# Class Notes

## PE&PLC (Theory)

Introduction to

Programmable Logic Controllers

(PLC'S)

Industrial Control Systems

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## The Need for PLCs :-

=> Hardwired panels were very time consuming to wire, debug and change.

=> GM identified the following requirement for computer controllers to replace hardwired panels.

- Solid-state not mechanical
- Easy to modify input and output devices
- Easily programmed and maintained by plant electricians
- Be able to function in an industrial environment

## The first Programmable logic Controllers (PLCs)

=> Introduced in the late 1960's

=> Developed to offer the same functionality as the existing relay logic systems

=> Programmable, reusable and reliable

- Could withstand a harsh industrial environment
- They had no hard drive, they had battery backup
- Could start in seconds
- Used ladder logic for programming

# Programmable Logic Controller :-

⇒ A programmable logic Controller (PLC) is a specialized Computer used to Control machines and process.

⇒ It uses a programmable memory to store instructions and specific functions that include on/off control, timing, counting, sequencing, arithmetic, and data handling.

## Advantages of PLC Control System

⇒ Flexible

⇒ Faster response time

⇒ Less and simpler wiring

⇒ Solid-state - no moving parts

⇒ Modular design - easy to repair and expand

⇒ Handles much more complicated systems

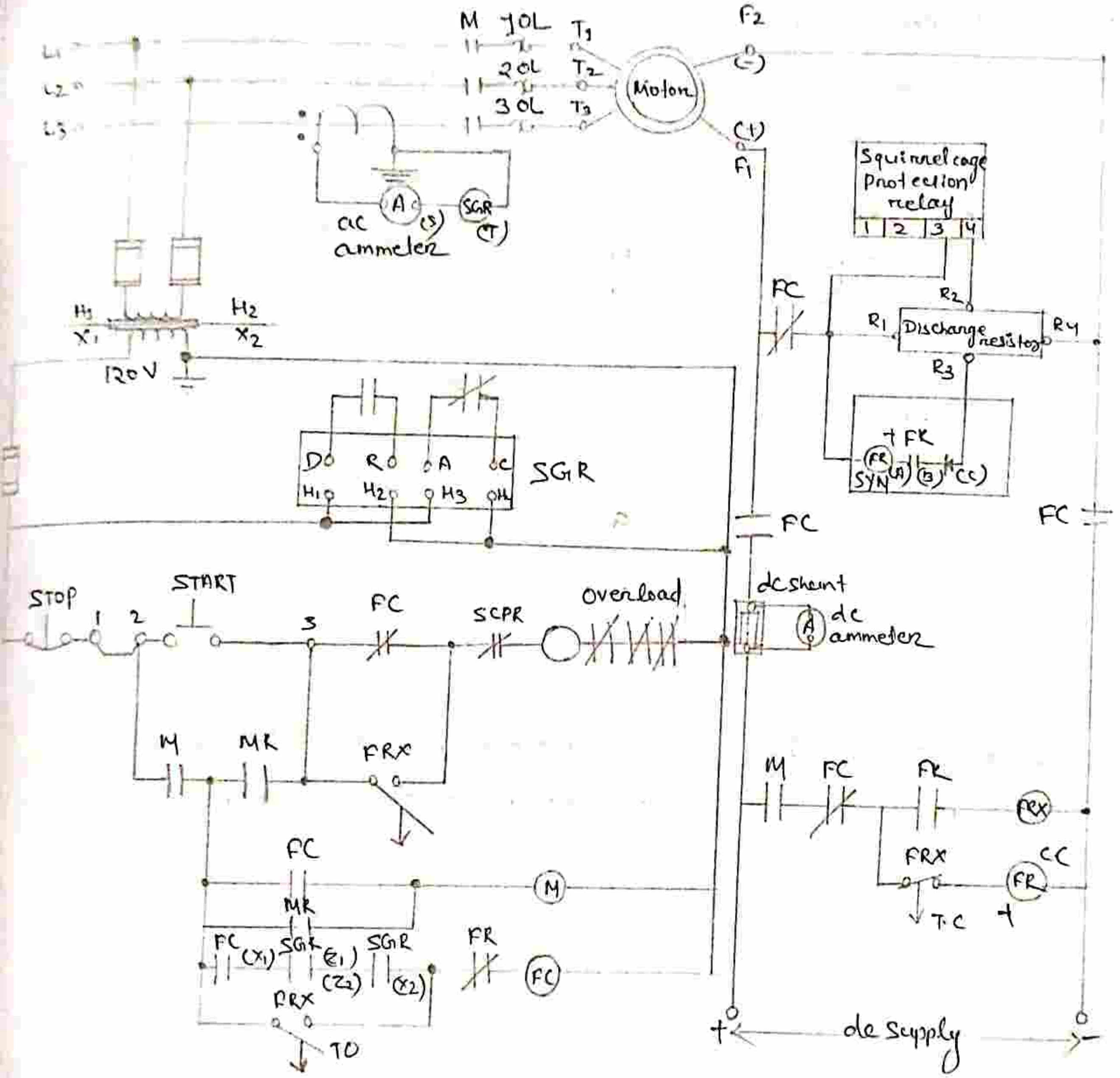
⇒ Sophisticated instruction sets available

⇒ Allows for diagnostics "easy to troubleshoot"

⇒ Less expensive

# Advantages of a PLC Control System

Eliminates much of the hard wiring that was associated with conventional relay control circuits.

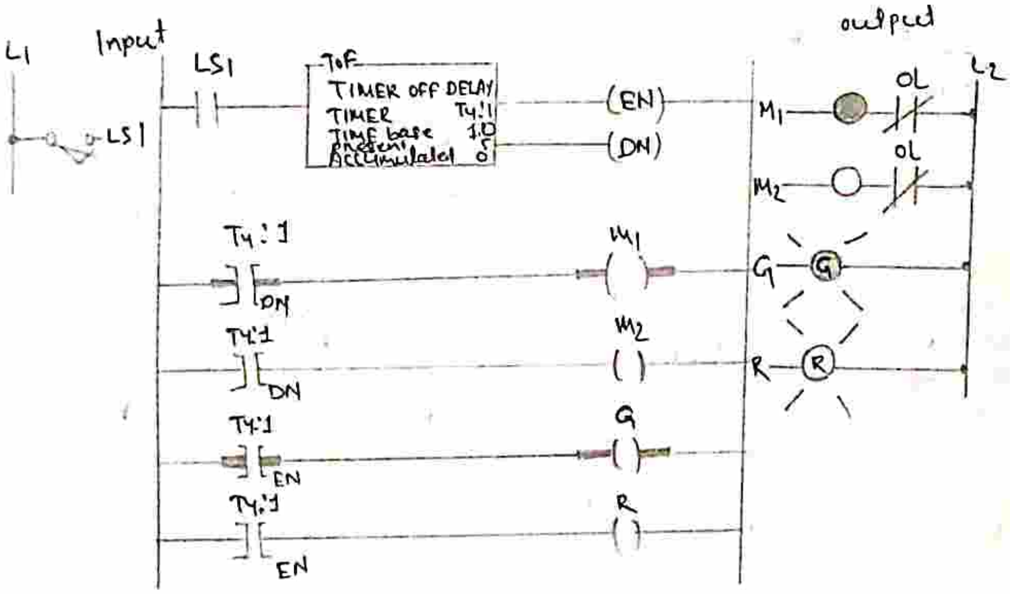


The program takes the place of much of the external wiring that would be required for control of a process.

## Advantages of a PLC Control system

Increased Reliability

Once a program has been written and tested it can be downloaded to other PLCs.



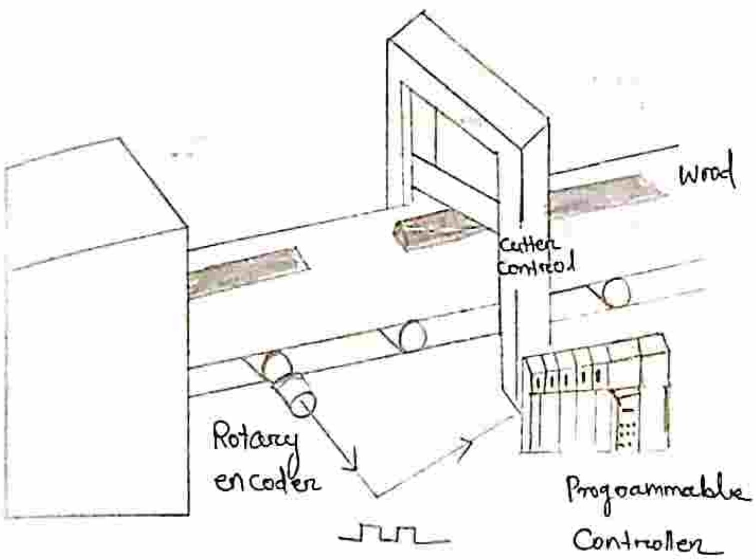

Since all the logic is contained in the PLC's memory there is no chance of making a logic wiring error.

Conversely . . . . . .

## Advantages of a PLC Control system

More flexibility:

Original equipment manufactures (OEMs) can provide system updates for a process by simply sending out a new program.

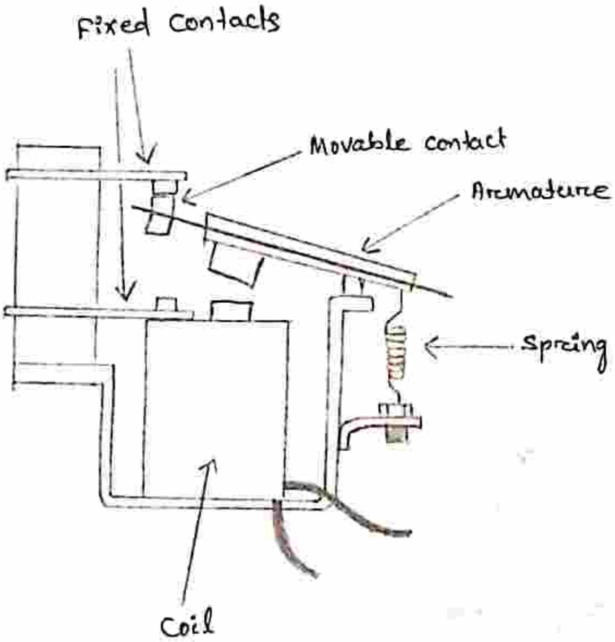



It is easier to create and change a program in a PLC than to wire and rewire a circuit. End-users can modify the Program in the field.

## Advantages of a PLC Control system

Lower Costs:

Originally PLCs were designed to replace relay control logic. The cost saving using PLCs have been so significant that relay control is becoming obsolete, except for power applications.

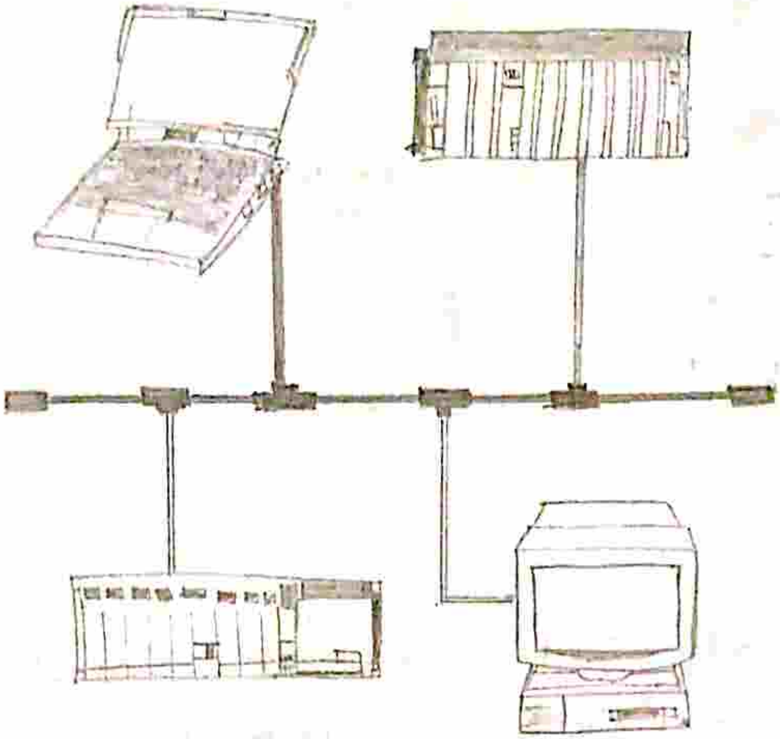



Generally, if an application requires more than about 6 control relays, it will usually be less expensive to install a PLC

## Advantages of a PLC Control system

### Communications Capability:

A PLC can communicate with other Controller or computer equipment.

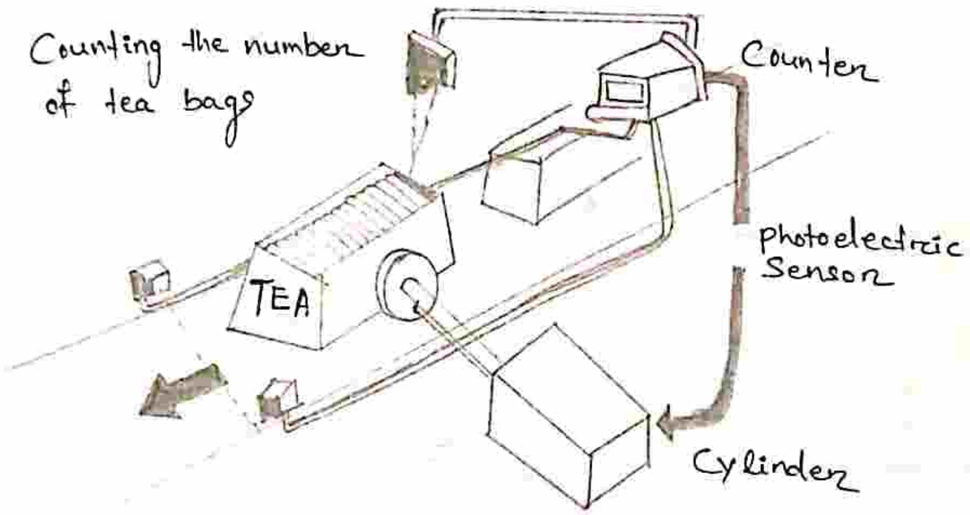


They can be networked to perform such functions as: Supervisory control, data gathering, monitoring devices and Process parameters, and downloading and uploading of programs.

# Advantages of a PLC Control system

Faster Response Time:

PLCs operate in real-time which means that an event taking place in the field will result in an operation or output taking place.

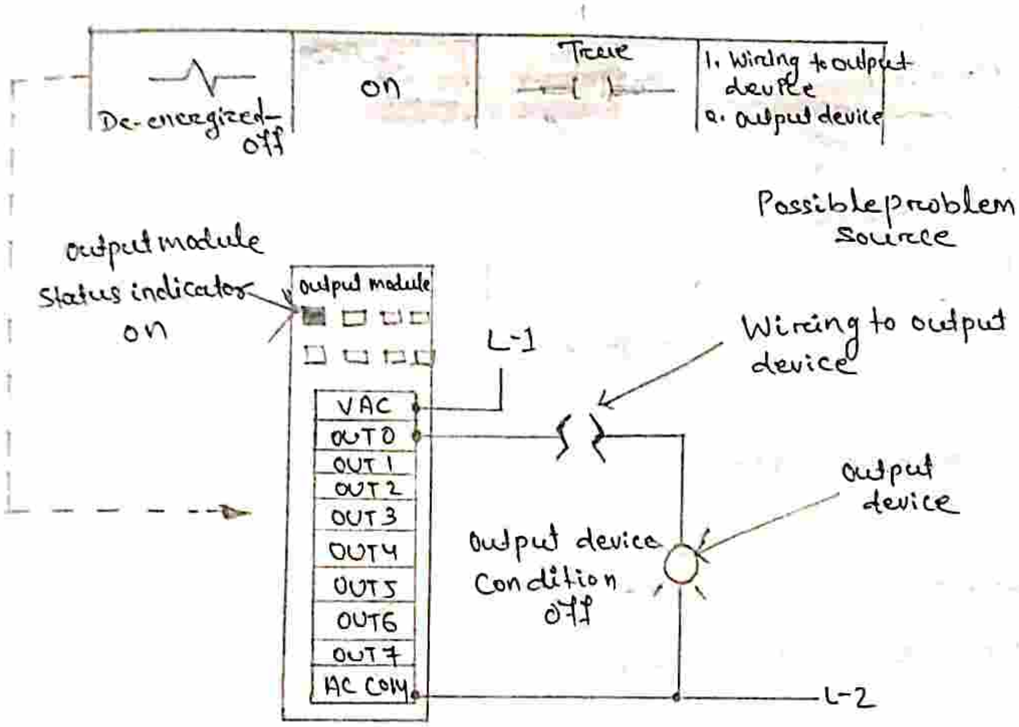



Machines that process thousands of items per second and objects that spend only a fraction of a second in front of a sensor require the PLC's quick response capability.

# Advantages of a PLC Control system

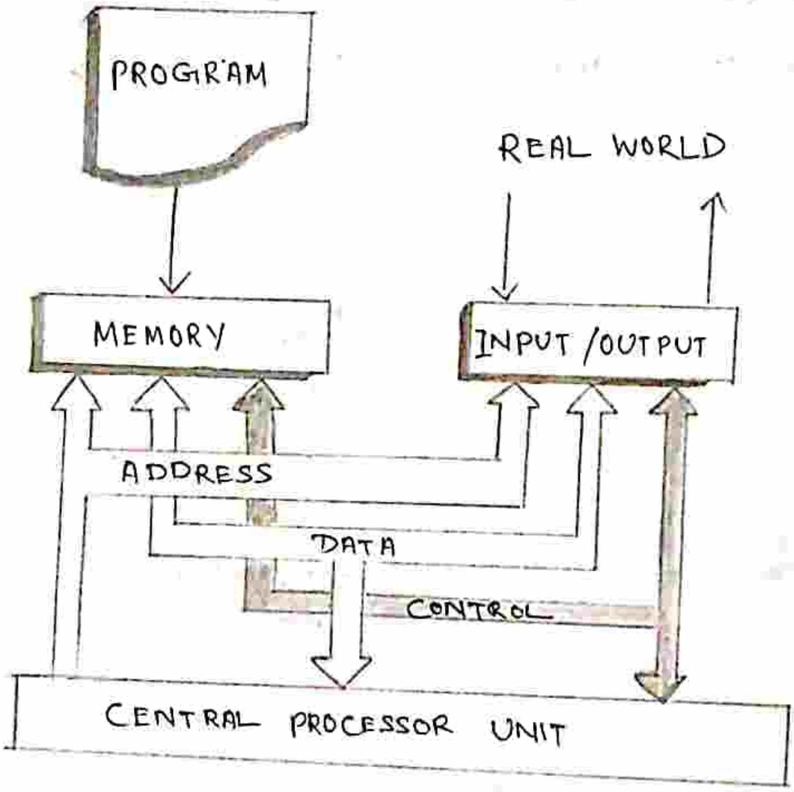
Easier To Troubleshoot:

PLCs have resident diagnostic and override functions allowing users to easily trace and correct software and hardware Problems.



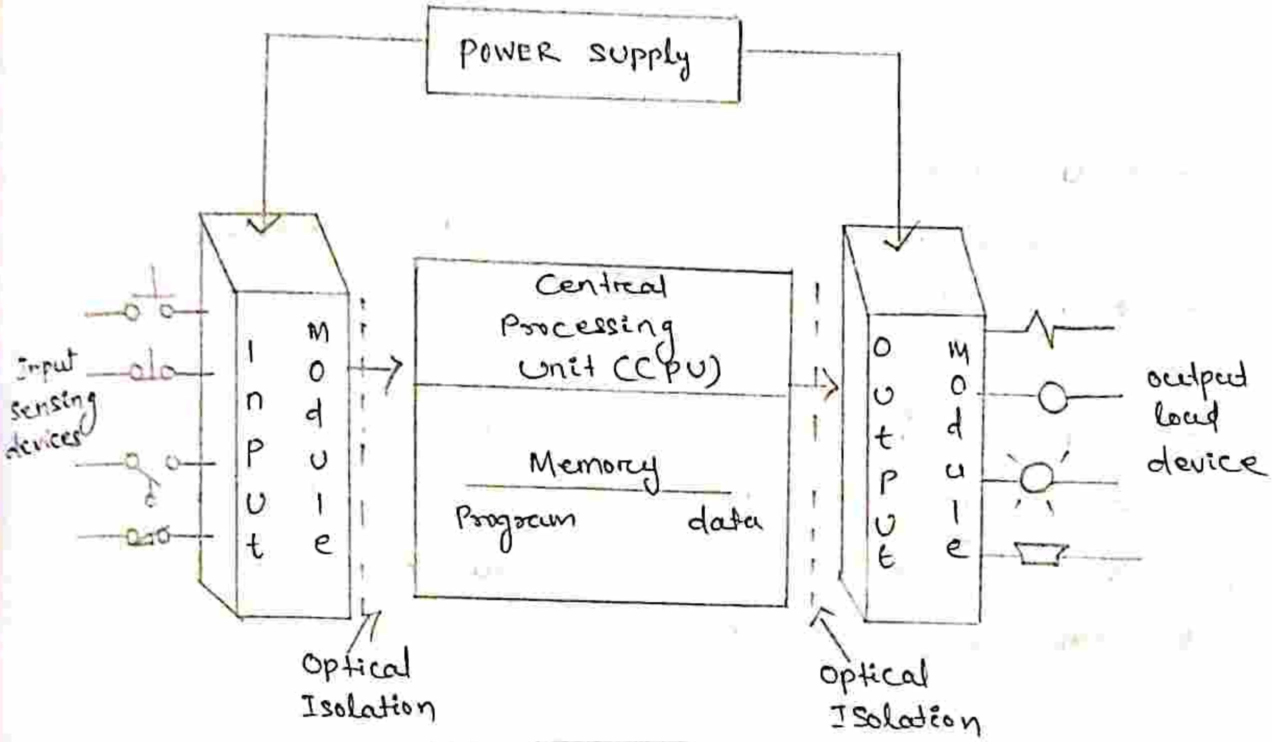

The Control program can be watched in real-time as it Executes to find and fix problems.

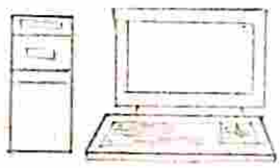
# PLC Architecture




The structure of a PLC is based on the same principles as those employed in computer architecture

# PLC SYSTEM



Programming device

## PLC Architecture

⇒ An open architecture design allows the system to be connected easily to devices and programs made by other manufacturers.

⇒ A closed architecture or proprietary system, is one whose design makes it more difficult to connect devices and Programs made by other manufacturers.

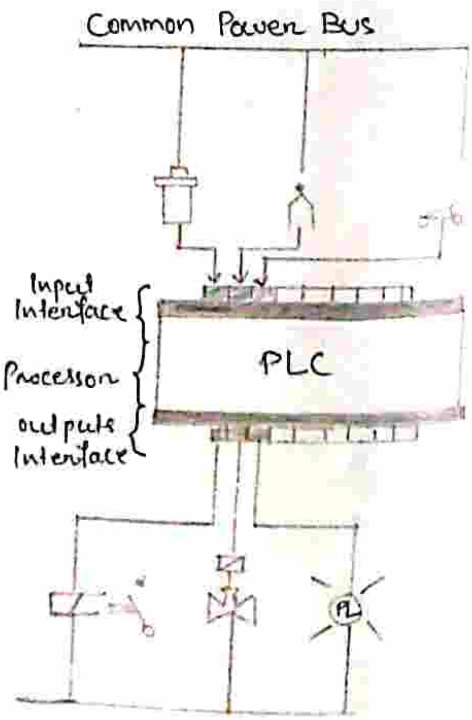
NOTE: When working with PLC systems that are Proprietary in nature you must be sure that any generic hardware or software you use is compatible with your particular PLC.

## I/O configuration

### Fixed I/O

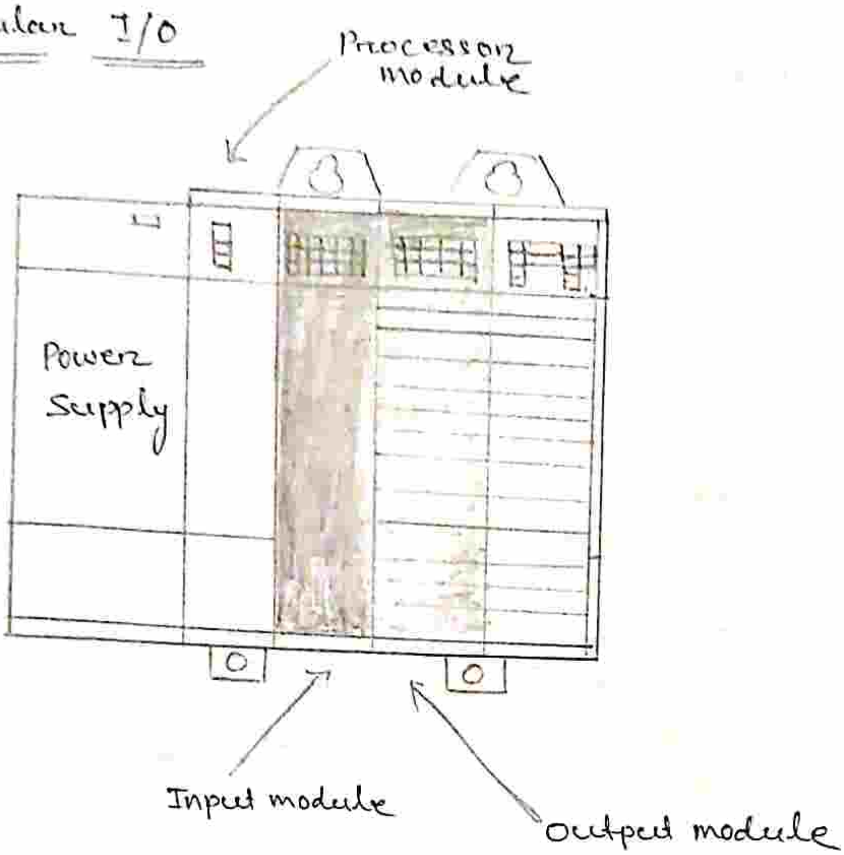
⇒ Is typical of small PLCs

- Comes in one package, with no Separate removable units.
- The processor and I/O are Packaged together.
- Lower in cost - but lacks flexibility.



## I/O Configuration

### Modular I/O

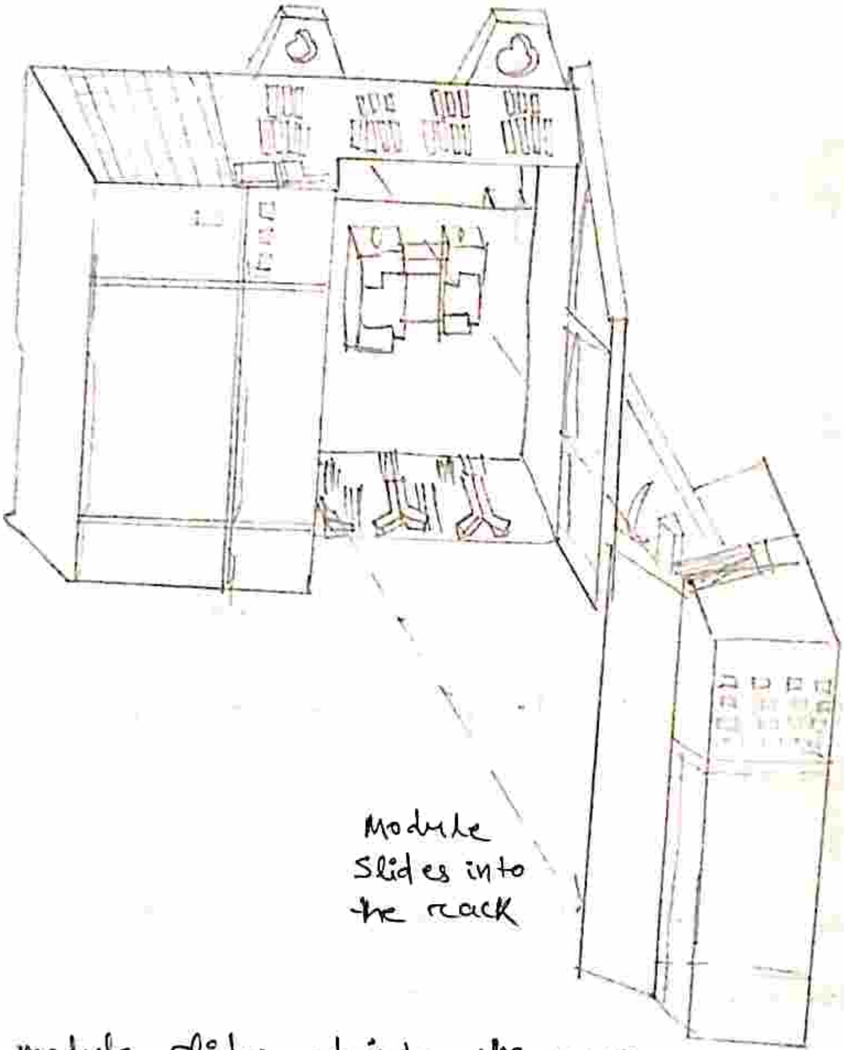



⇒ Is divided by compartments into which separate modules can be plugged.

⇒ This feature greatly increases your options and the unit's flexibility. You can choose from all the modules available and mix them in any way you desire.

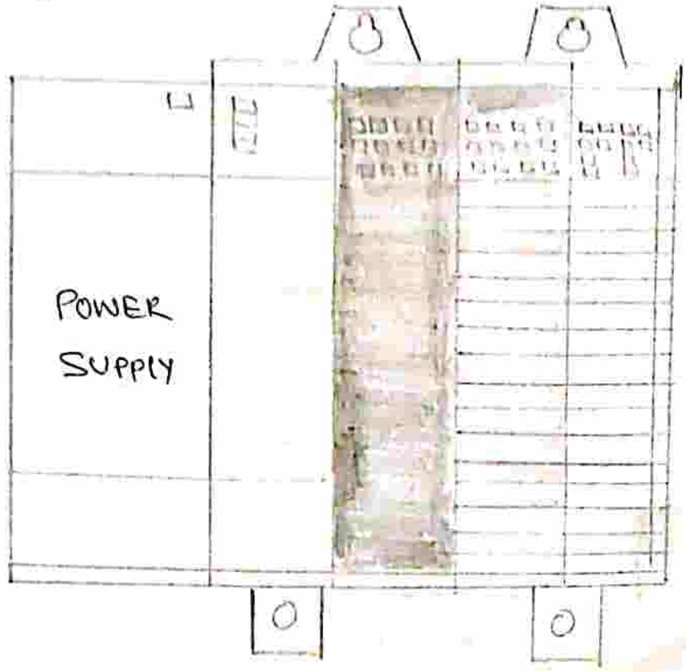
# I/O Configurations

## Modular I/O




When a module slides ~~not~~ 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

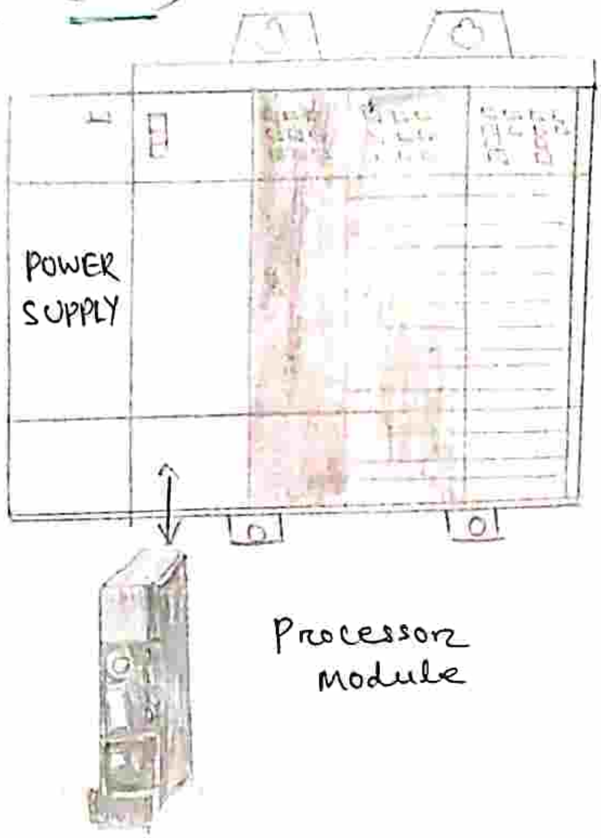



⇒ Supplies DC power to other modules that plug into the rack.

⇒ 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)



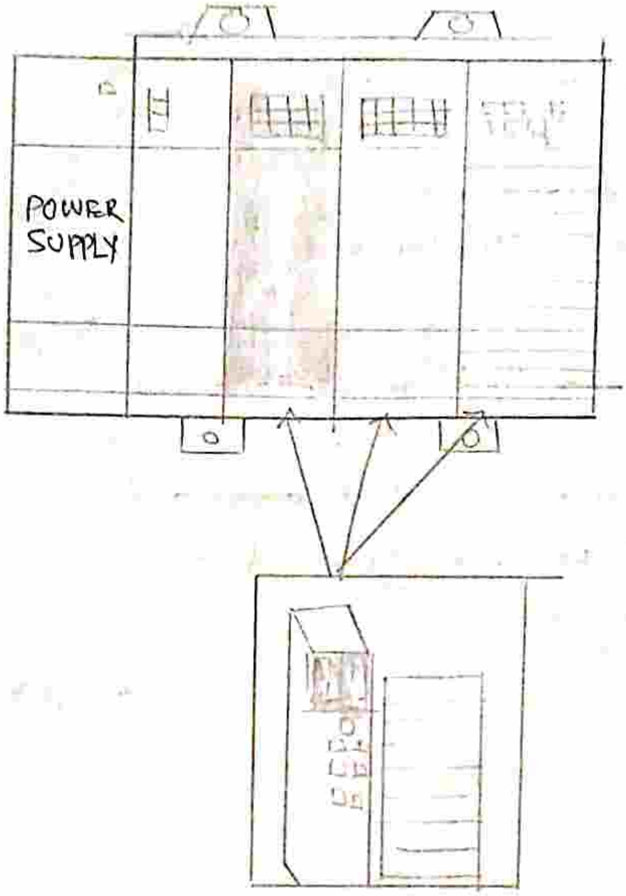

⇒ Is the "brain" of the PLC.

⇒ 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

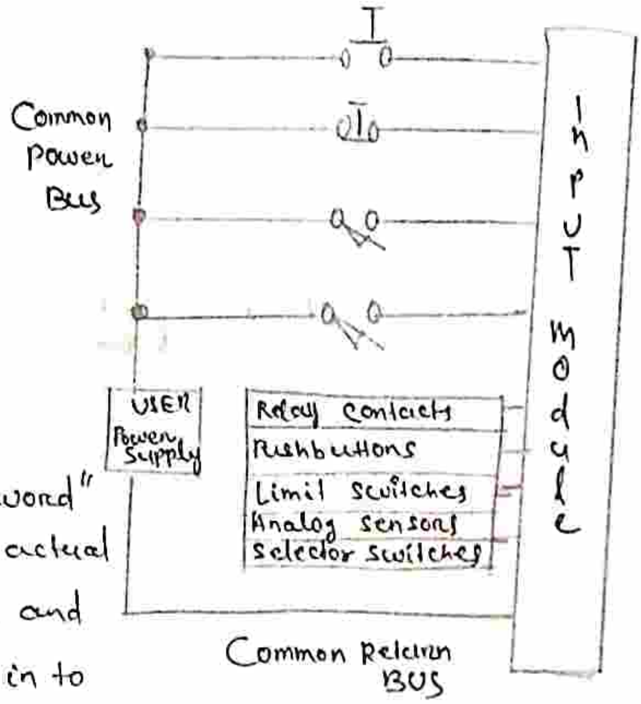
-) Output modules.

# I/O Section

## Input Module

- Forms the interface by which input field device are connected to the controller.

Input field devices

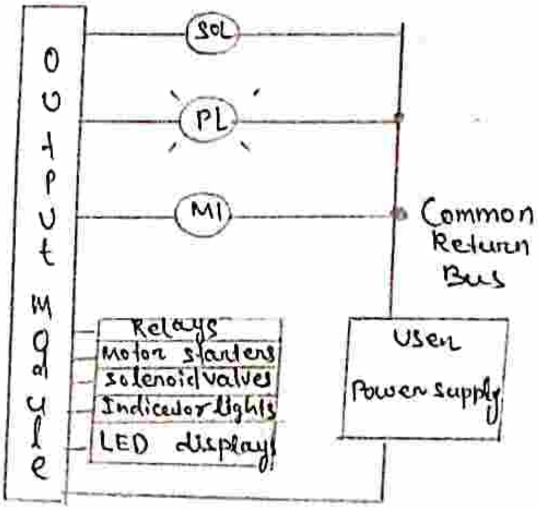



- The terms "field" and "real word" are used to distinguish actual external devices that exist and must be physically wired in to the system.

## Output Module

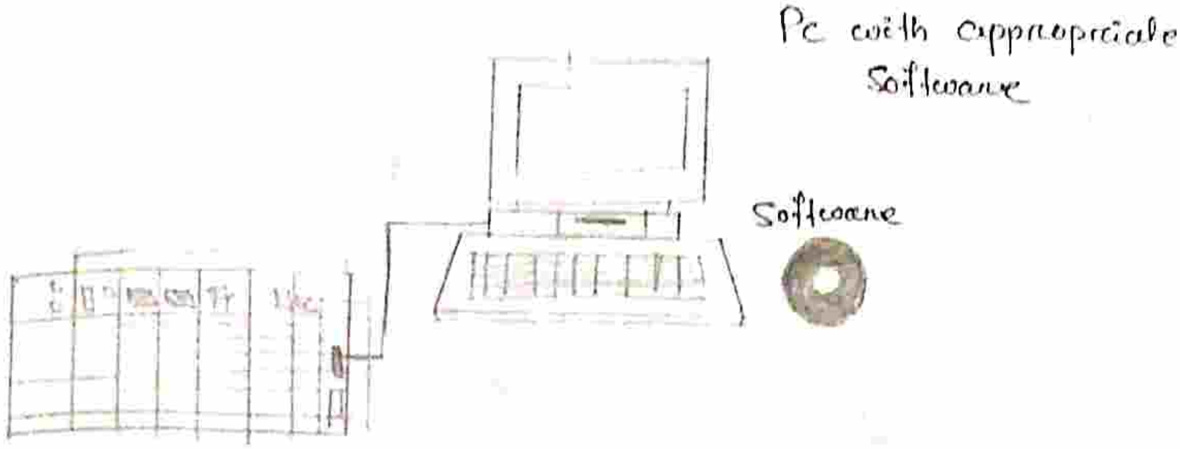
- Forms the interface by which output field devices are connected to the controller.

Output field devices




- PLCs employ an optical isolator which uses light to electricaly isolate the internal components from the input and output terminals.

## Programming Device



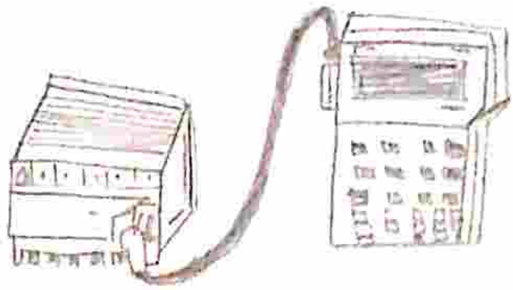

- A personal Computer (PC) is the most commonly used Programming device.

- The software allows users to create, edit, document, Store and troubleshoot programs.

- The personal computer communicates with the PLC processor via a serial or parallel data communications link.

# Programming Device

Hand-held unit
with display



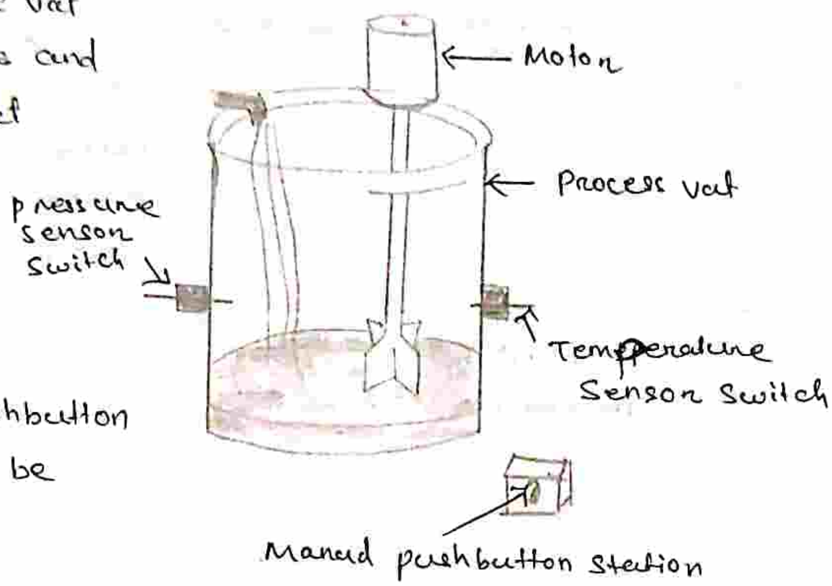
⇒ Hand-held programming devices are something used to Program small PLCs.

⇒ They are compact, inexpensive, and easy to use, but are not able to display as much logic on screen as a Computer monitor.

⇒ Hand-held units are often used on the factory floor for troubleshooting, modifying programs and transferring programs to multiple machine.

# PLC Mixer process Control problem

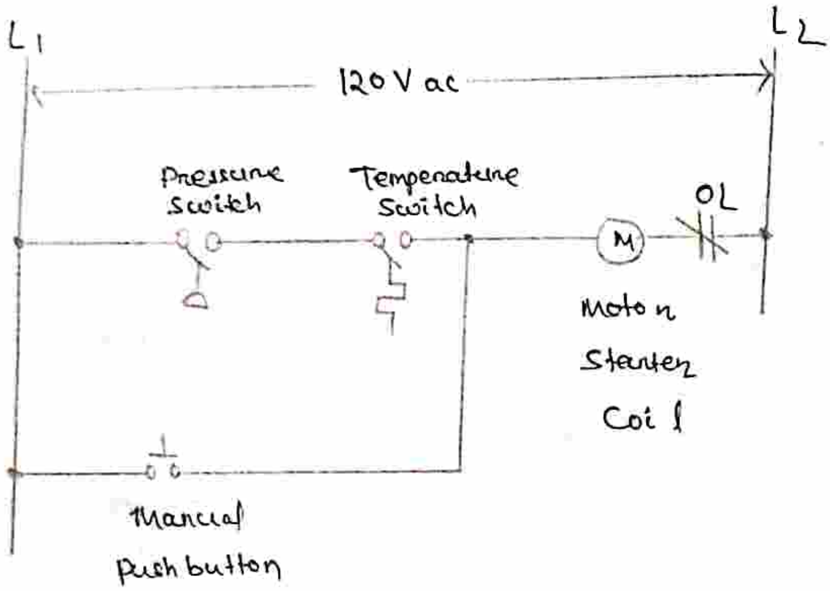
Mixer motor to automatically stir the liquid in the vat when the temperature and Pressure reach preset values.




Alternate manual pushbutton control of the motor to be provided

The temperature and Pressure sensor switches close their respective contacts when conditions reach their preset values.

# Process Control Relay Ladder Diagram

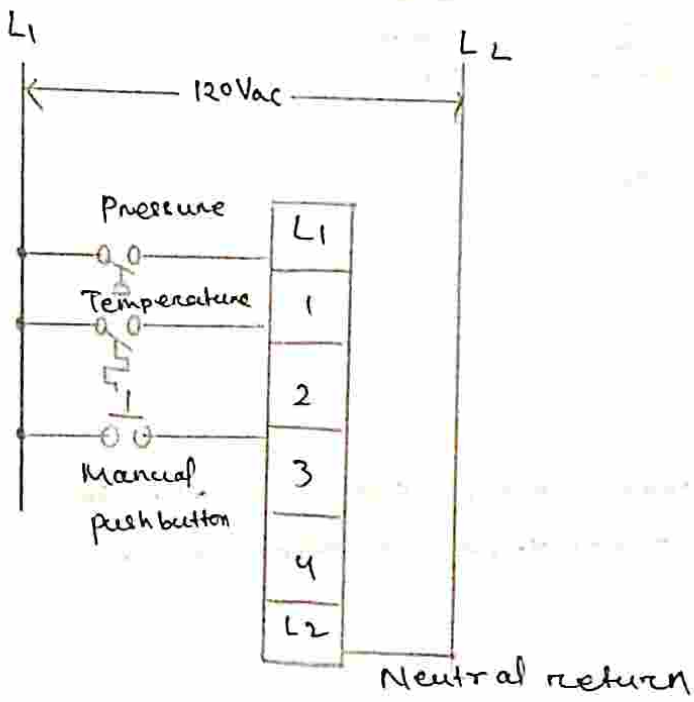



Motor Starter coil is energized when both the pressure and temperature switches are closed or when the manual pushbutto is pressed.

# PLC Input Module Connections

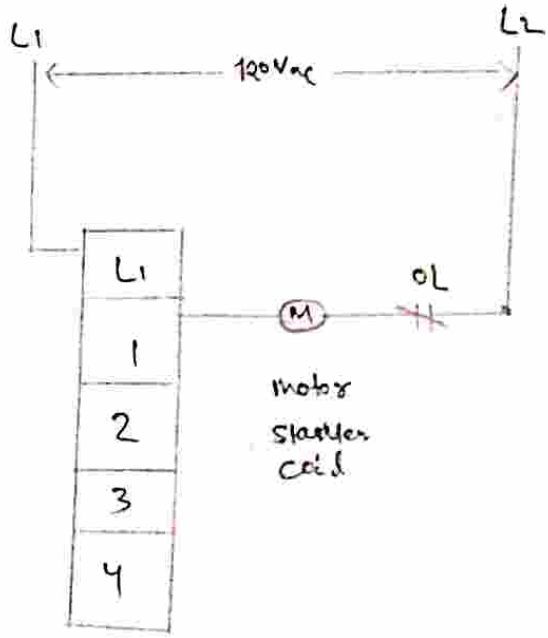
- The same input field devices are used

- These devices are wired to the input module according to the manufacturer's labeling scheme.

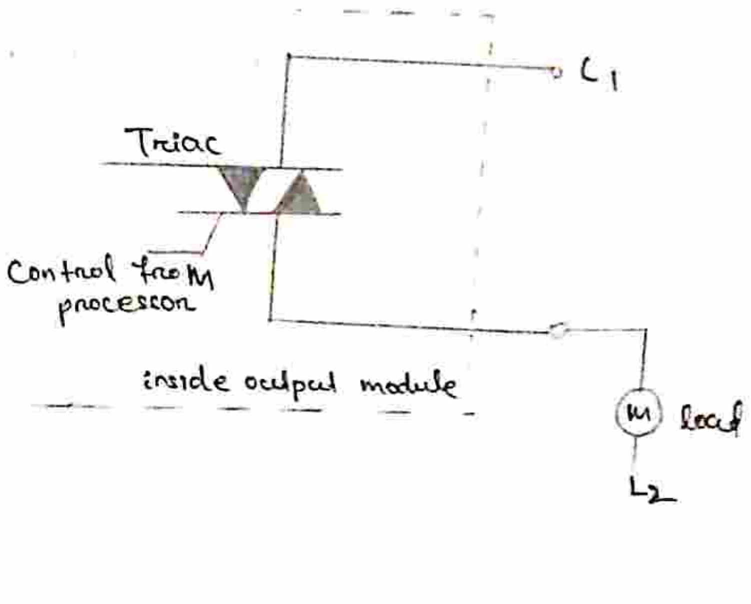


# PLC output Module Connections

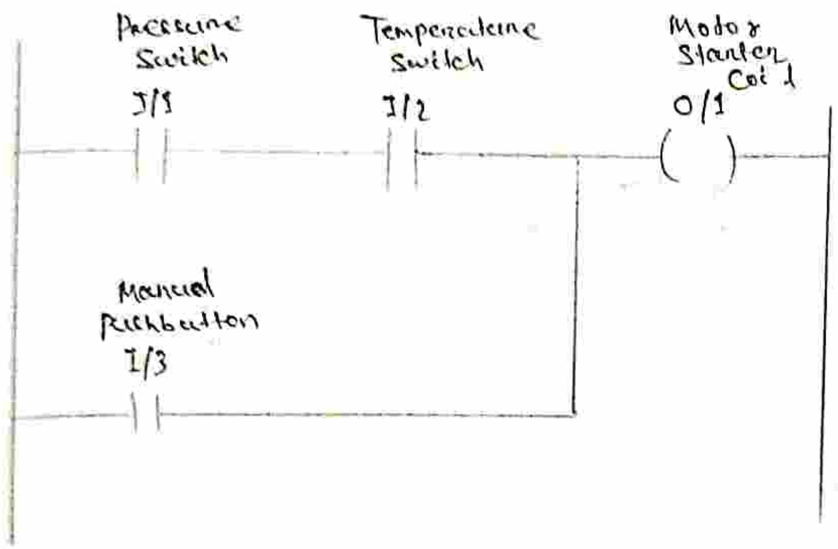
Same output field device is used and wired to the output module.



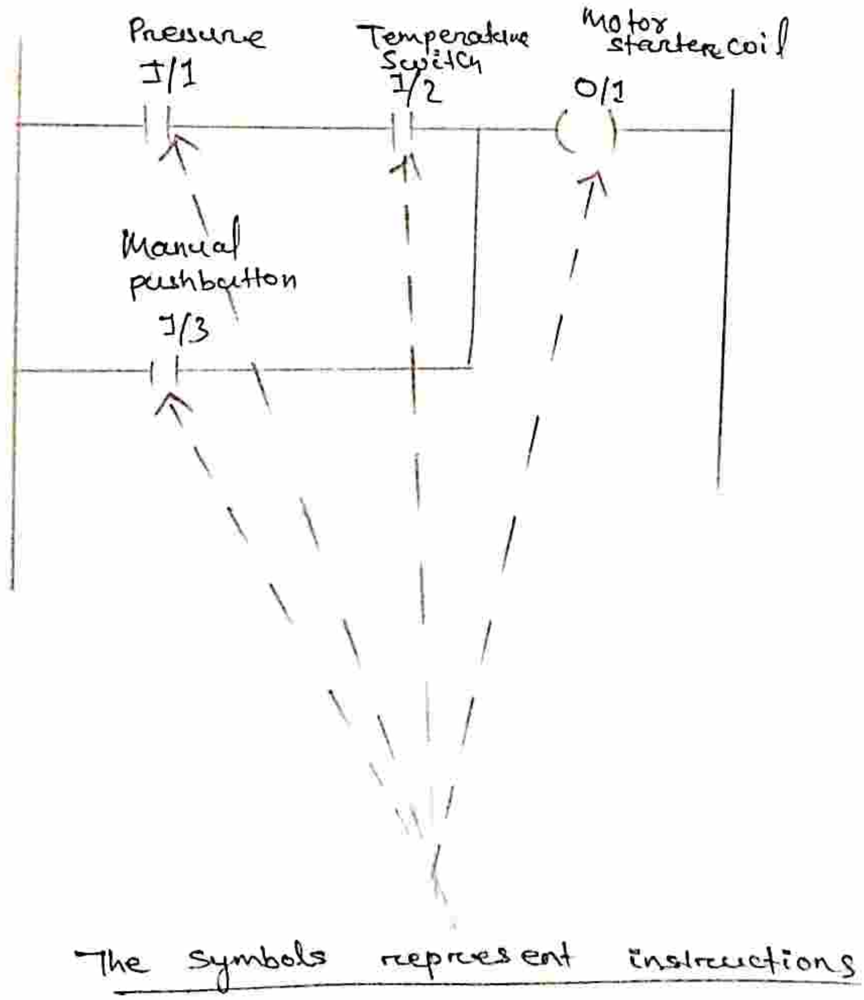

Triac switches motor ON and OFF in accordance with the control signal from the processor.



# PLC Ladder Logic program

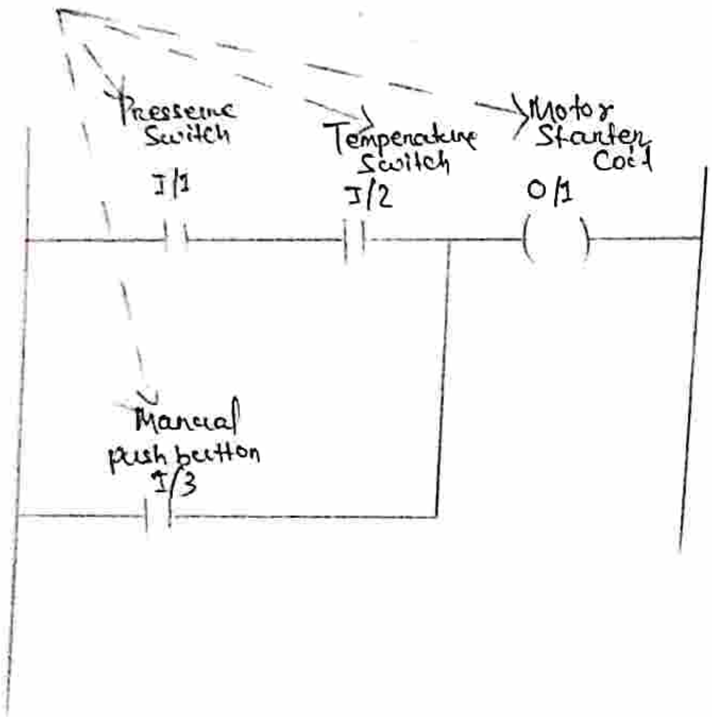



=> The format used is simillar to that of the hard-wired relay circuit.

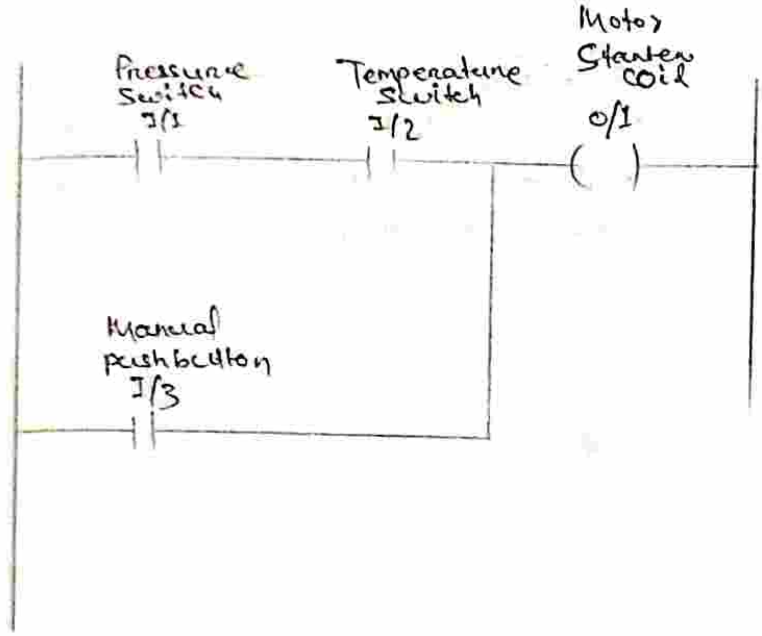


# PLC Ladder logic program

The numbers represent addresses

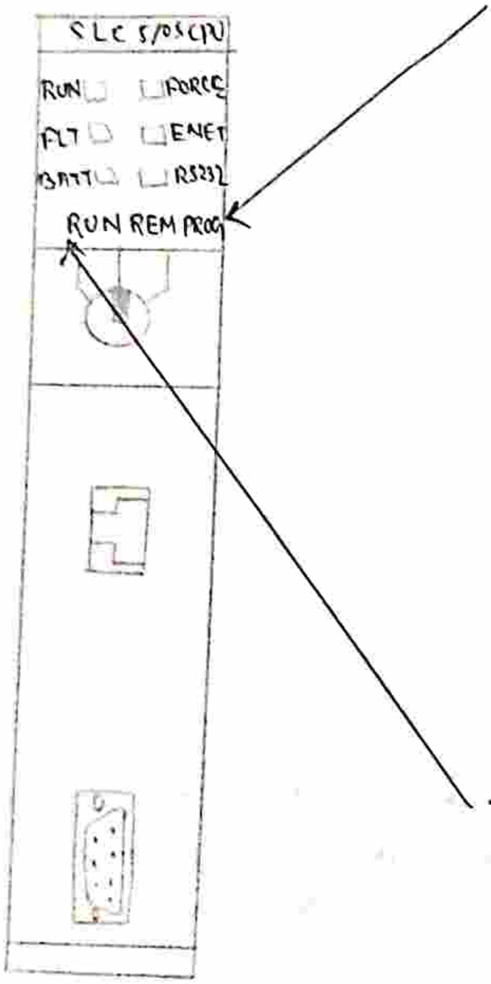


## PLC Ladder Logic program




⇒ I/O address format will differ, depending on the PLC manufacture. You give each input and output device and address. This lets the PLC know where they are physically connected.

# Entering And Running The PLC Program

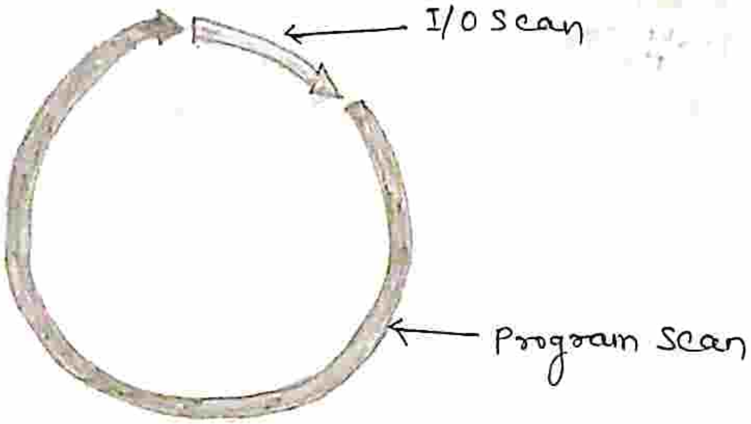



To enter the program into the PLC, pl[ace] the processor in the PROGRAM mode and enter the instructions one-by[-one] using the programming device.

To operate the program, the controller is placed in the RUN mode or operating cycle.

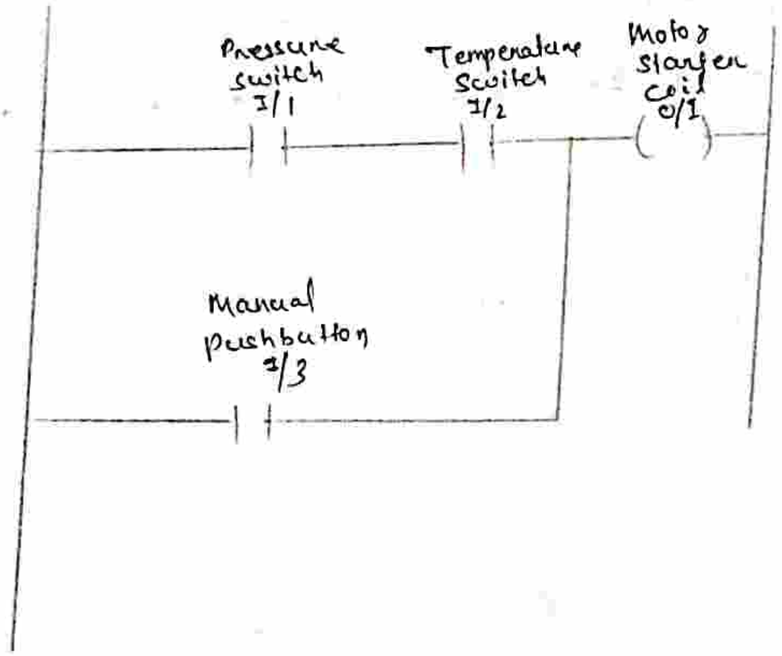
# PLC Operating Cycle

During each operating cycle, the controller examines the status of input devices, executes the user program, and changes outputs accordingly




The completion of one cycle of this sequence is called a scan. The scan time, the time required for one full cycle, provides a measure of the speed of response of the PLC.

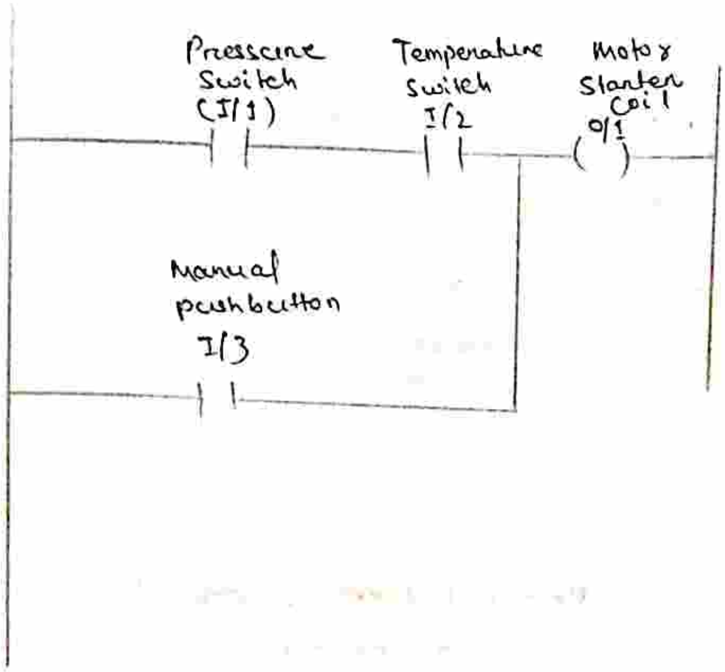
# PLC Operating Cycle




Each -||- can be though of as a set of normally open contacts

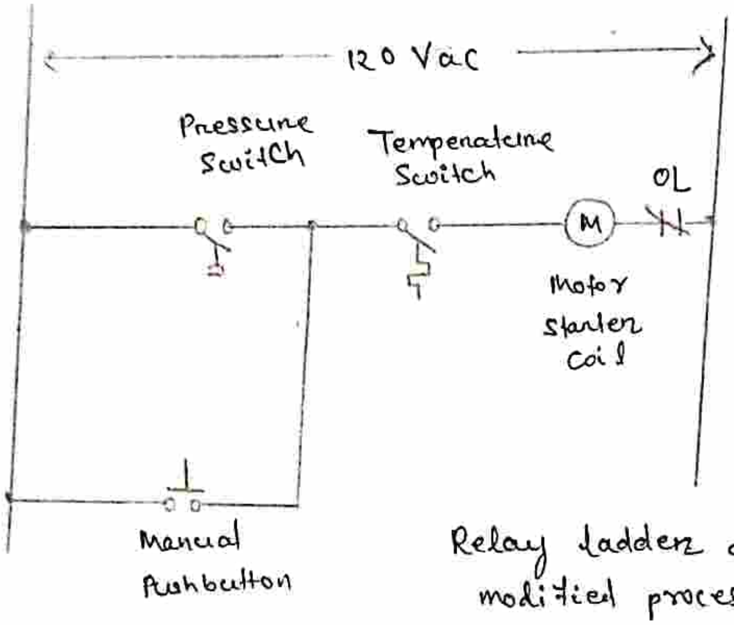
The -( )- can be considered to represent a coil that when energized, will close a set of contacts.

# PLC operating Cycle




Coil O/1 is energized when contacts 1/1 and 1/2 are closed or when contact 1/3 is closed. Either of these conditions provides a continuous path from left to right across the rung that includes the coil.

# Modifying A PLC Program

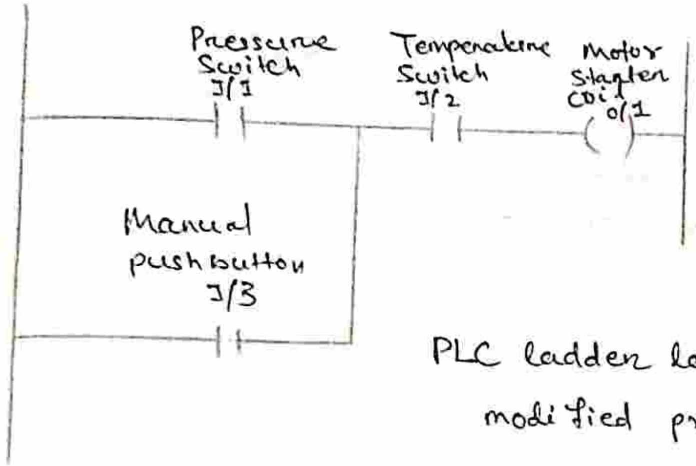



Relay ladder diagram for modified process.

The change requires that the manual pushbutton control should be permitted to operate at any pressure but not unless the specified temperature setting has been reached.

If a relay system were used, it would require some rewiring of the system, as shown, to achieve the desired change.

## Modifying A PLC program :



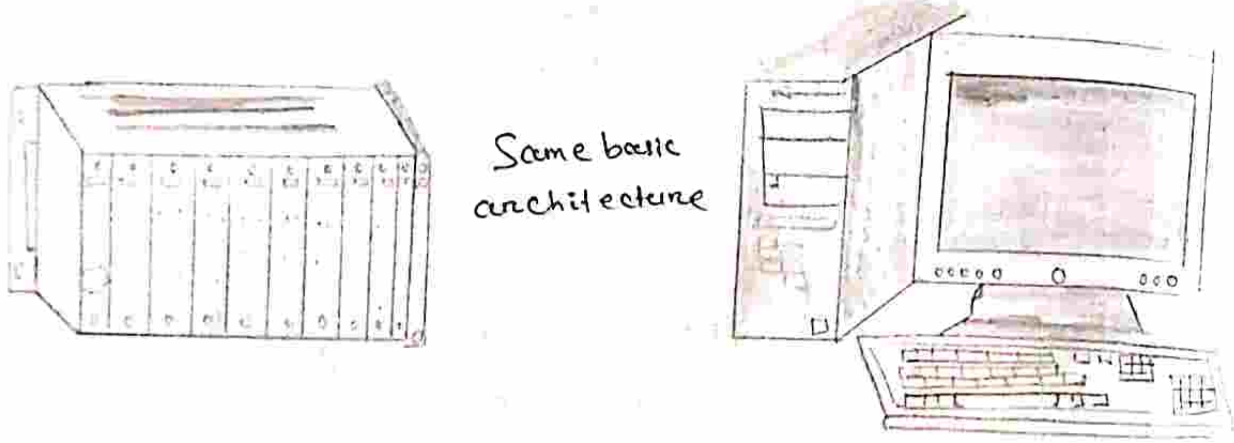

PLC ladder logic diagram for modified process

If a PLC is used, no rewiring is necessary!

The inputs and outputs are still the same.

All that is required is to change the PLC program.

## PLCs versus personal Computers




### PLC

=> Operates in the industrial environment.

=> Is programmed in relay ladder logic

-> Has no Keyboard, CD drive, monitor or disk drive.

-> Has communications ports, and terminals for input and output devices.

### PC

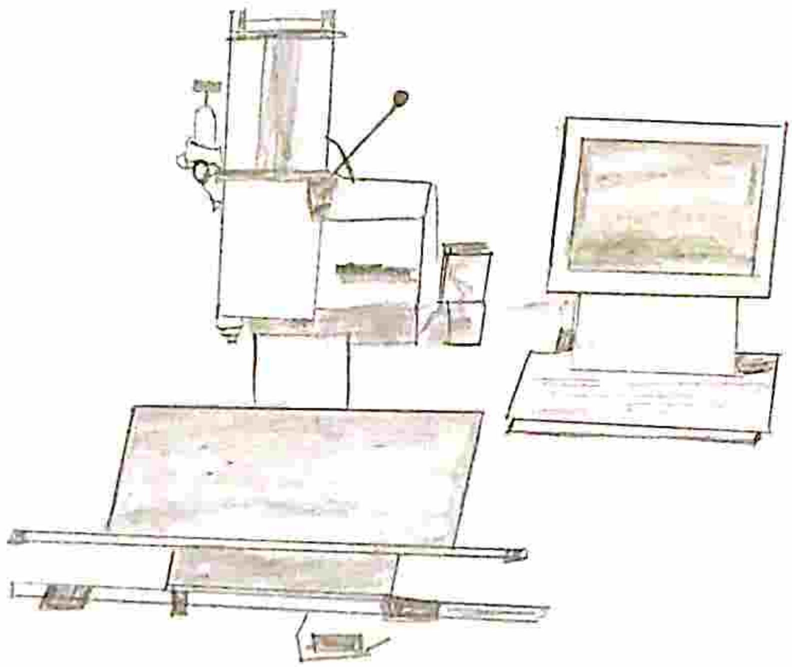
=> Capable of executing several programs simultaneously, in any order.

=> Some manufactures have Software and interface cards available so that a PC can do the work of a PLC.

# Pc Based Control Systems

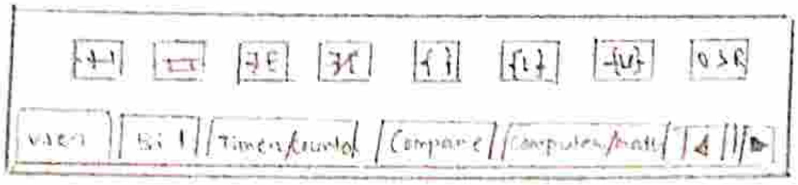
## Advantages

- => Lower initial cost
- => Less proprietary hardware and software required
- => Straight forward data exchange with other systems
- => Speedy information processing
- -) Easy customization



# PLC Instruction Set

The instruction set for a particular PLC type lists the different types of instructions supported.




An instruction is a command that will cause a PLC to perform a certain predetermined operation.

# Typical PLC Instructions

XIC (Examine ON) . . . . . Examine a bit for an ON condition

XIO (Examine OFF) . . . . . Examine a bit for an OFF condition

OTE (Output Energize) . . . . Turn ON a bit (non retentive)

OTL (Output Latch) . . . . Latch a bit (retentive)

OTU (Output Unlatch) . . . . Unlatch a bit (retentive)

TOF (Timer off-Delay) . . . . Turn an output ON or OFF after its rung has been OFF a preset time interval.

TON (Timer on-Delay) . . . . Turn an output ON or OFF after its rung has been ON for a preset time interval.

CTD (Count Down) . . . . . Use a software counter to count down from a specified value.

CTU (Count Up) . . . . . . Use a software counter to count up to a specified value.

# Power Electronics

In power electronics there is two words:-

(i) Power

(ii) Electronics

## Power:

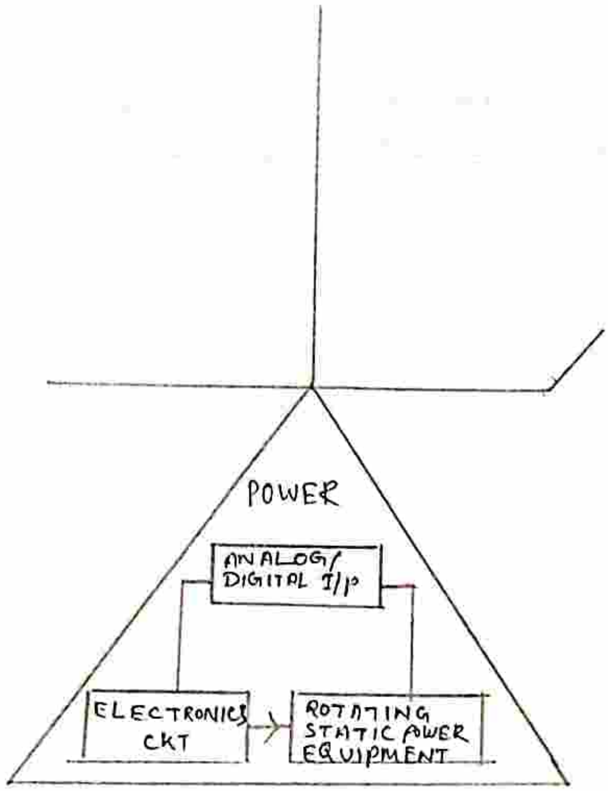
Here power refers to electrical power which is get general transmitted and distributed. which in the form of high power high voltage and high current.

## Electronics

Electronics deals smooth-performans of function by controlling different signals or electronics engineering deals generation, transmissions distribution of datas at low power, low voltage and low current.

So by combining two words power electronics, which defined as the application of electronics principle for the control and conversion of electric power in high power, high voltage and high current level.

Hence the function of power etc. Control the process during generation transmission and distribution of high power.



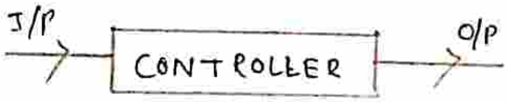

[BLOCK DIAGRAM OF POWER ELECTRONICS]

## Application of Power Electronics:

Power electronics devices are uses :-

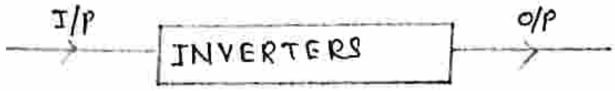
① **As a Control Rectifire : -**

It convert's fixed high value of A.C voltage to variable value of d.c voltage.



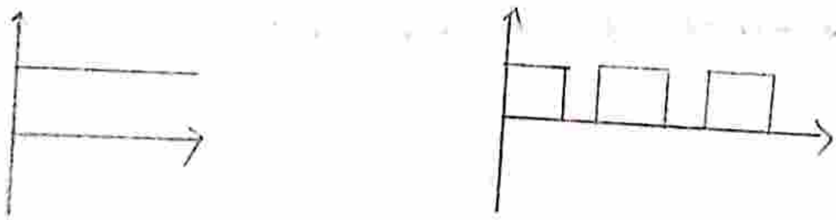

## ② INVERTERS :

It converts fixed high value of D.C voltage to variable A.C voltage which have variable frequency.




## ③ CHOPPERS

It converts fixed d.c voltage to variable d.c voltage

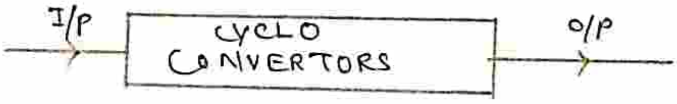



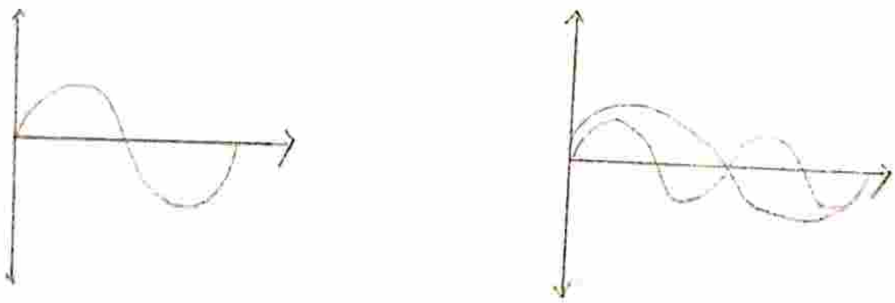
## 4) A.C VOLTAGE CONTROLLER :- (A.C Regulator)

It converts fixed value of A.C voltage to variable voltage of A.C voltage.


## 5) CYCLO CONVERTORS :-

It converts fixed frequency A.C to variable voltage, variable frequency of A.C o/p voltage.



Besides this power electronics devices the P. Etco. also used for :-

(i) Battery charging system.

(ii) Speed control of d.c motor

(iii) HVDC transmission system

(iv) Electric device control intraction.

(v) UPS (Un-interruptable power system)

(vi) Induction heating and ARC furnace

(vii) Welding power supply

# Power Electronics Devices :

## THYRISTOR :

⇒ As diode is an electronics semi-conductor electronics switching devices.

⇒ Similarly Thyristor is the semiconductor power electronics switching family.

⇒ In thyristor family there are more than one power electronics devices or components.

⇒ The name "THYRISTOR" is derive from the words THYR + ISTOR.

⇒ "THYR" comes from Thyratron tube & "ISTOR" comes from Transistor.

⇒ The Thyratron tube has function to control the rectifire which is used as high power electronic switch which is filled with gas.

⇒ And the function of Transistor is to amplify the weak signal.

⇒ By combining both the words. Thyristor which is a solid device like transistor and it's characteristic is same as Thyratron Tube.

⇒ In Thyristor family there are more family member like:-

1- SCR (Silicon Control Rectifier)

2- DIAC (Bi-directional Diode Thyristor)

3- TRIAC (Bi-directional Triode Thyristor)

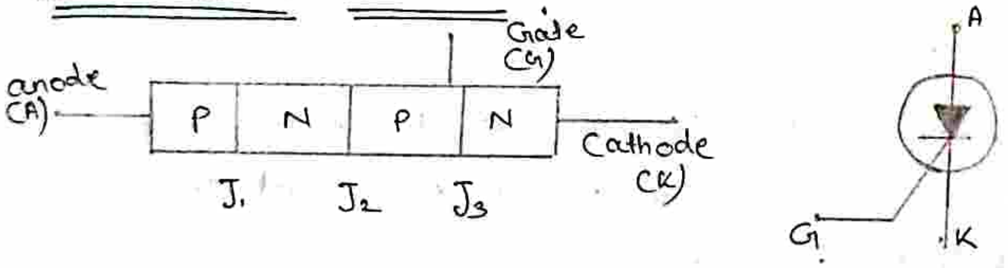
4- GTO (Gate Turn off SCR)

## SCR

⇒ It stands for silicon control Rectifier.

⇒ SCR is most widly used power semiconductor device about 99%.

### Construction of SCR.




⇒ SCR has 4 layer & 3 junction devices.

The material which is used for formation p-type & N-type layer is silicon.

So by alternating combining (cascoding) p-type & N-type material SCR is formed which have 3 terminals i.e Anode (A), cathode (K) & Gate (G)

## Anode

Anode is a out side terminal of p- region.

## Cathode

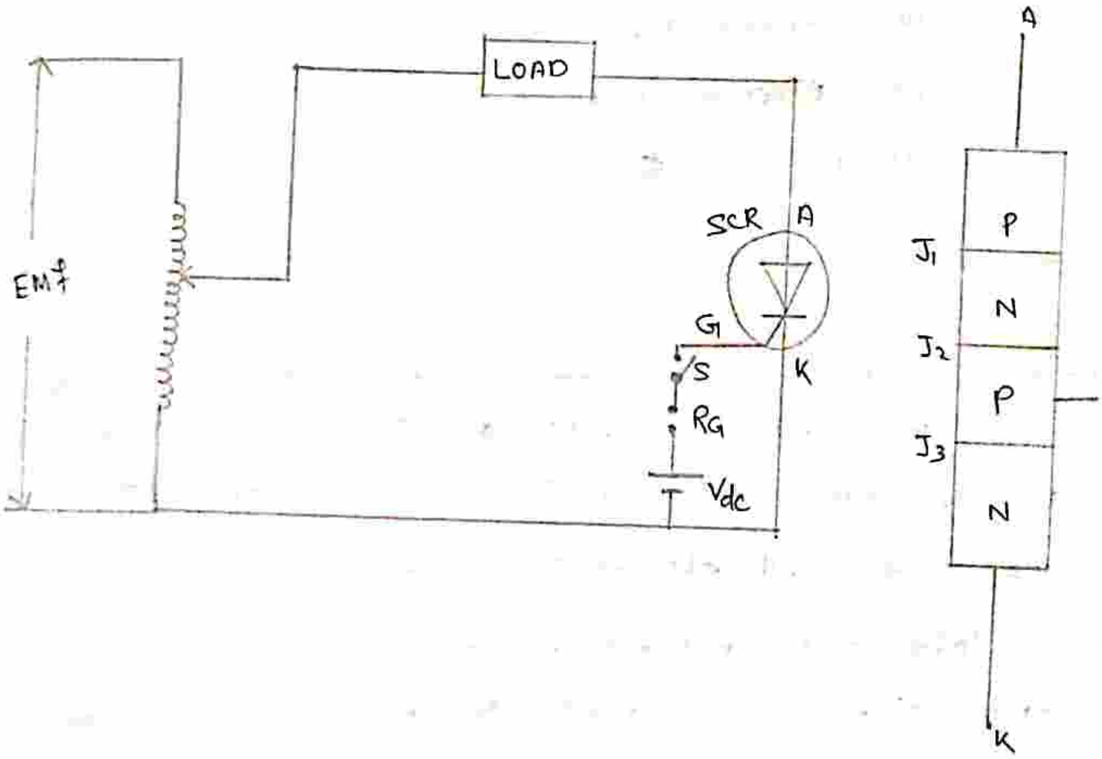
Cathode is a out side terminal of N- region.

## Gate

A terminal welded to p-type layer nearest to cathode (K) is known as Gate terminal.

## V-I CHARACTERISTICS OF SCR :-

### CKT Diagram



⇒ As SCR is a 4 layer 3 junction device and there is 3 terminals i.e. ANODE, CATHODE & GATE.

⇒ Among 3 junction generally $J_1$ & $J_3$ are forward biased where as $J_2$ is reverse biased.

⇒ In the above ckt a SCR is connected to fed power from source to load.

⇒ When SCR conductor (ON state) then power transfer source to load.

⇒ According to the supply feed to load there are 3 mode of operation i.e. (A) Forward Blocking mode
(B) Reverse Blocking mode
(C) Forward Conduction mode

## FORWARD BLOCKING MODE :-

When Anode is +ve w.r.t cathode & Gate ckt is open then the SCR is said to be F/w biased. At that time recombination take place at $J_1$ & $J_3$ layer and F/w biased where as at $J_2$ junction the amount of holes and electrons get reduced. Hence no recombination take place and get reverse biased.
As no current flow from anode to cathode ($J_2$ is reverse b...) so the mode of operation is known as F/w Blocking mode.

If f/w voltage increases (Anode to cathode voltage) then the reverse junction is will have Avalanche break down (force recombination of e.s & holes)

⇒ When the F/W voltage applied a "Avalanche break down take place at $J_2$ junction then the voltage is known as F/W Break over voltage ($V_{BO}$).

⇒ In F/W Blocking mode the SCR is treated as open switch (OFF state).

| |
|---|
| $E > V_{BO}$ (ON) |
| $E < V_{BO}$ (OFF) |

(B) <u>Reverse Blocking Mode</u> :

(i) When cathode is +ve w.r.t Anode and Gate ckt is open the SCR is reverse biased.

(ii) At that time $J_1$ & $J_3$ are reverse biase where as $J_2$ junction is f/w biased.

(iii) So there is no current flow from Anode to cathode.

(iv) The reverse blocking mode is known as off state and the characteristic is same the diode.

(v) If reverse voltage increases (Cathode to Anode) then avalanche break down take place at a critical voltage known as Reverse Breakdown voltage ($V_{BR}$)

## F/W CONDUCTION MODE :-

In the F/W Blocking mode the Anode is +ve where as the Cathode is -ve and as $J_1$ & $J_3$ are F/W biased but $J_2$ is reverse biased so it is in blocking mode.

To bring the SCR from blocking mode to conduction mode by exceeding F/W Anode to cathode voltage (break over voltage) or by applying a gate pulse between gate and cathode.

Now the SCR is ON state and behaives like a switch & the voltage drop having 1-2 volt across to it, which is negligibl

Once SCR conduct by F/W current $J_2$ Junction no longer reversed biased exist.

As no Gate current is required for device to remain in ON st

## LATCHING CURRENT ($I_L$) :-

The minimum value of Anode current required to turn ON the SCR even after the Gate pulse is remove and the SCR is remai in ON state.

## HOLDING CURRENT ($I_H$):-

It is the minimum value of Anode current below which Thyristor is turn off. Generally Latching current is greater than holding current ($I_L > I_H$).
Which is two to three times of $I_H$.

•) Latching current is usefull for keeping the SCR in ON state where as Holding current is use for keeping the SCR.

Difference betn:

DIODE | SCR

(i) Diode is 2 layer one junction device.

(i) SCR is 4 layer 3 junction device.

(ii) It is bring only reverse blocking mode.

(ii) It is bring both F/W & reverse blocking mode.

(iii) It is a Un Control Switch.

(iii) It is a Control Switch.

(iv) Voltage drop across diode is 0.3 - 07 volt.

(iv) Voltage drop across SCR is 1-2 volt.

(v) Fig:

(v) Fig:

Difference betn:

TRANSISTOR | SCR

(i) It has 3 layer 2 junction

(i) It has 4 layer 3 junction.

(ii) In transistor emitter - base is F/W biased and base collector is reversed biased.

(ii) In SCR $J_1$ and $J_3$ are F/W biased and $J_2$ is reverse biased.

(iii) It is not a latching ckt.

(iii) It is a Latching ckt.

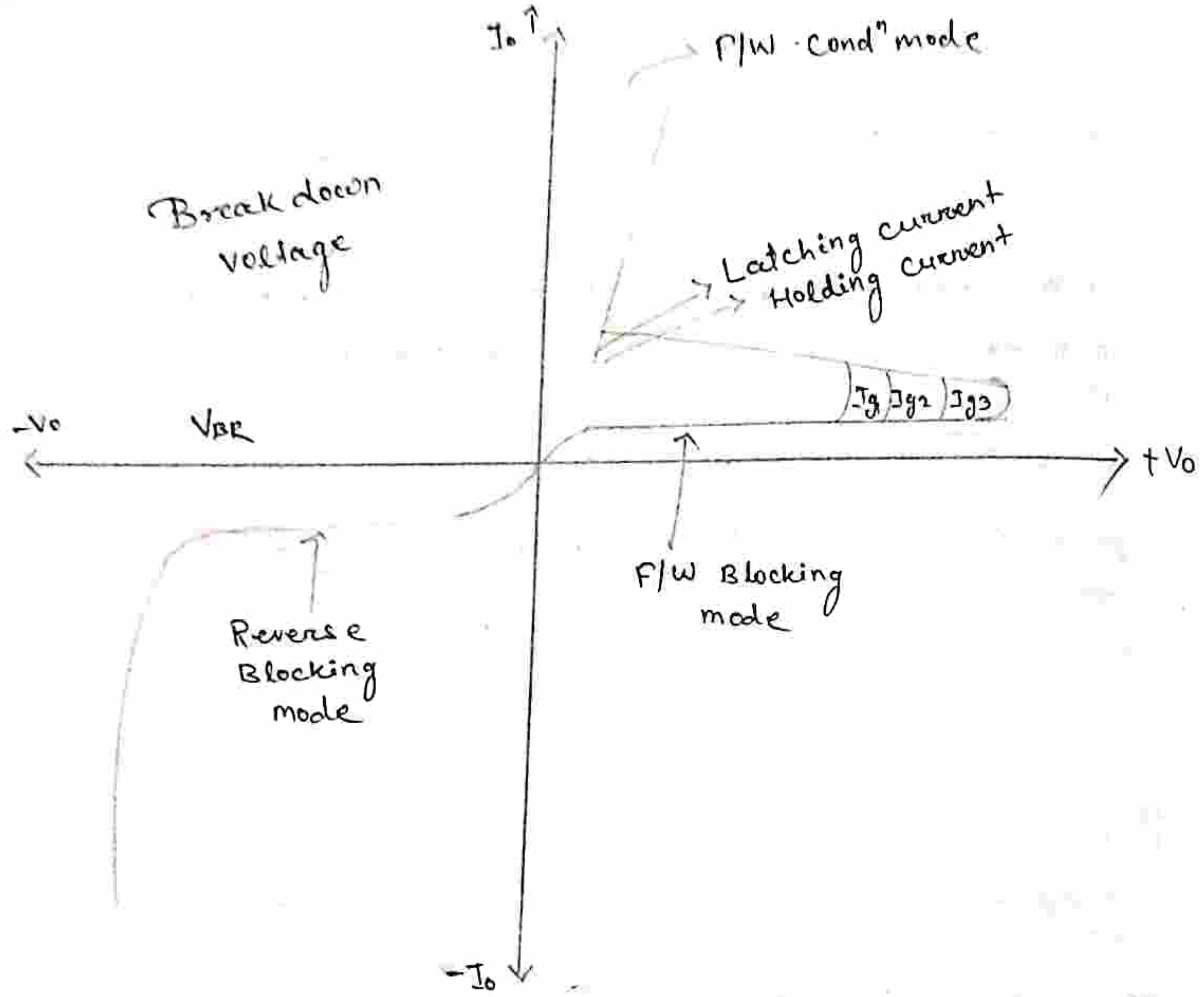
(iv) Switching frequency is high as compair to SCR.

(iv) Switching frequency is low as compair to Transistor.

(v) Fig:-

(v) Fig:

## V-I CHARACTERISTIC OF SCR




⇒ For bringing the SCR from forward blocking mode to conduction mode if greater the F/W voltage (+ve lesser will be required Ga pulse current and vice versa (If lesser the F/W voltage greate gate current required to turn on)

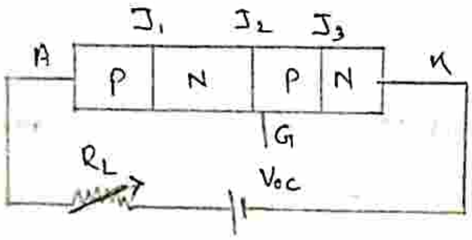
$$I_{g1} < I_{g2} < I_{g3}$$

## Turn - ON method of SCR :

There are five methods for turning ON the SCR :-

(i) Increasing the F/W voltage
(ii) Gate turn ON method
(iii) $\frac{d}{dt}(V)$ turn ON method
(iv) Light turn ON method
(v) Thermal turn ON method

### (i) Increasing the F/W voltage :



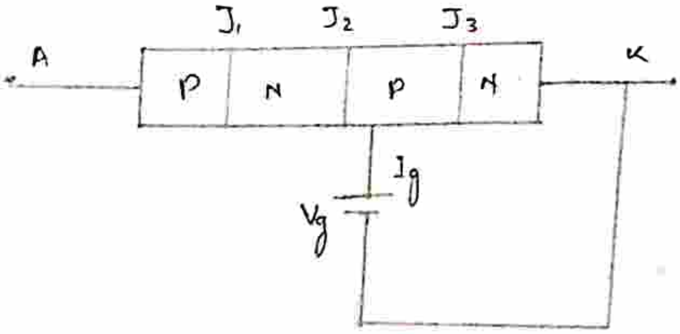

⇒ When SCR is F/W biased $J_1 + J_3$ acts as a close switch where as $J_2$ acts as open switch since it is reverse biased.

⇒ When the Foward Voltage increase beyond the break over voltage.

$V_0 > V_{BO}$, Then $J_2$ breakdown & through current start flowing. between Anode to cathode.

⇒ This method is not generally used because required voltage is large.

## GATE TURN ON METHOD :-



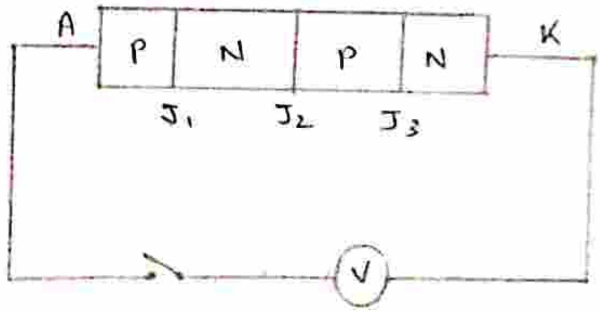

During f/w blocking mode. $J_1$ & $J_3$ are f/w biased and $J_2$ is reverse biased.

To bring the $J_2$ to f/w biased we applied a +ve gate pulse between Gate and cathode.

If Gate current is high then low f/w voltage is required to turn ON the SCR.

When Gate pulse is applied to p-layer it generate large amount of holes which brings the '$J_2$' junction to f/w bias.

⇒ (iii) $\frac{d}{dt}$V TURN ON METHOD :-



(i) When anode is made +ve w.r.t cathode function $J_1$ and $J_3$ are F/W biased and $J_3$ junction is reverse biased.

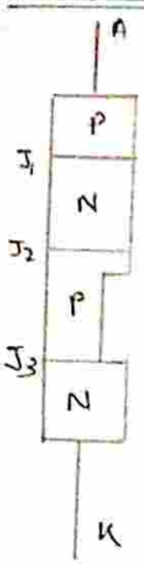
(ii) The depletion layer around the junction $J_2$ acts as di-electric but $J_1$ and $J_3$ are acts as good conductor so SCR entirely acts as a capacitor.

(iii) When switch is suddenly closed the $\frac{dv}{dt}$ is very very high.

(iv) As a result large changing current $(i_c = C_{j_2} \frac{dv}{dt})$ flow through SCR can breaks the $J_2$ junction and SCR conducts from anode to cathode.

(v) This method is not generally used as high changing current may demage the SCR.

(iv) <u>Light Turn ON Method</u> :-



(i) Here the energy required for breaking co-valent bond is given by light Source.

(ii) This can be achived by a special wavelength of light (λ)

(iii) When light falls it breaks co-valent bond & emitt electron which generats electron-holes pair and trigger the SCR by breaking $J_2$ junction.

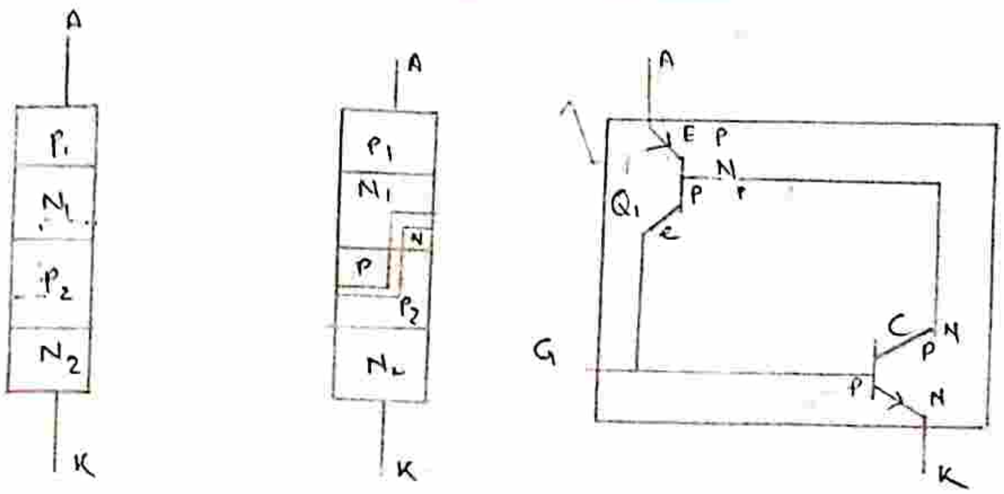
(iv) This type of SCR are known as LA-SCR (light Activated SCR)

(V) **Thermal Turn ON method** :-

(1) In this method the energy required for breaking the co-valent bond is obtained by heat energy.

(ii) The area around $J_2$ is heated by external thermal source and $J_2$ Junction break and current start following from anode to cathode.

# TWO-TRANSISTOR ANALOGY OF SCR :-




(i) The latching ckt of SCR can be understood by 02 transistor analogy of SCR.

(ii) Here the SCR is broken into 02 transistor (PNP+ NPN)

(iii) When gate is +ve w.r.t Cathode the NPN transistor ($Q_2$) Starts conducts.

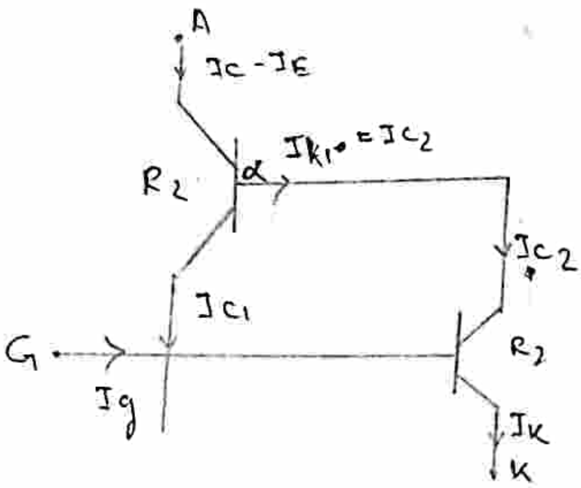
(iv) As a result this provide a base current to PNP transistor and turn ON.

(v) The o/p of PNP is the i/p of NPN since collector of $Q_1$ is connected to base of $Q_2$.

(vi) Even after gate voltage is remove the transistor Continue to conduct Since they are connected back to back.

(vii) Both the transistor able to ~~or~~ Conductor the SCR acts as close switch conduct anode to cathode upto it is not turn off forcefully or naturally.

# Derivation of two transistor Analogy !




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

$I_K = I_a + I_g$

$\alpha$ = Common base current gain

$I_{CBO}$ = Common base leakage current of collector base junction.

**for R1**

$I_{c1} = \alpha_1 I_{E1} + I_{CBO1} = \alpha_1 I_a + I_{CBO}$ . . . . . (1)

**for R2**

$I_{c2} = \alpha_2 I_{E2} + I_{CBO2} = \alpha_2 I_k + I_{CBO2}$ - - - - (2)

Putting $I_K$ value in eq^n (2)

$I_{c2} = \alpha_2 I_K + I_{CBO2}$

$\Rightarrow \alpha_2 (I_a + I_K) + I_{CBO2}$ - - - - (3)

The sum of two collector current given by eqⁿ ① and eqⁿ ③ is equal to external circuit current 'Ia' entering

$$I_a = I_{c1} + I_{c2}$$

$$= \alpha_1 I_a + I_{cBO1} + \alpha_2 (I_a + I_g) + I_{cBO2}$$

$$= \alpha_1 I_a + I_{cBO1} + \alpha_2 I_a + \alpha_2 I_g + I_{cBO2}$$

$$= \alpha_1 I_a + \alpha_2 I_a + I_{cBO1} + \alpha_2 I_g + I_{cBO2}$$

$$= I_a (\alpha_1 + \alpha_2) + \alpha_2 I_g + I_{cBO1} + I_{cBO2}$$

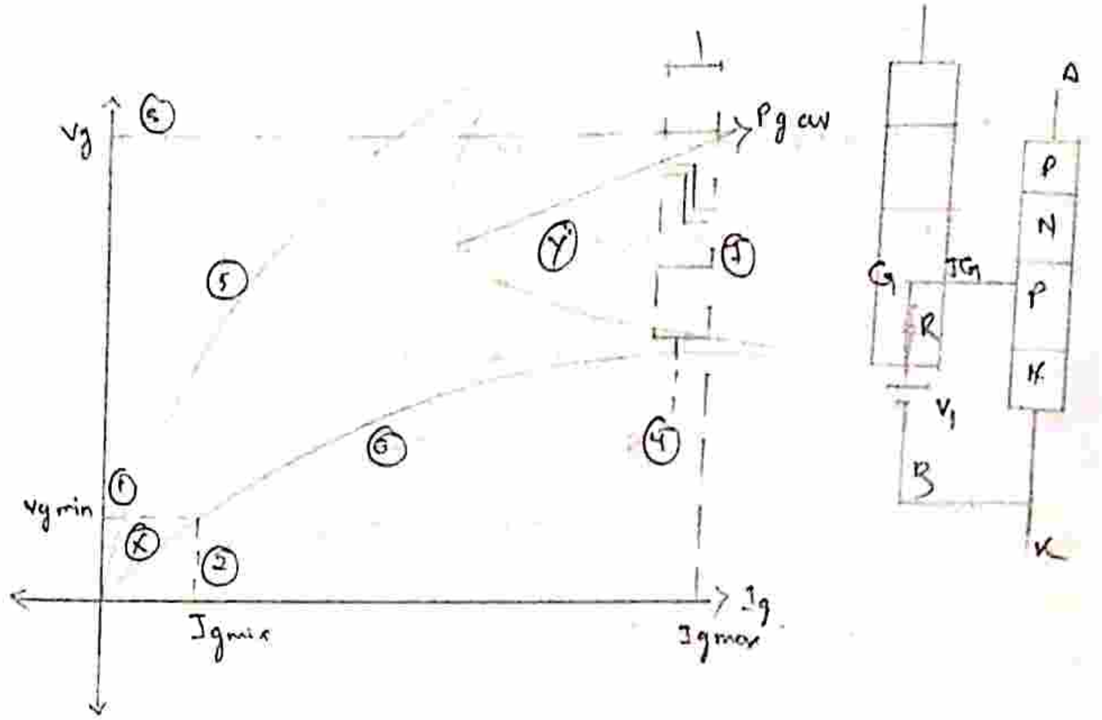
$$= I_a - I_a (\alpha_1 + \alpha_2) = \alpha_1 I_g + I_{cBO1} + I_{cBO2}$$

$$\Rightarrow I_a \{1 - (\alpha_1 + \alpha_2)\}$$

$$= \alpha_2 I_g + I_{cBO1} + I_{cBO2}$$

$$\Rightarrow \boxed{I_a = \frac{\alpha_2 I_g + I_{cBO1} + I_{cBO2}}{1 - (\alpha_1 + \alpha_2)}}$$

# Gate characteristics of SCR :-




Gate is nothing but a PN junction

Here we found the characteristic Gate voltage & Gate current. (Vg ~ Ig) seen across a F/w biased SCR.

According to dropping level there are 02 no. of graph is obtained between Vg ~ Ig

The curve - ⑤ represent Vg ~ Ig graph when dopping level is low curve-⑥ represent that of when dopping level is high.

The ckt for triggering SCR through gate is design according to the dopping level.

(v) Curve -① is represent the low curve voltage value must be applied across gate to turn on the SCR.

(vii) Curve -③ represent highest possible voltage that can be applied to Gate ckt safely.

(viii) Curve -② & curve ④ is represent $min^m$ & $max^m$ value of gate curve required to turn ON the SCR.

(ix) The $max^m$ limit should be not excided in order to avoid Permanent demage of junction.

(x) Curve -⑦ indicates average power that can be discipitade by the devices.

(xi) The area enclosed by curve ⑤.⑥.⑦ represent save operating area (SOA) for the SCR.

(xii) So when we designed gate ckt for triggering SCR, the operating point should be lies is soa.

(xiii) If the operating point lies in the cross ⊗ area then can'nt turn on the SCR.

If operating point lies in the (Y) region it is not safe for device operating.

$P_{g_{av}}$ : Avarage Gate power disscipation

$V_{g_{max}}$ : Max$^m$ permissible Gate voltage

$I_{g_{max}}$ = Max$^m$ permissible Gate current

$V_{g_{min}}$ = Min$^m$ Gate voltage required trigger on SCR.

$I_{g_{min}}$ = Min$^m$ Gate current required trigger ON SCR.

## TURN OFF METHOD OF SCR :-

⇒ To turn off the SCR we brought it from F/W conduction mode to F/W blocking mode or Reverse blocking mode for turn off.

-) It is also known as commutation of SCR.

-) Different types of turn off process :-

Turn off (Commutation)

- Forced turn off
  - Class (A)
  - Class (B)
  - Class (C)
  - Class (D)
- Natural turn off
  - Class (F)

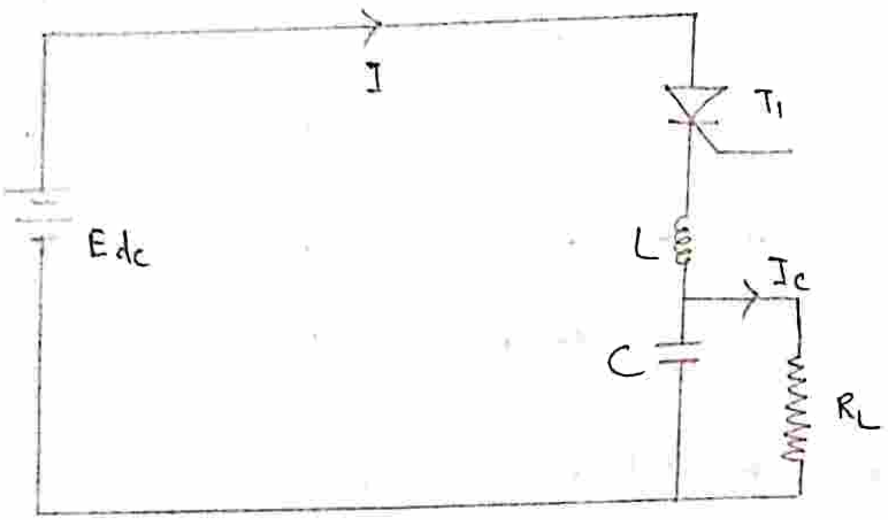
## Natural Turn off.

- When SCR is connected to an AC source, the current goes through it's natural zero at the end of every half cycle & Reverse voltage acts automatically across SCR. Therefore SCR Turn off.
- This is known as Natural turn off
- As no-special ckt is required for turn off the SCR.
- The line commutated rectifier inverter used natural commutation or turn off for turn off the SCR.
- It is also known as class-F type commutation Turn off or line commutation.

## Forced Turn off :

- In case of dc ckt there is no natural current zero & we have to turn off the SCR by designing special commutated ckt.
- In this process forcefully the current has to reduced to zero & the SCR is forcefully commutated.
- The components like Resistance, Inductance & Capacitance are used to achived forced commutation so these are known as commutating components.
- There are five types of forced commutation process.

## Class - A {Resonant commutation / Load Commutation}




### Ckt description :-

=) The ckt diagram for class A type commutation is shown in the fig.

-) In this case thyristor $T_1$ is connected series with L+C and the load resistance $R_L$ connected either series or parallel with capacitor.

-) During initial condⁿ the upper plate is -ve & lower plate is +ve.

-) The SCR is trigger at t = 0 by applying Gate pulse.

-) At initially I = 0 and the capacitor in fully discharge condⁿ.

- After turning ON the SCR, I starts flowing through $T_1 + L_1$ and oscillation with I which help for charging of the capacitor & $I_c$ start flowing -ve to +ve plate & charge of capacitor.

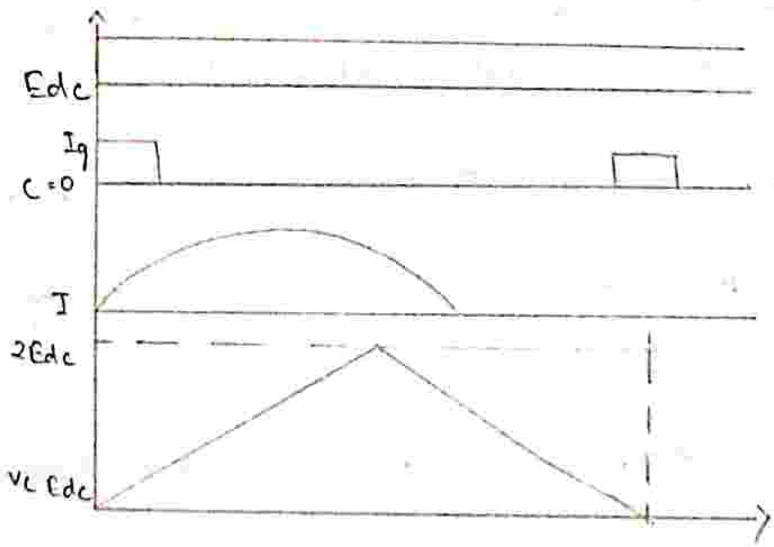
- At that time $I_L$ circulate through $R_L$.

- After charging the capacitor a voltage $2E_{dc}$ build up across it & the upper plate +ve & lower plate -ve.

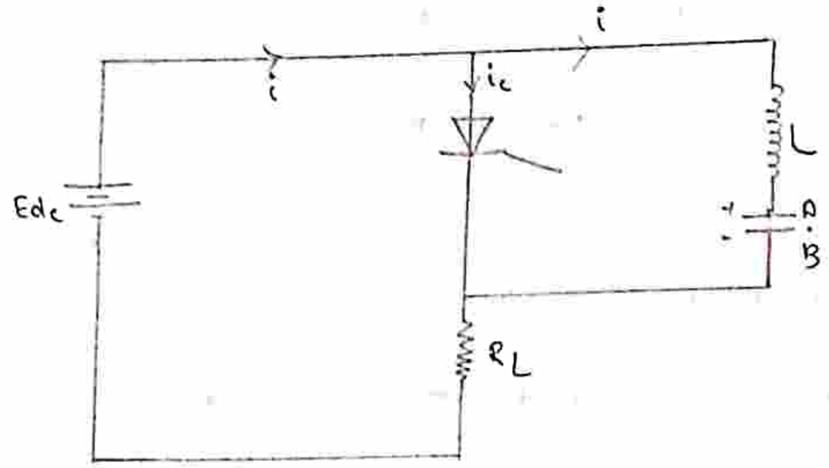
Now the capacitor starts discharging through $R_L$.

When the current I less than $I_c$ then the SCR automatically turn OFF. As $I_c$ forced turn OFF the SCR.

WAVE FORM :~



Class - B (Self Commutation)




CKt description :-

(i) In class - B Commutation L & C are connected parallel with Thyristor & it constitute a R, L, C resonating ckt with load resistance $R_L$.

(ii) The thyristor $T_1$ is series with $R_L$ across switch Edc is applied.

(iii) When d.c supply is given it constitute Q, R, L, C ckt as Y is in OFF condn.

(iv) The capacitor get fully charged with plated +ve & plate-B-ve

(v) SCR is trigger by given Gate pulse.

(vi) There are 02 current passes i.e the load current 'i' flow through + Edc → $T_1$ → $R_1$ → - Edc and another is i.e. resonating current (discharging current) flow through

A → C → $T_1$ → B

(vii) After discharging the voltage across capacitor gets reversed (A -> -ve & B -> +ve) as a result the load current comes towards capacitor as a reverse voltage acts across capacitor.

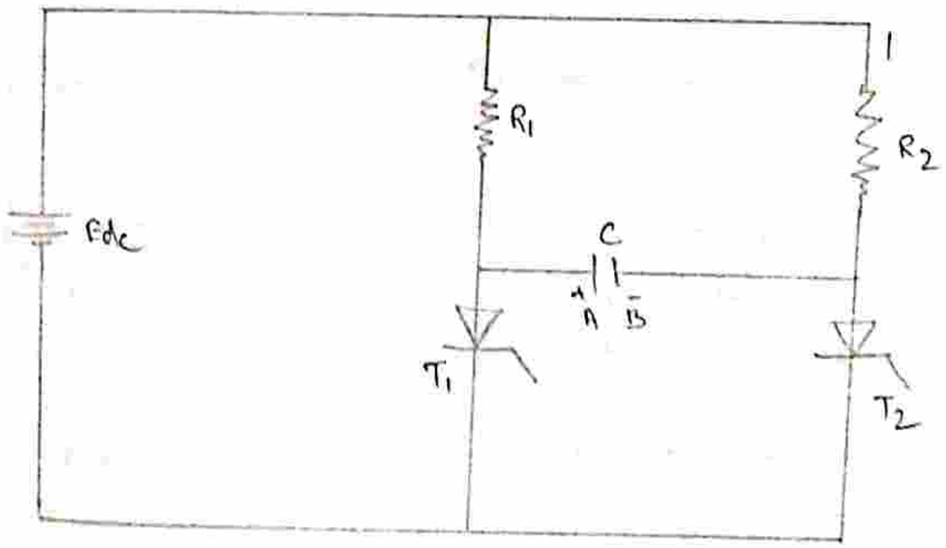
(viii) Now current through $T_1$ i.e

$i_L = I - I_c$

(ix) when difference is reduces is zero the SCR is turn off.

(x) There is some extend the operation of class-A & class-B are same but the only difference is the load current carry by commutating component where as in class-B i.e not show.

## Class - C (Complementary Commutator)



## Ckt description

(i) This is also known as complementary commutation.

(ii) Here 02 thyristor $T_1$ & $T_2$ are connected series with $R_1$ & $R_2$ & a capacitor is connected in between the 02 branches.

(iii) ~~Now~~ Initial capacitor point A is +ve & point B is -ve

(iv) Now $T_1$ will turn on by giving Gate pulse.

(v) So there are 02 current starts flowing from. Source i.e load current & charging current.

(vi) Load current flow $+E_{dc} \to R_1 \to T_1 \to E_{dc}$ & Charging current flow $+E_{dc} \to R_2 \to B \to A \to T_1 \to -E_{dc}$

(vii) After charging the capacitor plate B +ve & plate -A -ve which reduces the charging current to zero & load current allow flow through the ckt.

(viii) At that time it is time to turn off the SCR $T_1$ by turning on the $T_2$

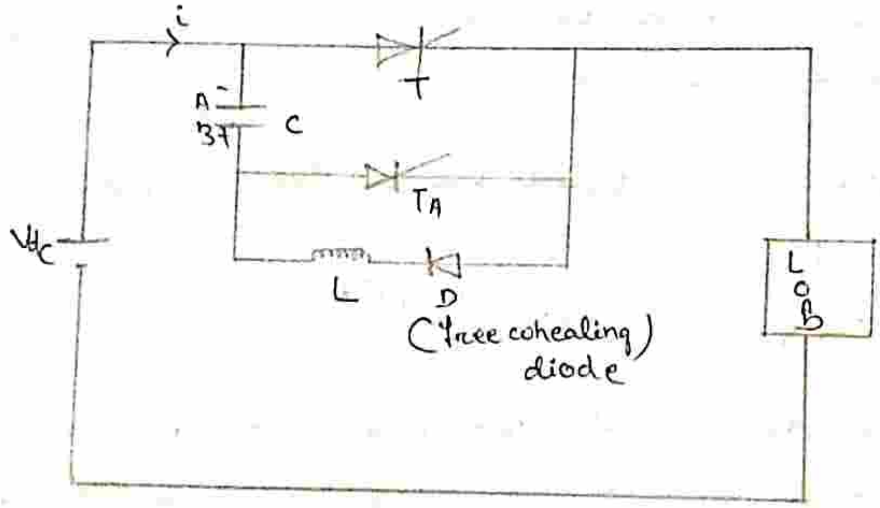
(ix) As capacitor polarity is reversed (A→-ve, B→+ve) So it forms large current towards $T_2$ & current across $T_1$ is reducess to zero and it is turn off.

(x) Now the current direction also reverse i.e the charging current flows through the $R_1$ and change the capacitor and the load current flow $+E_{dc} \to R_2 \to T_2 \to -E_{dc}$

Charging current flow $+E_{dc} \to R_1 \to A \to B \to T_2 \to -E_{dc}$

(v) The $T_2$ will be turn off when is will be reducess to zero by turning on the $T_1$ & above cycle repeated.

Class - D (Auxiliary commutation)




CKt description

(i) The basic CKt shows an auxillary thyristor & a main thyristor for CKt operation.

(ii) The auxilary thyristor ($T_A$) is use forcefully commutation of main thyristor (T). So it is known as Auxilary turn off / Auxilary commutation.

(iii) The SCR $T_A$ turn on initially to free charge the capacitor plate A (+ve) & plate B (-ve).

) At t=0 thyristor 'T' turn on by giving gate pulse & the 'i' flowing

$V_{dc}^{+} \rightarrow T \rightarrow load \rightarrow V_{dc}^{-}$

At the mean time the capacitor start discharging through SCR (T). by circulating $I_c$ current which is flow through i.e $I_c$ flow

$A^{+} \rightarrow T \rightarrow D \rightarrow L \rightarrow B^{-}$

(vi) After free wheeling Ic current flow from capacitor 'c' the polarity get reverse i.e A(-ve) + B(+ve)

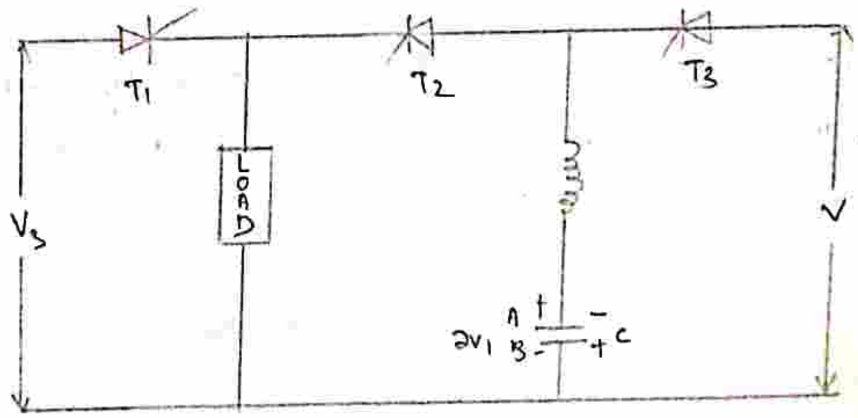
(vii) At the mean time $(t+t_1)$ $T_A$ turn on by giving gate pulse so no. current available at SCR 'T' & it turn off forcefully known as voltage commutation.

(viii) So both charging current & load current flow through $T_A$ the current flow path.

$$V_{dc}^{+} \rightarrow A^{-} \rightarrow B^{+} \rightarrow T_A \rightarrow Load \rightarrow V_{dc}^{-}$$

(ix) After charging the capacitor the polarity get reverse A(+ve) & B(-ve) and 'T' is turn on by giving Gate pulse and above cycle repeated.

**CLass - E** (External pulse commutation Resonant pulse commutation)



## Ckt description

(i) Here 2 no of thyristor $T_2$ + $T_3$ are used for the turn off SCR '$T_1$' external voltage '$V_1$' also used for turn off the thyristor T so it is known as external pulse Commutator.

(ii) At time t=0 SCR $T_1$ + $T_3$ simaultanious on by giving gate pulse so a load current starts flowing through $T_1$ to load.

(iii) Similarly in the mean time current $I_c$ start flowing from $V_1$ to through $T_3$ & charge up the capacitor.

(iv) After charging the capacitor A-plate +ve & B plate -ve & a voltage 2v develop across it.

(v) At the is ntype time $T_A$ turn on by giving gate pulse in $T_3$ automatically turn off due to voltage commutation.

(vi) As $V_3$ < $2V_1$ a large starts flowing through $T_2$ towards load.

(vii) Due to this a reverse voltage acts across $T_1$ + it automatically turn off.

# THYRISTOR PROTECTION :

-) As thyristor is 1st acting switching device which is used for converting controling & switching purpose. Subjected to protect in different pe fault condⁿ.

-) There are mainly 02 fault occurs in the power system i.e

(i) over voltage

(ii) over current

-) So thyristor has to protected from thus 02 fault.

## Over voltage Protection :

=) The thyristor subjected to over voltage :-

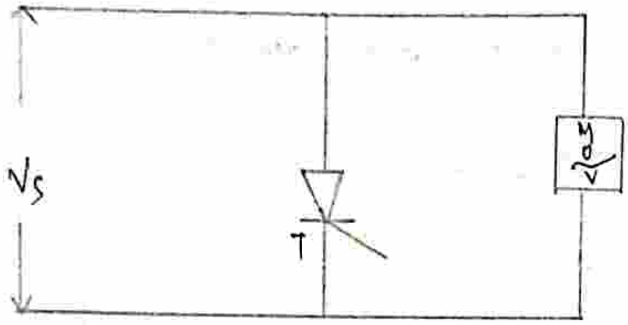
(1) Bad commutation (Turn off)

(2) Short ckt condition cleaning by ckt breaker

(3) Transient due to switching operation

(4) Leghting stroke.

Clearing of over voltage fault




NONLINEAR : High resistance at low voltage & low resistance at high voltage.

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

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

* Varistor - Working [ High voltage - less resistance
-> Low voltage - High resistance

(iii) At normal operating condn mov show high resistance, so load current flow through thyristor when over voltage condn. occurs at that time mov. offer low resistance which produced a short cut across thyristor & high voltage source discharge through the mov & protect the SCR from over voltage.

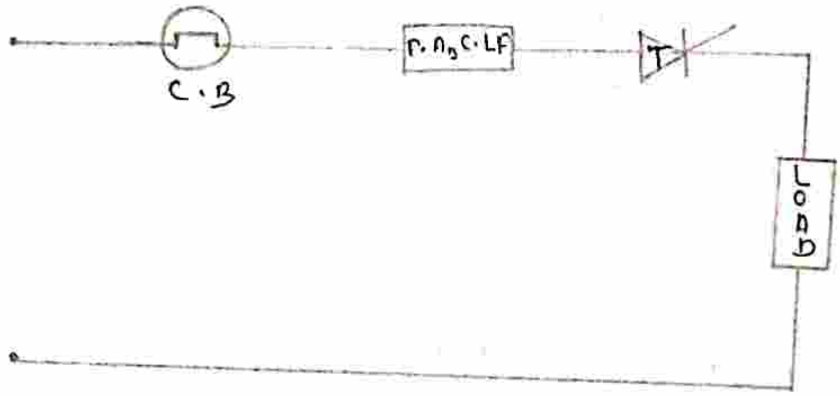
(iv) Generally mov ~~silicon~~ selenium thyristor diodes are used for over voltage protection.

# Over Current protection :-

① The thyristor subjected to over current due to short ckt cond^n of any of lines, lightining stroke.

② Sudden increasing of loads.

③ Line to ground faults.




F.A.C.L.F - First Acting current limiting fuse.

(i) During over current a heavy current pass through thyristor

(ii) As the junction have some resistance (J1, J2, + J3) it produced heat across the device due to $I^2Rt$ if it circulate for more time.

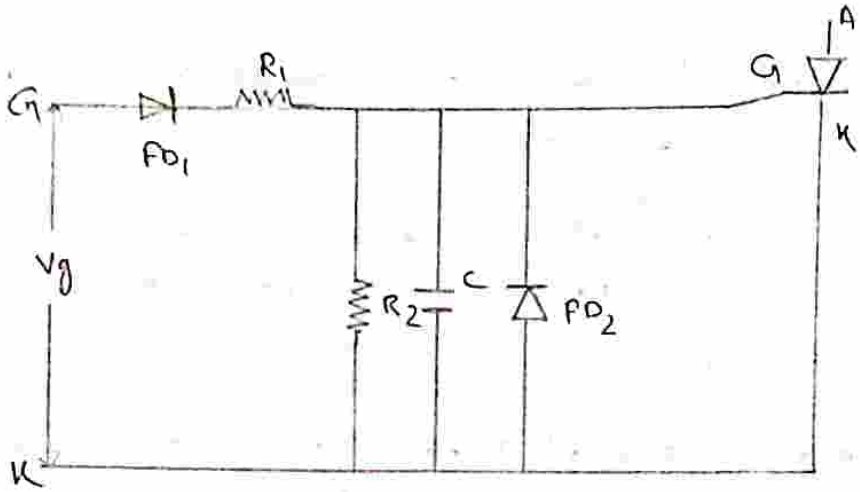
(iii) The temperature with standing capacity of SCR is very small if high temp develop due to over current may damage device.

(iv) So to protect the SCR from over current a ckt breaker + FACLF are connection in series with thyristor.

(v) The CB is used to protect the thyristor agains continuous over lo for a long direction

(vi) The FACLF is used to protect the thyristor from over current for short direction.

## Gate protection




(i) For turn on the SCR by Gate ckt method we applied Gate pulse betn Gate & cathode so the necessity Gate pulse is given to Gate terminal in a control method.

(ii) For giving Gate pulse in control manner we used different ckt elements which are connected in the above diagram.

(iii) On the starting of the ckt a free wheeling diode is connected in series with the supply for allow only +ve pulse.

(iv) The $R_1$ connected series the diode which will limiting the current in safe value.

(v) Another resistance $R_2$ connected parallel with Gate & cathode.

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

(vii) Capacitor 'C' removes high frequency component by connecting parallel which acts as filter ckt.

(viii) The diode $FD_2$ avoids the flow of the -ve pulse from cathode to Gate.

## $\frac{di}{dt}$ protection :

(i) A Thyristor require min^m time to spread current conduction uniformly through out the junction.

(ii) If the rate of rise of anode current is very first of the turn ON process a hotsport is created in the $J_2$ junction due to high temp.

(iii) To avoid this creation of hotsports in the $J_2$ junction an inductor $L_S$ is connected in series with SCR.

## $\frac{dv}{dt}$ protection :

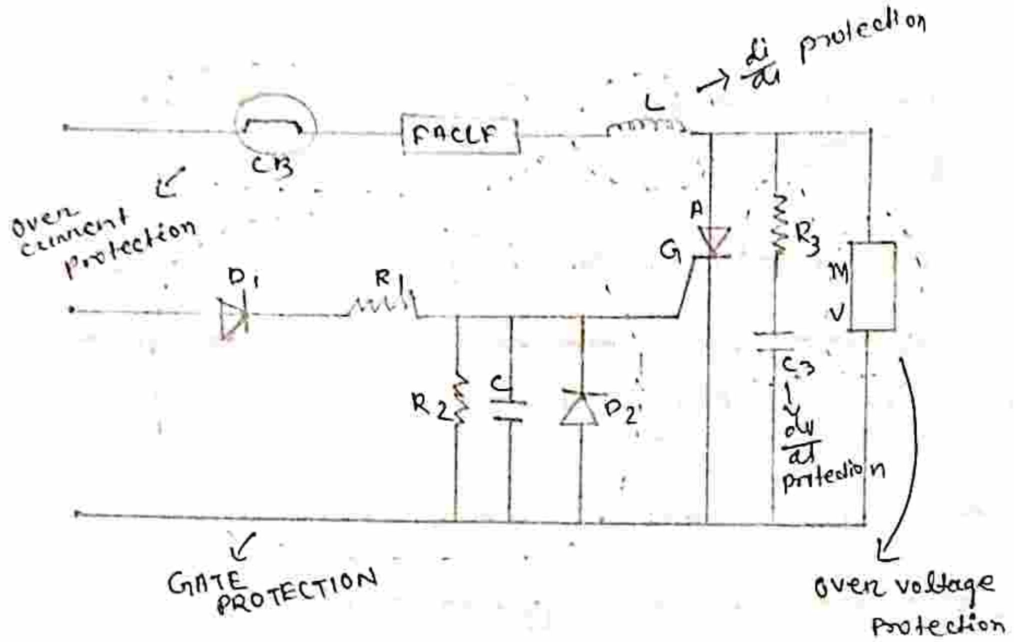
(i) When anode is +ve w.r.t cathode & no Gate pulse is applied $J_2$ behaives like a capacitor & the total source voltage $V_s$ appiers across '$J_2$' junction.

(ii) Result a changing current start flowing if $\frac{dv}{dt}$ value is high the $I_c$ value also high which is able to turn ON the SCR without giving any Gate pulse.

(iii) This is known as mall operation of SCR which is called $\frac{dv}{dt}$ turn

(iv) The $C_s$ is parallel with device to prevent unwanted $\frac{dv}{dt}$ triggering & $R_s$ also connected in series with $C_s$ to limit the changing current.

TOTAL PROTECTION CKT OF SCR :-



# CHAPTER - 2

## TRIGGERING CKT / FIRING CKT

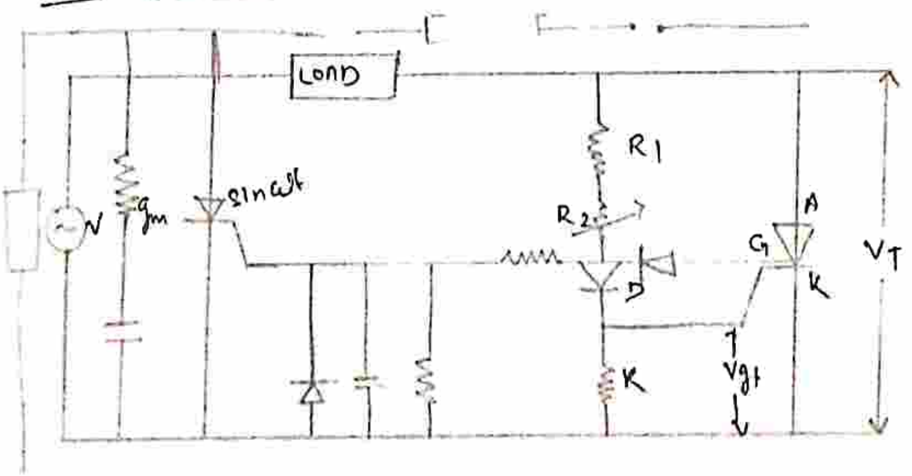
-) To turn on the SCR by Gate triggering method we design triggering ckt.

-) During f/w blocking mode as $J_2$ junction is reverse biased +ve Gate pulse required to turn on the SCR by brigging it to f/w conduction mode.

-) So there are 4 types of firing ckt :-

1. Resistance or R- Triggering ckt
2. R-C triggering ckt
3. UJT triggering ckt
4. Cosine low of triggering ckt

### R- Triggering CKT :



(i) The CKT shows a half control rectifier with R- triggering.

(ii) The SCR conducts during only +ve half cycle.

(iii) Hence the conduction from $0-\pi$ + $2\pi - 3\pi$ and show on.

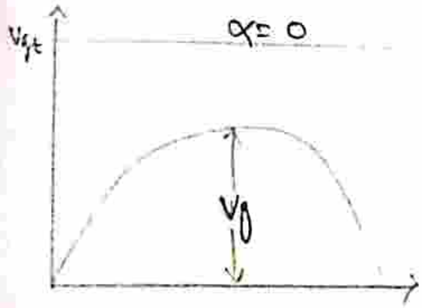
(iv) Let $V_{gt}$ is the minimum voltage required at the gate to cathode to turn on the SCR.

(v) The Current through R can be varried by varing the resistance $R_2$

(vi) If $R_2$ is large than the current value is small due to increase.

(vii) So the $V_g$ amount is small as $V_{gt}$ is greater than $V_g$ ($V_{gt} > V_g$) when $\alpha = 0$.

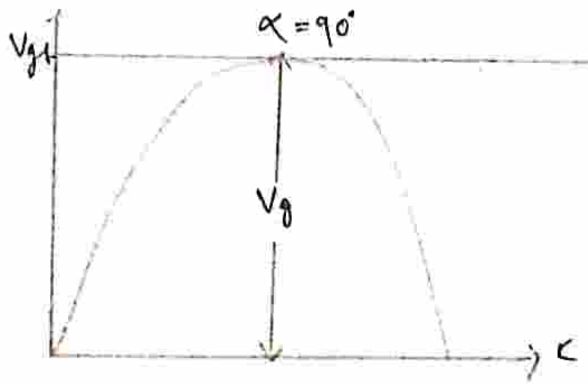
($\alpha$ = fringl (triggering angle)





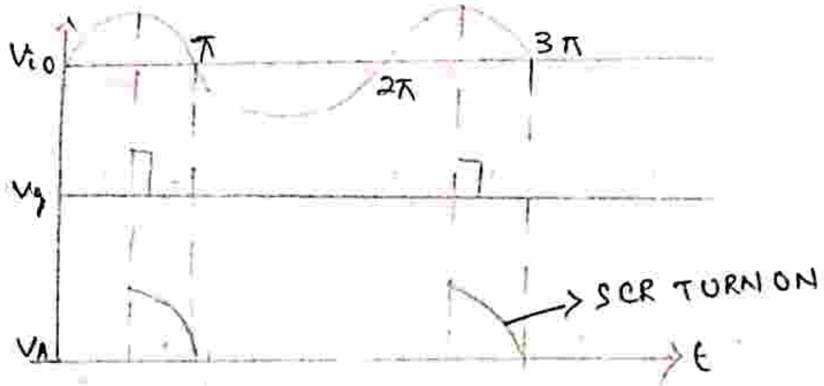
(viii) If $R_2$ is moderate i.t developmoderate amount of current flow through R and drop $V_g$ in accuring.

(ix) And the Cond$^n$ arries that $V_g = V_{gt}$ + $\alpha = 90°$

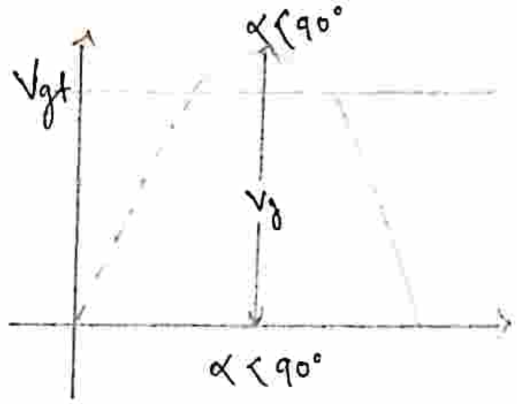



(when $R_2$ is moderate)

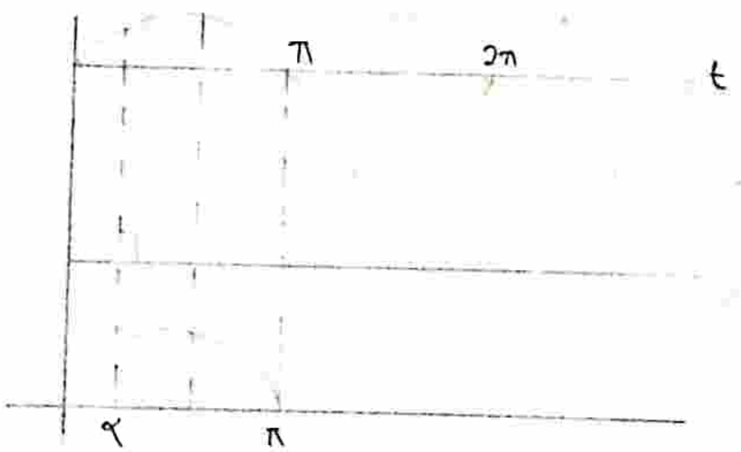
(x) The voltage $V_g$ attend the value $V_{gt}$ at $\alpha = 90^\circ \alpha$ turn ON the SCR for a quater cycle




(xi) When $R_2$ is low a heavy current starts flowing & $V_g$ occuring at which is applied across Gate and $V_g > V_{gt}$ So SCR turn on at



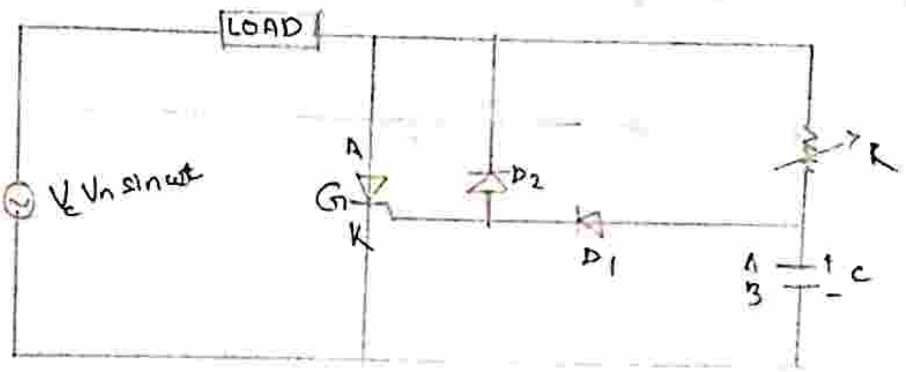

(when $R_2$ is low)



(xi) In this triggering or firing ckt the $\alpha$ value lies betn 0 to 90°

$$0 < \alpha \leq 90^\circ$$

## R-C Triggering Ckt :-




(i) In this firing method the $\alpha$ can vary from 0 - 180°.

(ii) The above ckt consisting a series combination of a variable resistance 'R' & capacitor 'C'.

(iii) The capacitor 'C' connected across cathode & Gate through diode $D_1$ another diode $D_2$ used for charging of capacitor connected betn $D_1$ & anode.

(iv) In the -ve half cycle of source capacitor charge up through $D_1$ & $D_2$.

(v) With low plate +ve & upper plate -ve.

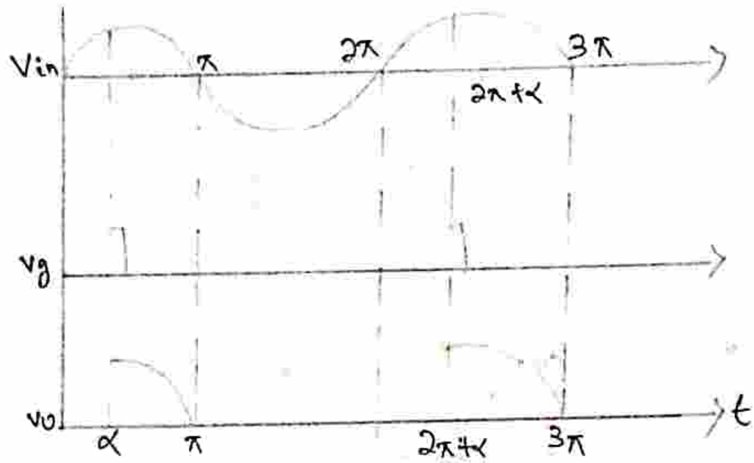
(vi) At that time capacitor takes current through V resistance 'R' to rase up the voltage to $V_{gt}$ & then $V_m$.

(vii) When capacitor attened the voltage $+V_{gt}$ then gate pulse moves through $D_1$ to Gate & turn ON the SCR.

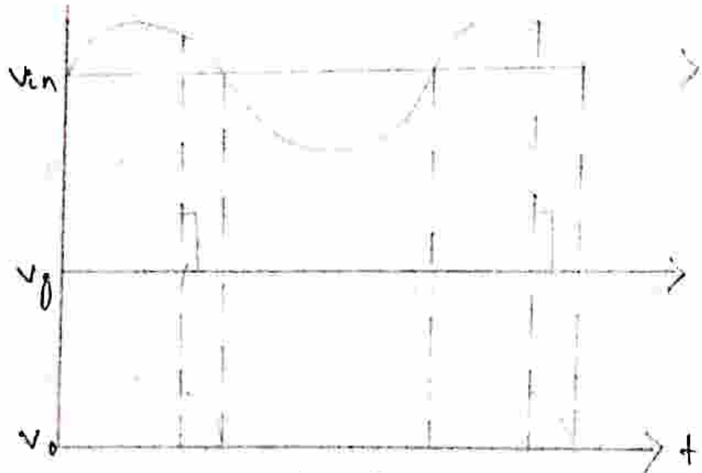
(viii) This firing angle (attending the value of $V_{gt}$) is depend upon the value of R.

(ix) If R is high then less amount of current is flow to charge up the capacitor and α values increases.

(x) Where as if R is low then heavy current flow through capacitor & in less time it attend the value of $V_{gt}$ and turn on the SCR.

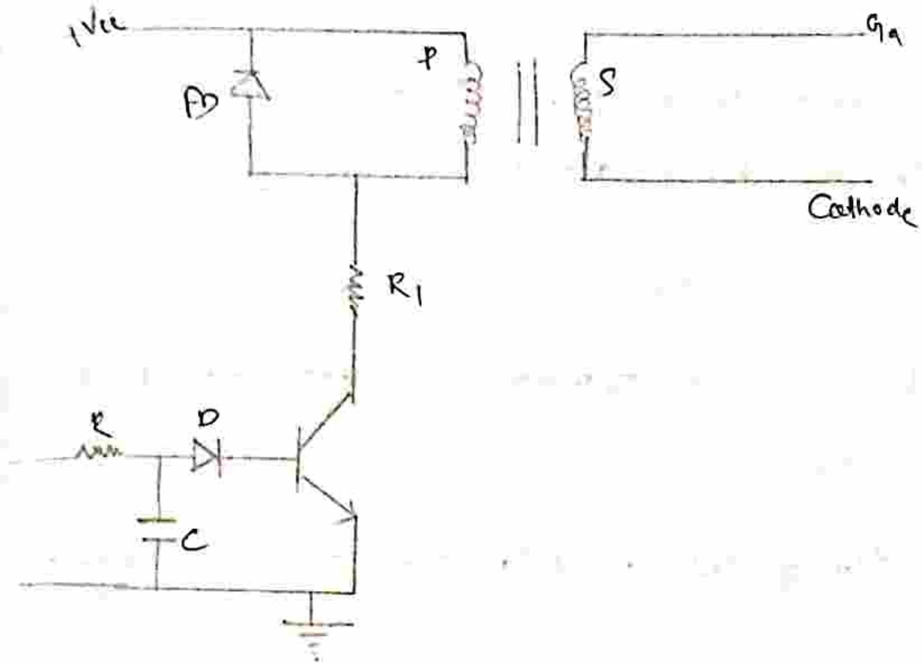



α<90°
(R value low)




α<180°

PULSE TRANSFORMER TRIGGERIN




Pulse T/F :-

It is a small size T/F commo used in thyristor triggering

CKt description

=) In this CKt diagram R, C + diode connected to base of transistor which is used to control the pulse o/p of pulse T/F.

=) When square wave i/p to the RC CKt it converts it into pulse.

=) Diode (D) elements the -Ve part of the pulse.

=) When this +ve pulse applied to the base of transistor 'T' the transistor turn on + the voltage Vcc applied to the primary wdg.

-) There is a voltage induced across the secondary wdg.

-) And this secondary voltage used as triggon voltage of thyristor

-) when pulse is remove transistor is off. So a voltage of opposite polarity is induced across primary wdg.

## Advantages

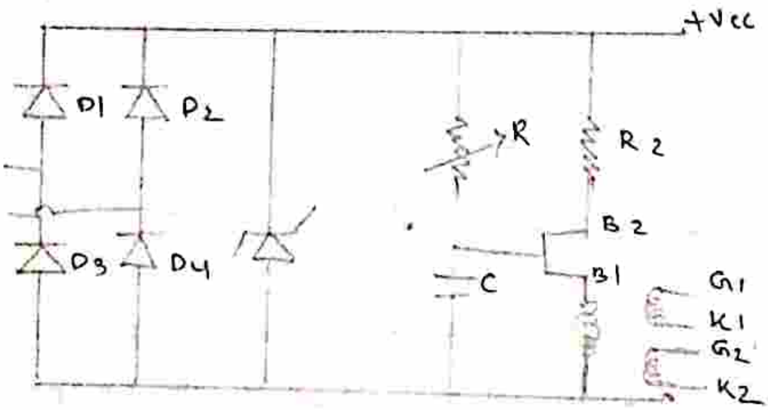
(i) By this method a isolation between low voltage gate ckt + high voltage power ckt.

(ii) By using one firing ckt used to turn on more than one thyristor.

(iii) Here power drop decreases as compair to R + R-C triggering ckt.

(iv) The layer is get reduced.

## UJT Triggering ckt :




$EB_2$ + F/w Biased.

$EB_1$ → R/V Biased

(i) The unijunction Transistor (UJT) have 3terminal device i.e. emitter, Base1 & Base 2.

(ii) It consist of lightly dopped N-layer as base & 02 heavily dopped p-type base & injected inside it.

(iii) The 3 Leads are welded to the 3-layer so there are 02 junction form i.e $EB_1$ & $EB_2$ junction.

(iv) This 02 junction are acts 02 resistance i.e $RB_1$ & $RB_2$

(v) The emitter leads is placed nearer to the $B_2$ Leads so $EB_2$ junction is F/w biased as the $B_1$ leads is away from 'E' so $EB_1$ junction is reverse biase.

(vi) If $EB_1$ junction is break the conduction start through UJT.

(vii) The above CKt shows 4 diode ($D_1$, $D_2$, $D_3$ & $D_4$) acts as rectifier which convert A.C to D.C & $V_{dc}$ applied across the UJT.

(viii) A zener diode connected across the CKt to maintain the constant voltage.

(ix) A variable resistance 'R' & a capacitor 'c' acts as R-C charging CKt used for charged the capacitor 'c'.

(x) By the variable resistance 'R' we control the firing angle 'α' i.e it R value is high then capacitor hence α increases and if 'R' is low & viceversa.

(xi) when the capacitor charge reaches to Vc which is acts bet^n E & $B_1$ result the break down of junction.

(xii) As a result current '$I_2$' flowing through $R_1 \to B_2 \to E \to B_1$ and the pulse T/P.
T/P

(xiii) The pulse T/P shows transformation in the secondary and voltage applied to the thyristor Ckt.

## Phase Controlled Rectifier Converter

=) The conversion of A.C to D.C is known as Rectification.

=) For power conversion or power ckt is form A.C to D.C we used thyristor in place of diode.

=) There are 02 types of rectifier.

(1) uncontrol Rectifier

(2) Control Rectifier.

## Uncontrol Rectifier

(i) In case of uncontrol rectifier for rectification we used power diodes because the fixed value of A.C voltage converted into fixed value of D.C voltage.

(ii) It is used incase of some low power device where control of o/p voltage is not required.

(iii) It is low cost & simple Ckt.

## Control Rectifier

(i) Rectifier CKt using thyristor known as control rectifier because thyristor is a control device.

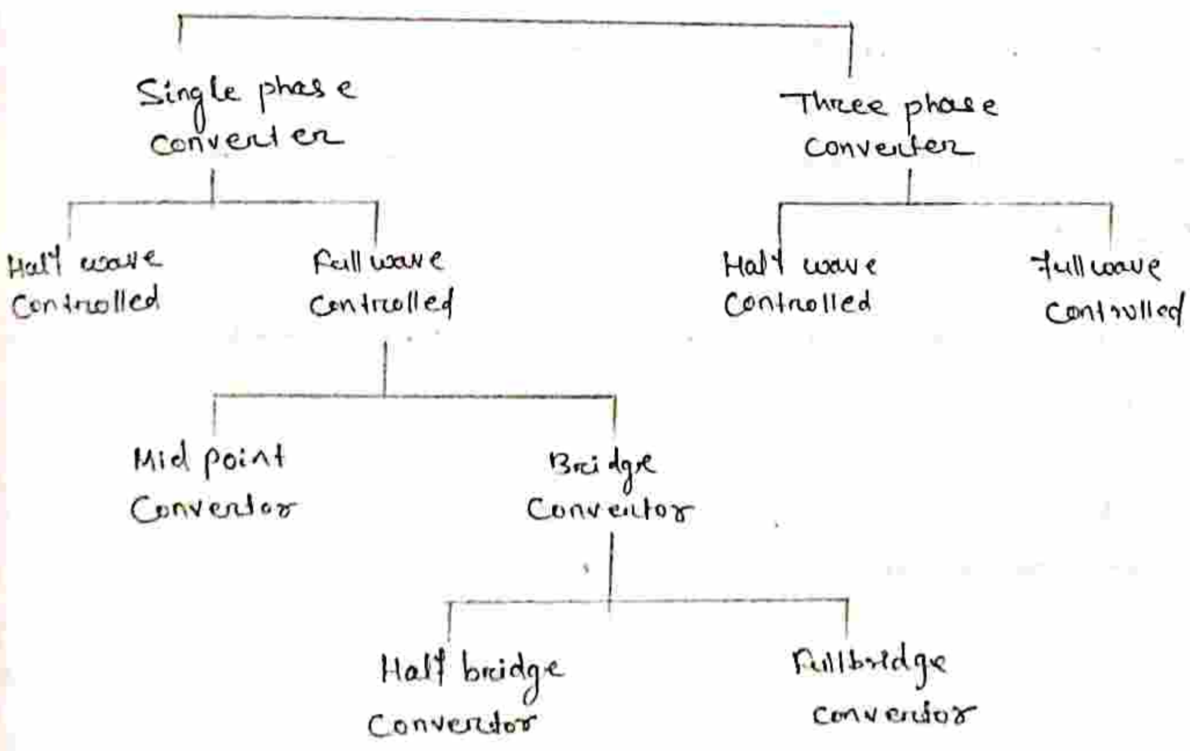
(ii) The thyristor o/p can be vary by varying the firing angle & hence o/p value of dc also vary.

(iii) Since thyristor is a control device it is available in high current, high voltage, high power rating.

(iv) It may be either 1 ϕ or 3 ϕ as i/p

(v) It may be either semi convertor or fully convertor having different quadrant operation.

### Classification of Convertor :



## Application of Converter :

(i) For high voltage D.C Transmission.

(ii) Speed control of D.C motor.

(iii) It also used for battery charging.

(iv) Magnetic power supply

(v) Excitation control of alternator

## Principle of operation of Convertor

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

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

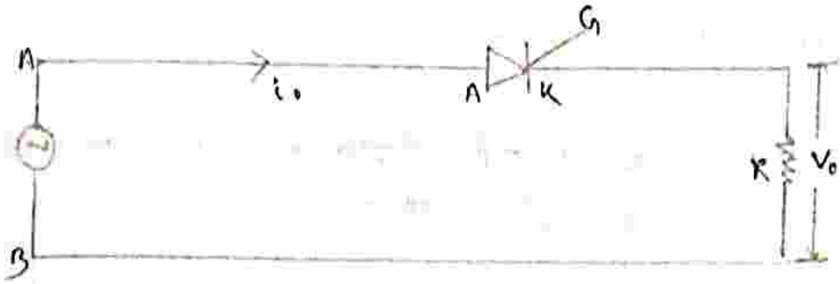
(iii) When we applied gate pulse with some delay angle / firing angle (α) it would start conducting.

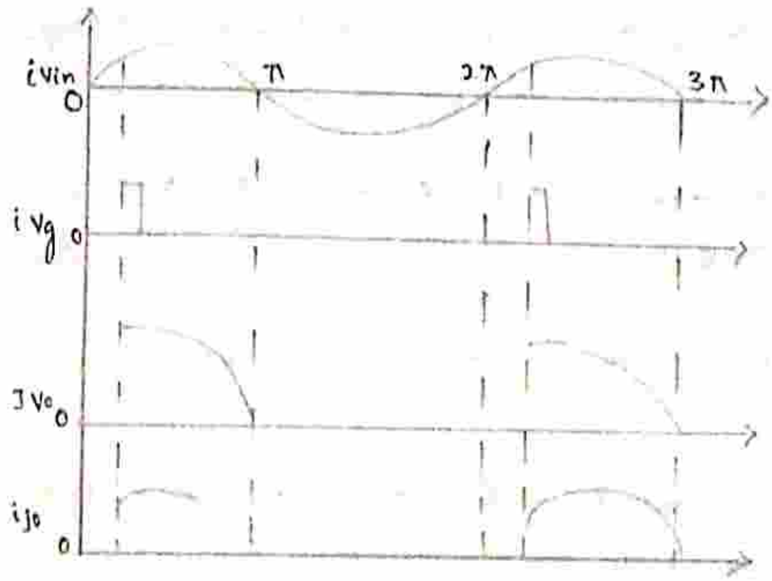
(iv) So a thyristor may conduct during +ve half cycle i.e α-π, 2π+α - 3π and so in.

(v) If thyristor is replaced by a diode then it conduct 0-π, 2π-3 and soon as it is a Un-Control device.

(vi) So by varing the firing angle α of thyristor which a vary rough o/p voltage as per requirment.

## 2ϕ half wave Control rectifier or convertor with R-Load




(i) The above ckt shows 2ϕ half wave Convertor with R-Load.

(ii) The SCR is connected to a load Resistance (R) which is feed by a.c supply $V_s = V_m \sin\omega t$.

(iii) So the SCR is F/w biased when the +ve half cycle appear across it i.e 0-π and 2π-3π and s on.

(iv) During the half cycle A-point +ve, B point is -ve & the thyristor is subjected to F/w biased.

(v) So as soon as gate pulse is given with firing angle (α) it Start conducting and o/p voltage appear across the load.

(vi) So it is conduct upto α-π & 2π+α -3π

(vii) When -ve cycle appears at π R of SCR subjected to reverse biase Condn and hence it is off.

(viii) And again able to triggen with +ve cycle seen across it so by the conduction of SCR we element -ve half cycle and o/p seen is pulsating dc or unidirectional a.c

(ix) The o/p voltage seen across load is given by the

$$V_0 = I_0 R$$

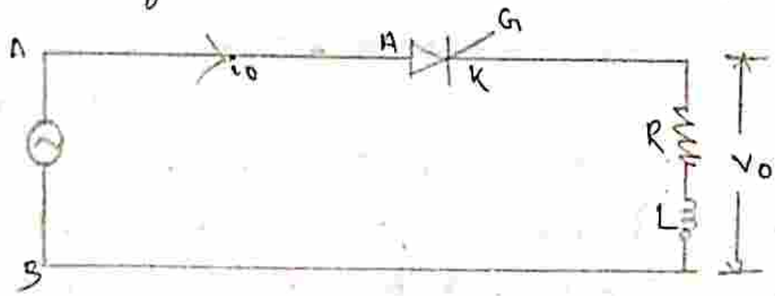
(x) The different current & voltage curve are shown in the above fig.

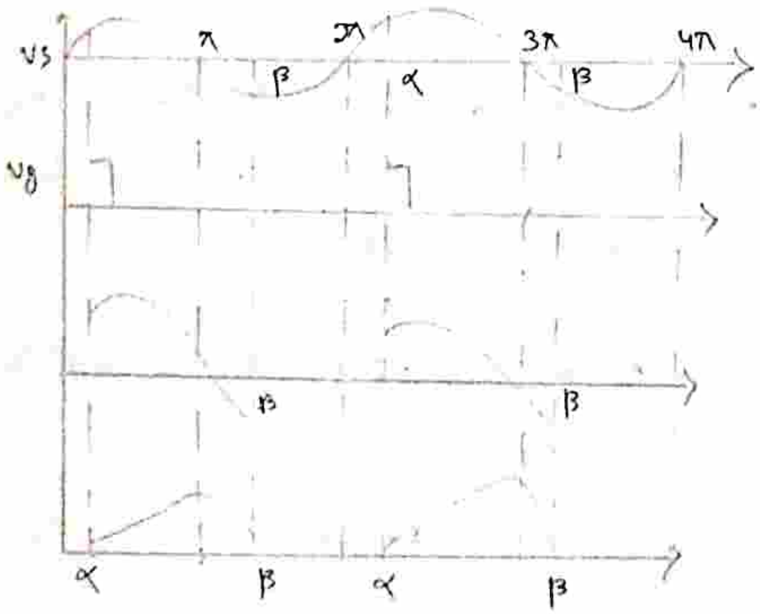
(xi) ~~Since thyristor is a control device it is available in high current, high voltage, high power rating~~.

(xii) ~~It m~~

## 1ϕ half wave converter with R-L Load :

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



Operation

-) The above ckt diagram show semi converter or 1ϕ half wave converter with R-L load so it is conduct only during +ve half cycle.

-) At angle α when gate pulse is given to SCR it start conducting & voltage across the load is same as the source voltage with R-L load.

-) The SCR conduct upto π and π-β Sence the load inductance L forcess the load current to in gradually reaches maxm and then beings to decreases (Inductor dose not allow the sudden change of current), so even through of the source voltage comes to zero and the current reducess slowly to zero.

-) From α-π Vo & Io which as appearing & flowing through load from source it R +ve hence power is +ve hence power flow from source to load.

-) From π-β Io is +ve but Vo is -ve the power is hence -ve.

-) Hence the power is feed back to load to source. This is called recycling.

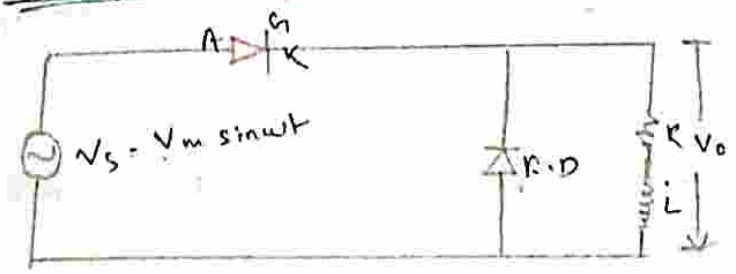
-) The recycling is continues the energy in the Inductor given back to the source. The avarage o/p voltage get reducess due to -ve segment.

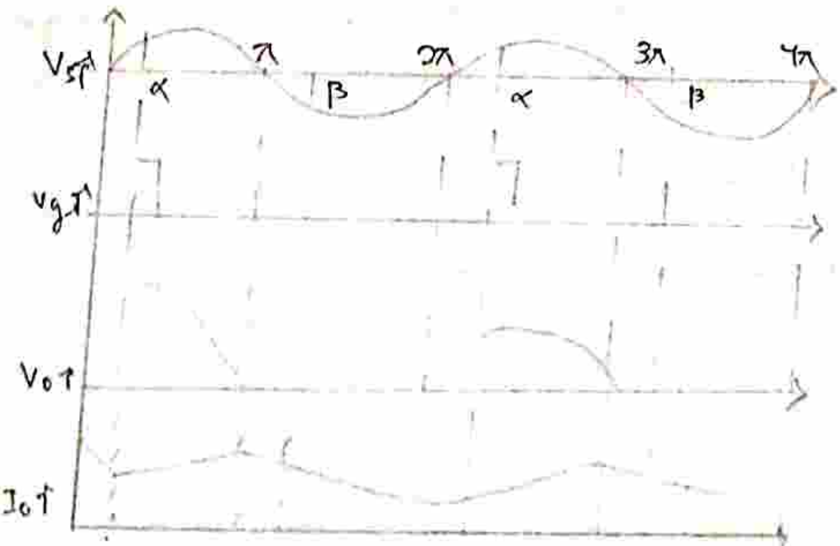
- If larger the inductance then larger the -ve area & hence lesser is the average o/p voltage & vice-versa.

- when SCR is triggered due to $V_0$, $i_0$ starts flowing from $\omega t = \alpha$ & gradually increases & reaches max^m.

- And after $\pi$ it start decreasing upto '$\beta$' known as extinction angle and hence the SCR conducts $\beta - \alpha = \gamma$ known as conduction angle.

1 $\phi$ half wave control rectifire with R-L load & free wheeling diode



-) Here a F.D connected across the load for free wheels (easy move charge of inductor inside itself.

-) During +ve half cycle at angle SCR is triggered by giving gate pulse and source voltage $V_s$ appears across load i.e $V_0$

-) At $\omega t = \pi$ source voltage is zero & tends to reverse now F.D is fully biased.

-) As a result load current '$I_0$' immedietly transfer from SCR to F.D & SCR is turn off and o/p voltage $V_0$ became zero.

-) Now F.D recycle or free wheeling the load current as the ckt passes high inductance.

-) And it maintain to a certain load current untill it doesnot decade to zero.

-) Again when SCR is triggered at $\omega t = 2\pi + \alpha$ o/p voltage seen again across the load & maintain the load current.

-) Advantages ~~the~~ of using F.D :-

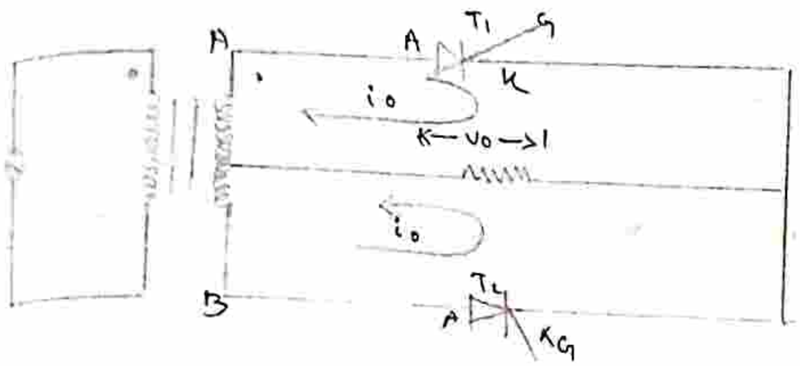
① Now the wave from of load current is improve.

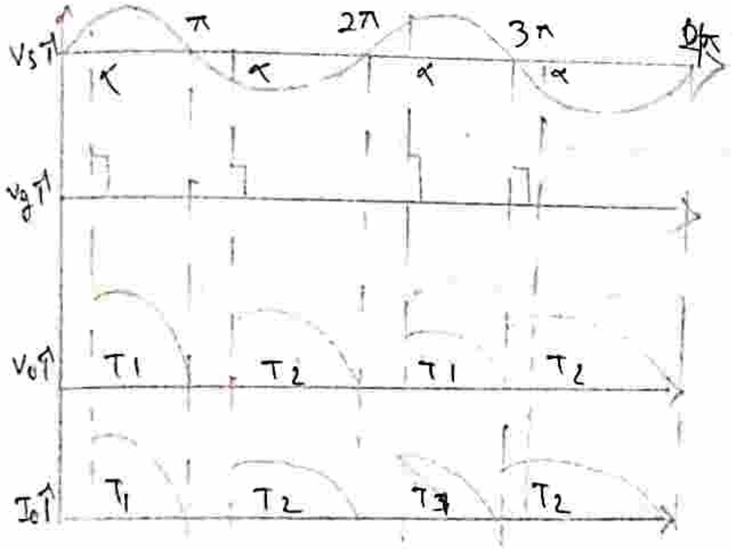
② Improvement of o/p. voltage.

③ Input P.F also improved

④ Load performance improve due to more power.

# Midpoint full wave type Convertor with R-Load




In fullwave mid point type convert with resistive load the 2 SCR $T_1$ & $T_2$ connected in 02 disting branch (A & B) & feed current to resistive load 'R' which is get centre tap.

1) During +ve half cycle A- point is +ve B point is -ve, hence SCR $T_1$ is f/w biased & $T_2$ is reverse biased.

2) $T_1$ turn on at $\omega t = \alpha$ by giving gate pulse so load current start flow in & across appearing upto $\omega t = \pi$.

-) At $\omega t = \pi$ the source voltage $V_s = 0$ and $T_1$ turn off & -ve half cycle starts.

-) During -ve half cycle B-point is +ve w.r.t point so $T_2$ is F/W biased and $T_1$ is turn off.

-) At $\omega t = \pi + \alpha$ $T_2$ turn on by giving gate pulse & load current start flowing across the load R is same direction in as that of before.

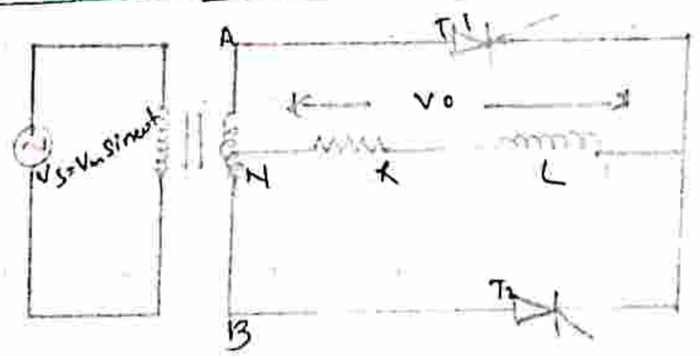
-) So O/P voltage is also same as that of before i.e unidirectio

-) $T_2$ conducts upto $\omega t = 2\pi$ and turn off As reverse voltag reached zero.

-) Again $T_1$ turn on at $\omega t = 2\pi + \alpha$ and above cycle repeted.

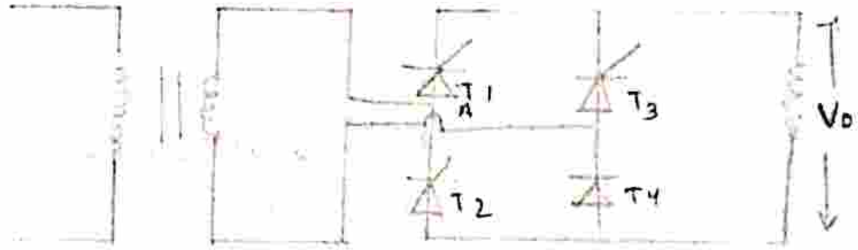
-) SCR's assume same firing angle ($\alpha$) and hence they share same load current.

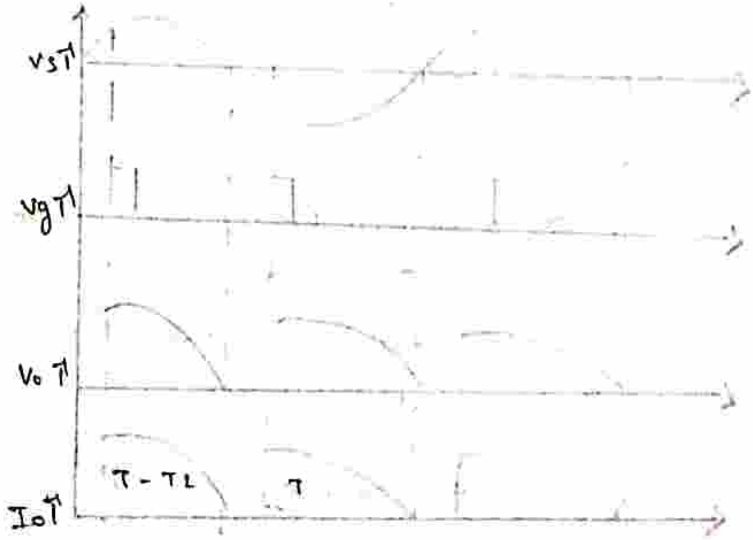
## Mid point full wave Convertor with R-L Load




- The ckt diagram shows 1$\phi$ full wave Convertor with R-L. load.
- During +ve half cycle 'A' is +ve w.r.t B So $T_1$ is F/w biased and $T_2$ is reverse biased.
- At $\omega t = \alpha$ gate is given and '$T_1$' is fired & o/p voltage seen across load and current is flowing through the load shown in the fig.
- During the interval $\omega t = \pi - \pi+\alpha$ before triggering of $T_2$ (as -ve half cycle start + $T_2$ is F/w biased)
- The load current is handed over from $T_1$ to F.D. and flow in same direction by reducing as a result the -ve half cycle seen during this duraction is get eliminating.
- Again $\omega t = \pi+\alpha$ "$T_2$" is triggering by giving gate pulse and load current I maintain by $T_2$ insted of F.D till $\omega t = 2\pi$
- At $\omega t = 2\pi$ there is initiation of +ve half cycle hence $T_2$ OFF
- During the interval $\omega t = 2\pi - (2\pi$ again to maintain by F.D instead of $T_2$ by eleminating -ve
- half cycle and current direction same.

## 1φ fully control Bridge convertor with R-Load




- The above fig. shows 1φ fully control bridge convertor with R-Load
- Here 4 nos of SCR is ($T_1, T_2, T_3, T_4$) are connected and form a bridge ckt such that $T_1$ $T_2$ & $T_3$ are in same branch.
- The T/F secondary is connected to bridge ckt at point A&B and the bridge ckt is connected across R load.
- During +ve half cycle A-point +ve w.r.t B-point.
- Hence $T_1$ & $T_4$ are F/w biased.
- When gate pulse are given to $T_1$ & $T_4$ it start conducting and load current flow through.

  A → $T_1$ → R → $T_4$ → B.

...nce o/p voltage seen across the load. They conduct upto α-π ... -ve half cycle starts..

During -ve half cycle B point is +ve w.r.t A-point Hence $T_2$ & $T_3$ are f/w biased.

When gate pulses are given to $T_2$ & $T_3$ current starts flowing B → $T_3$ → R → $T_2$ → A and o/p voltage ($V_0$) seen across the load which is shown in the wave form.

$T_2$ & $T_3$ conducts upto end of -ve half cycle and this cycle repeted for other half cycle.

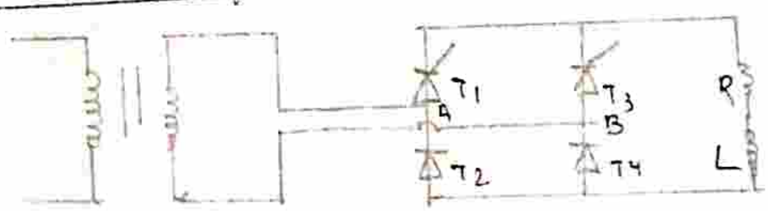
•) As the current direction is same across the load hence the o/p is unidirectional.

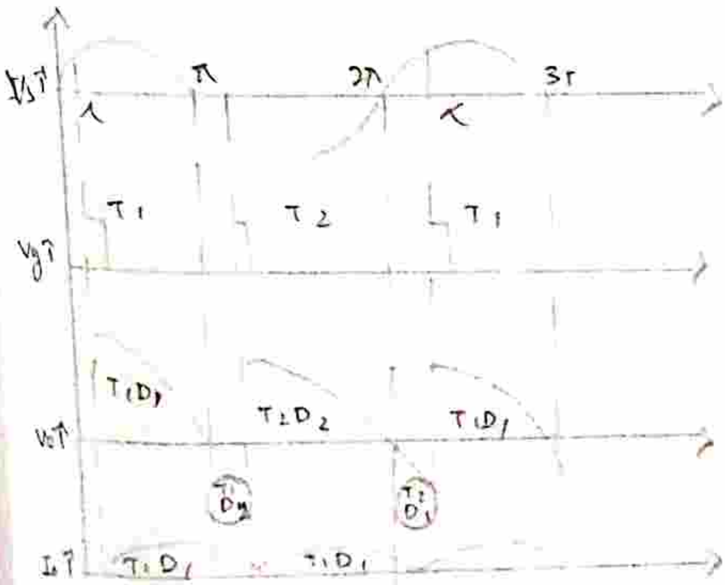
## 1ϕ Half control Bridge convertor with R-L load :

•) It has 02 alternate configuration i.e (1) Symetrical configuration.
(2) Asymetrical configuration.

•) In this case 02 SCR are replaced by 02 power diodes

### (1) Symetrical configuration




[ Symetrical configuration )

-) During the half cycle the SCR ($T_1$) turn on at firing angle d.

-) The current start flowing in the path $A \to T_1 \to R \to L \to D_1 \to B$

-) And source voltage appears across the load Assume that the load inductance is very high to produce continuous a constant load current.

-) $T_1$ & $D_1$ flow upto $\omega t = \pi$, as source voltage is reverse so $D_2$ is now f/w biased.

-) $D_1$ turn off due to reverse biased condition.

-) Hence the charge of inductor free wheels by the $T_1$ & $D_2$ and the load current flow in the path $T_1 \to R \to L \to D_2$.

-) The load is S.C ~~reduces to zero~~ during interval ($\pi+\alpha$) and voltage reduces to zero.

-) At $\omega t = \pi + \alpha$ $T_2$ turn on & reverse voltage flow through.

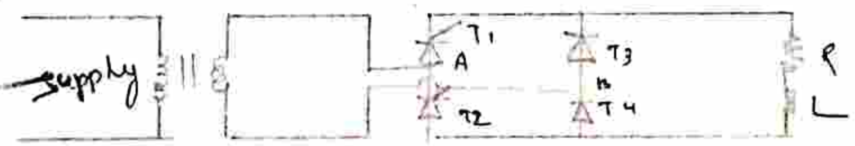
$B \to T_2 \to R \to L \to D_2 \to A$

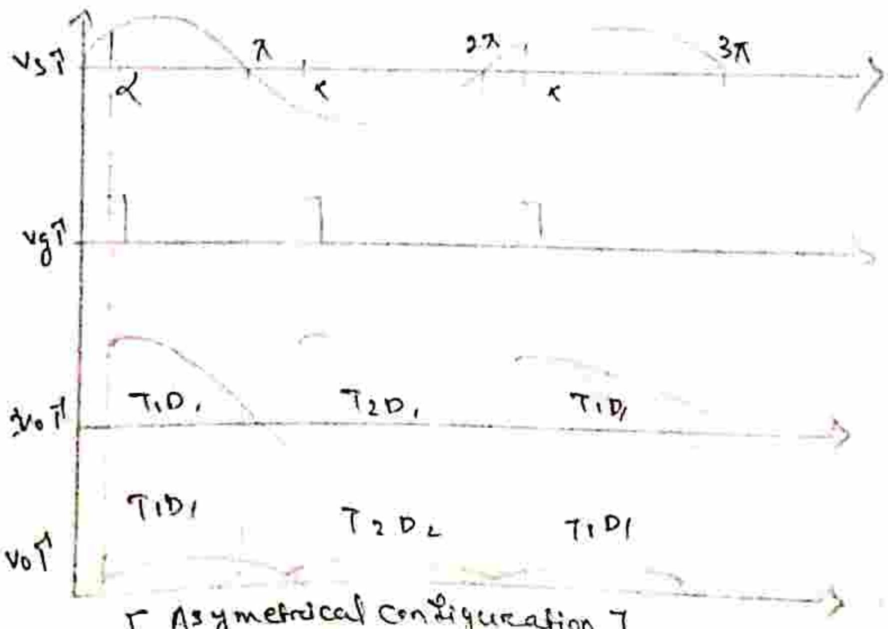
-) $T_1$ turn off when $T_2$ fired & o/p voltage seen across the load during -ve half cycle due to $T_2$ & $D_2$ upto $\omega t = 2\pi$

-) During the interval $\omega t = 2\pi - 2\pi + d$ before triggering of $T_1$ & $D_2$ off as reverse biased but $D_1$ turn on and current flow through.

R-L - $D_1 \to T_2$ which is S.C.R the load and this above cycle is repeted.

## Asymetrical Configuration




[ Asymetrical Configuration ]

In this configuration the 02 thyristor $T_1$ & $T_3$ and 02 Diodes $D_1$ & $D_2$ are placed in same branch.

The above bridge configuration is connected across load R & L

During +ve half cycle "A-point" is -ve w.r.t B point so $T_1$ & $D_1$ are F/w biased.

when $T_1$ fired load current to start flowing through.

A -> $T_1$ -> R -> L -> $D_1$ -> B which are conducts upto α to π.

During -ve half cycle at α B point +ve w.r.t A point so $D_2$ is F/w biased.

The charge contain by the inductor is free wheel $D_1$ & $D_2$ from π - π+α when "$T_2$" fired at "π+α" during -ve half cycle the load current gradually increased and flow through the path

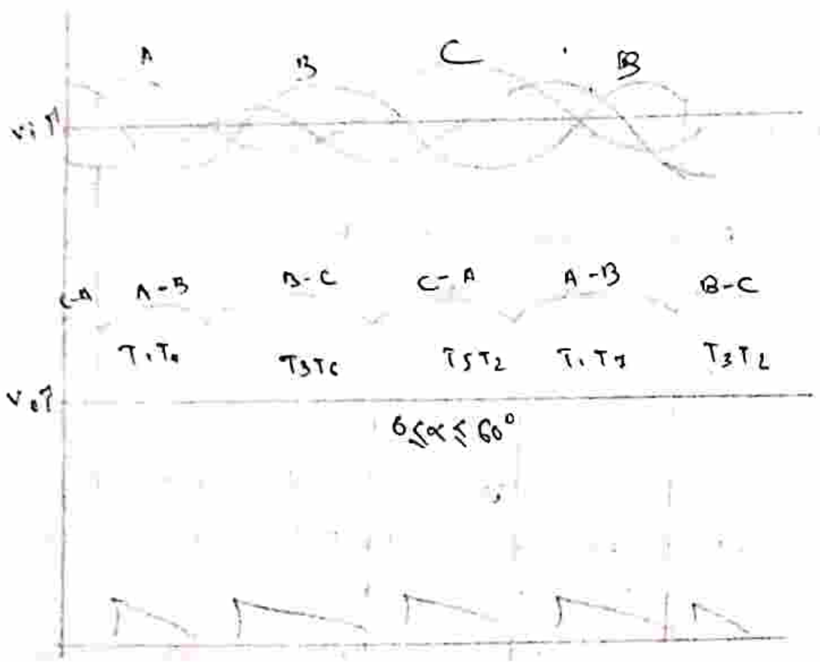
B -> $D_2$ R -> L -> $T_3$ -> A and the o/p $V_0$ & $I_0$ are seen in the above wave form.

As the current direction across load is same as that of before so the o/p is unidirectional.

Again during the initiation of +ve half cycle from 2π - 2π+α $D_1$ F/w biased and charged store in inductor free wheels by $D_1$ & $D_2$

## 3ϕ full wave converter

### 3ϕ fully control bridge converter with R-LOAD:




$60° \le \alpha \le 120°$

- The above ckt shows 3ϕ fully convertor with R-load
- Here 3 pairs of SCR $T_1T_2$ $T_3T_4$ & $T_5T_6$ are placed in same branch
- There are 3 points A, B, C where 3ϕ supply is fed to the above bridge ckt.
- The 3ϕ wave form of source is shown in the above fig.
- There are 6-points mark on source voltage wave form i.e P,Q,R,S,T,U
- At point 'P' A & C are same polarity i.e A-C=0 or C-A=0 after point-P, A is more +ve and 'B' is more -ve so now $T_1$ & $T_4$ are F/W biased.
- As soon as they are triggered i.e. $0 \le \alpha \le 60°$ then the o/p seen is a continuous mode and if $60° < \alpha < 120$ then the o/p wave form is a discontinuous mode
- During the interval P & Q current flow through $A \to T_1 \to R \to T_4 \to B$ and the o/p voltage seen across the load.
- After point-Q 'B' is higher polarity and 'C' is more -ve so $T_3$ & $T_6$ are F/W biased and the load current start flowing $B \to T_3 \to R \to T_6 \to C$

At point - Q the $T_1$ & $T_4$ SCR are automatically turn off due to voltage commutation & $T_3$, $T_6$ are conduct Q to R.

- The mode of o/p of both the SCR are depend upon the firing angle
- And the interval from 'R' to 'S', 'C' is positive and 'A' is more -ve so $T_5$ & $T_2$ are f/w biased and the current start flowing.

C → $T_5$ → R → $T_2$ → A

- The current direction across the load is same at every interval (P→Q, Q→R, R→S, S→T) hence the o/p is unidirectional.

# INVERTER

**Inverters :**

- Inverters are derived from the word inversion i.e to change from one state to another state.
- So inverters are power electronics devices which convert d.c electrical energy to A.C electrical energy.
- Inverter is a device which convert d.c power to A.C power at desired voltage + frequency.

## Application of Inverter Ckt

(i) Variable speed of AC motor drives

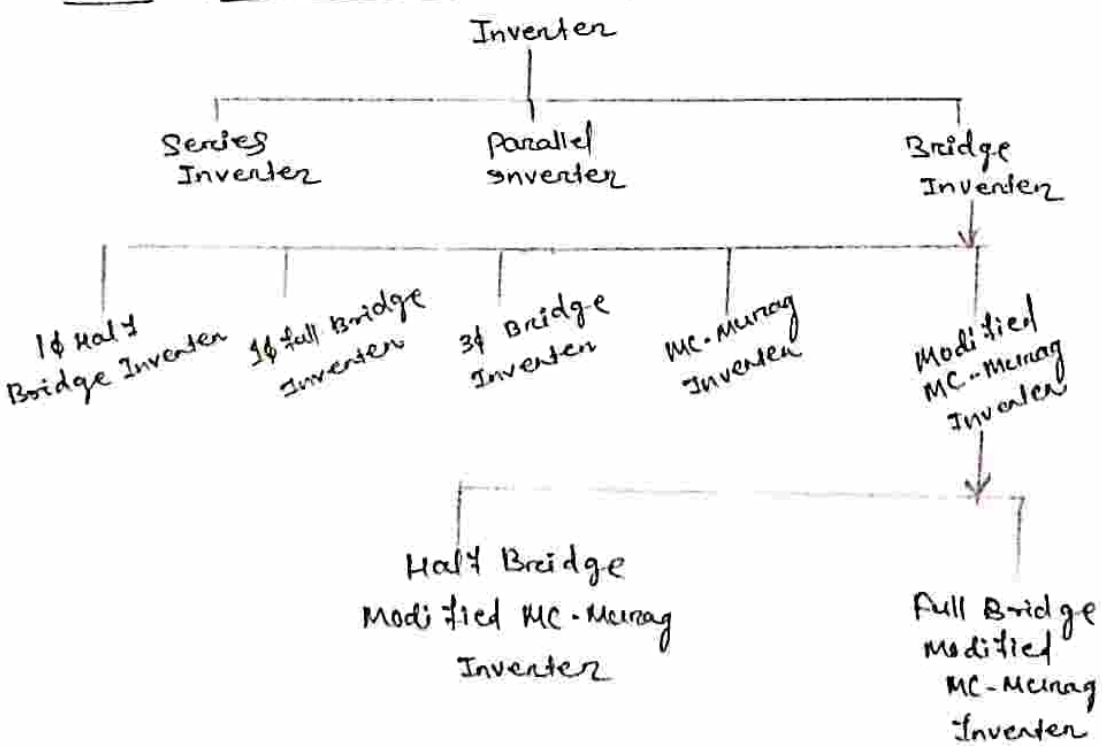
(ii) Induction heating in the industrial for melting of ores.

(iii) UPS (Un-interruptable power supply)

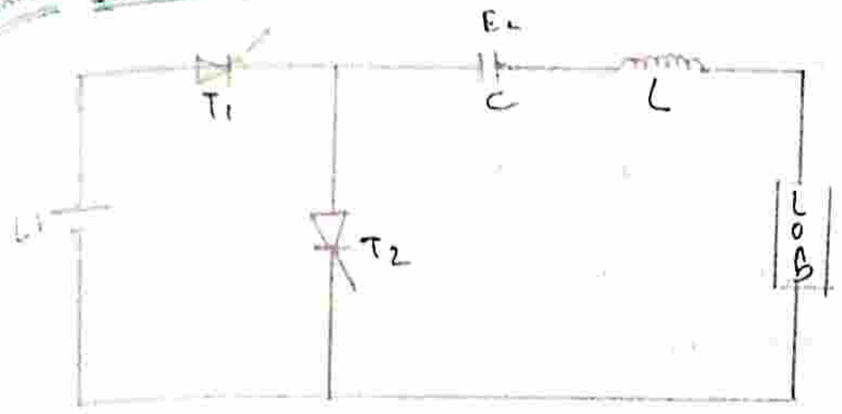
(iv) Stand by aircraft power supply.

(v) HVDC transmission line where long dist d.c voltage converted into a.c voltage.

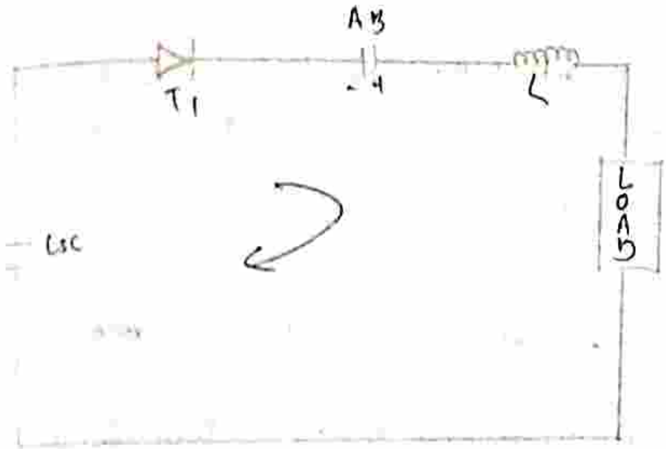
## Classification of Inverter :



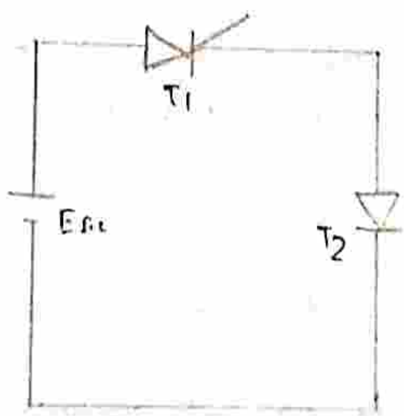
Series Inverter :



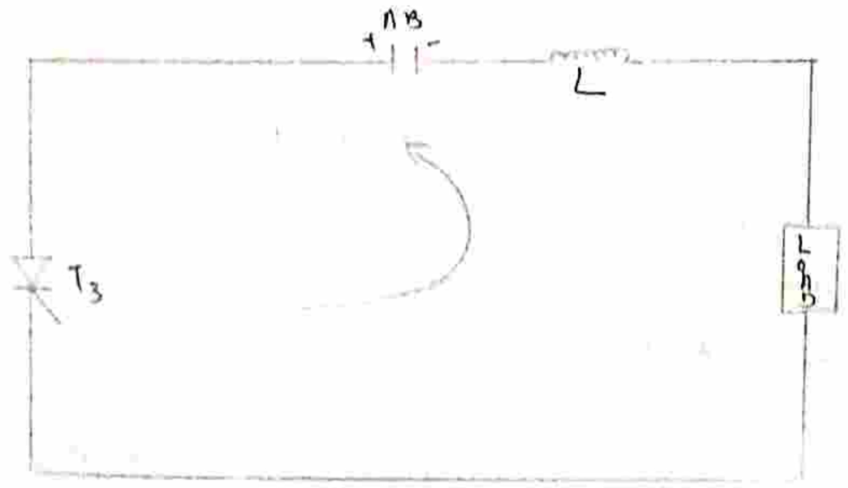

Mode-I




Mode-II




Mode-III



## CKT description :

=) Here 02 SCR $T_1$ + $T_2$ are used for inverting purpose.

-) $T_1$ is the main SCR connected across d.c supply.

-) L + C are commutating element which are connect in series with load resistance $R_L$.

-) $T_2$ is connected bet$^n$ $T_1$ terminal + load terminal for free wheel the charge of capacitor.

-) As the commutating component L+C are connected in series with load resistance $R_L$ so it is known as series inverter.

-) The series R-L-C ckt formed a underground ckt.

-) The o/p frequency of inverter ranges from 800 Hz to 1000 KHz

-) So the size of commutating components reduced for this high frequency.

## Principle of operation of the Ckt

### Mode - I

=) Let capacitor have initial charge of Ec.

-) When SCR '$T_1$' is triggered by giving gate pulse $T_1$ start conducting + current flow through R-L-C Ckt.

-) So load current flow through $+Ed \rightarrow T_1 \rightarrow A \rightarrow B \rightarrow L \rightarrow R_L \rightarrow Edc^-$

=) As the current flow through R-L-C series ckt it produced ossilation / frequency associated with load current.

=) When load current reaches it peak value ($I_m$), the capacitor voltage reaches to Edc.

Now the capacitor has voltage of "Edc + Edc" and it does not allow for there current flow towards load as source voltage is less than capacitor voltage & $T_1$ is turn off.

Mode - II

The SCR '$T_2$' should not be triggered immideatly after the current through $T_1$ reducess to zero.

If $T_2$ triggered without time delay, the battery source get shorted through $T_1$ & $T_2$ & get damaged the battery.

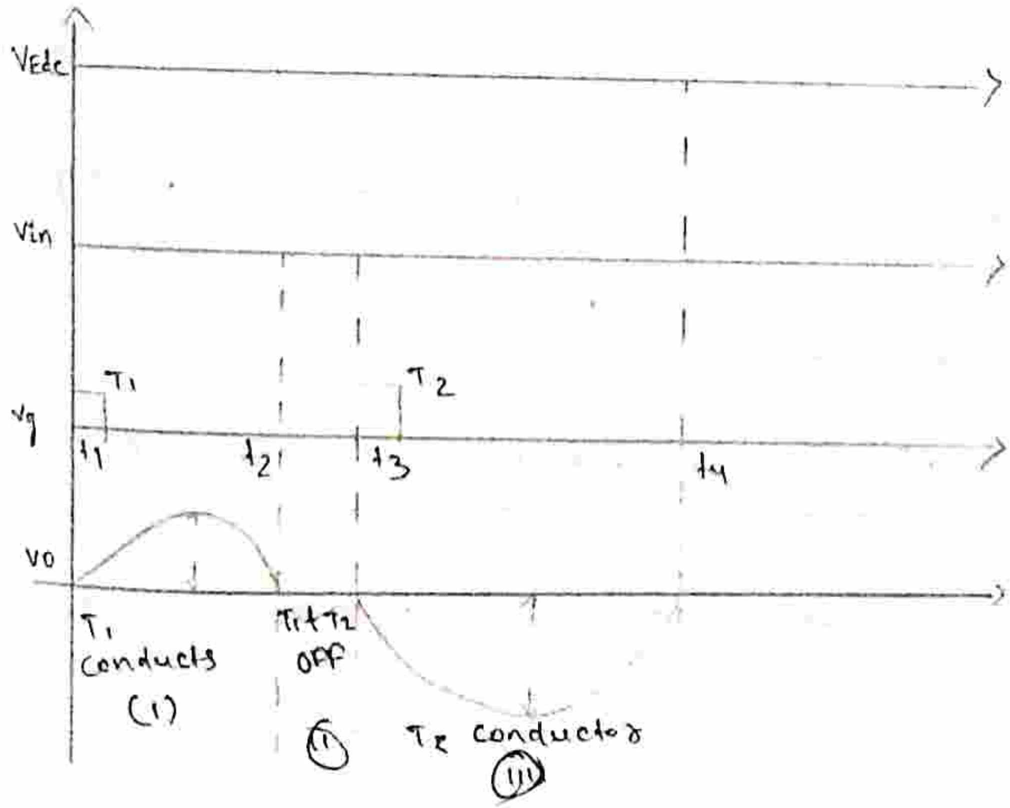
So in mode II operation no SCR in conduction mode.

Mode - III

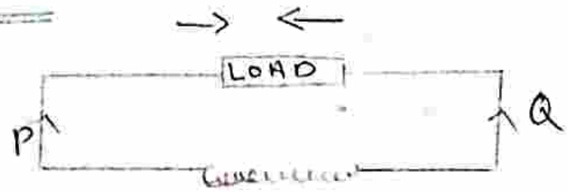
In mode III operation SCR '$T_2$' triggered after some time delay which cause initiation of -ve half cycle as current through the load is reverse.

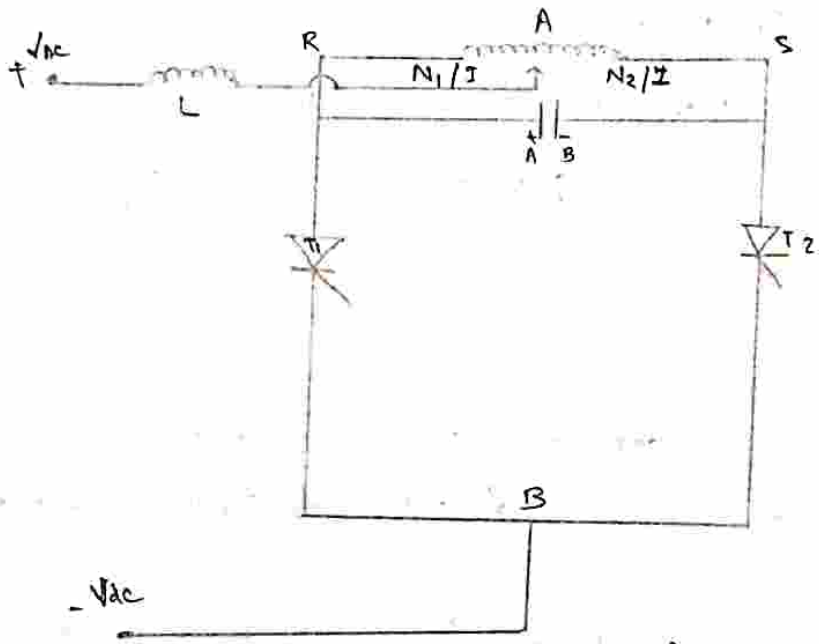
The capacitor discharge through '$T_2$' which cause giving rise to -ve half cycle across load. So current flow through the path.

A → $T_2$ → Load → L → B



## Parallel Inverter




This is known as parallel inverter then inversing 'c' is connected parallel across the load.

### Ckt description

⇒ There is a centretap T/F i.e the primary is centre tap where 02 thyristor $T_1$ & $T_2$ are connected.

⇒ Here capaciter 'c' is connected parallel with load via T/F

⇒ The inductor 'c' connected series with supply which is centre tap in the primary wdg.

⇒ The function of L is to make the source current constant in order to avoid in stand discharge of capacitor.

⇒ The o/p wave form of this invertor is in the form of square.

# Principle of operation :

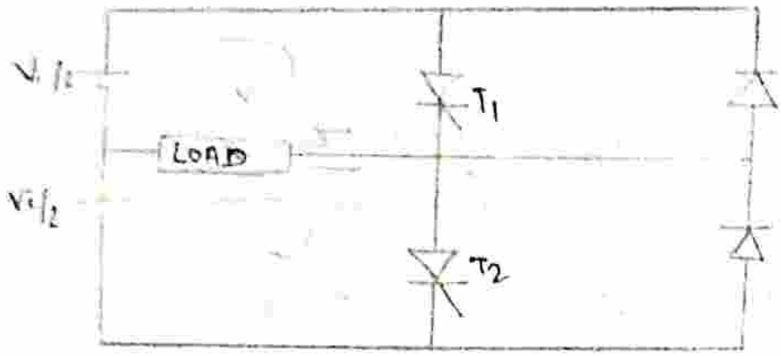
## Mode-I

- At the time "t = 0" '$T_1$' turn on.
- The current start flowing through the ~~hal~~ left half of the primary +Vdc → L → A → R → $T_1$ → B → -Vdc
- Initially capacitor has "A-plate +ve and B-plate -ve
- As primary wdg's are closedly coupled and they are same no. of turns ($N_1/2$) so same voltage induced in the right half.
- Now capacitor is charged by 2 Edc of primary wdg which cause changing of polarity of capacitor "A-plate is +ve & "B-plate" is +ve.

## Mode-II

- At time t = to commutating capacitor 'c' applied a voltage 2Edc across '$T_1$' so due to r/v biased condition and '$T_1$' is turn off.
- Now $T_2$ turn on by giving Gate pulse so current start flowing in the right half primary wdg in the direction +Vdc → L → A → S → $T_2$ → B →

# Single phase half Bridge Inverter with R-Load




## Ckt description

- The above ckt shows 1 ϕ half wave bridge inverter with R-load.
- This type of inverter is very popular and commenly used for D.C to A.C conversion because it is easily extended for multiphase operation.
- In the 1 ϕ bridge inverter there is no need transformer because the o/p voltage can be stabilised by the help of bridge ckt.
- It consist of 02 source i.e $V/2$
- There are 02 switches $D_1$ & $D_2$ diodes for freewhelling action. If the load is inductive or Capacitive.
- The 02 SCR $T_1$ & $T_2$ acts as 02 switches for controlling the o/p voltage.
- Here the 02 thyristor $T_1$ & $T_2$ able to generate a.c by using 02 difference source for giving rise to 02 individue half cycle so it is known as 1 ϕ half bridge inverter.

Operation

When $T_1$ triggered is by giving gate pulse at time $T_m$ to, $T_1'$ start conducts and it it is condects up to $T = t_1$ which is the interval $(t_1 - t_0)$ & having frequency $f = \frac{1}{t_2 - t_0}$

$= T/2 =$ (T = half of period)

and commuted after $T = t_1$ as a result it gives half cycle of operation having frequency

$F = T/2$

At $T = t_1$ again gate pulse is given to SCR $T_2$. The current start flowing through the load is opposite direction as that of previous one.

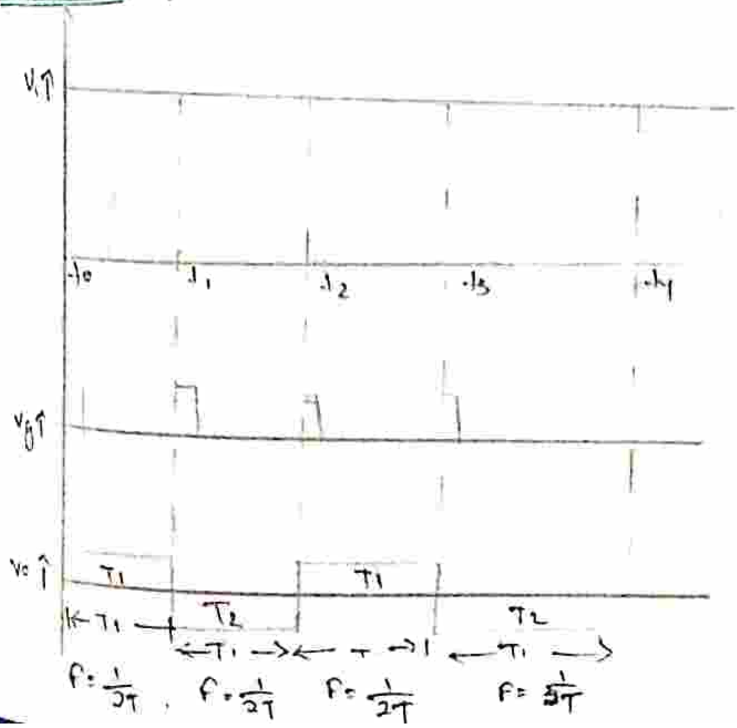
and it again conducts upto $T = t_1$ such that the time period $T = t_2 - t_1$ which is same as that of before and indeccus a opposite cycle across the load having frequency

$f = \frac{1}{T}$ and forcely commutated at

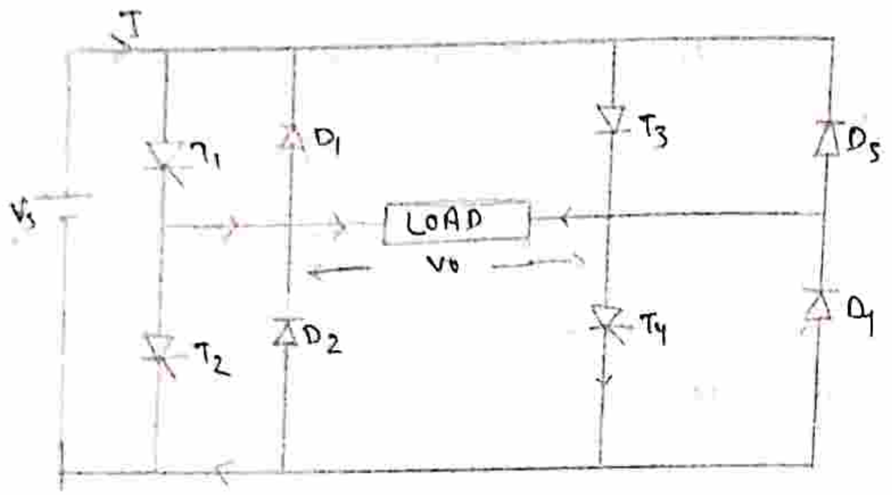
$T = t_2$ and above cycle repeted

→ The diodes are used for if the load is inductive but if the load is non inductive the diodes are not use.

Wave form :



Single φ full Bridge inverter with R-Load




=) In case of half bridge inverter 02 different sources & leads of supply are required for converting D.C to A.C so for overcome this problem the full bridge inverter is used.

=) As there is single source is used for inverting so it is known as full bridge inverter.

**CKt description**

=) The CKt contain 02 pairs of SCR and 02 pair of diode.

=) The load is bridge connected i.e. it is contertap betn two pair of SCR.

=) There are also 02 pairs of diodes antiparally connected across the load for free wheeling purpose if the load is inductive or capacitive.

=) Separate, firing CKt and commutated CKt is required for 'ON' & 'OFF' for pair of SCR.

=) As the load is resistive so there is no used of $D_1$ $D_2$ & $D_3$ $D_4$.

Operation

- For conduction through load simoultenoiously or SCR is to fired.
- So At time $t = t_0$ gate pulse is given $T_1$ & $T_4$ hence the current 'I' start flowing

$V_s^+ \rightarrow T_1 \rightarrow$ load $\rightarrow T_4 \rightarrow V_s^-$ and the voltage $V_0$ seen across the load.

- Both $T_1$ & $T_4$ conducts upto

$T = t_1$ i.e $t_1 - t_0 = T/2$ i.e half of time period.

- So the o/p wave fore is given for a half cycle of frequency 'f'.

- At time $T = t_1$, $T_1$ & $T_4$ are forcely commutated and $T_2$ & $T_3$ are fired by giving gate pulse.

- Now current start flowing in the direction.

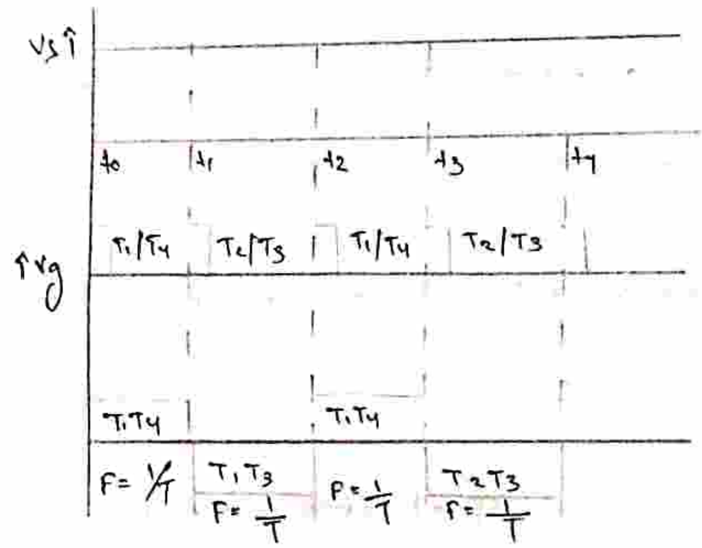
$V_s^+ \rightarrow T_3 \rightarrow$ Load $\rightarrow T_2 \rightarrow V_s^-$

which is opposite direction of previous one by including the o/p voltage $V_0$ appears across the load for time period $T = T/2$ and giving rise to opposite half cycle as that of previous.

- It conducts upto $T = t_2$ i.e

$t_2 - t_1 = T/2$ and forcelly commutated $T_2$ & $T_3$ and the above cycle repeated further.

- As there is no inductive and capacitive load so $D_1$, $D_2$ & $D_3$ $D_4$ are not conduct.




## CURRENT SOURCE INVERTER (CSI) :

Current source inverter (CSI) in which the i/p current is constant and adjustable.

The current feeding to the ckt by CSI does not depends upon nature of load.

The nature of the current is d.c which may be obtained from a a.c source having fixed voltage + connected by means of a bridge rectifier.

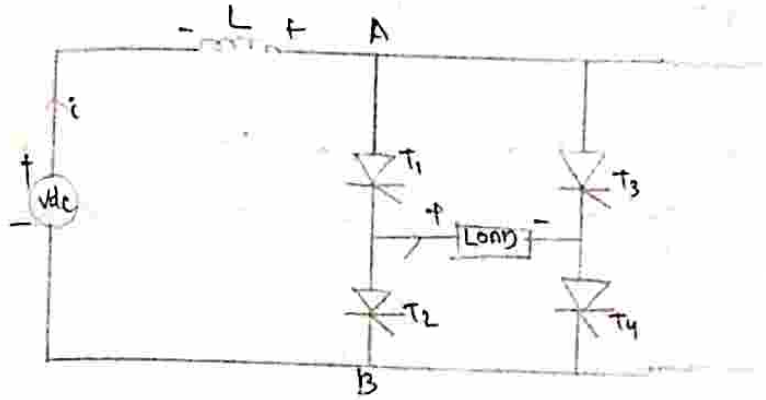
## VOLTAGE SOURCE INVERTER (VSI)

-) In this type of inverter the i/p voltage is maintain constant whatever the load connected to the ckt.

-) Amplitude of voltage remain constant and does not depend upon the load.

-) So this may be obtained from battery and d.c shunt generator.

## 1ϕ current source inverter with ideal Switches




### Ckt Description

- The above Ckt shows 1 ϕ CSI with ideal Switches
- The ideal switches are $T_1, T_2, T_3$ & $T_4$ having zero Commutation time
- The Ckt consist of a voltage source (Vdc) which is series with the L.
- The function of high impedance reactor (L) is to maintain current Constant at i/p terminal of CSI.
- In other word the voltage source (V) with inductor "L" feeding a d.c const current to C.S.I.
- There are 02 branch where 4 ideal switches ($T_1, T_2, T_3$ & $T_4$) are connected in bridge manner and load is centre tap.

## Operation

- When $T_1$ + $T_4$ are on the current i --- start flowing through +Vdc → L → $T_1$ → Load → $T_4$ → Vdc and o/p voltage $v_i$ seen across load.

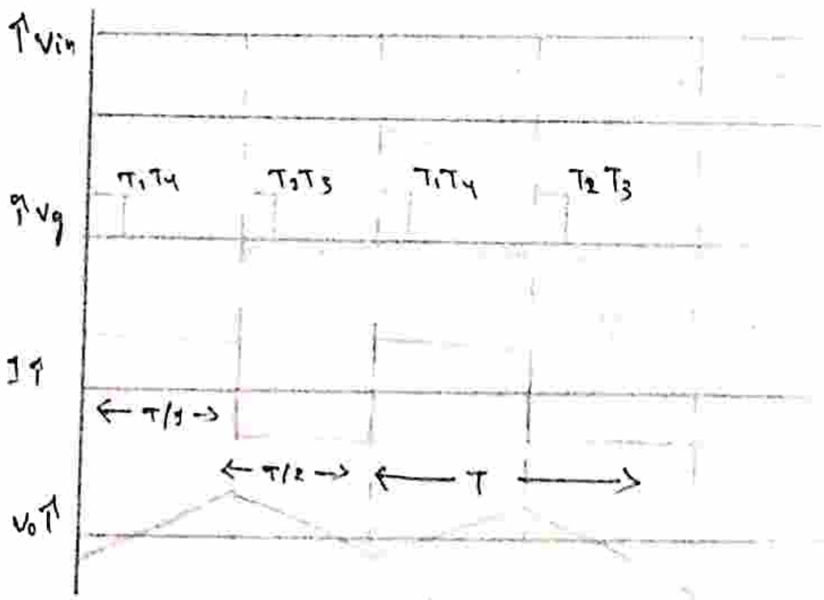
- After time t = T/2 '$T_1$' & '$T_2$' are automatically off and $T_2$ + $T_3$ are automatically on, giving rise opposite direction of load current. ∴

  i.e. +Vdc → L → $T_3$ → Load → $T_2$ → - Vdc

  and -ve o/p voltage (-V.) appears the load.

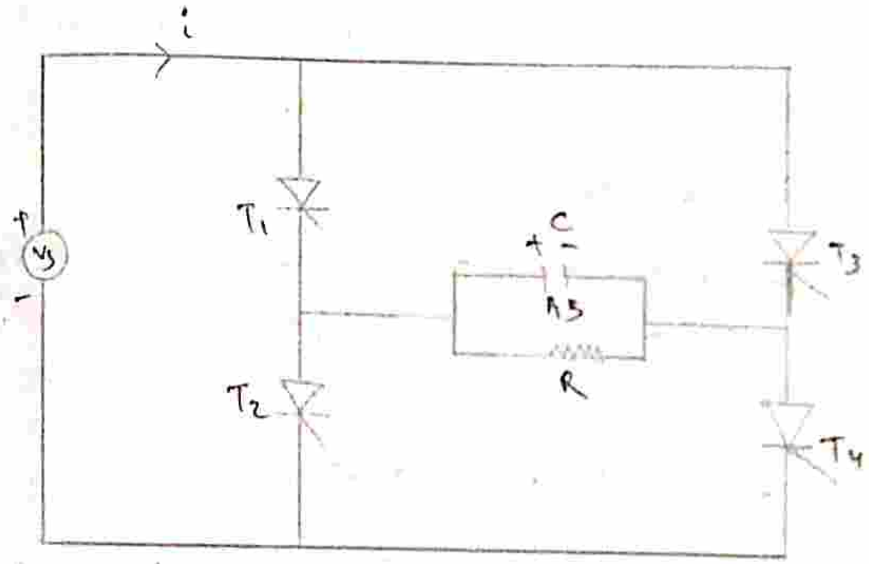
- Here the direction of current fed to CSI is always unidirection.

- If Vin is the i/p voltage to CSI and average value of Vin is +ve then power flow is source to load or if it -ve then power flow is load to source which is known as regulation of power



## 1ϕ Capacitor commutated CSI with R-Load

NOTE:- Full wave Rectifier
frequency - 100 Hz
$1/_{T/2} = \frac{2}{T} = 2\times f = 2\times 50$
$= 100 Hz$




- The above ckt shows capacitor commutated 1ϕ CSI.
- Here a capacitor is connected across load resistance (R) which is identify the capacitor commutated CSI.
- The source connected to the ckt is a constant current delivaring to the CSI but it is a adjustable source.
- There are 02 pairs of SCR $T_1T_4$ & $T_2T_3$ which provides simoultenioualy the gate current for turn on.
- A capacitor (C) is connected parallel with load resistance R which A-plate is -ve & B-plate is +ve.

## Operation

=> A time $t=0$ $T_1$ & $T_4$ are 'on' by giving gate pulse.

=) As capacitor plate - A ' -ve so current "i" starts - flowing through.

$V_s^+ \rightarrow T_1 \rightarrow R+C \rightarrow T_4 \rightarrow V_s^-$

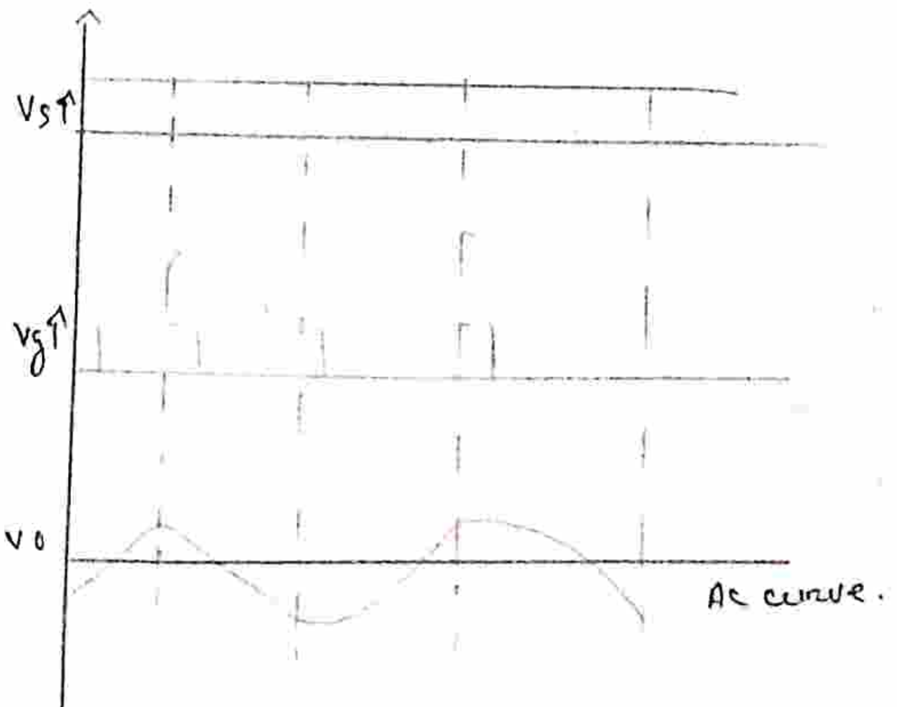
-) As a result capacitor charges to $V_c$ which is at time $t = T/2$

-) As polarity is reversed and biased. The SCR in r/v biased so they are automatically turn off.

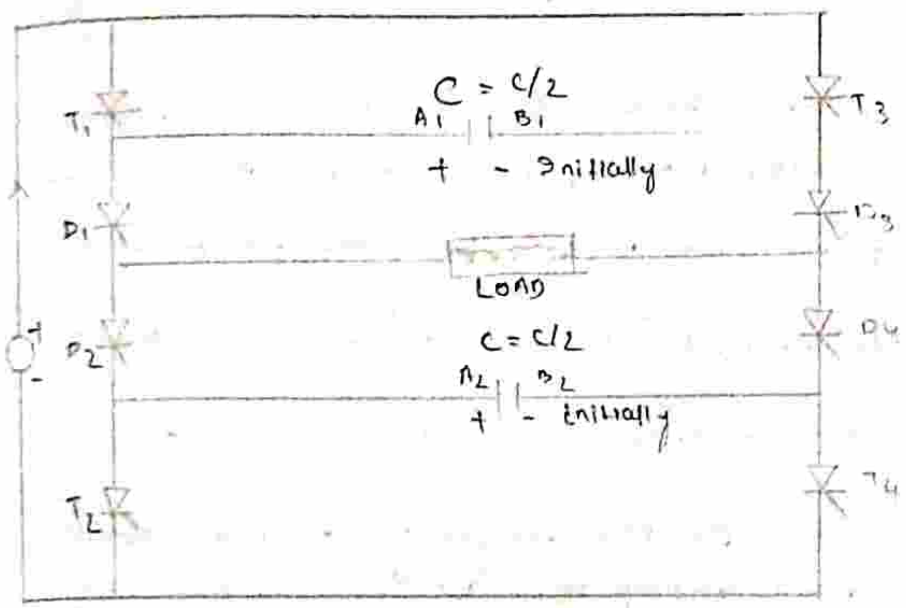
-) This need to turn on $T_2$ & Hence $T_2$ & $T_3$ fired simultaneously & load current 'i' start flow through $+V_s \rightarrow T_3 \rightarrow R+C \rightarrow T_2 \rightarrow V_s^-$ and again charge up the capacitor a opposite voltage $-V_c$

-) Hence $T_2$ & $T_3$ automatically turn off after time $t = T$

-) In duration $0 < t < T/2$ $T_1$ & $T_2$ left to Right through load in the time duration $T/2 < t < T$.
T & $T_3$ are conducts & load current 'i' flow right to left Hence the o/p is in alternating in nature.



## Auto sequential Commutated inverter (ASCI) :-




- The above ckt shows 1ϕ Auto sequential commutated inverter which is widely used in industries.
- It is more popular than force commutated CSI.
- Here a constant current source 'i' is feed to load 'L' through a bridge inverter ckt.
- The SCR $T_1, T_4$ & $T_2, T_3$ are alternatively switch for getting a square wave.
- There are 02 commutating capacitor $C_1$ & $C_2$ having capacitance C/2 connected lower half & upper half of the above fig.
- There are 4 diodes $D_1, D_3$ avoied $C_1$ to discharge through L.
- Similarly $D_2, D_4$ avoided $C_2$ to discharge through L.

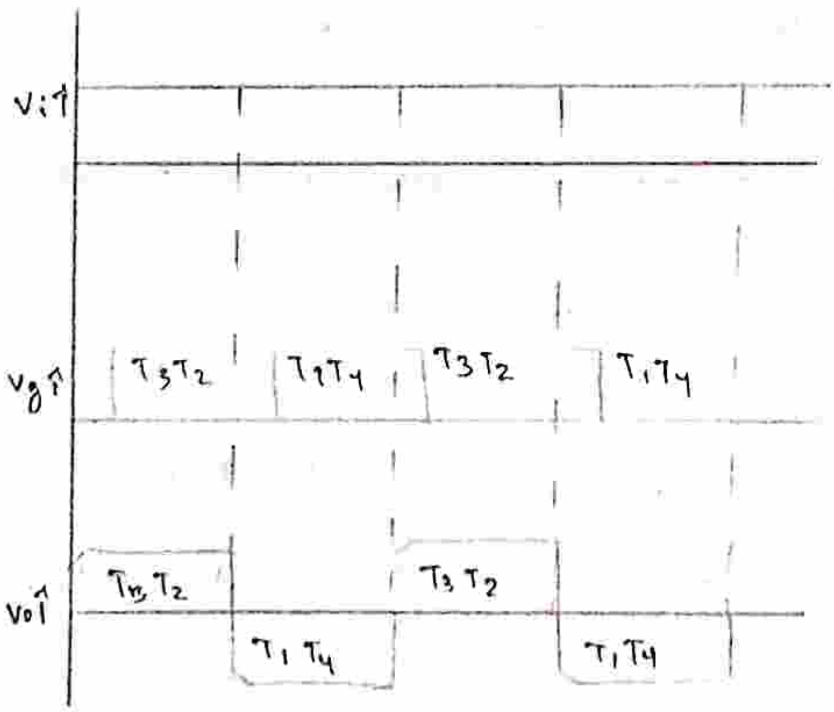
Operation

- At time t=0 $T_3$ & $T_2$ are conducts by giving gate pulse.
- Hence 'i' start flowing. +i → $T_3$ → $C_1$ → $D_1$ → L → $D_4$ → $C_2$ → $T_2$ → i

And charge up the capacitor $V_{C1} = V_{C2} = +V_c/2$ with reverse in Polarity of capacitor & $T_2$ & $T_3$ automatically turn off at time t = T/2

- At time t = T/2 the $T_1$ & $T_4$ are "on" by giving gate pulse
- Again "i" flowing in the direction +i → $T_1$ → $C_1$ → $D_3$ → L → $D_2$ → $C_2$ → $T_4$
- And charge the capacitor $C_1$ & $C_2$ $V_{C1} = V_{C2} = -V_c/2$
- Hence the current direction changes by the help of capacitor Polarity automatically and o/p is in the form of A.C.
- The o/p frequency can be varies by adjusting the triggering time of either $T_1$, $T_4$ or $T_2$, $T_3$

Wave form



# CHOPPER

- It is a static device.

## D.C CHOPPER

- It is a static device which convert fixed value of d.c to variable value of d.c
- D.C chopper is a nothing but A.C T/P. i.e. it produced desire voltage at desired time.
- So a d.c chopper may be either Stepup or step down.
- In d.c chopper we required process commutation (Turn off)
- Hence the type of chopper depend upon the nature of commutation.

## Application of Chopper

1. Speed control of d.c drives (Trains & Trams)
2. Battery driven vehicles
3. Trolly car
4. Marine Hoists.

## Advantages of chopper

1. The voltage control ability of the chopper are Smooth or the ckt of Chopper are smoothly operated.
2. High efficiency (o/p is high losses is low)
3. 1st responce & regeneration capability.

## Types of chopper

CHOPPER

Step UP
$V_o > V_s$

Step down
$V_o < V_s$

$V_o$ = o/p voltage of chopper in d.c

$V_s$ = D.C i/p supply voltage to chopper.

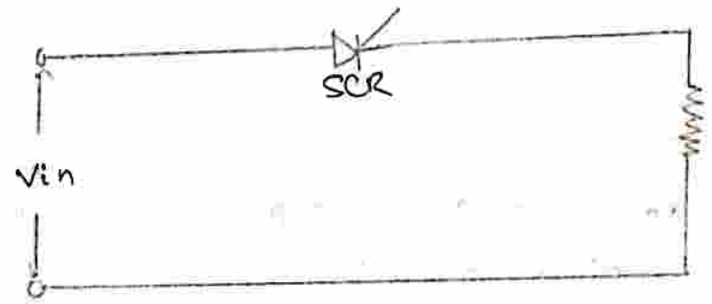
## Principle of chopper

-) A chopper is a high speed ON-OFF semi conductor switch.

-) It connects & disconnect the load with source with very fa[st]
speed.

-) So generally we used power BJT, GTO, SCR & P-MOSFET

## Step down chopper {Buck chopper}

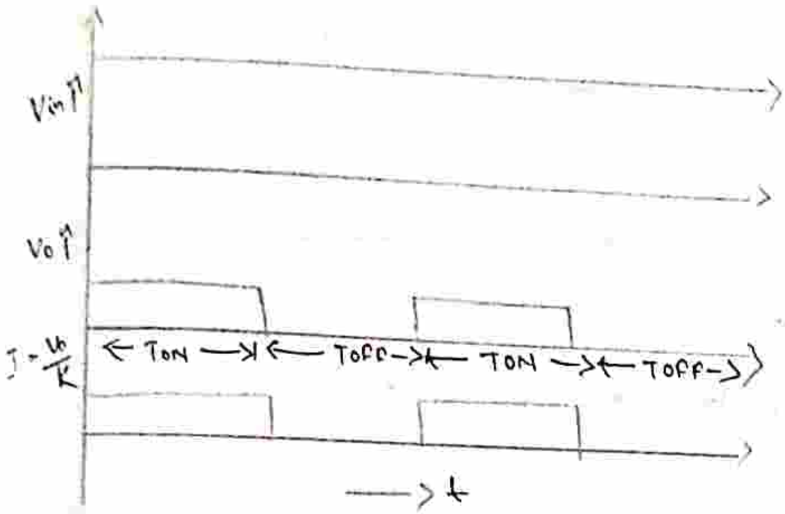



-) It is also known as Buck chopper.

-) It is a chopper in which $V_o$ is less than Vin.

-) The operation of the ckt is such that when SCR is conducting.

Hence let TON represents "ON" time period of SCR where are TOFF represents "OFF" time of SCR"




→ Here avarage value of i/p voltage is ~~given~~ greater than avarage value of o/p voltage.

→ So $V_o(avg) = \alpha \cdot V_{in}(avg)$

where, $\alpha$ = duty cycle

$$\& \quad \alpha = \frac{T_{ON}}{T} = \frac{T_{ON}}{T_{ON} + T_{OFF}}$$

where $T_{ON} < T$

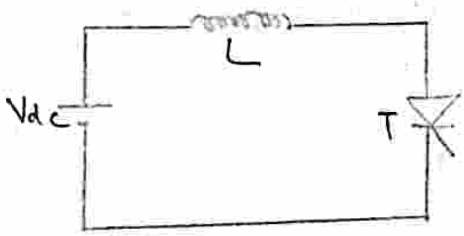
Hence $\alpha$ is less then 1 ($\alpha < 1$)

& Vo is less then Vin ($V_o < V_{in}$)

## Step up chopper {Boost Chopper}


- It is also known as Boost chopper.
- The o/p voltage is greater than i/p voltage.

### mode-I




- When SCR T is on for the time period TON the current from a constant voltage Vdc is applied to inductor (L) & it store charges lineraly to a value of $V_L$.
- After time period TON SCR turn off

### mode-II

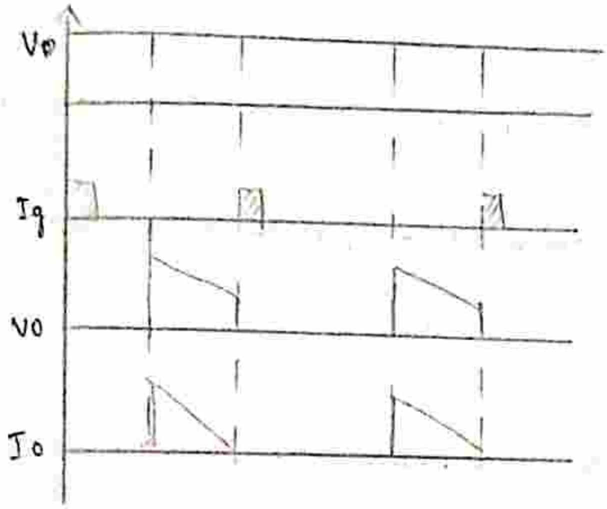
- When SCR T is turn off the energy store by inductor is transfer to load through diode D.

so the voltage $V_c + V_{dc}$ is applied to load during turn off

$V_c + V_{dc}$.

As during turn on $V_{dc}$ is applied to inducer & turn off $V_c + V_{dc}$ is applied to load ($\because$ $V_{dc} - 0$ during $T_{on}$)

Hence average o/p is greater than avg. i/p voltage




## Classification chopper

According to the o/p voltage $V_0$ & o/p current $I_0$ the Chopper are work at different quadrants.

So this may be devided in to five sub category i.e.

(i) class-A / Type-A

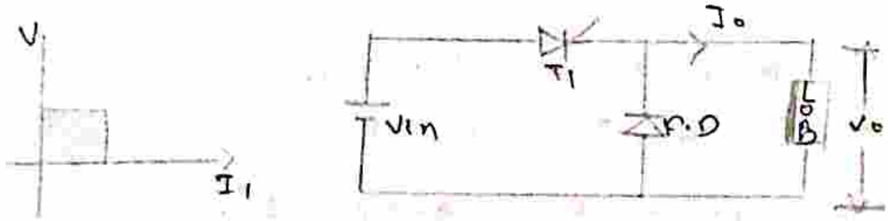
(ii) class-B / Type-B

(iii) class-C / Type-C

(iv) Class-D / Type-D

(v) class-E / Type-E

## Class - A / Type - A : (Forward motoring)




=) This type of chopper give rise to 1st quadrant operation i.e bot Vo & Io are +ve.

=) The above ckt contain a SCR T₁ which is acts as a switch for load.

=) A free wheeling diode is connected antiparallel across the load.

=) The fixed d.c supply is given as i/p.

=) When T₁ is off then $V_o = 0$
Now the F.D is used for maintaining the load current Io.

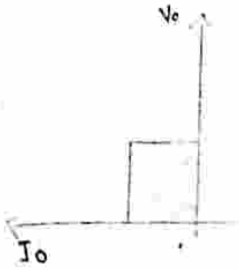
=) Hence a current Io flows from source to load.

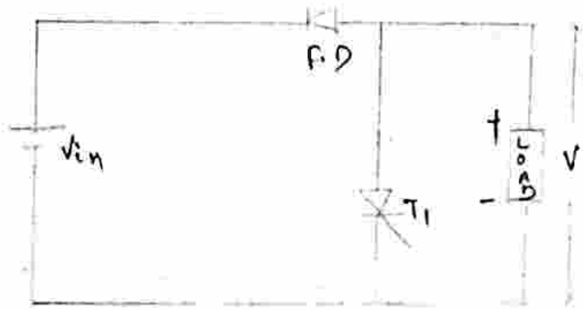
=) Hence the power applied to the load i.e the average value of o/p power is less than i/p power & hance Vo is low than Vi

=) Here $V_t$ & $I_A$ are +ve i.e (source to load) which is the 1st quadrant operation.

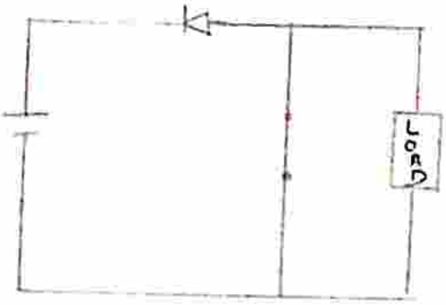
=) It is a step down chopper i.e. $V_{o\,Avg} < V_{in\,Avg}$

## Class - B / Type - B chopper.




- It is a 2nd quadrent chopper.
- It is a step up chopper i.e the power flow is allways from load to source.
- In the above ckt dig. $T_1$ is connected parallel across the load. The F.D is connected series between load + source.
- ~~In the above ckt~~ And the load polarity Vo is show above (General Re breaking)
- When D is ON + $T_1$ is off the total voltage Vo across the load is equale to source voltage Vin i.e $V_0 =$ Vin. And Io flow from load to source ($-I_0$)
- When T is ON $V_1 - 0$ (i) and Io continous flowing from load through $T_1$.



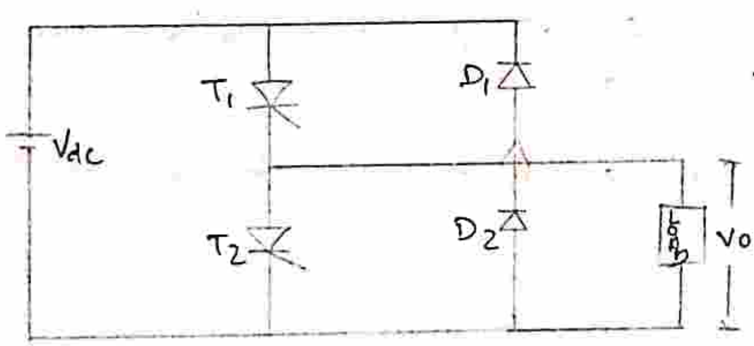
=) Hence the average load voltage gain is less than the source voltage since $V_0$ is +ve and $I_0$ is -ve the power flow is allo.. from load to source.

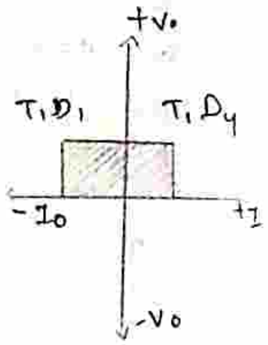
-) As the power flow is from load to source so it is known as step up chopper.

-) Reversal of power flow (source total) possible if load is active an example of active load is d.c motor acting on Regenarating Breaking mode.

Note! -


## Class-C (Type-c / Two Quandent Class-A chopper




=) In this type of chopper is the combination of class-A + class-B type chopper i.e power flow may be from source to load or from load to source.

=) So this type of chopper is used where F/w motoring + Reganera.. Breaking is required.

=) When $T_1$ ON during ON periods to current start flowing from source towards loads + current direction is shown in the above.

- After turn off the $T_1$ the load free wheels through $D_2$ maintaining current direction is same.

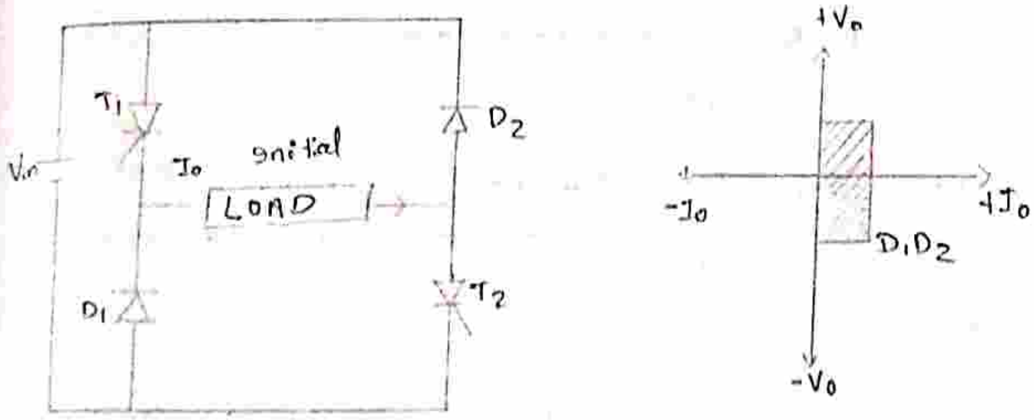
- Hence power flow is from source to load, which gives rise to 1st quardent operation.

- When due to any reason $V_0$ is greater than $V_{dc}$ ($V_0 > V_{dc}$ or $V_{in}$)

- Then any device among $D_1$ & $T_2$ used for return back power to load to source.

- Hence the above CKt used in both f/w motoring as well as regenerative breaking.

## Class - D / Type - D / Two quardent class - B Type chopper




Here this CKt gives 02 quandent operation i.e. quandent 1 & quanden 4 i.e f/w motoring & reverse motring.

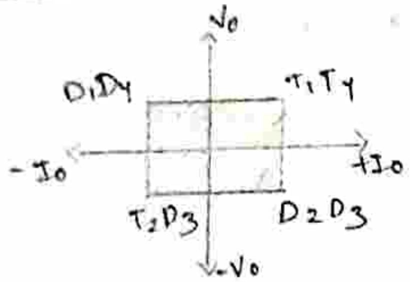
Here 02 SCR $T_1$ & $T_2$ & 02 diode $D_1$ & $D_2$ which are anti parallel connected in bridge manner the load is centre tap.

When $T_1$ & $T_2$ are ON load voltage $V_0$ is +ve & $I_0$ also +ve

When $T_1T_2$ off but $D_1D_2$ conducts at that time the $V_0$ accross load is reversed i.e $-V_0$ but current flow is same.

Hence we say that here power flow is both +ve & -ve (source to load or load to source).

Class-E / Type-E / 4 Quandent chopper


→ This CKt is used for 4 quandent operation i.e 1,2,3 & 4 i.e 4 no of operation is possiable.

→ Hence the CKt designed for f/w motoring, regenerative breaking reverse motoring & reverse regenerate breaking.

1st quandent :

When $T_1$ & $T_4$ is ON the $V_0$ & $I_0$ are +ve gives rise to 1st quandent operation which indicates f/w motoring.

2nd Quandent :

When $D_1$ & $D_4$ are conducts the current direction reversed i.e ($-I_0$), but $V_0$ polarity is same $V_0$ is +ve which 2nd quandent operatio This indicate regenerative breaking (o/p power in greater than supply power).

3rd quardent :

...en $T_2$ & $T_3$ are conducts voltage applied across the load is ...versed i.e. $V_o$ is -ve & also the current direction is change. ...ence $I_o$ is -ve which gives rised to 3rd quardent operation, ...ence indicate reverse motoring.

4th quardent

...hen $D_2$ & $D_3$ are conducts the voltage polarity is -ve but current polarity is +ve hence power flow is -ve that indicates reverse regenerative breaking.

## CYCLO CONVERTER.

A device which converts ~~field~~ fixed voltage, fixed frequency of AC supply to variable voltage.
variable frequency at one stage of conversion known as cyclo converter.

We also convert fixed voltage fixed frequency into variable voltage, variable frequency by rectifier - inverter ckt which is we two-stage conversion but cyclo converter converts it one-stage.

Application

(1) Induction heating
(2) Static VAR (volt Ampere Reactive generation.)
(3) Speed control of A.C drives.

## Disadvantages

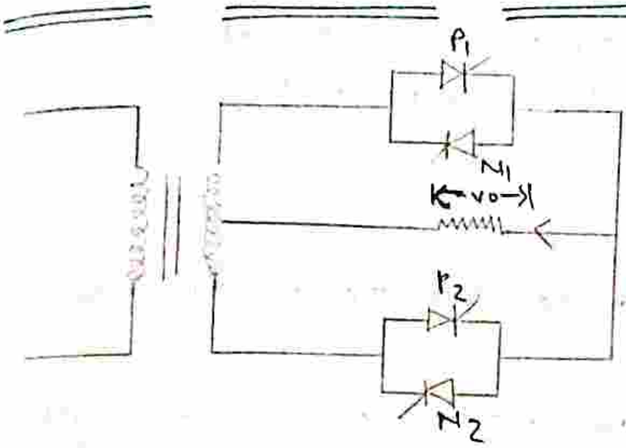
1. As the o/p is variable frequency hence o/p voltage contains Harmonits.
2. Smooth variation of o/p frequency is not possiable.
3. A complicated firing ckt is required.

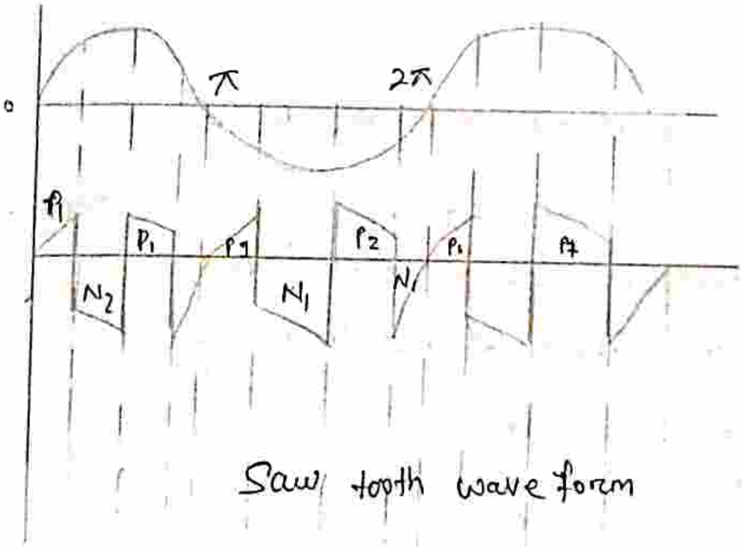
## Types

CYCLO CONVERTER

- 1ϕ to 1ϕ cyclo converter
  - Step Up ($f_o > f_i$)
    - Bridge type cyclo converter
    - Mid point type cyclo converter
  - Step down ($f_i > f_e$)
    - Bridge type cyclo converter
    - Mid point type cyclo converter
- 3ϕ to 1ϕ cyclo converter
- 3ϕ to 3ϕ cyclo converter

Mid point type step up cyclo converter with R-load




Saw tooth wave form

## Ckt description

The ckt represent of mid point type step up cyclo converter with R-load i.e o/p frequency ($f_o$) is greater than i/p frequency ($f_i$).

The ckt consist of 2 sets of antiparallel SCR's which have centre tap T/P which is connected by means of load.

The ckt required firing ckt as well as forcelly commuted ckt.

The SCR $P_1$ & $P_2$ constitute +ve group but $N_1$ & $N_2$ constitute -ve group.

## Operation

### Mode - I $(0 < \omega t < \pi)$

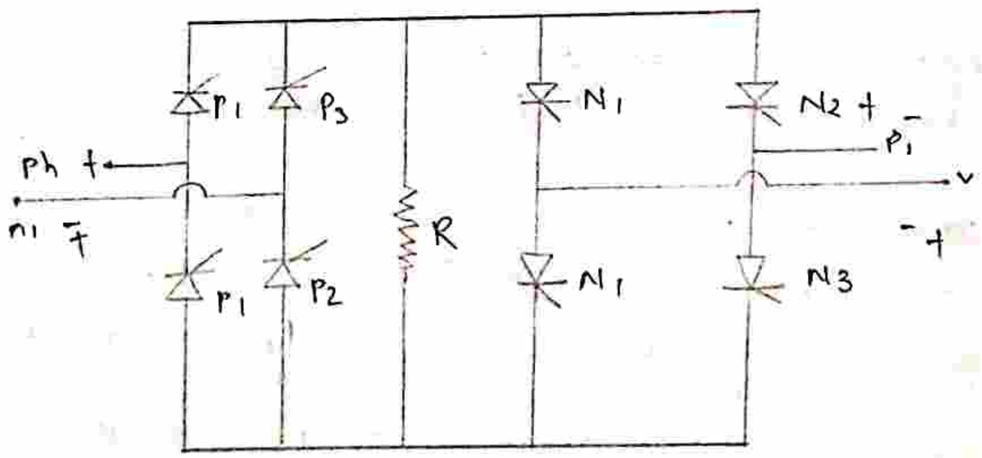
- During +ve half cycle $P_1$ & $N_2$ are f/w biased at $\omega t = 0$, P trigger by giving gate pulse for giving +ve half cycle & turn off at ~~cot~~ $\omega t = \omega t_1$ & gate pulse given to $N_2$.

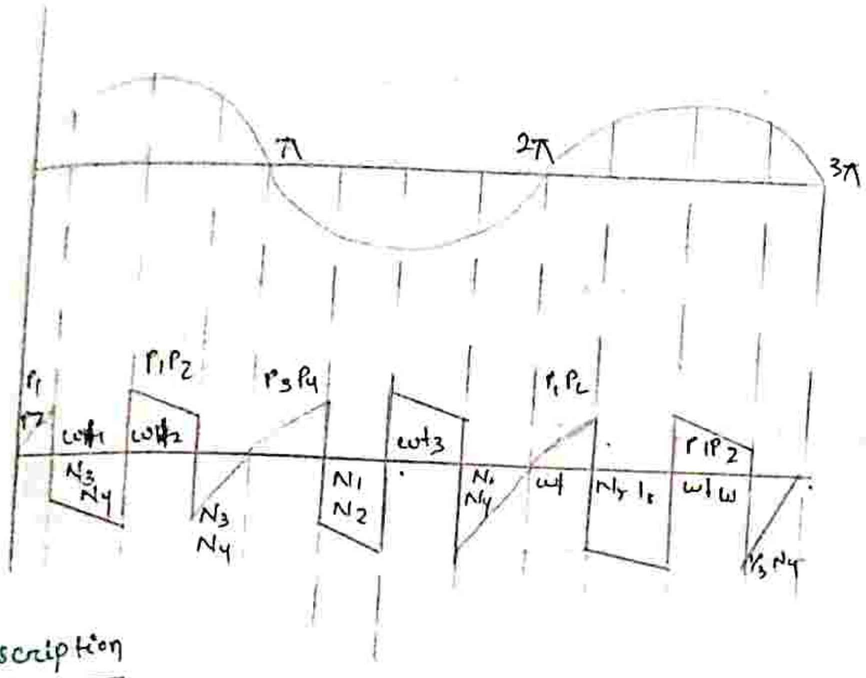
- Hence $N_2$ give -ve half cycle then the above repeted for $\omega t = \omega t_2, \omega t_3, \omega t_4$.
- Result one +ve half cycle spited into 2 no. of complete cycle.

### Mode - II $(\pi < \omega t < 2\pi)$

- During -ve half cycle $N_1$ & $P_2$ are f/w biased.
- the similar process is repeted i.e. $P_2 - N_1$, $P_2 - N_1$ "ON" which again split -ve half cycle into 02 no. of complete cycle.
- so the o/p frequency is 4 times of i/p frequency.

### Bridge type step up cyclo converter with R - Load






## ckt description

- Here there are 4 nos of SCR's constitute +ve group as well as -ve group i.e $P_1P_2$ $P_3P_4$ and give rise to +ve half cycle & $N_1N_2N_3N_4$ are gives rise to -ve half cycle.
- Here again 02 mode of operation.

## Operation

**Mode-I** $(0 < \omega t < \pi)$

- During +ve half cycle $P_1P_2$ & $N_3N_4$ are F/W biased.
- During 0 to $\omega t_1$, $P_1$ & $P_2$ fires and conducts at $\omega t = \omega t_1$, $P_1P_2$ off & $N_3N_4$ are fires & conducts upto $\omega t_1 \to \omega t_2$.
- If $P_1P_2$ gives ~~re is~~ rise to +ve half cycle then $N_3N_4$ gives rise to -ve half cycle.
- This cycle is repeated for $\omega t = \omega t_2$ & $\omega t = \omega t_3$ & the wave form shown in the above.

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

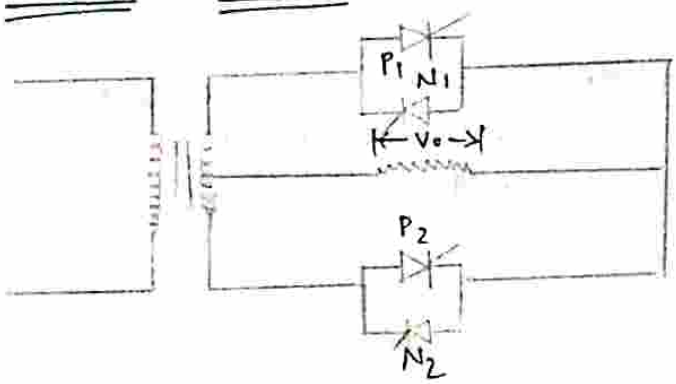
=) During this half cycle $P_3 P_4$ + $N_1 N_2$ are F/w biased.

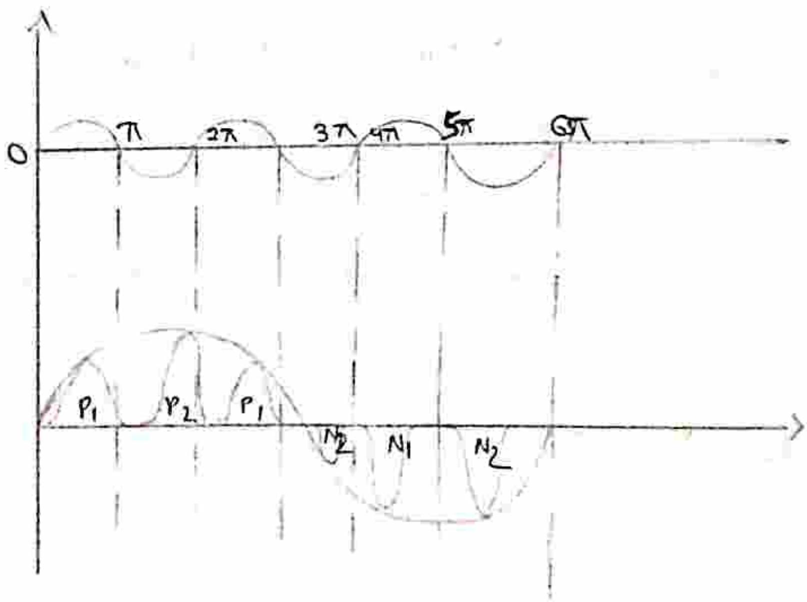
-) $P_3 P_4$ gives rise to +ve half cycle + $N_1 N_2$ gives rise to -ve half cycle.

=) The triggering of $P_3 P_4 \rightarrow N_1 N_2 \rightarrow P_3 P_4 \rightarrow N_1 N_2$ repeted for -ve half cycle + the wave form when in the above fig.

-) Hence one cycle of i/p will be converted into 4 no. of o/p cycle hence frequency step up.

Midpoint type step down cyclo converter with R-Load



## Ckt description

- The ckt represent of midpoint type stepdown cyclo converter with R-load i.e o/p frequency ($f_o$) is less than i/p frequency ($f_i$)

- The ckt consist of 2 sets of antiparallel SCR's which have centre tap T/F which is connected by means of load.

- The ckt required firing ckt as well as forcefully commutated ckt
- The SCR $P_1$ & $P_2$ constitute +ve group but $N_1$ & $N_2$ constitute -ve group.

Mode-I ($0 < \omega t < 3\pi$)

- As we know that during +ve half cycle of i/p $P_1$ & $N_2$ are f/w biased and during -ve half cycle $P_2$ & $N_1$ f/w biased.

- During $0 \rightarrow \pi$, $P_1$ "ON", $\pi \rightarrow 2\pi$ $P_2$ "ON" & again $2\pi \rightarrow 3\pi$. P "ON".

- The o/p of 3 half cycle combinly gives one +ve half cycle.

Mode-II ($3\pi < \omega t < 6\pi$)

- In this mode we turn on only "-ve" groups of SCR.

- During $3\pi \rightarrow 4\pi$ $N_2$ "ON" & $4\pi \rightarrow 5\pi$ $N_1$ "ON" & $5\pi \rightarrow 6\pi$ "$N_2$" ON.

- If we combine the o/p of above half cycle it gives rise a one -ve half cycle.

- Hence we step down the frequency.

# THYRISTOR APPLICATION

## SMPS :

① It stands for switch mode power supply.

② It is based on a d.c chopper with a rectifier & possiable transform o/p.

③ It is used for medium to high power application & also used for power supply to computer.

④ It is prefer because of small size & low weight.

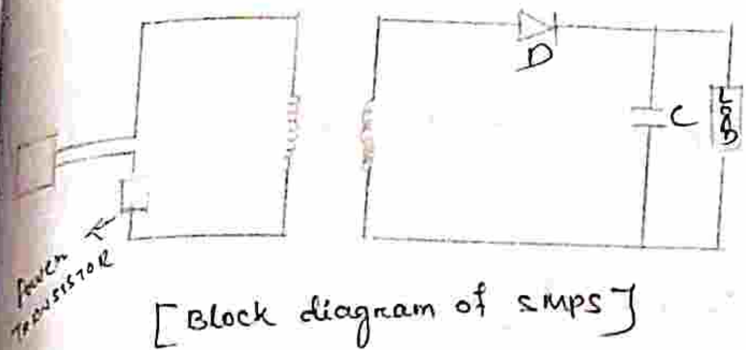
⑤ In general rectifier operats on 50 Hz or 60 Hz A.C supply and inorder to obtained negligible repple (distrurbance frequency) in o/p of rectifier the filter ckt is required and the ckt is become quite large & losses is high, hence efficiency is less.

⑥ To avoid this bulky ckt SMPS is develop.

⑦ ON/OFF switch vary rappidly A.C ripple rises this is now chacked by L & C Such are used for operation power electronic devices power, MOSFET, power , power BJT etc.

⑧ Due to this SMPS became small in size & less weighthy.

⑨ It is develop by NASA, for use in its space vehichle.




[Block diagram of SMPS]

(x) Here A.C supply is give to a Thyristor rectifier which is used for contron d.c o/p.

(xi) The AC supply is given by inverter ckt which is acts inverter as well as filter.

(xii) Now the ripples checked by own ckt filter ~~elem~~ elements like L+C.

(xiii) The d.c o/p is applied power transistor for amplification at desired value.

(xiv) Now the d.c o/p regulated by T/F connected in the amplification ckt and applied to load.

(xv) Hence smps perform 4 no. of operation ie.

(i) Rectification

(ii) Controlling

(iii) Trans formation

(iv) Filteration.

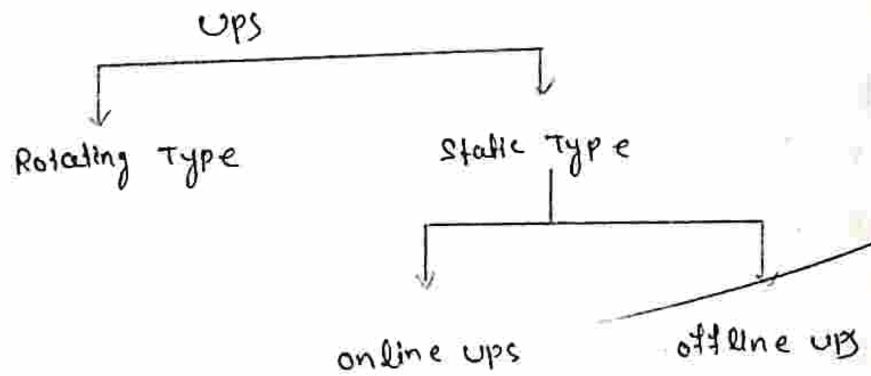
## UPS :

- Stand for Uninterruptable power supply.
- UPS mean there is no interruption (failour) of power supply to the equipment or device.
- Compansation during faillour of grid.

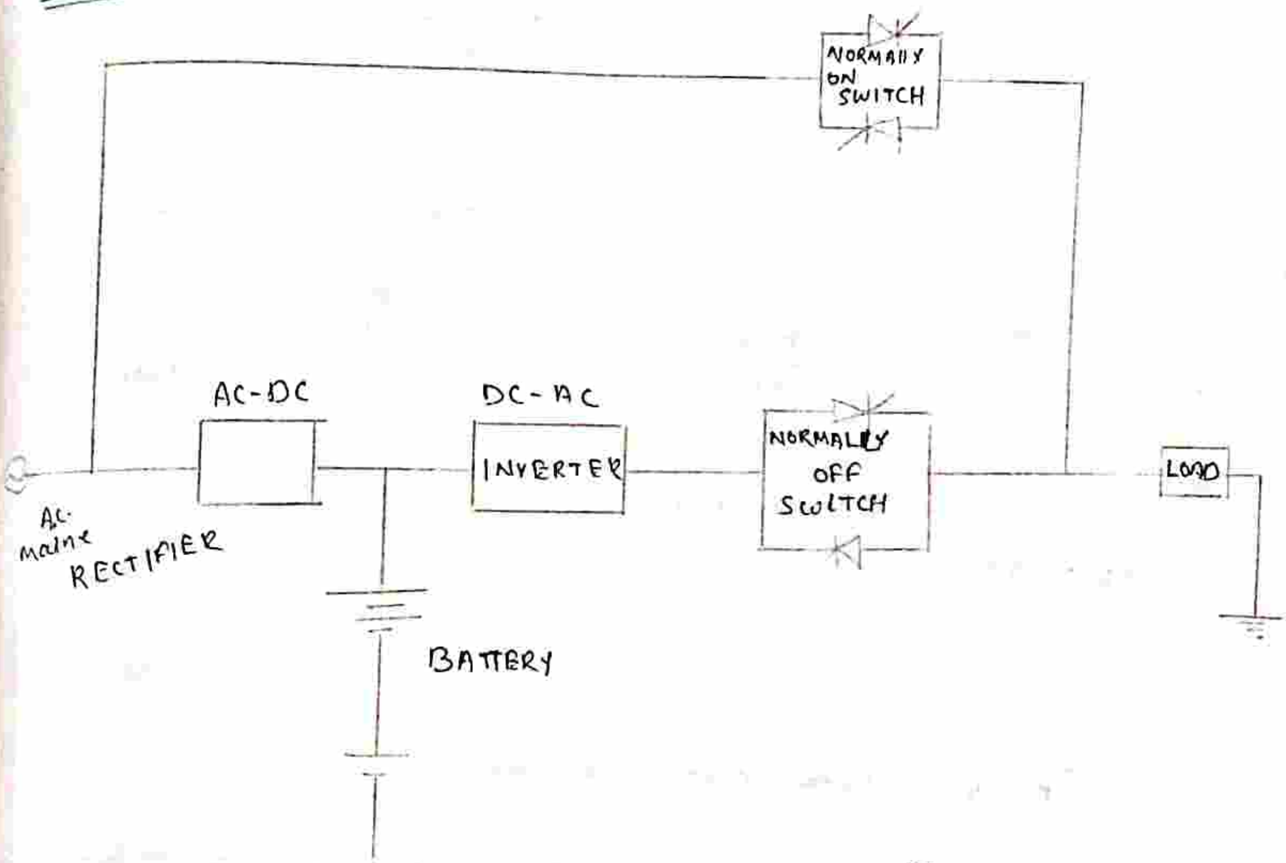
## Uses :

- Hospital I.C.U
- Air lines and Railway reservation.
- Computer system.
- Process Control in plant.
  (Different s/w control like P.L.C & scada)
- USP convert bad quality commercial signal or supply of const. voltage & constant frequency.

## Types



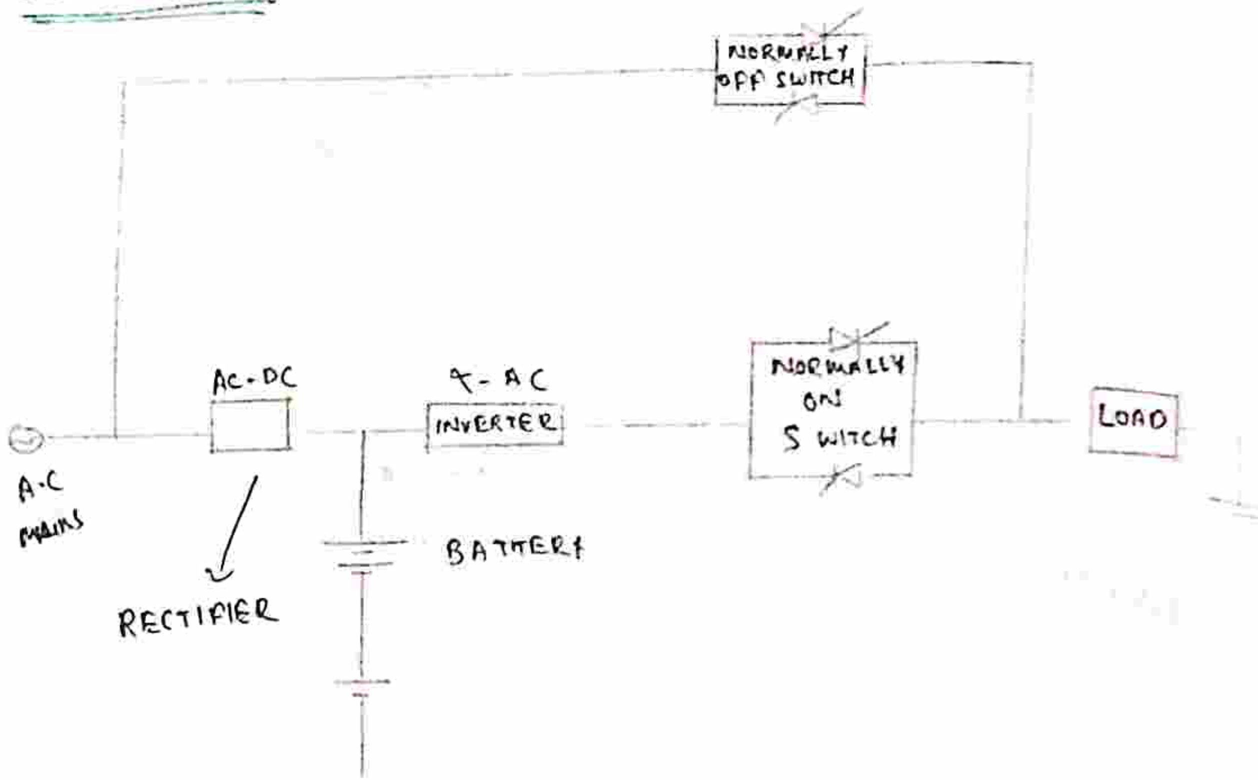
## Off LINE Ups




[ BLOCK DIAGRAM OF OFF LINE UPS ]

- This type of UPS the converter ckt is normally in off state so it is named as off line UPS.
- The load is fed by direct main through normally ON static switches.
- During A.C power available rectifire convert A.C to A.C of charge up the batter.
- When there is a power failour low the battery supply the store power to inverter which convert d.c to A.C.
- During power switches which is off position be came 'ON' automatically & A.C supply is fed to load.

* ON LINE UPS:




[BLOCK DIAGRAM OF ON LINE UPS]

(i) In this type of UPS the inverter ckt is normally on by Static switch Continious i/p is fed to load by inverter ckt so it is named as ON Line UPS

(ii) When A.C supply is available it is rectify by rectifier a to d.c & fed to both for charging battery and inverter ckt

(iii) The inverter inverting by D.C to A.C and by the help normally ON static switch to load.

(iv) During power failour battery by necessary power to i/p inverter & by the help normally ON static switch fed to load.

There is a fault occurs inverter CKT then normally "ON" switch became "off" and normally "OFF" Switch become "ON" direct A.C power is fed to load.

# POWER SEMICONDUCTER DEVICES AND IT'S PROTECTION

## Power Transistors :

i) The transistor which operate as high voltage & high current known as power transistor which is available recent years.

ii) In power electronics the power transistor are used as a switch.

iii) The transistor are operate f/w biased.

iv) Hence during this mode the voltage drop is minimum i.e 0.5V to 0.8V

v) For faster turn on & keep conducting mode of power transistor access base current as well as continious Bas current is required.

vi) If Base current is removed the transistor is turn off & the value of base collector voltage predict about the time of turn ON.

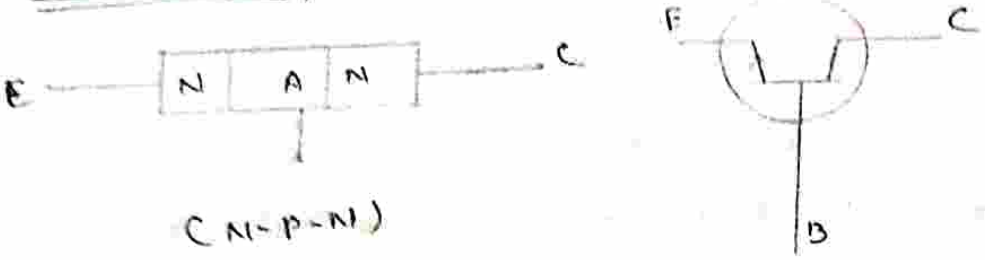
vii) There are 3 types.

1- Power BJT

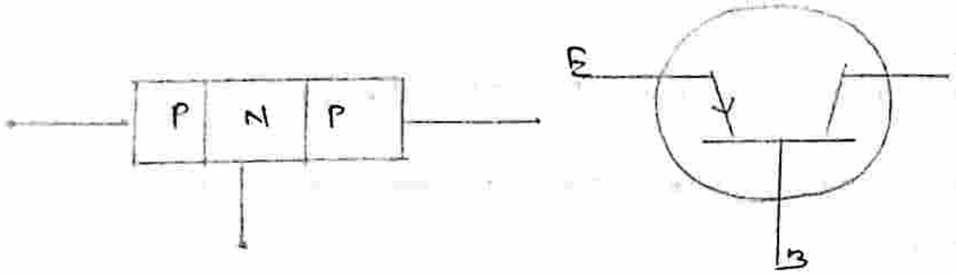
2- Power MOSFET

3- IGBT (Insulated Gate Bipolar Transistor)

POWER BJT :




(N-P-N)




(P-N-P)

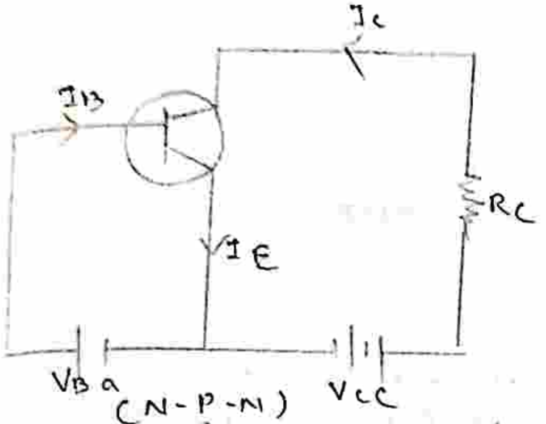
(i) Power BJT is a 3 layer 3 terminal 2 junction semiconduct devices,

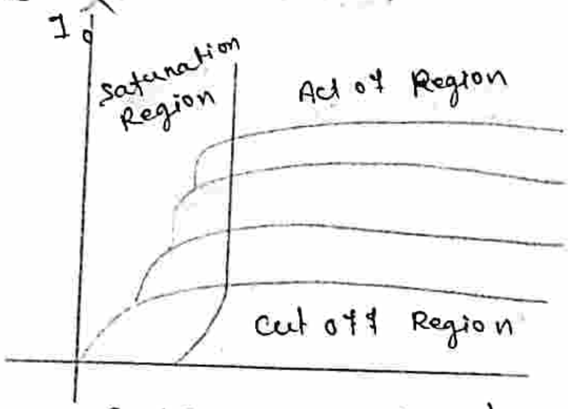
(ii) It is known as Bipolar junction transistor because there are 02 types of bipole are involve for current flow i.e holes & electron.

## Steady state characteristic :-

-) The 3 possible configuration i.e Common Emitter, Common Base, Common Collector.

-) The common emitter configuration is widely used for switching application.

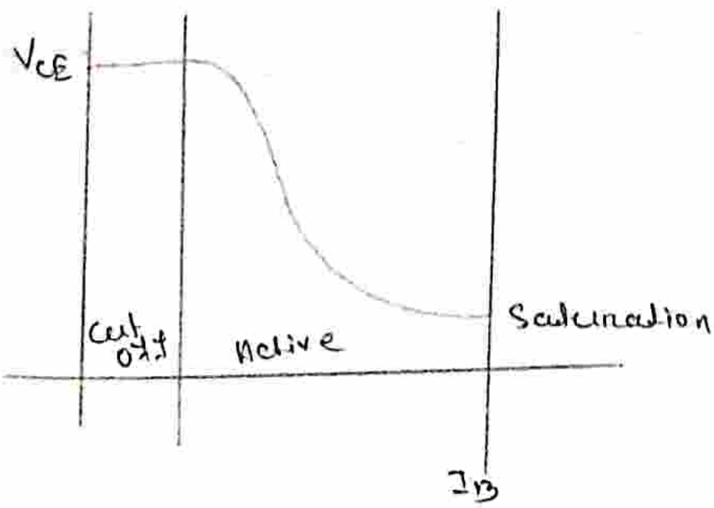



(O/P characteristic)

## I/P characteristic :

- The i/p characteristic of BJT is obtained by ploting the graph be '$I_B$' & $V_{BE}$
- This characteristic Same as that of diode i.e if f/w voltage increases then Base current increase Hence the curve form is looks like hyparabola.

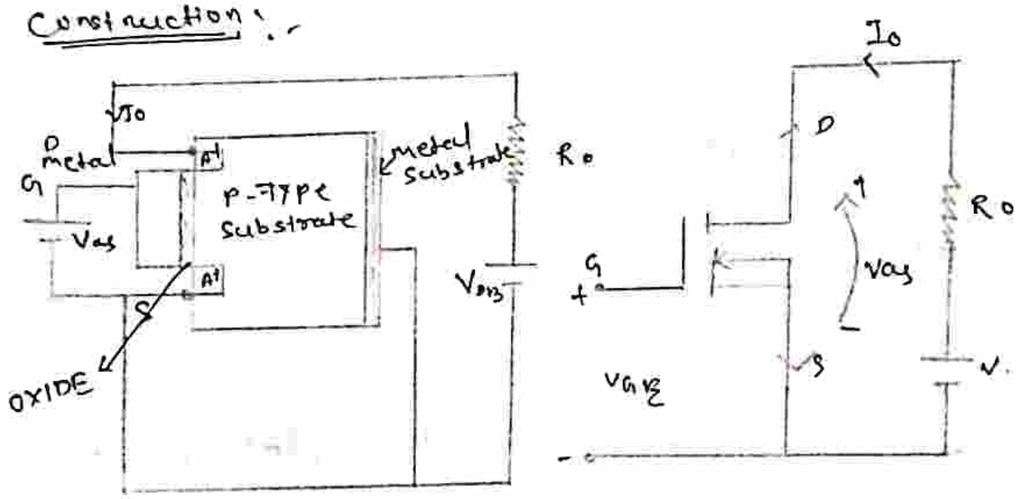


## Types:

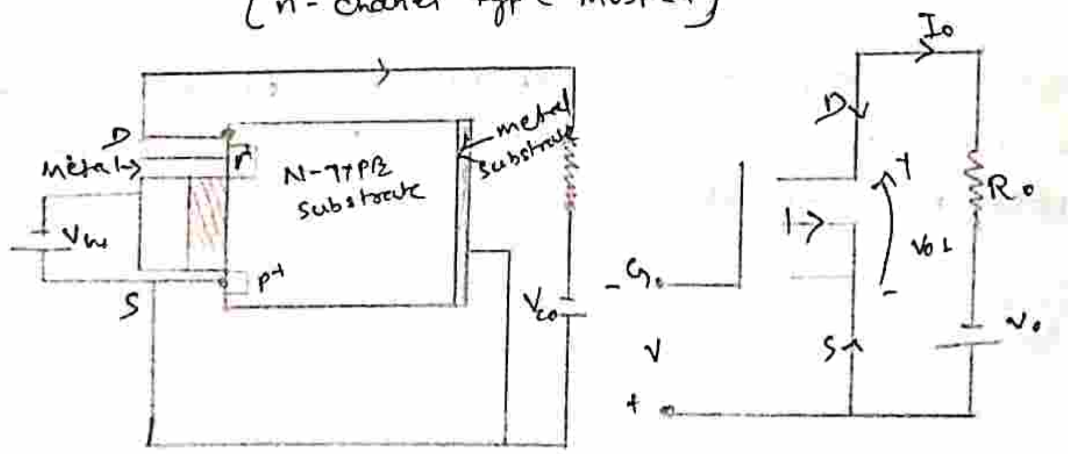
- MOSFET
  - Depletion type MOSFET
    - P-chanel MOSFET
    - N-chanel MOSFET
  - Enhancement MOSFET
    - P-chanel MOSFET
    - N-chanel MOSFET

The power MOSFET is generally enhancement type

## Construction:-




[n-chanel type MOSFET]



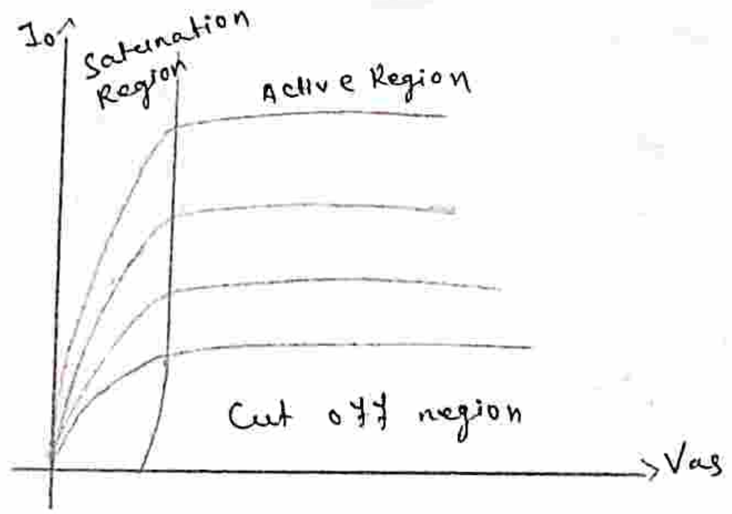
- N chanel Enhacement type MOSFET having p-type substrate where we found higher mobility e⁻s.

- In p-channel enhacement type MOSFET having n-type substrate where we found as mobility of $e^{-}$s

- Due to higher mobility of electran
  N-channel enchacement type
  MOSFET is used.

o/p characteristic :

- The o/p characteristic is drawn betn $V_{GS}$ & $I_D$




we also found 3 region particular value of $V_{GS}$.

- Cut off Region ($V_{GS} \leq V_T$)

  $V_T$ = Threshold voltage of $V_{GS}$ i.e minm. value of $V_{GS}$ below which MOSFET does not turn on.

- Saturation Region ($V_{DS} \geq V_{GS} - V_T$)

- Active Region ($V_{DS} \leq V_{GS} - V_T$)

# IGBT

-) It stand for Insulated Gate Bipolar junction Transistor.

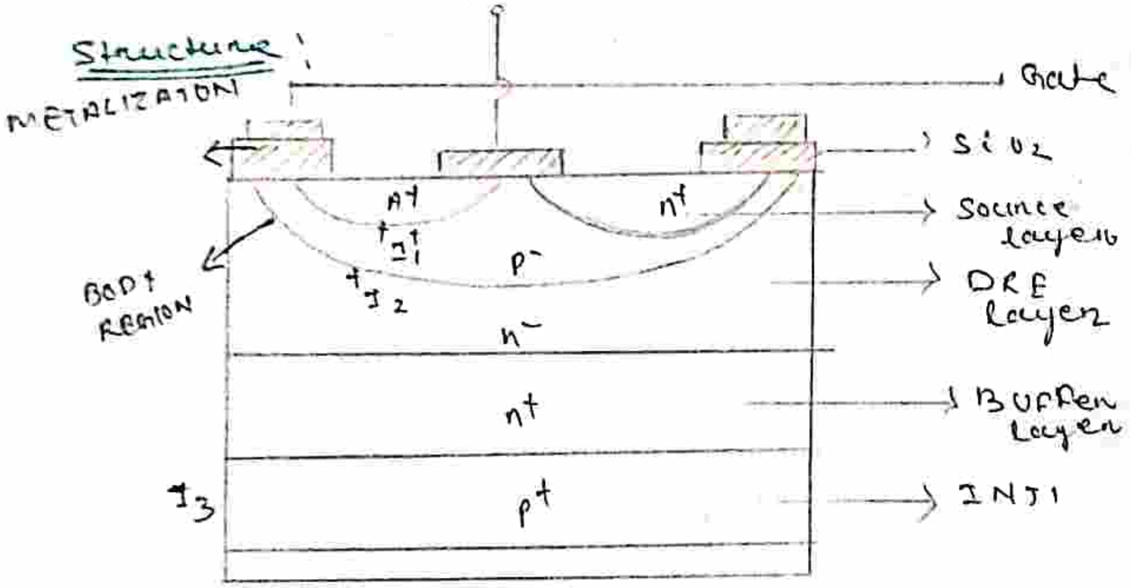
-) By combining the characteristic of power MOSFET & power BJT

-) IGBT is develop i.e It has a characteristic of voltage control similar to power MOSFET & current source similar to power BJT.

-) Hence IGBT is a voltage control current source.

-) It has significantly greater turn off time, than power MOSFET

**Structure :**




-) The above fig show vertical crossection of n- channel IGBT.

-) Here the n- layer is used for majority charge carrier which maximum the current source.

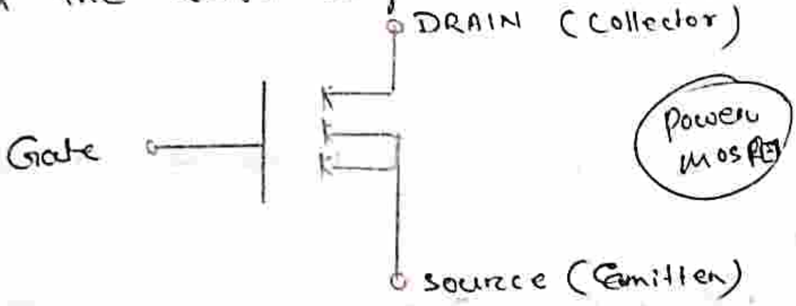
-) This will reduce the resistance offer to the current flow & hence the n state power los taking place in the device.

-) The IGBT is also used highly integrated Gate - source structure in order to reduce the possible to source/ Emitter current crowding.

• When difference in the structure MOSFET as compare to that of MOSFET is the existance of p+ for that forms drain of the IGBT.

• It is also possible to make channel IGBT by changing the doping type in each of the layer of the device.

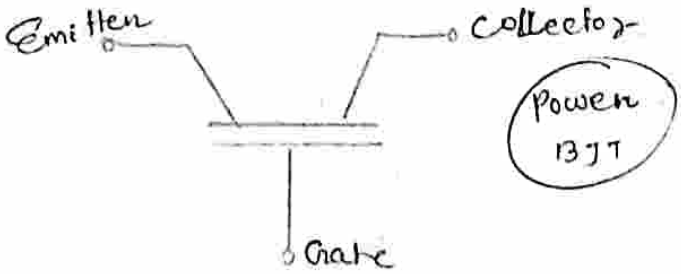
• The n+ Buffer layer bet p+ drain layer & n- drift layer is not essential for the operation of IGBT but it insulated the drift layer + drain layer (p+).




(n-Channel)

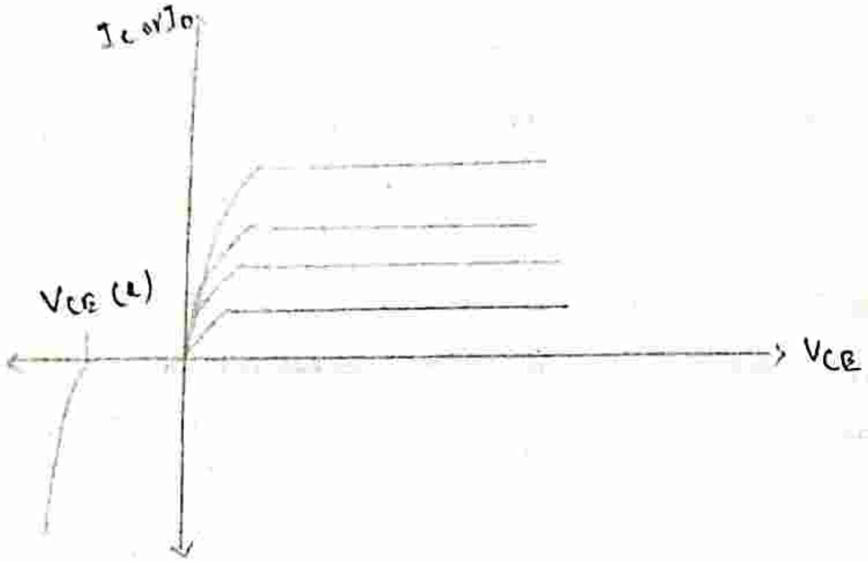
• It is a ③ terminal devices Gate, Source + Drain.

• In p. channel IGBT the direction of arrow head could be reversed.




• The above 02 symbol are represent as power MOSFET + power BJT

## V-I characteristic :




- When there is no voltage applied to the Gate the IGBT is in off state.
- In this state the current Io or Ic is equal to zero & voltage across IGBT is equal to zero & voltage across IGBT is Same as source voltage.

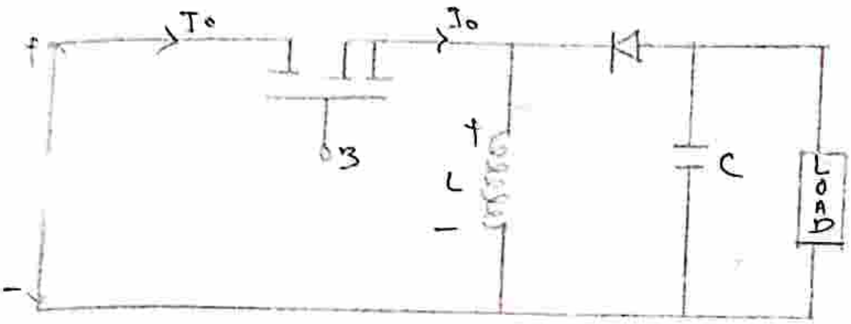
- In ON state the voltage IGBT is equal to zero.

- V.I characteristic the in current increase with increase in gate to source voltage for +ve VGS & the . breakdown occur when voltage is -Vce (R) & F/W Breakdown occur when the voltage is Vce (F)

Hence voltage is in betn

$V_{CE}(R) < V_{CE} < V_{CE}(F)$

## BUCK-BOOST CONVERTER :

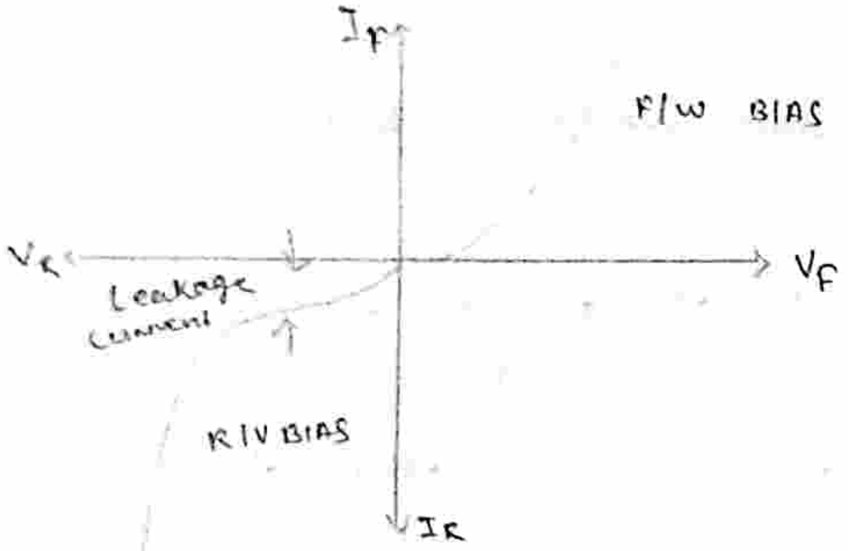



- As the name indicates the Buck-Boost Converter cascading of 02 converter one it step down other is step up.
- The main application of such ckt or convertor is in regulating the d.c power supply.
- Here in -ve polarity o/p may be desired of i/p voltage & the o/p voltage can be either higher or lower that the i/p voltage.
- when the power MOSFET is switch on the supply current flow through the path $Edc^+ \to M \to L \to Edc^-$ (M-MOSFET)

### Construction :

- A power diode is a 02 terminal 02 layer one junction device.
- Here the symbol is a diode with circle which represents power diode.
- The p-layer act as anode while N-layer acts as cathode.

## V-I characteristic : (Power diode)


→) V-I characteristic of a power diode is the curve betⁿ voltage across the junction & the CKt current.

→) voltage is taken in x-axis & current is taken in y-axis.

→) when the anode is +ve w.r.t cathode than the diode is known as F/W biased.

→) In this condⁿ the diode conduction from anode to cathode.

→) Hence the voltage drop across diode is vary less or negligible.

→) This voltage drop is ~~dependany~~ depends up manufacturing technology as well as the metal which is used.

→) So the voltage & current graph is gradually increases the voltage is increases.

→) when anode is -ve w.r.t cathode then the condⁿ is known as reverse biased condⁿ.

-) Under reverse biased condⁿ a small reverse current (leakage current) in the range of mili ampere flow in reverse direction.

-) Hence the inductor 'L' stores the energy during the turn on period hence 'L' stores the energy during turn on.

-) When m is switch off the inductor current tends to decreases as a result the polarity of the emf induced in 'L' is reversed & thus inductor (L) discharge the energy through load. The current flow $L^+ \rightarrow$ load $\rightarrow D \rightarrow L^-$.

-) The ckt acts as step up or step down depending upon the turn on time.

-) Here capacitor is used as filter ckt.

## Power Diode


1) As we know that Diode is a electronic device which is use as switch for turn on or off an electronics ckt.

2) Similarly in the power ckt power diodes are used which is acts as a switch to perform various function these are as follows:

(A) Rectification
(B) Free wheeling in switching regulator.
(C) Energy transfer betⁿ componente
(D) Voltage Isolation. (Distinguise betⁿ. source voltage to load voltage).
(E) Energy feed back from load to power source.

The reverse voltage increases with increase in leakage current of reverse voltage is so high an avalanche breakdown of junction is occurs as a result reverse current increases rappidly which is shown in the above gra

=) The voltage at which r/v break down occur is known as reverse breakdown voltage which is depends upon manufacturing technology as well as nature of matatri

=) So Power diodes mostly used as an ideal switch in a Power ckt in general practice.

* Differenceiate betn

| Power BJT | Power MOSFET |
| --- | --- |
| (i) Power BJT is a Bipolar device depends upon holes and electrons. | (i) Power MOSFET is a Unipolar device, which charge flow is depends upon either holes or electron. |
| (ii) It is current control device o/p current + voltage is the function of i/p. | (ii) It is voltage control devic |
| (iii) The i/p impedance is high in the range of K-Ω. | (iii) The i/p impedance is very high in the range of M-Ω |
| (iv) Switching frequency is flow in the range of KHz. | (iv) Switching frequency is hig in the range of MHz. |
| (v) It is availocble at high power rating. | (v) It is available at low pow rating. |
| (vii) It is lower thermal stability. | (vii) It is better thermal stabi |
| (viii) More noising | (viii) Less noising. |

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