LECTURE NOTES

ON

POWER ELECTRONICS AND PLC

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TH.5 POWER ELECTRONICS AND PLC

Name of the Course: Diploma in Electrical Engineering			
Course code:	Th.5	Semester:	5^{th}
Total Period:	60 Periods	Examination:	3 Hrs
Theory periods:	4 P / Week	Internal Assessment:	20
Tutorial:	-	End Semester Examination:	80
Maximum marks:	100		

A. Rationale:

The development of high power semiconductor devices has facilitated electronic control techniques for electrical power control in a simple, economic and efficient manner. Thus a new area of power electronics has now emerged which replaced the old and bulky method of power control through the use of small electronic devices. Power electronics application has occupied an indispensible position in industrial applications like heating, welding, uninterrupted power supply, battery charging etc. Industrial drives, lighting control are most efficiently controlled by power electronics devices to achieve optimum performance. The objective of this paper is to familiar students with the principles and operations of Power electronics devices in Industrial applications with drives control.

B. Objectives:

After completion of this subject the student will be able to:

1. Understand construction, working principle & application of various power electronics devices.
2. Know different gate triggering circuits and commutation methods.
3. Understand working principle of phase controlled rectifier.
4. Know the types and working principle of inverter.
5. Understand working principle and voltage control of chopper.
6. Understand frequency variation using Cyclo-converter.
7. Understand control principle of AC & DC industrial drive.
8. Know different application of SCR / Thyristor.
9. Concept in PLC & its Programming

C. TOPIC WISE DISTRIBUTION OF PERIODS

Sl. No.	**Topics**	**Periods**
1.	Understand The Construction And Working Of Power Electronic Devices	18
2.	Understand The Working Of Converters, Ac Regulators And Choppers.	12
3.	Understand The Inverters And Cyclo-Converters	08
4.	Understand Applications Of Power Electronic Circuits	10
5.	PLC And Its Applications	12
	Total	**60**

D. COURSE CONTENT:

1. UNDERSTAND THE CONSTRUCTION AND WORKING OF POWER ELECTRONIC DEVICES

- 1.1 Construction, Operation, V-I characteristics & application of power diode, SCR, DIAC,TRIAC, Power MOSFET,GTO &IGBT
- 1.2 Two transistor analogy of SCR.
- 1.3 Gate characteristics of SCR.
- 1.4 Switching characteristic of SCR during turn on and turn off.
- 1.5 Turn on methods of SCR.
- 1.6 Turn off methods of SCR (Line commutation and Forced commutation)
  - 1.6.1 Load Commutation
  - 1.6.2 Resonant pulse commutation
- 1.7 Voltage and Current ratings of SCR.
- 1.8 Protection of SCR
  - 1.8.1 Over voltage protection
  - 1.8.2 Over current protection
  - 1.8.3 Gate protection
- 1.9 Firing Circuits
  - 1.9.1 General layout diagram of firing circuit
  - 1.9.2 R firing circuits
  - 1.9.3 R-C firing circuit
  - 1.9.4 UJT pulse trigger circuit
  - 1.9.5 Synchronous triggering (Ramp Triggering)
- 1.10 Design of Snubber Circuits

2. UNDERSTAND THE WORKING OF CONVERTERS, AC REGULATORS AND CHOPPERS.

- 2.1 Controlled rectifiers Techniques(Phase Angle, Extinction Angle control), Single quadrant semi converter, two quadrant full converter and dual Converter
- 2.2 Working of single-phase half wave controlled converter with Resistive and R-L loads.
- 2.3 Understand need of freewheeling diode.
- 2.4 Working of single phase fully controlled converter with resistive and R- L loads.
- 2.5 Working of three-phase half wave controlled converter with Resistive load
- 2.6 Working of three phase fully controlled converter with resistive load.
- 2.7 Working of single phase AC regulator.
- 2.8 Working principle of step up & step down chopper.
- 2.9 Control modes of chopper
- 2.10 Operation of chopper in all four quadrants.

3. UNDERSTAND THE INVERTERS AND CYCLO-CONVERTERS

- 3.1 Classify inverters.
- 3.2 Explain the working of series inverter.
- 3.3 Explain the working of parallel inverter
- 3.4 Explain the working of single-phase bridge inverter.

3.5 Explain the basic principle of Cyclo-converter.
3.6 Explain the working of single-phase step up & step down Cyclo-converter.
3.7 Applications of Cyclo-converter.

4. UNDERSTAND APPLICATIONS OF POWER ELECTRONIC CIRCUITS

4.1 List applications of power electronic circuits.
4.2 List the factors affecting the speed of DC Motors.
4.3 Speed control for DC Shunt motor using converter.
4.4 Speed control for DC Shunt motor using chopper.
4.5 List the factors affecting speed of the AC Motors.
4.6 Speed control of Induction Motor by using AC voltage regulator.
4.7 Speed control of induction motor by using converters and inverters (V/F control).
4.8 Working of UPS with block diagram.
4.9 Battery charger circuit using SCR with the help of a diagram.
4.10 Basic Switched mode power supply (SMPS) - explain its working & applications

5. PLC AND ITS APPLICATIONS

5.1 Introduction of Programmable Logic Controller(PLC)
5.2 Advantages of PLC
5.3 Different parts of PLC by drawing the Block diagram and purpose of each part of PLC.
5.4 Applications of PLC
5.5 Ladder diagram
5.6 Description of contacts and coils in the following states
i)Normally open ii) Normally closed iii) Energized output iv)latched Output v) branching
5.7 Ladder diagrams for i) AND gate ii) OR gate and iii) NOT gate.
5.8 Ladder diagrams for combination circuits using NAND,NOR, AND, OR and NOT
5.9 Timers-i)T ON ii) T OFF and iii)Retentive timer
5.10 Counters-CTU, CTD
5.11 Ladder diagrams using Timers and counters
5.12 PLC Instruction set
5.13 Ladder diagrams for following
(i) DOL starter and STAR-DELTA starter (ii) Stair case lighting (iii) Traffic light Control (iv) Temperature Controller
5.14 Special control systems- Basics DCS & SCADA systems
5.15 Computer Control–Data Acquisition, Direct Digital Control System (Basics only)

Syllabus coverage up to Internal assessment

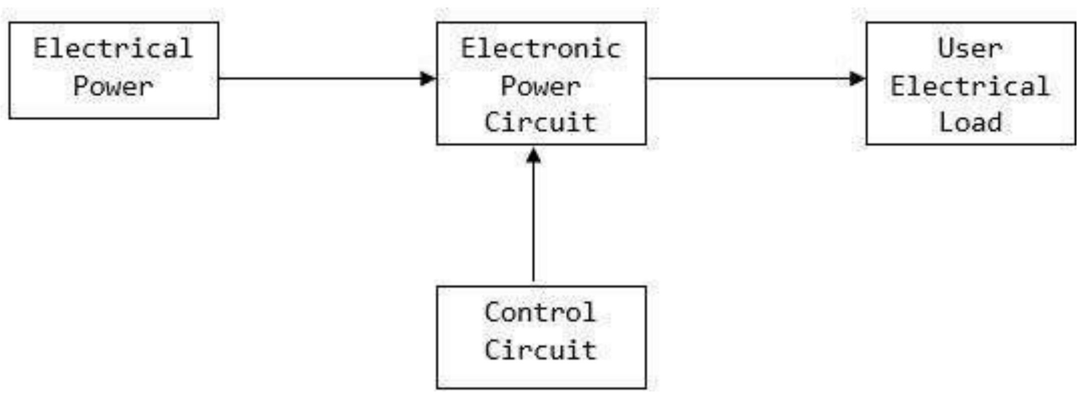
Chapters: 1 and 2.

Learning Resources:			
Sl.No	***Title of the Book***	***Name of Authors***	***Name of the Publisher***
1.	*Power Electronics*	*Dr. P. S. Bhimbhra*	*Khanna Publisher*
2.	*Modern Power Electronics*	*B.K.Bose*	*PHI Publisher*

	and AC Drives		
3.	*Power Electronics*	*M. D. Singh and K.B Khanchandani*	*TMH*
4.	*Power Electronics*	*M H Rashid*	PHI Publisher
5.	*Power Electronics*	*P C Sen*	*TMH*
6.	*Power Electronics*	*N Mohan*	*Willey (India)*
7.	*Programmable logic Controllers*	*Frank D. Petruzela*	TMH
8.	*Programme logic controller*	*Dr.M.Mitra&Dr.S.Sengupta*	*Penram*

CHAPTER-I: Introduction to power electronics:

Power Electronics is a field which combines Power (electric power), Electronics and Control systems. Power engineering deals with the static and rotating power equipment for the generation, transmission and distribution of electric power. Electronics deals with the study of solid-state semiconductor power devices and circuits for Power conversion to meet the desired control objectives (to control the output voltage and output power). Power electronics may be defined as the subject of applications of solid-state power semiconductor devices (Thyristors) for the control and conversion of electric power.



Power electronic applications

Commercial applications -Heating Systems Ventilating, Air Conditioners, Central Refrigeration, Lighting, Computers and Office equipments, Uninterruptible Power Supplies (UPS), Elevators, and Emergency Lamps

Domestic applications- Cooking Equipments, Lighting, Heating, Air Conditioners, Refrigerators & Freezers, Personal Computers, Entertainment Equipments, UPS

Industrial applications- Pumps, compressors, blowers and fans Machine tools, arc furnaces, induction furnaces, lighting control circuits, industrial lasers, induction heating, welding equipments

Aerospace applications- Space shuttle power supply systems, satellite power systems, aircraft power systems.

Telecommunication- Battery chargers, power supplies (DC and UPS), mobile cell phone battery chargers

Transportation Traction control of electric vehicles, battery chargers for electric vehicles, electric locomotives, street cars, trolley buses, automobile electronics including engine controls

Utility systems - High voltage DC transmission (HVDC), static VAR compensation (SVC), Alternative energy sources (wind, photovoltaic), fuel cells, energy storage systems, induced draft fans and boiler feed water pumps

Types of power electronic converters

1. Rectifiers (AC to DC converters): These converters convert constant ac voltage to variable dc output voltage.

2. Choppers (DC to DC converters): Dc chopper converts fixed dc voltage to a controllable dc output voltage.

3. Inverters (DC to AC converters): An inverter converts fixed dc voltage to a variable ac output voltage.

4. AC voltage controllers: These converters convert fixed ac voltage to a variable ac output voltage at same frequency.

5. Cycloconverters: These circuits convert input power at one frequency to output power at a different frequency through one stage conversion.

Power semiconductor devices

I. Power Diodes.
ii. Power transistors (BJT's).
iii. Power MOSFETS.
iv. IGBT's.
v. Thyristors

Thyristors are a family of p-n-p-n structured power semiconductor switching devices

PN Junction Diode

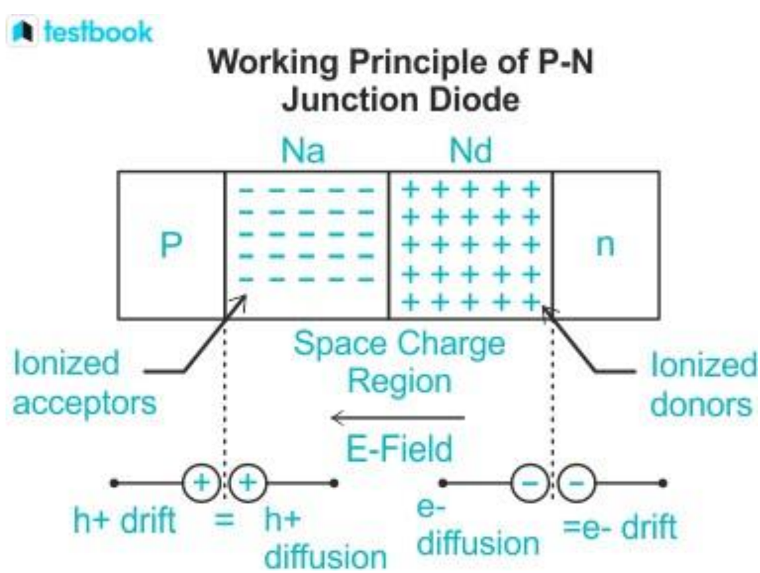
A PN-junction diode is formed when a p-type semiconductor is fused to an n-type semiconductor creating a potential barrier voltage across the diode junction.

The PN junction diode consists of a p-region and n-region separated by a depletion region where charge is stored.

To make N-type semiconductor material, atoms with one additional valence electron than silicon are employed. For this purpose, elements from group V of the periodic table are used. These elements have 5 valence electrons out of which 4 participate in the covalent bond formation with silicon and an additional valence electron is left unbound. As a result, more electrons are introduced to the conduction band, increasing the total amount of electrons in the system.

Working Principle of PN Junction Diode

In a PN junction diode, an ionized donor is left behind on the N-side when an electron diffuses from the N-side to the P-side and a layer of positive charge develops on the N-side of the junction. When a hole moves from the P-side to the N-side, an ionized acceptor is left behind on the P-side, causing a layer of negative charges to accumulate on the P-side of the junction. The depletion area is defined as a region of positive and negative charge on each side of the junction. An electric field with a direction from a positive charge to a negative charge develops on either side of the junction.



The electric potential between P and N-regions changes when an external potential is supplied to the PN junction terminals. As a result, the flow of the majority of carriers is altered, allowing electrons and holes to diffuse through the PN junction. The diode is thought to be in the forward bias state if the applied voltage reduces the width of the depletion layer, and reverse bias if the applied voltage increases the width of the depletion layer. The diode is said to be in the zero bias or unbias state if the breadth of the depletion layer remains unchanged

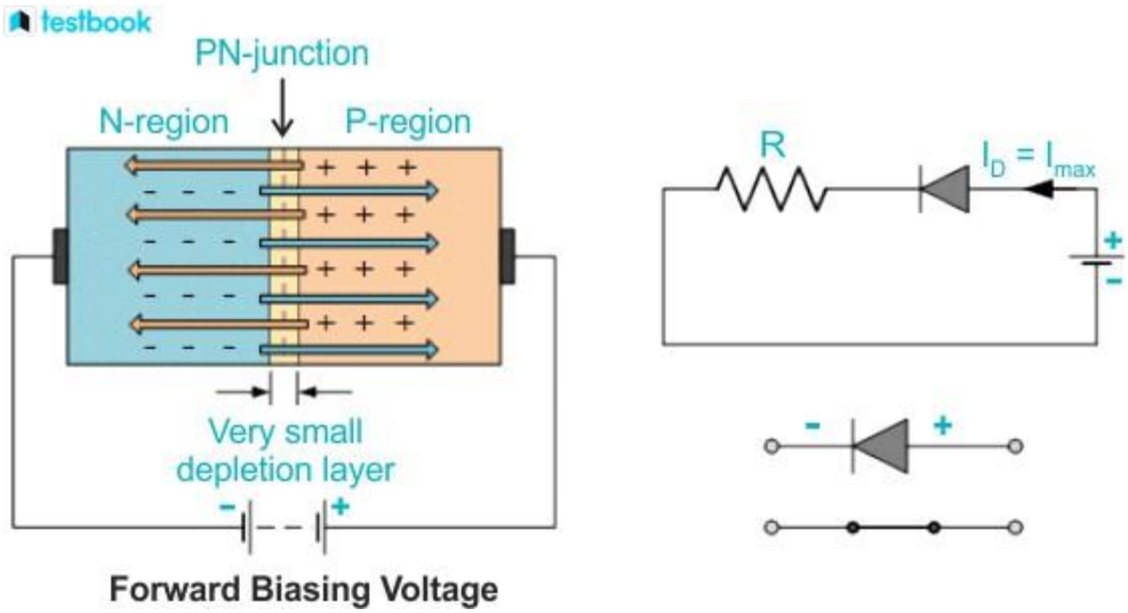
Forward & Reverse Biasing Conditions of PN Junction Diode

Let us understand the working principle of forward and reverse bias conditions of the PN junction in detail.

Forward Bias;

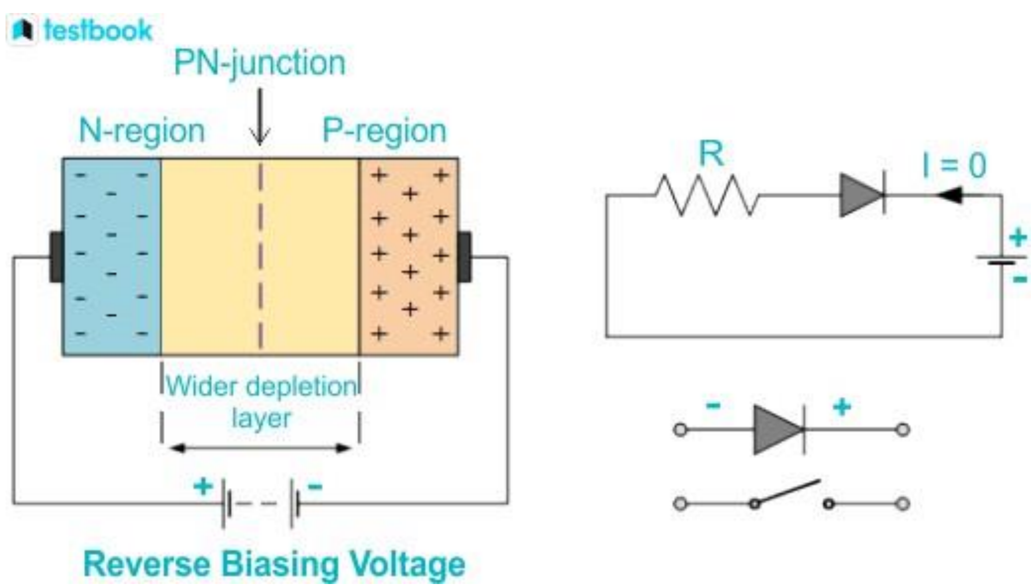
The PN junction is forward-biased when the P-type is connected to the positive terminal of the battery and the N-type is connected to the negative terminal. In this condition, the applied electric field and the built-in electric field at the PN junction are in opposing directions.

Adding both the electric fields gives a resultant electric field, thus the resulting electric field is found to be smaller than the built-in electric field. As a result, the depletion area becomes thinner and less resistant. When the applied voltage is high, the resistance of the depletion area becomes insignificant. At 0.6 V, the resistance of the depletion zone in silicon becomes absolutely insignificant, allowing current to flow freely over it.



Reverse Bias

The PN junction is reverse biased when the P-type is connected to the negative terminal of the battery and the N-type is connected to the positive side. In this condition, the applied electric field and the built-in electric field are both in the same direction. The resultant electric field and the built-in electric field are also in the same direction, resulting in a more resistive, thicker depletion area. Increasing the applied voltage results in a thicker and more resistant depletion area.



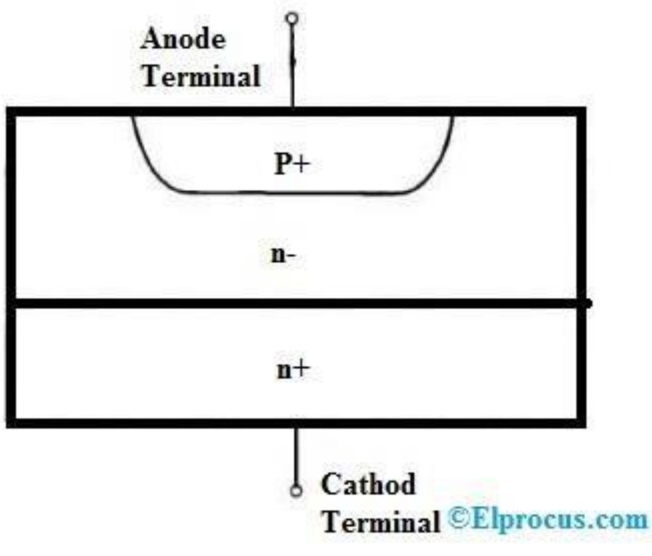
Power Diodes

Definition: A power diode or high-power diode is one of the power semiconductor devices that have two terminals (cathode and anode) similar to the normal PN junction diode but exhibit higher power handling capability. These are designed to handle several kiloamps of current in forward biased condition with negligible power loss and must block several kilovolts under reverse-biased state.

More simply, we can say that power diodes are devices that are designed to carry a large amount of current at high voltage. Power semiconductor devices mainly find their use in **power electronic circuits**.

Construction

The construction of this diode includes three layers like the P+ layer, n– layer and n+ layer. Here the top layer is the P+ layer, it is heavily doped. The middle layer is n– layer, it is lightly doped and the last layer is n+ layer, and it is heavily doped.



power-diode-construction

Here p+ layer acts as an anode, the thickness of this layer is 10 μm & the level of doping is 10^{19} cm^{-3}.

The n+ layer acts as a cathode, the thickness of this layer is 250-300 μm & the level of doping is 10^{19} cm^{-3}.

The n- layer acts as a middle layer/drift layer, the thickness of this layer mainly depends on the breakdown voltage & the level of doping is 10^{14} cm^{-3}. Once this layer width increases then breakdown voltage will be increased.

Working Principle of Power Diode

The working principle of this diode is similar to the normal PN junction diode. When the voltage of the anode terminal is high than the voltage of the cathode terminal, the diode conducts. The range of forwarding voltage drop in this diode is very small approximately 0.5V – 1.2V. In this mode, the diode works as a forward characteristic.

If the voltage of the cathode is high than the voltage of anode, the diode performs as blocking mode. In this mode, the diode performs like the reverse characteristic.

Types of Power Diode

The classification of these diodes can be done based on the reverse recovery time, the process of manufacturing & the depletion region penetration in reversed bias condition.

The power diodes depending on the reverse recovery time as well as the process of manufacturing are classified into three types such as

- General Purpose Diodes
- Fast Recovery Diodes
- Schottky Diodes

General Purpose Diodes

These diodes have huge reverse recovery time around 25μs; therefore they are applicable in low frequency (up to 1 kHz) & low-speed operations (up to 1- kHz).

Fast Recovery Diodes

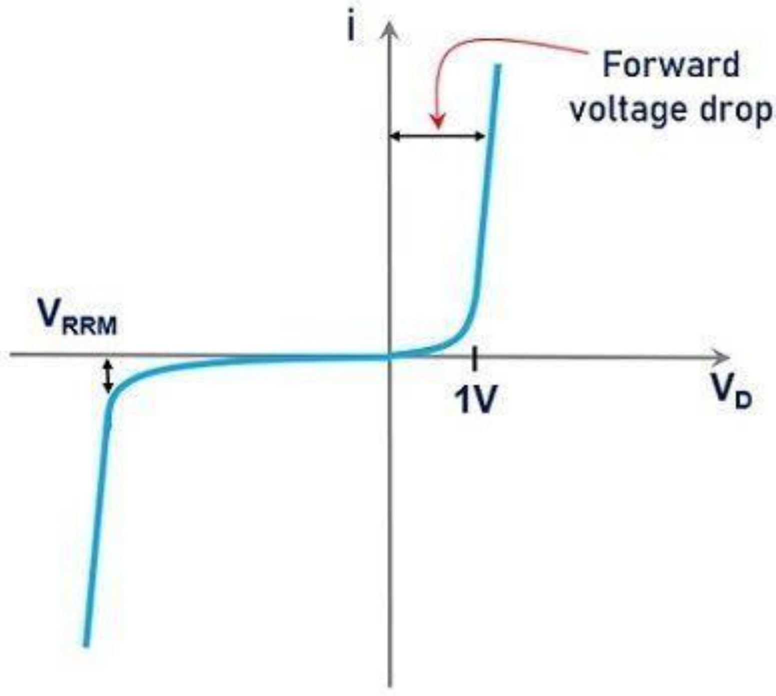
These diodes have quick recovery act due to their very small reverse recovery time less than 5μs, used in high-speed switching applications

Schottky Diodes

In these diodes instead of p-n junction, metal-semiconductor junction is formed where generally aluminium is preferred for metal and silicon for semiconductor. Its current rating lies between 1 A to 300 A while the reverse voltage rating is about 100 V.

V-I CHARACTERISTICS

Initially with no supply voltage forward current is 0 but as the supply input increases, and reaches the threshold value (of about 0.7 V), a small amount of forward current flows through the device. Once the threshold value is surpassed, a considerable increase in diode current (at 1V) is noticed as it starts conduction. Here linear rise in forward current is noticed when voltage increases beyond the threshold.



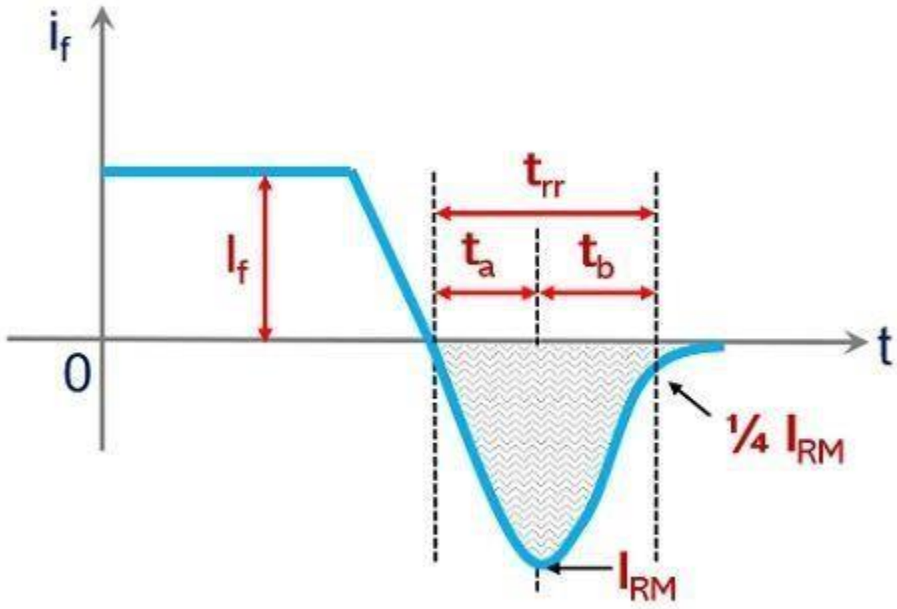
I-V characteristics of Power Diode

In reverse biased mode, leakage current flows through the device which is independent of the applied potential but once breakdown is achieved then even at approximately constant voltage, a high amount of reverse current flows.

Reverse Recovery Characteristics

As we have discussed recently even after removal of forward applied voltage, the diode conducts due to stored charge in the depletion region and the semiconductor layer. So, the time being for which this leakage current flows is called **reverse recovery time, t_{rr}**. The blocking ability of the diode is regained till the time the leakage current becomes 0.

The t_{rr} is the time between the moment forward current vanishes and the moment the reverse recovery current remains only 25% of its peak value I_{RM}.



Reverse recovery characteristics of Power Diode

From the figure, it is clear that

$$\mathbf{t_{rr} = t_a + t_b}$$

: t_a is the interval between zero crossings of forward current and peak reverse current I_{RM}. During t_a the charge within the depletion region, is vanished. While t_b is the duration from the peak of reverse current I_{RM} to 0.25% I_{RM}. During t_b, the charge from the layers of semiconductors is removed.

The ratio of t_b and t_a is termed as **softness factor** given by S. It is generally unity, hence such diode with S equal to 1 is called soft recovery diode. While if S>1 hence it is called fast recovery or snappy recovery diode.

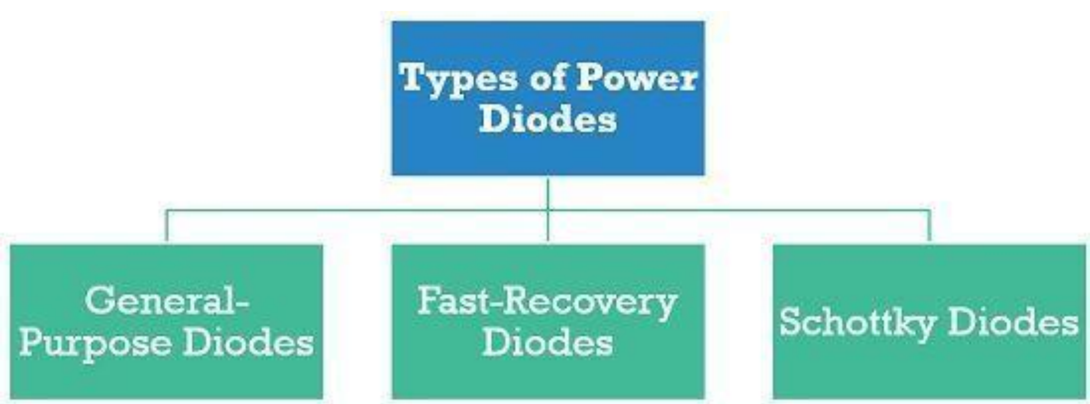
Advantages and Disadvantages of Power Diode

The advantages and disadvantages of power diode include the following.

- The PN-junction region of this diode is large & can supply huge current, however, the capacitance of this junction can also be large, which works at a lower frequency & it is generally used for rectification only.
- It will resolve AC at high current and a high voltage.
- The main disadvantage is its size & probably needs to be fixed to a heat sink while conducting a high current.
- It needs specialized hardware for installing and insulating from the metal frames which are available in the surrounding.

Applications.

- This diode provides uncontrolled power rectification
- It is used in different applications like DC power supplies, for charging the battery, inverters and AC rectifiers.
- These are used like snubber networks and free-wheeling diodes due to their characteristics like voltage & high-current.
- These diodes are used as feedback, freewheeling diodes, and high-voltage rectifier.
- In reverse breakdown condition, when the current and voltage of this diode are huge, the power dissipation can be high so the device can be destroyed.



1. **General Purpose Diodes**: These possess t_{rr} quite high i.e., of about **25 microseconds**. Low-frequency applications such as rectification, converters operated nearly up to 1KHz uses this diode. Its current rating lies between 1 A to several thousand amperes and its voltage rating lies between 50 V to 5 KV.
2. **Fast Recovery Diodes**: These exhibit t_{rr} quite low i.e., of about **5 microseconds**. Mainly used in electrical power conversion systems. Its current rating lies between 1 A to several thousand amperes and its voltage rating lies between 50 V to 3 KV.
3. **Schottky Diodes**: In these diodes instead of p-n junction, metal-semiconductor junction is formed where generally aluminium is preferred for metal and silicon for semiconductor. Its current rating lies between 1 A to 300 A while the reverse voltage rating is about 100 V.

Applications

Due to the characteristics of power diodes, these are mainly used as freewheeling diodes, in ac to dc and dc to ac conversion systems, rectification, battery charging, etc. Along with these, power diodes are also used in electroplating, UPS, choppers, SMPS, and induction heating as well.

Silicon Controlled Rectifier (SCR)

Silicon controlled rectifier (SCR) also known as **Thyristor** is a **three-terminal** and four-layer unidirectional current-controlling **semiconductor** device. It is made up of silicon materials and is mainly used for controlling **high power** and conversion of high ac current into dc current. Hence the named silicon-controlled rectifier.

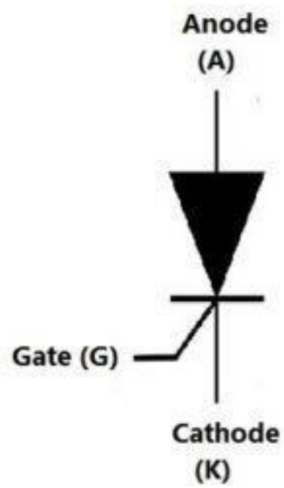
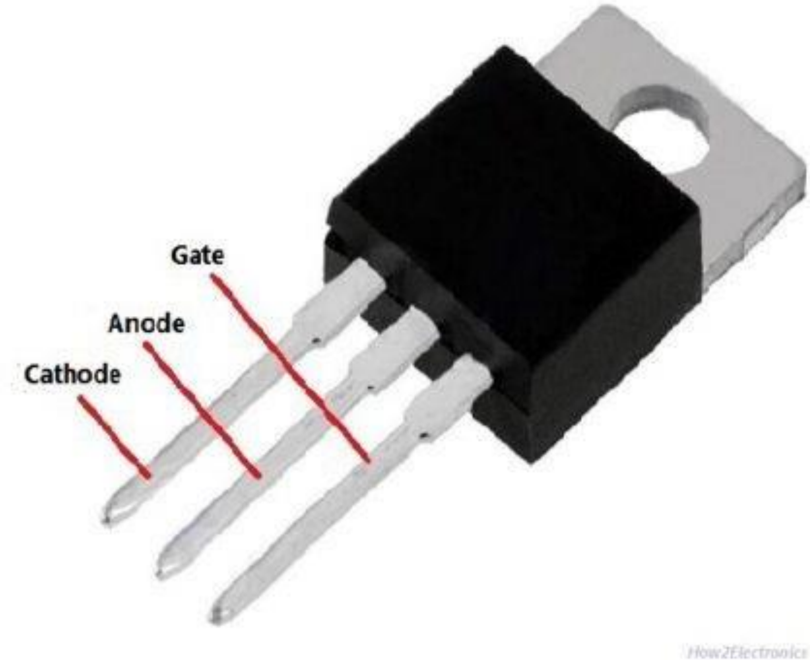


Fig: SCR Symbol



Construction of Silicon Controlled Rectifier (SCR):

Basically, **Silicon controlled rectifier (SCR)** is a **four-layer** and **three-terminal semiconductor** device. It is made up of four semiconductor layers of alternating **p-type** and **n- materials** which form a **PNPN** or **NPNP** structure. Hence it has three p-n junctions ***J1***, ***J2***, and ***J3***. These junctions may alloyed or diffused based on the type of construction.

The three terminals **Anode (A)**, **Cathode (K)**, and **Gate (G)** are arranged in such a way that Gate (G) terminal is attached to the p-type layer nearer to the Cathode (K) terminal in the **PNPN structure**. A typical structure of SCR with **P-N-P-N layers** (PNPN form) is shown in the figure below.

The outer layers (first P-type and last N-type layer) of SCR are **heavily doped** whereas middle P and N- type layers are l**ightly doped**.

Modes of operation in Silicon Controlled Rectifier (SCR):

Depending on the biasing given to SCR, there are three modes of operation. They are

1. *Forward Blocking Mode (OFF State)*

2. *Forward Conducting Mode (ON State)*
3. *Reverse Blocking Mode (OFF State)*

1. Forward Blocking Mode (OFF State):

In this mode of operation, a **positive voltage (+)** is given to the **Anode (A)** terminal of SCR, and a **negative voltage (-)** is given to **Cathode (K)**. The Gate (G) terminal is **open-circuited** as shown in the figure below.

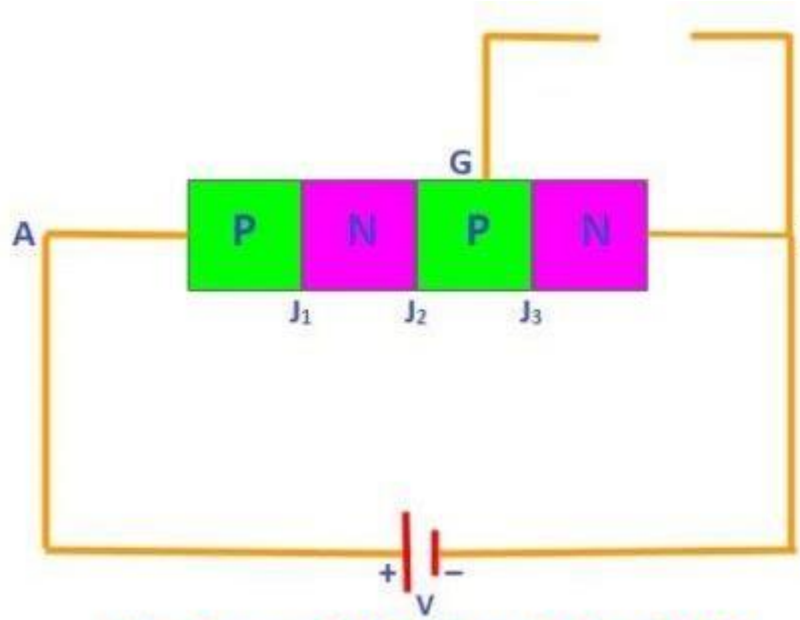


Fig: Forward Blocking Mode of SCR

Under this condition, junctions J_1 and J3 are **forward biase**d whereas junction J_2 is in **reverse biased** condition. The **depletion region** at junction J_2 blocks the flow of current from junction J1 to junction J3 as it acts obstacle or wall between them. However, a small amount of **leakage current** flows between these junctions J2 and J3.

When the applied voltage across the SCR reaches a **breakdown voltage**, the **avalanche breakdown** occurs due to high energy minority carriers. The current starts flowing through the SCR at this breakdown voltage and there is no current flow below the breakdown voltage because SCR offers very **high resistance** to the current below the breakdown voltage and acts as an **open switch** by blocking the forward current. Hence it will be in an **OFF state**.

From above, it is observed that the SCR is in **forward biasing condition** but there is no current flow through it. Hence this mode of operation is named **forward locking mode**.

2. Forward Conducting Mode (ON State):

In this mode of operation, the SCR comes into the **conduction mode** from blocking mode. It can be done in two ways, i.e. either by **increasing the forward bias voltage** (voltage across Anode and Cathode) beyond the **breakdown voltage** or by **applying positive pulse** or voltage at the **Gate** terminal. The biasing of SCR in this mode is shown in the figure below.

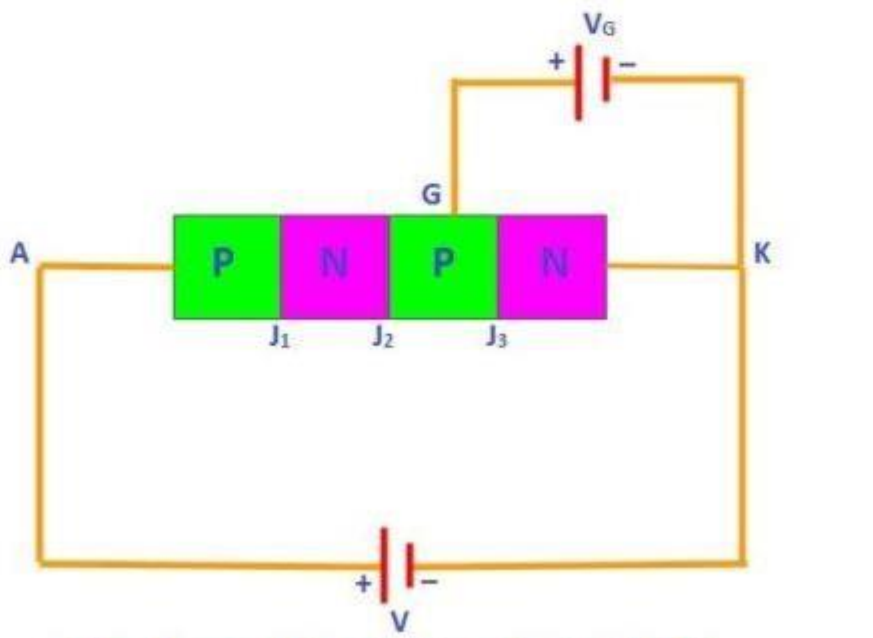


Fig: Forward Conducting Mode of SCR

In the first case, the forward bias voltage applied between Anode and Cathode is increased beyond the breakdown voltage, the **depletion region breakdown** occurs at J_2, and the current starts flowing through SCR. In this condition, the SCR will be in an **ON state**. After the occurrence of junction breakdown, the current flow in SCR increases rapidly as shown in **V-I Characteristics** below.

In the second case, a small **positive pulse** or voltage VG is applied to the Gate terminal of SCR as shown in the figure above. When the gate voltage is applied to the gate terminal, the **reverse biased junction** J_2 in forward blocking mode will become forward biased, and the **depletion region** width becomes very narrow. In this condition, a small forward bias voltage between **Anode** and **Cathode** can easily penetrate this narrow depletion region. Therefore on applying a small **forward bias voltage**, an electric current starts flowing through the SCR and it will be in an **ON state**.

Once the SCR starts conducting, no more gate voltage is needed to maintain it in the ON state. The **minimum current** required to maintain the SCR in the ON state on the removal of gate voltage VG is called **latching current**.

Any one of these methods results in **avalanche breakdown** at junction J_2 and hence the SCR turns into **conduction mode** and acts as a **closed switch** thereby current starts flowing through it. Here, the SCR is forward biased and current flows through it. Hence this mode of operation is named as **forward conducting mode**.

3. Reverse Blocking Mode (OFF State):

In this mode of operation, a **positive voltage (+)** is given to Cathode (K) terminal, and a **negative voltage (-)** is given to Anode (A), Gate (G) terminal is an **open circuit** as shown in the figure below.

Under this condition, junctions J_1 and J3 are **reverse biased** whereas junction J_2 is in **forward biased** condition. As junctions J_1 and J3 are reverse-biased, there is **no current flow** through the

SCR. But due to the drift of the charge carrier in a forward-biased junction J_2, there is small **leakage current** flow in SCR which is not sufficient to turn **ON** the device. Hence the SCR will be in an **OFF** state and acts as an **open switch**.

The SCR offers **high impedance** in this mode of operation until the **applied voltage** is less than the **reverse breakdown voltage VBR**. If the reverse applied is greater than the reverse breakdown voltage, the **avalanche breakdowns** occur at junction J_2 and hence increase reverse current flow in the SCR device. This reverse current causes more losses in SCR and produces **heat** on more increasing it. When the reverse voltage applied to SCR is more than VBR, There will be considerable **damage** to the device.

V-I Characteristics of Silicon Controlled Rectifier (SCR):

The **V-I characteristics** of SCR are shown in the figure below. In this V-I characteristic, the horizontal line represents the amount of voltage applied $\mathbf{V_A}$ across the SCR and the vertical line represents the amount of current flow $\mathbf{I_A}$ in the SCR.

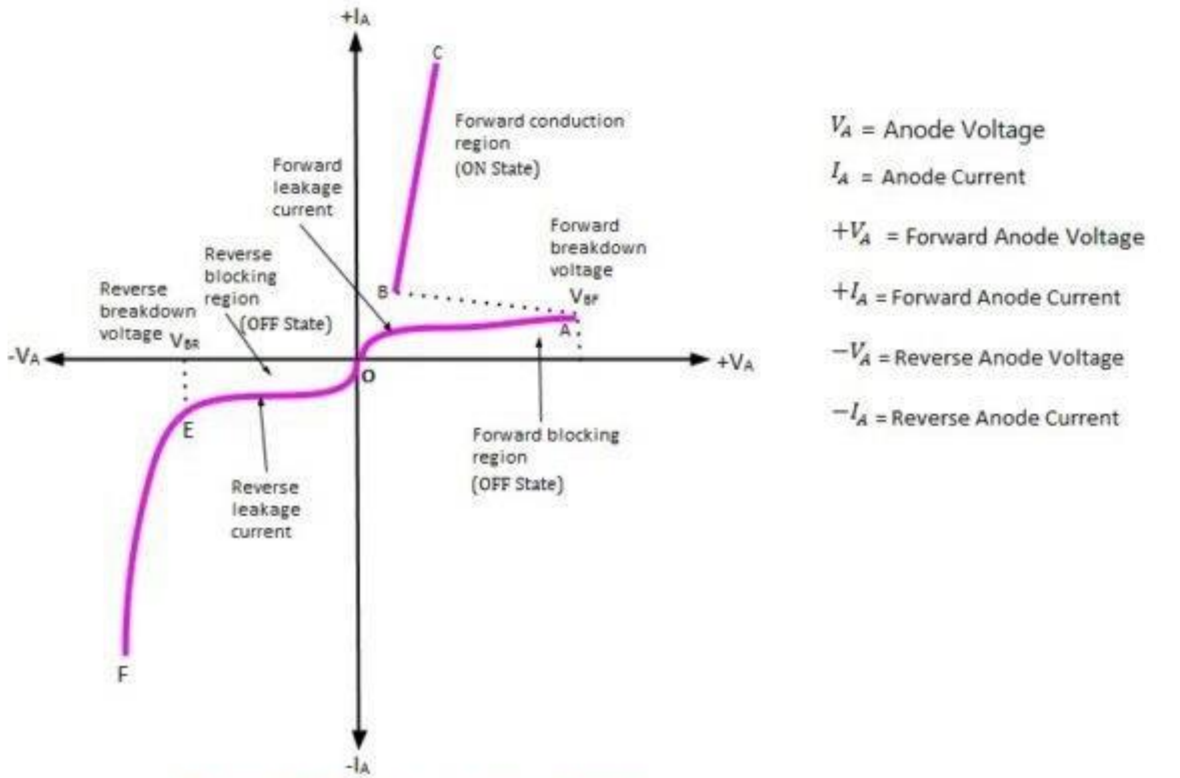


Fig: V-I Characteristics of SCR

Here, the **V-I characteristics** of SCR are divided into **three regions**. They are:

1. Forward Blocking Region

The region OA in V-I characteristics is called the forward blocking region. This region represents the forward-blocking mode of SCR operation. In this region, the forward bias voltage is given to SCR where positive voltage is given to Anode, the negative is given to SCR and Gate is open- circuited. In this condition, the junctions J_1 and J3 become forward biased whereas junction

J_2 becomes reverse biased. A small leakage current flows from the Anode terminal to the Cathode terminal of SCR which is known as a forward leakage current. The SCR does not conduct electric current and the device is in an OFF state in this region.

2. Forward Conduction Region

The region BC in V-I characteristics is called the forward conduction region. This region represents the forward conduction mode of SCR operation. In this region, the current flowing from Anode to Cathode increases rapidly. When the forward bias voltage applied between Anode and Cathode is increased beyond the breakdown voltage, the depletion region breakdown occurs at junction J_2 and the current starts flowing through the SCR and it will be in the ON state. The current flow in this region increases rapidly after junction J_2 breakdown occurs. The voltage at which the junction breakdown occurs when the Gate is open is known as forward breakdown voltage (V_{BF})

The region AB in V-I characteristics indicates that as soon as the SCR becomes ON, the voltage across the SCR drops to some volts.

3. Reverse Blocking Region

The region OE in the V-I characteristics is called the reverse blocking region. This region represents the reverse blocking mode of SCR operation. In this region, the reverse bias voltage is applied to SCR where a positive voltage is given to Cathode, a negative voltage is given to Anode, and the Gate terminal is open-circuited. In this condition, junctions J_1 and J3 are reverse biased whereas the junction is forward biased. As junction J_1 and J3 are in reverse biased condition, there is no current flow through SCR. But due to the drift of the charge carrier in forward-biased junction J_2, there is small leakage current flow in SCR which is not enough to turn ON the device. Hence the SCR will be in an OFF state in this region.

When the reverse bias voltage between Anode and Cathode is increased beyond the reverse breakdown voltage V_{BR}, an avalanche breakdown occurs, and the current increases rapidly. The region EF in V-I characteristics is known as the reverse avalanche region.

Applications of SCR:

The main **application of SCR** is **switching** and **power control**. The followings are some applications that use switching and power control properties of SCR.

- It is used as a switch
- It is used b in AC voltage stabilizers
- It is used in choppers (DC to Dc converters)
- It is used for inverters (DC to AC converters)
- It is used in battery charger

- It is used for power control circuits
- It is used in DC circuit breaker
- It is used for AC power control with a solid relay
- It is used to control motors speed
- It is used to adjust the light dimmer
- It is used in fan speed regulators

Advantages of SCR:

The followings are some **advantages** of SCR.

- It can handle large voltage, current, and power.
- The voltage drop across conducting SCR is small which will reduce the power dissipation.
- Triggering circuits are simple.
- Easy to turn ON.
- It has a higher switching speed.
- It can be protected with the help of a fuse.
- It is simple to control.

Disadvantages of SCR:

The followings are the **disadvantages** of SCR.

- It can conduct only in one direction. So power control can be done only during half cycle of ac.
- The gate current cannot be negative
- It cannot be used at high frequency as it can be operated at a maximum frequency of 400 HZ.
- It needs to be turned on each cycle in ac circuits.

SCR Turn ON Methods (SCR Triggering)

The SCR can be made to conduct or switched from blocking (non-conducting or OFF) state to Conduction (ON) State by any one of the following methods.

1. Forward Voltage Triggering
2. Temperature Triggering
3. dv/dt Triggering
4. Light Triggering
5. Gate Triggering

Forward Voltage Triggering

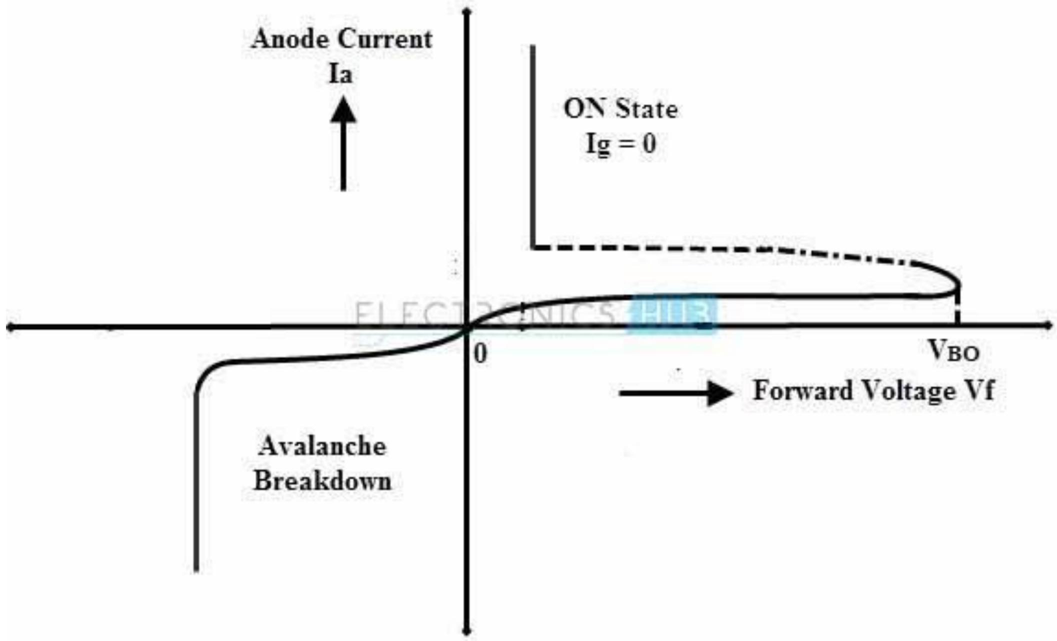
In forward voltage triggering method, the SCR is forward biased i.e., anode is more positive than cathode but this voltage is increased significantly. The gate terminal is kept open.

As the voltage increases, junction J_2's depletion layer width increases, which in turn increases the accelerating-voltage of minority carriers at this junction. At a particular voltage, there will be an Avalanche Breakdown at the inner junction J_2 as a result of minority charge carriers colliding with atoms and releasing even more minority charge carriers.

This voltage is known as Forward Breakover Voltage V_{BO}. At this voltage, the junction J_2 becomes forward biased and the SCR turns into conduction state. A large current flows through the SCR (from Anode to Cathode, which is limited by the load resistance) with a very low voltage drop across it.

During the turn ON state, the forward voltage drop across the SCR is in the range of 1 to 1.5 volts and this may be increased with the load current.

In practice this method is not employed because it needs a very large anode to cathode voltage. And also once the voltage is more than the V_{BO}, the SCR turns on and a very high current flows through it instantly, which may cause damage to the SCR. Therefore, most of the cases this type of triggering is avoided.



Temperature Triggering

This type of triggering is also known as Thermal Triggering as the SCR is turned by heating it. The reverse leakage current depends on the temperature. If the temperature is increased to a certain value, the number of hole-pairs also increases. This causes to increase the leakage current and further it increases the current gains of the SCR. This starts the regenerative action inside the SCR since the ($\alpha 1 + \alpha 2$) value approaches to unity (as the current gains increases).

By increasing the temperature at junction J_2, the width of the depletion layer decreases. So, when the forward bias voltage is near to V_{BO}, we can turn ON the SCR by increasing the junction temperature (J_2). At a particular temperature, the reverse bias of the junction breaks down an the device starts to conduct.

This triggering occur in some circumstances particularly when it the device temperature is more (also called false triggering). This type of triggering is practically not employed because it causes the thermal runaway and hence the device or SCR may be damaged.

dv/dt Triggering

In forward blocking state i.e., anode is more positive than cathode, the junctions J_1 and J_3 are forward biased and the junction J_2 is reverse biased. So, the junction J_2 behaves as a capacitor (J_1 and J_3 as conducting plates with a dielectric J_2) due to the space charges in the depletion region.

The charging current of the capacitor is given as:

$$I_C = dQ / dt$$

$$= d(C_j v) / dt$$

Using Product Rule of Differentiation, we get

$$= C_j dv / dt + v dC_j / dt$$

As the junction Capacitance is always almost constant, we can ignore the rate of change of junction Capacitance dC_j / dt. So, the final Charging Current is:

$$I_C = C_j dv/ dt$$

where, I_C is the Charging Current

C_j is the Junction Capacitance

Q is the charge

v is the voltage applied across the device

dC_j / dt is the rate of change of junction Capacitance dv / dt is the rate of change of applied voltage

From the above equation, if the rate of change of the applied voltage is large (i.e., it is applied suddenly), then the flow of charging current will increase, which causes the SCR to turn on without any gate voltage.

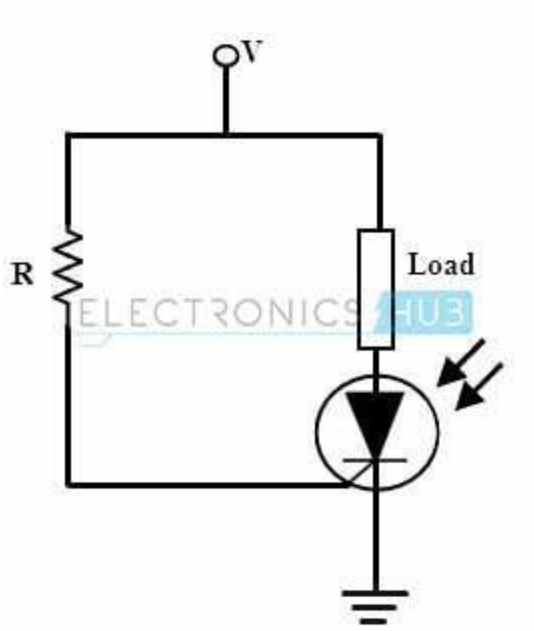
It is clear that we can turn SCR just by increasing the rate of change of voltage across the device rather than applying a large forward bias voltage (as we did in the previous case). However, this method is also practically avoided because it can cause a false turn ON process and also this can produce very high voltage spikes across the SCR so there will be considerable damage to it.

Light Triggering

An SCR turned ON by light radiation is also called as Light Activated SCR (LASCR). Hence, Light Triggering is also known as Radiation Triggering. Generally, this type of triggering is employed in phase controlled converters in HVDC transmission systems. In this method, light rays with appropriate wavelength and intensity are allowed to strike the junction J_2. The bombarded energy particles from the light (neutrons or photons) causes to break electron bonds as as result, new electron – hole pairs are formed in the device.

As the number of charge carriers are increased, there is an instantaneous increase in the flow of current, causing the SCR to turn ON.

NOTE: For successfully turning ON the SCR with the help of light radiation, the rate of change of applied voltage (dv / dt) must be high.



Gate Triggering

This is most common and most efficient method to turn ON the SCR. When the SCR is forward biased, a sufficient positive voltage at the gate terminal injects some electrons into the junction J_2. This results in an increase in the reverse leakage current and hence the breakdown of junction J_2 occurs even at a voltage lower than the V_{BO}.

Depending on the size of the SCR, the gate current varies from a few milli-amps to 250 milli-amps or more. If the gate current applied is more, then more electrons are injected into the junction J_2 and results to come into the conduction state at much lower applied voltage.

In gate triggering method, a positive voltage applied between the gate and the cathode terminals. We can use three types of gate signals to turn On the SCR. Those are DC signal, AC signal and pulse signal.

SCR Turn OFF Methods

To turn OFF a conducting SCR properly, the following conditions must be satisfied:

- The anode or forward current of SCR must be reduced to zero or below the level of holding current and then,
- A sufficient reverse voltage must be applied across the SCR to regain its forward blocking state.

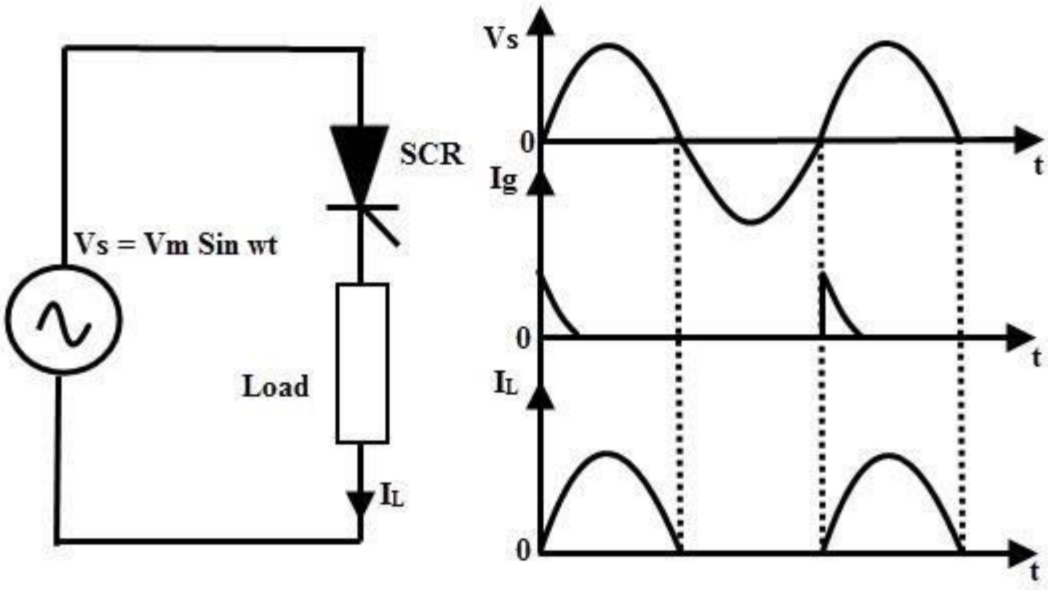
The reverse voltage, which causes to commutate the SCR, is called the Commutation Voltage. Depending on the type of switching of SCR (Cyclic or Sequential), the commutation methods are classified into two major types. They are:

- Natural Commutation
- Forced Commutation

Natural Commutation

In natural commutation, the source of commutation voltage is the supply source itself. If the SCR is connected to an AC supply, at every end of the positive half cycle, the anode current naturally becomes zero (due to the alternating nature of the AC Supply). As the current in the circuit goes through the natural zero, a reverse voltage is applied immediately across the SCR (due to the negative half cycle). These conditions turn OFF the SCR.

This method of commutation is also called as Source Commutation or AC Line Commutation or Class F Commutation. This commutation is possible with line commutated inverters, controlled rectifiers, cyclo converters and AC voltage regulators because the supply is the AC source in all these converters.



During the positive half cycle of the AC Supply, the load current flows normally. But, during the negative cycle, the SCR will turn OFF (due to momentary zero current and immediate negative polarity). For successful natural commutation, the turn OFF time t_{OFF} must be less than the duration of half cycle of the supply.

Forced Commutation

In case of DC circuits, there is no natural current zero to turn OFF the SCR. In such circuits, forward current must be forced to zero with an external circuit (known as Commutating Circuit) to commutate the SCR. Hence the name, Forced Commutation.

This commutating circuit consist of components like inductors and capacitors and they are called Commutating Components. These commutating components cause to apply a reverse voltage across the SCR that immediately bring the current in the SCR to zero.

Depending on the process for achieving zero current in the SCR and the arrangement of the commutating components, Forced Commutation is classified into different types. They are:

- Class A – Self Commutation by Resonating the Load
- Class B – Self Commutation by Resonating the Load

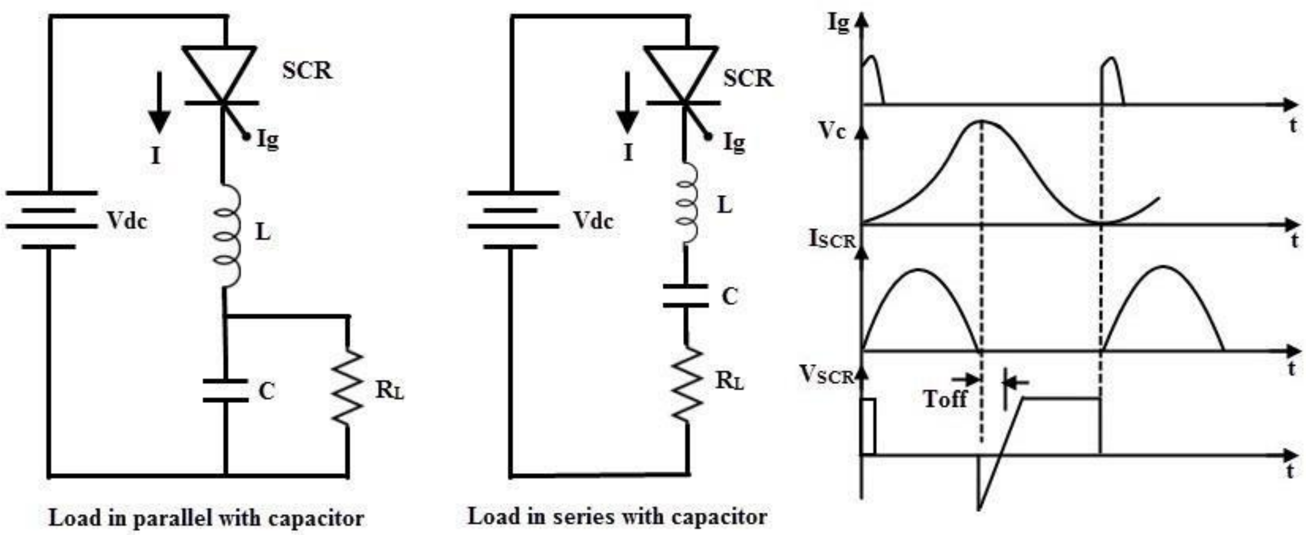
- Class C – Complementary Commutation
- Class D – Auxiliary Commutation
- Class E – Pulse Commutation

such as class A, B, C, D, and E. This commutation is mainly used in chopper and inverter circuits.

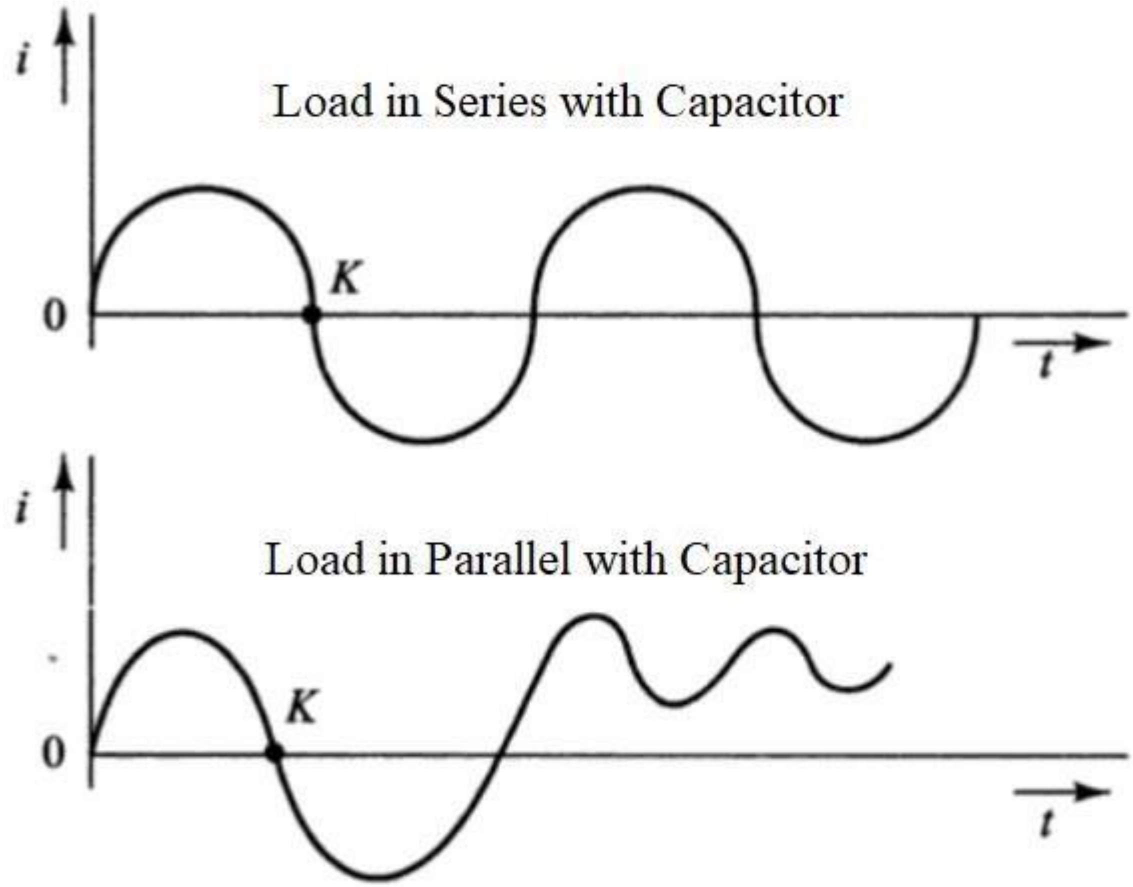
Class A Commutation

This is also known as Self Commutation by Resonating the Load or simply the Resonant Commutation. In this commutation, the source of commutation voltage is in the load. The commutating components are L and C and the Capacitor can be connected either in parallel or in series with the load resistance R_L as shown below.

There are also waveforms of SCR current, voltage and capacitor voltage.



The value of load resistance and the commutating components are selected in such a way that they form an under-damped RLC resonant circuit. When the circuit is applied with a DC Source, the forward currents starts flowing through the SCR and during this period, the capacitor is charged up to the value of V_{dc}. The current in the circuit will be either of the two waveforms shown below, depending on how the load is connected to the capacitor (parallel or series).



When conducting, the current in the SCR is the charging current of the capacitor. From the waveforms, it is clear that the current becomes zero at the point 'K'. At this point, the SCR turns OFF.

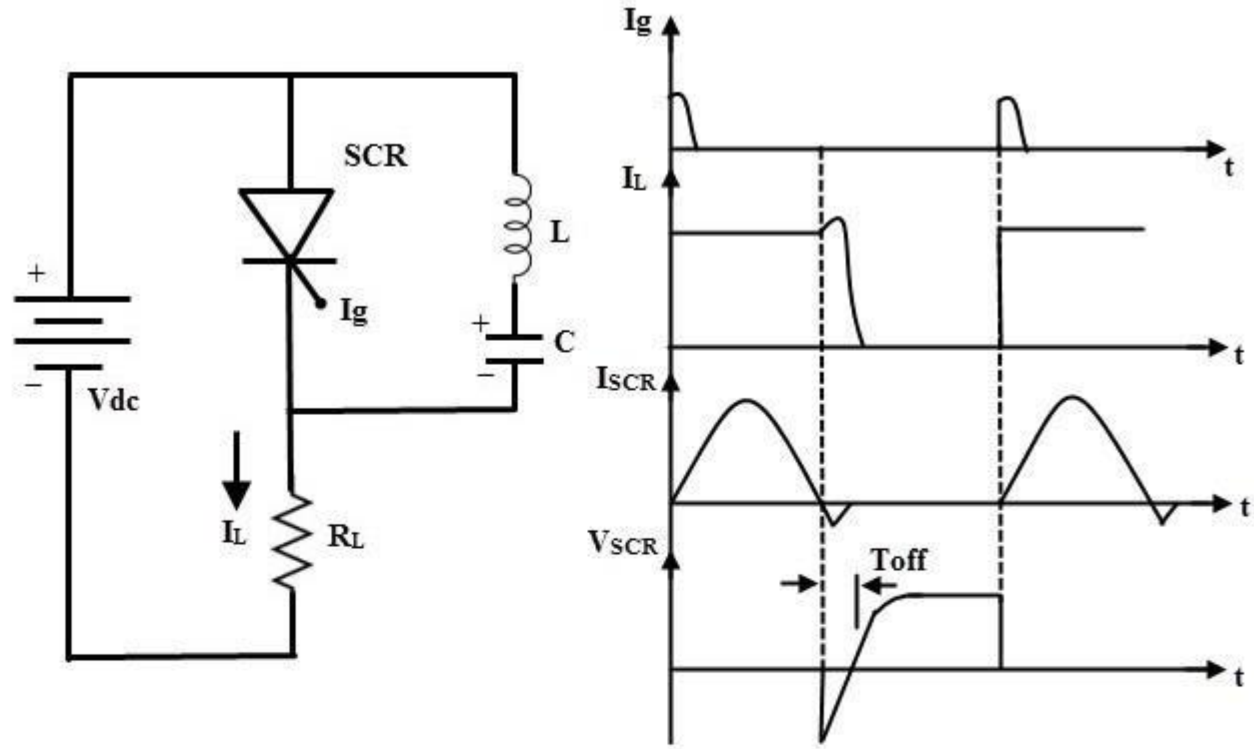
The resonant frequency of the circuit, which depends on the Commutation Components L and C and also on the load resistance, determines the time for switching OFF the SCR.

Class A Commutation method is simple and reliable and is usually used in high frequency operations i.e., frequencies in the range of 1000 Hz and above due to the high values of L and C components (as they carry the full load current). This type of commutation is generally used in Series Inverters.

Class B Commutation

This is also a self commutation circuit in which commutation of SCR is achieved by a resonating LC Circuit. But the main difference between Class A and Class B Commutation is that the LC resonant circuit is connected across the SCR but not in series with the load as in case of Class A Commutation. As a result, the commutating circuit and the L and C components in it doesn't carry the load current.

The following image shows the Commutating Circuit and also the waveforms associated with Class B Commutation.



When a DC supply is applied to the circuit, the capacitor charges up to V_{dc}, with an upper plate positive and lower plate negative. When the SCR is triggered, the current flows in two directions: one is through V_{dc+} – SCR – R – V_{dc-} and the another one is the commutating current (I_C) through L and C components.

When the SCR is turned ON, the capacitor starts discharging in the path C_+ – L – SCR – C_-. When the capacitor is fully discharged, it starts charging with a reverse polarity. As a result of the reverse voltage, a commutating current I_C, will flow in the opposite direction of the load current I_L.

When the commutating current I_C becomes higher than the load current, the SCR will automatically turn OFF and the capacitor charges with its original polarity (through Inductor and Load).

From the above explanation, we can understand that the SCR is turned ON for some time and then automatically turned OFF for some time. This is a continuously repeating process. The frequency of ON/OFF state depends on the values of L and C in the commutating circuit. This type of commutation is mostly used in chopper circuits.

Thyristor | SCR Specifications and Ratings

There is a large number of ratings associated with thyristors. These ratings are in terms of voltage, current, power, temperature and derivatives of voltage and current and time to switch on and off. In practice, it may not be necessary to give consideration to each and every rating to make choice of a thyristor.

A thyristor can be chosen on the basis of manufacturer's recommendations depending on maximum voltage and current rating and grade (converter or inverter).

The complexity of ratings is due to thermal characteristics of silicon and behavior of junctions. Normal symbols are used for currents and voltages followed by subscripts, which denote direction or state as:

D=off
state
R=reverse
P=forward
T=on-
state

Except the gate, second letter defines whether the rating is working, repetitive, or non-repetitive value, where:

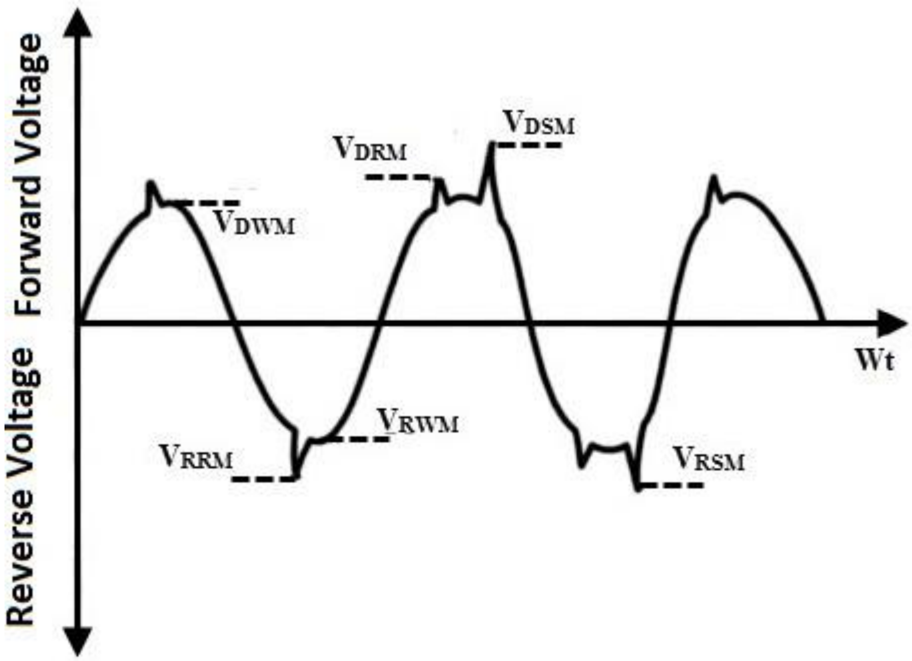
W=workingvalue,
R=repetitive
and
S=Non-repetitive.

The third letter is M indicate peak value when required.

Anode Voltage Ratings of Thyristor | SCR

A.C. mains voltage is not smooth voltage and some transient component occurs regularly and others occurs only sometimes. Figure indicates such components. It is difficult to observe all such transient components on ordinary C.R.O. if high intensities are not used for the beam.

V_{RWM} – The crest working reverse voltage, neglecting transients. In practice it is the peak negative value of sine wave supply voltage.



V_{TM}: Maximum on-state or forward voltage. It is usually defined in terms of SCR rated average of RMS forward current, V_{TM} is the peak or maximum on-state anode-cathode voltage. Some manufacturers refer to this specification as V_F or V_{FM}. For most SCRS, V_{TM} is in the order of 1.6 V.

V_{DRM}: Maximum forward blocking voltage. It is the peak repetitive off-state anode-cathode voltage. **Beyond this value, the SCR will break down in forward conduction**. This is referred to as the breakover voltage with no input gate current.

V_{RRM}: Maximum reverse blocking voltage. The peak repetitive off-state reverse anode-cathode voltage. **Beyond this value, the SCR will break down into reverse conduction**.

V_{RSM} – Non-repetitive peak reverse voltage. It is the peak value of surge voltage that lasts up to 10 ms but does not repeat.

V_{DWM} – Crest working on state voltage, applied in the forward direction.

V_{DSM} – Non-repetitive peak off state voltage applied in the forward direction.

Repetitive and non-repetitive values are determined by voltage limit and by instantaneous energy that can be dissipated within the device. Exceeding these voltage ratings may not damage the device but exceeding V_{RSM} can damage the device.

V_1 – Continuous off-state voltage. It is the voltage between anode and cathode with specified forward current and junction temperature.

dv/dt – The dv/dt characteristic of a thyristor is the maximum rate of rise of the anode voltage which will not trigger the thyristor. It is dependent on junction temperature. It is called Critical Rate of rise of off- state voltage.

Reapplied dv/dt – Rate of rise of forward voltage following turn-off commutation.

Current Ratings of SCR | Thyristor

I_{TAV} – Average on state current. The limit to current rating is set by the junction temperature. Average current limit is however set by heat sink temperature.

I_{RMS} – RMS value of on-state current. This is important at small conduction angles.

I_{TRM} – Repetitive peak on-state current that can be drawn through the device when rms and mean current ratings are not exceeded.

I_{TSM} – Non-repetitive peak on-state current. This value is chosen for selection of fuses.

I^2t – This is the measure of maximum forward non-recurring over-current capability for very short pulse durations. The value is valid for specified pulse duration. **I** is in RMS amps and **t** is pulse duration in seconds. (This is used for fuse co-ordination).

di/dt – The di/dt ratings of a thyristor indicates maximum rate of rise of on-state current. Maximum current of a thyristor assumes steady state condition, when all the area of the device is carrying current. However, when a thyristor is first triggered ‘on’ condition starts at one or more places near the gate. Small area of conduction then spreads from these points to the whole crystal. Higher value of di/dt may cause ‘hot spots’ in junction and subsequent failure. **It must be limited by additional inductance in series with thyristor**.

I_{DRM}: Peak forward blocking current. It is the maximum forward leakage current resulting from specified forward blocking voltage (V_{DRM}) and operating temperature. In some cases, the maximum allowable case or junction temperature is specified. A typical value for I_{DRM} ranges from less than 1 mA for low-power SCRs to about 100 mA for high-power SCRs.

I_{RRM}: Peak reverse blocking current. It is the maximum reverse leakage current resulting from specified reverse blocking voltage (V_{RRM}) and operating temperature. In some cases, the maximum allowable case or junction temperature is specified. A typical value for I_{RRM} ranges from less than 1 mA for low-power SCRs to about 100 mA for high-power SCRs.

I_L – Latching current. It is the minimum on-state current needed to keep the device in the on-state after the triggering pulse has been removed.

I_H: Holding current. It is the minimum load current required to maintain the SCR in on-state. Typically values of holding current ranges from about 6mA for low power SCRs to 80mA for high power (65 A) SCRs.

It is the current below which a thyristor fails to conduct when the anode current is smoothly fails to conduct when the anode current is smoothly decreased. The holding current occurs when the current in a device in on-state is being decreased till it turns off. (Latching current occurs when the device is in off state and is being turned on).

Temperature Ratings of Thyristor | SCR

T_i – Junction temperature (Normally not possible to measure).
T_{mb} – Mounting temperature.
T_{amb} – Ambient temperature.
Z_{th} – Transient thermal resistance.

Gate Ratings of Thyristor | SCR

P_{GAV} – Average gate power dissipation.
P_{GM} – Peak gate power dissipation.

I_{GT}: The minimum forward gate current to turn on the SCR. Since I_{GT} varies with the operating temperature, load resistance and forward blocking voltage, many SCR manufacturers specify I_{GT} in terms of these operating parameters. Low-power SCRs require an I_{GT} of about 100 to 300 μA for turn on; the I_{GT} for medium and high power SCRs normally ranges from about 5 to 150 mA.

I_{RG} – Reverse gate current.
I_{FGM} – Forward peak gate current.
V_{FGM} – Forward peak gate to cathode voltage.
V_{GD} – Maximum continuous gate to cathode voltage not to trigger the device.
V_{RGM} – Gate to cathode voltage to trigger the device.

V_{GT}: The minimum positive gate voltage required to turn on the SCR. V_{GT} varies with the operating temperature, load resistance, forward blocking voltage, and gate-cathode resistance. For temperatures of about 25ºC, SCR gate trigger voltage is typically 0.7 to 0.8 V. For higher temperatures of about 100 to 125ºC , V_{GT} drops to approximately 0.2 V.

V_{RGM} – Gate to cathode peak reverse voltage.

t_q – Turn-off time. The time interval between the instant when the principal current has decreased to zero after external switching of the principal voltage circuit and the instant when the thyristor is capable of supporting a specified anode to cathode voltage without turning on.

t_{on} – Turn-on time. The time interval between a specified point at the beginning of the gate pulse (say 50% of maximum) and the instant when the principal voltage (current) has dropped (risen) to a specified low (high) value during switching of a thyristor from off-state to the on-state by a gate pulse.

t_d – Delay time. The time interval between a specified point at the beginning of a gate pulse and the instant when the principal voltage (current) has dropped (risen) to a specified value near its initial value during switching of a thyristor from the off-state to the on-state by a gate pulse.

t_r – Rise time. The time interval between the instants at which the principal voltage (current) has dropped (risen) to a specified low (high) value during switching of a thyristor from the off-state to the on-state by a gate pulse.

SCR Protection

Overvoltage

Over voltages are the greatest causes of failure of SCRs. These transient over voltages often lead to unscheduled turn ON of the SCR. Also, may lead to the permanent destruction of the SCR if the reverse transient voltage is more than the VBR across the SCR.

There are several causes of appearing these over voltages like commutation , chopping , lightening , etc. Depends on these sources , over voltages are divided into two types internal and external over voltages.

Internal Overvoltages

Internal over voltages arise while the SCR is in operation. During the turn OFF of an SCR, a reverse current continues to flow through the SCR after the anode current decreased to zero to sweep away the earlier stored charge. This reverse current decay at a faster rate at the end of reverse recover interval.

Due to the inductance of the circuit, this high di/dt produces a high voltage. This voltage value may be much higher than the rated value of the SCR and hence the SCR may be damaged.

External Overvoltages

These voltages are arises from the supply source or load. Some of these are

- If SCRs are in blocking mode in a converter circuit which is supplied with transformer, a small magnetizing current flow through the primary of the transformer. If the primary side switch is suddenly removed, a high voltage transient is produced in the secondary of the transformer and hence it is applied across the SCR. This voltage is several times that of the break over voltage of the SCR.

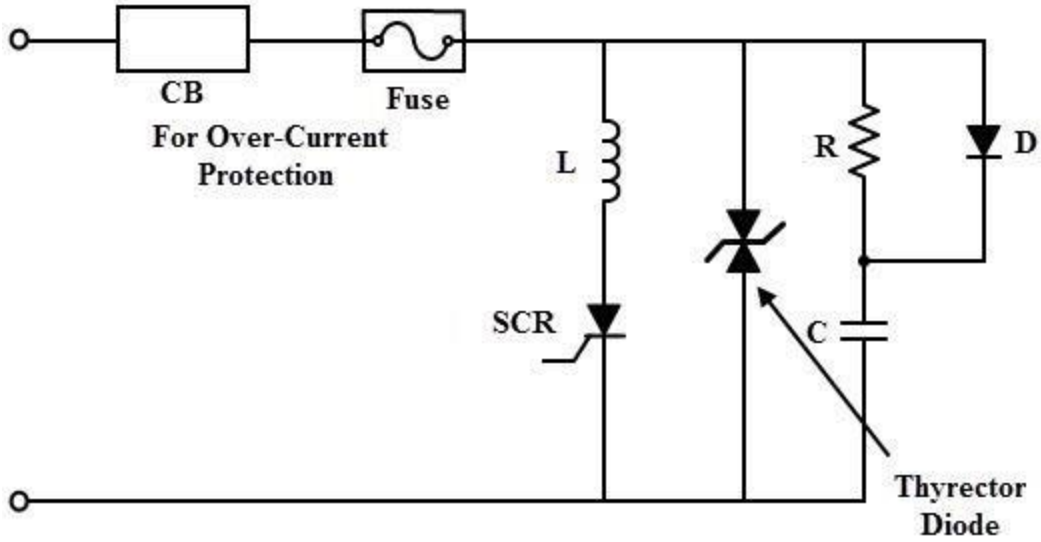
- Lightning surges on the HVDC systems to which SCR converters are connected causes a very high magnitude of over voltages.
- If the SCR converter circuit is connected to a high inductive load, the sudden interruption of current generates a high voltage across the SCRs.
- If the switches are provided on DC side, a sudden operation of these switches produces arc voltages. This also gives rise the over voltage across the SCR.

Protection Against Over voltages

To protect the SCR against the transient over voltages, a parallel R-C snubber network is provided for each SCR in a converter circuit. This snubber network protects the SCR against internal over voltages that are caused during the reverse recovery process. After the SCR is turned OFF or commutated, the reverse recover current is diverted to the snubber circuit which consists of energy storing elements.

The lightning and switching surges at the input side may damage the converter or the transformer. And the effect of these voltages is minimised by using voltage clamping devices across the SCR. Therefore, voltage clamping devices like metal oxide varistors, selenium thyrector diodes and avalanche diode suppressors are most commonly employed.

These devices have falling resistance characteristics with an increase in voltage. Therefore, these devices provide a low resistance path across the SCR when a surge voltage appears across the device. The figure below shows the protection of SCR against over voltages using thyrector diode and snubber network.



Overcurrent

During the short circuit conditions, over current flows through the SCR. These short circuits are either internal or external. The internal short circuits are caused by the reasons like failure of SCRs to block forward or reverse voltages, misalignment of firing pulses, short circuit of converter output terminals due to fault in connecting cables or the load, etc. The external short circuits are caused by sustained overloads and short circuit in the load.

In the event of a short circuit, the fault current depends on the source impedance. If the source impedance is sufficient during the short circuit, then the fault current is limited below the multi-cycle surge rating of the SCR. In case of AC circuits, the fault occurs at the instant of peak voltages if the source resistance is neglected.

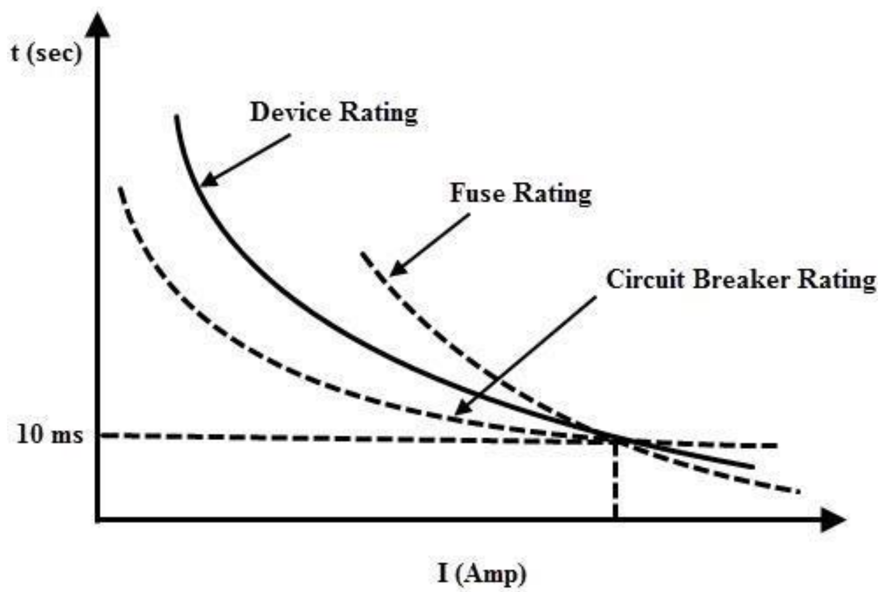
In case of DC circuits, fault current is limited by the source resistance. Therefore, the fault current is very large if the source impedance is very low. The rapid rise of this current increase the junction temperature and hence the SCR may get damaged. Hence the fault must be cleared before occurrence of its first peak in other words fault current must be interrupted before the current zero position.

Protection Against Overcurrent

The SCRs can be protected against the over currents using conventional over current protection devices like ordinary fuses (HRC fuse, rewirable fuse, semiconductor fuse, etc,), contractors, relays and circuit breakers. Generally for continuous overloads and surge currents of long duration, a circuit breaker is employed to protect the SCR due to its long tripping time.

For an effective tripping of the circuit breaker, tripping time must be properly coordinated with SCR rating. Also, the large surge currents with short duration (are also called as sub-cycle surge currents) are limited by connecting the fast acting fuse in series with an SCR.

So the proper coordination of fusing time and the sub-cycle rating must be selected for a reliable protection against over currents. Therefore, the proper coordination of fuse and circuit breaker is essential with the rating of the SCR.



The selection of fuse for protecting the SCR must satisfy the following conditions.

- Fuse must be rated to carry the full load current continuously plus a marginal overload current for a small period.
- I2t rating of the fuse must be less than the I2t rating of the SCR
- During arcing period, fuse voltage must be high in order to force down the current value.

- After interrupting the current, fuse must withstand for any restricted voltage.

di/dt Protection of SCR

The anode current starts flowing through the SCR when it is turned ON by the application of gate signal. This anode current takes some finite time to spread across the junctions of an SCR. For a good working of SCR, this current must spread uniformly over the surface of the junction.

If the rate of rise of anode current (di/dt) is high results a non-uniform spreading of current over the junction. Due to the high current density, this further leads to form local hot spots near the gate-cathode junction. This effect may damage the SCR due to overheating. Hence, during turn ON process of SCR, the di/dt must be kept below the specified limits.

To prevent the high rate of change of current, an inductor is connected in series with thyristor. Typical SCR di/dt ratings are in range between 20- 500 ampere per microseconds.

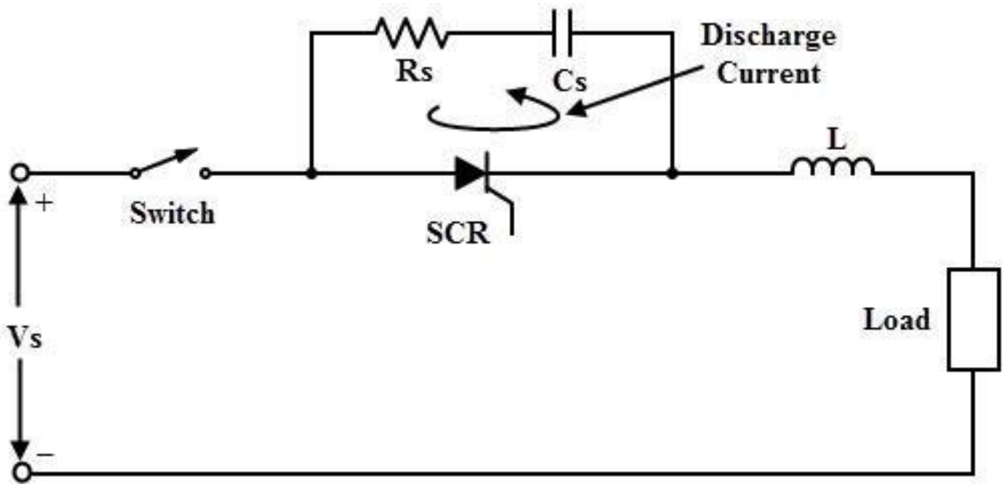
dv/dt Protection of SCR

When the SCR is forward biased, junctions J1 and J3 forward biased and junction J2 is reverse biased. This reverse biased junction J2 exhibits the characteristics of a capacitor. Therefore, if the rate of forward voltage applied is very high across the SCR, charging current flows through the junction J2 is high enough to turn ON the SCR even without any gate signal.

This is called as dv/dt triggering of the SCR which is generally not employed as it is false triggering process. Hence, the rate of rise of anode to cathode voltage, dv/dt must be in specified limit to protect the SCR against false triggering. This can be achieved by using RC snubber network across the SCR.

Working of Snubber Circuit

As we discussed above, the protection against high voltage reverse recovery transients and dv/dt is achieved by using an RC snubber circuit. This snubber circuit consists of a series combination of capacitor and resistor which is connected across the SCR. This also consist an inductance in series with the SCR to prevent the high di/dt. The resistance value is of few hundred ohms. The snubber network used for the protection of SCR is shown below.



When the switch closed, a sudden voltage appears across the SCR which is bypassed to the RC network. This is because the capacitor acts as a short circuit which reduces the voltage across the SCR to zero. As the time increases, voltage across the capacitor builds up at slow rate such that dv/dt across the capacitor is too small to turn ON the SCR. Therefore, the dv/dt across the SCR and the capacitor is less than the maximum dv/dt rating of the SCR.

Normally, the capacitor is charged to a voltage equal the maximum supply voltage which is the forward blocking voltage of the SCR. If the SCR is turned ON, the capacitor starts discharging which causes a high current to flow through the SCR.

This produces a high di/dt that leads to damage the SCR. And hence, to limit the high di/dt and peak discharge current, a small resistance is placed in series with the capacitor as shown in above. These snubber circuits can also be connected to any switching circuit to limit the high surge or transient voltages

Firing Circuits of Thyristor or SCR – R, RC & UJT Triggering

There are many ways to turn ON a thyristor, like forward-voltage firing, dv/dt triggering, temperature triggering, light triggering, and gate triggering. But other than these methods, the most commonly employed method to turn-ON a thyristor is by controlling the gate pulse.

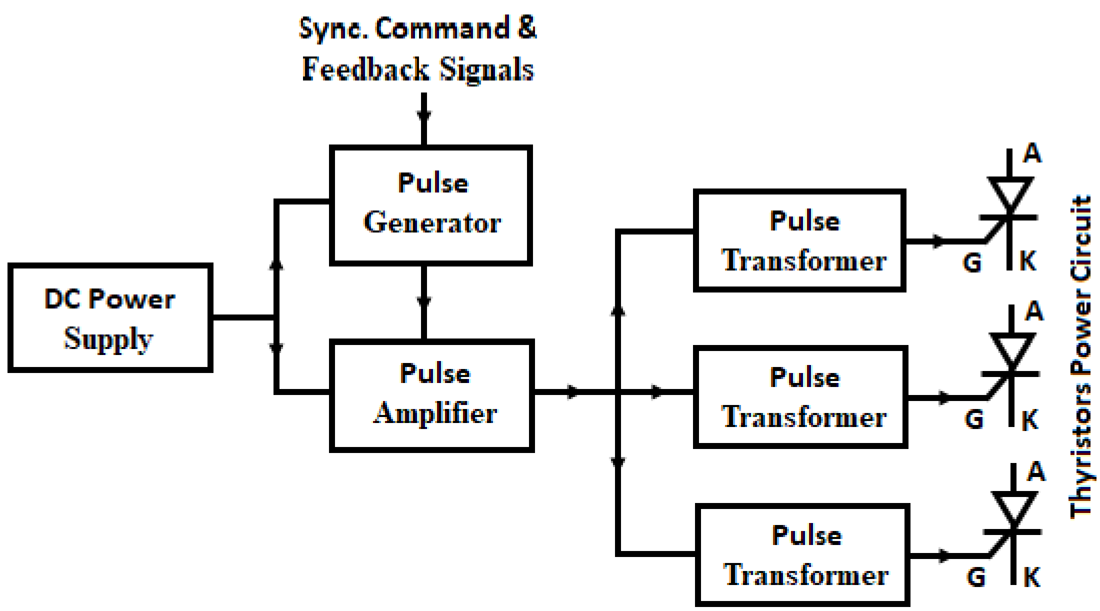
The circuit used for turning ON the thyristor by giving gate pulses is called the Firing or Triggering Circuit of SCR. But in order to employ the firing circuit method for turning ON thyristor, the circuit must fulfill some conditions,

Conditions for Triggering or Firing Circuits of Thyristors :

Certain conditions are to be met for firing the thyristors are,

- Gate current should be of sufficient amplitude and should flow in the circuit for the required duration.
- Voltage pulses should be fed to the driver circuit first and then to the gate-cathode circuit.
- For a circuit with more than one thyristor, the gate current for each thyristor must be provided at the desired instant of time.

The general layout for firing the thyristor is shown below.



Basic Triggering Circuit of SCR

The firing circuit consists of a control circuit, a driver circuit, and a power circuit. The output of the pulse generator is fed to the pulse amplifier for amplification. Amplified pulses are given to the pulse transformer through shielded cables. The pulse transformer separates the low-voltage gate-cathode circuit from the high-voltage anode-cathode circuit.

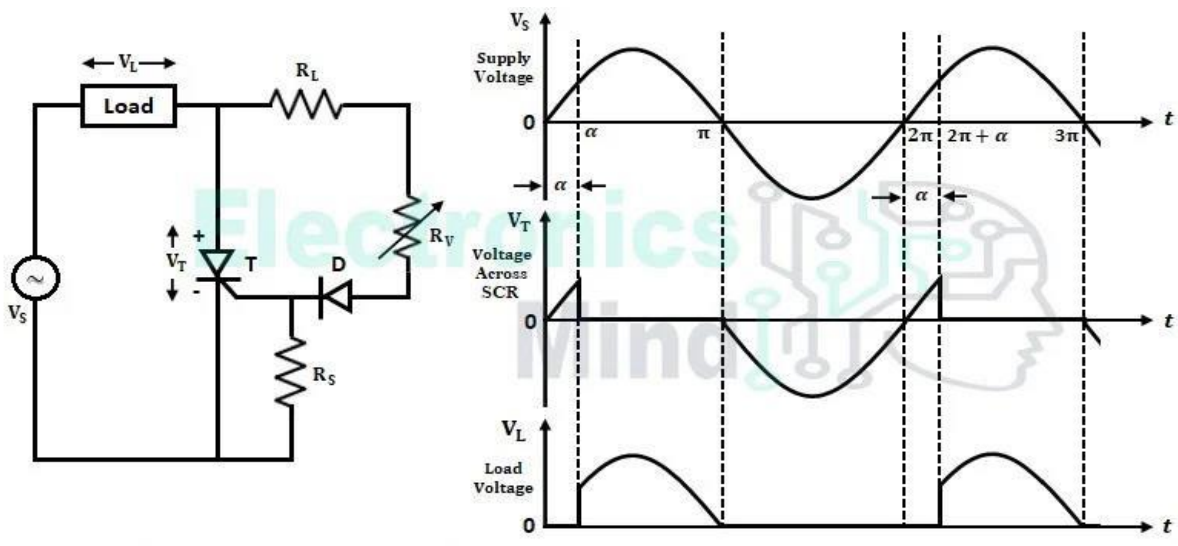
Triggering or Firing Circuits of Thyristor or SCR :

The most commonly used firing or firing circuits for thyristor or SCR are,

- Resistance Firing Circuit (R-Firing),
- Resistance-Capacitance Firing(RC-Firing),
- UJT-Firing Circuit.

Resistance Firing Circuit (R-Firing)
:

The below shows the circuit configuration and waveforms of the resistance firing circuit. This firing circuit is the simplest method of controlling the firing angle of SCR. In this firing circuit, the firing angle can vary over a limited range of 0° to 90°. Instead of giving gate pulses to the thyristor, an ac supply is given to the gate terminal for firing.



Resistance Triggering Circuit of Thyristor and Related Voltage Waveforms

Working of Resistance Firing Circuit (R-Firing) :

The working of the resistance firing circuit is as follows,

- During the positive half-cycle of the voltage source V_S, thyristor, T is forward-biased, but it doesn't conduct because of insufficient gate current. Hence, load voltage V_L is zero.

- As voltage source V_S increases, thyristor and diode both are forward-biased, and gate current I_G flows in the circuit. When gate current I_G reaches to value equal to $I_{G(min)}$, the thyristor is turned-ON and load voltage follows source voltage, and the voltage drop across the thyristor is equal to the on-state drop.
- During the negative half cycle of the supply voltage, the thyristor is reverse-biased, and hence it is turned OFF. Thus load voltage V_L becomes zero and voltage across the thyristor V_T will be equal to source voltage V_S.

The diode in the gate circuit prevents the reverse voltage of the thyristor during the negative half-cycle from exceeding peak reverse voltage. The limiting resistance R_L placed between anode and gate of thyristor limits the gate current not to exceed peak gate current $I_{G(max)}$.

From the waveforms above, the firing angle and the output voltage can be controlled by varying the variable resistance R_V. If R_V is large, then the current will be small, and hence firing angle (α) increases and vice versa.

Advantages of Resistance Firing Circuit :

- The firing circuit is very easy and simple to operate.
- The firing angle can be varied from 0° to 90°.
- By using a capacitor and a diode, the limited firing angle issue is

resolved. Disadvantages of Resistance Firing Circuit :

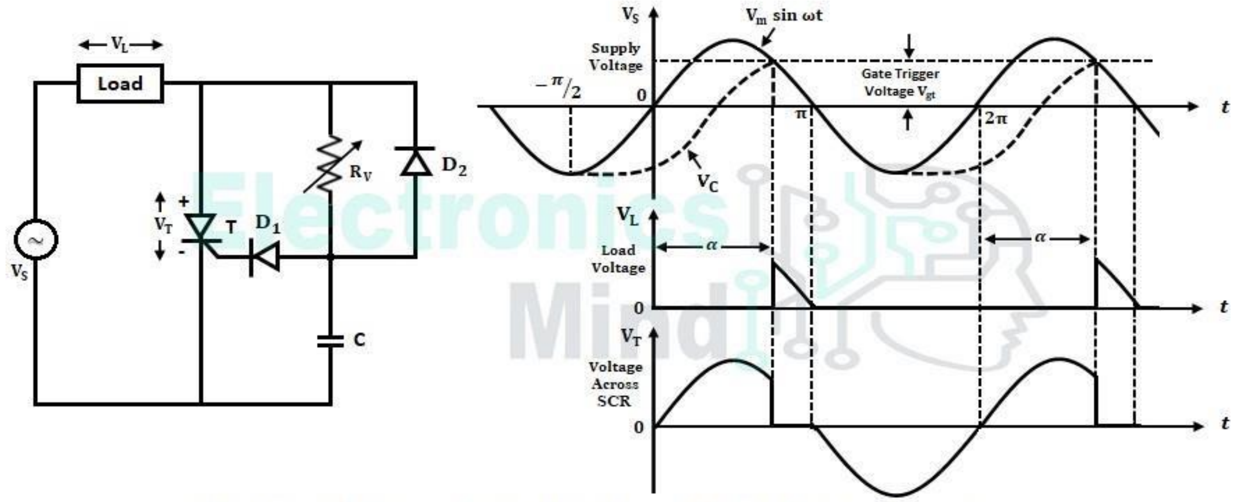
- Limited firing angle i.e., up to 90° only.
- The firing angle is totally dependent on the minimum gate current of thyristors.
- The value of minimum gate current changes between the thyristors.
- It is a temperature-dependent circuit.

Resistance-Capacitance Firing Circuit (RC-Firing)
:

The limitations of the resistance firing circuit can be overcome by using a resistance-capacitance firing circuit. Using an RC-firing circuit the firing angle can be controlled from 0 to 180 electrical degrees. There are two types of RC-firing circuits,

- RC half-wave firing circuit, and
- RC full-wave firing

circuit. RC Half-Wave Firing Circuit :



RC Half Wave Triggering Circuit of Thyristor and Related Voltage Waveforms

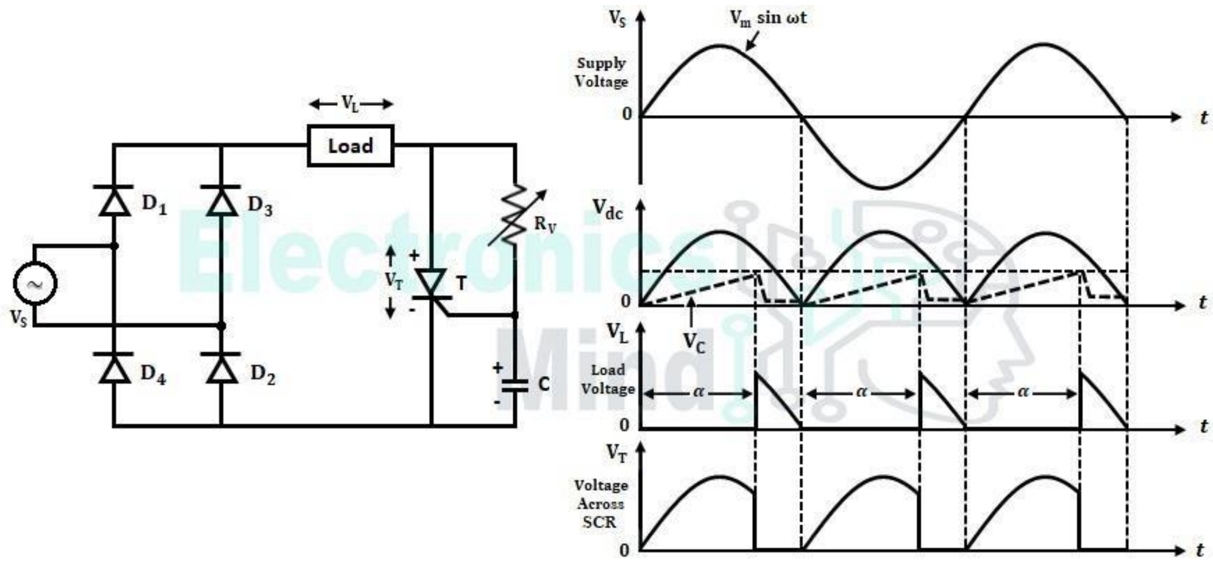
The above figure illustrates the RC half-wave firing circuit. The capacitor charges to the negative peak of the ac voltage in every negative half-cycle through the diode D_2. During the positive half-cycle, it begins to charge through the resistance R_V. When the voltage across the capacitor reaches the required positive value, the thyristor is fired and the capacitor voltage remains almost constant.
The diode D_1 prevents the breakdown of the gate-cathode junction during the negative half-cycle.

If the value of R_V is high, then the capacitor takes more time to charge. Hence the firing angle is more but the average output is low and vice-versa. In order to have more output, the value of R_V should be less.

RC Full-Wave Firing Circuit :

The advantages of a full-wave firing circuit over a half-wave firing circuit are,

- Power can be delivered to load both during positive and negative half-cycles because of the full- wave bridge diode.
- The firing angle can be controlled from 0° to 180°.
- The power delivered to the load is doubled.
- The output voltage is present even in the negative half cycle. The below figures illustrates the RC full-wave firing circuit.



RC Full Wave Triggering Circuit of Thyristor and Related Voltage Waveforms

Initially, the capacitor starts charging from zero voltage, and this low voltage is achieved by the clamping action of the SCR gate. When V_C reaches V_{gt}, SCR is turned-ON and ac line voltage which is rectified into dc by a full-wave diode bridge appears across the load.

Advantages of RC Firing Circuit :

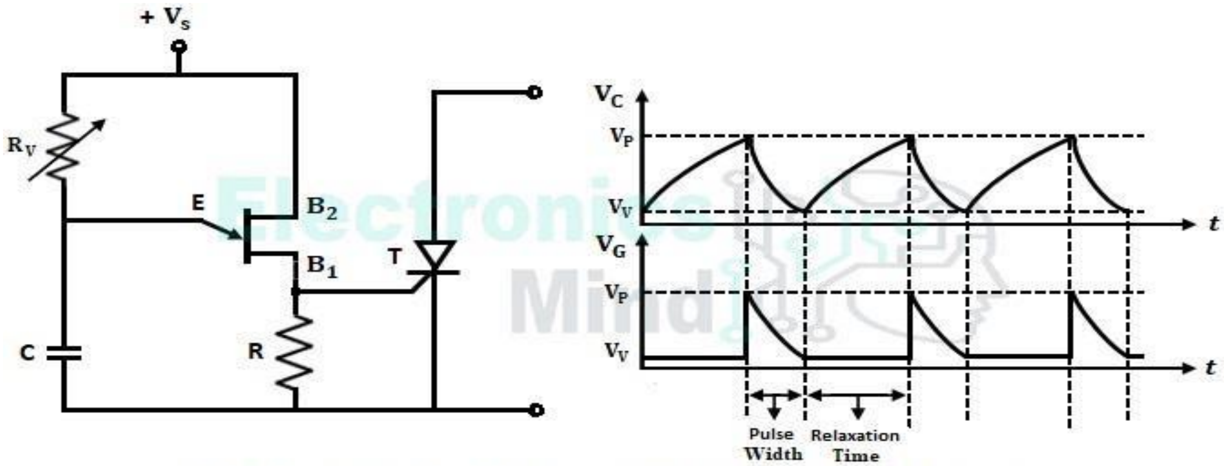
- The firing angle limitation in the R-firing circuit is overcome by the RC-firing circuit.
- The firing angle range is between 0 and 180°.
- The circuit is cheap, simple, and also acts as a snubber

circuit. Disadvantages of RC Firing Circuit :

- The values of R_V and C changes with respect to temperature.
- The firing angle depends upon the RC time constant.
- Supply fluctuations have effects on firing angle.
- It is only applicable in power circuits where only one thyristor is used.
- It can be used only in open-loop control systems.

UJT Firing Circuit :

The above discussed R-firing and RC-firing circuits produce continuous gate pulses due to which there will be quite high power dissipation at the gate circuit of the thyristor. This power dissipation in the gate circuit can be reduced by using a UJT in the firing circuit. The UJT will work as a relaxation oscillator that produces sharp repetitive pulses with good rise time, and it also has good frequency stability under voltage fluctuations and temperature variations.



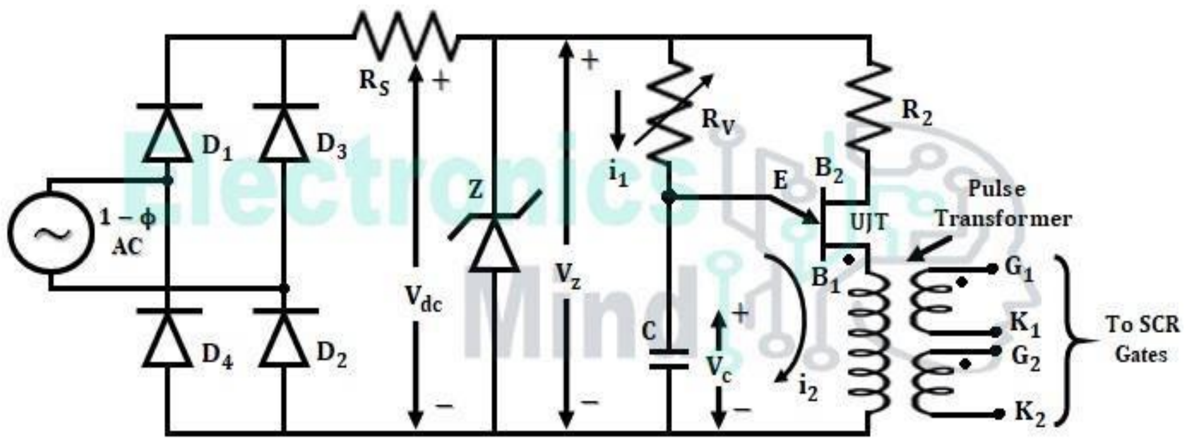
UJT Firing Circuit of SCR and Related Voltage Waveforms

In the above UJT firing circuit, the UJT starts conducting once the value of the voltage across the capacitor is equal to or more than the peak voltage V_P value of the UJT. Now the capacitor starts discharging, and once its voltage decreases to the valley voltage V_V of UJT, the UJT will be turned OFF. The capacitor again gets charged to supply voltage and the above process repeats.Thus whenever UJT conducts it produces pulses at the gate terminal of the thyristor as shown in the waveform. The capacitor charging time depends upon the value of variable resistance R_V. Therefore, by varying the value of R_V the firing angle can be varied.

Ramp Triggering or Synchronized UJT Triggering of SCR

December 4, 2021

The ramp firing circuit is also known as a synchronized UJT triggering circuit. The below shows the ramp circuit used for triggering SCR.



Ramp Firing Circuit for SCR

In the circuit diagram shown above, we have,

- D_1, D_2, D_3 and D_4 = Diodes form full-wave bridge
- Z = Zenor diode
- R_v = Variable resistor
- V_C = Voltage across capacitor
- V_z = Voltage across zener diode.

Single-phase 230 Volts is rectified into dc voltage with the help of a full-wave diode bridge. Resistance R_s steps down V_{dc} to a value that is desirable for Zener diode Z and UJT. This voltage V_{dc} is then clipped to a constant value with the help of the Zener diode, as V_z. V_z is given to the RC network and the capacitor starts charging through R_v. UJT is switched-ON when V_c reaches trigger voltage V_p of UJT.

After UJT is turned ON, the capacitor discharges through the emitter of UJT, the primary winding of the pulse transformer and current flows through it. Pulse voltage is generated at the secondary winding terminals of the pulse transformer because of the current i_2. These pulses are given to SCR gates to trigger them. SCR turns-ON when it is forward biased. In this firing circuit, firing angle α can be controlled upto 150^o.

As in this firing method, power can be controlled by varying R_v, this triggering is termed as manual control or open-loop control. If R is small, then V_c reaches V_p of UJT twice in every half-cycle as shown in the below waveform.

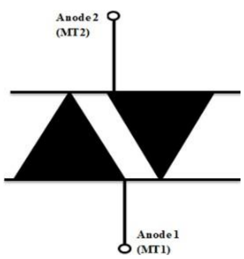
DIAC

The term DIAC stands for the **DI**ode for **A**lternating **C**urrent (DIAC), it is a **bidirectional semiconductor switch** that can be turned ON in both forward and reverse direction. The device is a member of the Thyristor family and it is mostly used in triggering TRIAC and other Thyristor based circuits. The DIAC starts conducting electric current if the applied voltage goes beyond its break-over voltage.

DIACs are available in **different types of DIAC packages** such as discrete components in small leaded packages, surface-mount packages, large packages that are bolted to chassis and various other packages. Most of the time the **DIAC and TRIAC** are used together, so they are available in integrated packages also.

DIAC - Symbol

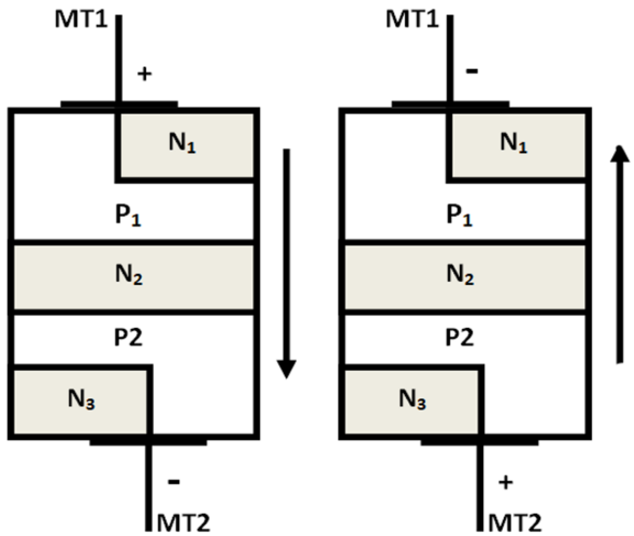
DIAC is given by the symbol of two Diodes connected in parallel and opposite to one another and has two terminals. Since the DIAC is bidirectional, we can't name those terminals as anode and cathode, the **terminals of DIAC** are simply called A1 and A2 or MT1 and MT2 where MT stands for Main terminals. Hence the **pinouts of DIAC** are reversible just like a resistor or ceramic capacitor.



You could have noticed, although it belongs to the thyristor family it **does not have a controlling gate terminal** because they can be turned on or off by simply reducing the voltage level below the **avalanche breakdown voltage** and it can be done in both the polarities.

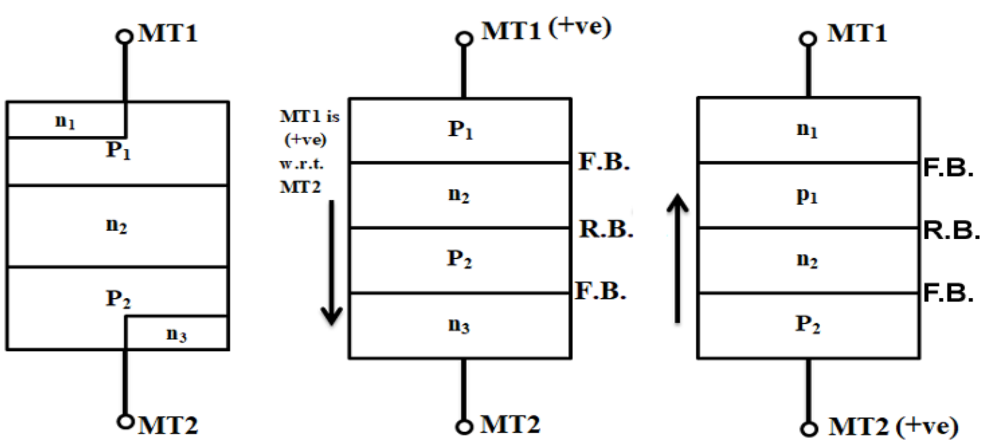
DIAC Construction

The construction of DIAC will be quite similar to the structure of the transistor, but they have some differences like the DIAC does not have any base terminal, all the three layers have the same amount of doping and it delivers symmetrical switching properties in both the polarities of the applied voltage.



The above diagram shows the typical **construction of the DIAC**. As mentioned earlier the DIAC has two terminals namely MT1 and MT2 and it can **deliver current flow in both directions**. The DIAC is made of a five-layered structure; the layers closer to the terminals are the combination of both positive and negative layers. When the voltage is passed to the terminals the layer with respective polarity to the voltage gets activated, this combination of both the polarities helps in operating the DIAC in both the directions

DIAC Working Principle

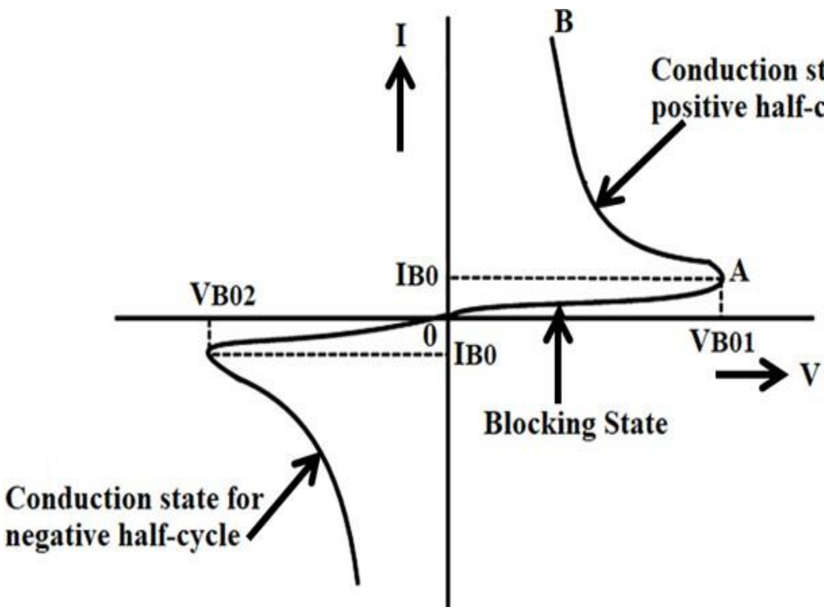


The above image shows the clear operation of the DIAC with respective to the polarities. Consider the MT1 terminal to be positive, then the P1 layer near MT1 will be activated, so the conduction will be taking place in the order of P1-N2-P2-N3. When the current is flowing from MT1 to MT2 the junction between P1-N2 and P2-N3 are Forward Biased and the junction between N2-P2 is reverse biased.

Similarly, if we consider MT2 terminal to be positive, then the P2 layer near MT2 will be activated and the conduction will be taking place in the order of P2-N2-P1-N1. The current will be flowing from MT2 to MT1 and the junctions between P2-N2 and P1-N1 are forward biased and the junction Between N2- P1 is reverse biased. Hence the conduction will be possible in both the directions.

VI Characteristics of DIAC

The **V-I characteristic curve of the DIAC** will be in the shape of a Z and the curve will be lying on the first and third quadrants because they conduct in both the positive and negative polarity. The First quadrant represents the positive half cycle where the current will be flowing from MT1 to MT2 and the second quadrant represents the negative half cycle where the current will be flowing from MT2 to MT1.



Initially, the resistance of the DIAC will be higher because of the Reverse Bias junction between the layers so there will be **small leakage current** flowing through the DIAC, it is mentioned as the **blocking state** in the curve. Once the applied voltage reaches the breakdown voltage the resistance of the DIAC drops abruptly and then it starts conducting which leads to a sharp decrease in voltage and the current starts increasing, which is mentioned as a **conduction state** in the curve. Most of the DIACs will be having the breakdown voltage around 30 Volts, the exact breakdown voltage will be based on the type of the device. The DIAC will be in the **conducting state** until the current reaches the particular value called the **holding current**, where holding current is the minimum current that required for a device to keep it in the ON state.

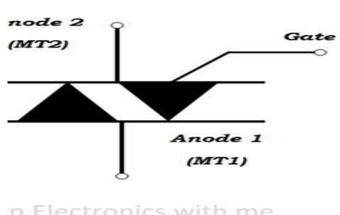
Applications of DIAC

If you want a TRIAC to conduct you need to provide a positive or negative pulse to the gate, in order to provide symmetric firing the DIAC are mostly used along with the TRIAC circuit. The **DIACs are used for triggering TRIAC** or other kinds of thyristors, apart from this they do not possess many applications. The DIACs are used as a trigger device in various applications such as **Phase control circuits of motor speed control, light dimmers, heat controls**, and many other control circuits. Let's look into the examples of Light Dimmer and heat control circuits.

TRIAC

Triac is a three terminal bidirectional semiconductor device. Triac stands for Triode for Alternating Current. It conducts current in both directions and gate terminal controls it. Triac belong to the Thyristor family. The difference between thyristor and Triac is SCR conducts current in only one direction, but Triac conducts in both directions. It is used as AC Switch.

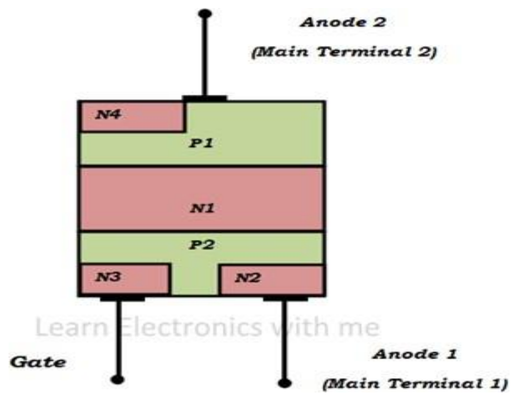
Symbol of Triac:



bol of Triac

The symbol of Triac has three terminals Anode1, Anode2 and Gate. The Anode1 and Anode2 terminals are commonly called as Main terminal1 and Main terminal2. Gate terminal acts like a trigger to turn the device ON. The symbol looks like two thyristors connected in inverse parallel direction merged together with Gate terminal in common.

Construction of Triac:



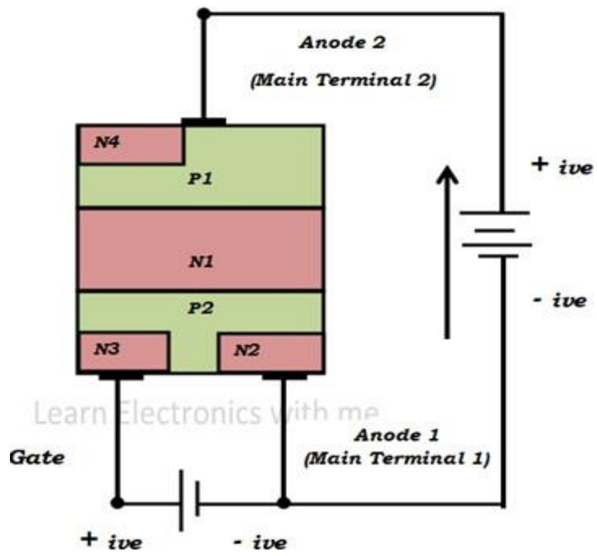
truction of Triac

Triac is a four layer, six doped region and a three terminal device. Gate terminal is connected to both N3 and P2 so that gate triggers the device when both positive and negative voltage is applied. In the Same way MT1 or Anode1 is also connected to N2 and P2 regions, and MT2 or Anode2 is connected to the P1 and N4 regions. So the polarity between the terminals decide the direction of the current through the layers.

Working of Triac:

There are four possible combinations of the potentials applied to the terminals.

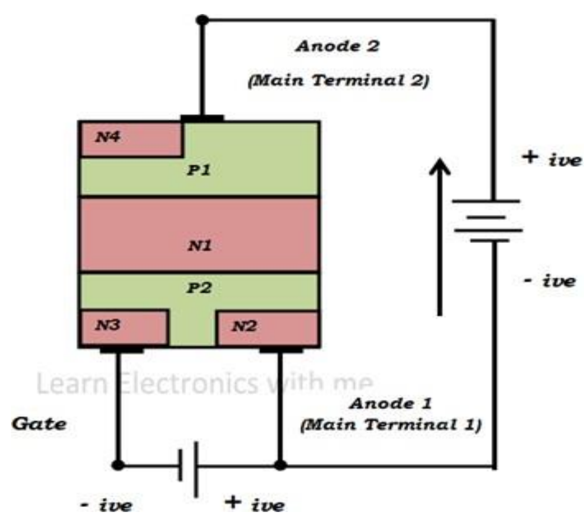
Mode1: MT2 is positive and Gate terminal is positive.



e1: MT1 and Gate positive

When the MT2 terminal is made positive with respect to the terminal MT1 and when positive voltage is applied at the gate terminal the path of the current flow from MT2 to MT1 will be P1-N1-P2-N2. The junction between P1N1 and P2N2 are forward biased and junction between N1P2 is reverse biased and breakdown occurs at this junction.

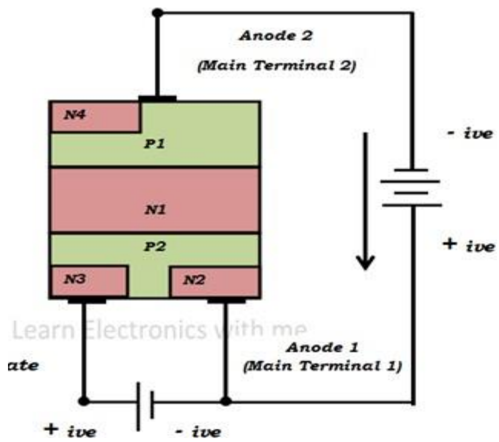
Mode2 : MT2 is positive and Gate terminal is Negative.



e 2: MT2 positive and Gate negative

When the MT2 terminal is made positive with respect to the terminal MT1 and when negative voltage is applied at the gate terminal, initially the path of the current flow from MT2 to MT1 will be P1-N1-P2-N3. When the voltage applied at the MT2 terminal is further increased the junction P2N2 is forward biased and the path of the current flow will be P1-N1-P2-N2. More Gate current is needed to turn the Triac.

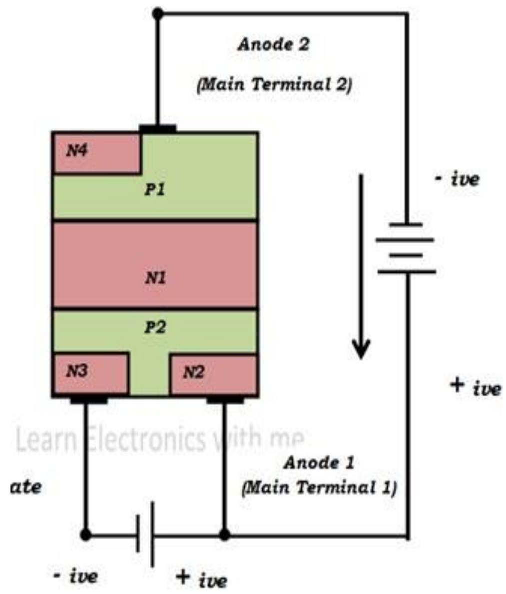
Mode3: MT2 is negative and Gate terminal is positive.



e 3: MT2 negative and Gate positive

When the MT2 terminal is made positive with respect to the terminal MT1 and when negative voltage is applied at the gate terminal the path of the current flow from MT2 to MT1 will be P2N1P1. The Junctions P2N1 and P1N4 are forward biased and the junction N1P1 is reverse biased. So in this mode Triac work in a negative biased region.

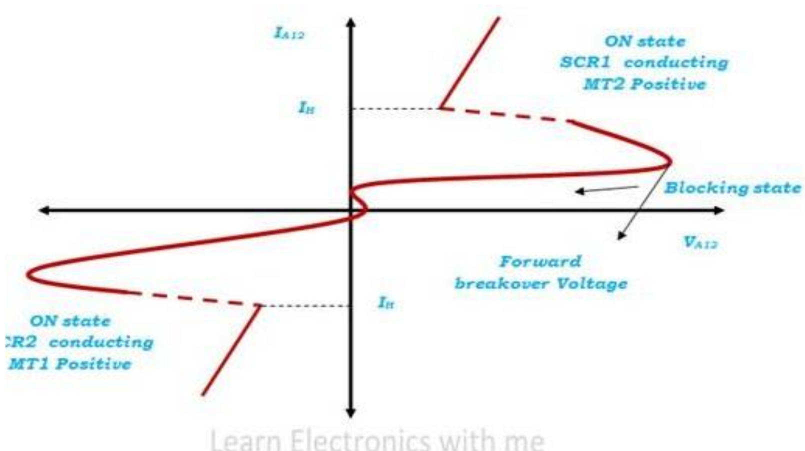
Mode4: MT2 is negative and Gate terminal is negative.



e 4: MT2 and Gate negative

When the MT2 terminal is made negative with respect to the terminal MT1 and when negative voltage is applied at the gate terminal the path of the current flow from MT2 to MT1 will be P2N1P1N4.Mode2 and mode3 are less sensitive and need more gate current to turn ON the device. Mode1 and mode4 have greater sensitivity when gate polarity and MT2 are of same polarity.

V-I characteristics of Triac:



haracteristics of Triac

Triac is made up of two SCRs in inverse parallel. It operates in four modes. Initially the Triac operates in forward and reverse blocking mode and only small leakage current flows through it. When the applied voltage at the MT2 terminal is further increased and when it crosses the breakover voltage Triac starts conduction.

The current start to flow and the voltage applied at the Gate terminal controls this current flow.

Advantages:

- Traic needs single fuse for protection
- It can be triggered either with positive or negative voltages
- It has safe breakdown in either directions
- It turns off when the voltage is zero

Disadvantages:

- Triac is not suitable for DC applications
- Since it is triggered at either directions, triggering circuits should be considered carefully
- Reliability is lesser than SCR

Application of Triac:

- Used in high power lamp switching
- Used to Control AC power
- Used in light dimmers

Power MOSFET Structure & Characteristics

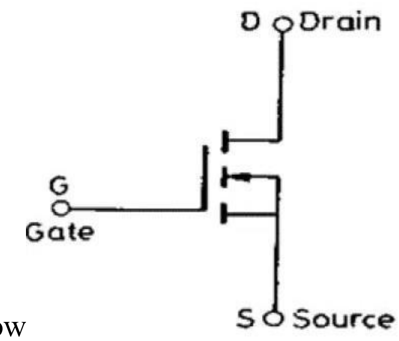
Last Updated on July 1, 2022 by Electricalvolt

In this article, we will discuss the power MOSFET structure and its characteristics. The MOSFET is an important power electronics device developed by combining MOS technology and areas of field-effect transistor concept.

What is a MOSFET?

- It is a three-terminal device of the drain, gate, and source.

- The circuit symbol of MOSFET is given below

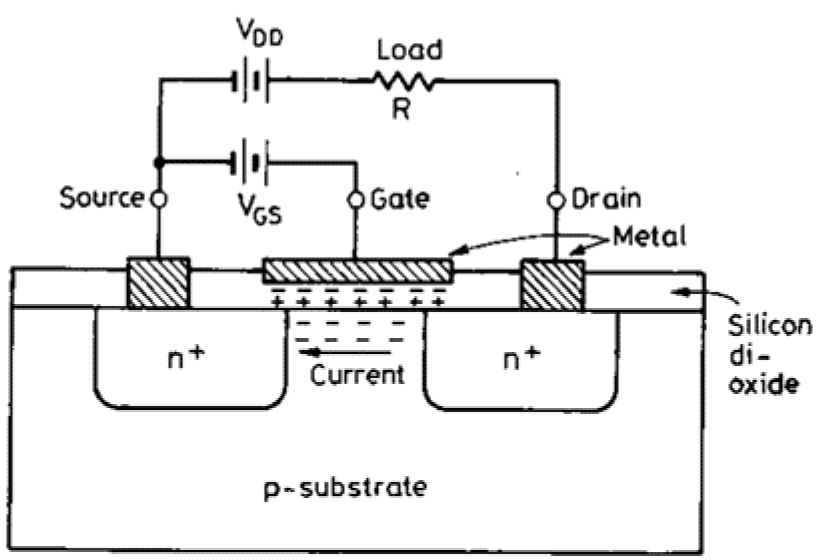


. Arrow indicates the direction of electron flow.

- MOSFET is a voltage-controlled device.
- MOSFET is a unipolar device as a current through MOSFET depends upon the majority- carriers.
- For MOSFET gate terminal is the control terminal, where the gate current is very low. This is because the gate circuit impedance is very large. This large impedance permits the MOSFET gate to be driven directly from the microelectronics circuit.
- Power MOSFETS are generally applicable for low-power high-frequency converters.
- Power MOSFETS are of two types n-channel enhancement type and p-channel enhancement type MOSFET. n-channel MOSFET is used commonly because of the high mobility of electrons.

STRUCTURE OF MOSFET

A simplified planar structure of n-channel MOSFET is given below.



On P-substrate two heavily doped n^+ regions are diffused as shown in the above figure. An insulating layer of silicon dioxide (SiO_2)is grown on the surface. Now, this insulating layer is etched in order to embed metallic sources and drain terminals. Note that n^+ regions make contact with the source and drain terminal as shown. A layer of metal is also deposited on SiO_2 so as to form the gate of MOSFET.

GATE circuit decides the state of MOSFET. When the gate circuit is open the current through the MOSFET (drain to source) is zero. Because one n+-p reverse biased. The Load is connected between the drain and source.

When a positive voltage is given to the gate an electric field is established as shown in the figure, eventually, a layer of negative is formed in a p-substrate region in between two n+ layers. In between the layer of positive charge and negative charge Sio2 layer acts as a dielectric. These negative charges form an n-channel and current flows as shown in the figure. If the positive voltage of the gate increase then electron concentration in the n-channel increases which increases the current ID(Drain to source) Drain current is enhanced with increase of gate voltage that is why it is called an **enhancement type MOSFET**

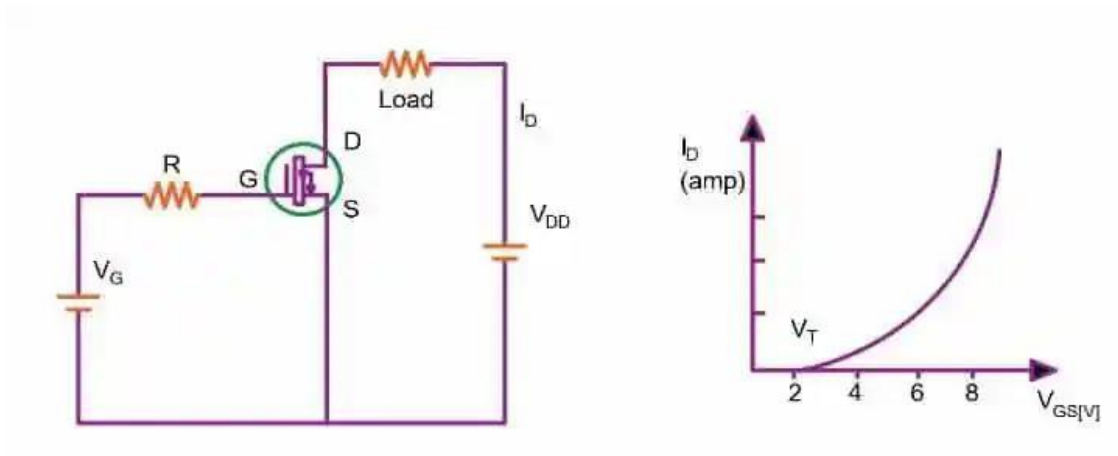
One disadvantage of the n-channel MOSFET is that on-state resistance is high which leads to one-state power loss. That is the reason MOSFET is preferred for low-power applications.

Characteristics of MOSFET

There are three types of static characteristics of MOSFET.

Transfer characteristics

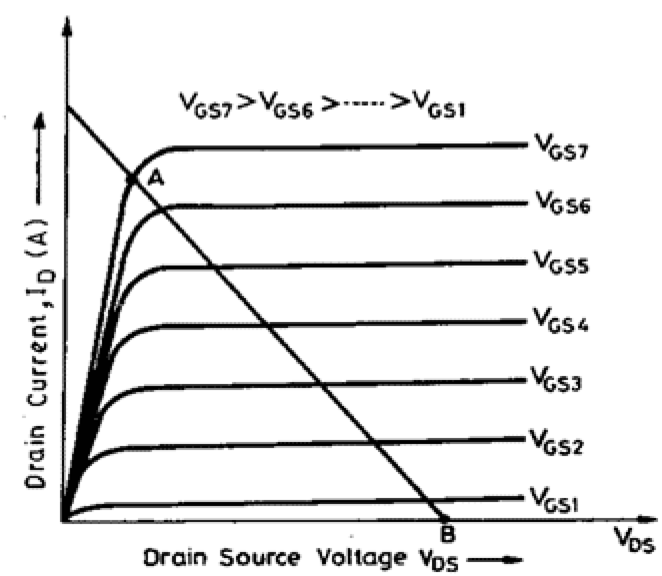
Transfer characteristics is the plot between drain current and gate to source voltage (I_D Vs V_{gs}).



V_T is the **threshold voltage**, which is the minimum voltage required to start the flow of drain current. The threshold voltage is of the order of 2 to 3 volts.

Output (O/P) Characteristics

Power MOSFET output characteristics are shown in the figure below.



From characteristics, it can be concluded that at the low value of VDS the current is linear i.e the on-state resistance is constant. But at a high value of VDS, the current remains constant and varies with V_{GS}. The load line intersects between A and B.

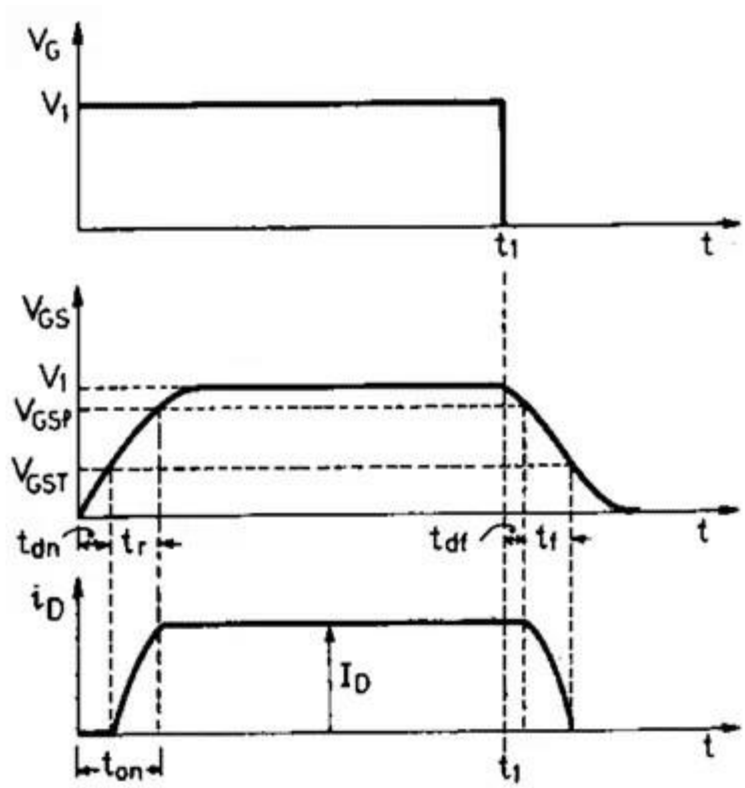
Switching Characteristics

The switching characteristics of a power MOSFET are influenced to a large extent by the internal capacitance of the device and the internal impedance of the gate drive circuit. At turn-on, there is an initial delay
tdn during which input capacitance charges to gate threshold voltage VT. Here tdn is called turn-on delay time. There is a further delay time called rise time (tr), during which gate voltage rises to VGSP, a voltage sufficient to drive the MOSFET into the on-state. During rise-time, the current rises from zero to the drain current (ID). Thus, the total turn-on time can be written as;

$$t_{on} = t_{dn} + t_r$$

The turn-on time can be reduced by using the low impedance gate drive source.

As MOSFET is a majority carrier device, the turn-off process is initiated soon after the removal of gate terminal voltage at time t1. The turn-off delay time tdf, is the time during which input capacitance discharges from overdrive gate voltage V1 to VGSP. The fall time, tf is the time during input capacitance discharges from VGSP to the threshold voltage. During fall time drain current falls to zero. So when VGS is less than threshold voltage then MOSFET goes off. The switching characteristics are given below.



IGBT

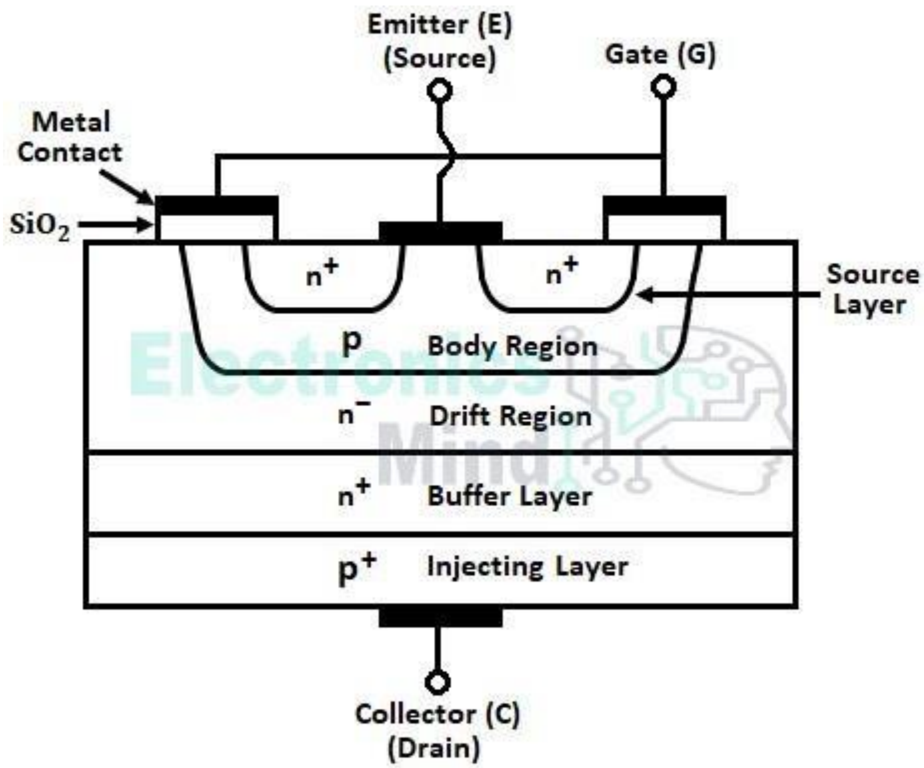
IGBT standards for Insulated Gate Bipolar Transistor. It is another development in the power electronics field also called COMFET (conductivity modulated field-effect transistor), IGT (insulated gate transistor), GEMFET, or bipolar MOSFET. IGBT combines the properties of BJT (bipolar junction transistor) and MOSFET (metal-oxide semiconductor field-effect transistor).

We know that BJT has low ON-state losses but its drive circuit is a little complicated. Whereas a MOSFET has high ON-state losses with a simple and cheap drive circuit. The input characteristics of MOSFET and output characteristics of BJT are combined together forming IGBT.

IGBT is a voltage-controlled device similar to MOSFET with three terminals emitter, collector, and gate. It starts conducting current when a positive voltage across the gate and emitter terminals is applied. It offers high input impedance with low ON-state conduction loss. Let us see the construction and working of IGBT.

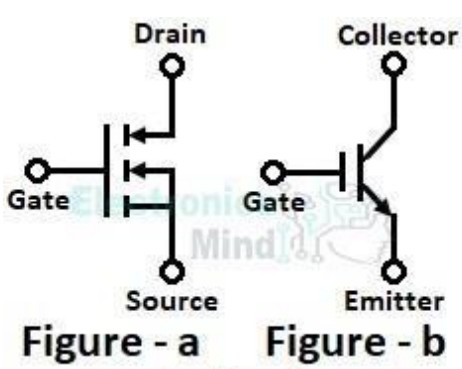
Construction of IGBT :

The below shows the construction of IGBT with three terminals emitter, collector, and gate which sometimes are also called the source, drain, and gate terminals respectively. The doping of each layer in IGBT is similar to layers of vertical MOSFET structure.



Construction of IGBT

The main difference between the construction of IGBT and MOSFET is it has an additional p^+ layer known as injecting layer which forms the collector of IGBT. This layer is heavily doped with an intensity of 10^{19} per cm^3.



Symbols of IGBT

The figure-a above shows the symbol of IGBT which is the same as that of n-channel MOSFET with an arrow in the drain terminal representing injecting contact. The symbol in figure-b represents when IGBT is considered as the basic BJT with MOSFET gate input.

Types of IGBT :

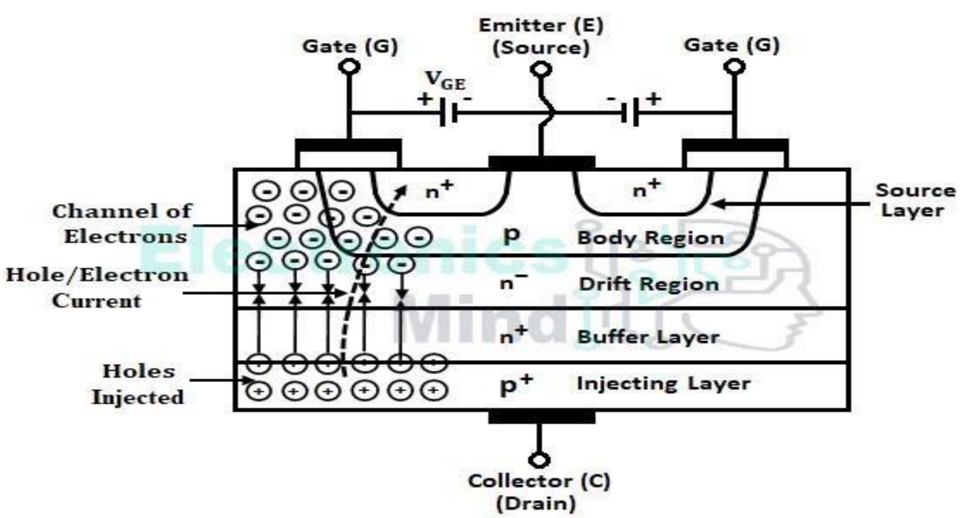
The n^+ buffer present between the injecting and drift layers of IGBT is not essential for its operation. Depending upon the existence of the n^+ layer, IGBTs are classified into two types,

- Non-punch Through IGBTs (Symmetric IGBTs), and
- Punch Through IGBTs (Asymmetric IGBTs).

The IGBTs without an n^+ layer are called non-punch through or symmetric IGBTs. The IGBTs with an n^+ layer are called punch-through or asymmetric IGBTs. Punch Through IGBTs are more popular they have faster turn OFF times and are well suited for inverter and chopper circuits. Non-punch Through IGBTs have symmetric voltage blocking capabilities, thus they are well suited for rectifier circuits.

Working of IGBT :

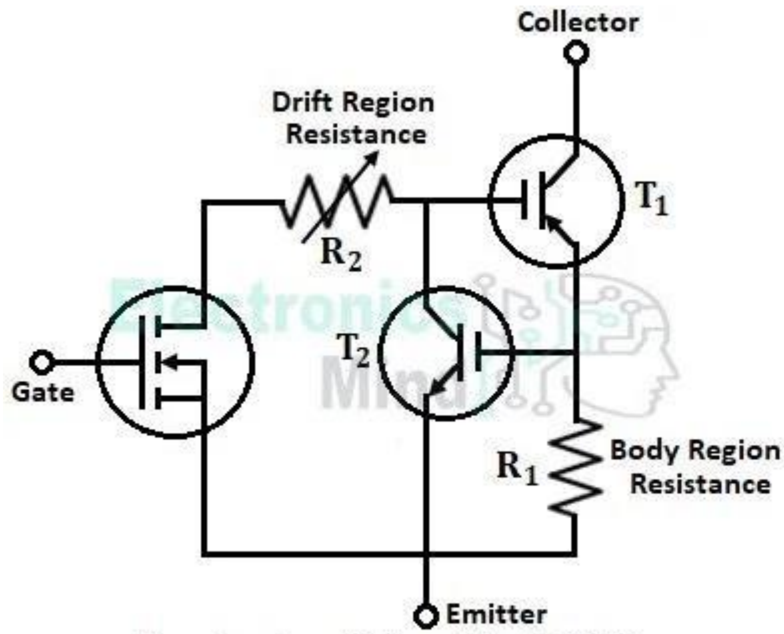
The operation of IGBT is very similar to power MOSFET. When a positive voltage signal greater than the threshold value is applied to the gate terminal, electrons are drawn towards the gate terminal in the body region and attract holes from the p^+ layer as shown below. This forms a conductive channel across the body region, allowing current to flow from the collector to the emitter.



Operation of IGBT

Equivalent Circuit of IGBT :

The below shows the equivalent circuit of IGBT which consists of equivalent MOSFET connected to a coupled NPN and PNP transistor pair which represents a parasitic thyristor structure. On applying a positive voltage signal at the gate terminal, the internal MOSFET turns ON due to which transistor T_1 also triggers.



Equivalent Circuit of IGBT

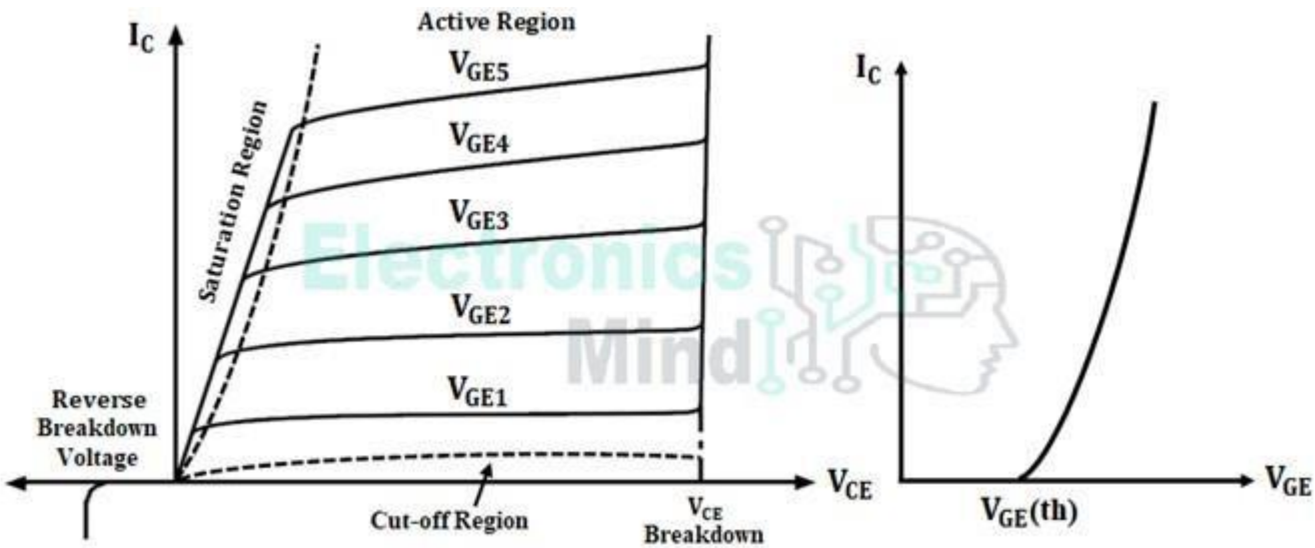
Since the base drive of T_2 is connected to T_1, T_2 will also get turned ON by T_1 forming a regenerative loop. Thus there will be a significant increase in the hole injection resulting in a reduction of ON-state voltage drop like BJT.

However, once the gate signal is removed the conductive channel across the body region is varnished, turning OFF the internal equivalent MOSFET. If body region resistance R_1 is very very small, T_2 gets turned OFF and also turns OFF T_1. If R_1 is very very small, T_2 will never conduct and the equivalent circuit will be modified as shown below.Due to the reduction of drift region resistance because of the p^+ injecting layer. On the application of gate signal, the ON state losses are less in IGBT compared to MOSFET. If in case the body region resistance is significant, the drop due to it is sufficient to turn ON transistor T_2. Due to this T_1 also gets turned ON and forms a regenerative loop.

Under this condition, the gate loses its control over the operation of the IGBT, and a latch-up occurs. The IGBT remains in conduction even if the gate signal is removed, which can cause damage due to excessive power dissipation. This latchup of IGBT into ON-state can be avoided by designing the IGBT by optimizing the doping levels and geometry of the various layers.

V-I Characteristics of IGBT :

The below shows the V-I characteristics of IGBT plotted for the collector or drain current I_C with respect to collector-emitter voltage V_{CE}. It should be noted that sometimes the emitter terminal is also known as the source terminal and the collector as the drain terminal. Since IGBT is a voltage-controlled device, a small voltage is enough across the gate and emitter terminals to turn ON.



V-I Characteristics of IGBT

Transfer Characteristics

In the above V-I characteristics, collector current I_C is being controlled for different values of gate-emitter voltage V_{GE}. When there is no voltage applied across the gate and emitter, there is no conduction of current (i.e., $I_C = 0$) through IGBT and thus it will remain in OFF-state.

In order to turn ON the IGBT, the positive gate voltage applied should be greater than the threshold voltage V_{GE}(th). Once a voltage greater than the threshold value is applied to the gate, the IGBT turns ON and the current I_C starts following through it. The conduction of collector or drain current I_C will increase with an increase in voltage V_{GE}.

The V_{CE} breakdown is the forward breakdown voltage above which the current and voltage through the device will high resulting in huge power dissipation. This will cause damage to the device, thus it is important to operate the device below this voltage.

Advantages of IGBT :

The advantages of IGBT are,

- Compared to other power electronic devices, the power losses in IGBT are less.

- It has good peak current capability.
- It has high input impedance.
- The gate terminal has full control over the operation of the IGBT.
- IGBT has an almost flat temperature coefficient, due to which voltage drop and power loss during conduction are less.
- Since IGBT is a voltage-controlled device, the drive circuit will be simple and cheap.
- Compared to thyristors, high switching frequencies are obtained from IGBT.
- The power gain of IGBT is higher than BJT and MOSFET. Disadvantages of IGBT :

The disadvantages of IGBT are,

- The cost of IGBT is more than MOSFET and BJT.
- Latching up problem.
- The switching speed of IGBT is between BJT and MOSFET.
- Higher turn OFF time compared to MOSFET. Applications of IGBT :

Some of the applications of IGBT are,

- In inverter circuits for ac motor drives.
- In chopper circuits for dc to dc power conversion.
- It is used in various domestic applications such as air conditioners, refrigerators, etc.
- It is used in UPS (Uninterruptible Power Supply) and SMPS (Switched Mode Power Supply) systems.
- Used for traction motor control and induction heating.

What is a Gate Turn Off Thyristor & Its Working

A solid-state semiconductor device like a thyristor is not a completely controlled switch. The operation of this can be done like this, it can be switched ON through a gate terminal however cannot switch OFF using a gate terminal. When the thyristor switch is turned ON and it will not turn OFF even if we detach the gate pulses.

So there is no control to deactivate the thyristor switch. Once the main current is interrupted then the switch will be turned off. Thus, it is difficult to utilize in the application wherever the main supply should not disrupt.

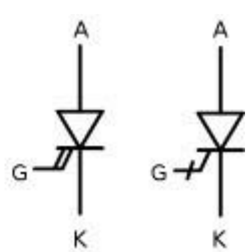
Like the conversion of DC-AC & DC-DC circuit. An expensive, as well as a bulky communication circuit, must be used to deactivate the thyristor. To overcome this problem, the GTO (Gate Turn-Off Thyristor) device is used. It is a current-controlled device similar to a normal thyristor. This article discusses an overview of a **Gate Turn off Thyristor**.

What is a Gate Turn Off Thyristor?

The term GTO stands for "Gate Turn off Thyristor". It is a bipolar semiconductor switching device that includes three terminals namely anode, cathode & gate like a conventional thyristor. It has the capacity of gate turn off. This device is used to turn ON and OFF the main current supply through a gate drive circuit. The basics of Gate Turn-Off Thyristor are discussed below.

Gate Turn Off Thyristor

The **Gate Turn-Off Thyristor symbol** is shown below. To activate the GTO into the mode of conduction, a small positive gate current is required as well as through a negative pulse on the gate terminal; and it is capable of being switched off. In the following image, it includes double arrows on it which differentiate the thyristor from the ordinary thyristor. These arrows mainly specify the flow of current in the bidirectional throughout the gate terminal.



GTO Symbol

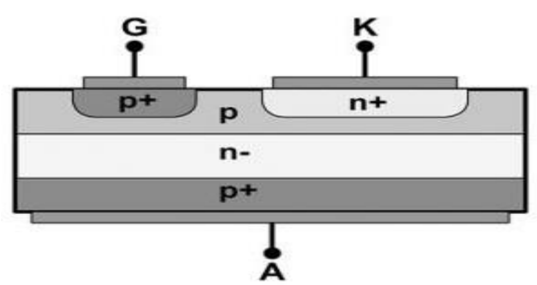
To deactivate the GTO, it uses a high gate current. Alternatively, in the conduction state, thus thyristor works like a normal thyristor including a small ON condition voltage drop. The switching speed of this gate turn-off thyristor is faster as compared to normal thyristor and also it has high current and voltage ratings as compared with power transistors.

At present, different types of GTOs are obtainable in the market including the capabilities of symmetric & asymmetric voltage. The symmetric GTOs are nothing but a GTO that has the capabilities of identical forward as well as reverse blocking which are applicable in current source inverters, however, these are fairly slow.

Asymmetric GTOs (A-GTOs) are mostly applicable because of their lower ON-state voltage drop as well as constant temperature characteristics.

Construction Gate Turn Off Thyristor

The structure of the gate turn off thyristor is similar to a normal thyristor because it includes 3-junctions and 4- PNPN layers. A GTO is a three-terminal PNPN device like anode, cathode, and gate. In this kind of thyristor, the anode terminal is composed of a p+ layer through n+ type fingers diffused within it.The N+ layer of this thyristor is doped highly to get high emitter efficiency and it provides a cathode terminal. Thus,
the junction like J3 breakdown voltage is low and the typical breakdown voltage value ranges from 20 to 40V. The P-layer doping level must be low to maintain excellent emitter efficiency. Similarly, to have a good switch OFF properties, the region doping must be high.



Construction of Gate Turn off Thyristor

The anode junction can be defined as the junction among the P+ anode as well as N base is known as anode junction. The high-efficiency anode junction can be obtained through a P+ anode region which is heavily doped so that the properties of a good switch ON can be achieved. But, the switch OFF capabilities are influenced through such GTOs.

So, this issue can be solved by initiating N+ layers which are heavily doped at normal intervals within the P+ anode layer. So at junction J1, this N+ layer will make direct contact through the N layer. So, the electrons can be moved from the base region to anode metal contact from the P+ anode without causing hole-injection, so this is known as a GTO structure with anode shorted.

Because of these anode shorts, the GTO's reverse blocking capacity can be reduced toward the reverse breakdown voltage of the J3 junction & therefore the turn OFF device can be increased. But, using several anode shorts, the anode junction's efficiency can be reduced & therefore the GTO's switch ON performance can be degraded. So, careful considerations must be taken regarding the anode shorts density for a good switch ON/OFF performance.

Principle of Operation

The GTO's principle of operation is the same as a conventional type thyristor. Once the positive gate current is applied to make the anode terminal positive to the cathode terminal, then the electrons can be generated from the cathode terminal to the anode. So, this induces the hole-injection with the help of an anode terminal in the base region. These electrons as well as holes-injection continuous till the gate turn off thyristor enters into the conduction region.

In thyristor, at first, the conduction begins through switch ON the region of cathode contiguous to the gate terminal. Thus, the remaining region comes into the conduction through plasma spreading.
Not like a thyristor, gate turn off thyristor includes narrow cathode elements which are interdigitated heavily through gate terminal, thus early turned ON region is extremely large & plasma spreading is little. Therefore, the gate turns off thyristor comes into the conduction region very fast.

At the gate terminal, a reverse bias can be applied to switch OFF a conducting thyristor by making the gate terminal negative as compared with the cathode. In the P-layer, a fraction of the holes can be extracted using the gate terminal to hold back the electrons injection from the cathode terminal.

In reply to this, an extra hole current can be removed by the gate terminal which results in more control of electrons from the cathode terminal. Finally across the p-base junction, the voltage drop can cause reverse bias in the cathode junction of the gate & therefore the thyristor will be deactivated.

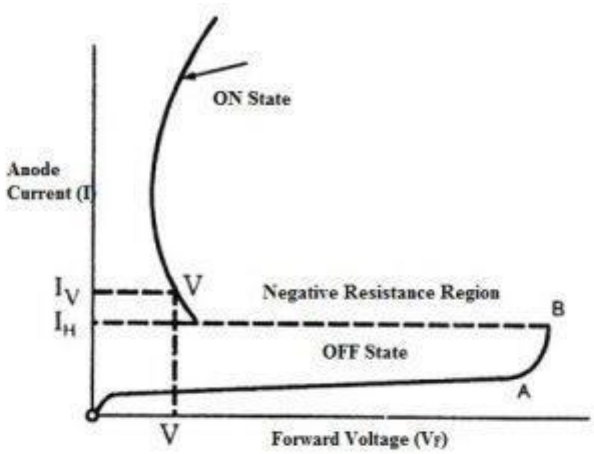
Throughout the process of hole extraction, the area of the p-base is slowly exhausted so that the conduction region can be squeezed. As this procedure continues, then the anode current supplies in remote areas by forming filaments with high current density. So, this can cause limited hot spots which can damage the device if not these filaments are extinguished rapidly.

During the high negative gate voltage application, these filaments are extinguished quickly. Because of the stored charge in the N base region, the anode terminal to gate current flows continuously although the cathode current is stopped. So, this is known as a tail current which decomposes exponentially when the surplus charge carriers are decreased through the recombination procedure. When the tail current level is decreased to a leakage current level, then the device keeps the characteristics of forwarding blocking.

V-I Characteristics

The Gate Turn Off thyristor V-I characteristics are related to a CT or conventional thyristor. The GTO's latching current is more than a CT. For GTO, the latching current is 2A whereas, for a CT, it ranges from 100 mA – 200 mA. The V-I characteristics of GTO are shown below.

The above characteristics mainly include four regions or modes like forward blocking, forward conduction, reverse blocking & reverse conduction.



Characterisitcs of GTO

In the first mode like forwarding blocking, the voltage is applied across the thyristor without applying the +ve gate signal. Therefore, it does not conduct in this mode. But, there is a little leakage current which is very much higher as compared to a thyristor's leakage current. Actually, in this mode, the gate turns off thyristor works like a transistor with high voltage & low gain which means, the anode current is low. In this mode, the GTO simply blocks the rated forward voltage when the gate terminal is biased negatively to the cathode. When a positive gate signal is given with appropriate amplitude to the GTO, then it moves into the mode of forwarding conduction. Similarly, whenever a reverse voltage is to this thyristor, then it blocks the reverse voltage up to a limit but as soon as the reverse voltage reaches a critical value, called the reverse break over-voltage, the GTO starts conducting in the reverse direction.

This mode of operation does not destroy the device if the gate is negatively biased and the time of this operation is small. In reverse biased condition, the blocking capacity mainly depends on the GTO type. A symmetric type includes a high reverse blocking capability whereas an asymmetric type includes a small reverse blocking capacity that ranges from 20-30 V.

Advantages

The **advantages of gate turn off thyristor** include the following.

- The GTO has outstanding switching characteristics
- The configuration of the GTO circuit has less weight and size than the thyristor circuit unit.
- A commutation circuit is not required, hence cost, weight and size can be reduced.
- The switching speed of GTO is high as compared with SCR.
- Less maintenance
- The current surge capacity is similar to an SCR.
- The blocking voltage capacity of GTO is high
- di/dt ratings are more at turn ON
- Efficiency is high

Disadvantages

The **disadvantages of gate turn off thyristor** include the following.

- The associated loss, as well as ON-state voltage drop, is more
- The structure of GTO is multi-layered, so the gate triggering current value is high as compared to the conventional thyristor.
- High losses of Gate drive circuit
- The voltage drop of ON state across the gate turn off thyristor is more.
- The latching & holding current's magnitude is high as compared to SCR
- The latching current value is 2A whereas, for an SCR, it ranges from 100 mA to 500 mA.
- As compared with SCR, the triggering current of GTO is high

Applications

GTO is used in many applications because of many benefits as compared to another thyristor like outstanding switching characteristics, less maintenance and no require of commutation circuit, etc. The applications of gate turn off thyristor include the following.

- In choppers as well as inverters, It is used as the main control device.
- AC drives
- DC drives
- DC circuit breakers
- DC choppers otherwise DC drives
- Induction heating
- Used in traction applications because of less weight
- Low power applications
- AC stabilize power supplies
- It is used in inverters, SVCs (static VAR compensators)
- Used in drive systems like rolling mills, machine tools & robotics.

CHAPTER-2

UNDERSTANDING THE WORKING OF CONVERTERS, AC REGULATORS AND CHOPPERS.

RECTIFIERS

An electrical circuit that converts alternating current into a direct current is called a rectifier. Rectifiers incorporate semiconductor devices like diodes, thyristors, IGBTS, etc. for the conversion of alternating current into a direct current. Depending upon the type of switching device used, rectifiers are classified into two types uncontrolled and controlled rectifiers.

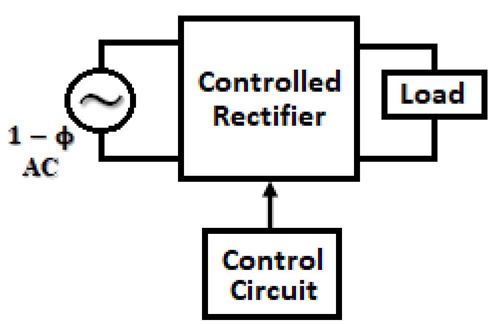
Rectifier circuits employing only diodes are called uncontrolled rectifiers. Unlike a thyristor, a diode doesn't have any gate terminal and it starts conducting when its anode-to-cathode voltage becomes positive. Thus we cannot control the conduction period for a diode, the conduction and commutation of the diode will depend upon the circuit conditions.

Thus the average dc output voltage of an uncontrolled rectifier cannot be adjustable which means the output voltage is fixed and cannot be varied. That is why rectifier circuits incorporating only diodes are called Uncontrolled Rectifiers.

However, for most of the applications, there is a requirement for a controllable dc power supply. A controllable or adjustable dc output can be obtained by using a controlled rectifier. Let us see the circuit construction and working of controlled rectifiers.

What is a Controlled Rectifier?

A controlled rectifier uses controllable semiconductor devices like thyristors, IGBTs, etc. We know that an uncontrolled rectifier gives a fixed dc output voltage, from a controlled rectifier we can get a controllable or adjustable dc output voltage.



Generally, thyristors are used in controlled rectifiers for which we can control the conduction period of the device even in forward bias conduction. A thyristor is turned ON by applying a voltage pulse to the gate terminal in its forward-biased condition and it is turned OFF when its anode current falls below the holding current value.

Thus by varying the time at which the thyristor is turned ON we can get a variable dc output voltage. Also, the thyristor is reverse-biased for each ac input cycle due to voltage reversal which reduces the anode current below the holding current value. Thus the thyristor is naturally commutated in a controlled rectifier which in turn eliminates the need for an extra commutation circuit.

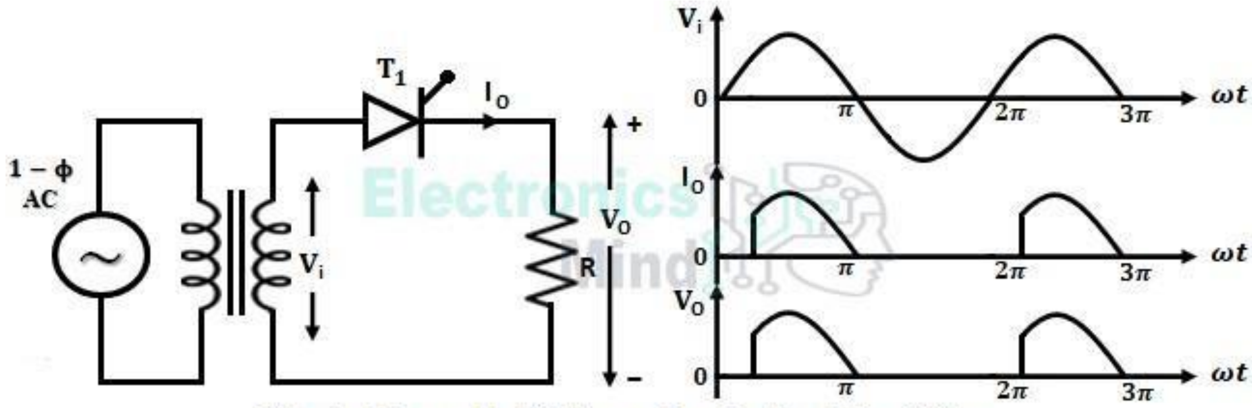
Types of Controlled Rectifiers:

Controlled rectifiers are classified into two types single-phase controlled rectifiers and three-phase controlled rectifiers. The single-phase and three-phase rectifiers are further classified as,

1) Single-phase Controlled Rectifiers
   a. Half-wave controlled rectifiers
   b. Full-wave controlled rectifiers
   c. Half-controlled rectifiers

2) Three-phase Controlled Rectifiers
   a. Half-wave controlled rectifiers
   b. Full-wave controlled rectifiers
   c. Half-controlled rectifiers

A half-wave controlled rectifier converts only either the positive or negative half-cycle of ac input supply into dc. The circuit diagram of a half-wave controlled rectifier is similar to a half-wave uncontrolled rectifier except the diode is replaced by a thyristor as shown below.



Single Phase Half-Wave Controlled Rectifier

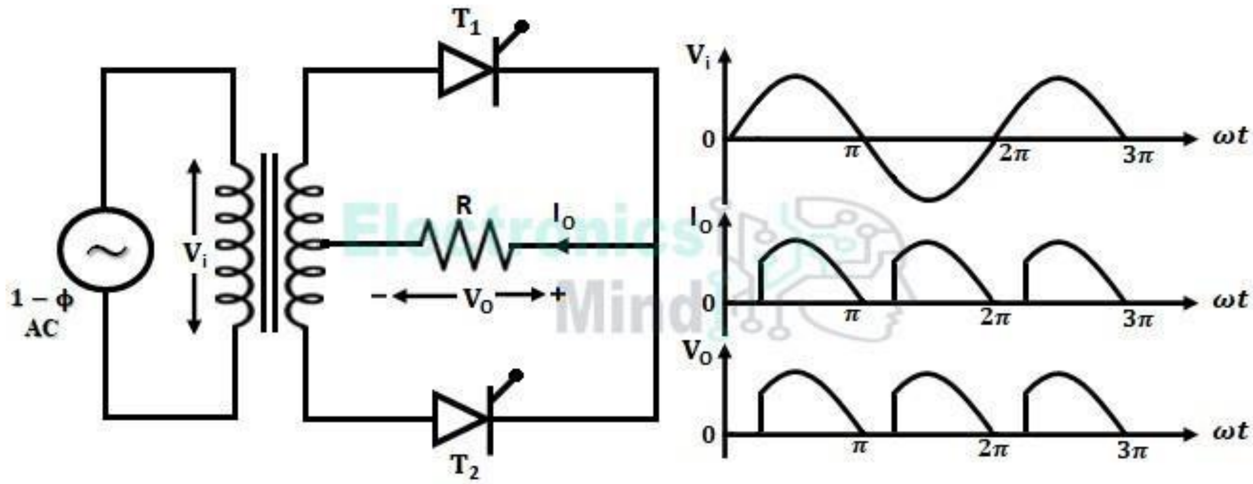
In the above circuit, the thyristor will be forward-biased during the positive half-cycle but it will be in forward blocking state and blocks the flow of current through it. As soon as the gate signal is applied, the thyristor switches from OFF-state (forward blocking state) to ON-state (forward conduction state), and thus load gets connected across the supply.

During the negative half-cycle, the thyristor will be reverse biased and no current flows through the load. Therefore, only a half-cycle of ac input reaches the load. By varying the time at which the gate pulse is applied to the thyristor we can control the average dc output voltage.

Full-wave Controlled Rectifier:

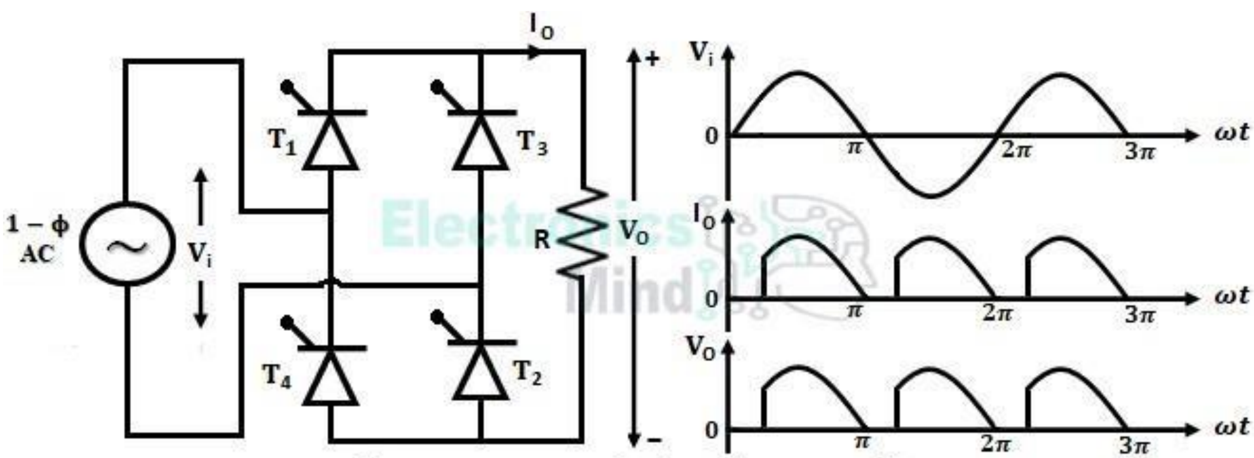
A full-wave controlled rectifier converts the full cycle (both positive and negative half-cycle) of ac supply into dc. There are two types of full-wave rectifiers, center-tapped configuration, and bridge configuration. The center-tapped configuration uses two thyristors whereas the bridge configuration uses four thyristors.

In a center-tapped controlled rectifier, two thyristors are connected at the secondary side of a center-tapped transformer as shown below. During the positive half-cycle, thyristor T_1 will be forward-biased and allows current once it is triggered. During the negative half-cycle, thyristor T_2 will be forward-biased and allows current once it is triggered.



Center-Tapped Full-Wave Controlled Rectifier

In bridge-type controlled rectifiers, four thyristors are connected in a closed-loop manner as shown below. During the positive half cycle, thyristors T_1 and T_2 will be forward-biased and allows current once it is triggered. During the negative half cycle, thyristors T_3 and T_4 will be reverse-biased and allows current once it is triggered.

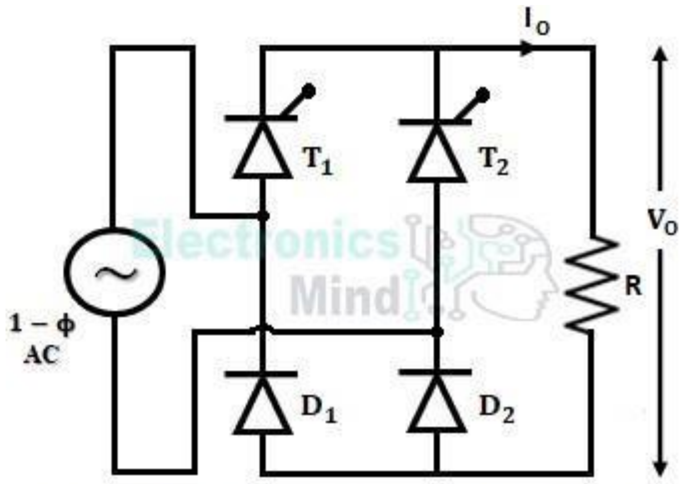


Full-Wave Controlled Bridge Rectifier

Thus both center-tapped and bridge rectifiers convert positive and negative half-cycles of ac input into pulsating dc. By controlling the triggering pulse delay of thyristors we can control the average dc output voltage.

Half-Controlled Rectifier:

A rectifier circuit employing both diodes and thyristors is called a half-controlled rectifier. Due to the use of diodes in combination with thyristors, we don’t have complete control over the output voltage. Hence the circuit is known as a half-controlled rectifier. The below shows the circuit of a half-controlled rectifier.



Single-Phase Half-Controlled Rectifier

By controlling the switching angle of the thyristors we can obtain a variable dc output voltage. A half-controlled rectifier is also known as a semi-converter.

Advantages of Controlled Rectifiers:

- A variable output voltage can be obtained from a controlled rectifier.
- Since thyristors are naturally commutated there is no need for a commutation circuit.
- A smooth control over the output voltage.
- Thyristors can handle large voltages, currents, and power.

Disadvantages of Controlled Rectifiers:

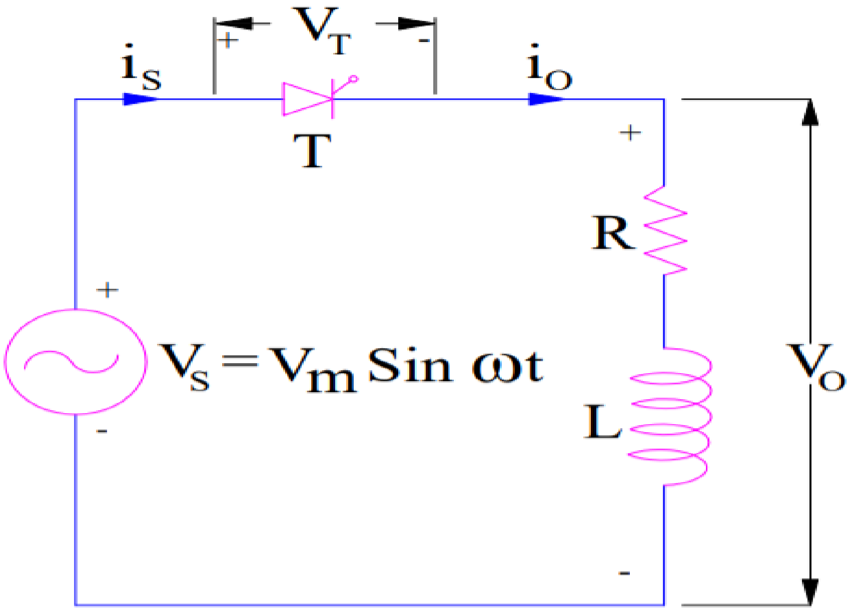
- Since the cost of thyristors is more than diodes, controlled rectifiers are costlier than uncontrolled rectifiers.
- Controlled rectifiers are a little bit more complex than uncontrolled rectifiers.

Single Phase Half Wave Controlled Rectifier with RL Load

A single phase half wave controlled rectifier is a thryristor based circuit which produces output voltage for positive half of the supply voltage. However, the phase relationship between the initiation of load current and supply voltage can be controlled by changing firing angle. This is the reason; it is called phase controlled half wave rectifier. In this article, we will discuss the circuit diagram, average load voltage, average load current and RMS load voltage for a Single Phase half Wave Controlled Rectifier with RL load.

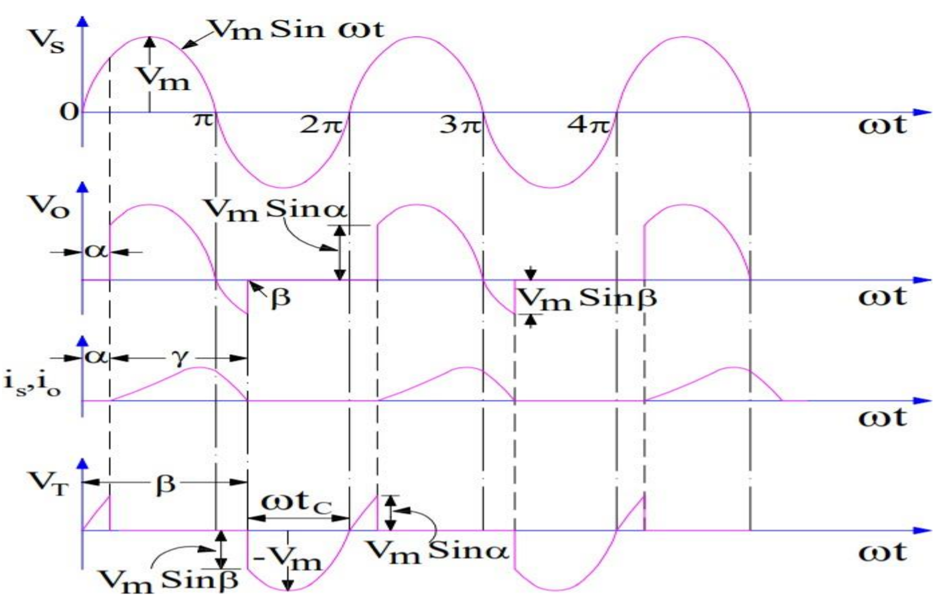
Circuit Diagram:

The circuit diagram of a single phase half wave controlled rectifier with RL load is shown below. This circuit consists of a thyristor T, source Vs and RL load. The output voltage is the voltage across the load and shown as V_o. Output current is the current through the load and shown as i_o.



Working Principle:

The waveform of source voltage, load voltage, load current and voltage across thyristor is shown below.



It is assumed that the thyristor T is fired at an angle $\omega t = \alpha$. As soon as the thyristor T is fired at $\omega t = \alpha$, load voltage equal to the source voltage instantaneously appears across the load terminal. This is because, the thyristor is forward biased in between $\omega t = 0$ to α. Hence, once the thyristor is gated, it stars conducting. However, the current does not start at this instant of firing. This is just because of the nature of load. Since, the load is inductive, it will not allow any sudden change. Therefore, at $\omega t = \alpha$, the output current will be zero and will gradually increase. The output current will become maximum and then start decreasing. It should be noted here that, this behavior of load current i_o will not be observed for purely resistive load.

At $\omega t = \pi$, the load voltage V_o reduces to zero. However, the load current will not be zero at this instant because of inductance L. Due to this, thyristor will not turn off, even though it is reversed biased. Rather it will continue to conduct till $\omega t = \beta$. At $\omega t = \beta$, the load current becomes zero and thyristor is reversed biased, hence it will turn off. This is a case of natural commutation.

After $\omega t = \beta$, $v_o = 0$ and $i_o = 0$. At $\omega t = (2\pi+\alpha)$, the SCR is triggered again, v_o is applied to the load and load current develops as discussed before. The angle β where the load current becomes zero is called ***extinction angle*** and the angle $(\beta-\alpha)$ for which thyristor is ON is called ***conduction angle***.

Carefully observe the voltage across the thyristor. The SCR is reverse biased from $\omega t = \beta$ to $\omega t = 2\pi$. During this period, the current through thyristor is also zero. Therefore, circuit turn off time is $t_c = [(2\pi - \beta) / \omega]$ second. This time must be greater than the thyristor turn-off time otherwise thyristor may turn on at undesired instant and will lead to commutation failure.

Calculation of Average Load Voltage and Current:

The average value of any function f(x) is given as below.

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

Now, we will apply the above formula to calculate the avg. load voltage of single phase half wave controlled rectifier with RL load. For this, carefully observe the waveform of load voltage. The time period of the voltage waveform is 2π and it is equal to VmSin(wt) for wt = α to wt = β. For $0<wt<\alpha$ and $\beta<wt<2\pi$, the value of load voltage is zero.

Therefore, the average voltage of this controlled rectifier with RL load may be calculated as below.

$$Avg.Voltage, Vo = \frac{1}{2\pi}\int_{\alpha}^{\beta} Vm\sin(\omega t)d(\omega t)$$
$$= \frac{Vm}{2\pi}(\cos\alpha - \cos\beta)$$

Average load current Io can be calculated by dividing the average load voltage by the circuit resistance. Mind that, average load current means DC quantity, therefore average voltage is divided by circuit resistance R instead of circuit impedance Z. Therefore, average load current of single phase half wave controlled rectifier is given as below.

$$Avg.Current, Io = \frac{Vm}{2\pi R}(\cos\alpha - \cos\beta)$$

Calculation of RMS Load Voltage:

RMS load voltage of single phase half wave controlled rectifier is given as below.

$$RMS\ Voltage, Vo = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\beta}(Vm\sin\omega t)^2\, d(\omega t)}$$
$$= \frac{Vm}{2\sqrt{\pi}}\sqrt{[(\beta-\alpha) - 1/2\{\sin 2\beta - \sin 2\alpha\}]}$$

Hope you enjoyed the article. In case you have any doubt/suggestion, kindly write in comment box. Kindly share the post if you like it.

Single Phase Full Wave Controlled Rectifier (or Converter):

In case of Single Phase Full Wave Controlled Rectifier (or Converter) both positive and negative halves of ac supply are used and, therefore, the effective value of dc voltage is high and ripple content is less compared to half-wave rectifiers. There are two basic configurations of Single Phase Full Wave Controlled Rectifier. Their classification is based on the type of configuration used i.e., mid-point converters and bridge converters. The diodes used in full-wave rectifiers, may be partially or completely replaced by thyristors.

Mid-Point Converters (M-2) Connection:

In a Single Phase Full Wave Controlled Rectifier circuit with midpoint configuration two thyristors and a single phase transformer with centre-tapped secondary windings are used. These converters are sometimes called the **two pulse converters** because two triggering pulses or two sets of triggering pulses are to be produced during every cycle of the supply to trigger the different thyristors. Such circuits are generally used for low rating outputs.

With Inductive Load: The effect of inductive load in case of mid-point converter is same as in case of half-wave converter, discussed earlier. The circuit of a mid-point converter using inductive load is shown in Fig. 27.9 and associated waveforms are shown in Fig. 27.10. In positive half cycle thyristor TH_1 conducts when it is fired at an angle α. When $\omega t = \pi$ the cycle reverses and the voltage at terminal A goes negative while at terminal B it goes positive. At this value of angle thyristor TH_1 still conducts due to current circulated as a result of decay of energy stored in the inductor. The rate of decay is determined by L/R ratio. When the energy stored in the inductor falls to zero, thyristor TH_1 is turned off and the load current falls to zero value at an angle called extinction angle β. The extinction angle β may be greater than, equal to, or less than the firing angle α depending upon whether the value of inductance is more than, equal to or less than the critical value respectively. In case the extinction angle β is more than the firing angle α, the device is said to be in continuous conducting mode and when both angles α and β have the same value, the mode is called just **continuous conduction mode**. The waveforms depicted in Fig. 27.10 are for just conduction mode i.e. $\beta = \alpha$. In case of discontinuous conduction mode extinction angle β has a value lesser than that of firing angle α.

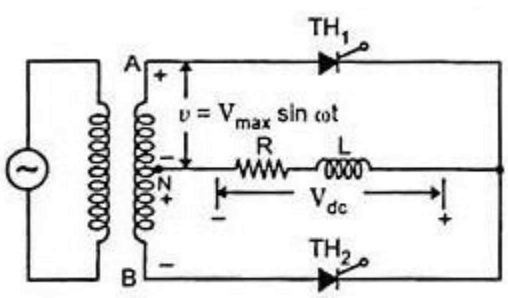


Fig. 27.9 *Mid-Point Converter With Inductive Load*

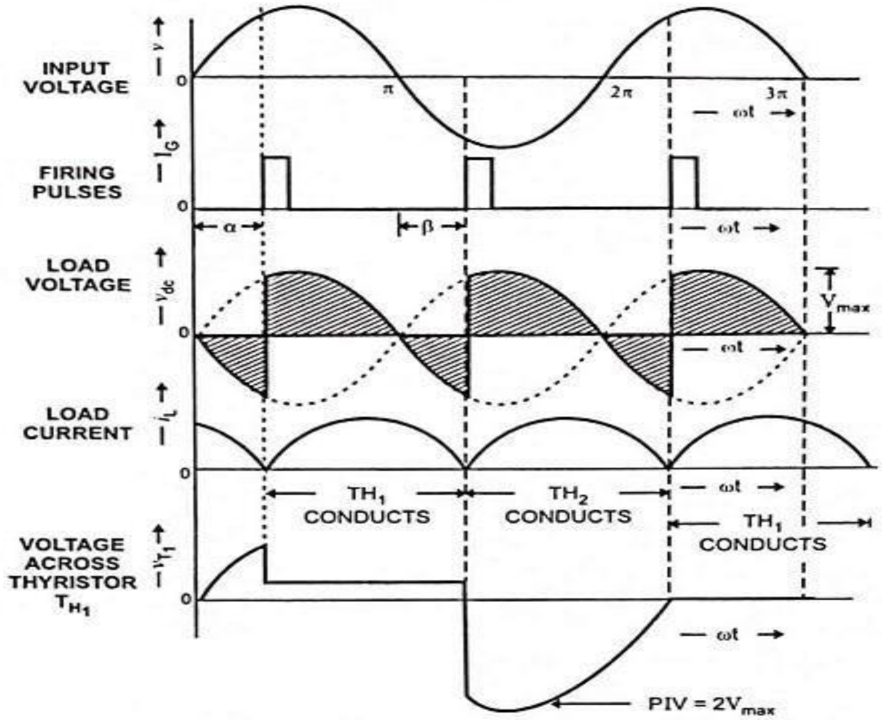


Fig. 27.10 *Waveforms For M-2 Connection With R-L Load*

The **output dc voltage** across the inductive load is given by

$$V_{dc} = \int_{\alpha}^{\pi+\alpha} V_{max} \sin \omega t \, d(\omega t) = \frac{2V_{max}}{\pi} \cos \alpha \qquad ...(27.16)$$

Some conclusions may be made from above equation:

1. Output voltage will have the highest value for α = 0.
2. Output voltage will be zero for α = 90°. It means that the output voltage will contain equal positive and negative areas, giving zero output voltage.
3. For firing angle α exceeding 90°, the converter operates in inversion mode. The voltage will be negative maximum for α = 180°.

It is observed that the output power can be controlled to any value by varying the firing angle α between 0 and 90° in case of inductive loads, while in case of resistive load, the firing angle α ranges from 0° to 180°.

3. Effect of Freewheeling Diode: Circuit shown in Fig. 27.9 can be modified by using a freewheeling diode as depicted in Fig. 27.11. The operating principle of the rectifier is the same as that of without freewheeling diode except the fact that during the negative cycle, the load voltage becomes zero. The function of freewheeling diode is to divert the load current from the supply to the diode. The net result is that the magnitude of the net magnetizing current in the transformer secondary is reduced i.e., I_{dc} sin Φ goes down.

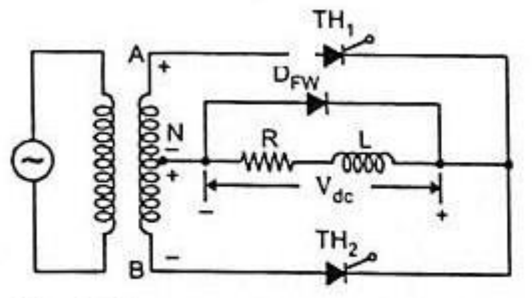


Fig. 27.11 *Mid-point Converter With R-L Load and Freewheeling Diode*

As I_{dc} is the load current and remains constant, only sin Φ decreases. It means that angle Φ decreases which leads to an increase in power factor. Thus, the use of freewheeling diode improves the power factor of the load. The presence of freewheeling diode results in change in waveforms. As the supply voltage reverses, the load voltage is reduced to zero as it is shorted by the diode conducting the current circulated by the energy stored in the inductor. From the waveforms shown in Fig. 27.12, it can be observed that switching behavior of thyristor in case of R-L load is like that in a pure resistive load.

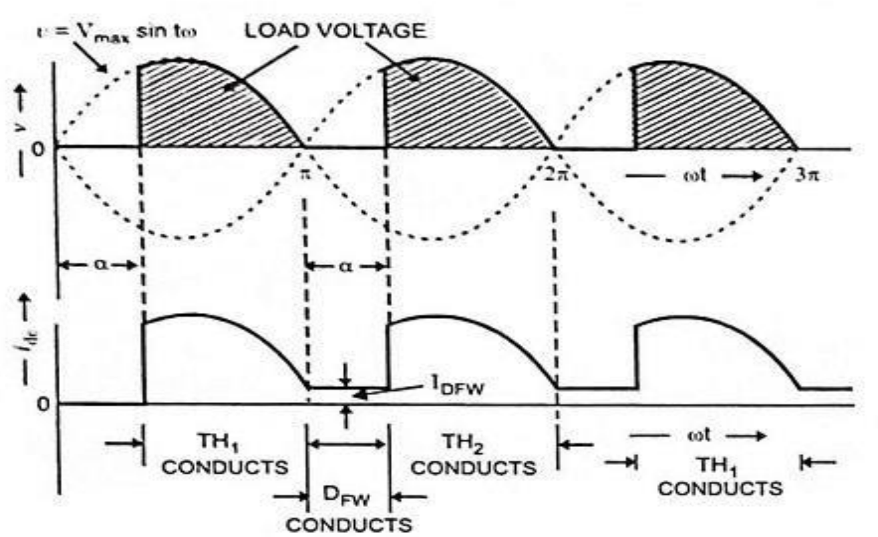


Fig. 27.12 *Waveforms For M-2 Connection With R-L Load and Freewheeling Diode*

The average dc output voltage is given by

$$V_{dc} = 2 \times \frac{1}{2\pi}\int_{\alpha}^{\pi} V_{max} \sin \omega t \, d(\omega t) = \frac{V_{max}}{\pi}(1+\cos\alpha) \quad ...(27.17)$$

The dc load current is given by

$$I_{dc} = \frac{V_{dc}}{R} = \frac{V_{max}}{\pi R}(1+\cos\alpha) \quad ...(27.18)$$

It is also observed from Fig. 27.10, that the freewheeling diode D_{FW} carries the load current during the firing angle α when the thyristors are not conducting. Hence the current through the freewheeling diode D_{FW} is given by

$$I_{DFW} = I_{dc}\frac{\alpha}{\pi} = \frac{V_{max}}{\pi R}(1+\cos\alpha)\times\frac{\alpha}{\pi} = \frac{V_{max}}{\pi^2 R}(\alpha+\alpha\cos\alpha) \quad ...(27.19)$$

<u>BRIDGE RECTIFIER</u> -The figure shows a single phase fully controlled bridge rectifier (or full converter) with R-L load. The fully controlled bridge rectifier provides two pulses in each cycle as in case of mid-point full-wave converter. The operating principle and waveforms of this circuit are similar to those obtained for mid-point full-wave converter. Firing angles for both the thyristor pairs are assumed to be equal. A large value of L will result in a continuous steady current in the load. A small value of L will produce a discontinuous load current for large firing angles. The waveforms with two different firing angles are depicted in Fig. 27.16.

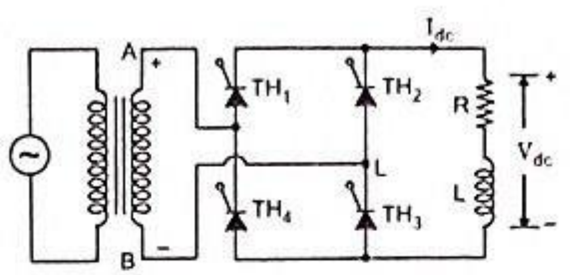
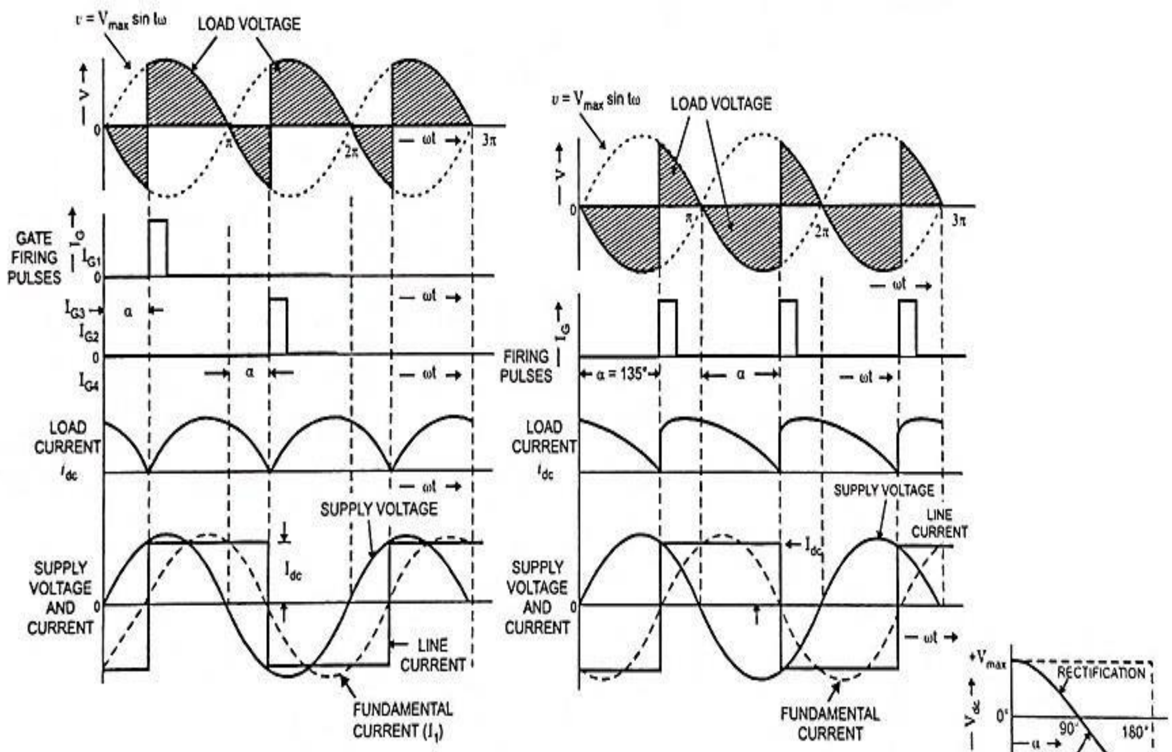


Fig. 27.15 *Single Phase Full-Wave Converter With Inductive (R-L) Load*

The voltage waveform at the dc terminals comprises a steady dc component superimposed with an ac ripple component, having a fundamental frequency equal to twice that of ac supply.



(a) Waveforms For Single-Phase Bridge Converter For α = 60°

(b) Waveforms For Single Phase Bridge Converter For α = 135°

(c)

Fig. 27.16

As illustrated in Fig. 27.16 (a), at firing angle $\alpha = 60°$, thyristors TH_1 and TH_3 are triggered. Supply voltage from this instant appears across the output terminals and forces the current through the load. The load current I_{dc} is assumed to be constant. This current also flows through the supply and the direction is from line to neutral, which is taken positive as depicted in Fig. 27.16 (a) along with the applied voltage. At instant π, the supply voltage reverses but because of very large inductance L, the current keeps flowing in the same direction at constant magnitude I_{dc}. Thus the thyristors TH_1 and TH_3 remain in conducting state and therefore, the negative supply voltage appears across the output terminals. At an angle $\pi + \alpha$, thyristors TH_2 and TH_4 are triggered. With this, negative supply voltage reverse biases thyristor TH_1 through thyristor TH_2 and thyristor TH_3 through thyristor TH_4 of commutating thyristor TH_1 and TH_3. The current continues flowing in every half cycle and output voltage is obtained as depicted in the figure. As illustrated the current is positive when

TH_1 and TH_3 are conducting and negative when TH_2 and TH_4 are conducting.

The average output dc voltage is given by

$$V_{dc} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_{max} \sin \omega t \, d(\omega t) = \frac{2V_{max}}{\pi} \cos \alpha \qquad ...(27.20)$$

The average value of output dc voltage can be varied, by varying firing angle α, continuously from positive maximum to negative maximum, assuming continuous current flow at the dc terminals. Because the average dc voltage is reversible even though the current flow in the load is unidirectional, the power flow in the convener can be in either direction. Thus full converter provides two modes of operation.

(a) Rectification Mode: For firing angle α less than 90°, the input ac supply is rectified by the circuit. The average value of voltage at the dc terminals is positive in the range from 0° to 90°, as illustrated in Fig. 27.16 (c) . In this mode, the power is transferred from the source to the load.

(b) Inversion Mode: For firing angle between 90° and 180°, the load voltage is negative which means that the power is supplied from the load to the source. Waveforms for α = 135° are shown in Fig. 27.16 (b) . Such an operation is used in the regenerative braking mode of dc drives and in high voltage direct current (HVDC) transmission.

AC Voltage Controller

Definition:

AC Voltage Controller is a thyristor based device which converts fixed alternating voltage directly to variable alternating voltage without a change in frequency.

AC Voltage Controller is a phase-controlled device and hence no force commutation circuitry is required. Natural or line commutation is used. Phase control means that the phase relationship between the start of load current and supply voltage is controlled by varying the firing angle of thyristor used in the circuit of ac voltage controller.

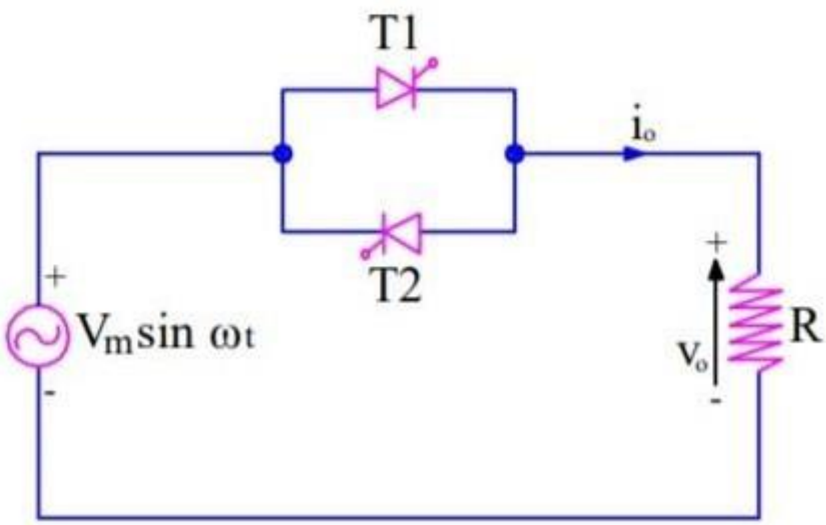
Working Principle of AC Voltage Controller:

The working principle of AC Voltage Controller is based on either of two methods: ***Phase Control or Integral Cycle Control.***

In Phase Control method, the phase relationship between the start of load current and the input supply voltage is controlled by controlling the firing angle of the thyristor.

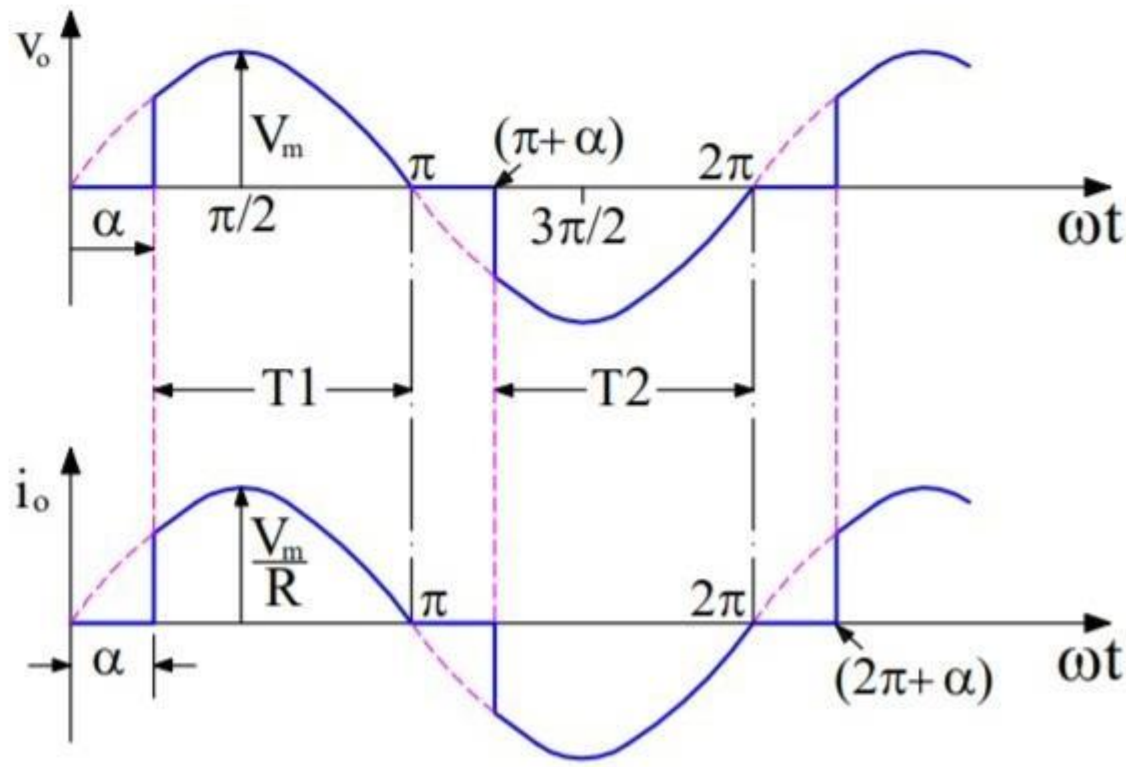
In Integral Cycle Control, the AC input supply is switched ON for some integral cycles and turned OFF for further number of integral cycles. Integral cycle control is mainly used for applications where the mechanical time constant or thermal time constant is quite high of the order of some seconds. For example, mechanical time constant for many of the speed control drives, or the thermal time constant of the heating loads is usually quite high. For such applications, almost no variation in speed or temperature will be noticed if the control is achieved by connection the load to the source for some on-cycles and then disconnecting the load for some off-cycles. This form of power control is the integral cycle control.

Figure below shows the circuit diagram of a single phase full wave AC voltage controller:



The circuit comprises of two thyristors connected in anti-parallel. Anti-parallel connection is done so that thyristor (T1) is forward biased for the positive half of the input supply voltage whereas thyristor (T2) is forward biased for the negative half cycle of the input AC supply. Method of phase control is used to achieve output voltage control.

When T1 is forward biased, it may be fired to turn it ON. The firing angle of thyristor may be chosen based on the required output voltage. If the output voltage requirement is more, the firing angle (α) should be less. Refer the figure below. This figure shows the method to control the voltage in this controller.



Suppose, T1 is fired at an angle α. As soon as T1 is fired, it connects the load to the source for positive half cycle of input. If the load is resistive in nature, the load output voltage follows the envelop of AC supply input. The load current at once becomes ($V_m\sin\alpha$ / R) and is in phase with the load voltage.

At ωt = π, the load voltage becomes zero and current, also, becomes zero. Since, thyristor T1 is reversed biased after ωt = π and current through it is zero, it gets naturally commutated.

At ωt = (π+α), forward biased thyristor T2 is gated. Hence, it conducts and connected load to the source. The load voltage now follows the negative envelop of the AC input supply and the load current does the same. Thus, the root mean square voltage may be controlled by having a control of firing angle. In this way, voltage control is achieved in AC voltage Controller.

Application of AC Voltage Controller:

Some of the main application of AC Voltage Controller are for the following:

- Domestic and industrial heating
- Transformer tap changing
- Lighting control
- Speed Control of single phase and three phase AC drives
- Starting of Induction Motors

Earlier the devices were used for the above applications were auto-transformer, tap-changing transformers, magnetic amplifiers, saturable reactors etc. But these devices are now replaced by thyristor and TRIAC based AC Voltage Controller because of their high efficiency, flexibility in control, compact size and less maintenance requirement. AC voltage controllers are also adaptable for closed-loop control system.

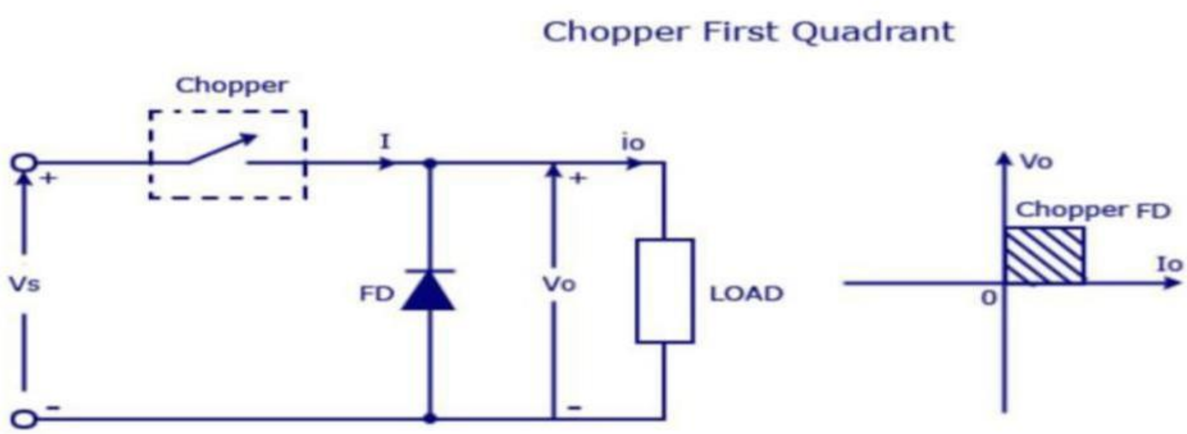
The main disadvantage of AC voltage controller is the introduction of objectionable harmonics in the supply current and load voltage waveform, particularly at reduced output voltage level.

Types of choppers

The semiconductor devices are arranged appropriately in a chopper to work in any of the four quadrants.we can classify chopper circuits according to their working in any of these four quadrants as type A, type B, type C, type D and type E.

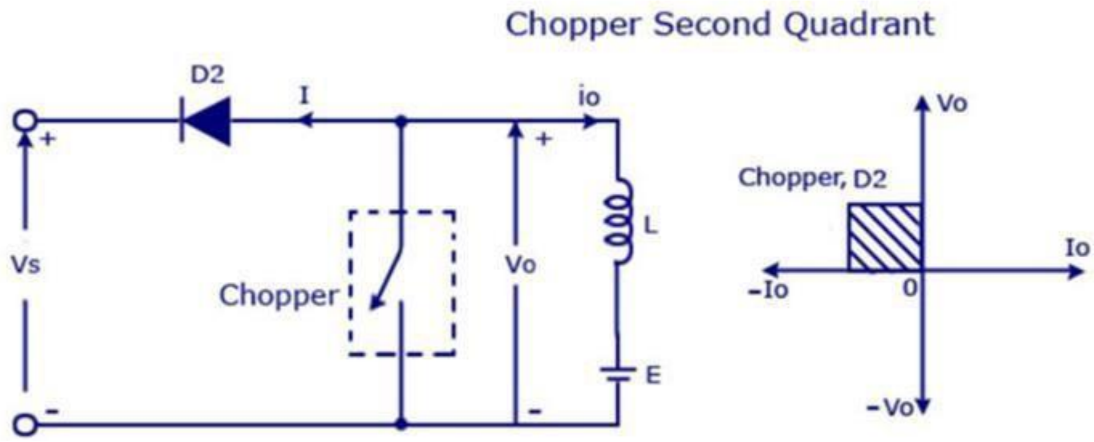
TYPE A CHOPPER OR FIRST–QUADRANT CHOPPER

This type of chopper is shown in the figure. It is known as first-quadrant chopper or type A chopper. When the chopper is on, v0 = VS as a result and the current flows in the direction of the load. But when the chopper is off v0 is zero but I0 continues to flow in the same



direction through the freewheeling diode FD, thus average value ofvoltage and current say V0 and I0 will be always positive as shown in the graph. In type A chopper the power flow will be always from source to theload. As the average voltage V0 is less than the dc input voltage Vs.

TYPE B CHOPPER OR SECOND-QUADRANT CHOPPER

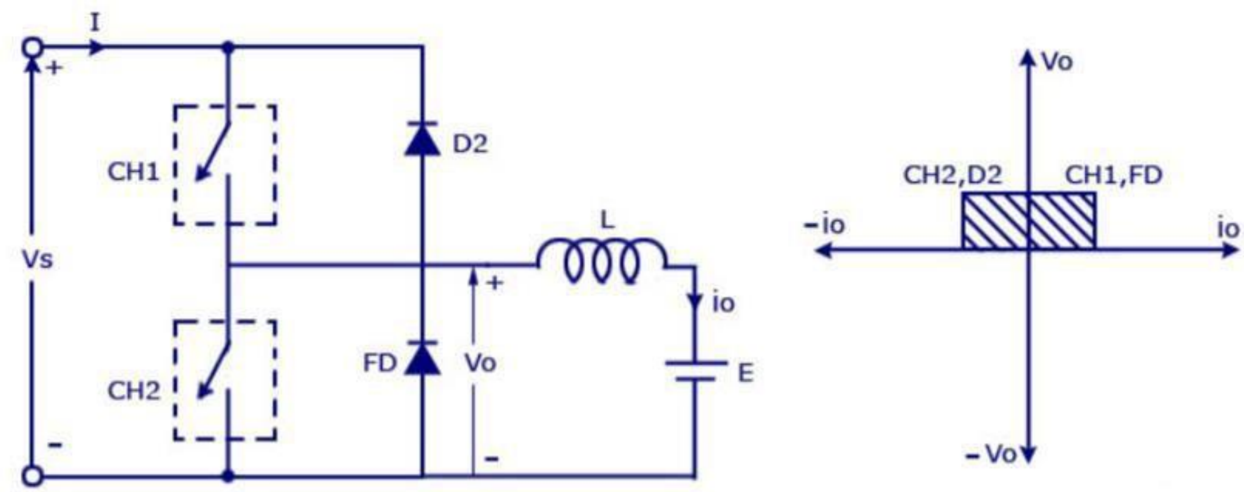


In type B or second quadrant chopper the load must always contain a dc source E. When the chopper is on, v0 is zero but the load voltage E drives the current through the inductor L and the chopper, L stores the energy during the time Ton of the chopper . When the chopper is off , v0 =(E+ L . di/dt) will be more than the source voltage Vs . Because of

this the diode D2 will be forward biased and begins conducting and hence the power starts flowing to the source. No matter the chopper is on or off the current I0 will be flowing out of the load and is treated negative . Since VO is positive and the current I0 is negative , the direction of power flow will be from load to source. The load voltage V0 = (E+L .di/dt) will be more than the voltage Vs so the type B chopper is also known as a step up chopper .

TYPE -C CHOPPER OR TWO-QUADRANT TYPE-A CHOPPER

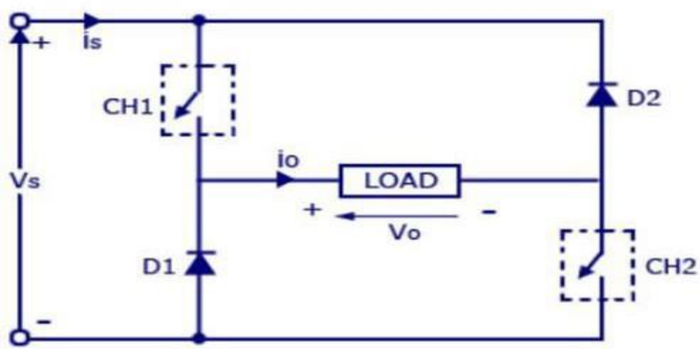
Type C chopper is obtained by connecting type –A and type –B choppers in parallel. We will always get a positive output voltage V0 as the freewheeling diode FD is present across the load. When the chopper is on the freewheeling diode starts conducting and the output voltage v0 will be equal to Vs . The direction of the load current i0 will be reversed. The current i0 will be flowing towards the source and it will be positive regardless the chopper is on or the FD conducts. The load current will be negative if the chopper is or the diode D2 conducts. We can say the chopper and FD operate together as type-A chopper in first quadrant. In the second quadrant, the chopper and D2 will operate together as type – B chopper.

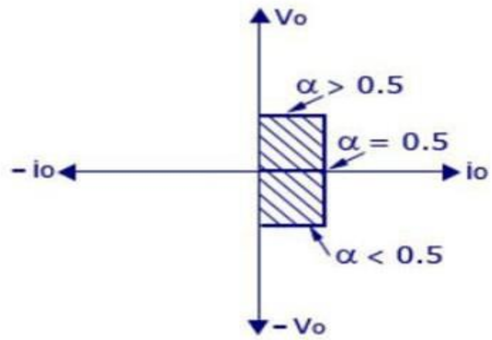


The average voltage will be always positive but the average load current might be positive or negative. The power flow may be life the first quadrant operation ie from source to load or from load to source like

the second quadrant operation. The two choppers should not be turned on simultaneously as the combined action my cause a short circuit in supply lines. For regenerative braking and motoring these type of chopper configuration is used.

TYPE D CHOPPER OR TWO-QUADRANT TYPE –B CHOPPER





The circuit diagram of the type D chopper is shown in the above figure. When the two choppers are on the output voltage v0 will be equal to Vs . When v0 = – Vs the two choppers will be off but both the diodes D1 and D2 will start conducting. V0 the average output voltage will be positive when the choppers turn-on the time Ton will be more than the turn off time Toff its shown in the wave form below. As the diodes and choppers conduct current only in one direction the direction of load current will be always positive.

The power flows from source to load as the average values of both v0 and i0 is positive. From the wave form it is seen that the average value of V0 is positive thus the forth quadrant operation of type D chopper is obtained.

From the wave forms the Average value of output voltage is given by

V0 = (Vs Ton-VsToff) / T

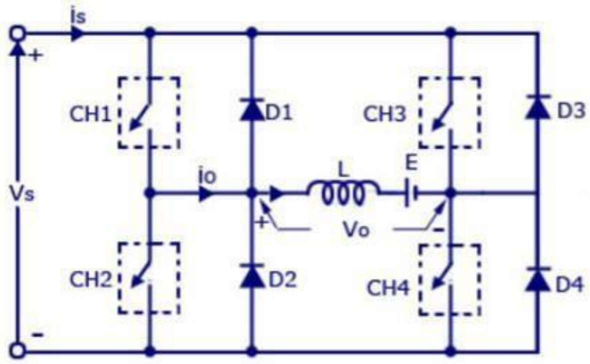
= Vs.(Ton-Toff) / T

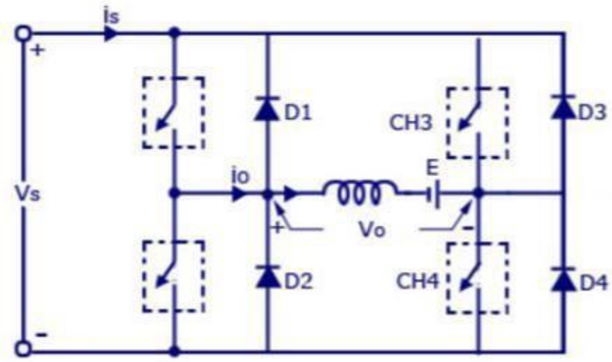
(a) Ton>Toff , Vo is Positive, First Quadrant Operation and

(b) Ton<Toff , Vo is Negative, Fourth Quadrant Operation

TYPE –E CHOPPER OR THE FOURTH-QUADRANT CHOPPER

Type E or the fourth quadrant chopper consists of four semiconductor switches and four diodes arranged in antiparallel. The 4 choppers are numbered according to which quadrant they belong. Their operation will be in each quadrant and the corresponding chopper only be active in its quadrant.





FIRST QUADRANT

During the first quadrant operation the chopper CH4 will be on . Chopper CH3 will be off and CH1 will be operated. AS the CH1 and CH4 is on the load voltage v0 will be equal to the source voltage Vs and the load

current i0 will begin to flow. v0 and i0 will be positive as the first quadrant operation is taking place. As soon as the chopper CH1 is turned off, the positive current freewheels through CH4 and the diode D2 . The type E chopper acts as a step- down chopper in the first quadrant.

SECOND QUADRANT

In this case the chopper CH2 will be operational and the other three are kept off. As CH2 is on negative current will starts flowing through the inductor L . CH2 ,E and D4. Energy is stored in the inductor L as the chopper CH2 is on. When CH2 is off the current will be fed back to the source through the diodes D1 and D4. Here (E+L.di/dt) will be more than the

source voltage Vs . In second quadrant the chopper will act as a step-up chopper as the power is fed back from load to source.

THIRD QUADRANT

In third quadrant operation CH1 will be kept off , CH2 will be on and CH3 is operated. For this quadrant working the polarity of the load should be reversed. As the chopper CH3 is on, the load gets connected to the

source Vs and v0 and i0 will be negative and the third quadrant
operation will takes place. This chopper acts as a step-down chopper.

FOURTH QUADRANT

CH4 will be operated and CH1, CH2 and CH3 will be off. When the chopper CH4 is turned on positive current starts to flow through CH4, D2 ,E and the inductor L will store energy. As the CH4 is turned off the current is feedback to the source through the diodes D2 and D3 , the operation will be in fourth quadrant as the load voltage is negative but the load current is positive. The chopper acts as a step up chopper as the power is fed back from load to source.

CHAPTER-3

INVERTERS & CYCLOCONVERTERS

INVERTERS

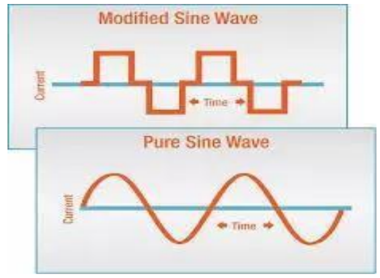
A **power inverter** or **inverter** is a power electronic device or circuitry that changes direct current (DC) to alternating current (AC).[1] The output AC can be controlled by varying its frequency and magnitude.

Classification

Inverters can be classified according to a number of different factors.

1) According to Output Waveform

First classification is based on the nature of output waveform for example, sine, square or quasi-square. Inverters can produce a pure sine wave or a modified sine wave. A modifiedsine wave is the one which is more close to a square wave.



2) According to connected load

This classification is based on types of load connected to the inverter. According to load inverters are classified into two types.

i) SINGLEPHASE INVERTER- They provide a Single phase voltage source. It is again divided into two types.

a) Single Phase Half Bridge

This type of inverters is used in low power applications and also known as inverter leg.The circuit of single phase half bridge inverter consists of 2 Switches/SCRs and a DC source with 3 wires.

b) Single Phase Full Bridge

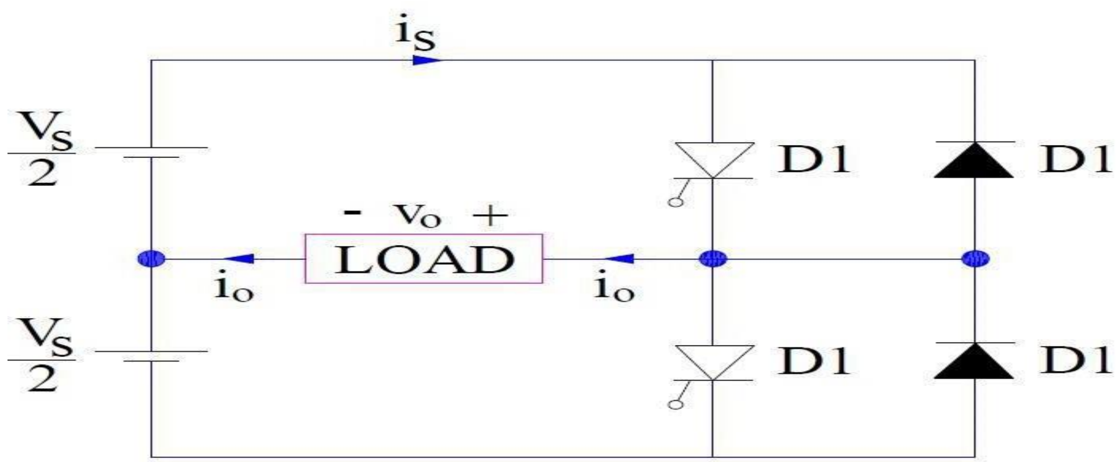
Full bridge inverters are also used for applications which require low power.The circuit consists of 4 choppers/SCRs/Switches and a DC source with 3 wires.

Single Phase Half Bridge Inverter

- Single Phase Half Bridge Inverter is a type of Single-Phase Bridge Inverter. It is a voltage source inverter. Voltage source inverter means that the input power of the inverter is a DC voltage Source. The output of single-phase bridge inverter is a single-phase output.
- Single Phase Half Bridge Inverter consist of two thyristors T1 & T2, two diodes D1 & D2 and three wire DC source.
- The working principle of half bridge inverter is that, for half of time period of output wave, one thyristor conducts whereas for another half of time period, another thyristor conducts. The output frequency of this type of inverter may be controlled by controlling the switch ON and switching OFF time of thyristors.

OPERATION

- It is assumed that each thyristor conducts for the duration its gate pulse is present and is commutated/turned off as soon as this pulse is removed.

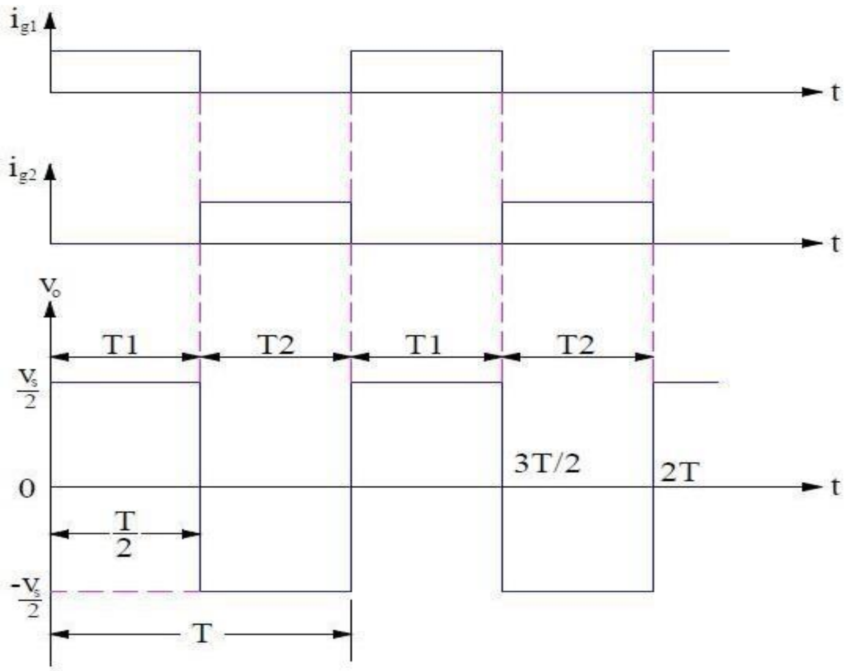


- The gating signal for thyristor T1 (ig1) and thyristor T2 (ig2) and output voltage waveform of this inverter is shown below.

- It can be seen that ig1 is applied for a period of $0<t\leq(T/2)$, this means thyristor T1 will conduct for this time period. During the time T1 conducts, load is directly connected to source (Vs/2) on the upper arm. Thus, the load voltage / output voltage will be equal to the input source voltage (Vs/2) for $0<t\leq(T/2)$.
- When ig1 is removed at t= T/2, thyristor T1 gets turned OFF. It may be seen from the waveform of gating signal that at t=T/2, ig2 is applied and hence, thyristor T2 gets turned ON. Thus, load gets directly connected to the source (Vs/2) on the lower arm.
- Now polarity of load voltage /output voltage is -(Vs/2) as shown in the output voltage waveform. Because the polarity of applied voltage to the load has reversed.
- It may also be seen form the output voltage waveform that load voltage is an alternating square voltage waveform of amplitude (Vs/2) and frequency (1/T) Hz. Thus, output frequency can be controlled by controlling T.

Drawbacks:

- The main drawback of single phase half bridge inverter is that it requires 3-wire DC supply source. However, this drawback can be overcome by the use of full bridge inverter.

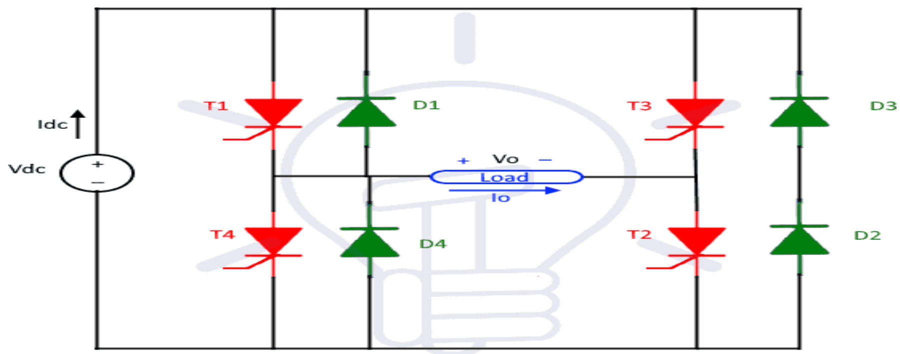


i_{g1}
t
i_{g2}
t
V_o
T1
T2
T1
T2
$\frac{V_s}{2}$
3T/2
2T
0
t
$\frac{T}{2}$
$-\frac{V_s}{2}$
T

Single Phase full Bridge Inverter

Single Phase Half Bridge Inverter is a type of Single-Phase Bridge Inverter. It is a voltage source inverter. Voltage source inverter means that the input power of the inverter is a DC voltage Source. The output of single-phase bridge inverter is a single-phase output.

The components required for conversion are two times more than that used in single phase Half bridge inverters. The **circuit of a full bridge inverter** consists of 4 diodes and 4 controlled switches as shown below.



Full Bridge Inverter

These diodes are known as freewheeling diodes or feedback diodes because these diodes feedback the stored energy in the load back into the DC source. The feedback action happens only when load is other than pure resistive load.

The controlled switches for Full-bridge inverters can be BJT, IJBT, MOSFET or thyristors.

Operation

Mode 1

Consider all the switches are initially off. By triggering T1 and T2, the input DC voltage (+Vdc) will appear across the load. The current flow in clockwise direction(+Vdc-T1-LOAD- T2- -Vdc) from source to the series connected load. The output current across the load will be

Io=Vdc/RL

Where RL is the load resistance, While the output voltage across the load will be

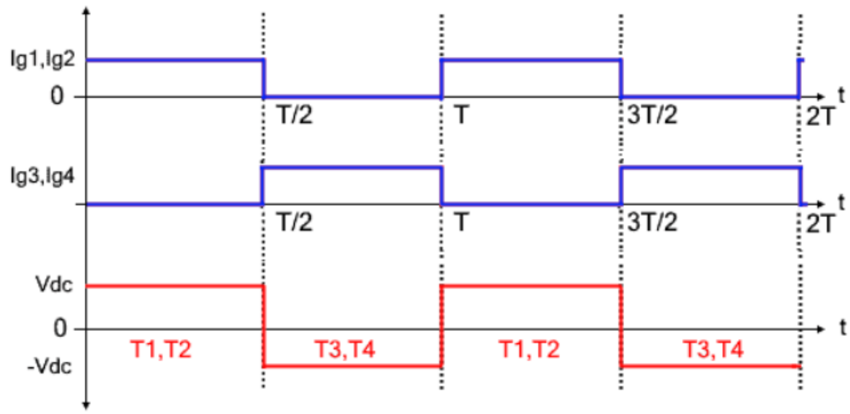
Vo= Vdc

Mode 2

Thyristors T3 and T4 are triggered immediately after completely commutating T1 and T2. The current flow in anticlockwise direction(-Vdc-T1-LOAD-T2- +Vdc) from source to the series connected load. So the output voltage across the load appear is negative

Vo= -Vdc

So during this period out voltage and current is negative. It may also be seen form the output voltage waveform that load voltage is an alternating square voltage waveform of amplitude (Vs/2) and frequency (1/T) Hz. Thus, output frequency can be controlled



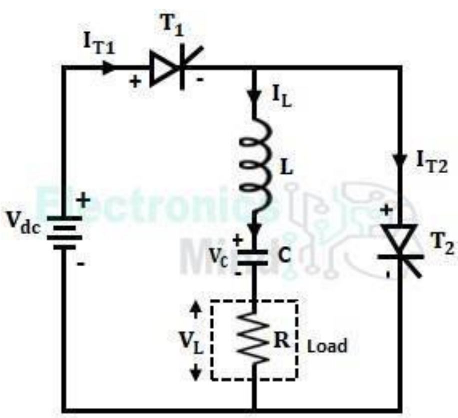
Full Bridge Inverter Gate Signals

by controlling T.

SERIES INVERTER

A series inverter is a type of inverter in which the commutating components are connected in series with the load. In series inverter class-A commutation is used to turn off the thyristors.

The basic circuit of a series consist of inductor (L) and capacitor (C) which are commutating components, T1 and T2 are two thyristors that conduct for positive and negative half-cycles of load current respectively.



Series Inverter

In a series inverter, values of the inductor (L) and capacitor (C) are chosen in such a way that the series RLC circuit should be underdamped to produce oscillating current in the circuit.

OPERATION:

The operation of a series inverter can be understood through three modes.

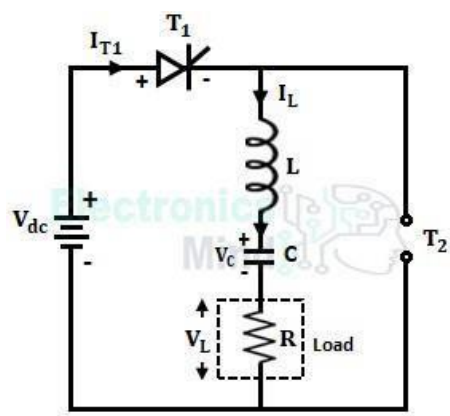
Mode I :

Mode I starts when thyristor T1 is triggered at instant t = t0 by applying gate pulses to it. As T1 is triggered, it starts conducting and the load current flows through the path Vdc+ → T1 → L → C → R → Vdc– as shown below.

Initially, the capacitor is charged to a negative voltage -VC, but once T1 is triggered capacitor starts charging to positive voltage with upper plate positive and lower plate negative as shown above. As the current increases and reaches its positive maximum value, the voltage across the capacitor becomes equal to supply voltage Vdc.

Now, the current starts decreasing after reaching its positive maximum value but the voltage across the capacitor does not decrease. Instead of decreasing it increases further and reaches a value higher than Vdc, and the capacitor retains this voltage for some time.

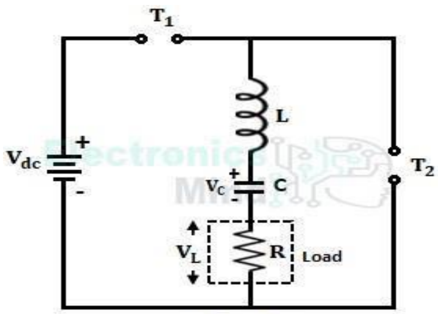
At t = t2, thyristor T1 is turned OFF when the current reaches zero by natural commutation, but still, the capacitor holds the voltage (VC + Vdc) in it.



Mode I

Mode II :

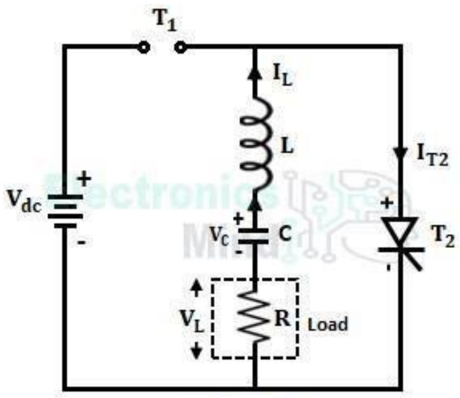
This mode starts from instant t2 when thyristor T1 is commutated and it remains in OFF state for a sufficient period of time (t2 to t3) as shown in the below waveforms. Hence, in this mode, both the thyristors T1 and T2 are in OFF-state and the capacitor voltage is maintained at a constant value of (VC + Vdc), and the load current IL remains zero in this mode i.e., from t2 to t3.



Mode II

Mode III :

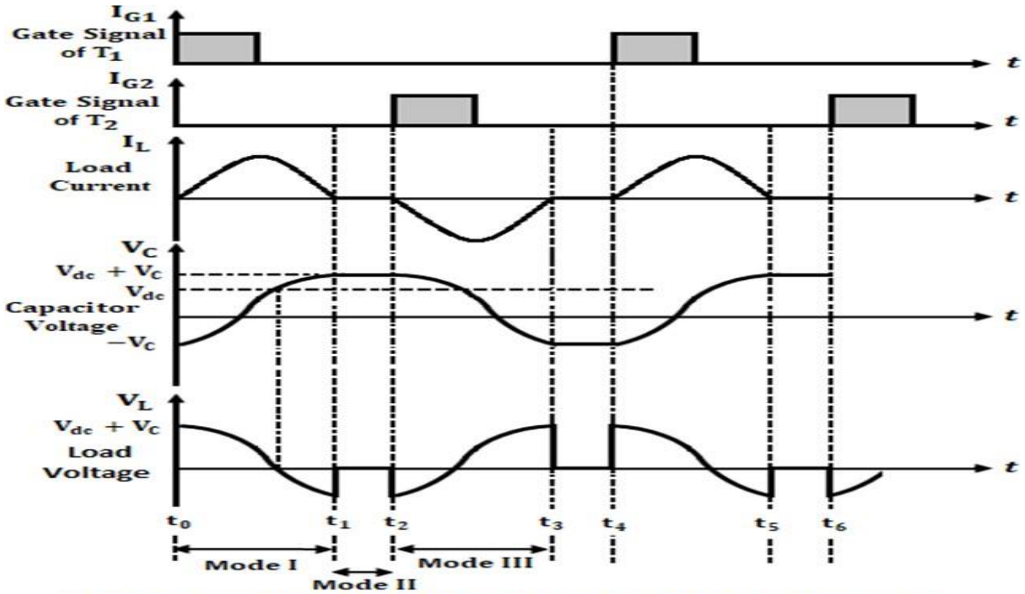
In this mode of operation, thyristor T2 is triggered at instant t3 since the positive polarity of the capacitor appears across the anode of T2 and it starts conducting. As thyristor T2 conducts, the load current starts flowing in the negative direction through the path C+ → L → T2 → R → C– as shown below.



Mode III

Now, the capacitor starts discharging and the load current IL flows in the reverse direction and reaches its negative maximum value. Then, load current starts decreasing and becomes zero at t3, due to this thyristor T2 gets turned OFF at t3. Then after capacitor again charges to negative voltage -VC as shown in the waveform. Again, after maintaining a certain amount of time delay, thyristor T1 is triggered and the cycle repeats.

In the waveforms, we can observe that the positive half-cycle of the load current is exactly equal to the negative half-cycle of load current since the capacitor stores charge during one half- cycle and releases the equal charge in the next half-cycle. But in practice, the output voltage wave of a series inverter is not a pure sine wave and distortions are present in it.



Voltage and Current Waveforms of Series Inverter

Disadvantages of Series Inverter :

As the load current is carried by the components L and C in both the cycles, high ratings are required for the components.

Since the load current is discontinuous, ripples are present in it.

Since load current depends upon components L and C, load regulation will be poor.

PARALLEL INVERTER

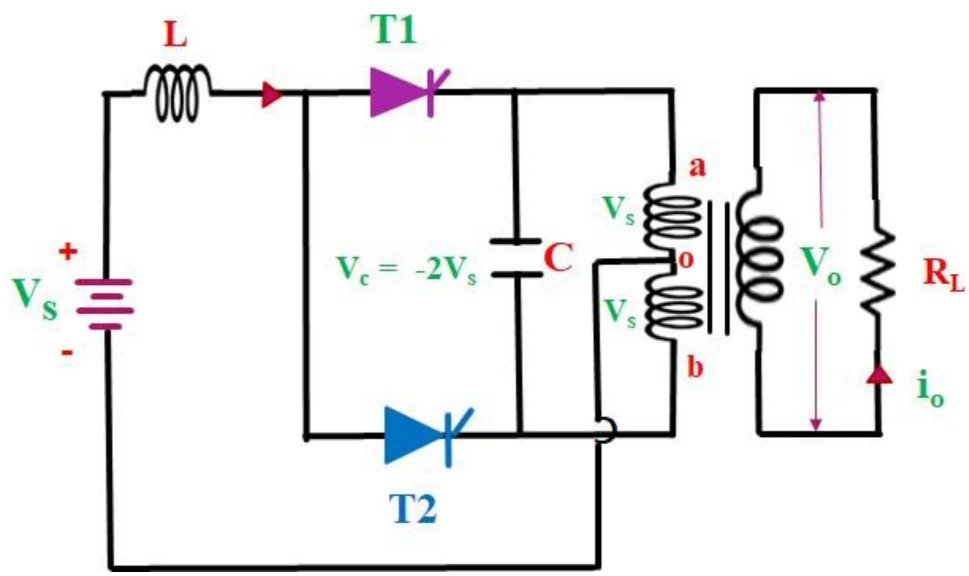
In parallel inverters, the commutating components are connected in parallel with the load, and hence the inverter is named Parallel Inverter.

This inverter produces square wave output voltage from a dc power input.

The circuit consists of two thyristors (T1 and T2), a center-tapped transformer, a commutating capacitor (C), and an inductor (L).

The load is connected to the secondary of the transformer. The dc power input is given between center tap primary and common cathode through thyristors as shown below.

The inductor (L) is connected in series with supply to make the source current constant.

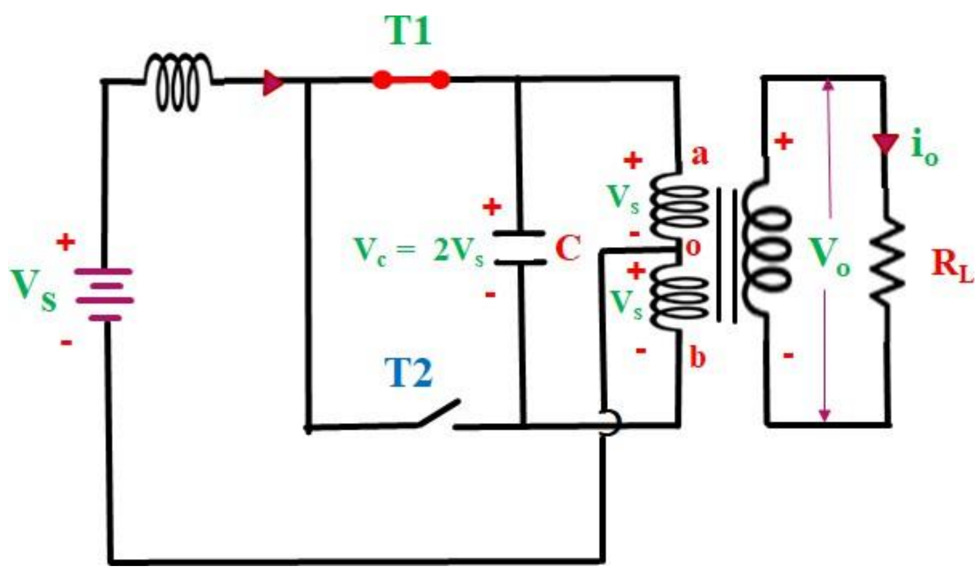


Operation of Parallel Inverter:

The operation is divided into four modes:

Mode I (0< t < t1): In this mode we give firing pulse to thyristor T1 and T1 get turned on and T2 is turned off. Current flow from Supply Vs …. T1…. ao (upper half of primary winding) …. back to Vs. As a result, Vs voltage is induced across upper as well as lower half of the primary winding of transformer. And Vs voltage is induced in secondary winding.

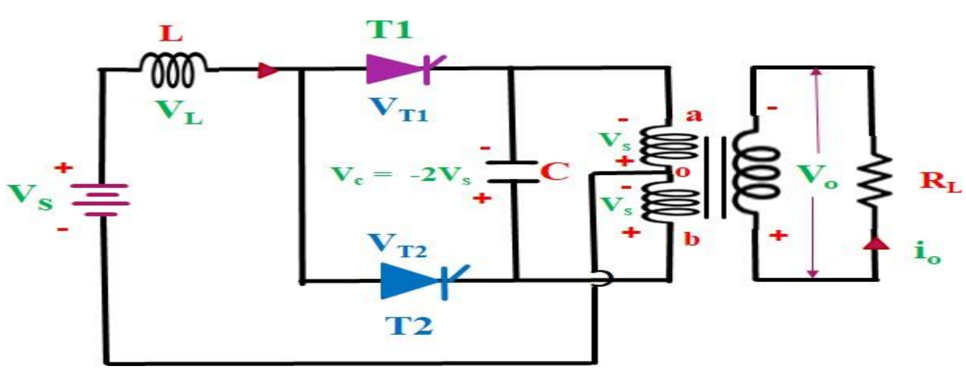
So, output voltage across load is Vs.



So, the total voltage across primary winding is 2Vs. Here capacitor is connected in parallel with primary winding therefore capacitor charge with 2Vs voltage with upper plate is positive and lower plate is negative.

Mode II (t1< t < t3): In this duration we give firing pulse to thyristor T2 and T2 get turned on and due to the capacitor voltage T1 turned OFF. This time current flow from supply Vs …. T2…. bo (lower half of primary winding) …. back to Vs.

Now this time capacitor charged with upper plate is negative, from +2Vs at t=t1 to -2Vs at t=t2. Load voltage also changes from Vs at t=t1



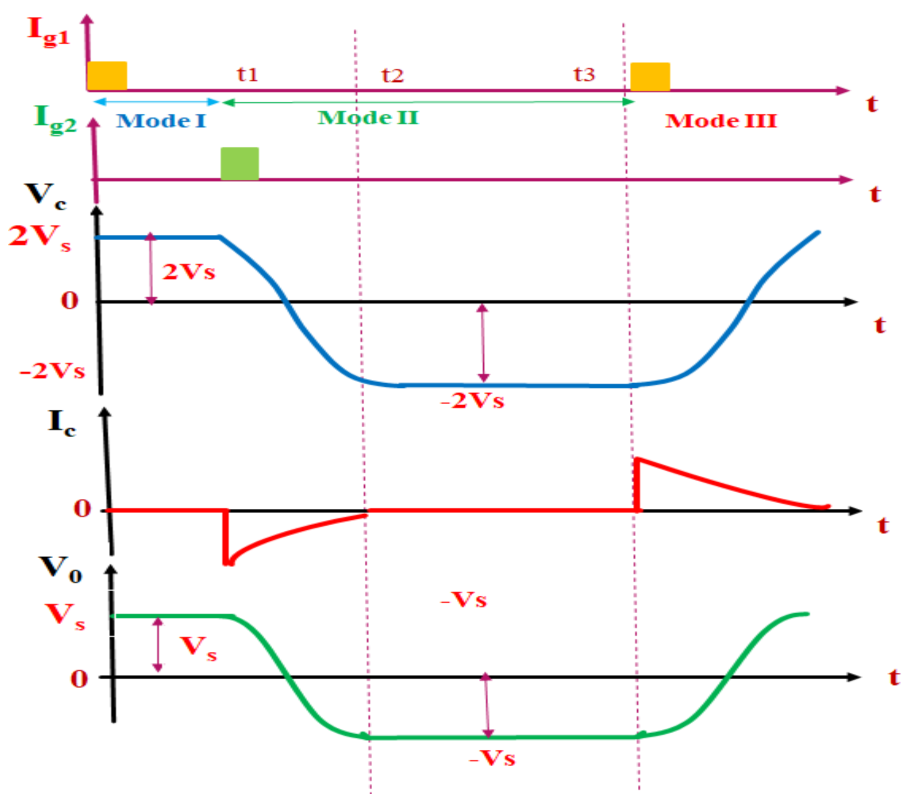
to -Vs at t=t2. After t=t2 voltage across capacitor is maintain constant -2Vs between t= t2 to t3.

So, load voltage is also constant -Vs.

Mode III (t3< t < t4): In this mode again, we give firing pulse to thyristor T1 and T1 get turned on. At this time capacitor start discharging through T2 therefore T2 turned OFF. This time current flow from supply Vs …. T1…. ao (upper half of primary winding) …. back to Vs. So, the total voltage across primary winding is 2Vs.

Now this time capacitor charged with upper plate is positive, from -2Vs at t=t3 to +2Vs at t=t4. Load voltage also changes from Vs at t=t3 to -Vs at t=t4.

So, output voltage across load is Vs.



Applications - Inverters got a variety of applications.

i) They are used in AC motor drives with adjustable speed.

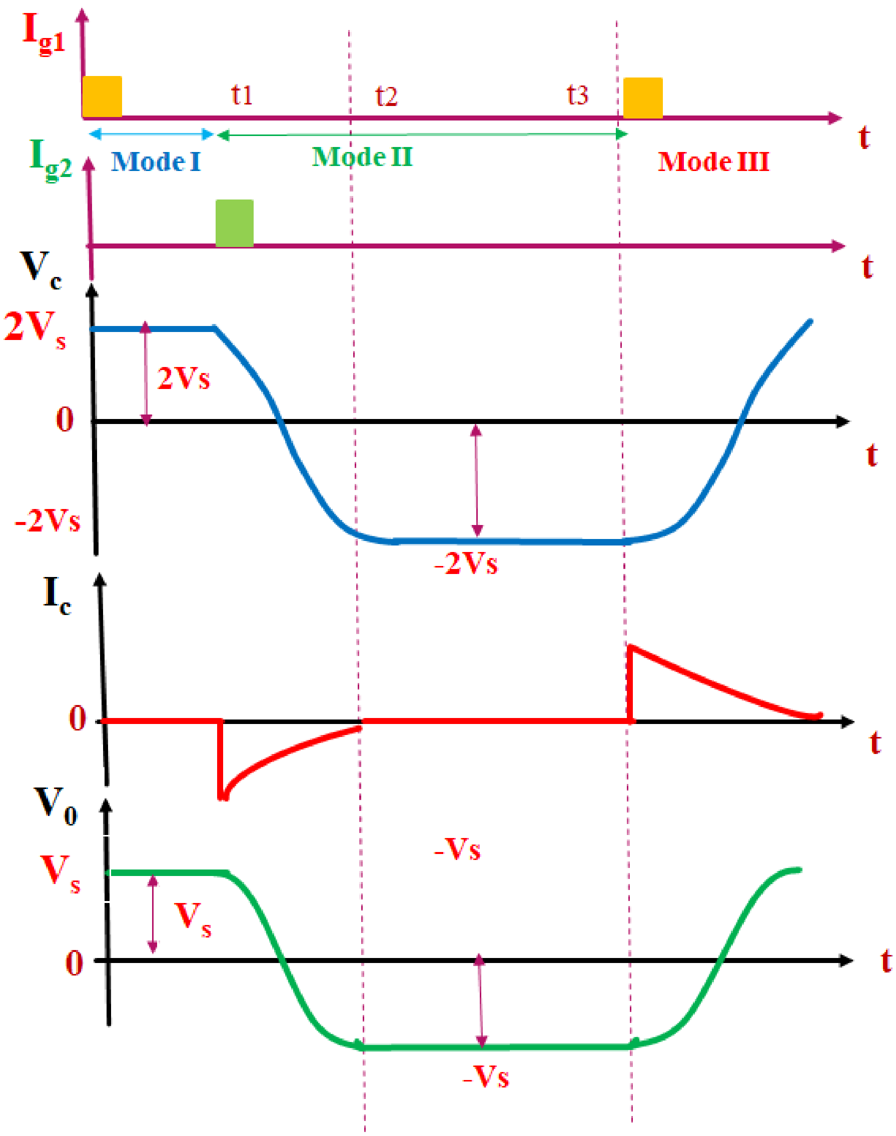
ii) They are used in UPS (Uninterruptable Power Supply) which is a very common application now a days.

iii) They are being used in portable devices.

iv) Inverters are used where there is a need to run AC devices from batteries.

v) They are used in industries in packaging machines, weighing machines and carts.

vi) They are also used in hybrid and electric cars.



Ig1
t1
t2
t3
t
Mode I
Mode II
Mode III
Ig2
t
Vc
2Vs
2Vs
0
t
-2Vs
-2Vs
Ic
0
t
V0
-Vs
Vs
Vs
0
t
-Vs

CYCLOCONVERTER

- Cycloconverter is a device which converts input power at one frequency to output power at a different frequency .
- The input AC supply is directly converted to variable frequency output with the use of power electronic switches such as thyristors. The thyristors are switched ON and OFF in a specific manner to get variable frequency AC output. It does not require any intermediate DC link. This is reason, it is very efficient.
- There are mainly two types of cycloconverter

  i) Step-up cycloconverter

  ii)Step-down

  cycloconverter.

- In step-up type of cycloconveter, the output frequency (f_o) is more than the input supply frequency (f_s) i.e. $f_o > f_s$. This type of CCV is not widely used. Forced commutation is used in this type which make it complex.
- However, in step-down type, the output frequency is lower than the supply frequency i.e. $f_o < f_s$. This is more common and widely used. Line or natural commutation is used to switch off a thyristor in this type of CCV which makes it simple.

Application of Cycloconverter:

- Speed control of high power AC drives
- Induction heating
- Static VAR compensation
- It is used for converting variable speed alternator voltage to constant frequency output voltage for use as power supply in aircrafts or shipboards.

Step-down Cycloconverter

- Step-down cycloconverter is a device which steps down the fixed frequency power supply input into some lower frequency. It is a frequency changer. If f_s & f_o are the supply and output frequency respectively , then $f_o < f_s$ for this cycloconverter.
- The most important feature of step-down cycloconverter is that it does not require force commutation. Line or Natural Commutation is used which is provided by the input AC supply.
- The circuit consist of four switches / thyristors and a centre tapped transformer. The secondary winding is centre tapped and load is connected at the tapping.

Working of Step-down Cycloconverter:

Discontinuous Load Current:

- For positive cycle of input AC supply, the terminal A is positive with respect to point O. This makes SCRs P1 forward biased. The forward biased SCR P1 is triggered at $\omega t = 0$. With this, load current i_o starts building up in the positive direction from A to O. Load current i_o becomes zero at $\omega t = \beta > \pi$ but less than $(\pi+\alpha)$ for inductive load. The thyristor P1 is thus, naturally commutated at $\omega t = \beta$ which is already reversed biased after π.
- After half a cycle, b is positive with respect to O. Now forward biased thyristor P2 is fired at $\omega t = (\pi+\alpha)$. Load current is again positive from A to O and builds up from zero.
- At $\omega t = (\pi+ \beta)$, i_o decays to zero and P2 is naturally commutated. At $\omega t = (2\pi+\alpha)$, P is again turned ON. Load current in figure-2 is seen to be discontinuous.
- After four positive half cycles of load voltage and load current, thyristor N2 is gated at $(4\pi+\alpha)$ when O is positive with respect to b. As N2 is forward biased, it starts conducting but the direction of load current is reverse this time i.e. it flows from O to A.
- After N2 is triggered, O is positive with respect to “a” but before N1 is fired, i_o decays to zero and N2 is naturally commutated. Now when N1 is gated at $(5\pi+\alpha)$, i_o again builds up but it decays to zero before thyristor N2 in sequence is again gated.
- In this manner, four negative half cycles of load voltage and load current, equal to number of positive half cycles of load voltage & current, are generated. It is clear that the

output frequency of load voltage & current is (¼) times of input supply frequency

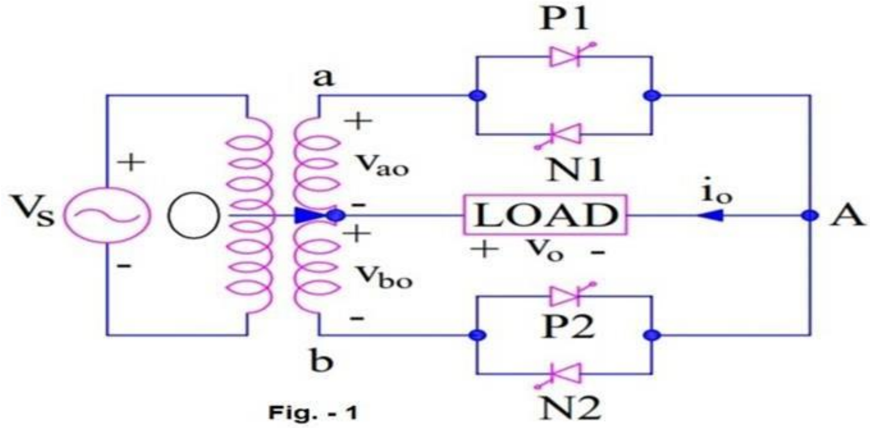


Fig. - 1

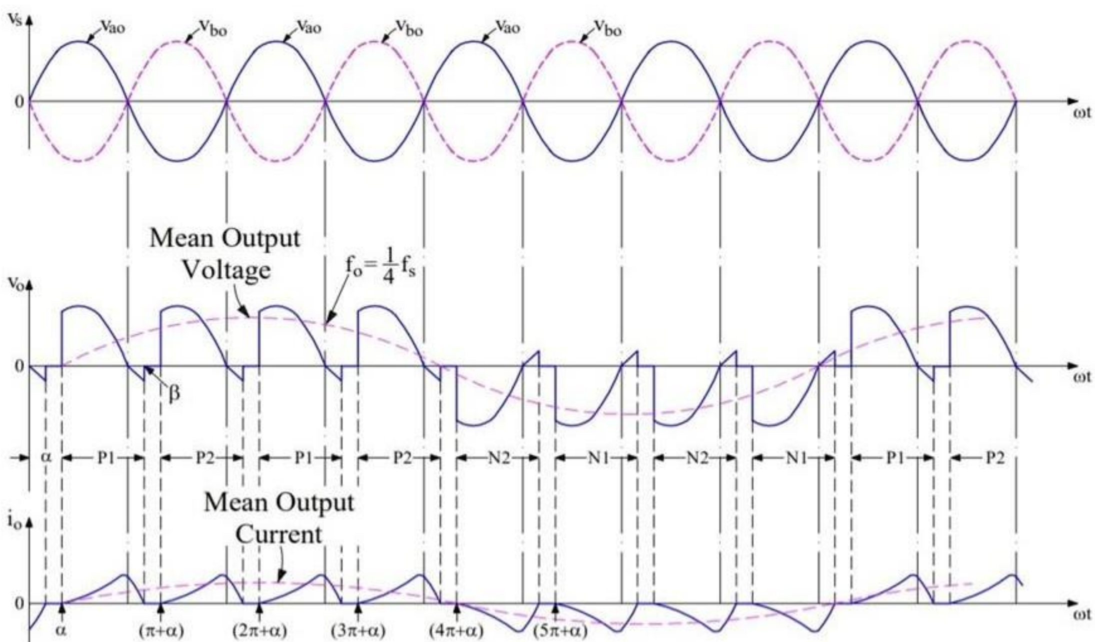


Fig.-2

STEPUP CYCLOCONVERTER

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- Step-up cycloconverter is a single phase to single phase device which converts input AC power at one frequency to output power at a different frequency. The output frequency is more than the input frequency for this cycloconverter.
- The circuit consists of a single phase transformer with mid tap on the secondary winding and four thyristors. Two of these thyristors P1 & P2 are for positive group. Here positive group means when either P1 or P2 conducts, the load voltage is positive. Other two thyristors N1 & N2 are for negative group. Load is connected between secondary winding mid-point O and terminal A. The load is assumed resistive for simplicity. Assumed positive direction for voltage and current are marked in the circuit diagram.
- The working principle of a step-up cycloconverter is based on switching of thyristors in a proper sequence.

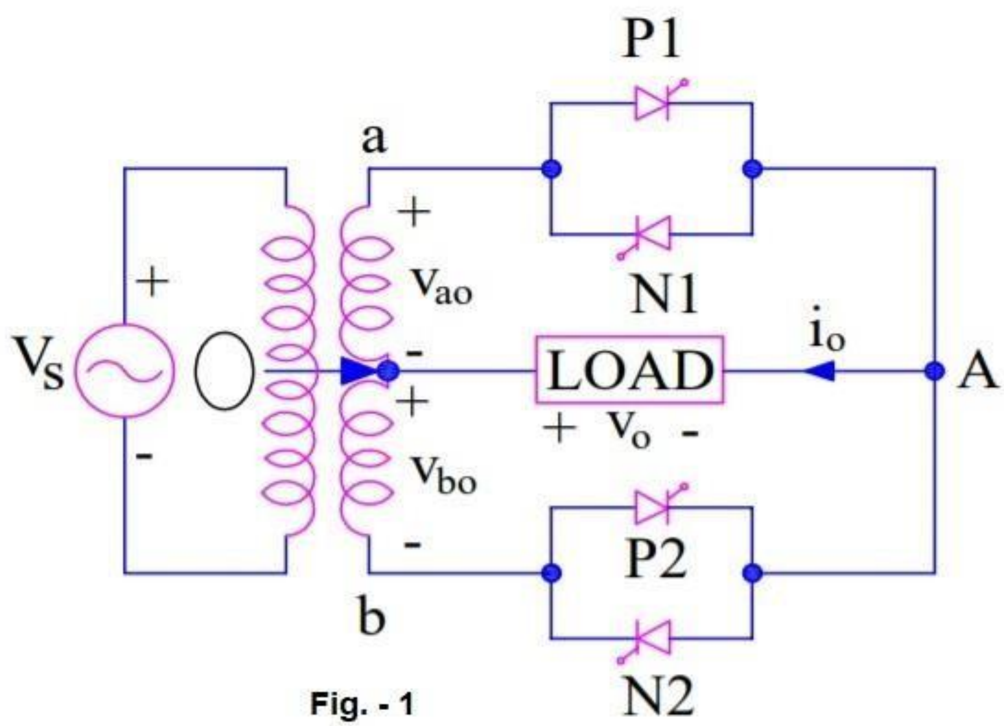


Fig. - 1

Operation of Step-up Cycloconverter:

- During the positive half cycle of input supply voltage, positive group thyristors P1 & N2 are forward biased for ωt = 0 to ωt = π.

- As SCR P1 is fired to turn it ON at $\omega t = 0$ such that load voltage is positive with terminal A positive and O negative.
- At some time instant $\omega t = \omega t_1$, the conducting thyristor P1 is force commutated and the forward biased thyristor N2 is fired to turn it ON. During this period N2 conducts, the load voltage is negative because O is positive & A is negative this time.
- At $\omega t = \omega t_2$, N2 is force commutated and P1 is turned ON and the load voltage is now positive.
- At $\omega t = \pi$, terminal "b" is positive with respect to terminal "a"; both SCRs P2 & N1 are therefore forward biased from $\omega t = \pi$ to $\omega t = 2\pi$.
- AT $\omega t = \pi$ forward biased SCR P2 is turned ON and output voltage is positive. When P2 is force commutated, forward biased SCR N1 is turned ON. This time, the load voltage is negative and follows the negative envelop of the supply input.Again when P2 is turned ON the load voltage is positive.
- In this manner, SCRs P1, N2 for the positive half cycle; P2, N1 in the negative half cycle are turned on alternatively to get a high frequency.

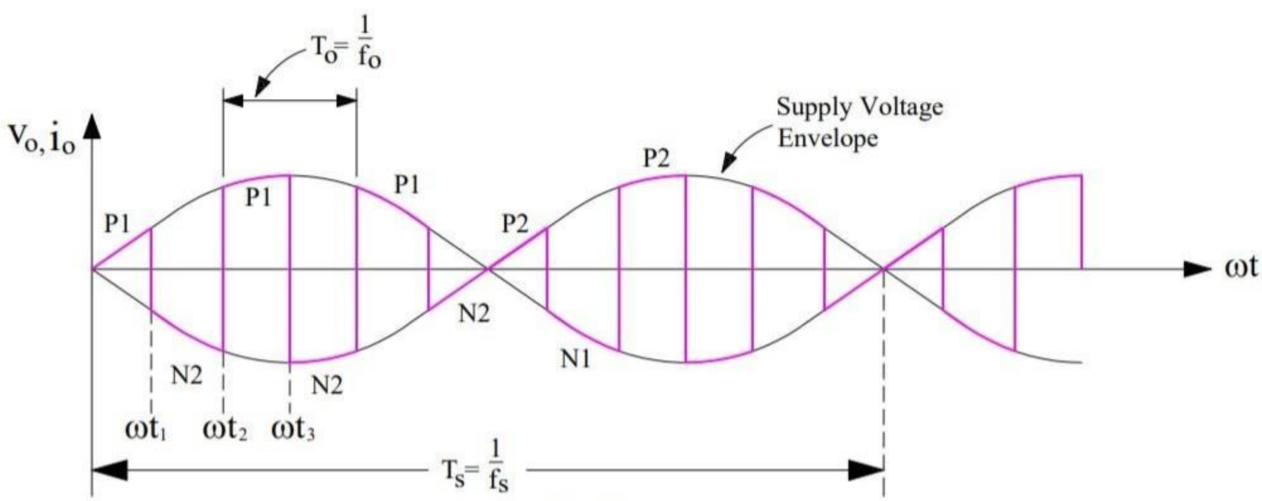
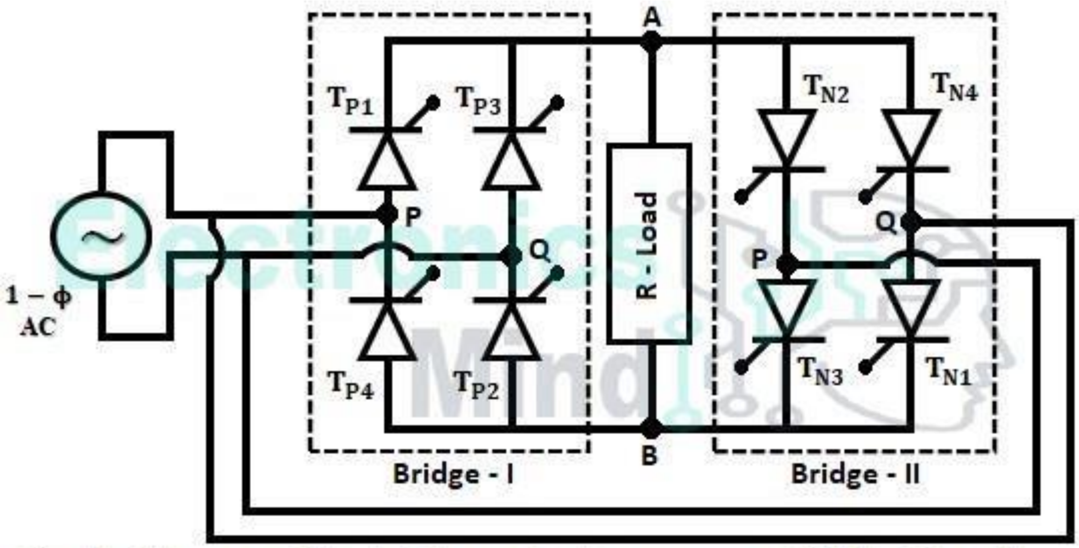


Fig. - 2

- From the output waveform we can see that there is a total of 6 cycles of output in one cycle of input supply. This means that frequency of output voltage is 6 times of input frequency i.e. $f_o = 6f_s$.

bridge type step down cycloconverter

- A single-phase step-down bridge-type cycloconverter consist of two separate group converters have been taken for positive cycle and negative cycle.



Single Phase to Single Phase Cycloconverter With R-Load

-
- The two bridges are connected to the load in such a way that, they are in an anti-parallel connection. Also, the two bridges should not conduct at the same time, otherwise, a shortcircuit is produced at the input.

OPERATION:

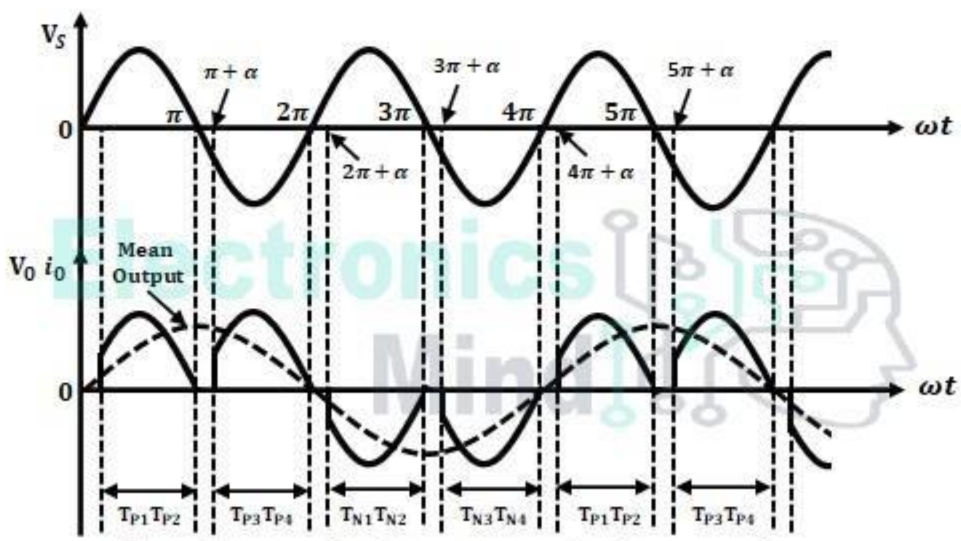
- During the positive half cycle of the supply voltage, thyristors T_{P1}, and T_{P2} are forward biased. At instant $\omega t = \alpha$, T_{P1} and T_{P2} are triggered and they start conducting current. Now, the load voltage is positive, with point A as positive and point B as negative, and the load current flows through the path,
    - $P \rightarrow T_{P1} \rightarrow A \rightarrow Load \rightarrow B \rightarrow T_{P2} \rightarrow Q$
- At $\omega t = \pi$, the negative half cycle of the supply voltage appears due to which thyristors T_{P1} and T_{P2} are turned OFF, and both the load voltage and load current become zero as shown in the waveform below.
- Thyristors T_{P3} and T_{P4} are triggered at $\omega t = \pi + \alpha$ and the load current and load voltage are zero till $\omega t = \pi + \alpha$. With the triggering of thyristors, T_{P3} and T_{P4} load current and load voltage increases and the current flows through the path,
    - $Q \rightarrow T_{P3} \rightarrow A \rightarrow Load \rightarrow B \rightarrow T_{P4} \rightarrow P$

- Even in this period also the load current and load voltage are positive similar to when the thyristors T_{P1} and T_{P2} are in conduction as shown in the below figure.
- At ωt = 2π, thyristors T_{P3} and T_{P4} are turned OFF and both the load voltage and load current become zero. Thus both positive and negative half cycles of the input supply are converted into two positive half cycles at the output.
- During the next positive half cycle of the supply voltage, thyristors T_{N1} and T_{N2} are forward biased. Thus at instant ωt = 2π + α, thyristors T_{N1} and T_{N2} are triggered. Now the load voltage is negative and also the load current builds up in a negative direction.

The path of the load current in this half-cycle is,

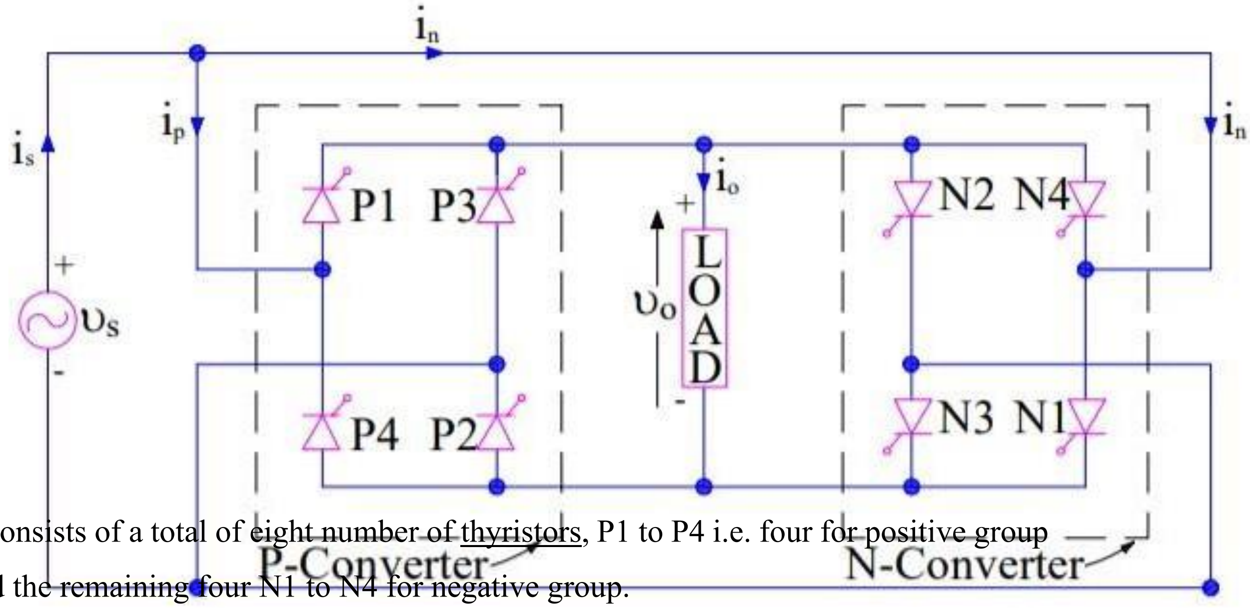
$$Q \rightarrow T_{N1} \rightarrow B \rightarrow Load \rightarrow A \rightarrow T_{N2} \rightarrow P$$

- From ωt = 3π, thyristors T_{N3} and T_{N4} will conduct. Hence, the load current and load voltage become negative for alternate cycles of input supply and it indicates that the input frequency is reduced to (1/2) at the output terminals.
-



Waveform for Single Phase to Single Phase Cycloconverter with R-Load

<u>Bridge type step up cycloconverter</u>

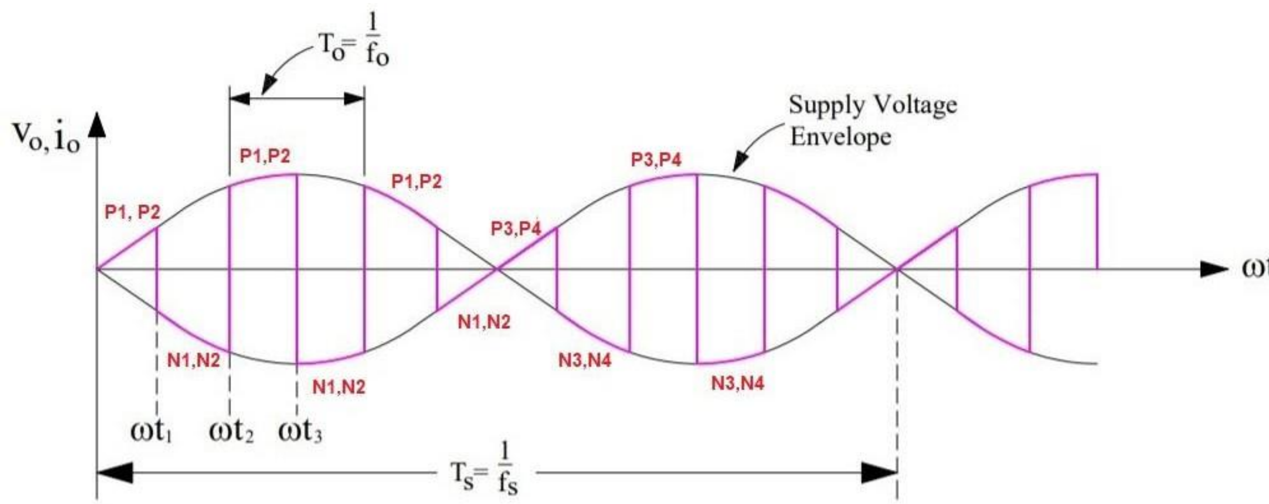


- It consists of a total of eight number of thyristors, P1 to P4 i.e. four for positive group and the remaining four N1 to N4 for negative group.
- The two bridges are connected to the load in such a way that, they are in an anti-parallel connection. Also, the two bridges should not conduct at the same time, otherwise, a shortcircuit is produced at the input.
-

OPERATION

- The working principle of a single phase to single phase bridge type step-up cycloconverter is based on the switching and commutation of thyristors in a proper sequence.
- In the circuit diagram, during positive half of the input supply voltage "a" is positive with respect to "x". This makes thyristor pairs (P1 & P2) and (N1 & N2) forward biased from $\omega t = 0$ to $\omega t = \pi$.
- When forward biased thyristors (P1 & P2) are turned ON together at $\omega t = 0$, the load voltage is positive with terminal "A" positive with respect to terminal "O".
- At ωt_1, the conducting thyristors P1 & P2 are force commutated and forward biased thyristor pair N1 & N2 are turned ON. As soon as (N1 & N2) are turned ON, the load voltage becomes negative with terminal "A" negative with respect to terminal "O"
- Again, at ωt_2, the thyristor pairs N1 & N2 are force commutated and forward biased thyristors P1 & P2 are fired to turn it ON. The load voltage is now positive

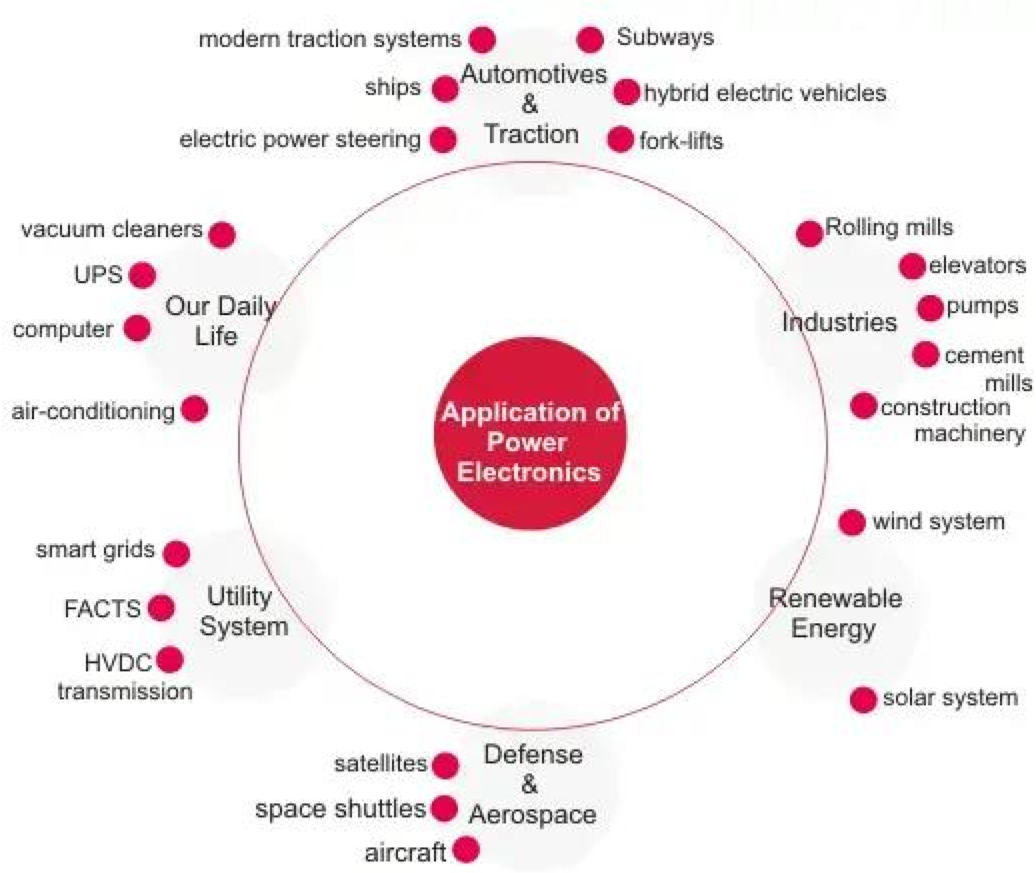
.

- After $\omega t = \pi$, thyristor pairs (P1 & P2) and (N1 & N2) becomes reversed biased but thyristor pairs (P3 & P4) and (N3 & N4) are forward ,biased.
- These forward biased thyristors can be turned ON and force commutated from $\omega t = \pi$ to $\omega t = 2\pi$.
- When P3 & P4 are turned on at $wt = \pi$, out voltage is positive. The P3 & P4 are forced commutated and N3 & N4 are turned on. Now the load voltage is negative.
- there is a total of 6 cycles of output in one cycle of input supply. This means that frequency of output voltage is 6 times of input frequency i.e. $f_o = 6f_s$ where f_o and f_s are output and supply frequency respectively.
- 

CHAPTER-4

UNDERSTAND APPLICATIONS OF POWER ELECTRONICS CIRCUIT

Application of Power Electronics



- Our Daily Life: If we look around ourselves, we can find a whole lot of power electronics applications such as a fan regulator, light dimmer, air-conditioning, induction cooking, emergency lights, personal computers, vacuum cleaners, UPS (uninterrupted power system), battery charges, etc.
- Automotives and Traction: Subways, hybrid electric vehicles, trolley, fork-lifts, and many more. A modern car itself has so many components where power electronic is used such as ignition switch, windshield wiper control, adaptive front lighting, interior lighting, electric power steering and so on. Besides power electronics are extensively used in modern traction systems and ships.
- Industries: Almost all the motors employed in the industries are controlled by power electronic drives, for eg. Rolling mills, textile mills, cement mills, compressors, pumps, fans, blowers, elevators, rotary kilns etc. Other applications include welding, arc furnace, cranes, heating applications, emergency power systems, construction machinery, excavators etc.

- Defense and Aerospace: Power supplies in aircraft, satellites, space shuttles, advance control in missiles, unmanned vehicles and other defense equipments.
- Renewable Energy: Generation systems such as solar, wind etc. needs power conditioning systems, storage systems and conversion systems in order to become usable. For example solar cells generate DC power and for general application we need AC power and hence power electronic converter is used.
- Utility System: HVDC transmission, VAR compensation (SVC), static circuit breakers, generator excitation systems, FACTS, smart grids, etc.

FACTORS AFFECTING SPEED OF A DC MOTOR

According to the speed equation of a d.c. motor we can write,

$$N \propto \frac{E_b}{\phi} \propto \frac{V - I_a R_a}{\phi}$$

But as the value of armature resistance R_a and series field resistance R_{se} is very small, the drop I_a $R_a$and $(R_a + R_{se})$ is very small compared to applied voltage V. Hence neglecting these voltage drops the speed equation can be modified as,

$$N \propto \frac{V}{\phi} \qquad \text{as } E_b \approx V$$

Thus the factors affecting the speed of a d.c. motor are,

1. The flux Φ

2. The voltage across the armature

3. The applied voltage V

depending upon these factors the various methods of speed control are,

1. Changing the flux Φ by controlling the current through the field winding called flux control methods.

2. Changing the armature path resistance which in turn changes the voltage applied across the armature called rheostatic control.

3. Changing the applied voltage called voltage control method.

SPEED CONTROL OF DC DHUNT MOTOR USING RECTIFIER

The Single Phase Fully Controlled Rectifier Control of DC Motor. Motor is shown by its equivalent R-L-E circuit. Field supply is not shown. When field control is required, field is fed from a controlled rectifier. The ac input voltage is defined by

$V_s = V_m \sin wt$

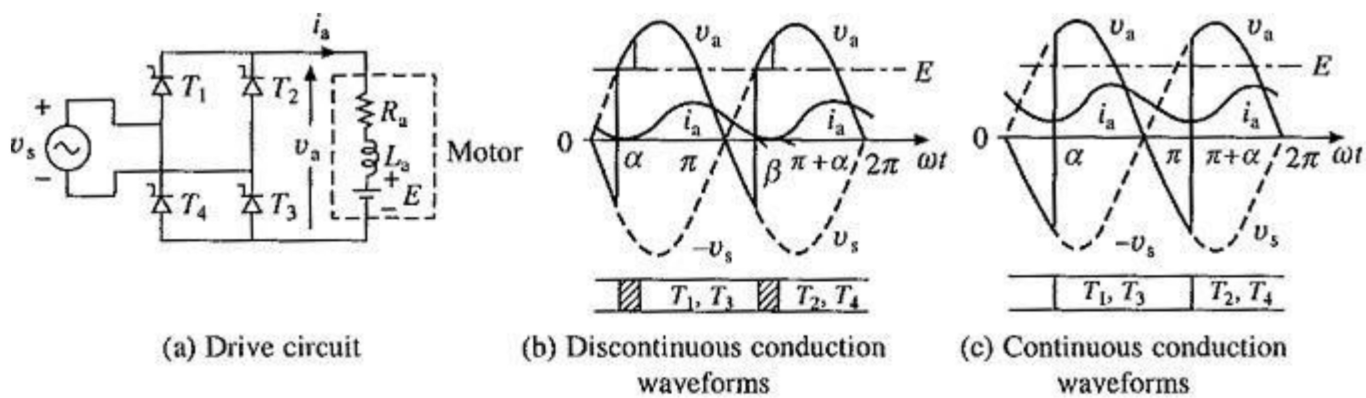


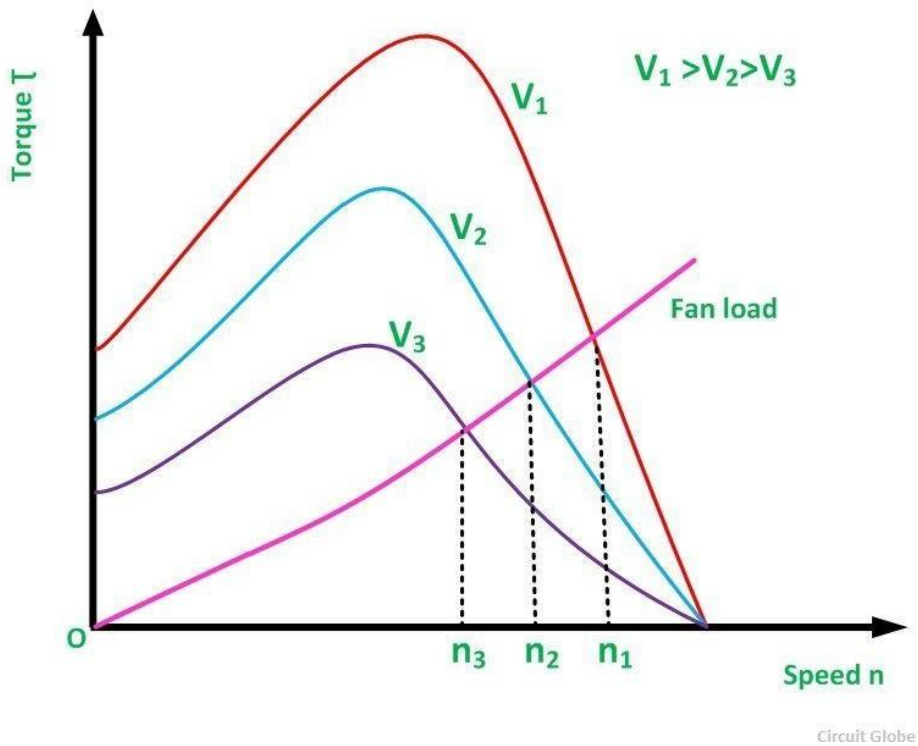
Fig. 5:26 Single-phase fully-controlled rectifier-fed dc separately excited motor

- In positive half cycle of source voltage, thyristors T_1 and T_3 are given gate signals from α to π, and thyristors T_2 and T_4 are given gate signals from (π + α) to 2π i.e. during negative half cycle of supply.

Stator Voltage Control of an Induction Motor by using AC Voltage Regulator

Stator Voltage Control is a method used to control the speed of an **Induction Motor.** The speed of a three-phase induction motor can be varied by varying the supply voltage. As we already know that the torque developed is proportional to the square of the supply voltage and the slip at the maximum torque is independent of the supply voltage. The variation in the supply voltage does not alter the synchronous speed of the motor.

The **Torque-Speed Characteristics** of the three-phase induction motors for varying supply voltage and also for fan load are shown below:



By varying the **supplying voltage**, the speed can be controlled. The voltage is varied until the torque required by the load is developed, at the desired speed. The torque developed is proportional to the square of the supply voltage and the current is proportional to the voltage.

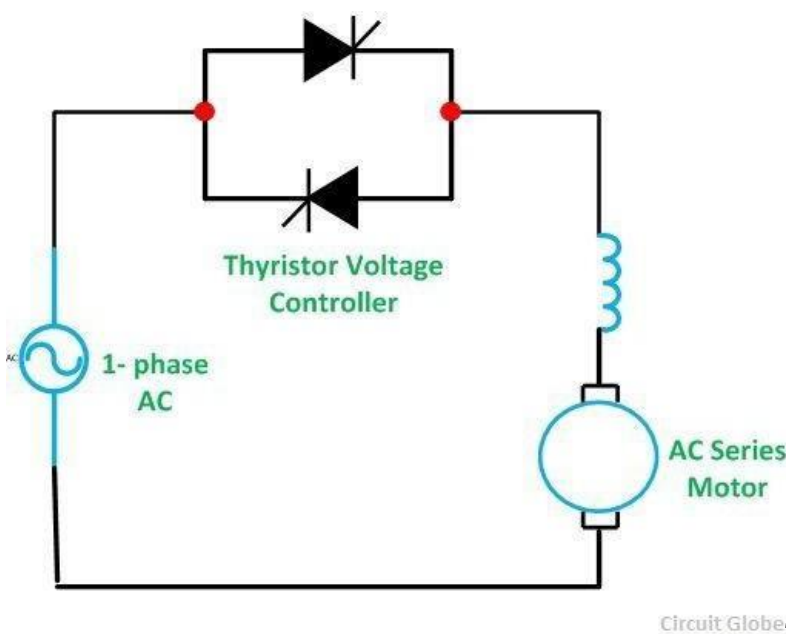
Hence, to reduce the speed for the same value of the same current, the value of the voltage is reduced and as a result, the torque developed by the motor is reduced. This stator voltage control method is suitable for applications where the load torque decreases with the speed. **For example-** In the fan load.

This method gives a **speed control** only below the normal rated speed as the operation of the voltages if higher than the rated voltage is not admissible. This method is suitable where the intermittent operation of the drive is required and also for the fan and pump drives. As in fan and pump the load torque varies as the square of the speed. These types of drives required low torque at lower speeds. This condition can be obtained by applying a lower voltage without exceeding the motor current.

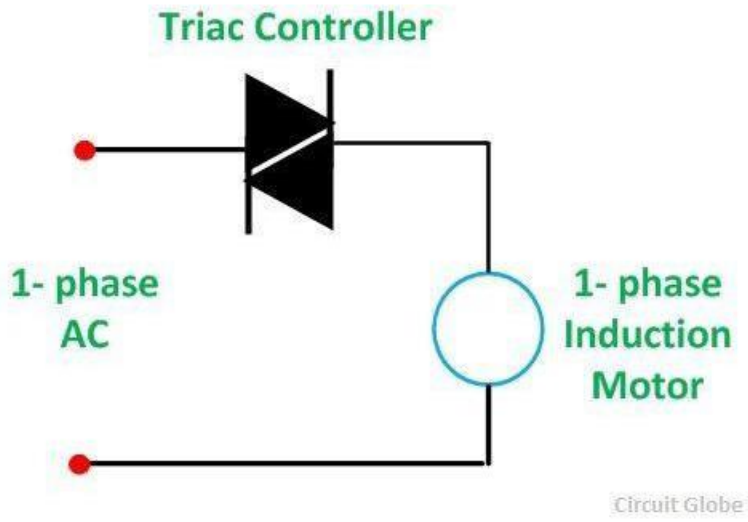
The variable voltage for speed control of small size motors mainly for single-phase can be obtained by the following methods given below:

- By connecting an external resistance in the stator circuit of the motor.
- By using an Auto-transformer.
- By using a Thyristor voltage controller.
- By using a Triac Controller.

Nowadays the **Thyristor voltage controller** method is preferred for varying the voltage. For a single phase supply, two thyristors are connected back to back as shown in the figure below:

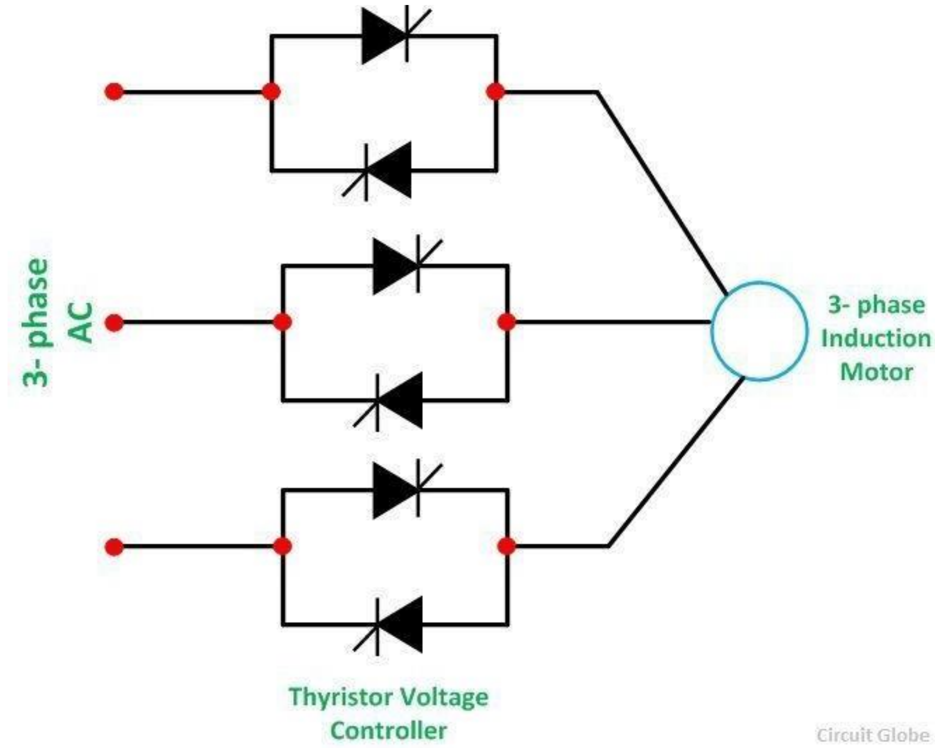


The domestic fan motors, which are single-phase are controlled by a single-phase **Triac Voltage Controller** as shown in the figure below:



Speed control is obtained by varying the firing angle of the **Triac**. These controllers are known as **Solid State fan regulators**. As the solid-state regulators are more compact and efficient as compared to the conventional variable regulator. Thus, they are preferred over the normal regulator.

In the case of a three-phase induction motor, three pairs of thyristors are required which are connected back to back. Each pair consists of two thyristors. The diagram below shows the **Stator Voltage Control** of the three-phase induction motors by **Thyristor Voltage Controller.**



Each pair of the thyristor controls the voltage of the phase to which it is connected. Speed control is obtained by varying the conduction period of the Thyristor. For lower power ratings, the back- to-back thyristor pairs connected in each phase are replaced by the Traic.

V / f Control or Frequency Control of induction motor

Whenever three phase supply is given to three phase induction motor rotating magnetic field is produced which rotates at synchronous speed given by

$$N_s = \frac{120f}{P}$$

In three phase induction motor emf is induced by induction similar to that of transformer which is given by

$$E\ or\ V = 4.44\phi K.T.f\ or\ \phi = \frac{V}{4.44KTf}$$

Where, K is the winding constant, T is the number of turns per phase and f is frequency. Now if we change frequency synchronous speed changes but with decrease in frequency flux will increase and this change in value of flux causes saturation of rotor and stator cores which will further cause increase in no load current of the motor . So, its important to maintain flux , φ constant and it is only possible if we change voltage. i.e if we decrease frequency flux increases but at the same time if we decrease voltage flux will also decease causing no change in flux and hence it remains constant. So, here we are keeping the ratio of V/f as constant. Hence its name is V/ f method. For controlling the speed of three phase induction motor by V/f method we have to supply variable voltage and frequency which is easily obtained by using converter and inverter set.

Uninterruptible Power Supply

An **Uninterruptible Power Supply** (UPS) is defined as a piece of electrical equipment which can be used as an immediate power source to the connected load when there is a fa

Types of UPS

Generally, the UPS system is categorised into On-line UPS, Off- line UPS and Line interactive UPS. Other designs include Standby on-line hybrid, Standby-Ferro, Delta conversion On-Line.

Off-line UPS

This UPS is also called as Standby UPS system which can give only the most basic features. Here, the primary source is the filtered AC mains (shown in solid path in figure 1).

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

Thus we can clearly see that the stand by system will start working only when there is any failure in mains. In this system, the AC voltage is first rectified and stored in the storage battery connected to the rectifier.

When power breakage occurs, this DC voltage is converted to AC voltage by means of a power inverter, and is transferred to the load connected to it.

This is the least expensive UPS system and it provides surge protection in addition to back up. The transfer time can be about 25 milliseconds which can be related to the time taken by the UPS system to detect the utility voltage that is lost. The block diagram is shown below.

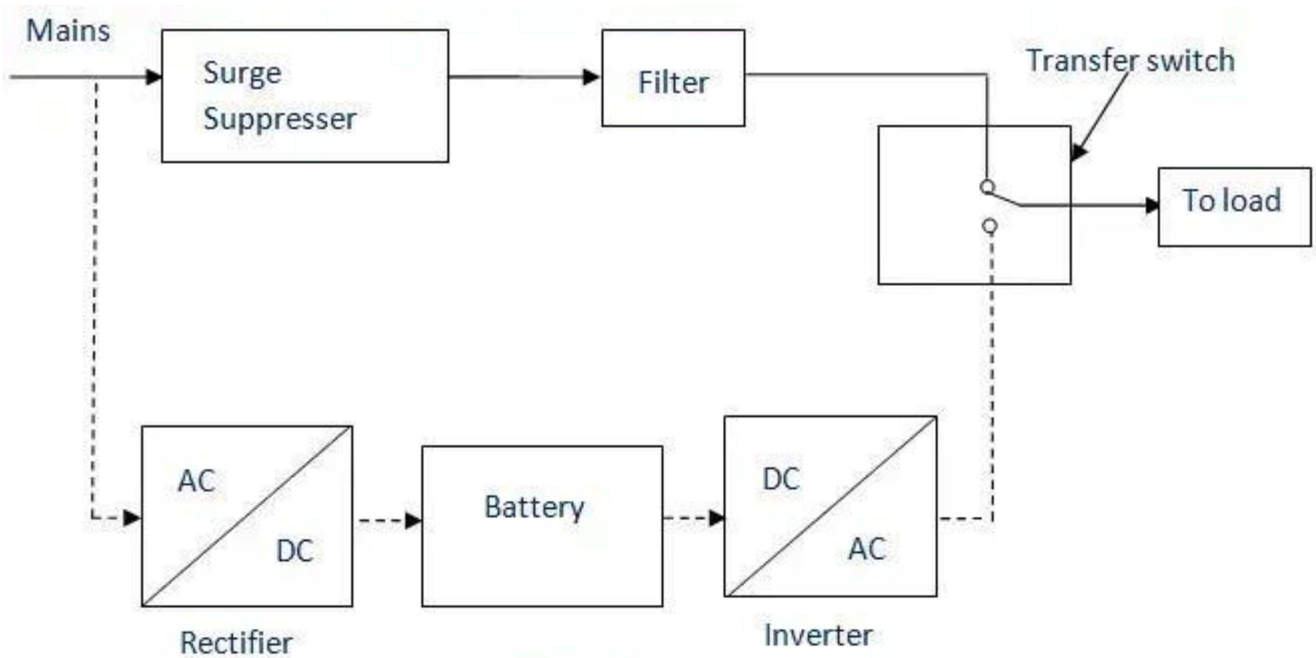


Figure 1

On-line UPS

In this type of UPS, double conversion method is used. Here, first the AC input is converted into DC by rectifying process for storing it in the rechargeable battery.

This DC is converted into AC by the process of inversion and given to the load or equipment which it is connected (figure 2).

This type of UPS is used where electrical isolation is mandatory. This system is a bit more costly due to the design of constantly running converters and cooling systems.

Here, the rectifier which is powered with the normal AC current is directly driving the inverter. Hence it is also known as Double conversion UPS. The block diagram is shown below.

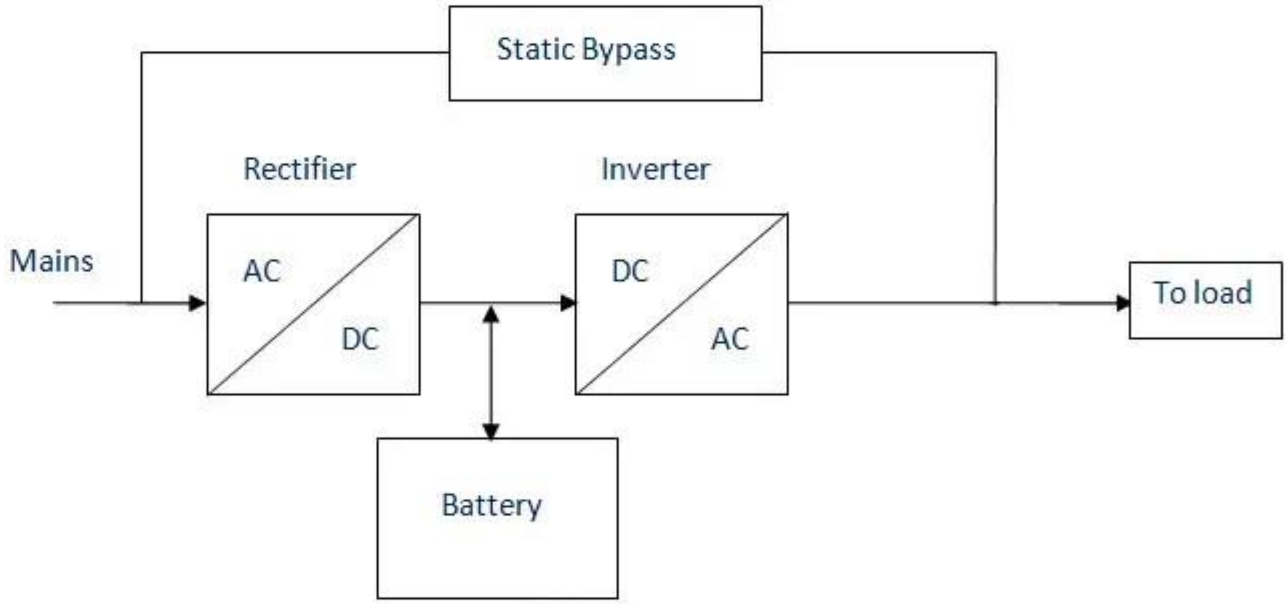


Figure 2

When there is any power failure, the rectifier have no role in the circuit and the steady power stored in the batteries which is connected to the inverter is given to the load by means of transfer switch.

Once the power is restored, the rectifier begins to charge the batteries. To prevent the batteries from overheating due to the high power rectifier, the charging current is limited. During a main power breakdown, this UPS system operates with zero transfer time.

The reason is that the backup source acts as a primary source and not the main AC input. But the presence of inrush current and large load step current can result in a transfer time of about 4-6 milliseconds in this system.

Line Interactive UPS

For small business and departmental servers and webs, line interactive UPS is used. This is more or less same as that of off-line UPS.

The difference is the addition of tap changing transformer. Voltage regulation is done by this tap- changing transformer by changing the tap depending on input voltage. Additional filtering is provided in this UPS result in lower transient loss. The block diagram is shown below.

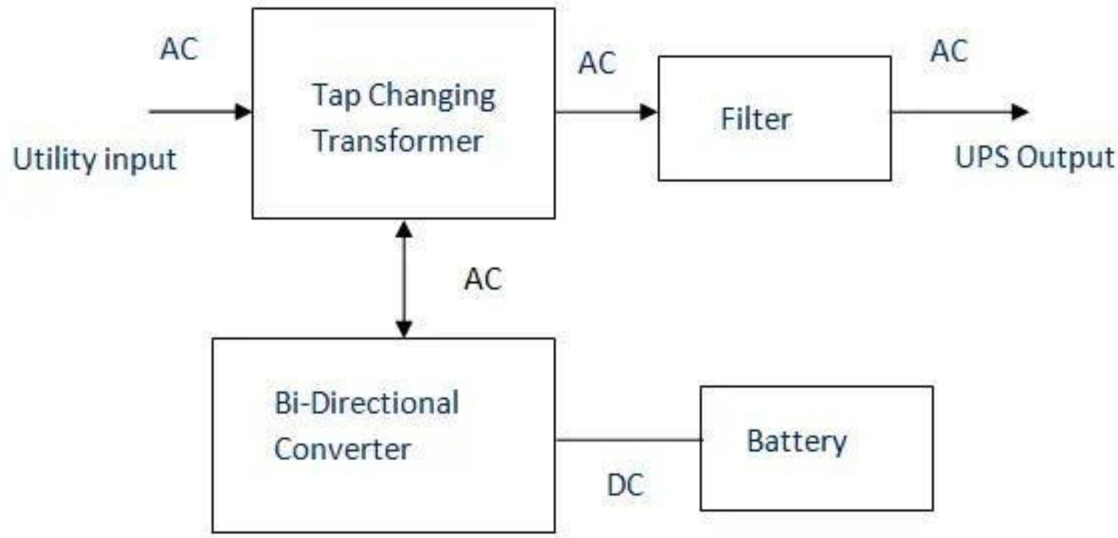


Figure 3

UPS Applications

Applications of a UPS include:

- Data Centers
- Industries
- Telecommunications
- Hospitals
- Banks and insurance
- Some special projects (events)

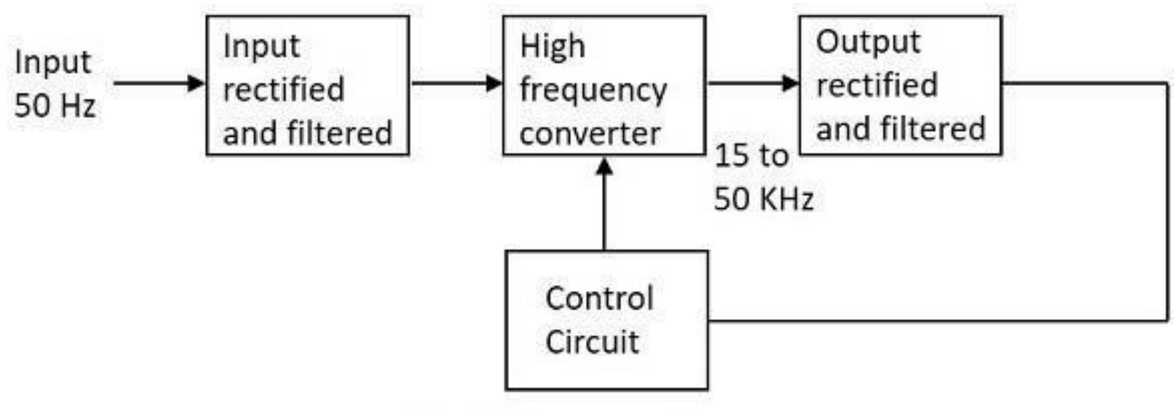
Switched Mode Power Supply (SMPS)

The disadvantages of LPS such as lower efficiency, the need for large value of capacitors to reduce ripples and heavy and costly transformers etc. are overcome by the implementation of **Switched Mode Power Supplies**.

The working of SMPS is simply understood by knowing that the transistor used in LPS is used to control the voltage drop while the transistor in SMPS is used as a **controlled switch**.

Working

The working of SMPS can be understood by the following figure.



Let us try to understand what happens at each stage of SMPS circuit.

Input Stage

The AC input supply signal 50 Hz is given directly to the rectifier and filter circuit combination without using any transformer. This output will have many variations and the capacitance value of the capacitor should be higher to handle the input fluctuations. This unregulated dc is given to the central switching section of SMPS.

Switching Section

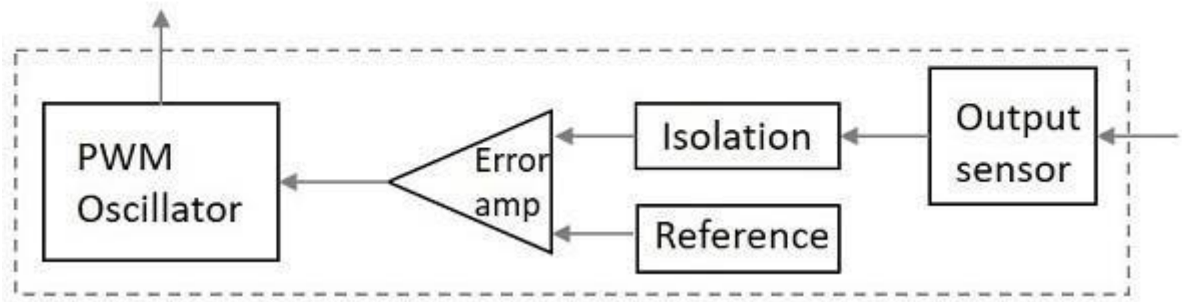
A fast switching device such as a Power transistor or a MOSFET is employed in this section, which switches ON and OFF according to the variations and this output is given to the primary of the transformer present in this section. The transformer used here are much smaller and lighter ones unlike the ones used for 60 Hz supply. These are much efficient and hence the power conversion ratio is higher.

Output Stage

The output signal from the switching section is again rectified and filtered, to get the required DC voltage. This is a regulated output voltage which is then given to the control circuit, which is a feedback circuit. The final output is obtained after considering the feedback signal.

Control Unit

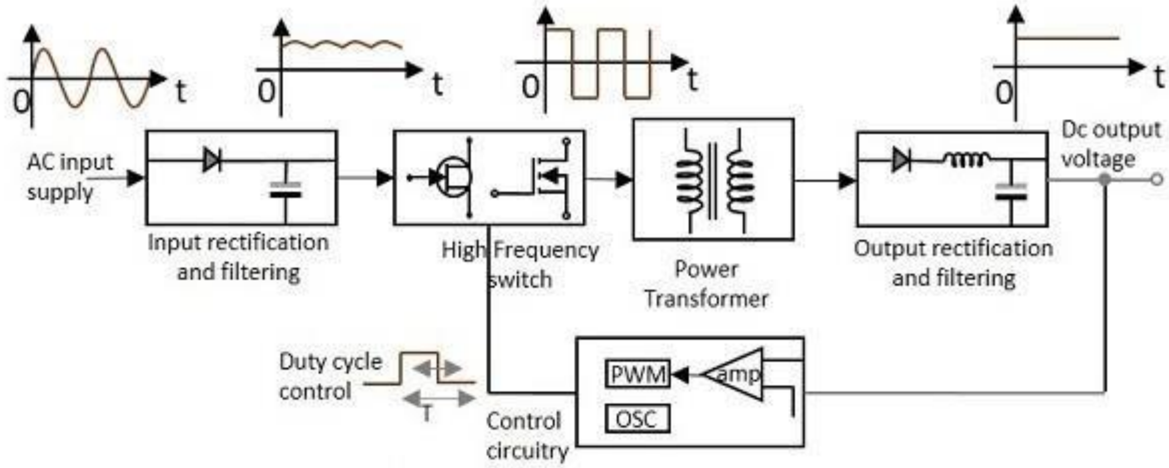
This unit is the feedback circuit which has many sections. Let us have a clear understanding about this from The following figure.



The above figure explains the inner parts of a control unit. The output sensor senses the signal and joins it to the control unit. The signal is isolated from the other section so that any sudden spikes should not affect the circuitry. A reference voltage is given as one input along with the signal to the error amplifier which is a comparator that compares the signal with the required signal level.

By controlling the chopping frequency the final voltage level is maintained. This is controlled by comparing the inputs given to the error amplifier, whose output helps to decide whether to increase or decrease the chopping frequency. The PWM oscillator produces a standard PWM wave fixed frequency.

We can get a better idea on the complete functioning of SMPS by having a look at the following figure.



Functional block diagram of SMPS

The SMPS is mostly used where switching of voltages is not at all a problem and where efficiency of the system really matters. There are few points which are to be noted regarding SMPS. They are

- SMPS circuit is operated by switching and hence the voltages vary continuously.
- The switching device is operated in saturation or cut off mode.
- The output voltage is controlled by the switching time of the feedback circuitry.
- Switching time is adjusted by adjusting the duty cycle.
- The efficiency of SMPS is high because, instead of dissipating excess power as heat, it continuously switches its input to control the output.

Disadvantages

There are few disadvantages in SMPS, such as

- The noise is present due to high frequency switching.
- The circuit is complex.
- It produces electromagnetic interference.

Advantages

The advantages of SMPS include,

- The efficiency is as high as 80 to 90%
- Less heat generation; less power wastage.
- Reduced harmonic feedback into the supply mains.
- The device is compact and small in size.
- The manufacturing cost is reduced.
- Provision for providing the required number of voltages.

Applications

There are many applications of SMPS. They are used in the motherboard of computers, mobile phone chargers, HVDC measurements, battery chargers, central power distribution, motor vehicles, consumer electronics, laptops, security systems, space stations, etc.

CHAPTER-5

PROGRAMMABLE LOGIC CONTROLLERS (PLC)

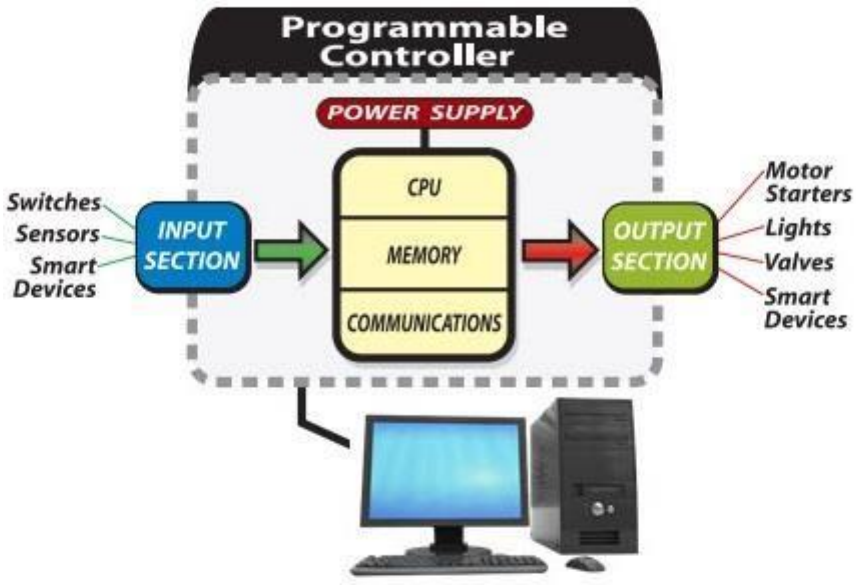
Basic Block Diagram of PLC System

The block diagram of PLC consists of different components. Each component has associated specific functions and operations in the PLC.

The list of basic components are.

- Input and Output Modules
- Power Supply
- Control Processing Unit (CPU)
- Memory System
- Communication Protocols
- Programming

You can see all these above PLC components in the below figure.



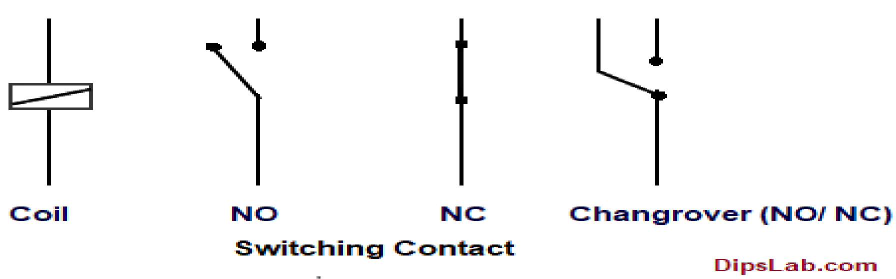
PLC System Image Source

Let’s see the description of the system one-by-one (PLC basics briefly explained).

1. Input and Output (I/O) Modules

The input/output modules in PLC are of two types. It can be either digital or analog.

Just like any other device or machine, we have to provide input to the PLC controller. It yields output.



For example, when the user presses a button, the motor starts. Here the switch button is input. The motor is an output device.

In PLC, to take the input and to return the output, there are an I/O modules.

The input modules are used for providing an interface for input devices like different types of switches (push button switch, selector switch, limited switch), sensors, etc.

The output modules are used for providing an interface for output devices like motor, fan, relay, light, lamp, electric heater, solenoid valve, buzzer, etc.

You can learn PLC input and output modules in detail.

2. Power Supply

There is no science to make the electrical device works without providing a power supply.

Every device operates around you need power whether if its electrical or mechanical or any other power supply.

For PLC, we need an electrical power supply.

The power supply provides power to all other components to operates. It provides power to the input/output modules, memory system, and processor.

The function of the power supply is to provide the DC or AC power to operate the PLC.

How much power does it require to operate PLC?

Most of the PLCs work at 220VAC or 24VDC. You can learn the difference between AC and DC in detail.

3. Central Processing Unit (CPU)

Central Processing Unit is the heart of the PLC system. The function of the CPU is to store and run the PLC software programs.

It helps to perform the basic arithmetic, logic, controlling, and input/output operations specified by the instructions. It consists of the three subparts as memory, processor and power supply.

4. Memory System

A memory system is responsible for storing and retrieving data and information. It consist of different type of memory such as RAM, ROM, EEPROM and Flash memory.

Overall memory is classified into four sections based on the types of data it stores.

- Input/Output Image Memory
- Data Memory
- User Memory
- Executive Memory

5. Communication Protocols

The communication protocols are useful for exchanging the information or data between connected devices through a network.

For further detail, kindly check topmost 10 communication protocols used in PLC.

6. PLC Programming

You need PLC programming instructions and programming to live the communication between different circuits of the PLC.

The useful information or data are communicated by the specific communication protocols.

Most of the PLC programmer works on the ladder diagram programming language. It is pretty easy as compared to other PLC programming languages.

How does Programmable Logic Controller Work?

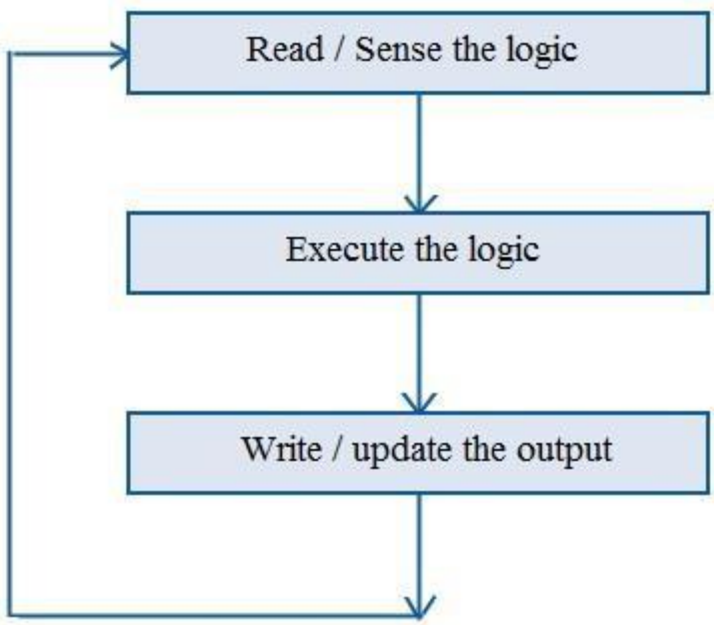
The most important working principle is- the PLC is operated by continuously scanning programs. Scanning happens every time per millisecond. So, it is called as the Scan Cycle.

For this scan cycle, PLC required a little amount of time in the range of milliseconds or ms.

What are the basic PLC Scan Cycle?

The scan cycle consists of the following three basic main steps.

1. Read the inputs
2. Execute the program by the CPU
3. Update the output



Scan Cycle of PLC DipsLab.com

Step 1: Read / Sense the input

Firstly, PLC reads the on/off status of the external input signals. After scanning the input, it gets stored in the input memory. This input included switches, pushbuttons, proximity sensors, limit switches, pressure switches, etc.

Step 2: Execute the logic by the processor

This scanned input gets transferred to the CPU for processing from input memory. The processor executes the programming instructions based on the input. After the execution, the result (on/off) will be stored in the device memory.

Step 3: Update / write the output:

When the program executes the last instruction, it will send the on/off status to the output device memory. The outputs include solenoids, valves, motors, actuators, and pumps.

All three steps get completed under the scan time.

What is Scan Time?

The amount of time is taken by the processor to read/sense the first input and execute the last output called the Scan time.

PLC is so fast as it can easily scan and execute the program in few milliseconds i.e. 10-15 milliseconds.

What are the Types of Programmable Logic Controller (PLC)?

Two types of PLCs are used for commercial or industrial purposes.

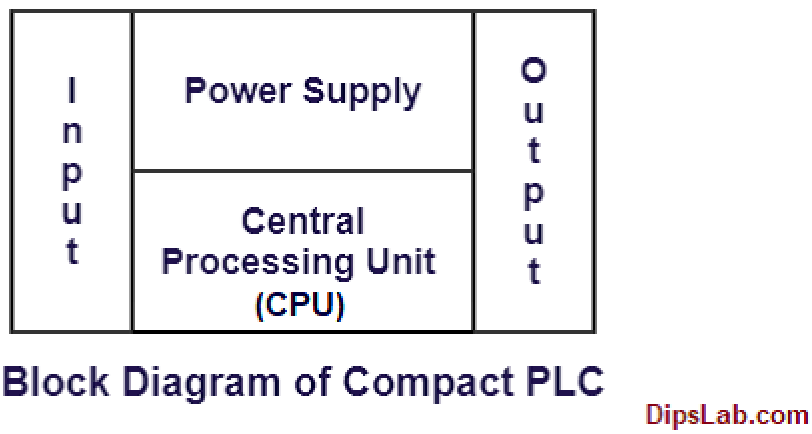
1. Compact PLC
2. Modular PLC

Knowing these two types is the part of PLC basics knowledge.

What is a Compact PLC?

It is also called as **Integrated PLC** or **Fixed PLC**.

The compact PLC has a fixed number of input/output modules along with power supply and CPU.

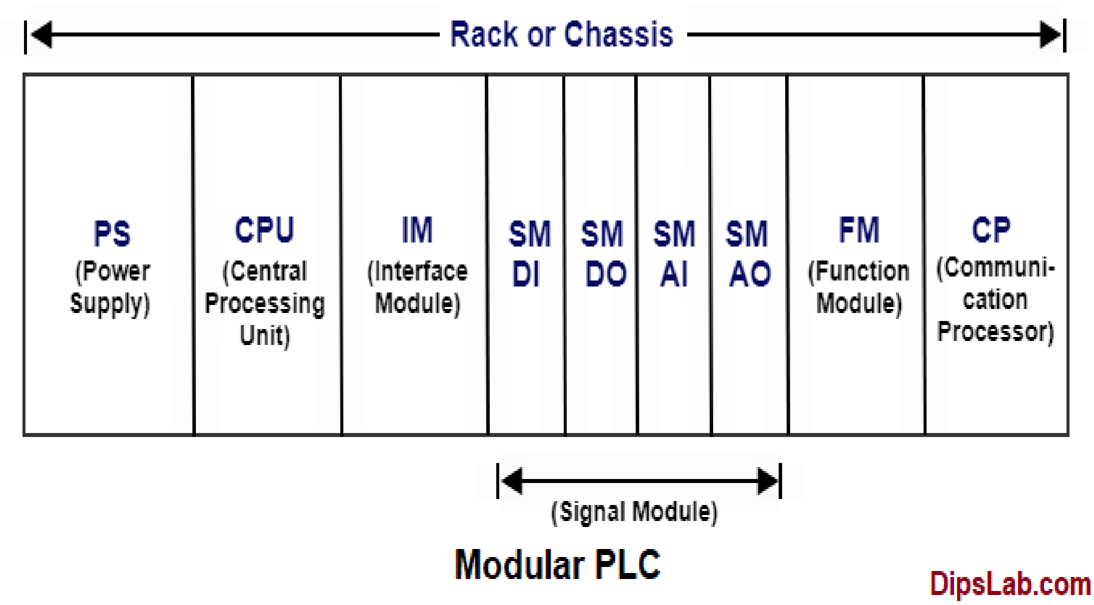


Block Diagram of Compact PLC

What is a Modular PLC?

It consists of a variable number of inputs and outputs. Inputs and outputs can be added to the modular PLC systems by the user.

If you look at the below PLC designing structure, it looks more like a rack. So, it is also called as **Rack-Mounted PLC**.



I have explained both compact and Modular PLCs in detail. Check the difference between modular and compact PLC.

What are the Most Popular PLC Programming Languages?

Based on the **International Electrotechnical Commission(IEC)** standard, PLC programming languages are classified into five main standards.

1. Ladder diagram (LD)
2. Instruction List (IL)
3. Structured Text (ST)
4. Function Block Diagram (FBD)
5. Sequential Function Charts (SFC)

These are the topmost 5 different type of PLC programming languages.

According to the study and operations, ladder diagram (LD) is the widely PLC language for writing easily understandable programming logic. This programming logic based on the logic gates.

LD has a graphical user interface. It comes with many features that give an edge over other programming languages.

What is the most popular PLC brand used?

In the automation environment, more companies are manufacturing and working on the control system by using PLC and SCADA.

Today, there are multiple brands available for PLC systems. The Asea Brown Boveri (ABB), Allen Bradley (AB), General Electric (GE), Siemens, Delta, Mitsubishi, Omron, and Schneider are some of the very popular PLC brands.
Based on the usage, Siemens PLC tops the position. Allen Bradley PLC is at the second position in Automation.

You can use any brand of PLC as per your project requirements, study, and industry need.

What are the Applications of PLC?

For automation, multiple PLCs are used to monitor and control building systems in production processes.

PLCs are used in various industries like the steel industry, glass industry, cement industry, paper mill, coal mine, automobile industry, chemical industry, textile industry, robotic system, and food processing system.

In this PLC basics, I have already listed popular applications of PLC in industrial automation companies.