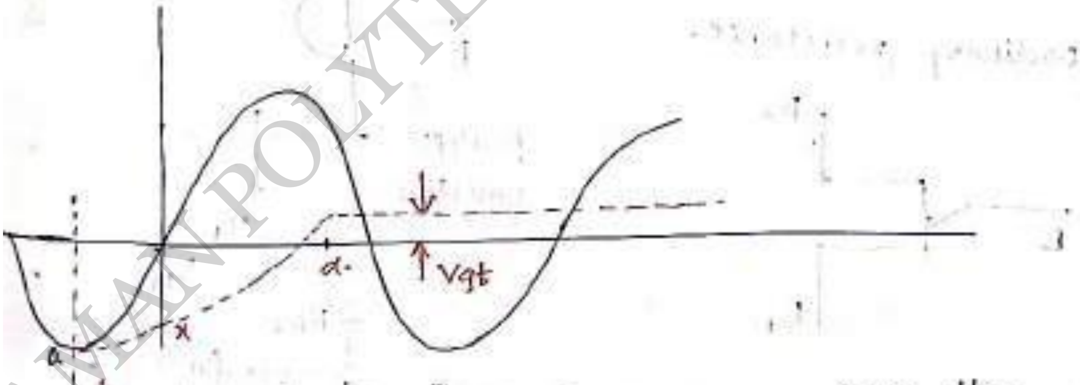
- The difference betn R- triggering & RC- triggering is that in RC-triggering we can vary the firing angle beyond $\alpha = 90°$.

RC Triggering :-



- Initially capacitor is fully charged.
- During negative half cycle of supply, with b plate +ve & a plate -ve. Here the capacitor charges, through the diode D_1.

$V_s = V_m \sin\omega t$



when the supply reverses to positive side the instant when supply voltage is zero, capacitor voltage is ox. Because capacitor charges through resistance R with the time const. RC.

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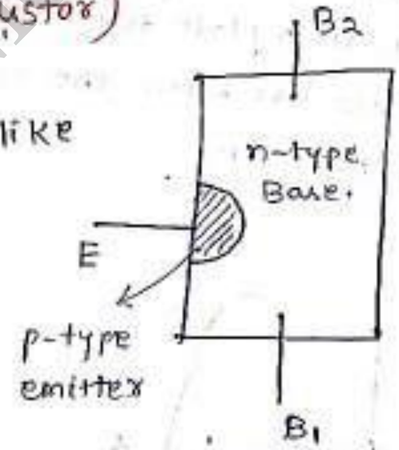
- when the supply reverses D_1 is reversed biased & capacitor charges through 'R_1' prior to that capacitor was charging through D_1.

when, $V_c = V_{gt} + V_d$
↳ Forward voltage drop of D_2

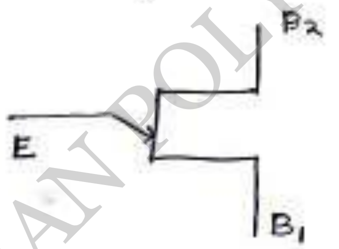
∴ then the thyristor is turned on.

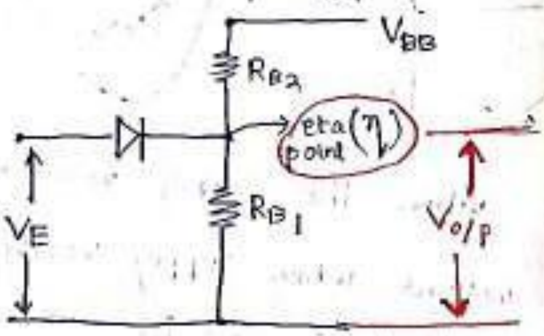
- The function of D_2 is to prevent gate-cathode junction, when capacitor charges through D_1.

UJT (Unijunction Transistor)



- Betn B_1 & B_2 it acts like ordinary resistance.





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

$$= \eta V_{BB}$$

where $\eta = \frac{R_{B1}}{R_{B1} + R_{B2}}$, $R_{BB} = R_{B1} + R_{B2}$ (Total Resistance from B_1 to B_2)

η ↳ Intrinsic standoff ratio.

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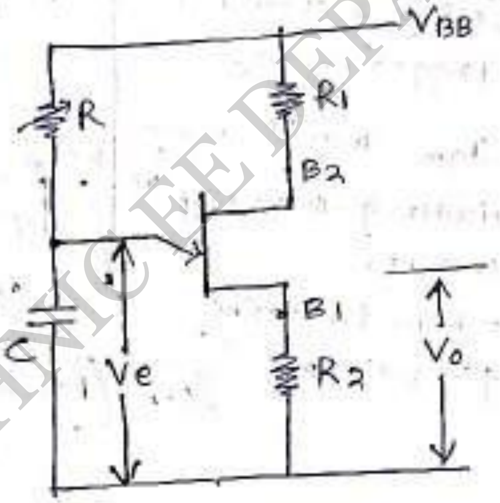
so when $V_E < \eta V_{BB}$ (Diode is reversed biased)

when $V_E > (\eta V_{BB} + V_D)$ (UJT is ON)

UJT Triggering circuit :—

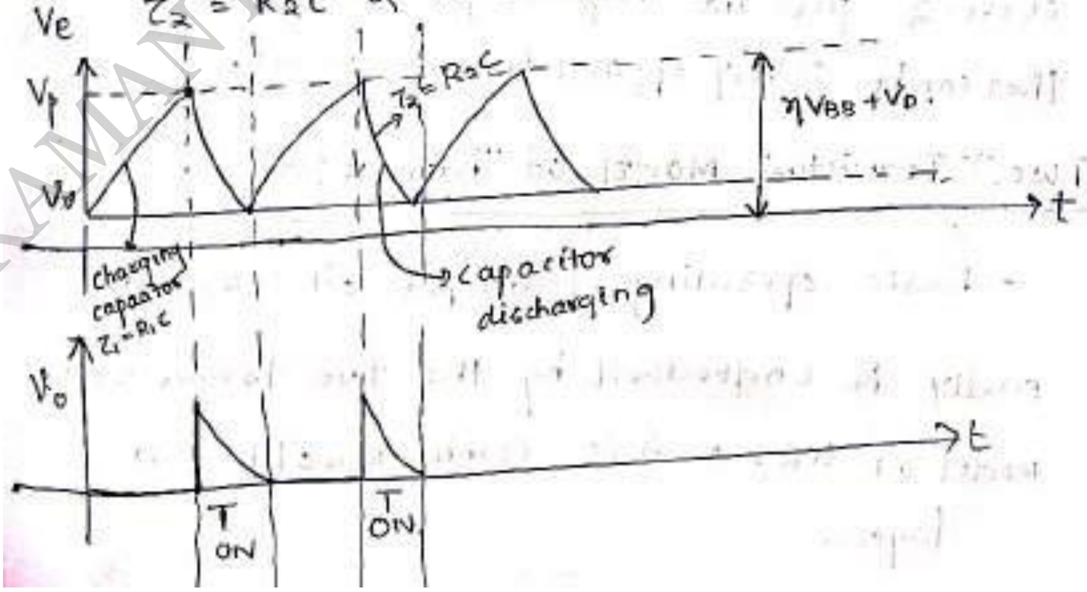
(Relaxation oscillator)



- Here capacitor charges through R to V_{BB} in the time constant, $\tau_1 = RC$,

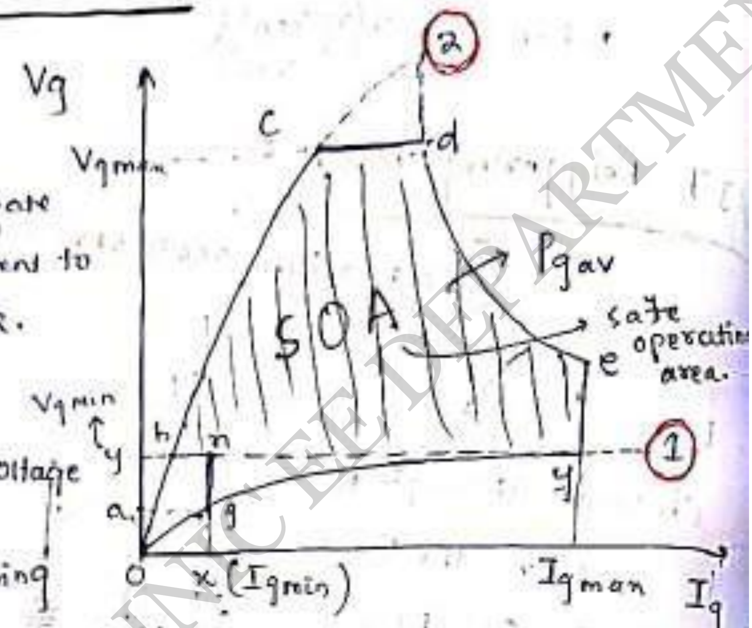
$$V_C = V_{BB}\left(1 - e^{-t/RC}\right)$$

- Then capacitor discharges through R_2, $\tau_2 = R_2C$ & here SCR turned on.



(page-26)

Gate characteristics



Vgmin, Igmin
OY, OX – Minimum gate Voltage & current to trigger an SCR.

Vgm, Igm = max^m permissible gate Voltage & current.

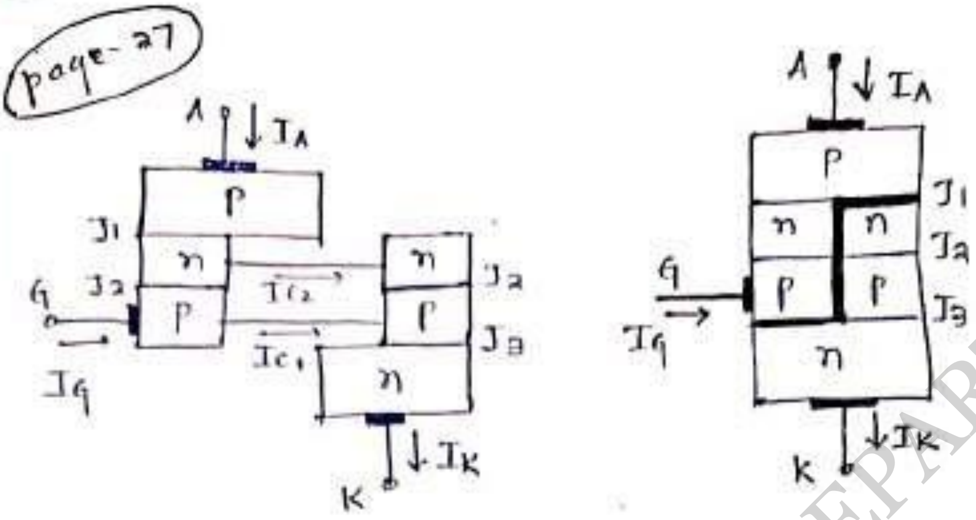
Oa – non-triggering gate voltage.

(Forward gate characteristics of Thyristor)

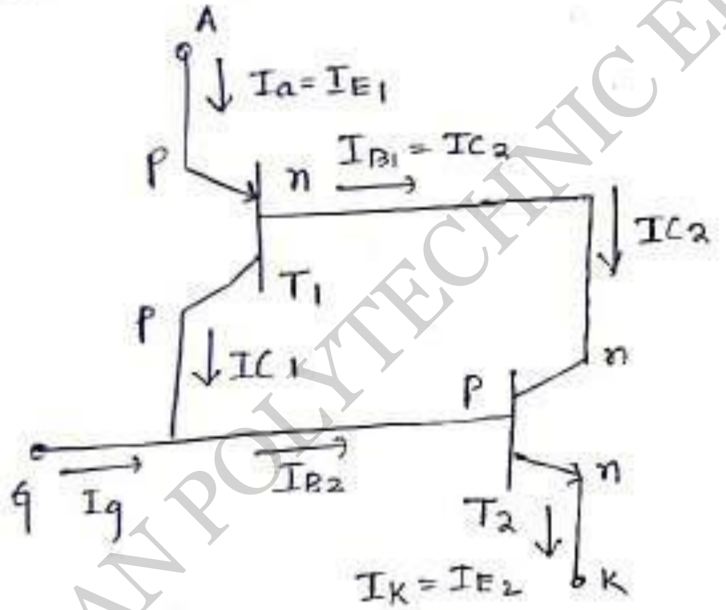
- Curve-1 represents the lowest voltage values that must be applied to turn on the SCR.
- Curve-2 gives the highest possible values of voltage that can be safely applied to gate circuit.

Two-Transistor Model of Thyristor :–

- Basic operating principle of SCR, can easily be understood by the two transistor model of SCR, as it is combination of p & n layers.



Two Transistor Model



2 Marks CHAPTER-1 PE & PLC (Average 35 marks - 40 marks)

1. what are the different turn-on methods of thyristor?
2. define holding current & latching current?
3. what is rise time?
4. What is the difference between power diode & signal diode?
5. write the name of any two members of thyristor family.
6. define firing angle & conduction angle of SCR.
7. what is the difference between 'R' & 'RC' firing circuit?
8. draw the symbol of GTO & state its two applications.
9. what are the advantages of using power electronics device?
10. what is commutation? what are the different methods of commutation?
11. How we can protect the gate from over current & over voltage?
12. Name any two firing i.e triggering methods.
13. what is the basic constructional difference between power diode & a signal diode?
14. What is natural commutation?
15. what is conduction angle in thyristor operation?

16. Draw two transistor model of SCR.
17. What are the features of Fast recovery Diodes (power Diodes)?
18. Define forward break over voltage.
19. Where light triggering method of SCR is used?
20. What do you mean by delay time of SCR.
21. For $\frac{di}{dt}$ protection of thyristor what is used & why?
22. What do you mean by gate triggering.
23. What is the symbol of MOSFET & IGBT?
24. Draw VI characteristics of a thyristor?
25. What is thyristors?
26. What is the difference between natural commutation & Forced commutation?
27. Define snubber circuit?
28. What is valley point in UJT?

5 marks

1. Describe the construction & operation of power diode.
2. Describe any one method of turn-off of Thyristor.
3. What is an UJT? Explain UJT as a relaxation oscillator?
4. What is commutation? Describe the resonant pulse commutation technique.

5. Explain the VI characteristics of SCR & applications of SCR.

6. How thyristor is protected by gate protection?

7. Explain gate triggering of thyristor by resistance firing.

8. Explain turn on Methods of thyristor?

9. Write the principle of operation of SCR & explain the static anode-cathode characteristics of SCR?

10. Explain the switching characteristics of SCR?

11. Show the two transistor model of SCR & explain its operation.

12. What is overvoltage protection & describe the working of a overvoltage protection circuit.

13. Current rating of SCR?

14. IGBT (short note)

15. Explain Gate characteristics of Thyristor?

16. Explain Gate protection of Thyristor?

17. Explain Reverse Recovery time of Thyristor.

18. Explain working & construction principle of MOSFET?

19. Class - A commutation (short note)

10 Marks

1. protection (describe over voltage & over current protection)
2. Resistance Firing
3. VI - characteristics

CHAPTER 2 PE &PLC NOTES

EE And ETC 5th SEMESTER

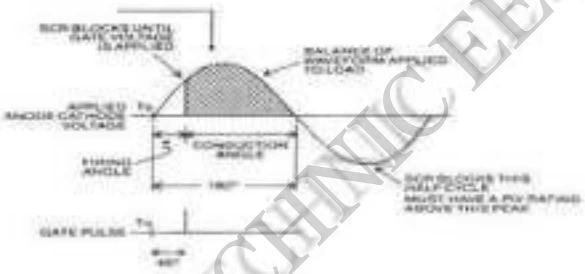
Controlled Rectifiers

Important Definitions

Firing Angle (Delay Angle): Firing angle is the reference to the voltage level at which the SCR is turned ON. Or The Firing Angle is the angle at which thyristors are triggered after zero crossing.

Conduction Angle: The Period of Positive Half-Cycle of AC wave during which a Silicon-Controlled Rectifier (SCR) is turned ON.

If α is the Firing angle, the conduction angle is $\pi - \alpha$



Note : The Following points must be kept in mind while discussing controlled rectifier:

1. The necessary condition for turn ON of SCR is that, it should be forward biased and gate signal must be applied. In other words, an SCR will only get turned ON when it is forward biased and fired or gated.
2. SCR will only turn off when current through it reaches below holding current and reverse voltage is applied for a time period more than the SCR turn off time.

Controlled Rectifier: " A controlled rectifier is a circuit which is used for converting AC Supply into Controlled DC supply & fed to the load."

This process of converting alternating current (AC) to direct current (DC) is also called as controlled rectification

In controlled rectifier, the diodes are replaced by Thyristors or SCRs (Silicon Controlled Rectifiers). As the diodes offer no control over the o/p voltage, so the Thyristors can be used to the controlled output voltage by adjusting the firing angle or delay.

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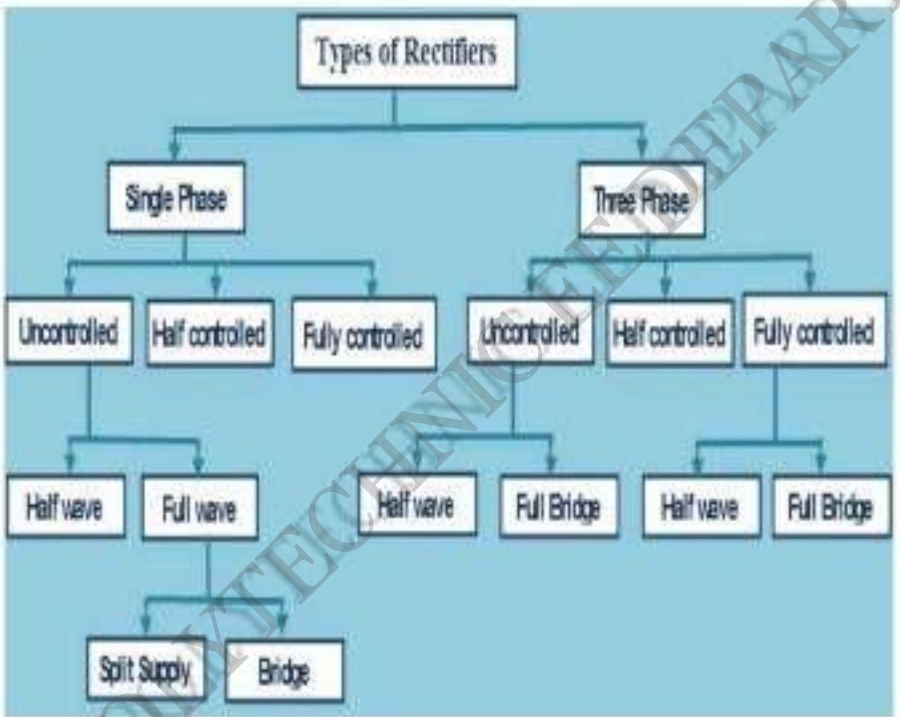
Types of Controlled Rectifier:

The phase controlled rectifier is classified into two types based on the type of input power supply.



Single Phase Half Wave Controlled Rectifier:

Single Phase Half Wave Controlled Rectifier is a rectifier circuit which converts AC input into "controlled" DC output only for Positive Half Cycle of the AC input supply.

The word "controlled" means that, we can change the starting point of load current by controlling the firing angle of SCR.

A Single Phase Half Wave Controlled Rectifier circuit consists by one SCR / thyristor, an AC voltage source and load. The load may be purely resistive, Inductive or a combination of resistance and inductance.

CHAPTER 2 PE &PLC NOTES

EE And ETC 5th SEMESTER

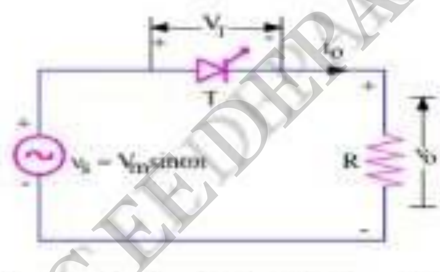
Single Phase Half Wave Controlled Rectifier with pure resistive (R) Load

Figure Shows the circuit diagram of Single Phase Half Wave Controlled Rectifier with Resistive Load. In this Circuit, an SCR (T) is used to rectify the incoming Sine Wave from the Input, and this rectified output will be supplied to an Resistive load,

V_0 = Load output voltage

i_0 = Load current

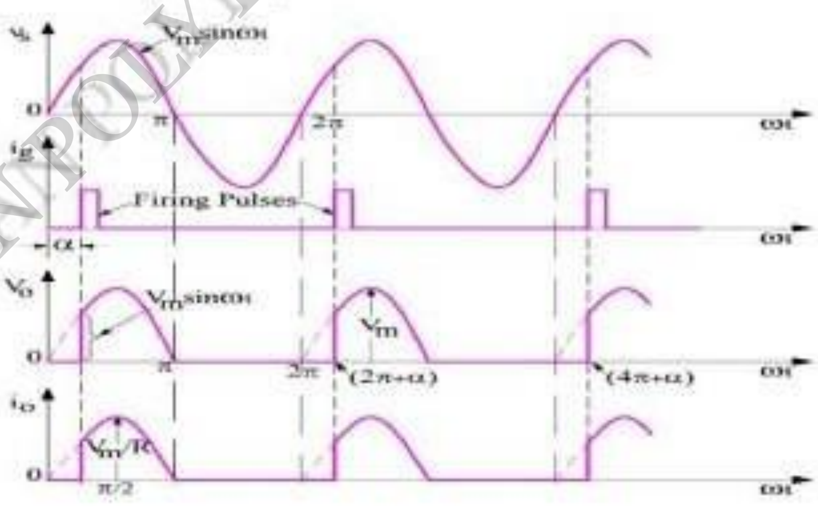
V_T = Voltage across the Thyristor



During the Positive Half Cycle of the Input Supply, the SCR (T) is forward biased. The load output voltage is zero till SCR triggered. During this cycle, the SCR is Triggered at a firing angle **ωt = α** and SCR (T) will Start conducting. But as soon as the supply voltage becomes zero at **ωt = π**, the load current will become zero

After **ωt = π** (During Negative Half Cycle), SCR (T) is reversed biased and will Turned OFF at **ωt = π** and will remain in OFF condition till it is fired again at ωt = (2π+α).

The wave shapes for voltage and current in case of Resistive load are shown below:



Therefore, the load output voltage and current for one complete cycle of input supply voltage may be written as

$v_0 = V_m \text{Sin } \omega t$ for $\alpha \le \omega t \le \pi$

$i_0 = V_m \text{Sin}\omega t / R$ for $\alpha \le \omega t \le \pi$

Calculation of Average Load Output Voltage:

As we know that, average value of any function f(x) cab be calculated using the formula

$$Average\ Value = (1/T)\int_0^T f(x)dx$$

Let us now calculate the average value of output voltage for Single Phase Half Wave Controlled Rectifier.

$$Average\ Value\ of\ Load\ output\ Voltage$$

$$= (1/2\pi)\int_0^{2\pi} VmSin\omega td(\omega t)$$

$$= (1/2\pi)\int_0^{\alpha} VmSin\omega td(\omega t) + \int_{\alpha}^{\pi} VmSin\omega td(\omega t) + \int_{\pi}^{2\pi} VmSin\omega td(\omega t)$$

Since the value of load output voltage is zero from $0 \le \omega t \le \alpha$ and $\pi < \omega t < 2\pi$, therefore

$$= (1/2\pi)\int_{\alpha}^{\pi} VmSin\omega td(\omega t)$$

$$= (Vm/2\pi)\int_{\alpha}^{\pi} Sin\omega td(\omega t)$$

$$= \left(\frac{Vm}{2\pi}\right)[1 + Cos\alpha]$$

For Single Phase Half Wave Controlled Rectifier:

$$Average\ Value\ of\ Load\ output\ Voltage$$

$$= \left(\frac{Vm}{2\pi}\right)[1 + Cos\alpha]$$

From the expression of average output voltage, it can be seen that, by changing firing angle α, we can change the average output voltage.

The average output voltage is maximum when firing angle is zero and it is minimum when firing angle α = π. This is the reason, it is called phase controlled rectifier.

Average load current for Single Phase Half Wave Controlled Rectifier can easily be calculated by dividing the average load output voltage by load resistance R.

Single Phase Half-Wave Controlled Rectifier with Inductive-Load

Figure Shows 1 (a) the circuit diagram of Single Phase Half Wave Controlled Rectifier with Inductive Load. In this Circuit, an SCR (T) is used to rectify the incoming Sine Wave from the transformer secondary, and this rectified output will be supplied to an inductive load, such as a motor winding or relay coil.

The wave shapes for voltage and current in case of an inductive load are given in Fig.1.b. The load is assumed to be highly inductive.

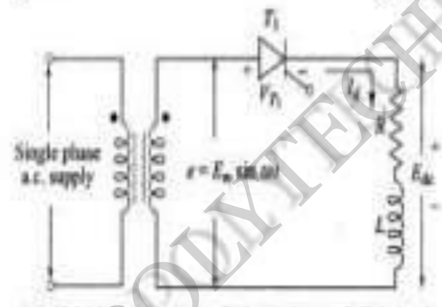


Fig.1(a) Half-wave controlled rectifier with R-L load

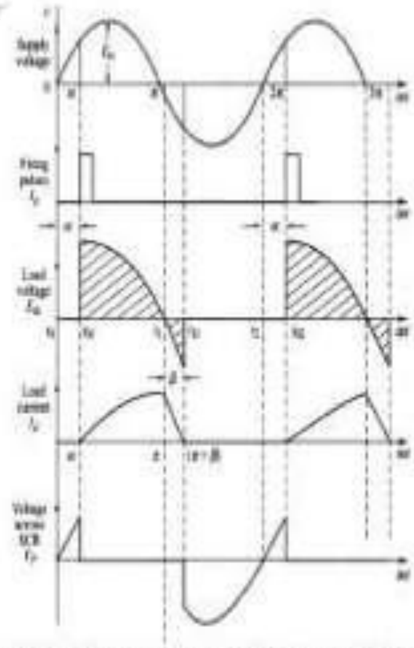


Fig.1(b) Waveforms for a half-wave controlled rectifier with R-L load

During the Positive Half Cycle of the Input Supply, the SCR (T) is forward biased. The load output voltage is zero till SCR triggered. During this cycle, the SCR is Triggered at a firing angle **ωt = α** and SCR (T) will Start conducting. The SCR will continue conducted in positive half cycle.

During Negative Half Cycle, when the supply voltage reverse, the SCR (T) is kept conducting continuously due to the fact that current through the inductance cannot be reduced to Zero. During negative voltage half-cycle, current will continuous flow till the energy stored in the inductance is dissipated in the load resistor and a part of the energy is fed back to the source.

The effect of inductive load is increased in the conduction period of SCR. Due to this reason, effective Load Voltage and Load Current will reduced. **This problem can be resolved by connecting a Free Wheeling Diode in anti- parallel with the inductive Load.**

Freewheeling Diode

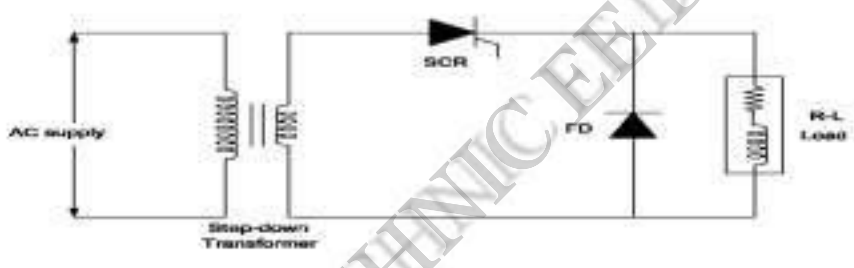
Freewheeling Diode:- A freewheeling diode is basically a diode connected across the inductive load terminals to prevent the development of high voltage across the switch. When the inductive circuit is switched off, this diode gives a short circuit path for the flow of inductor decay current and hence dissipation of stored energy in the inductor. This diode is also called Flywheel or Fly-back diode.

Purpose of using Freewheeling Diode:

1. The Freewheeling Diode improves the waveform of the load current of Rectifier circuits, inverter circuits, and chopper circuits by making it continuous.
2. The Freewheeling protect the SCRs from damage in the circuits with Inductive Load from the excessive reverse voltage creating by the Inductive Load.
3. The Freewheeling Diode improves the Input Power Factor of Phase controlled Rectifiers.
4. The Freewheeling diode sustains the average output voltage of the circuit with Inductive Load.
5. It also helps to reduce Ripple components in the output signal of the circuit with Inductive Load.

Single Phase Half-Wave Controlled Rectifier with Inductive-Load and Free Wheeling Diode

Figure Shows the circuit diagram of Single Phase Half Wave Controlled Rectifier with Inductive Load and Free Wheeling Diode. In this Circuit, an SCR is used to rectify the incoming sine wave from the transformer secondary, and this rectified output will be supplied to an inductive load, such as a motor winding or relay coil. The Free Wheeling Diode is connected across the Inductive Load in reverse biasing.



The wave shapes for voltage and current in case of an inductive load with Freewheeling Diode is shown below:

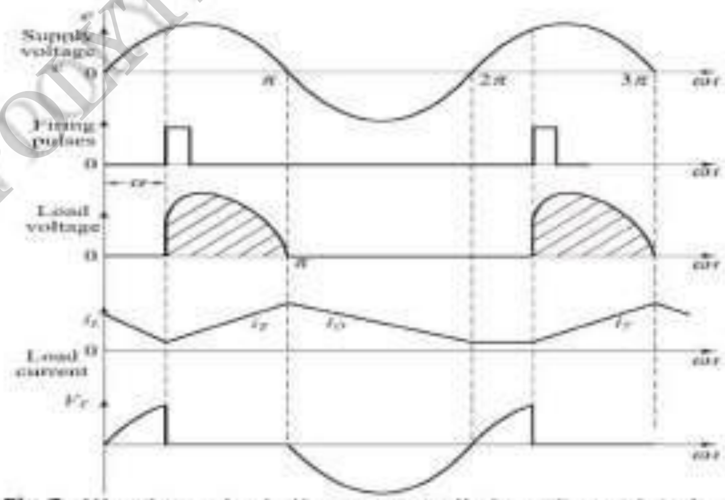


Fig.3 Waveforms for half-wave controlled-rectifier with inductive load and freewheeling diode

During the Positive Half Cycle of the Input Supply, the SCR is forward biased. The load output voltage is zero till SCR triggered. During this cycle, the SCR is Triggered at a firing angle **ωt = α** and SCR will Start conducting. The SCR will continue conducted in positive half cycle and allowing the current through Inductive (R-L) Load. The freewheeling diode (FD) is reverse biased During this half-cycle.

During the Negative Half-Cycle , the Freewheeling Diode becomes forward biased and the SCR will Turned OFF, the current that was previously flowing through the SCR and the load inductance, also starts to switch OFF, which causes the inductor to develop a large reverse voltage (positive on the bottom of the inductor, negative on the top) to try and maintain the previous current flow. This large reverse voltage spike would ordinarily be applied across the SCR (positive on the anode, negative on the cathode), potentially forcing it to continue to conduct when the gate is no longer enabled, and potentially damaging the SCR.

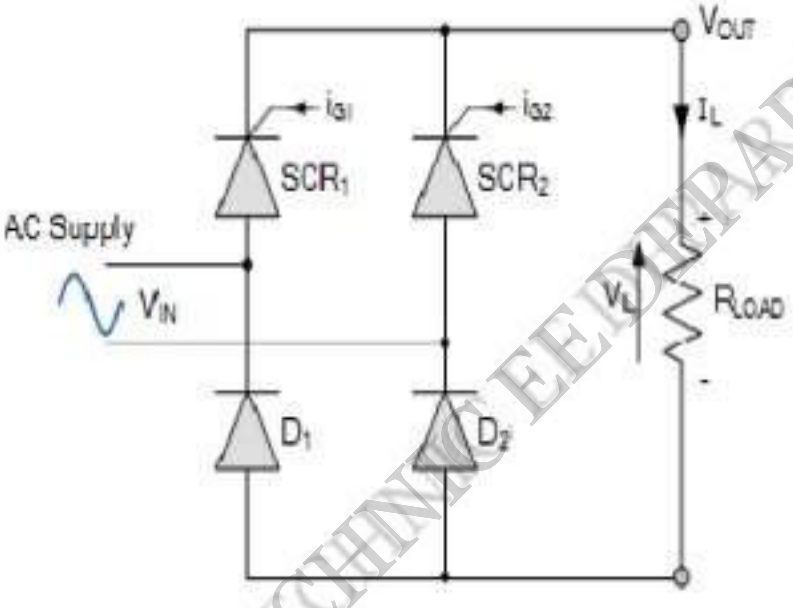
For this reason, a freewheeling diode (FD) is connected in parallel with the inductive load. With FD present, the large reverse voltage that would normally develop across the load inductance, causes FD to become forward biased, which acts like a short-circuit to clamp the reverse voltage spike that would otherwise occur to a safe level, corresponding to the forward voltage drop across FD and output voltage across the load will Zero during this Negative Half Cycle and current will flow continuously as shown in voltage & Current Wave shapes.

Single Phase Full Wave Half Controlled Rectifier with Resistive Load:

Single Phase Full Wave Half (Semi) Controlled Rectifier is a rectifier that convert the AC voltage into DC voltage during both the positive and Negative half cycles.

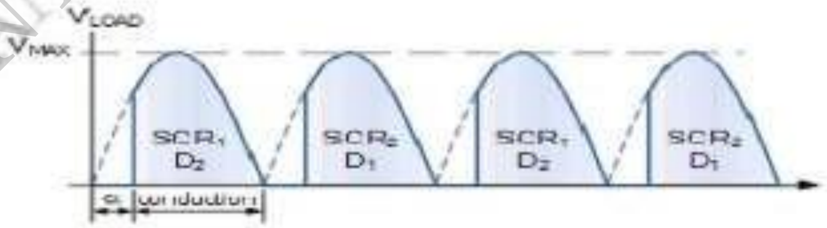
In Half Controlled Rectifier, One SCR and one Diode conducts for positive half cycle and other one SCR and other Diode conducts for negative half cycle to convert the AC voltage to DC voltage.

The Circuit Diagram Full Wave Half controlled rectifier is as shown below:



During the Positive Half Cycle of the Input V_{IN} Signal , The Current flowing through the path of: Upper Terminal of the Supply (+) , SCR_1 , Load (R_L) , D_2, and back to Lower Terminal (-) of the Supply .

Similarly, During the Negative Half Cycle of Input V_{IN}, The Current flowing through the path of : Lower Terminal (+) , SCR_2 , Load (R_L), D_1 and back to Upper Terminal (-) of the Supply.



It is clear that one SCR from the top group (SCR_1 or SCR_2) and its corresponding Diode from the bottom group (D_2 or D_1) must conduct together for any load current to flow.

Thus the average output voltage, V_{AVE} is dependent on the Firing Angle α for the two SCRs included in the Half-Controlled Rectifier as the two diodes are uncontrolled and pass current whenever forward biased. So for any gate firing angle α, the average output voltage is given by:

Average Output Voltage and Current

$$V_{AVE} = \frac{V_{MAX}}{\pi} \times (1 + \cos\alpha)$$

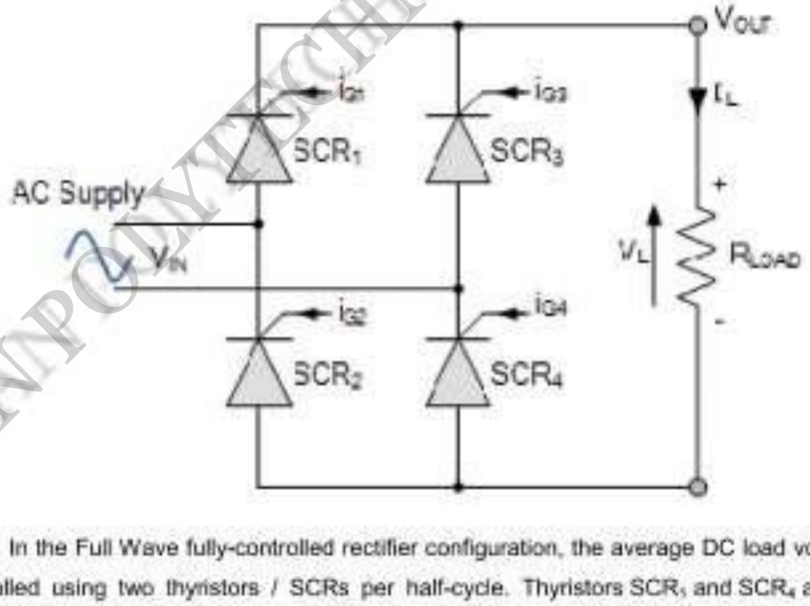
$$\therefore I_{AVE} = \frac{V_{AVE}}{R_L}$$

Single Phase Full Wave Fully-controlled Bridge Rectifier with Resistive Load:

A Full Wave Full controlled rectifier is a device, which converts AC supply into Controlled DC supply & This Fully controlled DC power supply fed to the load.

This process of converting alternating current (AC) into direct current (DC) is also called as controlled rectification.

The Circuit Diagram Full Wave Full controlled rectifier is as shown below:



In the Full Wave fully-controlled rectifier configuration, the average DC load voltage is controlled using two thyristors / SCRs per half-cycle. Thyristors SCR_1 and SCR_4 are fired together as a pair during the positive half-cycle, While thyristors SCR_3 and SCR_2 are also fired together as a pair during the negative half-cycle (i.e. 180^0 after SCR_1 and SCR_4).

During the Positive Half Cycle of the Input V_{IN} Signal , The Current flowing through the path of: Upper Terminal of the Supply (+) , SCR_1 , Load (R_L) , SCR_4, and back to Lower Terminal (-) of the Supply .

Similarly, During the Negative Half Cycle of Input V_{IN}, The Current flowing through the path of : Lower Terminal (+) , SCR_3 , Load (R_L), SCR_2 and back to Upper Terminal (-) of the Supply.

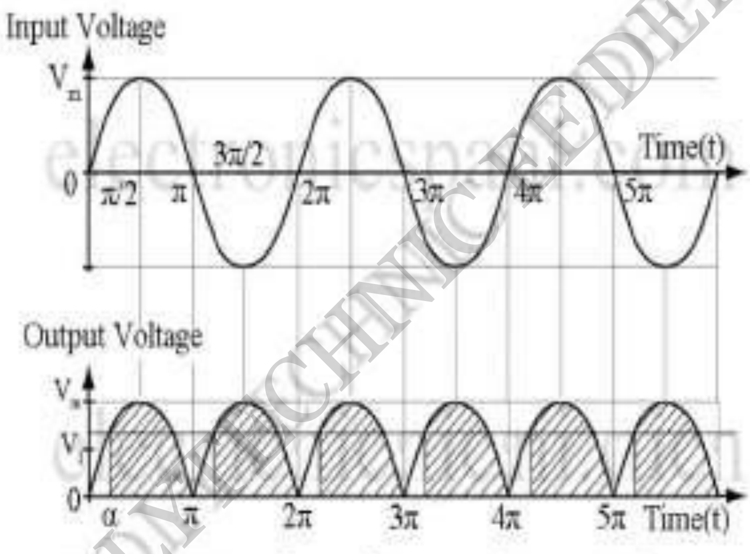


Figure 2: Waveform of Input and Output Voltages

As with the half-controlled rectifier, the output voltage can be fully controlled by varying the SCRs firing / delay angle (α).

Thus the expression for the average DC voltage from a single Full Wave phase fully-controlled rectifier in its continuous conduction mode is given as:

$$V_{AVE} = \frac{V_{MAX}}{\pi} \times \cos(\alpha)$$

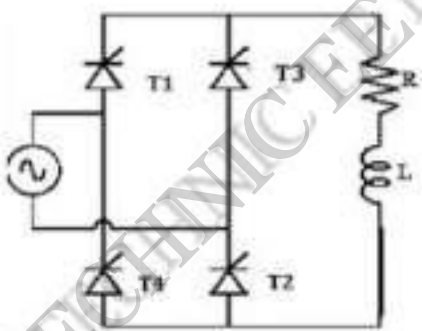
$$\therefore I_{AVE} = \frac{V_{AVE}}{R_L}$$

Full Wave Fully-controlled Bridge Rectifier With R-L Load :

In the Full Wave Fully-Controlled Rectifier Configuration, the average DC load voltage is controlled using two thyristors / SCRs per half-cycle. Thyristors T_1 and T_2 are fired together as a pair during the positive half-cycle, While thyristors T_3 and T_4 are also fired together as a pair during the negative half-cycle (i.e. 180° after T_1 and T_2).

When the load is Inductive, the Output Voltage can be Negative for part of the cycle. This is because an inductor stores energy in its magnetic field which is later released.

The Circuit Diagram Full Wave Full controlled rectifier with R-L Load is as shown below



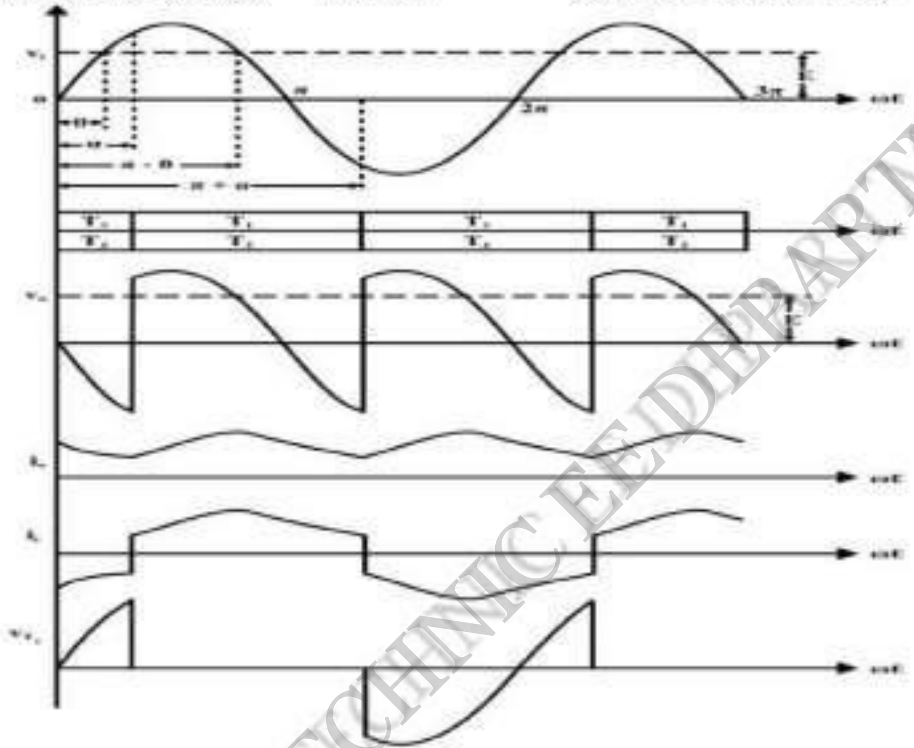
Operation of this mode can be divided between four modes

Mode 1 (α to π)

In positive half cycle of applied ac signal, SCR's T_1 & T_2 are forward biased & can be turned on at an angle α. Load voltage is equal to positive instantaneous AC supply voltage. The load current is positive, ripple free, constant and equal to Io. Due to positive polarity of load voltage & load current, load inductance will store energy.

Mode 2 (π to π + α)

At wt = π, input supply is equal to zero & after π it becomes negative. But inductance opposes any change through it. In order to maintain a constant load current & also in same direction. A self induced emf appears across 'L' as shown. Due to this induced voltage, SCR's T_1 & T_2 are forward biased in spite the negative supply voltage. The load voltage is negative & equal to instantaneous ac supply voltage whereas load current is positive. Thus, load acts as source & stored energy in inductance is returned back to the ac supply.



Mode 3 (π + α to 2π)

At wt = π + α, SCR's T_3 & T_4 are turned on & T_1, T_2 are reversed bias. Thus , process of conduction is transferred from T_1,T_2 to T_3,T_4. Load voltage again becomes positive & energy is stored in inductor T_3, T_4 conduct in negative half cycle from (π + α) to 2 π. With positive load voltage & load current energy gets stored.

Mode 4 (2 π to 2 π + α)

At wt = 2π, input voltage passes through zero. Inductive load will try to oppose any change in current if in order to maintain load current constant & in the same direction. Induced e. m. f. is Positive & maintains conducting SCR's T_3 & T_4 with reverse polarity also. Thus V_L is negative & equal to instantaneous AC supply voltage. Whereas load current continues to be positive. Thus load acts as source & stored energy in inductance is returned back to ac supply At wt = α or 2 π + α, T_3 & T_4 are commutated and T_1,T_2 are turned ON.

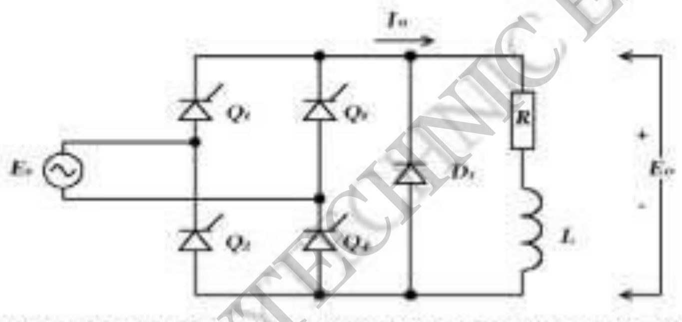
Full Wave Fully-controlled Bridge Rectifier With R-L Load & Free Wheeling Diode:

In the Full Wave fully-controlled rectifier configuration, the average DC load voltage is controlled using two thyristors / SCRs per half-cycle. Thyristors Q_1 and Q_4 are fired together as a pair during the positive half-cycle, While thyristors Q_2 and Q_3 are also fired together as a pair during the negative half-cycle (i.e. 180° after Q_1 and Q_4).

When the load is inductive, the output voltage can be negative for part of the cycle. This is because an inductor stores energy in its magnetic field which is later released.

A free-wheeling diode can be placed in the circuit to prevent the output voltage from going negative.

The Circuit Diagram Full Wave Full controlled rectifier with R-L Load & Free Wheeling Diode is as shown below:



When the load is inductive, the output voltage can be negative for part of the cycle. This is because an inductor stores energy in its magnetic field which is later released. Current continues to flow, and the same thyristors continue to conduct, until all the stored energy is released. Since this occurs some time after the AC source voltage passes through zero, the output voltage becomes negative for part of cycle.

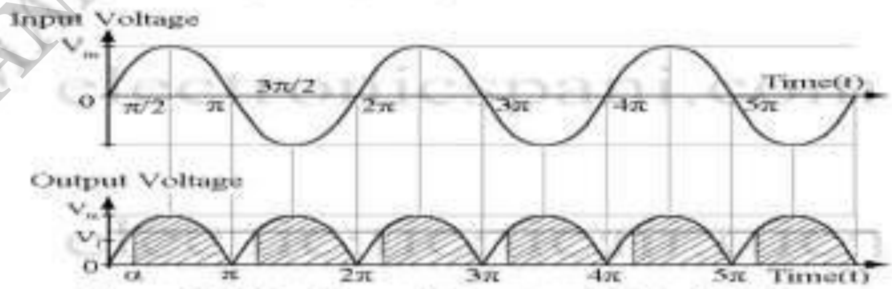
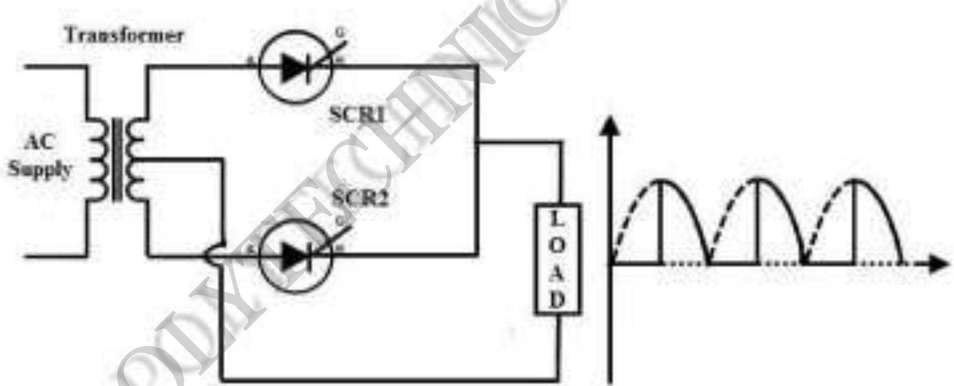


Figure 2: Waveform of Input and Output Voltages

The negative part of the output voltage waveform reduces the average output voltage E_0. A free-wheeling diode can be placed in the circuit to prevent the output voltage from going negative. When the output voltage begins to go negative, the free-wheeling diode conducts. This maintains the output voltage at approximately zero while the energy stored in the inductor is released. The output voltage waveform is the same as for a purely resistive load, and the average output voltage is therefore greater than it would be without the free-wheeling diode. The addition of a free-wheeling diode makes the output current waveform smoother.

Full Wave Full Controlled Centre Tapped Rectifier:

The full wave Full Controlled rectifier circuit consisting of two SCRs connected with centre tapped transformer. The Circuit Diagram Full Wave Full controlled Centre Tapped rectifier is as shown below:



During the positive half cycle of the input, SCR_1 is forward biased and SCR_2 is reverse biased. By applying the proper gate signal, SCR_1 is turned ON and hence load current starts flowing through it.

During the negative half cycle of the input, SCR_2 is forward biased and SCR_1 is reverse biased. With a gate triggering, SCR_2 is turned ON and hence the load current flows through the SCR_2.

Therefore, by varying the triggering current to the SCRs, the average power delivered to the load is varied.

CHAPTER 2 PE &PLC NOTES

EE And ETC 5th SEMESTER

FILL IN THE BLANKS:

1. A .... is a circuit that converts AC signal into unidirectional signal.
2. Main advantage of Bridge Converter is that it does not use any...................
3. In a Single Phase Fully Controlled Rectifier, The.............. of an uncontrolled Rectifier are replaced by.................
4. In a fully controlled Rectifier, the load voltage is controlled by controlling the .... of the Rectifier.
5. A Single Phase Half Wave Controlled Rectifier always operates in the ....conduction mode.
6. A Half Wave Controlled Rectifier contains................SCRs.
7. A Single Phase Full Wave Fully Controlled Bridge Rectifier uses.........SCRs.
8. A Single Phase Full Wave Half Controlled Bridge Rectifier Contains ...SCRs
9. A Free Wheeling diode is used in the Controlled Rectifier with ....Load.
10. A Single Phase Full Wave Controlled Rectifier operate in .... Quadrants.
11. Full Form of HVDC is ....
12. The output voltage of a controlled Rectifier is maximum, when firing angle is ....Degree.
13. The output voltage of a controlled Rectifier is controlled by controlling firing angle of ....
14. A Semi converter operate in .... quadrants and full converter operate in .... Quadrants.
15. The use of Free Wheeling Diode to improve wave shape of ....

Answers:

1) Rectifier	**2) Transformer**	**3) Diodes, SCRs**
4) Firing Angle	**5) Discontinuous**	**6) One**
7) Four	**8) Two**	**9) Inductive**
10) Two	**11) High Voltage Direct Current**	**12) Zero**
13) SCRs / Thyristors	**14) One, Two**	**15) Load Current**

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FILL IN THE BLANKS:

16. Conversion of AC into DC is called ………………..
17. Controlled Rectifiers are used to convert AC into ………………..
18. ………………Rectifier contains the mixture of diodes and SCRs.
19. ……………… Rectifier uses only SCRs in Rectification circuit.
20. When Firing Angle of SCRs increased in the Rectifier, output voltage will……
21. When Conduction Angle of SCRs increased in the Rectifier, output voltage will…………
22. The Voltage form factor of Single Phase fully Controlled Half Wave Rectifier with Resistive Inductive Load is ……….compared to same Rectifier with Resistive Load.
23. The Single Phase Fully Controlled Bridge Rectifier can either operate in the ………… or ………………. Conduction Mode.
24. In the continuous conduction mode, at least …….thyristors conduct at all times.
25. Free Wheeling Diode connected in…………with load in …….. bias mode.
26. When Firing Angle of SCRs in the rectifier circuit is Zero Degree, the behaves / output of SCRs will be like as …………
27. Firing Angle is also Known as ……..Angle.
28. Full Wave Full Controlled Centre Taped Rectifiers contains ……..SCRs.
29. …………….. Controlled Rectifiers have One SCR.
30. ………………… are used to convert AC into controlled D. C.

Answers:

16)Rectification	**17) Controlled DC**	**18) Half Controlled**
19) Full Controlled	**20) Decreased**	**21) Increases**
22) Poor	**23) Continuous, Discontinuous**	**24) Two**
25) Parallel, Reverse	**26) Simple Rectifier**	**27) Delay**
28) Two	**29) Half Wave**	**30) Controlled Rectifier**

TRUE / FALSE Statement:

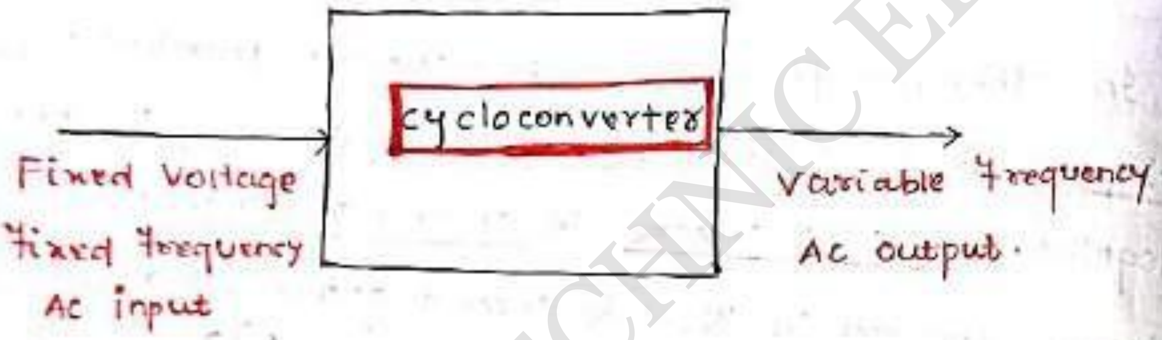
1. In a Single Phase Full Wave Half Controlled Bridge, both the SCRs conduct in the Half of the AC Supply simultaneously.
2. The Half Wave Rectifier is used most of the high power applications.
3. The average (DC) output voltage of Full Wave Rectifier is higher than Half Wave Rectifier.
4. When the rectification components are diodes, the circuits are termed as controlled rectifiers.
5. When the rectification components are SCRs / Thyristors, the circuits are termed as controlled rectifiers.
6. In Half Controlled Rectifier, Two SCRs are used.
7. Full Wave Controlled Rectifier allow the power to the Load from both cycles of the input.
8. The output voltage of controlled rectifier is controlled by variation of firing Angle of SCRs.
9. The uncontrolled Rectifiers contains SCRs in the circuit.
10. The output voltage of the Rectifier is decreased with the increase of conduction angle of SCRs
11. The output current can be continuous / discontinuous depending on the R / L (Resistance / Inductance) ratio of the Load and firing angle of SCRs.
12. The output voltage of the Rectifier is decreased with the increase of Firing angle of SCRs
13. A full Wave Rectifier can operate in Two Quadrant.
14. A Half Wave Rectifier can operate in all four Quadrant.
15. A Single Phase Full wave Half Controlled Bridge Rectifier contain four SCRs / Thyristors.
16. The output voltage of a controlled Rectifier is maximum, when firing angle of SCRs is Zero Degree.
17. Full Wave Full Controlled Centre Taped Rectifiers contains Four SCRs.
18. Half Controlled Rectifier contains the mixture of diodes and SCRs.
19. Firing Angle is also Known as Conduction Angle.
20. Free Wheeling Diode connected in parallel with inductive load.

Answers:

1) FALSE	2) FALSE	3) TRUE	4) FALSE
5) TRUE	6) FALSE	7) TRUE	8) TRUE
9) FALSE	10) FALSE	11) TRUE	12) TRUE
13) TRUE	14) FALSE	15) FALSE	16) TRUE
17) FALSE	18) TRUE	19) FALSE	20) TRUE

① # Cyclo - Converter

- A cycloconverter (also known as a cycloinverter or CCV) converts a constant voltage, constant freq AC waveform to another AC waveform of a different frequency.



- cycloconverter converts AC to AC, only changing the frequency so it is known as a frequency changer.

Step-up Cycloconverters :-

It can provide an output having the frequency greater than the input frequency by using Forced commutation.

Step down cycloconverters :-

It provides output having lower frequency than the input frequency by using Line/Natural commutation.

(2) Applications of cycloconverter

The applications of cycloconverters include:

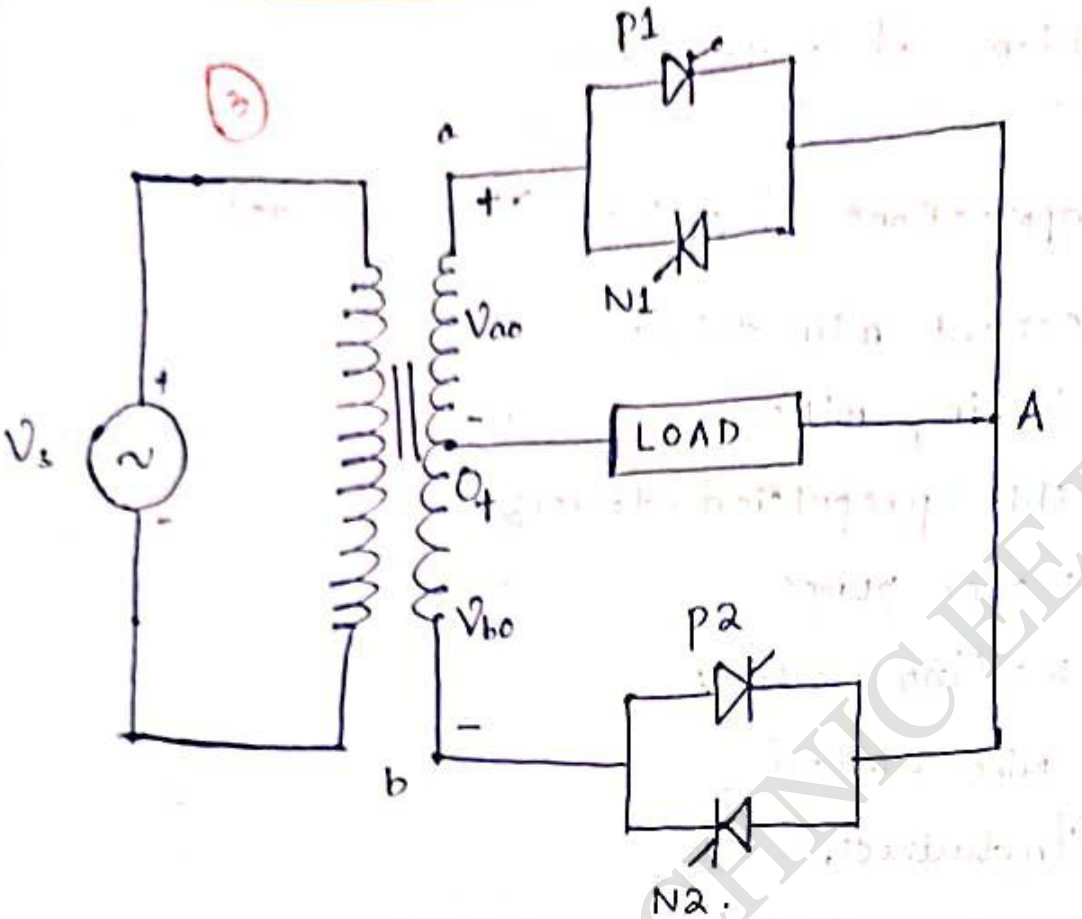
- cement mill drives
- Rolling mills
- ship propulsion drivers
- water pumps
- washing Machines
- Mine winders
- Industries.

1-φ step-up Cyclo-Converter:—

- The working principle of a step-up cycloconverter is based on switching of thyristors in a proper sequence. These switches are arranged in a specific pattern so that the output power is available for both the positive & negative half of the i/p power supply.

- Forced commutation technique is used to turn-off the conducting thyristor.

- mid-point Type cyclo-converters is illustrated here.



Operation of step-up Cycloconverter :-

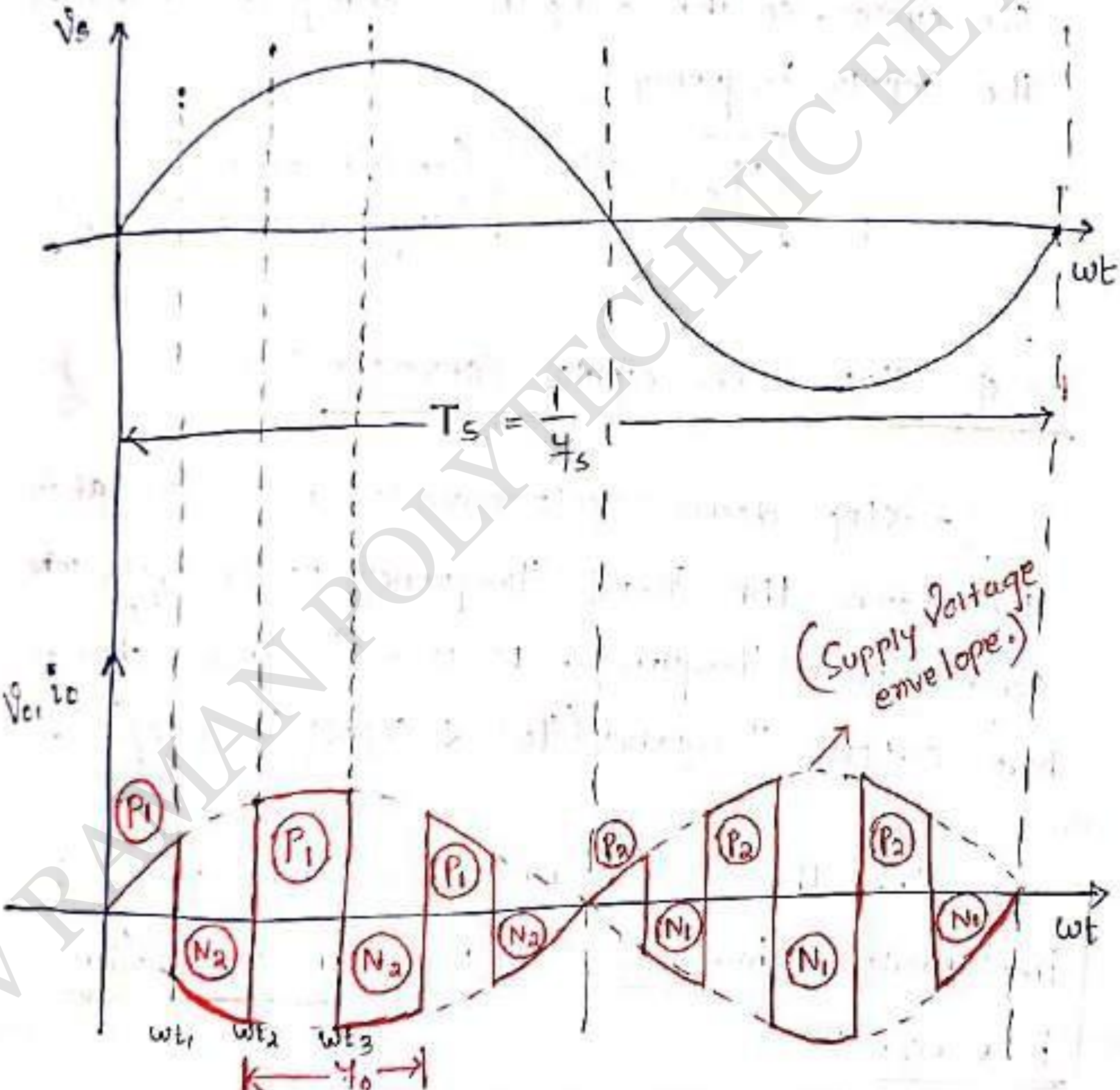
→ During +ve half cycle, of the input supply voltage, the thyristor P1 & N2 are forward biased. for $\omega t = 0$ to π.

→ As such SCR P1 is fired to turn it ON at $\omega t = 0$ such that load voltage is positive with terminal A positive & 'O' negative. The load voltage thus follows the positive envelope of the input supply voltage.

- At some time instant $\omega t = \omega t_1$, the conducting thyristor P1 is force commutated & the forward biased thyristor N_2 is fired to turn it ON.

(4)

- During the period N_2 conducts, the load voltage is negative because O is positive & A is negative this time. The load or output Voltage traces the negative envelope of the supply Voltage.



- In this manner, SCRs (P1, N2) for the +ve halfcycle (P2, N1) in -ve half cycle are switched alternately betn positive & negative envelopes at a high frequency.

(5)

- This results in output frequency to more than the Input supply frequency f_s.

- In the previous figure, when the input completes one complete cycle, then the output waveform completes six cycles. so the output frequency is six times of the supply frequency.

$$f_0 = 6f_s$$ (so it is called step-up cycloconverter).

1 - φ Step down cyclo - Converter :-

- step-down cycloconverter is a device which steps down the fixed i/p frequency power supply into some lower frequency. It is a frequency changer here output frequency (f_0) < supply frequency (f_s).

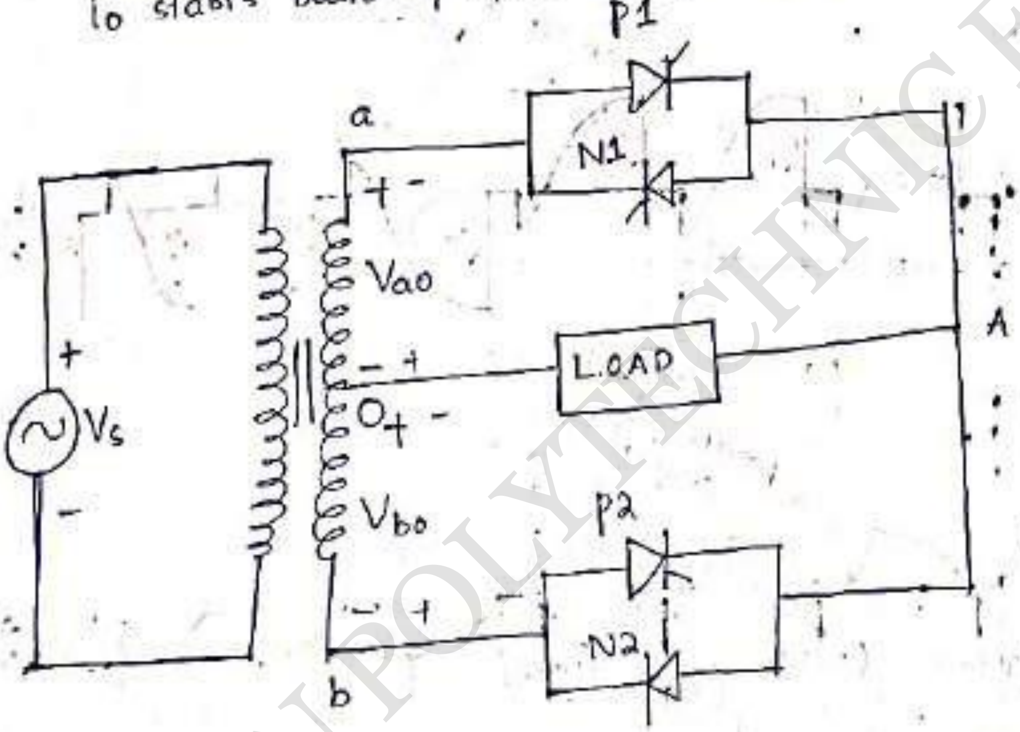
- Here the force commutation technique is not implemented; here Line or Natural Commutation is used.

The working principle of step-down cyclo-converter is explained for discontinuous & continuous load current. The load is assumed to be comprised of resistance (R) & Inductance (L).

(6)

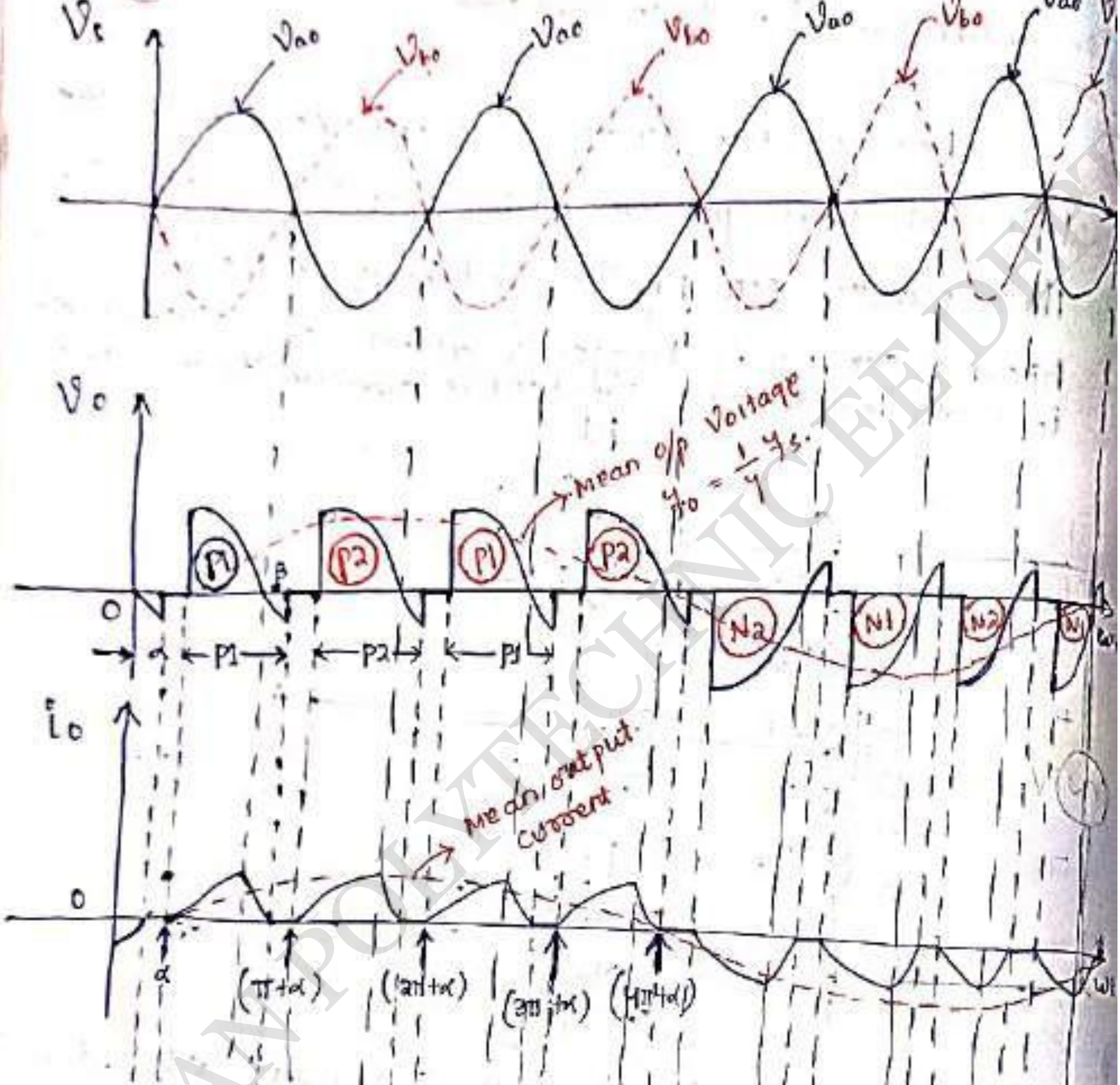
Discontinuous Load current :-

For positive cycle of input AC supply, the terminal A is positive with respect to point O. This makes SCR P1 forward biased. The forward biased SCR P1 is triggered at $\omega t = 0$. Here load current i_0 starts building up in the positive direction from A to O.



- Load current i_0 becomes zero at $\omega t = \beta$, which is greater than π, but less than $(\pi + \alpha)$. Here the thyristor P1 is thus, naturally commutated at $\omega t = \beta$ which is already reversed biased after π.

- After a half cycle, b is positive w.r.t 'O'. Now forward biased thyristor P2 is fired at $\omega t = \pi + \alpha$. Load current is again positive from A to O & built up from 'O' as shown in waveform. At $(\omega t = \pi + \beta)$, i_0 decays to zero and P2 is naturally commutated. At $\omega t = 2\pi + \alpha$, P1 is again turned ON. Load current is seen to be discontinuous.



here $f_o = \frac{1}{4} f_s$

$f_o < f_s$ hence it is step down cycloconverter.

Inverters

It is a static power electronic circuit which converts DC to variable AC i.e., Variation in magnitude of voltage, frequency and number of phases. Phase controlled rectifiers when operated with $\alpha > 90°$. They are line commutated inverters. It transfers the energy from DC to an existing AC supply network. The output AC voltage, frequency and number of phases cannot be controlled.

8.1 1-ϕ Half Bridge Inverters

Both thyristors are forward biased. So, triggering is given to them so that only one conducts at a time.

It consists of two SCR's, two diodes and three-wire supply. For $0 < t \leq T/2$, thyristor T_1 conducts and the load is subjected to a voltage $V_s/2$ due to the upper voltage source $V_s/2$. At $t = T/2$, thyristor T_1 is commutated and T_2 is gated on. During the period $T/2 < t \leq T$, thyristor T_2 conducts and the load is subjected to a voltage $(-V_s/2)$ due to the load voltage source $V_s/2$.

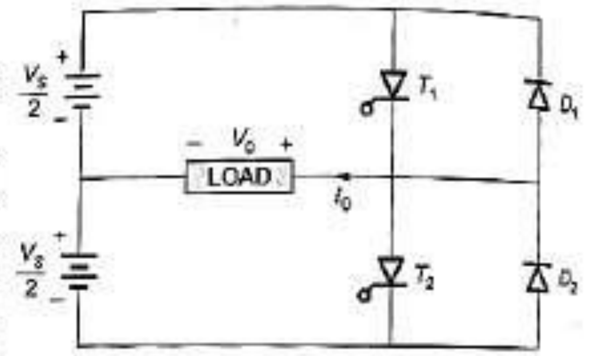


Figure-8.1

It is seen from the output waveforms that the load voltage is an alternating voltage waveform of amplitude $V_s/2$ and frequency $1/T$ Hz. The frequency of the inverter output voltage can be changed by controlling 'T'.

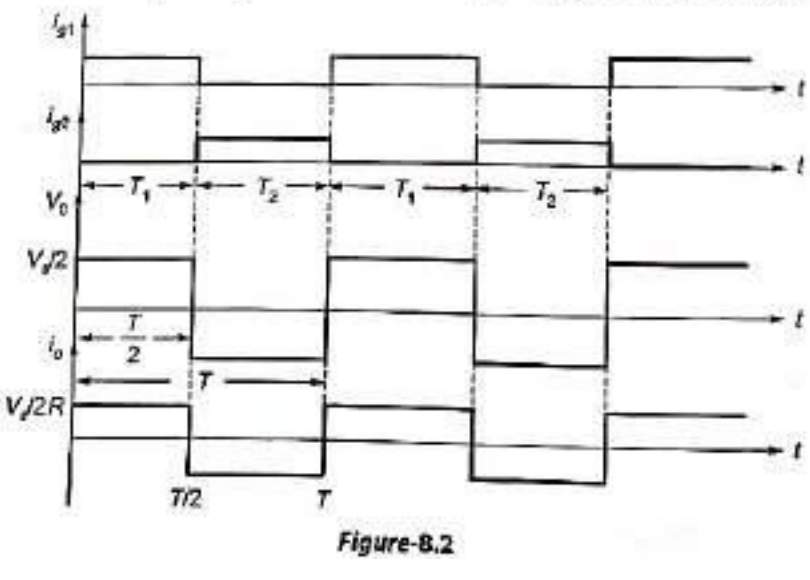


Figure-8.2

NOTE: Inverter operating principle based on forced commutation.

The output waveforms are square waveform. They will be passed through filters to eliminate unwanted harmonics.

Antiparallel diodes are required for all the loads except resistive load.

Antiparallel diodes are also called as feedback diodes.

$$\boxed{V_{or} = \frac{V_s}{2}}$$

Disadvantage

NOTE: At any time output voltage is half of the available supply voltage. So, the source utilization factor will be 50%.

8.2 1-ϕ Full Bridge Inverter / Voltage Source Inverter.

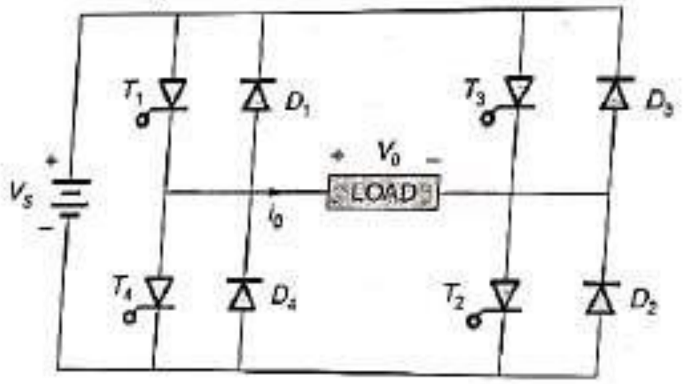


Figure-8.3

NOTE: If all the thyristors conduct at a time then the circuit will be short circuited.

- Choose a suitable combination of two thyristors triggering at different times so that current always passes through load.

$$\boxed{V_{or} = V_s}$$

- For a full bridge inverter, when T_1, T_2 conducts, load voltage is V_s and when T_3, T_4 conduct load voltage is $-V_s$ frequency of the output voltage can be controlled by varying the periodic time 'T'. At any time output voltage is same as the supply voltage. So the source utilization factor will be 100%.
- For a given input dc supply, load or output voltage is two times, output power is four times in the full bridge inverter compared to half bridge inverter.

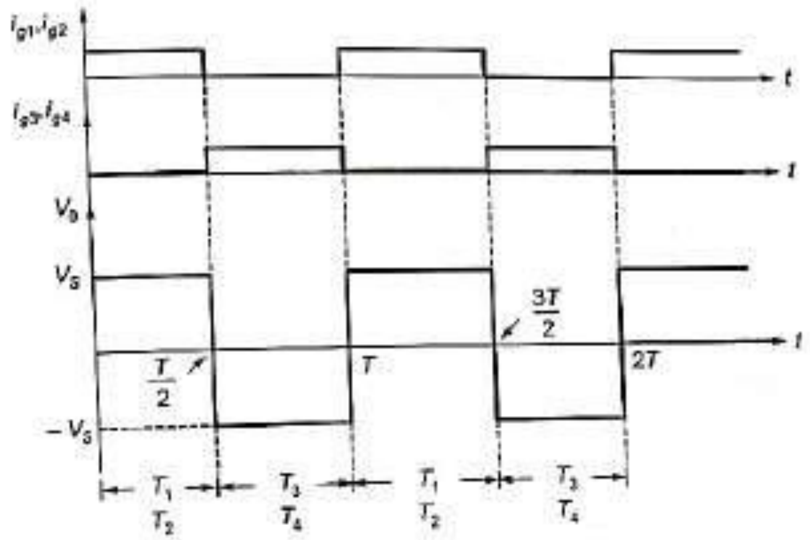


Figure-8.4

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

Series Inverters

Inverters in which commutating components are permanently connected in series with the load are called series inverters.

The series circuit so formed must be under damped.

The Basic 1-ϕ Series Inverters

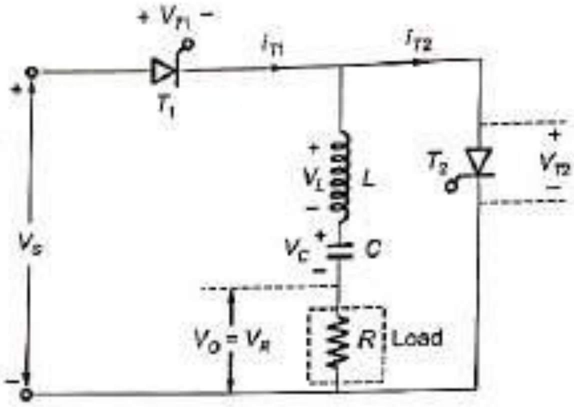


Figure-8.16

The commutating components L and C values are so chosen such that the series RLC circuit formes an underdamped circuit.

When thyristor T_1 is turned-on, with T_2 off, current i starts building up in the RLC circuit; As the circuit is underdamped, the load current after reaching some peak value, decays to zero at a point a.

SCR T_1 is turned-off. After instant a, sometime t_{qmin} must elapse for T_1 to regain its forward blocking capability.

After T_1 has commutated, upper plate of capacitor attains positive polarity. Now when T_2 is turned on at instant b, capacitor begins to discharge and load current in the reversed direction builds up to some peak negative value and then decays to zero at instant C.

Capacitor delivers the required energy during the negative half cycle.

$$T_{off} > t_q \Rightarrow T_{off} = \left(\frac{\pi}{\omega} - \frac{\pi}{\omega_r}\right) > t_q$$

$$\boxed{T_{off} = \frac{1}{2}\left(\frac{1}{f} - \frac{1}{f_r}\right)}$$

where, f = output frequency

f_r = ringing frequency

$T_{off} = ab$ or cd is called circuit turn-off time or dead zone time.

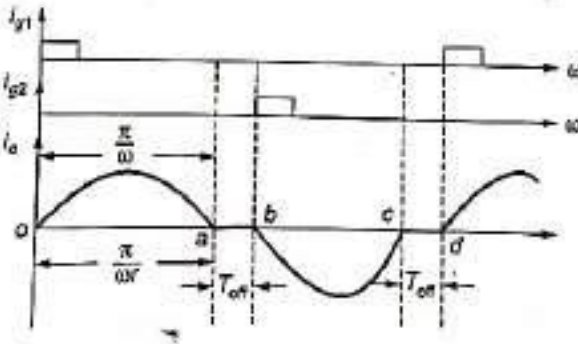
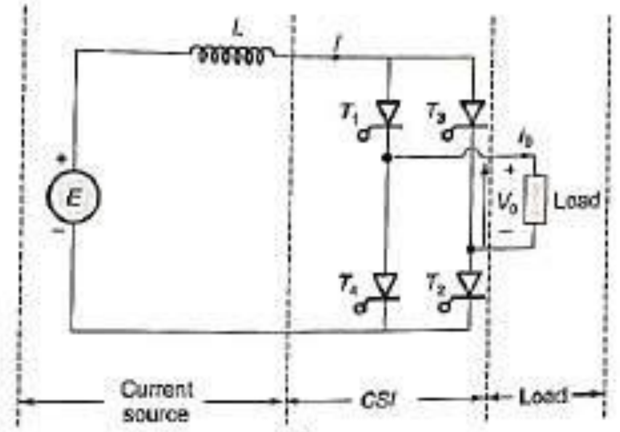


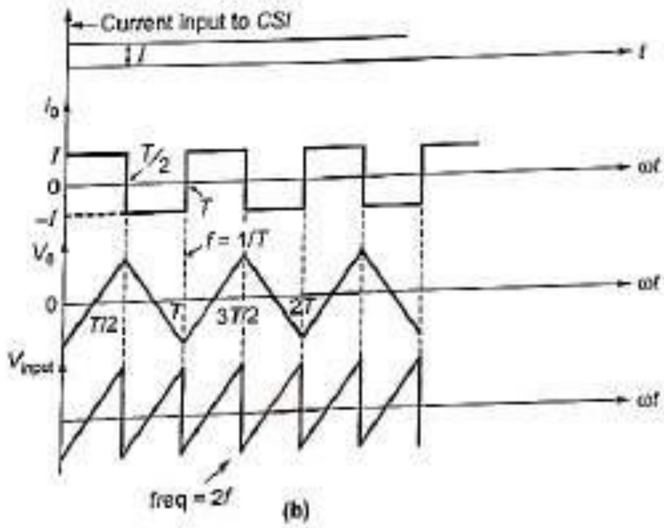
Figure-8.17

8.6 Current Source Inverter (CSI)



(a)

During positive half cycle of current T_1, T_2 conducts and
During negative half cycle of current T_3, T_4 conducts.



(b)

Figure-8.18 : (a) and (b)

(1) UNIT-4 PE & PLC

Working of UPS with Block Diagram:-

An Uninterruptible power supply (UPS) is defined as a piece of electrical equipment which can be used as an immediate power source to the connected load when there is a failure in the main input power source.

- In UPS, the energy is generally stored in flywheels, batteries or super capacitors. UPS can be used as a protective device for some hardware which can cause serious damage or loss with a sudden power disruption. Uninterruptible power source, Battery backup & flywheel back up are the other names often used for UPS.

- The available size of UPS units range from 200VA which is used for a solo computer to several large units upto 46MVA.

Major Roles of a UPS:-

- In failure of main power source, the UPS will supply power for a short time. This prime role of UPS.

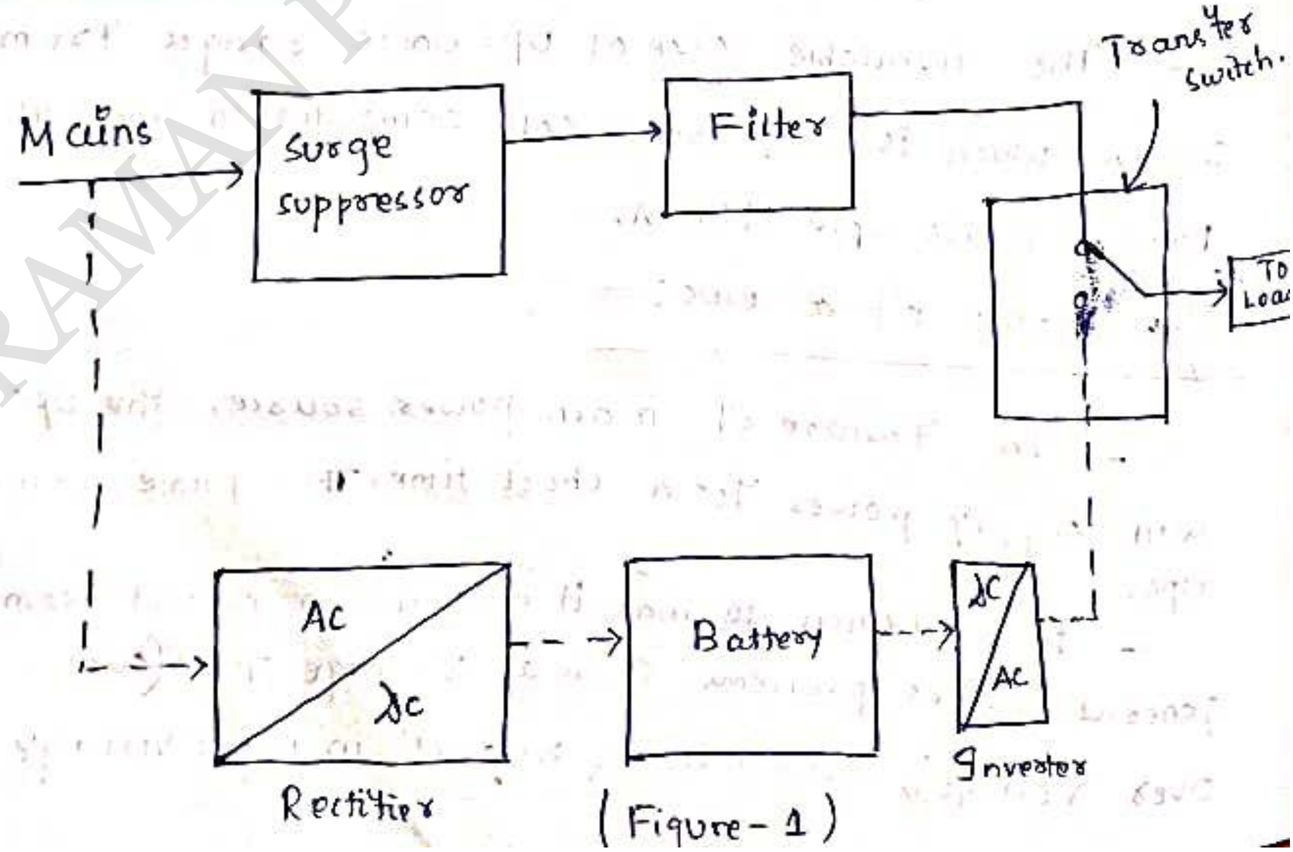
- In addition to that it can able to correct some general power problems such as voltage spike (sustained reduction in input voltage, over voltage), Noise, Quick

Harmonic distortion and the instability of frequency in mains.

Types of ups

- On line (it can be further devided into standby on-line hybrid, standby - Ferro, delta conversion on-Line)
- OFF-line
- Line Interactive

OFF Line ups :-



(Figure-1)

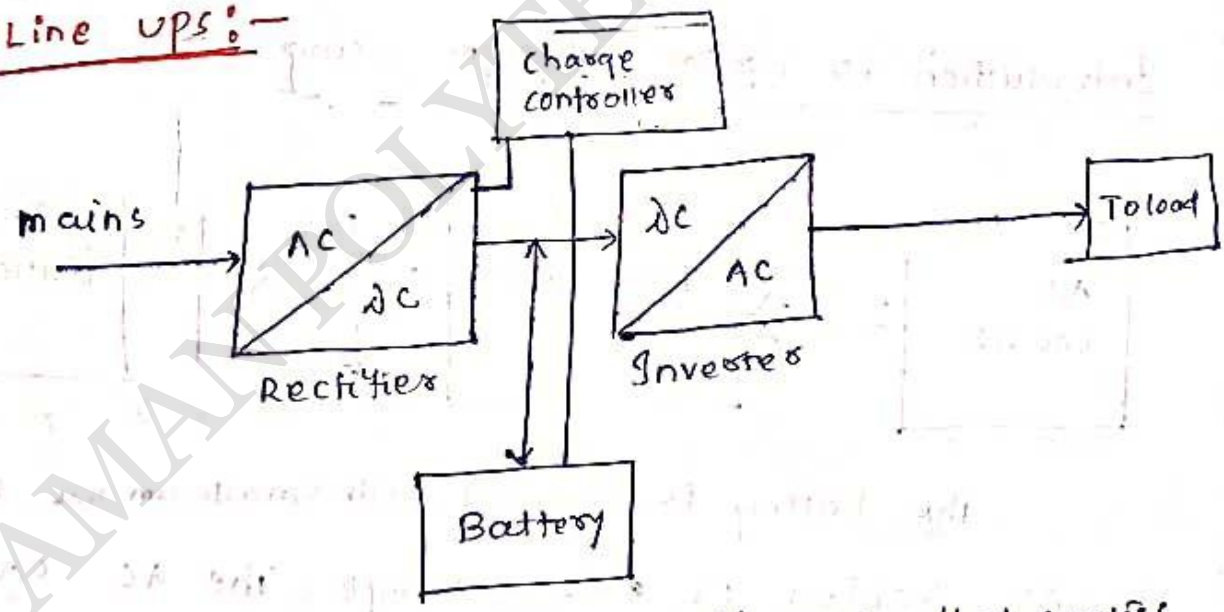
(3)

- In OFF line ups, the primary source is the filtered AC mains (shown in solid path in Fig 1).

- when the power breakage occurs, the transfer switch will select the backup source. (shown in dashed path in figure 1)

- when power breakage occurs, this DC Voltage is converted to AC voltage by means of power Inverters. & is transferred to the load connected to it. This is the least expensive ups s/s & it provides surge protection in addition to backup.

on-Line ups:-



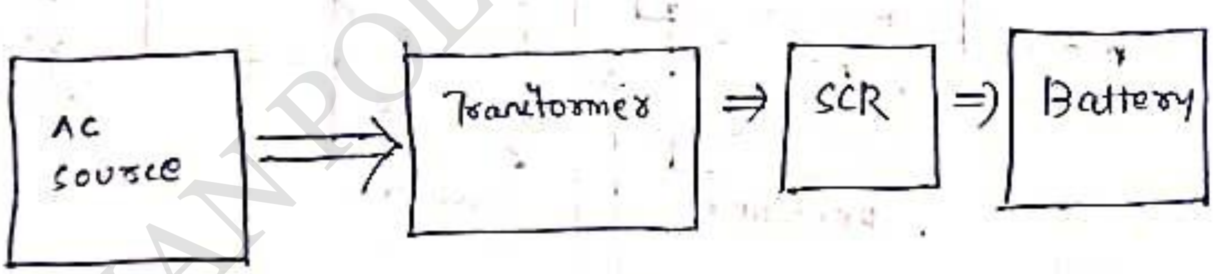
- The online ups is a type of ups that supplies power to the AC load through the Rectifier & inverter combo in normal operation & uses an inverter to supply AC power during a power failure.

(4)

- Therefore, the output power supply always stays ON & there is no need for switching. Hence there is no time delay in switching between its source.

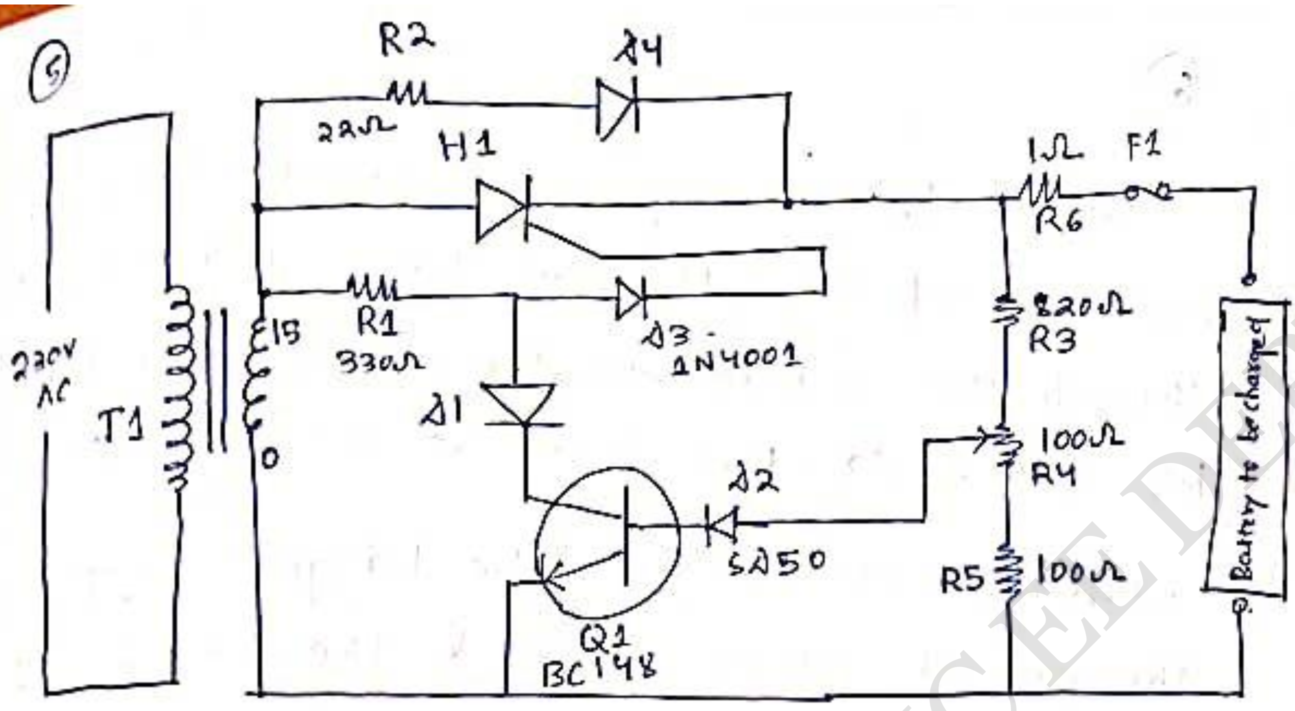
- The major point of difference between the online ups & offline ups is that, the online ups supplies power from the AC mains to the load through the rectifier & inverter combination while the offline ups directly supplies power from AC mains to the load.

Introduction to Battery charger using SCR :-



The battery is charged with small amount of AC voltage or dc voltage. The AC source is given to the step down transformer which converts the large AC source into limited AC source, filter the AC voltage & remove the noise & then give that voltage to the SCR where it will rectify the AC & give the resulting voltage to the battery for charging.

(5)



- A simple battery charger based on SCR is shown here. Here SCR (H1) Rectifies the AC mains voltage to charge the battery.

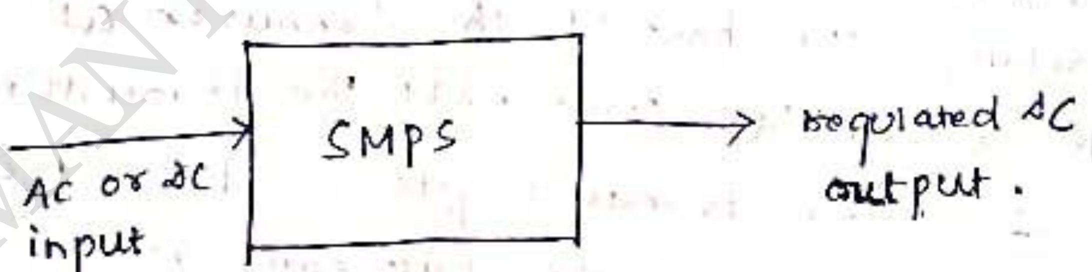
- when the battery connected to charger gets discharged, the battery voltage gets dropped. This Inhibits the forward biasing voltage from reaching the base of the transistor Q1 through R4 & D2. This switches off the transistor.

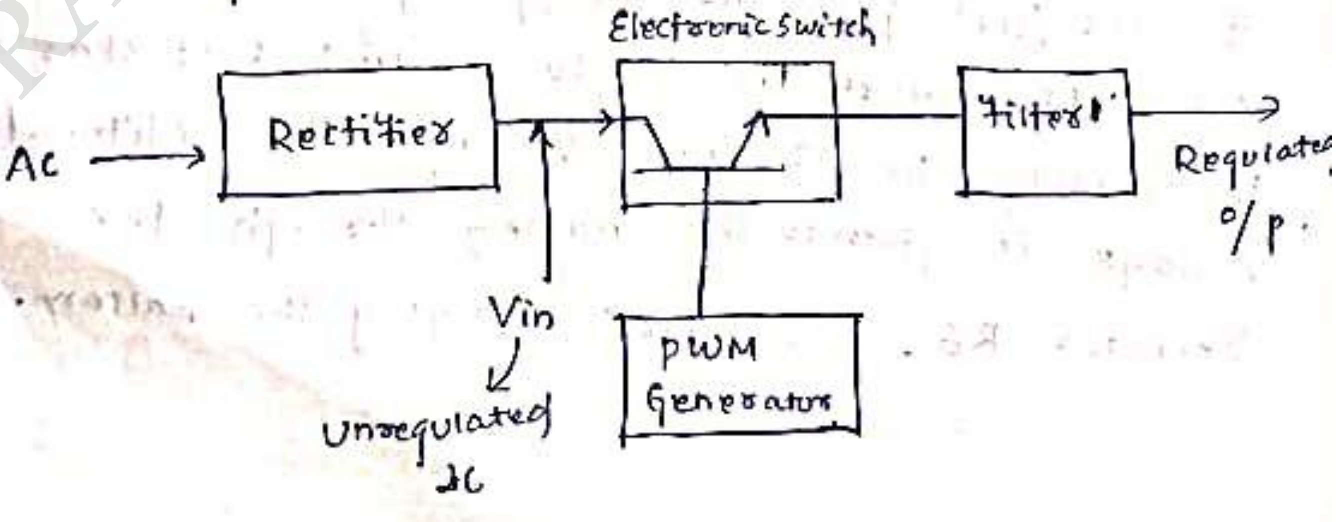
- when transistor gets turned off, the gate of SCR (H1) gets the triggering voltage via R1 & D3. This makes the SCR to conduct & it starts to rectify the AC input voltage. The rectified Voltage is given to the battery through the resistor R6. This starts charging the battery.

- when the battery is completely charged the base of Q1 gets the forward bias signal through the voltage divider circuit made of R3, R4, R5 & D2. This turns the transistor ON.
- when Q1 is turned on the trigger voltage at the gate of SCR is cut off & the SCR is turned OFF.

Basic Switched Mode power Supply (SMPS) :-

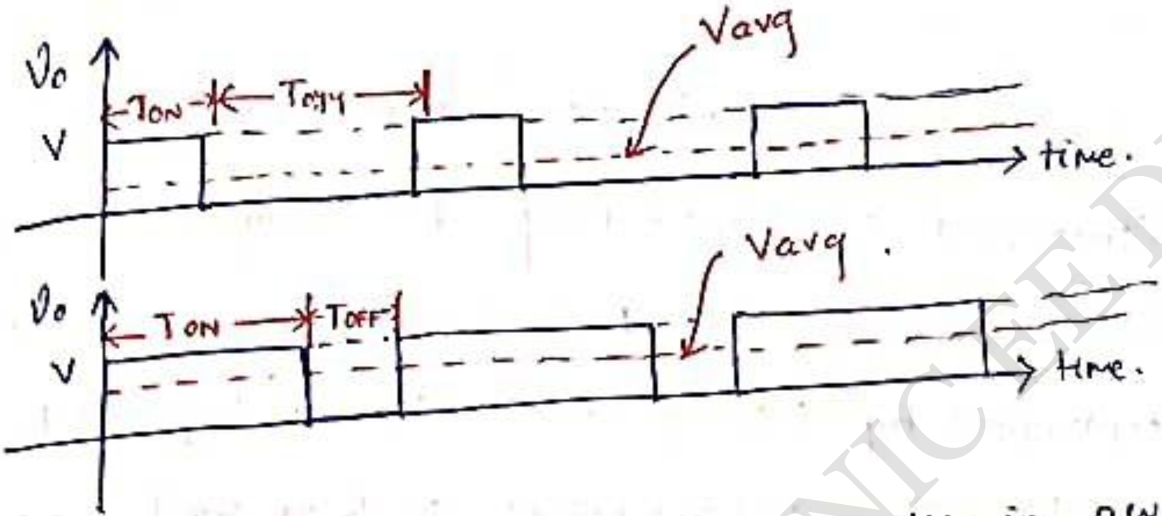
- The basic function of switched mode power supply is to convert AC or DC input to the regulated DC output. This device having high freq switch.





(7)

- As high frequency switch is used the size of the device decreases.



- By adjusting the pulse width in PWM generator, the output voltage can be regulated.

$$V_o = V\left[\frac{T_{ON}}{T_{ON}+T_{OFF}}\right] = V.\delta$$

δ → duty cycle → can be controlled by PWM.

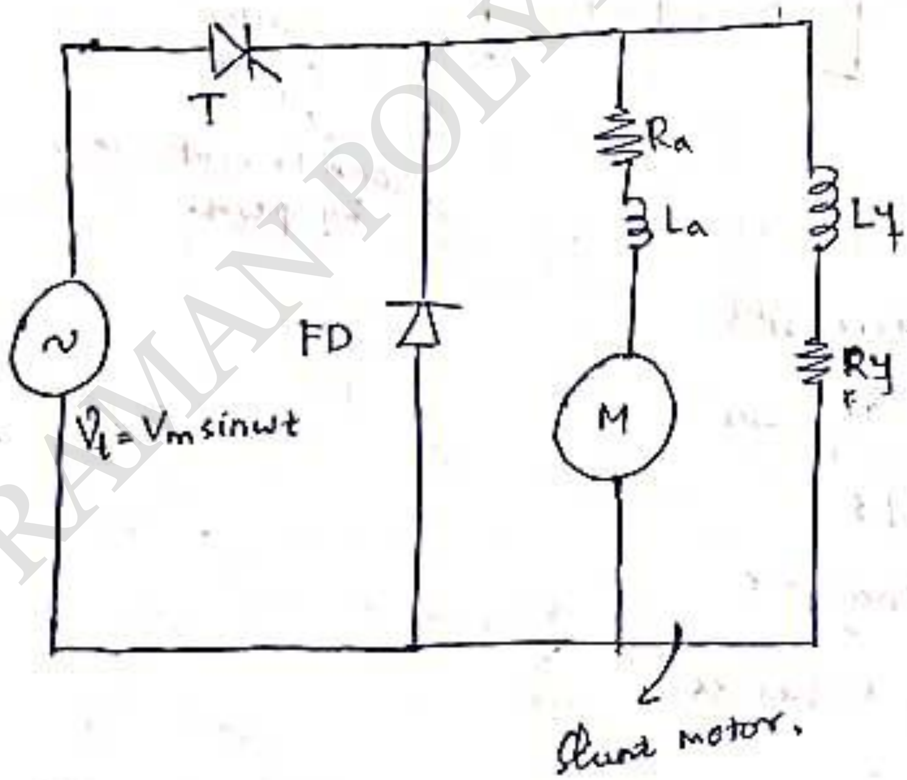
Application

- personal computers
- tool Industries
- security system
- Railway s/s
- Battery charger
- Used in vehicles.

(2)

Speed control of DC shunt Motor using Converter :-

- The speed of DC Motor has been controlled by controlling the armature voltage by using thyristors., The armature voltage is controlled by using the different types of AC to DC semiconverters such as half wave converter, semi converter & full wave converter by using thyristor - diodes.

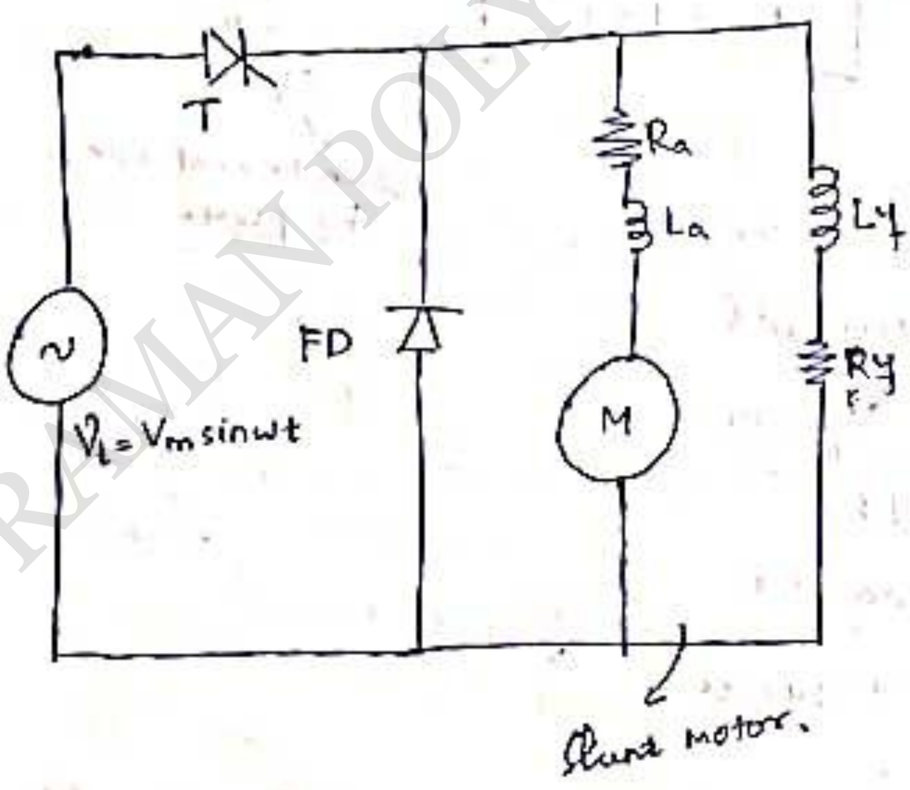


(Single phase half wave converter drive)

(2)

Speed control of DC shunt Motor using Converter :-

- The speed of DC motor has been controlled by controlling the armature voltage by using thyristors. The armature voltage is controlled by using the different types of AC to DC semiconverters such as half wave converter, semi converter & full wave converter by using thyristor - diodes.

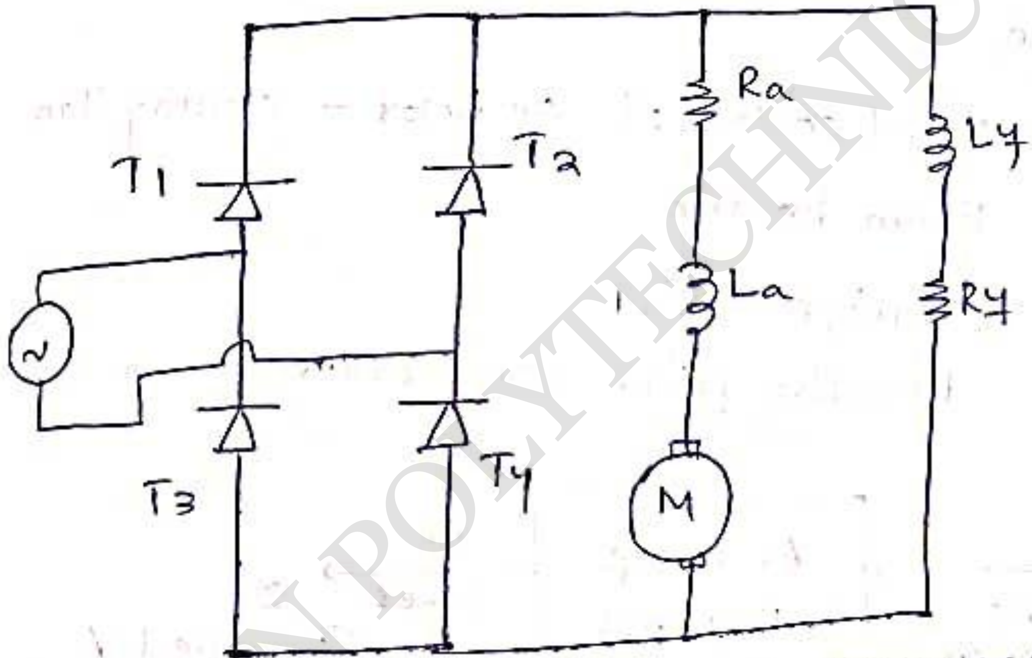


(Single phase half wave converter drive)

(9)

- A single phase half wave converter which is used to control the dc motor shown in previous figure. The average o/p voltage of 1-φ converter can be calculated from eq^n. It is a half-quadrant drive converter.

$$V_o = \frac{V_m}{2\pi}(1+\cos\alpha), \quad [\text{for } 0<\alpha<\pi]$$



(Single phase full wave converter drive)

- A 1-φ, full wave thyristor based converter is shown in upper figure. This converter is used for the dc motor up to the rating of 15kW. The average output voltage of 1-φ full wave converter can be calculated from eq^n. It is two quadrant converter.

$$V_o = \frac{2V_m}{\pi}(1+\cos\alpha), \quad 0<\alpha<\pi$$

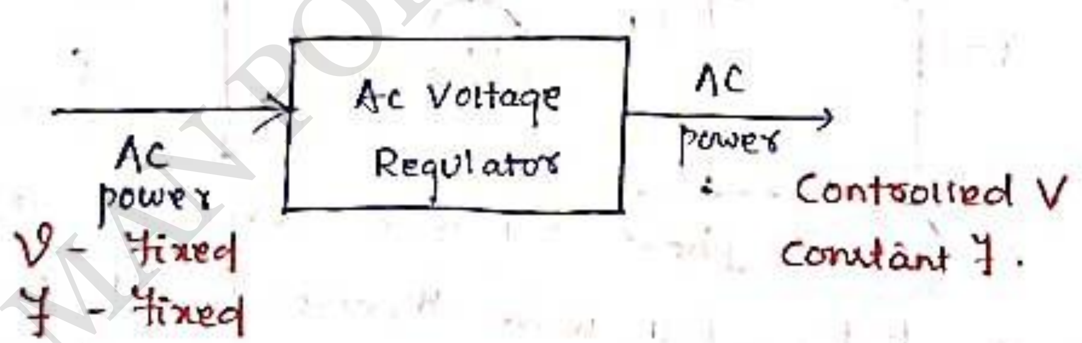
Ac Voltage Regulator :-

Ac Voltage regulator converts the Ac to Ac by keeping Voltage variable & freq. const.

(Ac voltage variable - V = Variable, f = Constant)

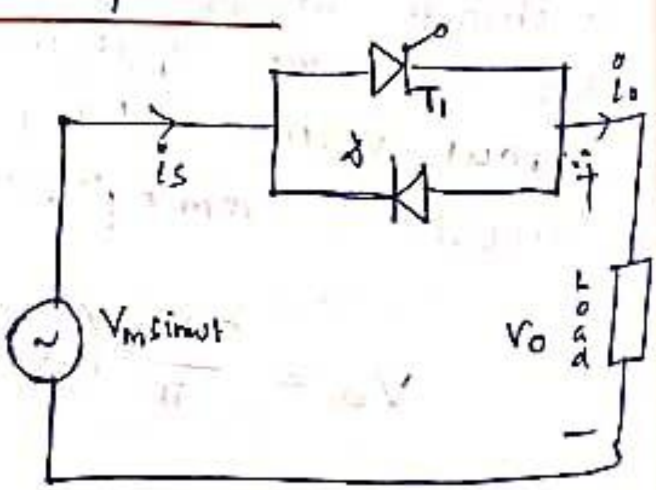
Application

(1) speed control of AC motor - Ceiling fan
(2) Room heater
(3) Voltage control
(4) Reactive power compensation.

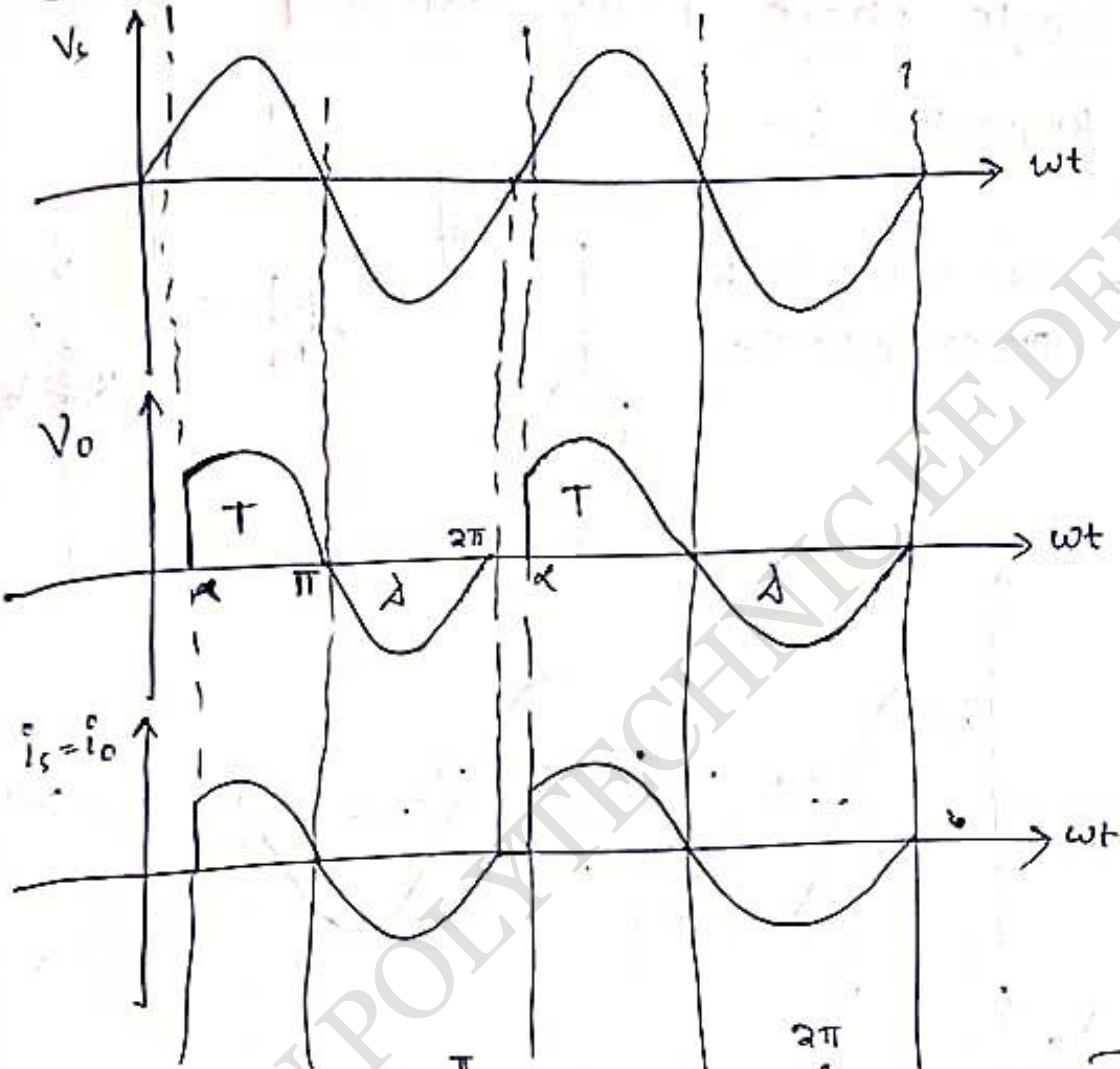


Single phase Ac Voltage Regulator :-

- during +ve half cycle, T_1 is ON & during -ve half cycle D is ON.



(11)



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

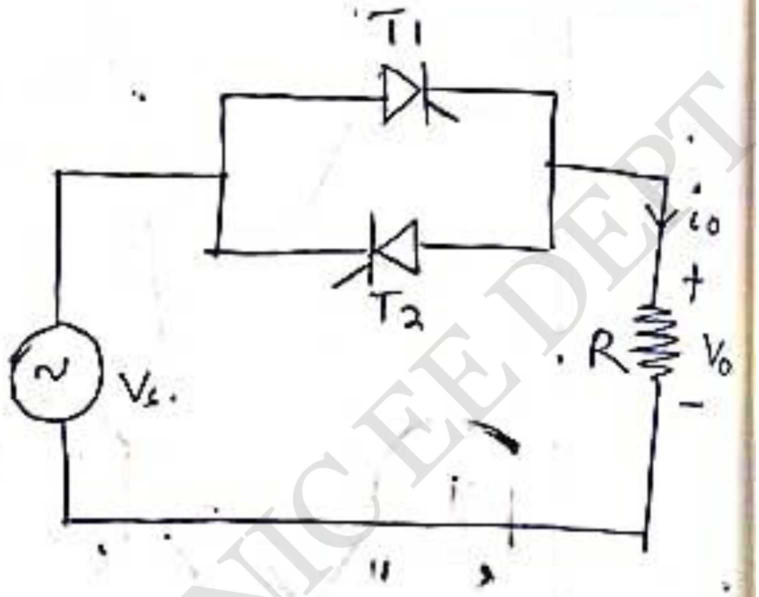
$$= \frac{V_m}{2\pi}\left[\cos\alpha + 1 + \cos\pi - \cos 2\pi\right]$$

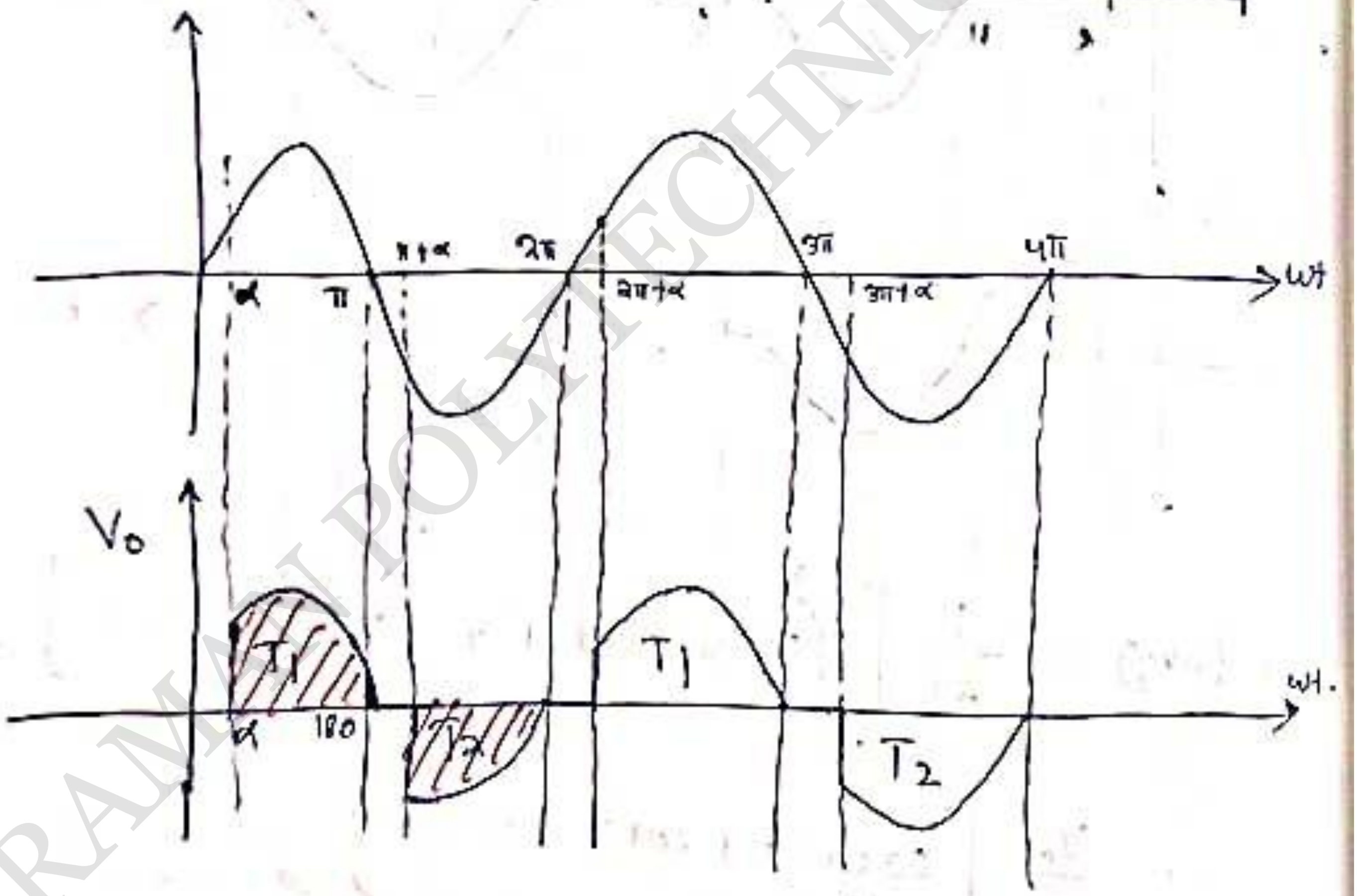
$$= \frac{V_m}{2\pi}(\cos\alpha - 1)$$

- Here +ve area is not equal to negative area so some DC is there which is one disadvantage.

Single phase Fully controlled Ac voltage Regulator :-

- Used for high power application.





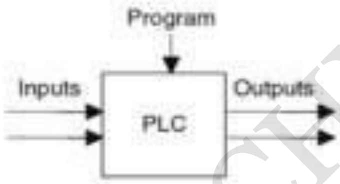
T_1 conducts from α to 180°

T_2 conducts from $180+\alpha$ to 360°.

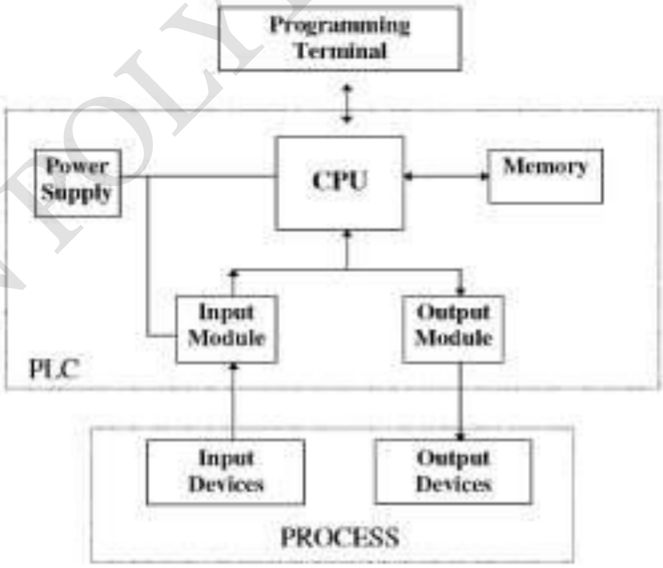
- Here the +ve area is equal to −ve area which signifies half wave symmetry so dc component is not there or average value of this wave form is zero.

A programmable logic controller (PLC) or programmable controller is an industrial digital computer which has been ruggedized and adapted for the control of manufacturing processes, such as assembly lines, or robotic devices, or any activity that requires high reliability control and ease of programming and process fault diagnosis.

PLCs were first developed in the automobile manufacturing industry to provide flexible, ruggedized and easily programmable controllers to replace hard-wired relays, timers and sequencers. Since then, they have been widely adopted as high-reliability automation controllers suitable for harsh environments. A PLC is an example of a "hard" real-time system since output results must be produced in response to input conditions within a limited time, otherwise unintended operation will result



PLC architecture



It consists of a central processing unit (CPU) containing the system microprocessor, memory, and input/output circuitry. The CPU controls and processes all the operations within the PLC.It is supplied with a clock that has a frequency of typically between 1 and 8 MHz. This frequency determines the operating speed of the PLC and provides the timing and synchronization for all elements in the system. The information within the PLC is carried by means of digital signals. The internal paths along which digital signals flow are called buses. In the physical sense, a bus is just a number of conductors along which electrical signals can flow. It might be tracks on a printed circuit board or wires in a ribbon cable. The CPU uses the data bus for sending data between the constituent elements, the address bus to send the addresses of locations for accessing stored data, and the control bus for signals relating to internal control actions. The system bus is used for communications between the input/output ports and the input/output unit.

The operator enters a sequence of instructions (a program) into the memory of the PLC. The controller monitors the inputs carries out the control rules .The control loop is a continuous cycle of the PLC reading inputs, solving the logic instructions, and then changing the outputs.

Advantages

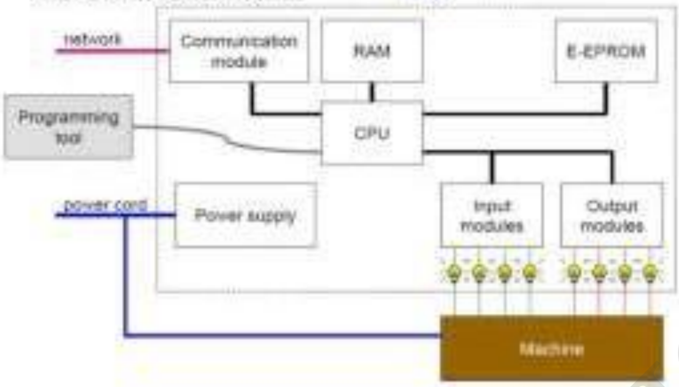
- The same basic controller can be used with a wide range of control systems.
- To modify a control system, the rules are to be modified (much easier to program and reprogram)
- There is no need to rewire
- The result is a flexible, cost-effective system

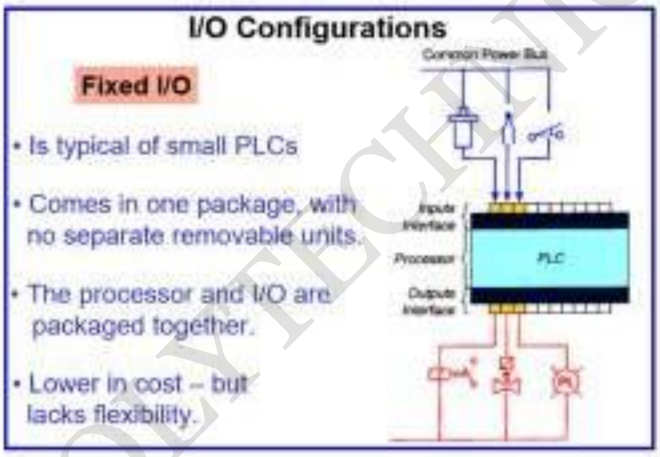
Comparison of PLC & PC

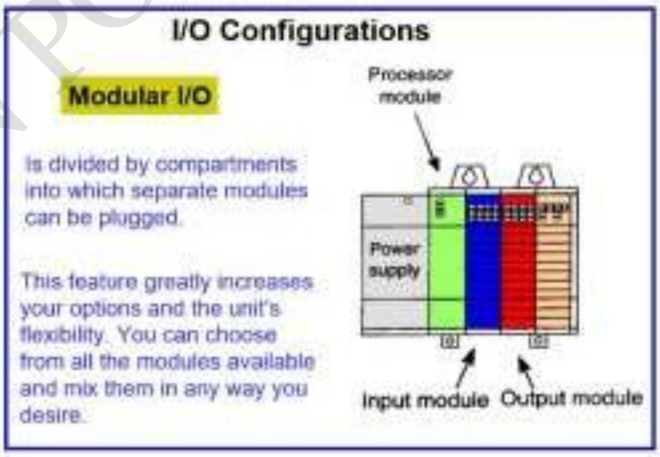
- PLCs are similar to computers, but computers are optimized for calculation and display tasks
- PLCs are optimized for control tasks and the industrial environment.
- PLCs: – Are rugged and designed to withstand vibrations, temperature, humidity, and noise –
- Have interfacing for inputs and outputs, already inside the controller –
- Are easily programmed and have an easily understood programming language – Primarily concerned with logic and switching operations

PLC vs Computer

How a PLC works: internal

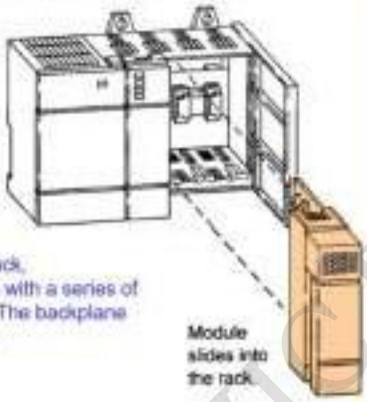






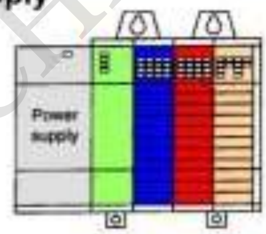
I/O Configurations

Modular I/O



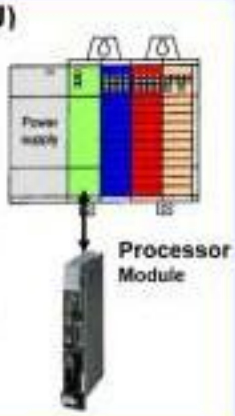
When a module slides into the rack, it makes an electrical connection with a series of contacts - called the *backplane*. The backplane is located at the rear of the rack.

Power Supply



- Supplies DC power to other modules that plug into the rack.
- In large PLC systems, this power supply does not normally supply power to the field devices.
- In small and micro PLC systems, the power supply is also used to power field devices.

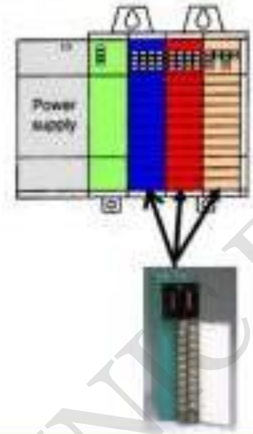
Processor (CPU)



- Is the "brain" of the PLC.
- Consists of a microprocessor for implementing the logic, and controlling the communications among the modules.
- Designed so the desired circuit can be entered in relay ladder logic form.
- The processor accepts input data from various sensing devices, executes the stored user program, and sends appropriate output commands to control devices.

I/O Section

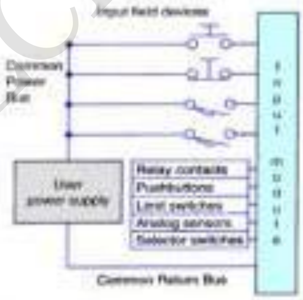
Consists of:
- Input modules
- Output modules.



I/O Section

Input Module

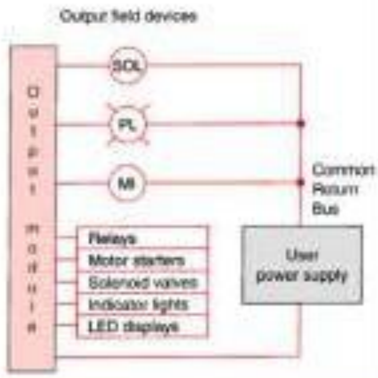
- Forms the interface by which input field devices are connected to the controller.
- The terms "field" and "real world" are used to distinguish actual external devices that exist and must be physically wired into the system.

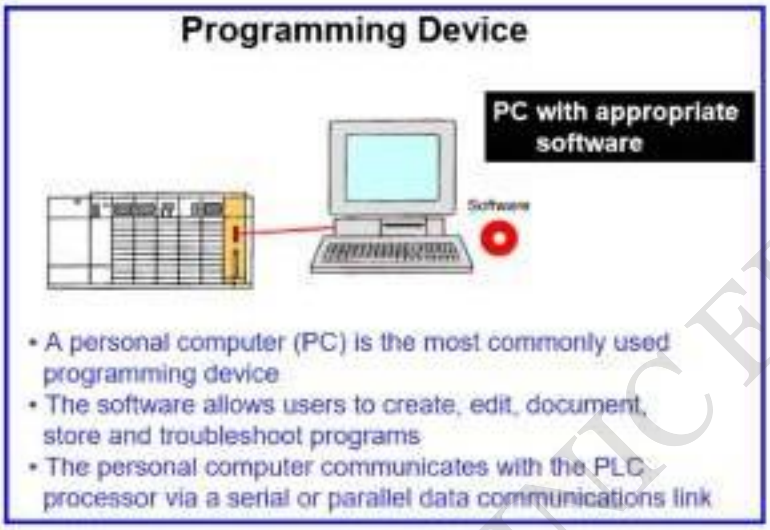


I/O Section

Output Module

- Forms the interface by which output field devices are connected to the controller.
- PLCs employ an optical isolator which uses light to electrically isolate the internal components from the input and output terminals.





Specifications of PLC Input Output Modules

1. Input modules convert process level signals from sensors
2. Output modules may be used to drive actuators

Typical Parameters for an Analog Input Module

Module Parameter	Type/Number/Typical Value
Number of input	8/16 voltage/current/Pt 100/ RTD
Galvanic isolation	Yes /No
Input ranges	±50 mV to ±10 V; ±20 mA; Pt 100
Input impedance for various ranges (ohm)	±50mV: > 10 M ; ±10 V: > 50k; ±20 mA : 25; Pt 100 : > 10 M
Types of sensor connections	2-wire connection; 4-wire connection for Pt 100
Data format	11 bits plus sign or 12 bit 2's complement
Conversion principle	Integrating /successive approximation
Conversion time	In ms (integrating) , μs (successive approx.)

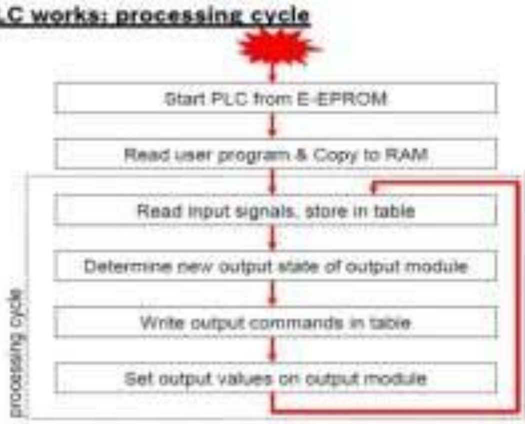
Typical Parameters for an Analog Output Module

Number of outputs	8 voltage and current output
Galvanic isolation	yes
Output ranges (rated values)	**± 10 V; 0…20 mA**
Load resistance - for voltage outputs min. - for current outputs max.	 3.3 k 300
Digital representation of the signal	11 bits plus sign
Conversion time	In µs
Short-circuit protection	yes
Short-circuit current approx.	25 mA (for a voltage output)
Open-circuit voltage approx.	18 V (for a current output)
Linearity in the rated range	±0.25% + 2 LSB
Cable length max.	200 m

Sequential control

- Sequential problems have long been solved using conventional logic gates as building blocks, but using certain techniques to express and identify the sequence logic equations that control the system outputs
- The software design procedure is as follows:
  - The process is verbally described
  - This description is translated into a function diagram
  - The conditions are identified and converted into Boolean equations
  - The Boolean equations are converted into ladder logic for the PLC

How PLC works: processing cycle



RELAY LOGIC

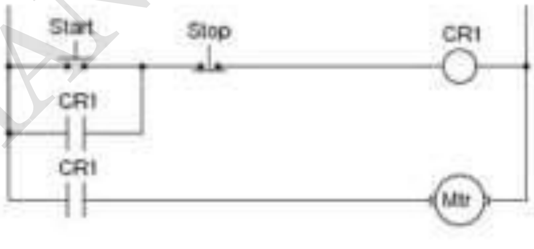
- Relays are the most popular components of the PLC hardware
- Relays are used as outputs in the ladder diagram
- They can be used to control ON/OFF actuation of powered device
- A relay can be latching or non latching
- A latching relay needs an electrical impulse to close the power circuit. Another impulse is needed to release the latch
- Non latching relays hold only while the switching relay is energized and require continuous electrical signal

Relay logic is a method of implementing combinational logic in electrical control circuits by using several electrical relays wired in a particular configuration.The schematic diagrams for relay logic circuits are often called line diagrams, A relay logic circuit is an electrical network consisting of lines, or rungs, in which each line or rung must have continuity to enable the output device. A typical circuit consists of a number of rungs, with each rung controlling an output. This output is controlled by a combination of input or output conditions, such as input switches and control relays. Relay logic diagrams represent the physical interconnection of devices.

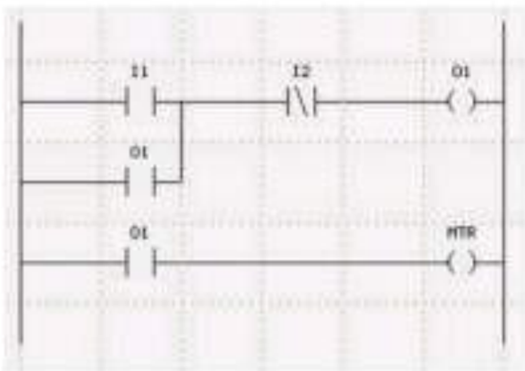
Main Elements of ladder logic

1. Rails- These are vertical lines and provide the sources of energy to relays and logic system
2. Rungs- These are horizontal and contains the branches ,inputs and outputs
3. Branches
4. Inputs
5. Outputs
6. Timer
7. Counter

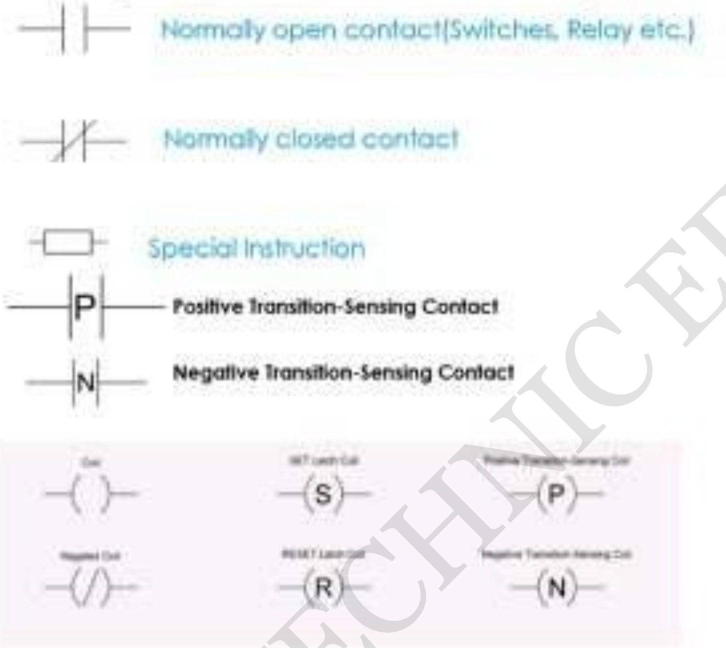
Motor Control PLC Ladder Logic



Motor Control Relay Logic



Symbol format in Ladder logic



PLC INSTRUCTION CODE

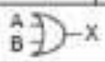
INSTRUCTION CODE	DESCRIPTION
LD	Start a rung with an open contact
LDI	Start a rung with closed contact
AND	A series element with an open contact
ANI	A series element with a closed contact
ANB	Branch two blocks in series
OR	A parallel element with an open contact
ORI	A parallel element with closed contact
ORB	Branch two blocks in parallel
OUT	An output

PLC Programming- realization of AND, OR logic

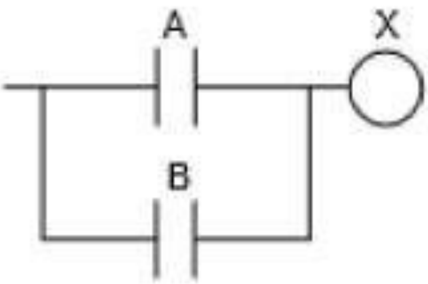
AND		
Input A	Input B	Out X
0	0	0
0	1	0
1	0	0
1	1	1
		

$$A \cdot B = X$$

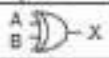
LD A
AND B
OUT X

OR		
Input A	Input B	Out X
0	0	0
0	1	1
1	0	1
1	1	1
		

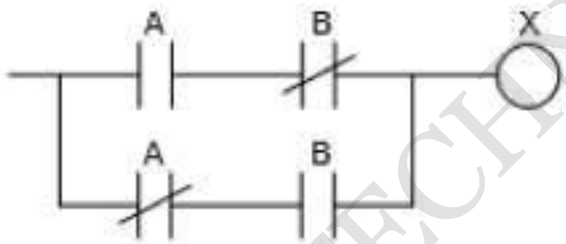
$$A + B = X$$

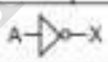


LD A
OR B
OUT X

XOR		
Input A	Input B	Out X
0	0	0
0	1	1
1	0	1
1	1	0
		

$$(A \cdot \overline{B}) + (\overline{A} \cdot B) = X$$

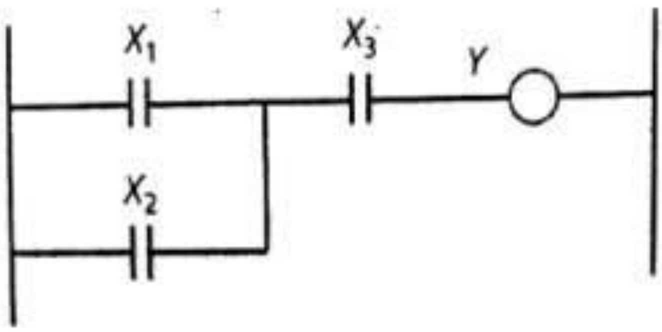


NOT	
Input A	Out X
0	1
1	0
	

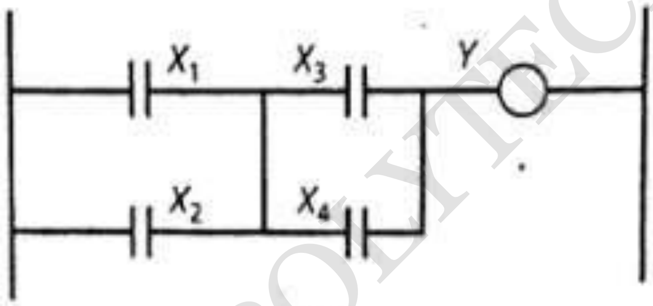
$$\overline{A} = X$$

Draw ladder diagram for the equations given below

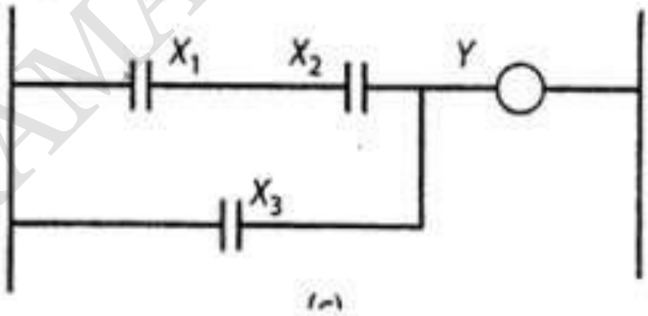
$Y=(X1+X2)X3$



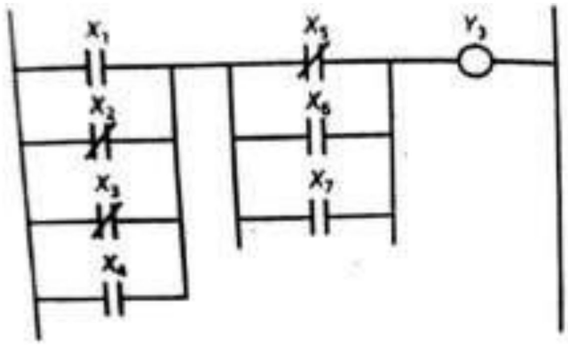
$Y=(X1+X2)(X3+X4)$



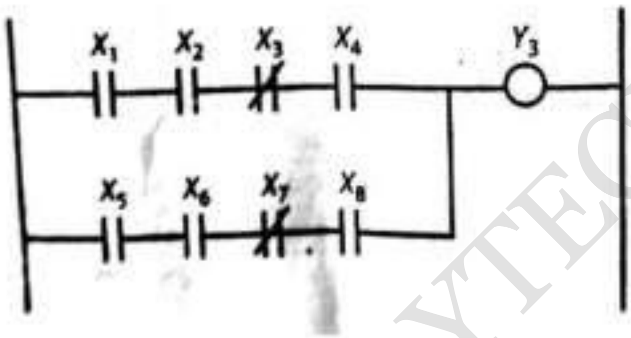
$Y=(X1X2)+X3$



Write PLC program for the given ladder diagram

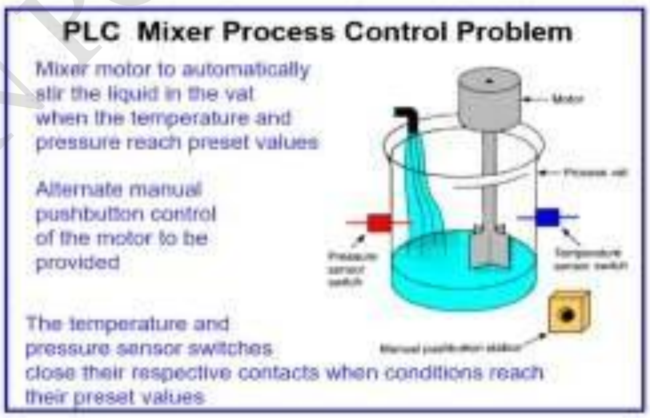


LD X1
ORI X2
ORI X3
OR X4
LDI X5
OR X6
OR X7
ANB
OUT Y3

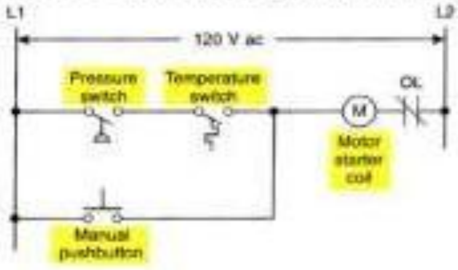


LD X1
AND X2
ANI X3
AND X4
LD X5
AND X6
ANI X7
AND X8
ORB
OUT Y3

Example of PLC program to automatically stir the liquid in the vat



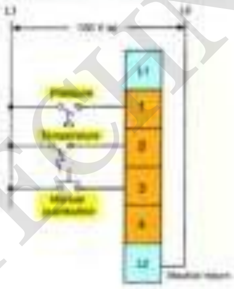
Process Control Relay Ladder Diagram



Motor starter coil is energized when both the pressure and temperature switches are closed or when the manual pushbutton is pressed

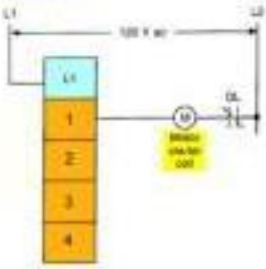
PLC Input Module Connections

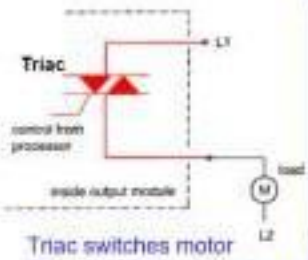
- The same input field devices are used
- These devices are wired to the input module according to the manufacturer's labeling scheme



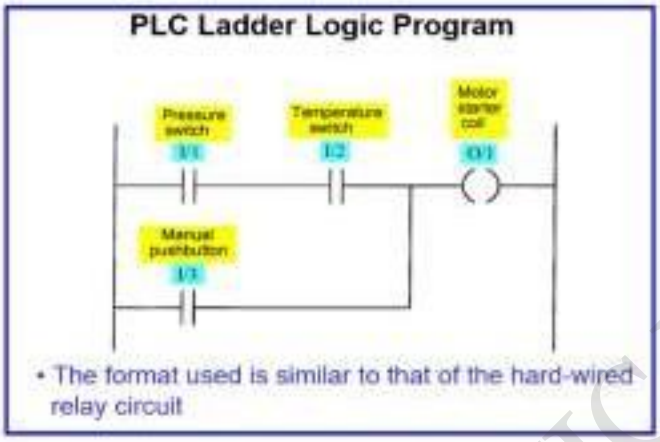
PLC Output Module Connections

Same output field device is used and wired to the output module





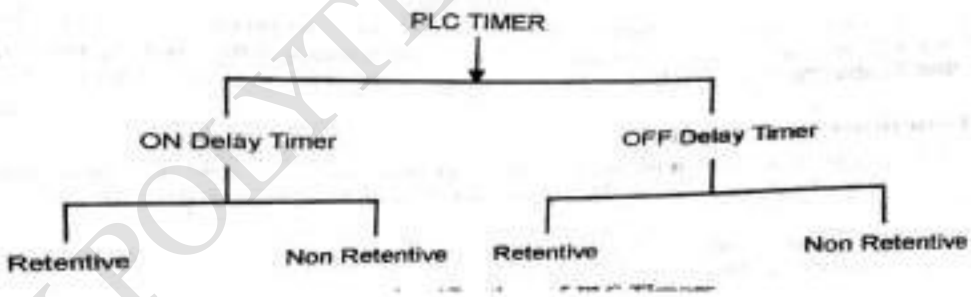
Triac switches motor ON and OFF in accordance with the control signal from the processor



TIMERS AND COUNTERS

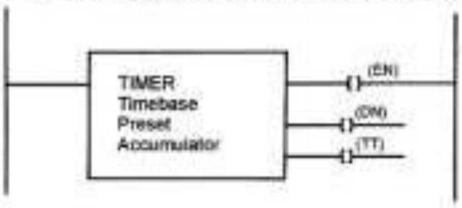
A timer is device that introduce a time delay in a circuit or system during its ON or OFF condition.PLC timer, the time delay is introduced by programming

Classification of timers



Schematic diagram of a function block PLC timer.

- The contacts on the left side of the timer function block are the timer enable contacts
- When they are closed, power passes to the left terminal of the timer, its clock is enabled and it starts timing.
- When they are open, power stops flowing through this terminal, and the timer stops functioning
- A timer function block has three output contacts.



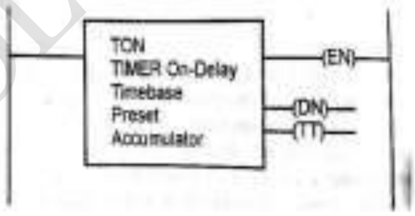
- When the timer is timed out, DONE BIT(DN) is set.
- The ENABLE BIT follows the input enable contact status.
- If the enable contact is true then output ENABLE BIT(EN) is true.
- The timer timing(TT) bit is set when the timer is operating

Functions in TIMER

1. Variety of time base is available
2. The most common time bases are 0.01 sec, 0.1 sec and 1 sec
3. Accumulator value(ACC)- This is the time that has elapsed, since the timer was last reset.
4. When enabled, a timer updates this continuously
5. Preset Value(PRF)- This specifies the value that the timer must reach before the controller sets the done bit
6. The programmer determines the preset time.
7. When the accumulator value becomes equal to or greater than the preset value, the timer stops operating and the done bit is set
8. This bit can be used to control an output device

TIMER ON DELAY

The instruction is used to delay turning an output ON or OFF. The TON instruction begins to count time base intervals when the rung condition become true. As long as the rung condition remains true the time increments its accumulator value, over each scan until reaches the preset value. The accumulator value is reset when the rung condition becomes false, regardless of whether the timer has timed out



FUNCTIONS OF AN **ON** DELAY TIMER

Output bit	Is set when	Remains set until use of the following
Timer Done Bit (DN)	Accumulator value is normally greater than the preset value.	Rung condition becomes false.
Timer Enable Bit (EN)	Rung conditions are true.	Rung conditions become false.
Timer Timing Bit (TT)	Rung conditions are true and the all values are less than the PRESET value.	Rung conditions become false or when the done bit is set.

TIMER OFF DELAY

The TOFF instruction begins t count time base intervals when the rung condition makes a true to false transition. As long as the rung condition remains false the timer increments its accumulator vale over each scan until it reaches the preset value. The controller resets the accumulated value when the rung conditions becomes true regardless of whether the timer has timed out

FUNCTIONS OF AN **OFF** DELAY TIMER

Output bit	Is set when	And remaining set until one of the following
DN	Rung conditions are true.	Rung condition becomes false and the accumulator value is greater than or equal to the preset value.
TT	Rung conditions are false and the accumulator value is less than the preset value.	Rung conditions become true or when the done bit is set.
EN	Rung conditions are true.	Rung conditions become false.

RETENTIVE AND NON RETENTIVE TIMERS

Retentive refers to the device's ability to remember its exact status such that when the circuit is again activated, the timer continues from the previous point. RTO - Retentive Timer. Counts time base intervals when the instruction is true and retains the accumulated value when the instruction goes false or when power cycle occurs. The Retentive Timer instruction is a retentive instruction that begins to count time base intervals when rung conditions become true.Non-retentive timers reset to zero and start from zero each time the timer function block is energized.

FUNCTION BLOCK

	15	14	13	12	11	10	9	8	7 … 0
Word 0	EN	TT	DN						Internal bit
Word 1	Preset value (PRE)								
Word 2	Accumulator value (ACC)								

EN, TT, DN are bit storage. EN is stored in bit 15 Word '0', TT is bit 14 and DN is bit of Word 0. 0-7 bits of Word 0 are the internal bits. Each preset value (PRE) and accumula value (ACC) are 16 bit Words stored in Word 1 and Word 2 of the timer file.

EN- timer enable bit

TT- Timer timing bit

DN-Timer done bit

Each timer address is made up of a 3 word element

Word 0 is the control word

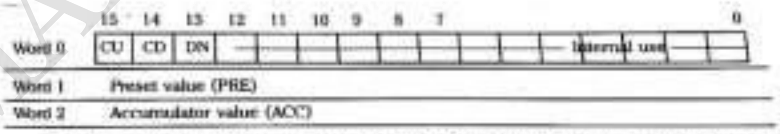
Word 1 stores preset value and word 2 stores accumulated value

COUNTERS

Counters are used to count the number of items produced, and the number of operations performed.PLC counter utilizes a sensor t count operations, which is processed by software execution in the PLC. Thus the failure rate is reduced and the accuracy level is increased in a PLC counter.he major difference between the counter and the timer is that timer instructions will continually increment its accumulative value at a rate determined by the time base when the enable contact is on. Counter must see a complete contact transition from 0 to 1 each time it increments the accumulative value.This means that the contact must returns to its zero state before it can have a transition for a second time.

COUNTER PARAMETERS

1. **Accumulative value(ACC)**-number of false to true transitions that have occurred since the counter was last reset
2. **Preset value(PRE)-** Specifies the value that the counter must reach, before the controller sets the done bit. When the accumulator value becomes equal to or greater than the preset value, the done status bit is set. This can be used to control an output device



'CU' is count-up bit, 'CD' is count down bit and 'DN' is done bit. A few counter instructions are given in the subsequent sections.

Count **UP(CTU)**

The CTU is an instruction that counts false to true rung transition

CTU Count up Counter Preset Accumulator

3.12.1 Count Up (CTU)

The CTU is an instruction that counts false-to-true rung transitions. Rung transition can be caused by events occurring in the program (from internal logic or by external field devices).

When the rung condition for a CTU instruction has made a false to true transition, the accumulated value is incremented by one count, provided that, the rung containing the CTU instruction is evaluated between these transitions. The ability of the counter to detect a false-to-true transition depends on the speed (frequency) of the incoming signal. The on and off duration of an incoming signal must not be faster than the scan time.

The accumulated value is retained when the rung condition again becomes false. The accumulated count is retained until cleared by a reset (RES) instruction that has the same address as the counter reset.

The accumulated value is retained after the CTU instruction becomes false, or when the power is removed from, and then restored to, the controller. Also the on or off status of a counter done, overflow and underflow bits is retentive. The accumulated value and control bits are reset when the appropriate RES instruction is enabled. The function block of a count-up CTU is shown in Fig. 3.14.

Count DOWN(CTD)

CTD Count down Counter Preset Accumulator

3.12.2 Count Down (CTD)

The CTD is a retentive output instruction that counts false to true rung transitions. When the rung condition for a CTD instruction has made a false-to-true transition, the accumulated value is decremented by one count, provided that the rung containing the CTD instruction is evaluated between these transitions. The accumulated counts are retained when the rung condition again becomes false. The accumulated count is retained until cleared by a reset (RES) instruction that has the same address as the counter reset. The function block of a count-down CTD is shown in Fig. 3.15.

BASICS CONCEPTS OF SCADA,DCS,CNC

1. Supervisory Control and Data Acquisition (SCADA)
2. distributed control system (DCS)
3. Computer Numerical Control(CNC)

Supervisory Control and Data Acquisition (SCADA)

Supervisory Control and Data Acquisition (SCADA) is a control system architecture that uses computers, networked data communications and graphical user interfaces for high-level process supervisory management, but uses other peripheral devices such as programmable logic controller (PLC) and discrete PID controllers to interface with the process plant or machinery

Why SCADA?

- Saves Time and Money
    - Less traveling for workers (e.g. helicopter ride)
    - Reduces man-power needs
    - Increases production efficiency of a company
    - Cost effective for power systems
    - Saves energy
- Reliable
- Supervisory control over a particular system

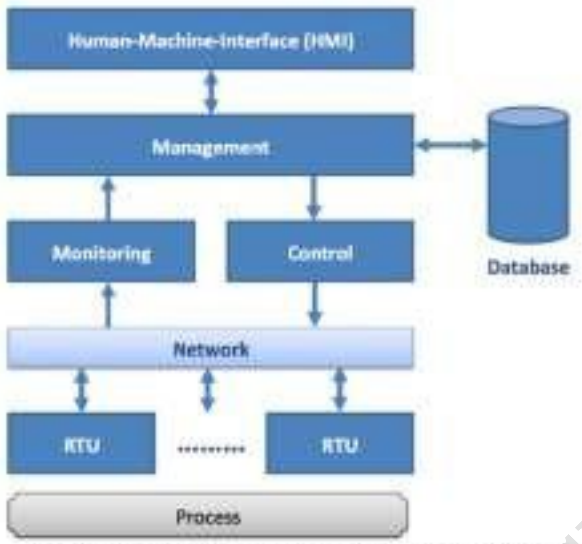
Objectives of SCADA

1. **Monitoring** : Continuous monitoring of the parameters of voltage , current, etc..
2. **Measurement**: Measurement of variables for processing.
3. **Data Acquisition**: Frequent acquisition of data from RTUs and Data Loggers / Phasor data Concentrators (PDC)..
4. **Data Communication**: Transmission andreceiving of large amounts of data from field to control centre's.
5. **Control**: Online real time control for closed loop and open loop processes.
6. **Automation**:: Automatic tasks of switching of transmission lines, CBs, etc.

Functions of SCADA

- Data Acquisition
- Information Display
- Supervisory Control
- Alarm Processing
- Information Storage and Reports
- Sequence of Event Acquisition
- Data Calculation
- Special RTU Processing/Control

ARCHITECTURE OF SCADA



RTU-REMOTE TERMINAL UNIT

A collection of equipment that will provide an operator at remote location with enough information to determine the status of a particular piece of a equipment or entire substation and cause actions to take place regarding the equipment or network.SCADA systems are used to monitor or to control chemical or transport processes in municipal water supply systems, to control electric power generation, transmission and distribution, gas and oil pipelines, and other distributed processes. Supervisory control and data Acquisition (SCADA) achieves this requirement collecting reliable field data through remote terminal units (RTUs) Intelligent Electric Devices (IEDs) and presenting them to user requirement.

The user interface or the man machine interface (MMI) provides various options of data presentation according to specific application and user needs. There are many parts of a working SCADA system. A SCADA system usually includes signal hardware (input and output), controllers, networks, user interface (HMI), communications equipment and software. All together, the term SCADA refers to the entire central system. The central system usually monitors data from various sensors that are either in close proximity or off site. SCADA refers to a system that collects data from various sensors at a factory, plant or in other remote locations and then sends this data to a central computer which then manages and controls the data.A SCADA system refer to a system consisting of a number of remote terminal units (or RTUs) collecting field data connected back to a master station via a communications system.

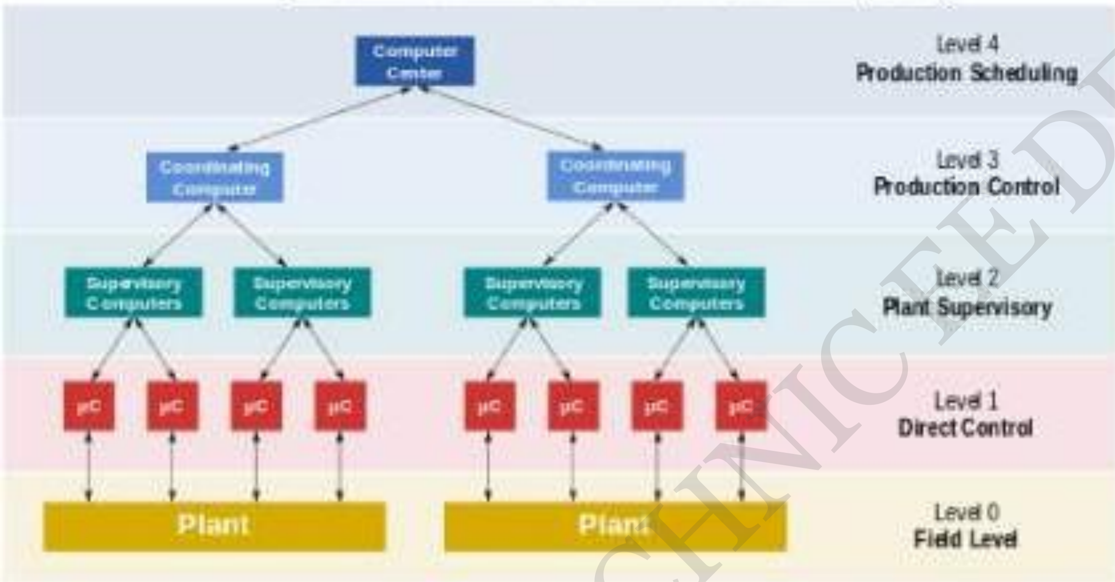
The master station displays the acquired data and also allows the operator to perform remote control tasks. The accurate and timely data (normally real-time) allows for optimization of the operation of the plant and process. A further benefit is more efficient, reliable and most importantly, safer operations. This all results in a lower cost of operation compared to earlier non-automated systems.The RTU provides an interface to the field analog and digital signals situated at each remote site.

- **Sensors** (either digital or analog) and control relays that directly interface with the managed system.
- **Remote telemetry units** (RTUs). These are small computerized units deployed in the field at specific sites and locations. RTUs serve as local collection points for gathering reports from sensors and delivering commands to control relays.
- **SCADA master units**. These are larger computer consoles that serve as the central processor for the SCADA system. Master units provide a human interface to the system and automatically regulate the managed system in response to sensor inputs.
- **Communications network** that connects the SCADA master unit to the RTUs in the field.

Usage of SCADA

1. **Electric power generation, transmission and distribution**: Electric utilities use SCADA systems to detect current flow and line voltage, to monitor the operation of circuit breakers, and to take sections of the power grid online or offline.
2. **Water and sewage**: State and municipal water utilities use SCADA to monitor and regulate water flow, reservoir levels, pipe pressure and other factors.
3. **Buildings, facilities and environments**: Facility managers use SCADA to control HVAC, refrigeration units, lighting and entry systems.
4. **Manufacturing**: SCADA systems manage parts inventories for just-in-time manufacturing, regulate industrial automation and robots, and monitor process and quality control.
5. **Mass transit**: Transit authorities use SCADA to regulate electricity to subways, trams and trolley buses; to automate traffic signals for rail systems; to track and locate trains and buses; and to control railroad crossing gates.
6. **Traffic signals**: SCADA regulates traffic lights, controls traffic flow and detects out-of-order signals.

DISTRIBUTED CONTROL SYSTEM(DCS)



A distributed control system (DCS) is a computerised control system for a process or plant usually with a large number of control loops, in which autonomous controllers are distributed throughout the system, but there is central operator supervisory control. This is in contrast to systems that use centralized controllers; either discrete controllers located at a central control room or within a central computer. The DCS concept increases reliability and reduces installation costs by localising control functions near the process plant, with remote monitoring and supervision

The key attribute of a DCS is its reliability due to the distribution of the control processing around nodes in the system. This mitigates a single processor failure. If a processor fails, it will only affect one section of the plant process, as opposed to a failure of a central computer which would affect the whole process. This distribution of computing power local to the field Input/Output (I/O) connection racks also ensures fast controller processing times by removing possible network and central processing delays

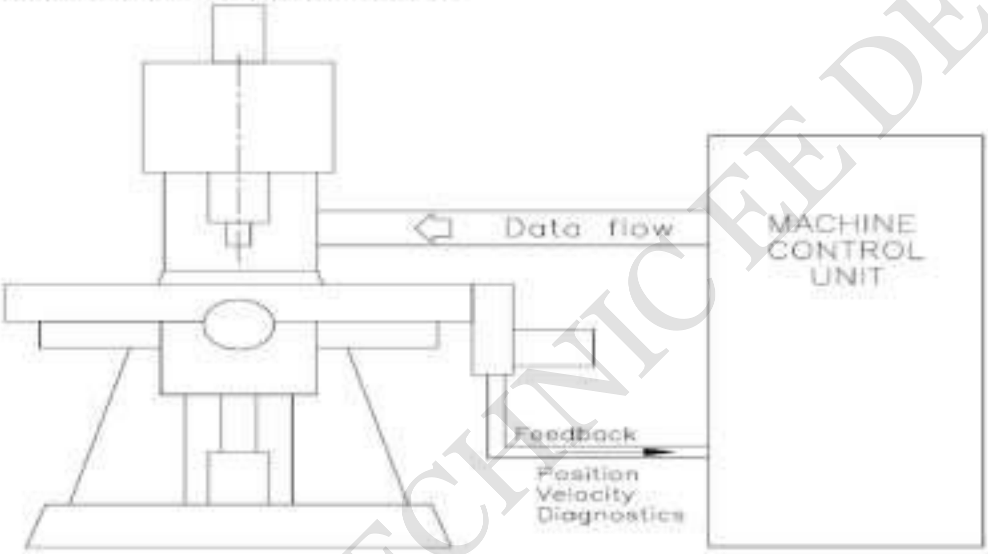
- **Level 0** contains the field devices such as flow and temperature sensors, and final control elements, such as control valves
- **Level 1** contains the industrialised Input/Output (I/O) modules, and their associated distributed electronic processors.
- **Level 2** contains the supervisory computers, which collect information from processor nodes on the system, and provide the operator control screens.
- **Level 3** is the production control level, which does not directly control the process, but is concerned with monitoring production and monitoring targets
- **Level 4** is the production scheduling level.

Advantages of DCS

- Access a large amount of current information from the data highway.
- Monitoring trends of past process conditions.
- Readily install new on-line measurements together with local computers.
- Alternate quickly among standard control strategies and readjust controller parameters in software.
- A sight full engineer can use the flexibility of the framework to implement his latest controller design ideas on the host computer.

Computer Numeric Control (CNC)

Numerical control (NC) refer to control of a machine or a process using symbolic codes consisting of characters and numerals.



Computer Numerical Control (CNC) Machine

Computer numerical control (CNC) is the numerical control system in which a dedicated computer is built into the control to perform basic and advanced NC functions. CNC controls are also referred to as softwired NC systems because most of their control functions are implemented by the control software programs. CNC is a computer assisted process to control general purpose machines from instructions generated by a processor and stored in a memory system.

Advantages and Disadvantages of CNC

Advantages:

- High Repeatability and Precision e.g. Aircraft parts.
- Volume of production is very high.
- Complex contours/surfaces can be easily machined.
- Flexibility in job change, automatic tool settings, less scrap.
- More safe, higher productivity, better quality.
- Less paper work, faster prototype production, reduction in lead times.

Disadvantages:

- Costly setup, skilled operators.
- Computer programming knowledge required.
- Maintenance is difficult.

QUESTION BANK

1. What is PLC
2. Draw and explain the architecture of PLC. Also mention advantages and disadvantages
3. Compare PLC and PC
4. How PLC works
5. What is sequential control
6. What do you mean by relay logic in PLC programming
7. Explain the concept of latching
8. Draw any three symbols used ladder programming
9. What are the basic instructions used in ladder logic
10. Realize AND,OR,NOT logic in PLC leader logic
11. Draw the ladder diagram of NAND,NOR and XOR gate
12. Write ladder program for the given expression and also draw ladder logic

Y=(X1+X2)+X3X4

Y=(X1+X2)(X3+X4)(X5X6)

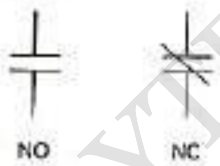
Y=(X1X2)+X3

Electrical Symbols

Control circuits can be represented pictorially in various ways. One of the more common approaches is to use control logic diagrams which use common symbols to represent control components. Although control symbols vary throughout the world, the symbols used in this course are common in the United States and many other countries.

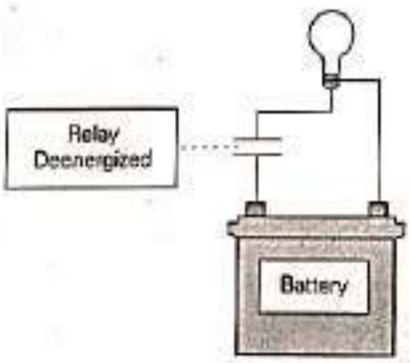
Contact Symbols

Various devices incorporate contacts to control the flow of current to other control components. When in operation, a contact my be either **open**, a condition which blocks current flow, or **closed**, a condition which allows current flow. Control logic diagrams, however, cannot show the dynamic operation of contacts. Instead, these diagrams show contacts as either **normally open (NO)** or **normally closed (NC)**.



The standard method of showing contacts is to indicate the circuit condition produced when the actuating device is in the **de-energized (off) state.**

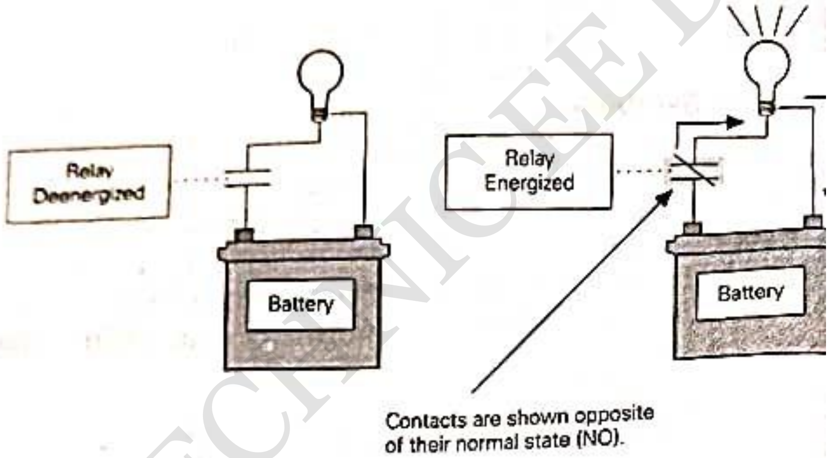
For example, in the following illustration, the contacts are part of a relay. The contacts are shown as normally open to indicate that, when there is no power applied to the relay's coil, the contacts are open. With the contacts open, there is no current flow to light.



Symbols on a control logic diagram are usually not shown in their energized (on) state. However, in this course, contacts and switches are sometimes shown in their energized state explanation purposes. In such cases, the symbol is highlighte

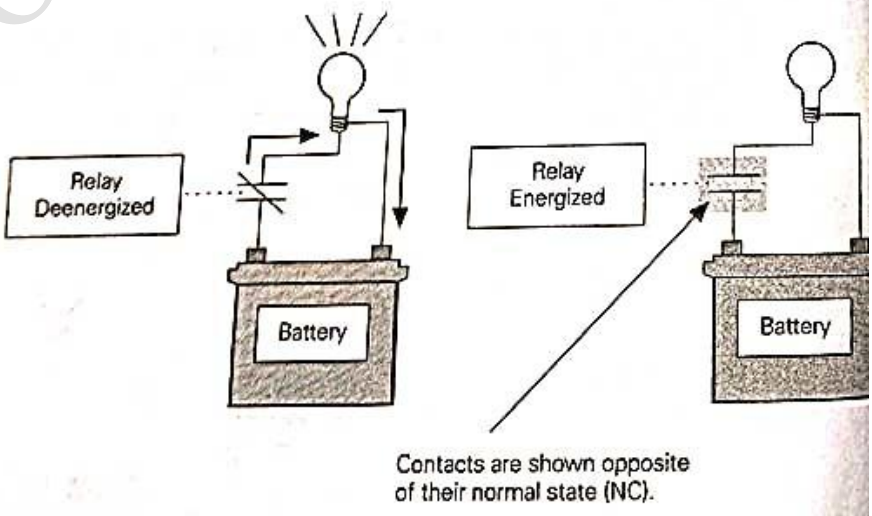
Normally Open Contact Example

For example, in the following illustration, the circuit is first shown in the de-energized state, and the normally open contacts are not highlighted. When the relay energizes, the contacts close, completing the path for current and illuminati the light. The contacts are then shown as highlighted to indic that they are not not their **normal** state. *Note: This is not a standard symbol.*



Normally Closed Contact Example

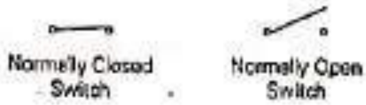
In the following illustration, when the relay is de-energized, t normally closed contacts are shown as closed and are not highlighted. A complete path of current exists at this time, a the light is on. When the relay is energized, the contacts ope turning the light off.



Switch Symbols

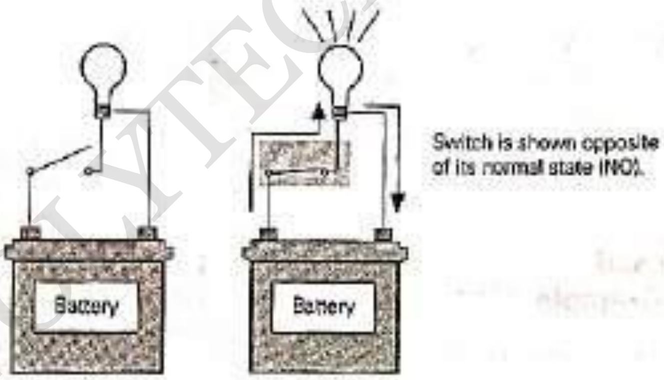
Various types of **switches** are also used in control circuits. Like the contacts just discussed, switches can also be normally open or normally closed and require another device or action to change their state. In the case of a manual switch, someone must change the position of the switch. A switch is considered to be in its normal state when it has not been acted upon.

Switch symbols, like the ones shown in the following illustration, are also used to indicate an open or closed path of current flow. Variations of these symbols are used to represent a number of different switch types.



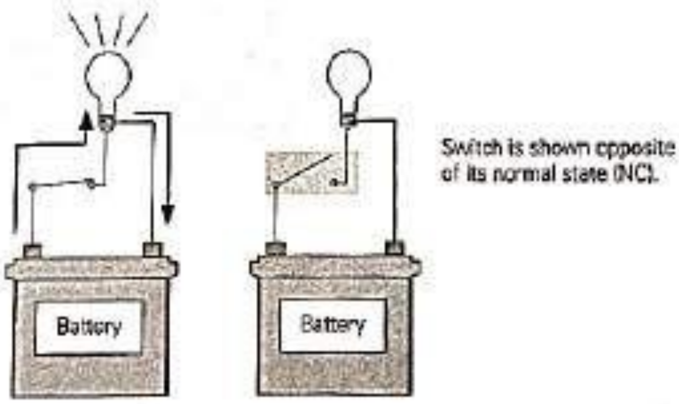
Normally Open Switch Example

In the following illustration, a battery is connected to one side of a normally open switch, and a light is connected to the other side. When the switch is open, current cannot flow through the light. When someone closes the switch, it completes the path for current flow, and the light illuminates.



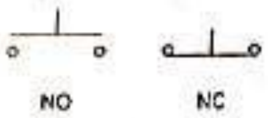
Normally Closed Switch Example

In the following illustration, a battery is connected to one side of a normally closed switch and a light is connected to the other side. When the switch is closed, current flows through the light. When someone opens the switch, current flow is interrupted, and the light turns off.



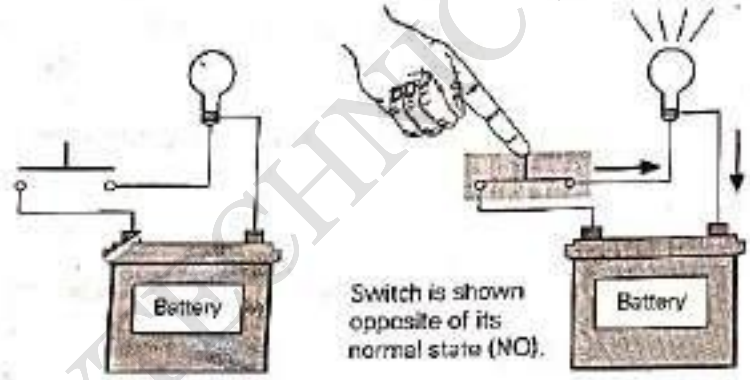
Pushbutton Symbols

There are two basic types of **pushbuttons**, **momentary** and **maintained**. The contacts of a momentary pushbutton change state, open to closed or vice versa, when the button is pressed. They return to their normal state as soon as the button is released. In contrast, a maintained pushbutton latches in place when pressed. It must be unlatched to allow it to return to its normal state.



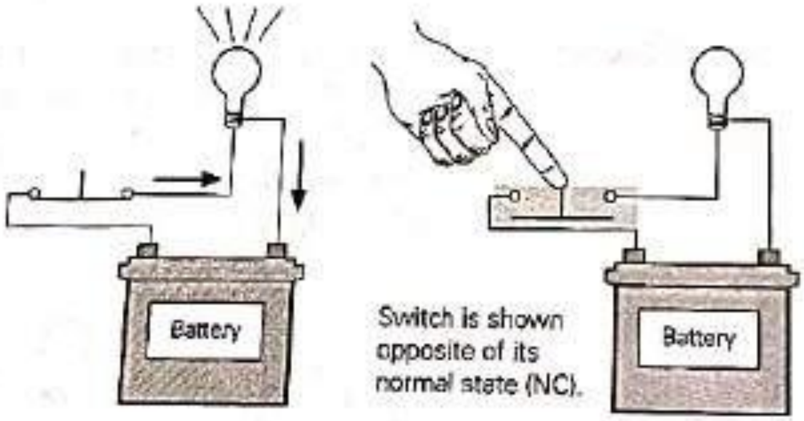
Normally Open Pushbutton Example

In the following illustration, a battery is connected to one side a normally open pushbutton, and a light is connected to the other side. When the pushbutton is pressed, current flows through the pushbutton, and the light turns on.



Normally Closed Pushbutton Example

In the following example, current flows to the light as long as the pushbutton is not pressed. When the pushbutton is pressed, current flow is interrupted, and the light turns off.

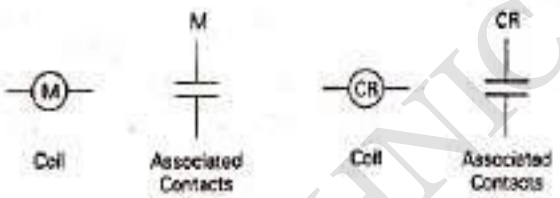


Coil Symbols

Motor starters, contactors, and relays are examples of devices that open and close contacts electromagnetically. The electromagnet in these devices is called a **coil.**

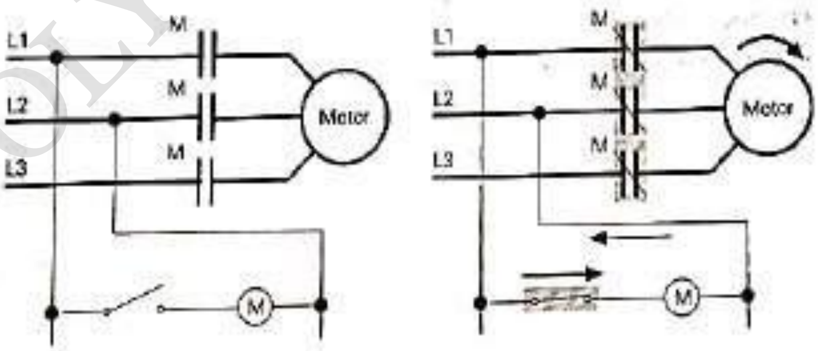
A coil is commonly symbolized as a circle with letters and number inside. The letters often represent the type of device, such as M for motor starter or CR for control relay. A number is often added to the letter to differentiate one device from another.

The contacts controlled by a coil are labeled with the same letter (and number) as the coil so that it is easy to tell which contacts are controlled by each coil. A coil often controls multiple contacts and each contact may be normally open or normally closed.



Coil Example Using Normally Open Contacts

In the following example, the "M" contacts in series with the motor are controlled by the "M" contactor coil. When someone closes the switch, current flows through the switch and "M" contactor coil. The "M" contactor coil closes the "M" contacts and current flows to the motor.



Overload Relay Symbols

Overload relays are used to protect motors from overheating. When excessive current is drawn for a predetermined amount of time, the overload relay's contacts open, removing power from the motor. The following symbol is for contacts associated with a thermal overload relay. An overload relay used with a three-phase motor has three such contacts, one for each phase.

Thermal Overload

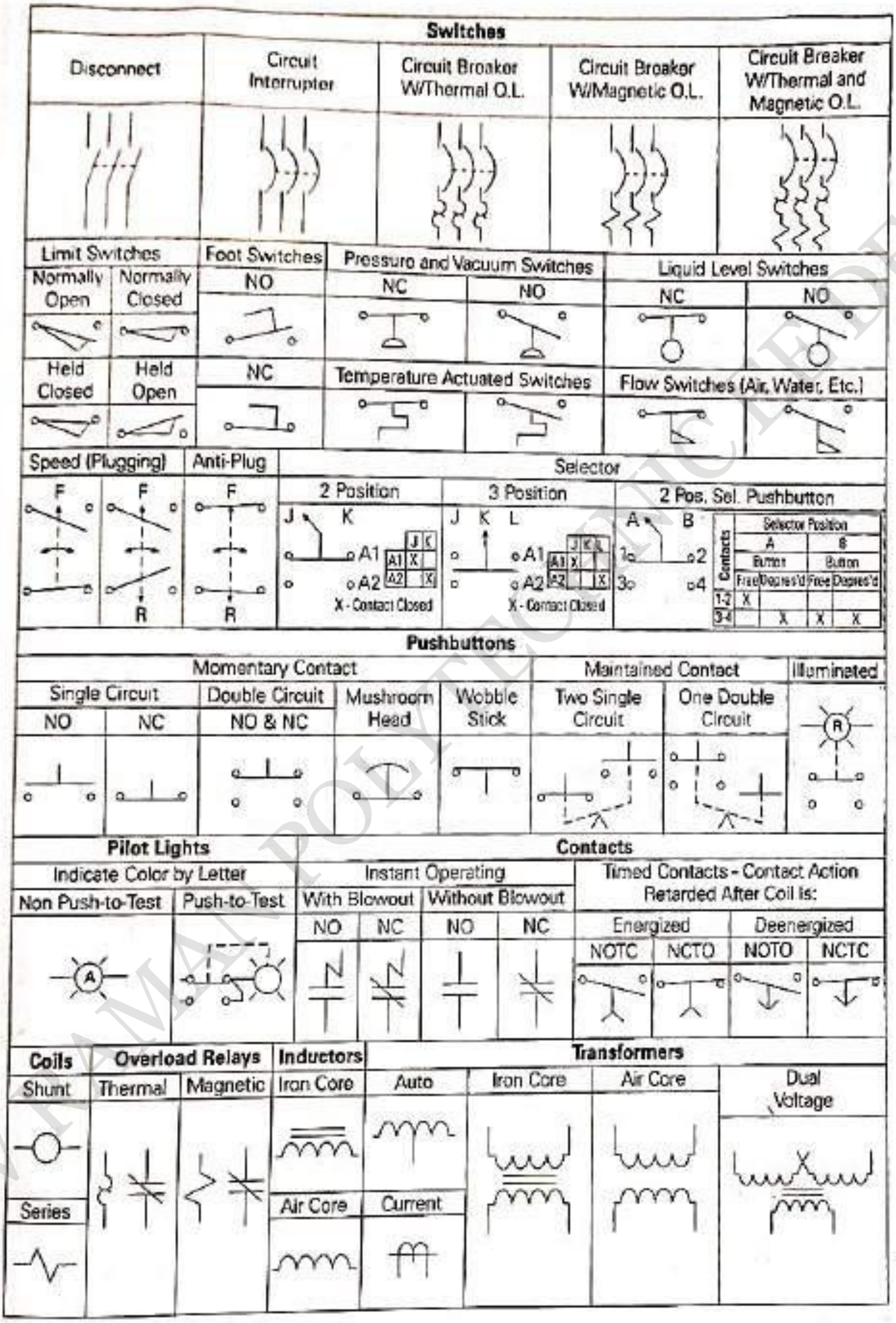
Indicator Light Symbols

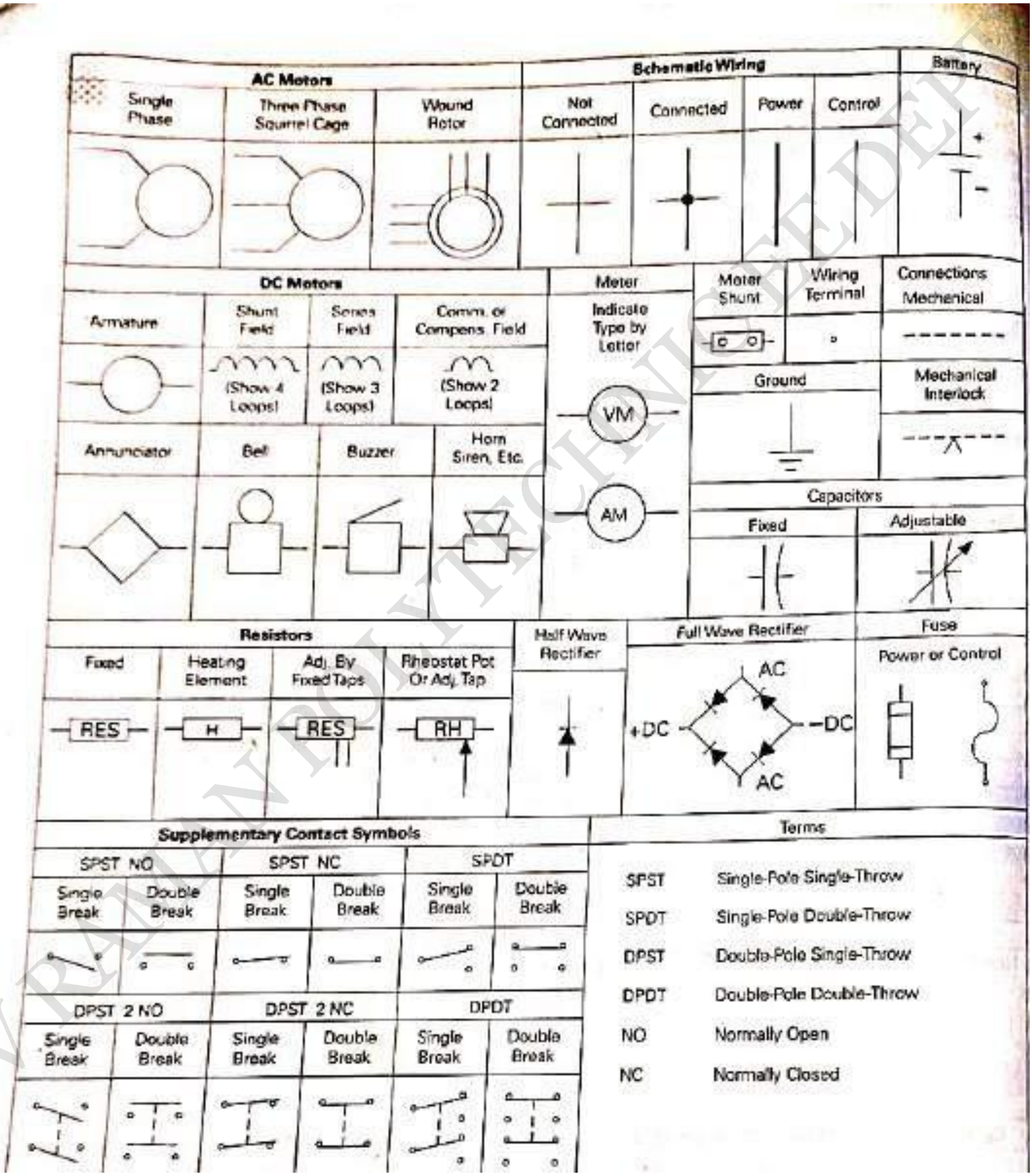
An **indicator light**, often referred to as a **pilot light**, is a smal electric light used to indicate a specific condition of a circuit. For example, a red light might be used to indicate that a moto is running. The letter in the center of the indicator light symbol indicates the color of the light.

Red Indicator Light   Amber Indicator Light

Other Symbols

In addition to the symbols discussed here, there are many oth symbols used in control circuits. The following charts show many of the commonly used symbols.


Switches
Disconnect
Circuit Interrupter
Circuit Breaker W/Thermal O.L.
Circuit Breaker W/Magnetic O.L.
Circuit Breaker W/Thermal and Magnetic O.L.
Limit Switches
Normally Open
Normally Closed
Held Closed
Held Open
Foot Switches
NO
NC
Pressure and Vacuum Switches
NC
NO
Temperature Actuated Switches
Liquid Level Switches
NC
NO
Flow Switches (Air, Water, Etc.)
Speed (Plugging)
F
R
Anti-Plug
F
R
Selector
2 Position
J K
A1
A2
X - Contact Closed
3 Position
J K L
A1
A2
X - Contact Closed
2 Pos. Sel. Pushbutton
A B
1 2
3 4
Selector Position
Contacts
Button
Free
Depres'd
1-2
3-4
Pushbuttons
Momentary Contact
Single Circuit
NO
NC
Double Circuit
NO & NC
Mushroom Head
Wobble Stick
Maintained Contact
Two Single Circuit
One Double Circuit
Illuminated
R
Pilot Lights
Indicate Color by Letter
Non Push-to-Test
Push-to-Test
A
Contacts
Instant Operating
With Blowout
Without Blowout
NO
NC
NO
NC
Timed Contacts - Contact Action Retarded After Coil is:
Energized
Deenergized
NOTC
NCTO
NOTO
NCTC
Coils
Shunt
Series
Overload Relays
Thermal
Magnetic
Inductors
Iron Core
Air Core
Transformers
Auto
Iron Core
Air Core
Current
Dual Voltage



AC Motors
Single Phase
Three Phase Squirrel Cage
Wound Rotor
Schematic Wiring
Not Connected
Connected
Power
Control
Battery
+
−
DC Motors
Armature
Shunt Field
(Show 4 Loops)
Series Field
(Show 3 Loops)
Comm. or Compens. Field
(Show 2 Loops)
Meter
Indicate Type by Letter
VM
AM
Motor Shunt
Wiring Terminal
Connections Mechanical
Ground
Mechanical Interlock
Annunciator
Bell
Buzzer
Horn Siren, Etc.
Capacitors
Fixed
Adjustable
Resistors
Fixed
RES
Heating Element
H
Adj. By Fixed Taps
RES
Rheostat Pot Or Adj. Tap
RH
Half Wave Rectifier
Full Wave Rectifier
AC
+DC
−DC
AC
Fuse
Power or Control
Supplementary Contact Symbols
SPST NO
Single Break
Double Break
SPST NC
Single Break
Double Break
SPDT
Single Break
Double Break
DPST 2 NO
Single Break
Double Break
DPST 2 NC
Single Break
Double Break
DPDT
Single Break
Double Break
Terms
SPST Single-Pole Single-Throw
SPDT Single-Pole Double-Throw
DPST Double-Pole Single-Throw
DPDT Double-Pole Double-Throw
NO Normally Open
NC Normally Closed

Symbols For Static Switching Control Devices

Static switching control uses solid-state devices instead of electromechanical devices. Many of the symbols used with this type of control are the same as those shown on the previous page, but enclosed in a square as shown in the following examples.

Control and Power Connections - 600 Volts or Less - Across-the-Line Starters (From NEMA Standard ICS 2-321A.60)

		1 Phase	2 Phase 4 Wire	3 Phase
Line Markings		L1,L2	L1,L3-Phase 1 L2,L4-Phase 2	L1,L2,L3
Ground When Used		L1 is always Ungrounded	—	L2
Motor Running Overcurrent Units In	1 Element	L1	—	—
	2 Element	—	L1,L4	—
	3 Element	—	—	L1,L2,L3
Control Circuit Connected To		L1,L2	L1,L3	L1,L2
For Reversing Interchange Lines		—	L1,L3	L1,L3

Abbreviations

Abbreviations are frequently used in control circuits. The following list identifies commonly used abbreviations.

AC	Alternating Current
ALM	Alarm
AM	Ammeter
ARM	Armature
AU	Automatic
BAT	Battery
BR	Brake Relay
CAP	Capacitor
CB	Circuit Breaker
CKT	Circuit
CONT	Control
CR	Control Relay
CT	Current Transformer
D	Down
DC	Direct Current
DISC	Disconnect Switch
DP	Double-Pole
DPDT	Double-Pole, Double-Throw
DPST	Double-Pole, Single-Throw
DT	Double Throw
F	Forward
FREQ	Frequency
FTS	Foot Switch
FU	Fuse
GEN	Generator
GRD	Ground
HOA	Hand/Off/Auto Selector Switch
IC	Integrated Circuit
INTLK	Interlock
IOL	Instantaneous Overload
JB	Junction Box
LS	Limit Switch
LT	Lamp
M	Motor Starter
MSP	Motor Starter Protector
MTR	Motor
MN	Manual
NEG	Negative
NEUT	Neutral
NC	Normally Closed
NO	Normally Open
OHM	Ohmmeter
OL	Overload
PB	Pushbutton
PH	Phase
POS	Positive
PRI	Primary
PS	Pressure Switch
R	Reverse
REC	Rectifier
RES	Resistor
RH	Rheostat
S	Switch
SEC	Secondary
SOL	Solenoid
SP	Single-Pole
SPDT	Single-Pole, Double Throw
SPST	Single-Pole, Single Throw
SS	Selector Switch
SSW	Safety Switch
T	Transformer
TB	Terminal Board
TD	Time Delay
THS	Thermostat Switch
TR	Time Delay Relay
U	Up
UV	Under Voltage
VFD	Variable Frequency Drive
XFR	Transformer

c) Write short notes (any *two*) : 8

(*i*) BUCK-boost converter

(*ii*) UJT relaxation oscillator

(*iii*) Turn-off methods of SCR.

5. (*a*) Define latching and holding currents as applicable to an SCR. 2

(*b*) Discuss the importance of $\frac{di}{dt}$ rating during the turn-on process of SCR. 6

(*c*) Explain with neat circuit diagram and waveform the operation of single-phase half-wave converter drive armature voltage control of D.C. motor. 8

6. (*a*) What is the role of optical isolator ? 2

(*b*) What is SMPS ? Give its operating principle and industrial applications. 6

(*c*) What is an IGBT ? What are its other names ? Describe the working mechanism of an IGBT.

7. (*a*) What are the necessary conditions for turning-off of an SCR ?

(*b*) Discuss the gate characteristics of an SCR.

(*b*) Explain any one methods for turning-on of SCRs with a neat diagram. 6

(*c*) What is a unijunction transistor ? Give its equivalent circuits. Draw and explain its current-voltage characteristic. 8

(*a*) What are the difference between converter and inverter ? 2

(*b*) Explain with circuit diagram the principle of operation of cycloconverter. 6

(*c*) Explain with circuit diagram and necessary waveform the principle of operation of single-phase half-bridge interter 8

(*a*) Write some applications of cycloconverters. 2

(*b*) What are the different techniques adopted for the protection of SCRs ? Explain in brief. 6

(*c*) Draw and explain the I-V characteristic of a SCR. Label the various voltages currents and the operating modes on this sketch. 8

5

POWER ELECTRONICS AND DRIVES

(Theory—2)

Full Marks : 80

Time : 3 hours

Answer any **five** questions

Figures in the right-hand margin indicate marks

1. (*a*) What are the different advantages we are getting due to the use of a freewheeling diode? 2

   (*b*) Explain with neat circuit diagram the principle of operation of chopper. 6

   (*c*) A step-up chopper has output voltage of two to four times the input voltage. For a chopping frequency of 2000 Hz, determine the range of off-periods for the gate signal. 8

2. (*a*) Name the different twin-on methods available for a SCR.

(Turn Ov

3. (*a*) What is hatching current ? 2

(*b*) Explain single phase voltage source half bridge inverter with resistive load. 5

(*c*) Explain single phase voltage source parallel inverter. 7

4. (*a*) What is the difference between uncontrolled rectifier and controlled rectifier ? 2

(*b*) Explain single phase full wave AC regulator. 5

(*c*) Explain Type -C chopper. 7

5. (*a*) What is the use of UPS ? 2

(*b*) Explain the operation of speed control of induction motor by stator frequency control. 5

(*c*) Explain single phase full converter DC drive with circuit diagram. 7

(*a*) What is the effect of free wheeling diode ? 2

(*b*) Explain single phase half-bridge converter. 5

(*c*) Explain construction and working principle of MOSFET. 7

7. (*a*) What is the difference between power diode and signal diode ? 2

(*b*) Explain the three turn on methods of Thyristor. 5

(*c*) Explain single phase full wave converter with R-L load, with circuit diagram. 7

V—Sem/ELECT/2015 (W)

POWER ELECTRONICS AND DRIVES

(Code : EET-502)

Full Marks : 70

Time : 3 hours

Answer any **five** questions

Figures in the right-hand margin indicate marks

1. (*a*) What is rise time ? 2

   (*b*) How thyristor is protected by gate protection ? 5

   (*c*) Explain principle of operation of thyristor with V-I characteristics. 7

2. (*a*) What do you mean by phase angle control of thyristor ? 2

   (*b*) Explain gate triggering of thyristor by resistance firing. 5

   (*c*) Explain single phase half controlled bridge converter for R-Load. 7

(Turn Over)

POWER ELECTRONICS AND DRIVES

(Code : EET-502)

Full Marks : 70

Time : 3 hours

Answer any **five** questions

Figures in the right-hand margin indicate marks

1. (*a*) What is delay time ? 2

   (*b*) Explain any three turn on methods of thyristor. 5

   (*c*) Explain working of RC firing circuit. 7

2. (*a*) What is the difference between natural commutation and forced commutation ? 2

   (*b*) Describe overcurrent and gate protection of thyristor. 5

   (*c*) Explain switching characteristics of SCR with necessary diagram. 7

(*Turn Over*)

3. (*a*) What is surge current rating of thyristor ? 2

(*b*) Explain resonant pulse commutation of thyristor. 5

(*c*) Explain operation of single phase full-wave converter with RL load and free wheeling diode. 7

4. (*a*) Classify Inverter. 2

(*b*) Describe operation of single phase half wave converter with RL load. 5

(*c*) Explain single phase voltage source series inverter. 7

5. (*a*) What is cycloconverter and where it is used ? 2

(*b*) Explain working of type B chopper. 5

(*c*) Describe working of single phase to single phase step-down cycloconverter. 7

6. (*a*) What do you mean by electrical drives ? 2

(*b*) Describe operation of Buck Boost converter. 5

(*c*) Explain construction and working of IGBT. 7

7. (*a*) What do you mean by power BJT ? 2

(*b*) Explain speed control of induction motor by stator voltage control method. 5

(*c*) Explain single phase Half-wave converter DC Drives. 7

5[TH] SEM./EEE/EME/ 2020(W)OLD

EET-502/EMT502 Power Electronics & Drives

Full Marks: 80

Answer any five Questions including Q No.1& 2

Figures in the right hand margin indicates marks

Time- 3 Hrs

1. Answer All questions 2 x
   a. What is thyristors?
   b. What is the difference between natural commutation & forced commutation?
   c. What do you mean by duty cycle?
   d. What is the function of buck converter?
   e. Define snubber circuit.
   f. What is cycloconverter & where it is used?
   g. What do you mean by electrical drives?
   h. Define delay time.
   i. What is power semiconductor diodes?
   j. Define inverter.
2. Answer **Any Six** Questions 6 x
   a. Explain V-I characteristics of thyristor with a neat sketch.
   b. *Explain mid-point cycloconvertor.*
   c. *What is an UJT? Explain UJT as a relaxation oscillator.*
   d. Explain the principle of operation of single phase half wave converter circuit with R load.
   e. Explain the principle of operation of step up chopper.
   f. Explain speed control of induction motor by stator voltage control method.
   g. Describe the construction & operation of power diode.
3. Explain the principle &operation of both online & offline UPS system.
4. Describe the operation of voltage source parallel inverter circuit.
5. Explain single phase half wave converter DC drive.
6. Explain switching characteristics of SCR with necessary diagram.
7. Describe the construction & working of IGBT.

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EET502 Power Electronics & Drives

Full Marks: 80

Time: 3 Hrs

Answer any five Questions including Q No.1& 2
Figures in the right hand margin indicates marks

1. **Answer All questions**
   a. What is holding current?
   b. What is rise time?
   c. What are the turn on methods of SCR?
   d. What is valley point in UJT?
   e. What is the use of free wheeling diode?
   f. What is firing angle of SCR?
   g. What is the use of a.c regulator?
   h. What is the use of electric drives?
   i. Draw the symbol of DIAC and MOSFET.
   j. What is the use of UPS?

2. **Answer Any Six Questions**
   a. Explain resistance firing of thyristor.
   b. Explain TYPE-C chopper.
   c. What are the difference between voltage source inverter and current source inverter?
   d. Explain gate protection of thyristor.
   e. Explain the operation of single phase half bridge voltage source inverter.
   f. Explain operation of buck converter.
   g Explain the speed control of induction motor by stator voltage control.

3 Draw and explain V-I characteristics of SCR.

4 Explain construction and working principle of MOSFET.

5 Explain the operation single phase full wave converter with R-L load and sketch the waveforms

6 Explain the operation of series inverter with wave forms of circuit parameter.

7 Explain the operation of single phase step up cyclo-converter with neat sketch of waveforms.