

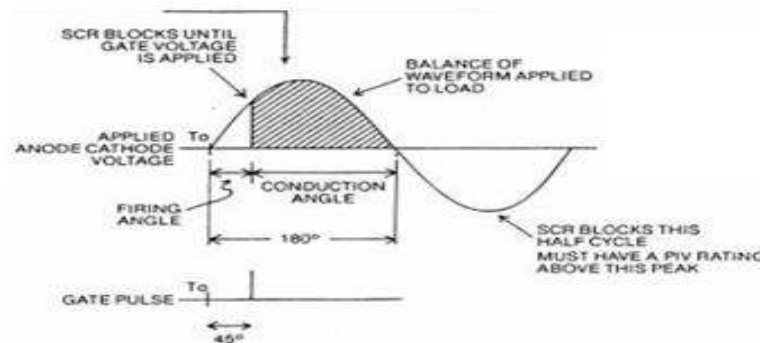
Controlled Rectifiers

Important Definitions

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

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

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



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

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

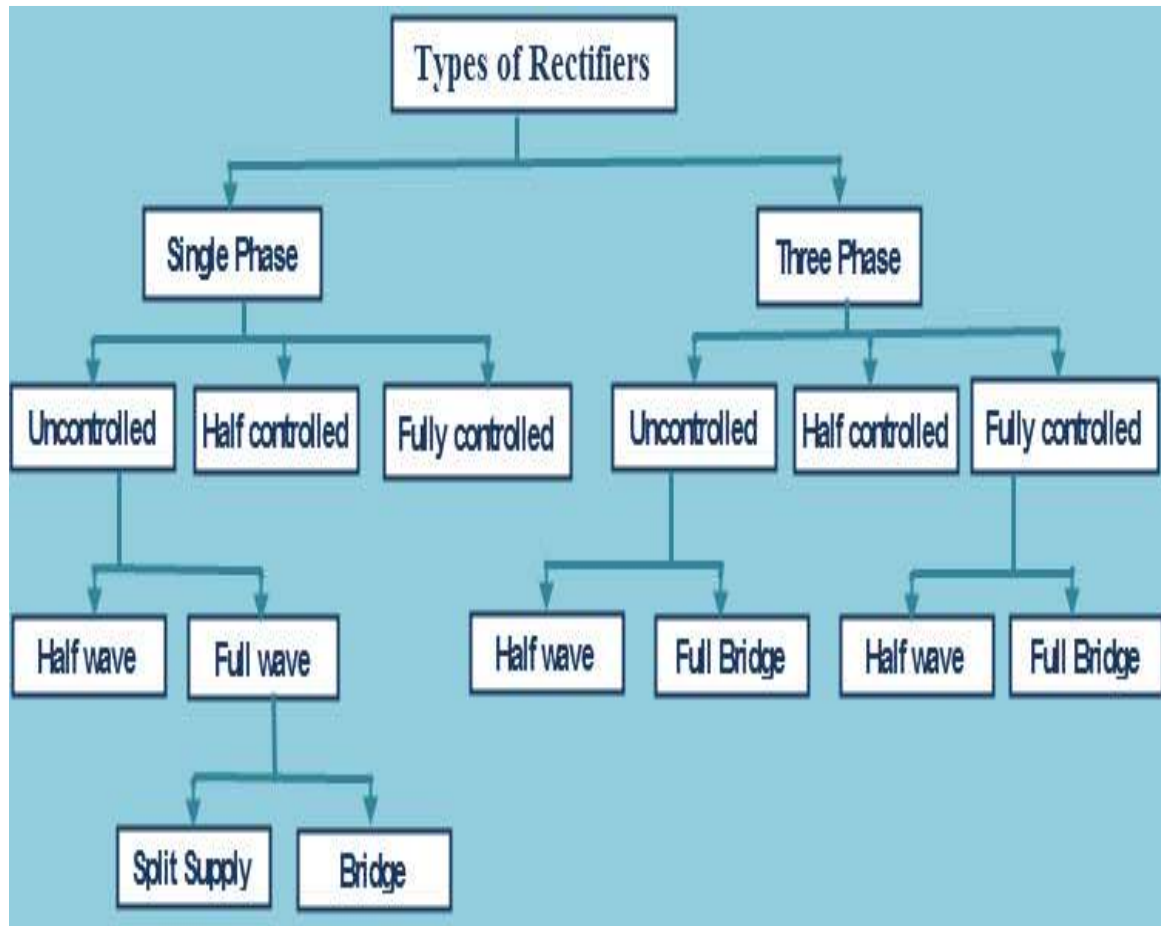
Controlled Rectifier: “ A controlled rectifier is a circuit which is used for converting AC Supply into Controlled DC supply & fed to the load.”

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

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

Types of Controlled Rectifier:

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

**Single Phase Half Wave Controlled Rectifier:**

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

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

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

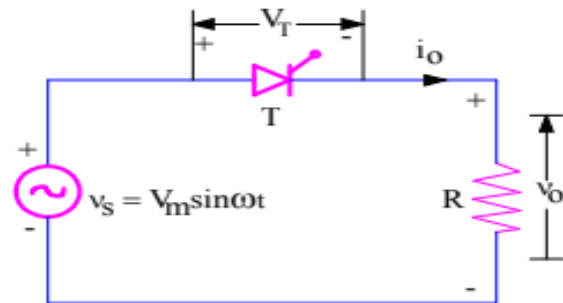
Single Phase Half Wave Controlled Rectifier with pure resistive (R) Load

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

V_0 = Load output voltage

i_0 = Load current

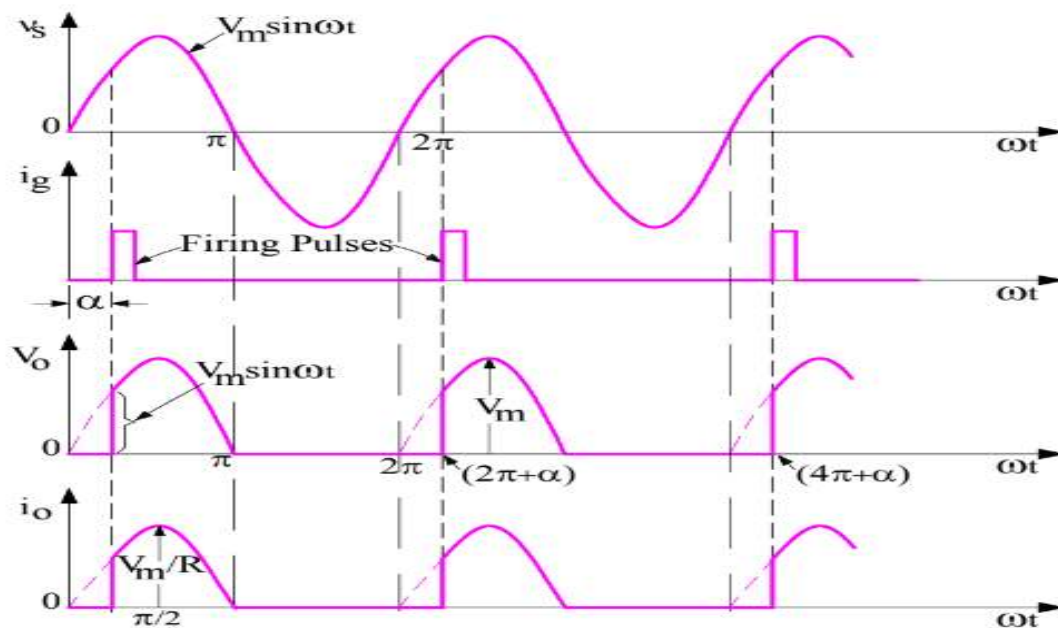
V_T = Voltage across the Thyristor



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

After $\omega t = \pi$ (During Negative Half Cycle), SCR (T) is reversed biased and will Turned OFF at $\omega t = \pi$ and will remain in OFF condition till it is fired again at $\omega t = (2\pi + \alpha)$.

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



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

$$v_0 = V_m \sin \omega t \quad \text{for} \quad \alpha \leq \omega t \leq \pi$$

$$i_0 = V_m \sin \omega t / R \quad \text{for} \quad \alpha \leq \omega t \leq \pi$$

Calculation of Average Load Output Voltage:

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

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

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

Average Value of Load output Voltage

$$\begin{aligned} &= (1/2\pi) \int_0^{2\pi} V_m \sin \omega t d(\omega t) \\ &= (1/2\pi) \int_0^{\alpha} V_m \sin \omega t d(\omega t) + \int_{\alpha}^{\pi} V_m \sin \omega t d(\omega t) + \int_{\pi}^{2\pi} V_m \sin \omega t d(\omega t) \end{aligned}$$

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

$$\begin{aligned} &= (1/2\pi) \int_{\alpha}^{\pi} V_m \sin \omega t d(\omega t) \\ &= (V_m/2\pi) \int_{\alpha}^{\pi} \sin \omega t d(\omega t) \\ &= \left(\frac{V_m}{2\pi} \right) [1 + \cos \alpha] \end{aligned}$$

For Single Phase Half Wave Controlled Rectifier:

Average Value of Load output Voltage

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

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

The average output voltage is maximum when firing angle is zero and it is minimum when firing angle $\alpha = \pi$. This is the reason, it is called phase controlled rectifier.

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

Single Phase Half-Wave Controlled Rectifier with Inductive-Load

Figure Shows 1 (a) the circuit diagram of Single Phase Half Wave Controlled Rectifier with Inductive Load. In this Circuit, an SCR (T_1) is used to rectify the incoming Sine Wave from the transformer secondary, and this rectified output will be supplied to an inductive load, such as a motor winding or relay coil.

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

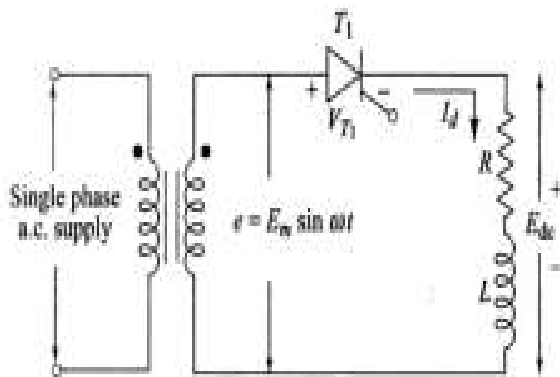


Fig.1(a) Half-wave controlled rectifier with R-L load

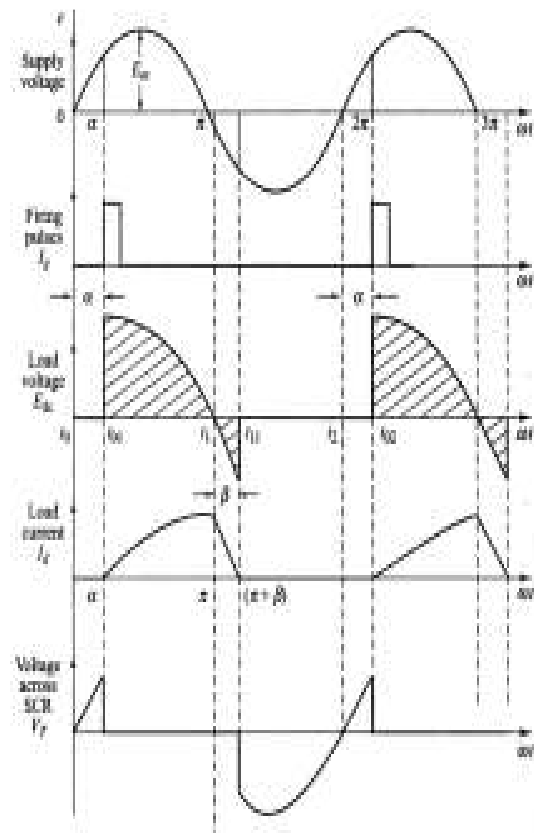


Fig.1(b) Waveform for a half-wave controlled rectifier with RL load

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

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

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

Freewheeling Diode

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

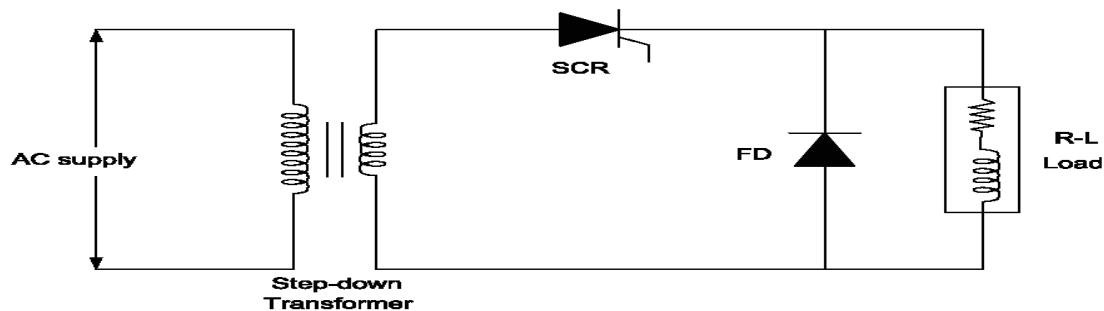
Purpose of using Freewheeling Diode:

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

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

Diode

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



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

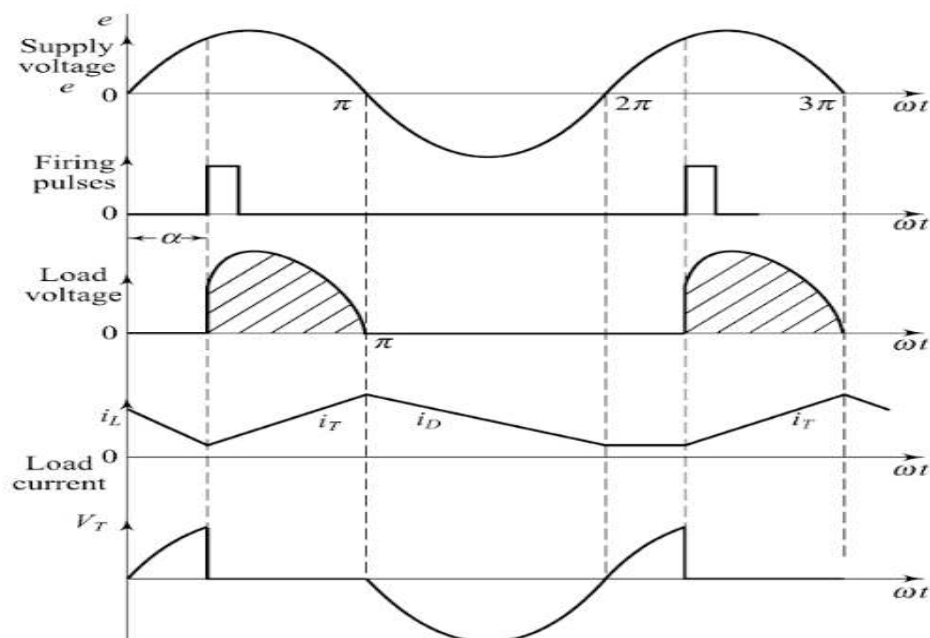


Fig.3 Waveforms for half-wave controlled-rectifier with inductive load and freewheeling diode

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

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

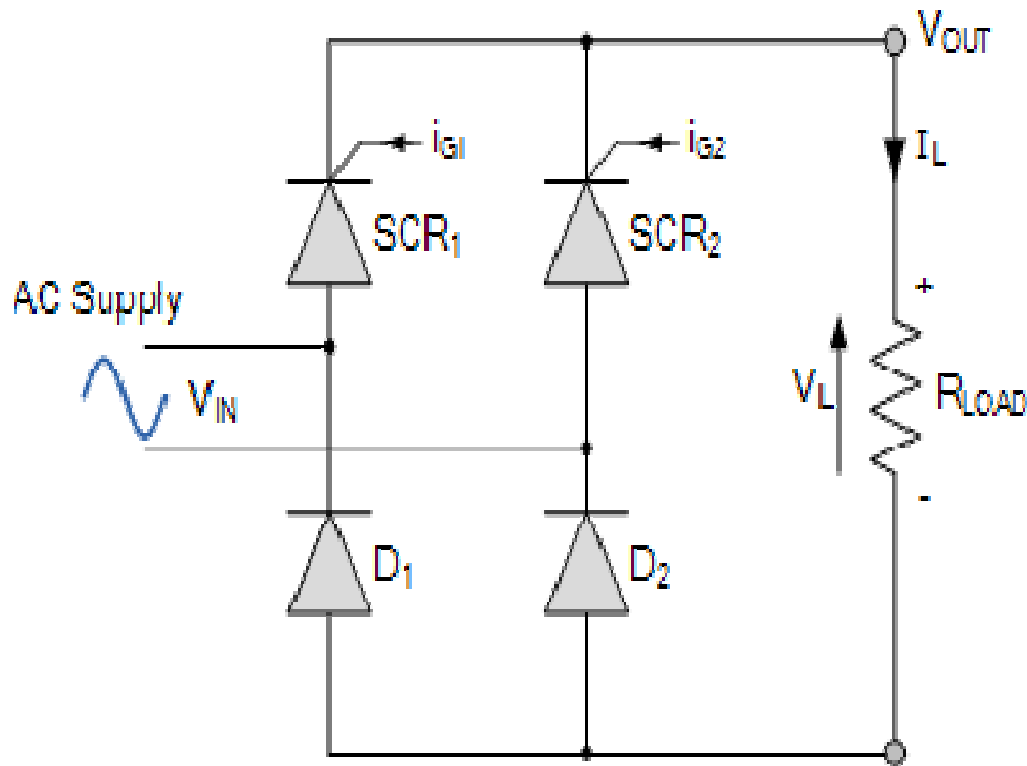
For this reason, a freewheeling diode (FD) is connected in parallel with the inductive load. With FD present, the large reverse voltage that would normally develop across the load inductance, causes FD to become forward biased, which acts like a short-circuit to clamp the reverse voltage spike that would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

Single Phase Full Wave Half Controlled Rectifier with Resistive Load:

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

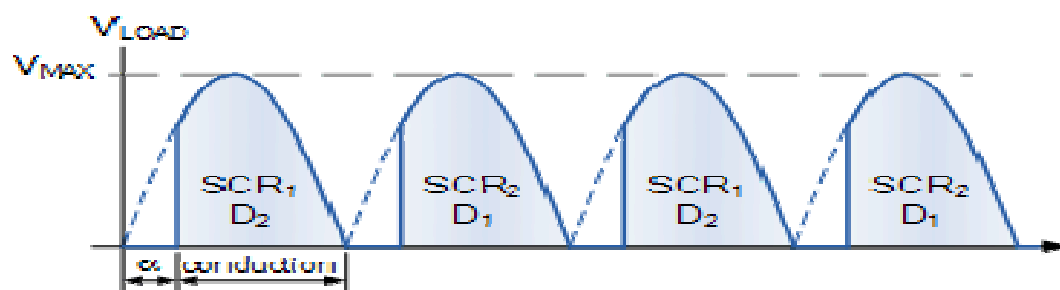
In Half Controlled Rectifier, One SCR and one Diode conducts for positive half cycle and other one SCR and other Diode conducts for negative half cycle to convert the AC voltage to DC voltage.

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



During the Positive Half Cycle of the Input V_{IN} Signal, The Current flowing through the path of: Upper Terminal of the Supply (+), SCR₁, Load (R_L), D₂, and back to Lower Terminal (-) of the Supply .

Similarly, During the Negative Half Cycle of Input V_{IN} , The Current flowing through the path of : Lower Terminal (+), SCR₂, Load (R_L), D₁ and back to Upper Terminal (-) of the Supply.



It is clear that one SCR from the top group (SCR₁ or SCR₂) and its corresponding Diode from the bottom group (D₂ or D₁) must conduct together for any load current to flow.

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

Average Output Voltage and Current

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

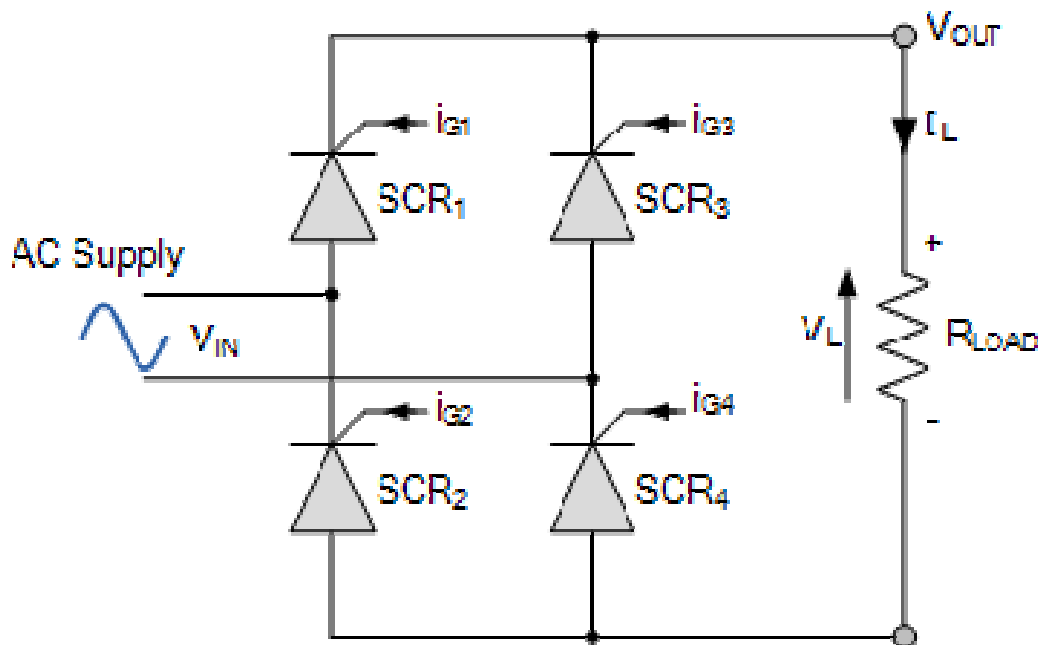
$$\therefore I_{AVE} = \frac{V_{AVE}}{R_L}$$

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

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

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

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



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

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

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

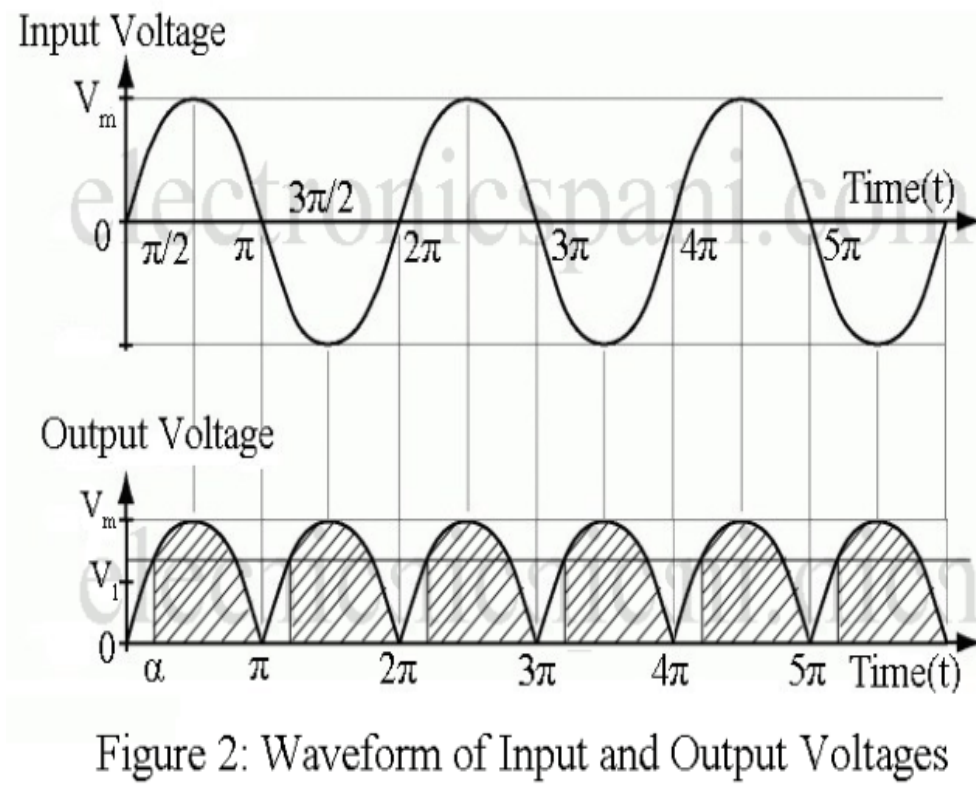


Figure 2: Waveform of Input and Output Voltages

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

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

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

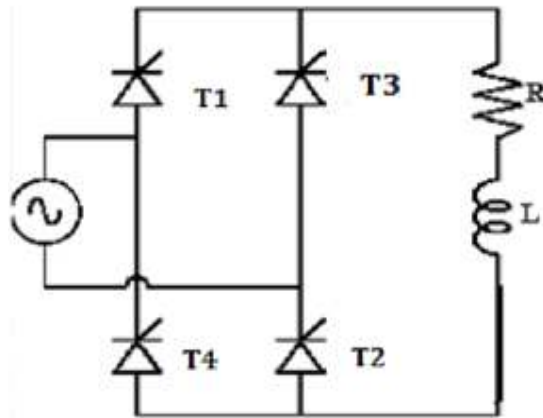
$$\therefore I_{AVE} = \frac{V_{AVE}}{R_L}$$

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

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

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

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



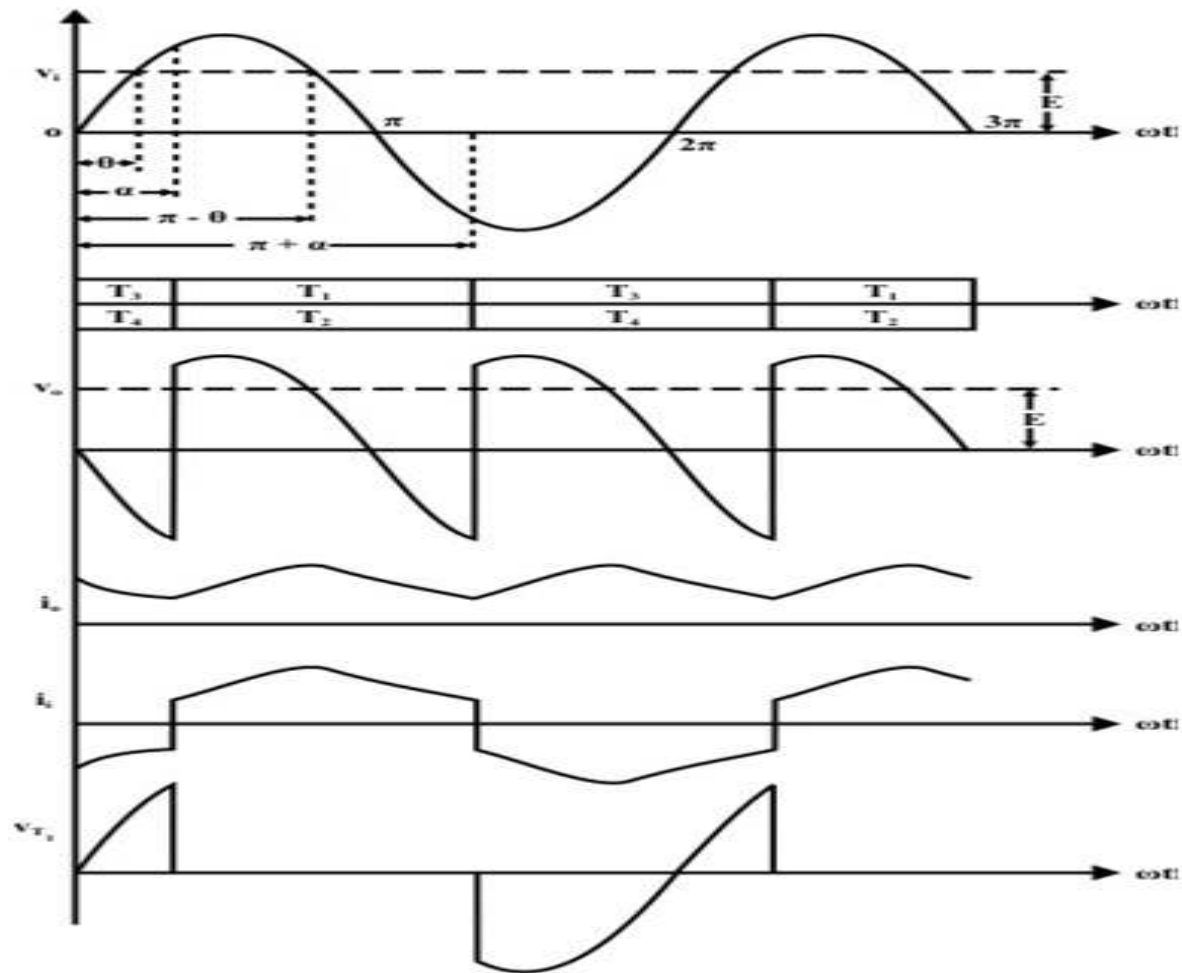
Operation of this mode can be divided between four modes

Mode 1 (α to π)

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

Mode 2 (π to $\pi + \alpha$)

At $\omega t = \pi$, input supply is equal to zero & after π it becomes negative. But inductance opposes any change through it. In order to maintain a constant load current & also in same direction. A self induced emf appears across 'L' as shown. Due to this induced voltage, SCR's T_1 & T_2 are forward biased in spite the negative supply voltage. The load voltage is negative & equal to instantaneous ac supply voltage whereas load current is positive. Thus, load acts as source & stored energy in inductance is returned back to the ac supply.



Mode 3 ($\pi + \alpha$ to 2π)

At $\omega t = \pi + \alpha$, SCR's T_3 & T_4 are turned on & T_1, T_2 are reversed bias. Thus, process of conduction is transferred from T_1, T_2 to T_3, T_4 . Load voltage again becomes positive & energy is stored in inductor T_3, T_4 conduct in negative half cycle from $(\pi + \alpha)$ to 2π . With positive load voltage & load current energy gets stored.

Mode 4 (2π to $2\pi + \alpha$)

At $\omega t = 2\pi$, input voltage passes through zero. Inductive load will try to oppose any change in current if in order to maintain load current constant & in the same direction. Induced e. m. f. is Positive & maintains conducting SCR's T_3 & T_4 with reverse polarity also. Thus V_L is negative & equal to instantaneous AC supply voltage. Whereas load current continues to be positive. Thus load acts as source & stored energy in inductance is returned back to ac supply At $\omega t = \alpha$ or $2\pi + \alpha$, T_3 & T_4 are commutated and T_1, T_2 are turned ON.

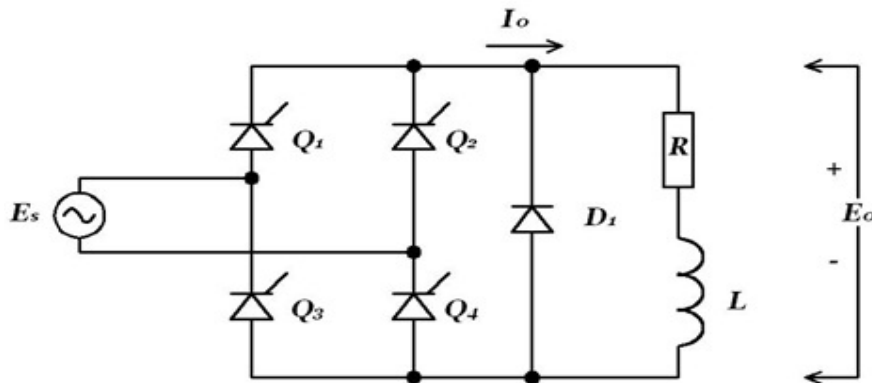
Full Wave Fully-controlled Bridge Rectifier With R-L Load & Free Wheeling Diode:

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

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

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

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



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

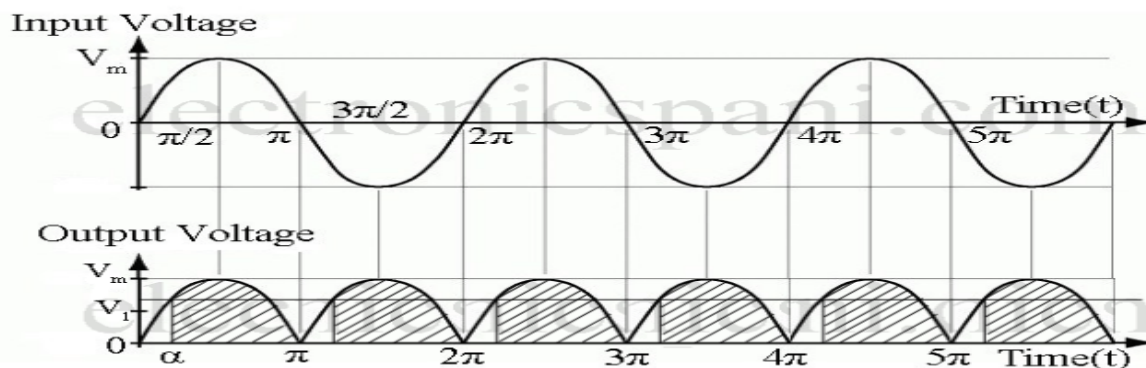
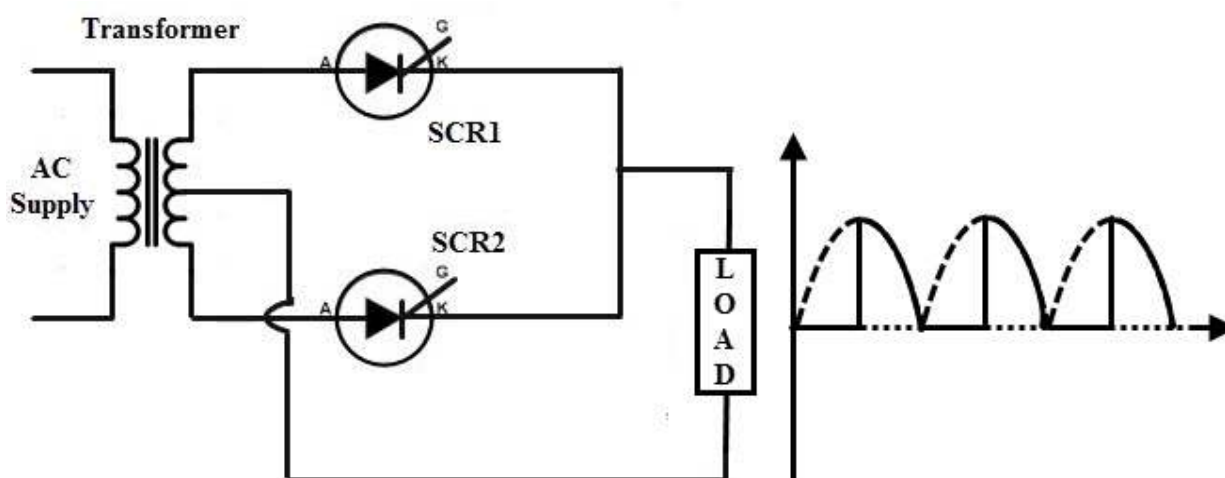


Figure 2: Waveform of Input and Output Voltages

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

Full Wave Full Controlled Centre Tapped Rectifier:

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



During the positive half cycle of the input, SCR₁ is forward biased and SCR₂ is reverse biased. By applying the proper gate signal, SCR₁ is turned ON and hence load current starts flowing through it.

During the negative half cycle of the input, SCR₂ is forward biased and SCR₁ is reverse biased. With a gate triggering, SCR₂ is turned ON and hence the load current flows through the SCR₂.

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

FILL IN THE BLANKS:

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

Answers:

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

FILL IN THE BLANKS:

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

Answers:

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

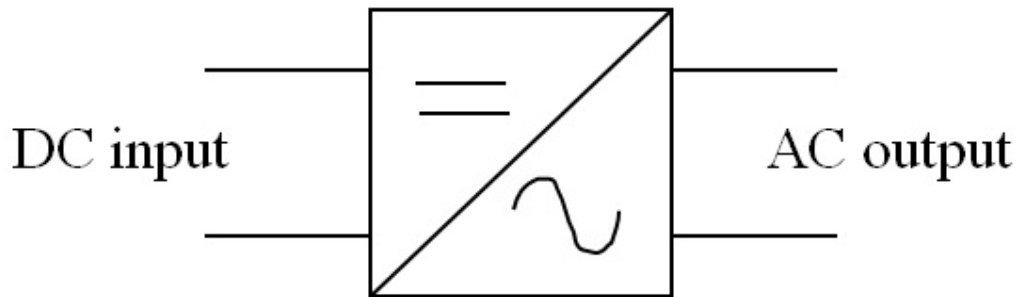
1. In a Single Phase Full Wave Half Controlled Bridge, both the SCRs conduct in the Half of the AC Supply simultaneously.
2. The Half Wave Rectifier is used most of the high power applications.
3. The average (DC) output voltage of Full Wave Rectifier is higher than Half Wave Rectifier.
4. When the rectification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

Answers:

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

Inverters, Choppers, Dual-Converters and Cyclo-Converters**INVERTERS**

Inverter: A Inverter is a electronic device which converts direct current (DC) into alternating current (AC).



The inverter does not produce any Power; the power is provided by the DC source and Inverter converts it into A. C. Power and supplied to the Load..

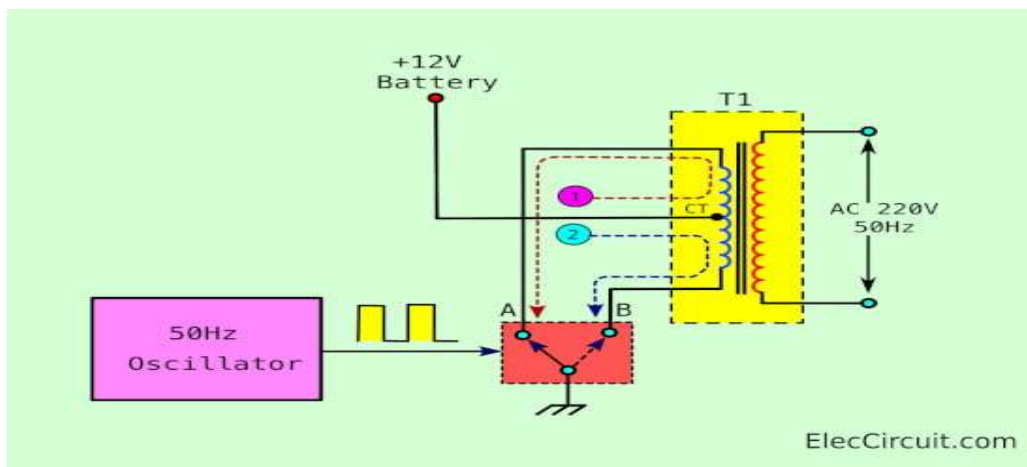
Basic Inverter Circuit and Working Principle :

Figure shows the basic circuit of Inverter circuit. The Inverter circuit consist of Battery, centre tapped Transformer, Electronics Switch controlled by Oscillator.

Working: The 12V D. C. Supply comes from the positive terminal of the battery to the center tap terminal of Transformer of 12V winding in the primary coil. The two ends of the primary coil (A and B point) are connected to the 2 ways electronic switch to the ground.

1. When the switch connects to A point. The current flowing through upper winding of Transformer (From Point 1 , Transformer upper Winding ,Contact point A of Switch to the ground).
2. When the switch turn from A into B. It causes the current flowing through lower winding of Transformer (From Point 2 , Transformer lower Winding ,Contact point B of Switch to the ground).

Inverters, Choppers, Dual-Converters and Cyclo-Converters

3. This Two ways Electronic switch is controlled with the square wave oscillator which generates a signal of frequency (approximately 50 Hz).
4. It causes the switch to select between A and B point with speed about 50 times per second. Also, the current in upper winding and lower winding flow to the transformer alternately in opposite directions at a rate of 50 times per second.
5. The current flows into the transformer Primary Winding alternately look like AC voltage and this current will be induced into the secondary, which causes AC voltage 220V 50Hz. This voltage supplied to the various types of electrical equipment that require AC 220 Volt in operation.

Applications of Inverter

- i. Inverters are used as an UPS-Uninterruptible power supplies
- ii. These are used in solar power systems
- iii. These are used in SMPS- switched mode power supply.
- iv. These are also used in houses to provide supply during main supply black out.
- v. These are used to run electrical / Electronic equipment like Centrifugal fans, pumps, mixers, extruders, test stands, Induction heating, Sonar transmitter, Fluorescent lighting Ultrasonic generator.

Type of Inverters: Inverters are classified into two types:

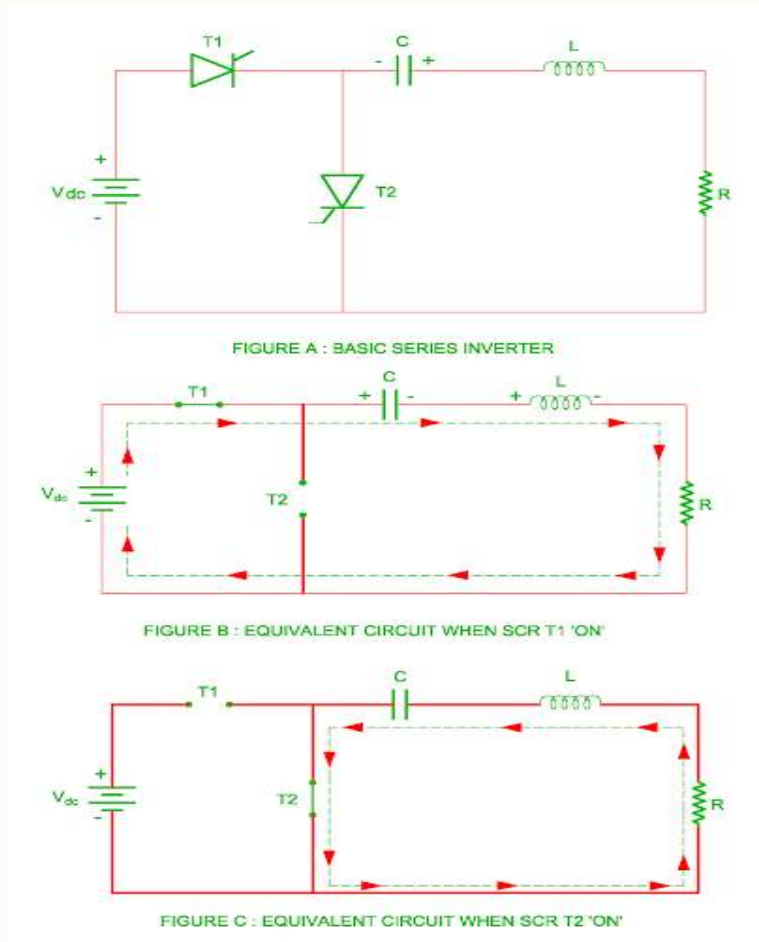
1. Series Inverter
2. Parallel Inverter

1. **Series Inverter:** Series Inverters are those inverters, in which the commutating elements L and C are connected in series with the load.

This inverter constitutes a series RLC resonant circuit. The value of commutating components is selected such that the circuit becomes under damped. The Two SCRs are used to produce the halves (positive and negative half cycle) in the output. The anode current itself becomes zero in this inverter resulting the SCR turns off automatically therefore this inverter is also called as **SELF COMMUTATED OR LOAD COMMUTATED INVERTER**.

Circuit Diagram

The circuit diagram of the series inverter is shown in the figure A. The SCR (T_1) and SCR (T_2) are turned on at regular interval in order to achieve desirable output voltage and output frequency. The SCR T_2 is kept off at starting condition and polarity of voltage across capacitor is shown in the figure A.



The Operation of the Series Inverter is explained as follows.

Mode 1

- When SCR T_1 Triggered, It will Turned ON and the voltage V_{dc} directly applies to RLC series circuit.
- The Capacitor will charge with the polarity $+ C -$ as shown in the figure B.
- The voltage across capacitor becomes $+ V_{dc}$ when the load current becomes maximum.
- The voltage across capacitor becomes $+2 V_{dc}$ when the load current becomes zero at point A and the SCR T_1 automatically turns off at this point A because the load current becomes zero.

Mode 2

- During the Period from A to B, the load current remains zero and Voltage across Capacitor becomes to $+2 V_{DC}$ as the SCR T_1 turns off during this time period and SCR T_2 is already in turned OFF Position.

Mode 3

- i. Now SCR T_2 is turned ON by triggering at point B, the Capacitor will discharge through SCR T_2 and R – L circuit as shown in the figure C.
- ii. The load current becomes zero after it becomes maximum in the negative direction.
- iii. The capacitor discharges from $+2V_{dc}$ to $-V_{dc}$ during this time and SCR T_2 turns off automatically at point C due to load current becomes zero.
- iv. During Point C to D, the SCR T_2 turns off and SCR T_1 again turns ON at point D. In this way, this cycle repeat after completing one turn.
- v. The Positive AC output voltage half cycle generates due to DC voltage source whereas Negative half cycle generates due to capacitor.

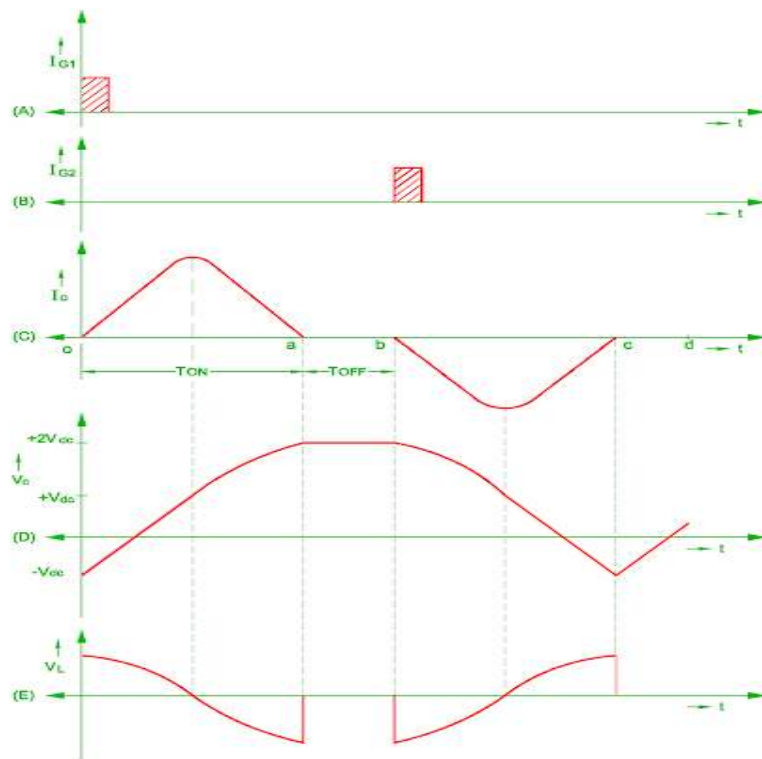


FIGURE D : VOLTAGE AND CURRENT WAVEFORMS OF SERIES INVERTER
 (A) Gate pulse for SCR T_1 (B) Gate pulse for SCR T_2 (C) output current,
 (D) Capacitor voltage (E) Load voltage

Important Note:

- i. There is always some time delay kept between one SCR turned on time and other SCR turned on time.
- ii. The time duration ab and cd must be greater than the SCR specific turn off time and it is called as **dead zone**.

Limitations / Disadvantages of Series Inverter

- i. The load current flows only during positive half cycle from supply source.
- ii. The DC supply source gets short circuited if SCR T1 and SCR T2 simultaneously turned on.
- iii. The rating of commutating components should high because the load current flows through it.
- iv. The load voltage waveform gets distorted if the dead zone time or SCR turns on time high.
- v. The maximum output frequency of the inverter should be less than the resonant frequency.
- vi. The DC supply source is short circuited if the output frequency of the inverter is higher than the resonant frequency.

2. Parallel inverter: Parallel Inverters are those Inverters in which commutating components are connected parallel with the load.

Circuit Detail: Parallel inverter circuit is shown in the figure A, which is consists of two SCRs T1 and T2, an inductor L, an output transformer and a commutating capacitor C. The function of L is to make the source current constant. During the working of this inverter, capacitor C comes in parallel with the load via the transformer. So it is called a parallel inverter. The turns ratio of half primary winding and secondary winding is kept unity.

Circuit Working:**Mode 1**

- I. When the SCR T₁ is triggered, it will turned on and the current flows through the path as shown in figure 'B' of the above circuit $V_{dc(+)} - L - c - a - SCR T_1 - V_{dc(-)}$.
- II. This will generate flux and resulting EMF in the Transformer Primary Winding ac and bc.
- III. Due to this induced EMF., the capacitor will charge up to + 2V_{dc} voltage.
- IV. As there is equal turns ratio between half primary and secondary winding, the same 2V_{dc} EMF will be induced in the secondary of transformer secondary and this EMF will result flow of current through load.

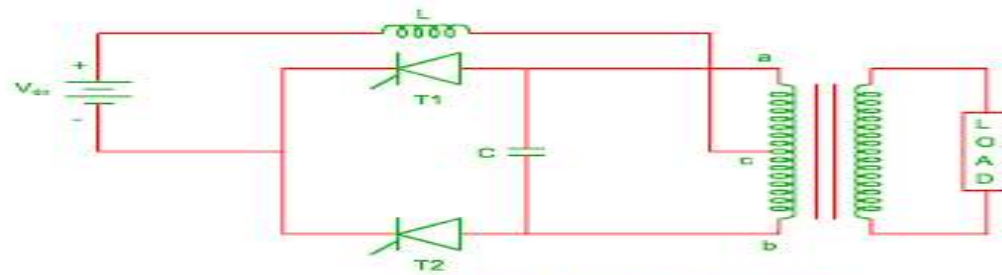


FIGURE A : PARALLEL INVERTER

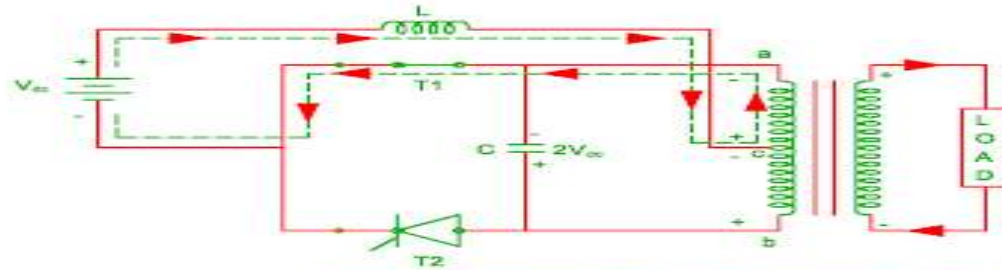


FIGURE B : EQUIVALENT CIRCUIT WHEN SCR T1 'ON'

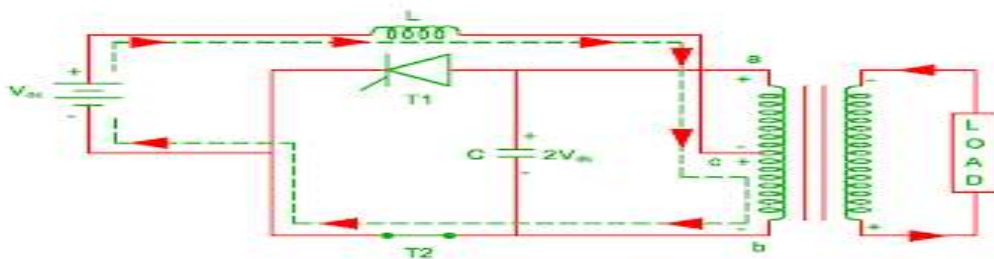


FIGURE C : EQUIVALENT CIRCUIT WHEN SCR T2 'ON'

Mode 2

- I. When the SCR T_2 is triggered, it will be turned ON and the SCR T_1 will be turned OFF due to capacitor reverse voltage $2V_{dc}$ applied across it.
- II. As the SCR T_2 is turned ON, the load current flows through path 'C' of the above circuit $V_{dc(+)} - L - c - b - \text{SCR } T_2 - V_{dc(-)}$ and capacitor will be discharged through SCR T_2 .
- III. This will generate flux and resulting EMF. in the transformer primary winding bc and ac.
- IV. The capacitor will again charged with opposite polarity upto $(-2V_{dc})$
- V. During this interval of time, the current will flow in reverse direction as that of when SCR T_1 was turned ON.
- VI. Similarly, again the SCR T_1 will be turned ON when it triggered and SCR T_2 will be in OFF condition during this interval and this process repeated again and again.

POWER ELECTRONICS

UNIT - III

Inverters, Choppers, Dual-Converters and Cyclo-Converters

- vii. Due to alternately switching of SCR T_1 and SCR T_2 , the output voltage become rectangular.

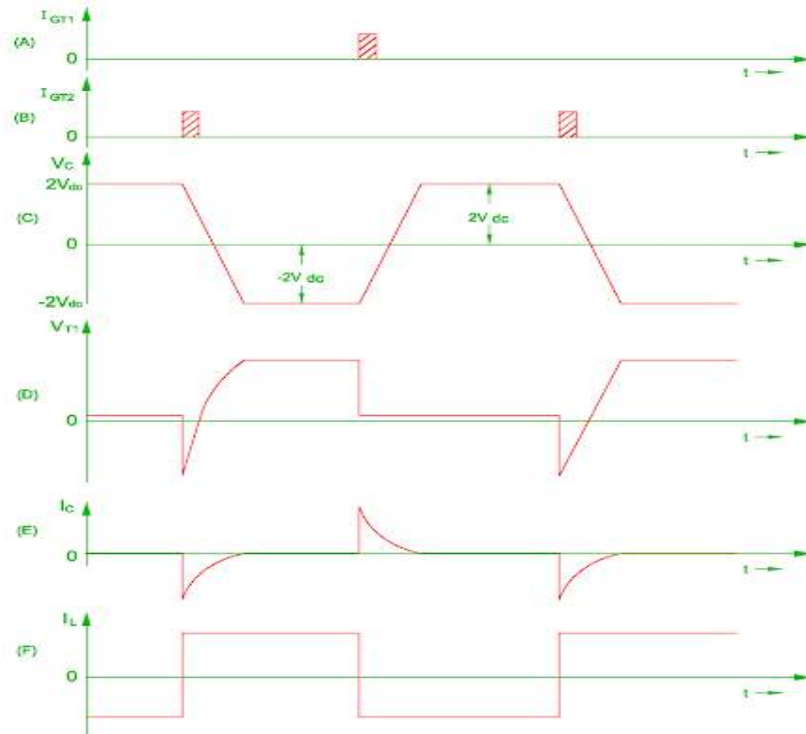


FIGURE D : VOLTAGE AND CURRENT WAVEFORMS FOR
PARALLEL INVERTER

(A) GATE PULSE FOR SCR T_1 (B) GATE PULSE FOR SCR T_2 (C) VOLTAGE ACROSS CAPACITOR
(D) VOLTAGE ACROSS SCR T_1 (E) CAPACITOR CURRENT (F) LOAD CURRENT

Advantages of Parallel Inverter:

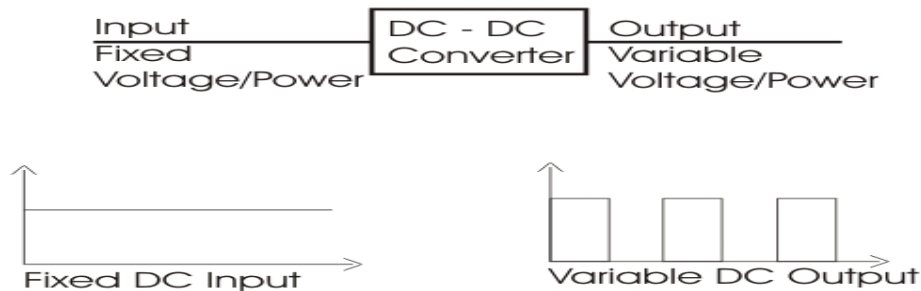
- I. It is Simple forced commutation circuit.
- II. It can give Sinusoidal waveform at output by using suitable filter circuit.

Disadvantages of Parallel Inverter:

- I. The parallel inverter is useful only when load is fixed.
- II. The parallel inverter does not useful for higher power for fixed value of inductor L and capacitor C .
- III. The design of inverter for fixed voltage is possible.

CHOPPERS

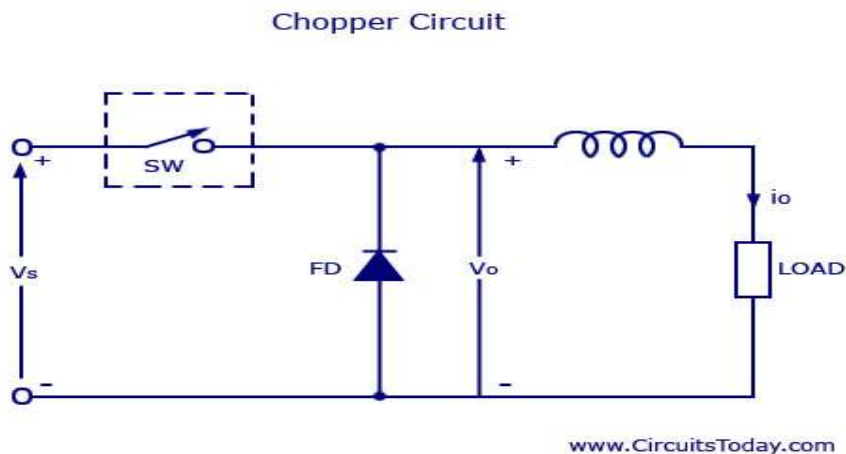
Chopper: A chopper is a device that converts fixed DC input to a variable DC output voltage directly.



Chopper circuits are also known as DC to DC converters. Choppers change the fixed DC power to variable DC power and are used to step up and step down the DC power. Using these devices, DC power supplied can be adjusted to the required amount.

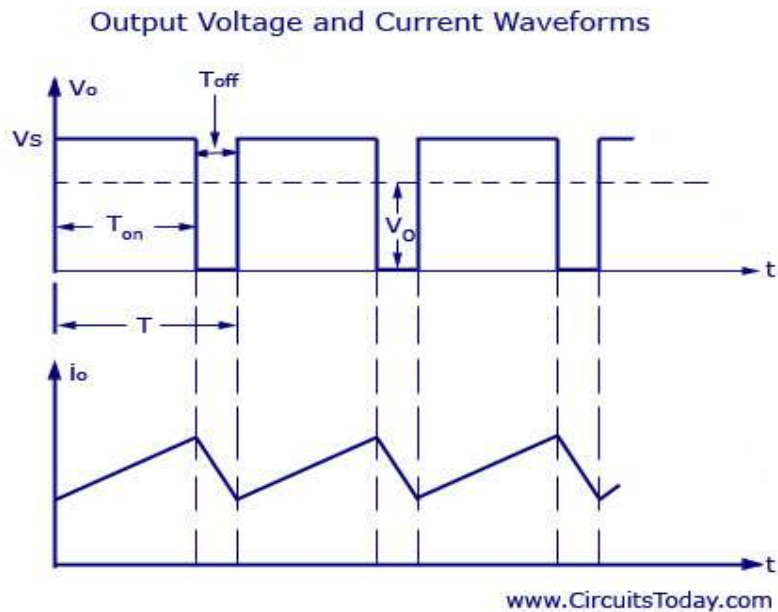
Principle of Operation

The Principle of operation of chopper can be understood from the circuit diagram below.



The circuit consists of a Freewheeling, Switch and a Inductive load. For all type of chopper circuit, the output voltage value is controlled by periodic closing and opening of the switches used in the circuit.

The chopper can be viewed as an ON / OFF Switch that can rapidly connect or disconnect the source to the load. DC Source (V_s) give continuous power supply to the chopper and chopped DC is obtained across the load as V_o .

Output Voltage and Current Waveforms

Above are the output voltage and current waveforms of a Chopper Circuit. During the time period T_{on} the Chopper is turned ON and the load voltage (V_o) is equal to source voltage (V_s) and During the interval T_{off} the Chopper is OFF load voltage is Zero. Thus, a chopped DC voltage is produced at the load terminals. The load current will be flowing continuously through the Freewheeling Diode FD. During the time period T_{on} , load current rises but during T_{off} load current decays.

Average load Voltage is given by

$$V_o = \frac{T_{on} \times V_s}{T_{on} + T_{off}} = \frac{T_{on} \times V_s}{T} = A \times V_s$$

Where:

T_{on} : On-Time Period

T_{off} : Off Time Period

$T = T_{on} + T_{off}$ = Chopping Period

$A = T_{on} / T$ = duty cycle

So we know that the load voltage can be controlled by varying the duty cycle A . The load voltage is independent of load current

Classification of Choppers:

1. Based on their operation principle and type of source voltage, chopper are classified into categories
 - i. DC chopper
 - ii. AC Link chopper.
2. Based on the commutation process, the choppers are classified into two categories:
 - i. Natural commutated chopper
 - ii. Forced commutated chopper
3. Based on the output value of the chopper, these are classified into Two Categories:
 - i. Step-Up Chopper
 - ii. Step-Down Chopper
4. Based on the quadrant of operation, choppers are categorized as Type A, B, C, D, E.
5. Based on the power loss occurred at switching time, The choppers are classified into Two Categories:
 - i. Hard switched Chopper
 - ii. Soft switched Chopper

1. **Based on their operation principle and type of source voltage**

- i. **DC Chopper :-** A DC chopper is a static device that converts fixed dc input voltage to a variable dc output voltage directly.

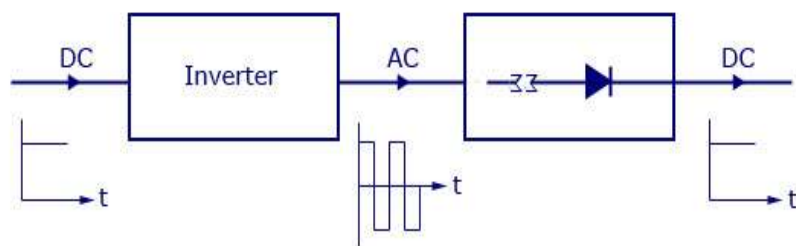
This type of choppers are more efficient as they involve one stage conversion. The chopper can be used to step up or step down the fixed dc output voltage and are used in many applications for various electronic equipments. D. C. chopper system has a high efficiency, fast response and a smooth control.

DC Chopper

Inverters, Choppers, Dual-Converters and Cyclo-Converters

- ii. **AC Link Chopper:** In the case of an ac link chopper, first dc is converted to ac with the help of an inverter. After that, AC is stepped-up or stepped-down by a transformer, which is then converted back to dc by a diode rectifier. Ac link chopper is costly, bulky and less efficient as the conversion is done in two stages.

AC Link Chopper



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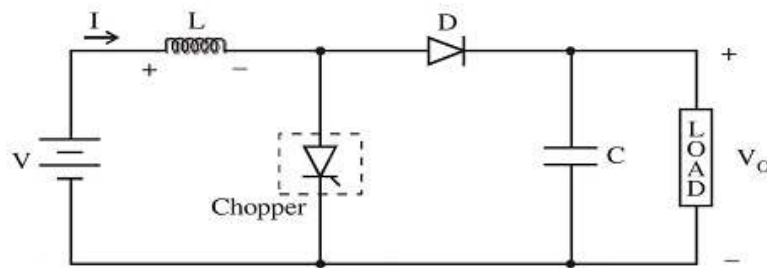
2. **Based on the commutation process:**

- i. **Natural Commutated Chopper:** The Choppers which are commutated naturally are called Natural Commutated Chopper. A. C. based Choppers are naturally commutated Chopper.
- ii. **Forced Commutated Chopper :** The Choppers which are commutated forcefully are called Forced Commutated Choppers. The D. C. Choppers are Forced Commutated Choppers.

3. **Based on the output value of the chopper:**

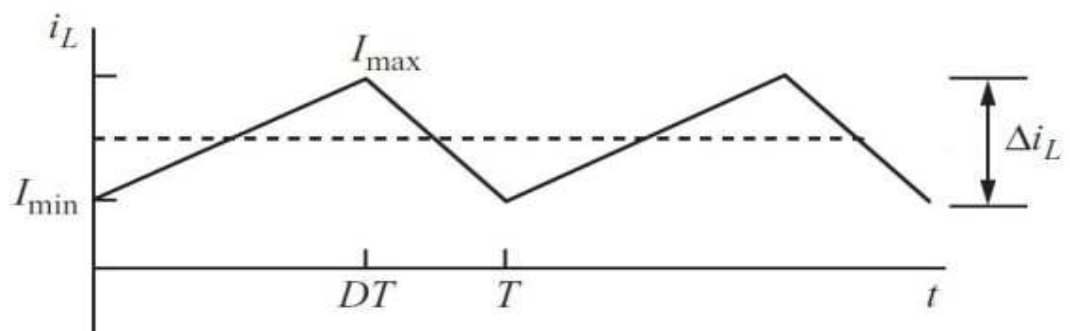
- i. **Step-Up Chopper:** Step-Up Choppers are those Choppers which gives Output Voltage is greater than input voltage. The increase in output voltage depends on the frequency of switching. While switch is OFF the output voltage almost same as input. While switch is ON, it is assumed as short and hence current flow in a shortest path. So inductor gets energized, and in continues flow we get output voltage greater than input.

Step-Up choppers are used, when the output DC voltage is required higher than the input voltage.



The working of a STEP-UP Chopper can be explained from the above diagram. In the circuit, a large inductor L is connected in series to the supply voltage. Capacitor maintains the continuous output voltage to the load. The diode prevents the flow of current from load to source.

When the Chopper is ON, supply voltage V_s is applied to the load .i.e. $V_0 = V_s$ and inductor starts storing energy. At this condition load current raises from I_{min} to I_{max} .



When the Chopper is switched OFF, the supply voltage takes the path from $+V_s - L - D - \text{Load} - -V_s$. During this period the inductor discharges the stored EMF (Voltage) through diode D to the load. Thus the total voltage at the load $V_0 = V_s + L \frac{di}{dt}$ which is greater than the input voltage. Current changes from I_{max} to I_{min} .

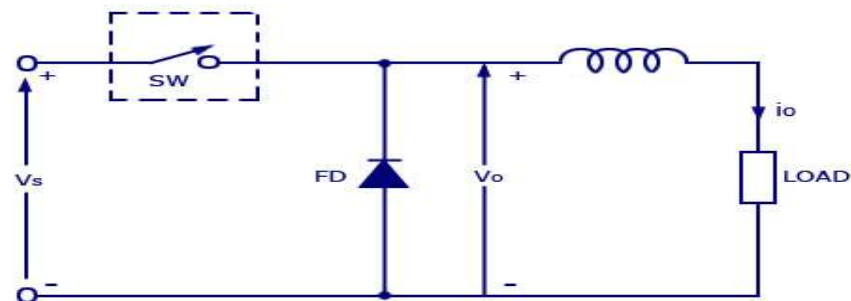
Step-up chopper is also known as Boost choppers.

Applications of the step up choppers include battery charging and as a voltage booster.

- ii. **Step-Down Chopper:** Step-Down Choppers are those Choppers which gives Output Voltage is less than input voltage.

Output (V_o) or the average output voltage of Step Down Choppers is always less than the input voltage V_s .

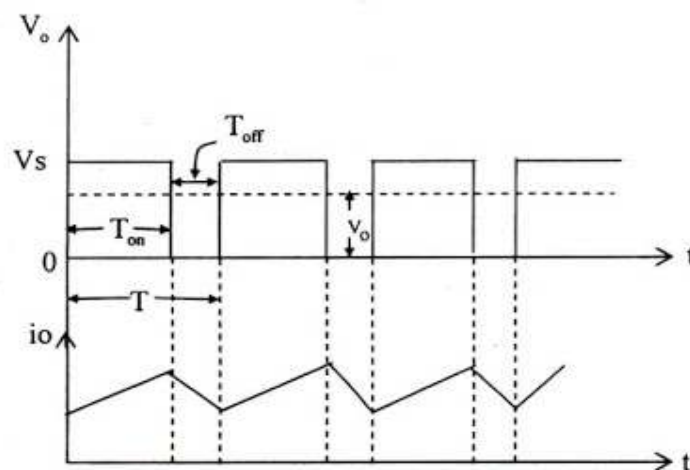
Chopper Circuit



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The circuit consists of a Freewheeling diode, Switch and a Inductive load. For all type of chopper circuit, the output voltage value is controlled by periodic closing and opening of the switches used in the circuit.

The chopper can be viewed as an ON / OFF Switch that can rapidly connect or disconnect the source to the load. DC Source (V_s) give continuous power supply to the chopper and chopped DC is obtained across the load as V_o .



Step Down Chopper waveform

Inverters, Choppers, Dual-Converters and Cyclo-Converters

During the period T_{on} , chopper is on and load voltage V_O is equal to source voltage V_S . During the interval T_{off} , chopper is off, load current flows through the freewheeling diode FD. As a result, load terminals are short circuited by FD and load voltage is therefore zero during T_{off} .

During turn on T_{on} , load current rises where as during turn off T_{off} load current decays.

Average load Voltage is given by

$$V_0 = \frac{T_{on} \times V_S}{T_{on} + T_{off}} = \frac{T_{on} \times V_S}{T} = A \times V_S$$

Where:

T_{on} : On-Time Period

T_{off} : Off Time Period

$T = T_{on} + T_{off} = \text{Chopping Period}$

$A = T_{on} / T = \text{duty cycle}$

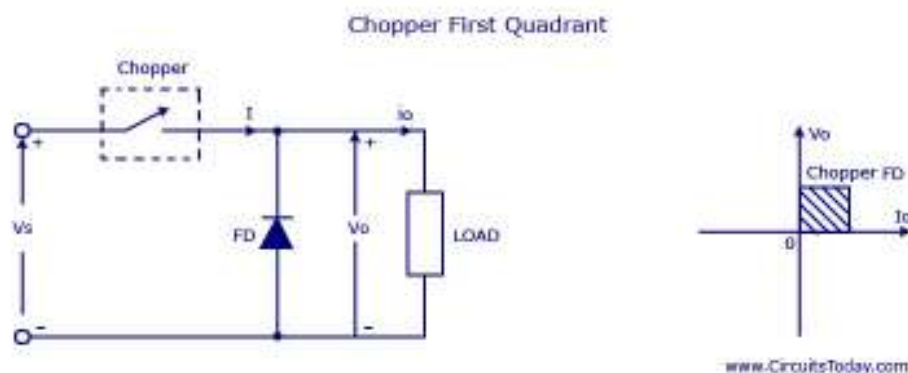
So we know that the load voltage can be controlled by varying the duty cycle A .

1. **Based on the quadrant of operation**

Based on the positioning of this semiconductor, choppers can be made to work in any of the four quadrant conditions. Depending on the quadrant of operation choppers are categorized as Type A, B, C, D, and E.

- i. **Type-A chopper: or First-Quadrant Chopper** : The Choppers that work in the first quadrant are called Type-A Chopper.

In this chopper, the voltage and current both are Positive and flows in the same direction. Power flow from source to load and the average output voltage is less than input DC voltage. This chopper is also known as a step-Down chopper.

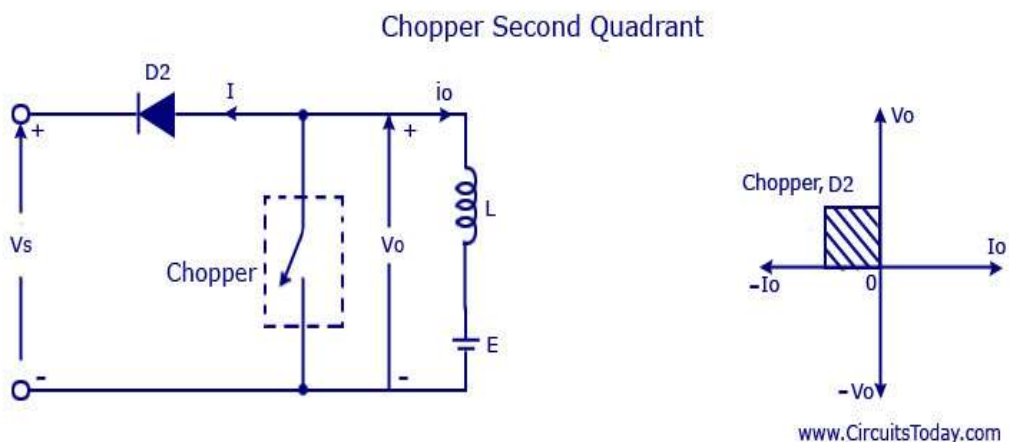


Inverters, Choppers, Dual-Converters and Cyclo-Converters

When the chopper is ON, $V_0 = V_s$, and the current flows in the direction of the load. But, when the chopper is OFF, V_0 is zero but I_0 continues to flow in the same direction through the Freewheeling Diode FD, thus average value of voltage and current say V_0 and I_0 will be always positive as shown in the graph.

- ii. **Type B Chopper or Second-Quadrant Chopper:** The Choppers that work in the second quadrant are called Type-B Chopper.

In this chopper, the load voltage is Positive and load current is Negative. Power flow from Load to Source and the average output voltage is greater than input DC voltage. This chopper is also known as a step-up chopper.



In Type-B or second quadrant chopper the load must always contain a dc source E .

When the chopper is ON, V_0 is zero but the load voltage E drives the current through the inductor L and the chopper, L stores the energy during the time T_{on} of the Chopper.

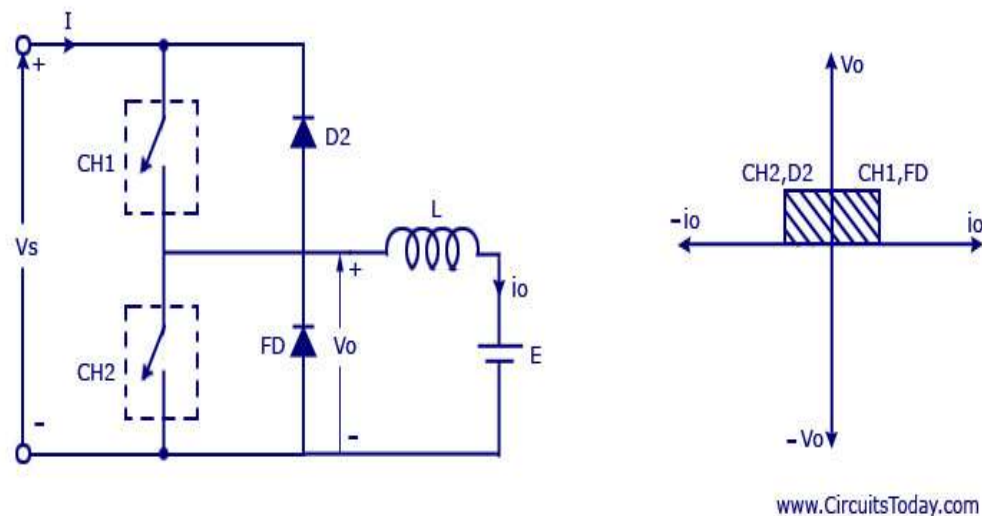
When the chopper is OFF, $V_0 = (E + L di/dt)$ will be more than the source voltage V_s . Because of this the diode D_2 will be forward biased and begins conducting and hence the power starts flowing to the Source. No matter the chopper is ON or OFF the current I_0 will be flowing out of the load and is treated negative.

Since V_0 is Positive and the current I_0 is Negative, the direction of power flow will be from load to source. The load voltage $V_0 = (E + L \cdot di/dt)$ will be more than the voltage V_s so the type B chopper is also known as a step up chopper.

Type -C chopper or Two-quadrant type-A Chopper: The Choppers that work in the First & second quadrant are called Type-C Chopper and formed by parallel connection of Type A and Type B choppers. Type-C chopper operates in two quadrants (Quadrant 1 and Quadrant 2).

The circuit diagram of the type C chopper is shown in the below figure:

Chopper Two Quadrant



Output voltage V_o will always be Positive in both Quadrant (1 & 2), as the Freewheeling diode FD is present across the load. When any chopper (CH_1 or CH_2) is ON, the Freewheeling Diode starts conducting and the output voltage V_o will be equal to V_s .

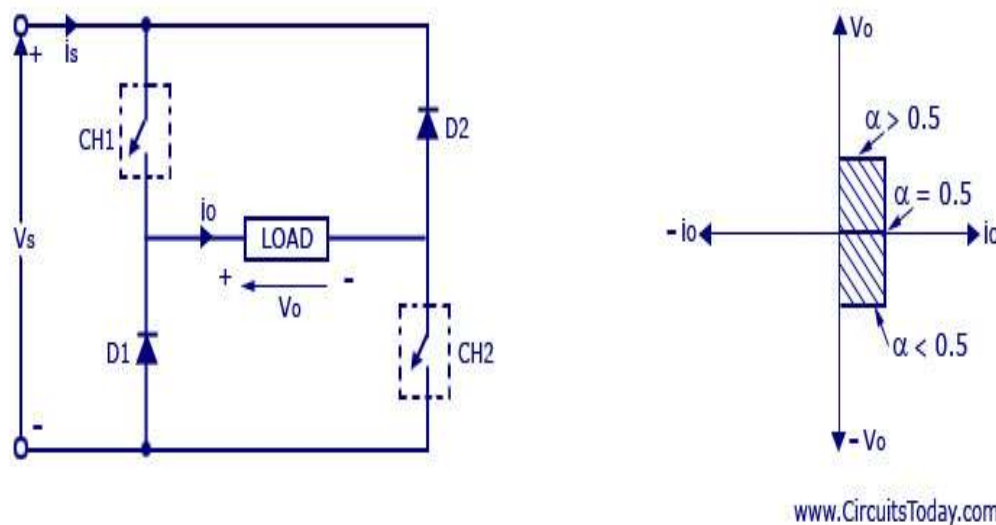
The load current will be Positive and flow from Source to Load, when the chopper CH_1 is on and the Freewheeling Diode FD conducts. The load current will be Negative and flow from Load to Source, when the Chopper CH_2 is ON and the diode D_2 conducts.

We can say the chopper CH_1 and FD operate together as type-A chopper in first quadrant. In the second quadrant, the chopper CH_2 and D_2 will operate together as type -B chopper.

- iii. **Type D Chopper or Two-Quadrant Type –B Chopper:** The Choppers that work in the First & Fourth quadrants are called Type-D Chopper. Type D chopper is also called Two Quadrant Type-B chopper.

Type-D Type chopper operates in two quadrants (Quadrant 1 and Quadrant 4). The circuit diagram of the type D chopper is shown in the below figure:

Two Quadrant Type B-chopper or D-chopper Circuit



Two Quadrant Type B chopper or D Chopper Circuit

Output current will always positive, as the diodes and choppers conduct current only in one direction.

When the both choppers (CH_1 & CH_2) are ON and both diodes (D_1 & D_2) are OFF, the output voltage V_o will be equal to $+V_s$. When both V_o and I_o are positive, the circuit operate in First quadrant and in rectifying. The energy is fed from source to load

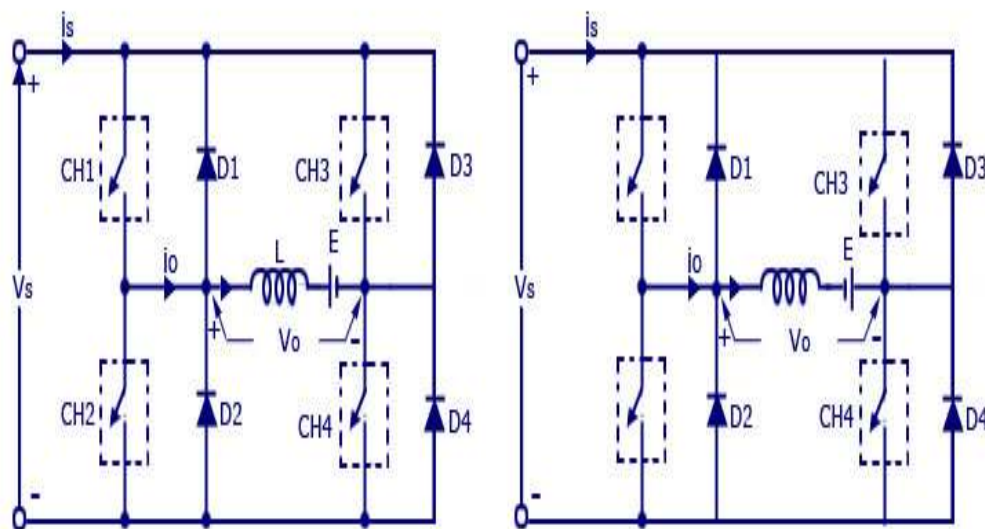
When the both choppers (CH_1 & CH_2) are OFF and both diodes (D_1 & D_2) are ON, the output voltage $V_o = -V_s$. When V_o is Negative & I_o is Positive, the circuit operate in Fourth Quadrant and in Inverting Mode. The Energy is fed from Load to Source.

The average output voltage V_o will be positive when the choppers turn-on Time (T_{on}) is more than the turn off time T_{off} as shown in the wave form below.

- iv. **Type E chopper :** The Choppers that work in the First, Second, Third & Fourth quadrants are called Type-E Chopper. It is a four quadrant chopper (i.e. it operates in all 4 quadrants). The load current and load voltage can be both positive and negative.

Type E consists of four Chopper switches CH_1 , CH_2 , CH_3 , & CH_4 and four diodes D_1 , D_2 , D_3 , & D_4 arranged in anti-parallel. 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.

E-type Chopper Circuit Diagram With Load emf E and E Reversed



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First Quadrant Operation:

During the first quadrant operation, CH_1 will be operational, the chopper CH_4 will be ON. Chopper CH_2 & CH_3 will be OFF.

As the CH_1 and CH_4 is ON, the load voltage V_o will be equal to the source voltage $+V_s$ and the load current I_o will begin to flow from source to load. Both V_o and I_o will be positive as the first quadrant operation. As soon as the chopper CH_1 is turned off, the positive current freewheels through CH_4 and the diode D_2 . The type E chopper acts as a step-down chopper in the first quadrant.

Second Quadrant Operation:

During Second Quadrant operation, the chopper CH_2 will be operational and the other three Choppers (CH_1 , CH_2 , & CH_3) are kept OFF.

As CH_2 is ON, Negative current will starts flowing through the inductor L . CH_2 , D_4 & E . and Energy is stored in the inductor L . When CH_2 is OFF the current will be fed back to the source through the diodes D_1 and D_4 . Here output voltage $V_O = (E + L \cdot di / dt)$ will be more than the source voltage V_s . In second quadrant the chopper will act as a step-up chopper as the power is fed back from load to source

Third Quadrant Operation:

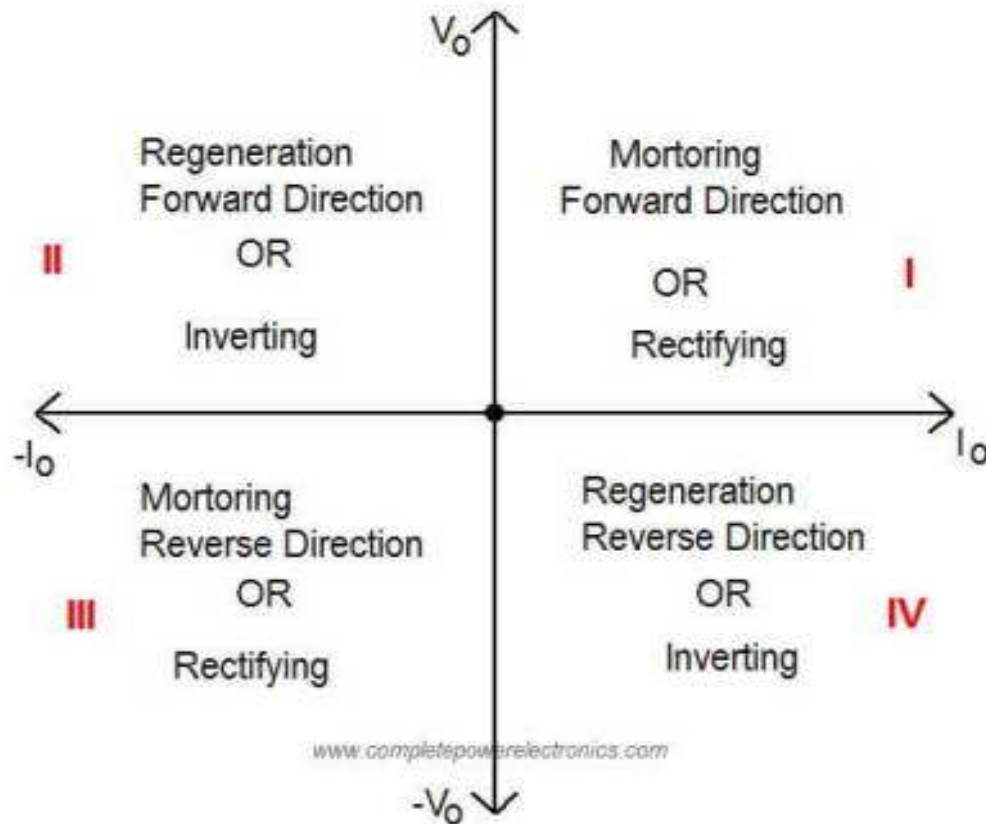
In third quadrant operation, CH_2 will be ON & CH_3 will be in operational and other both Choppers (CH_1 & CH_4) kept OFF. In this quadrant working the polarity of the load should be reversed. As the chopper CH_3 is ON, the load gets connected to the source V_s and V_O and I_O will be negative and the third quadrant operation will takes place. This chopper acts as a step-down chopper

Fourth Quadrant Operation:

CH_4 will be operational and CH_1 , CH_2 and CH_3 kept OFF. When CH_4 is ON, E and the inductor L will store energy. As when, the CH_4 is turned OFF, the current is feedback to the source through the diodes D_2 and D_3 , 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.

Remember the following points:

- i. Positive Load Current = Current flows from source to load
- ii. Negative Load Current = Current flows from load to source
- iii. When the chopper operates in the first and third quadrants, the motor receives energy and the motor operates in the driver mode.
- iv. When the motor operation is in second and fourth quadrant power is fed back to the supply and the motor operates in braking mode



2. **Based on the power loss occurred at switching time.**

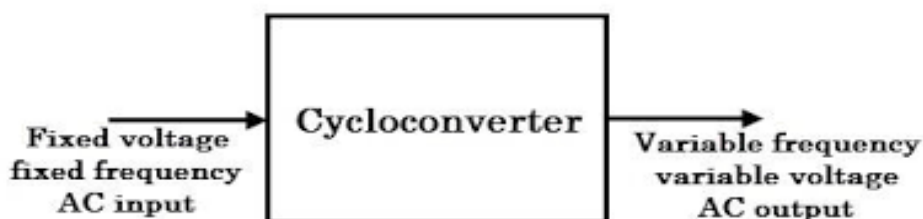
- i. **Hard switched Chopper:** Hard Switched Choppers are those Choppers in which the power loss is high during the switching (ON to OFF and OFF to ON).
- ii. **Soft switched Chopper:** Soft Switched Choppers are those Choppers in which the power loss is low during the switching (ON to OFF and OFF to ON).

Applications of Chopper

- i. Choppers are used in Switched Mode Power Supply (SMPS) System.
- ii. Choppers are used in DC motors as speed controllers.
- iii. These are used in DC voltage boosters.
- iv. These are used in Battery chargers.
- v. These are used in Railway systems.
- vi. These are used in Electric cars
- vii. Choppers are used in signal processing systems.

CYCLOCONVERTERS

CYCLOCONVERTER: A Cyclo-converter is a device (frequency changer) that convert AC Power from one (Fixed) frequency to AC Power at another frequency (Variable).



This process that convert the AC Power from one frequency to AC Power at another frequency is known as Cyclo-conversion (AC-AC conversion).

Besides the Frequency Control, Cyclo-converter output voltage can be varied / controlled by applying phase control technique.

Types of Cyclo-converters:

Based on the output frequency: The Cyclo-converters can be classified as below:

- i. Step-Up Cyclo-converters
- ii. Ste-Down Cyclo-converters
- i. **Step-Up Cycloconverters:** Step-up Cyclo-converters are those Cyclo- converters that provide output signal having frequency greater than that of input frequency.

But it is not widely used since it not have much particle application. Most application will require a frequency less than 50Hz. Also Step-Up Cyclo-Converter will require forced commutation which increases the complexity of the circuit.

- ii. **Step-Down Cyclo-converters:** Step-Down Cyclo-converters are those Cyclo-converters that provide output signal having frequency which lesser then the input frequency.

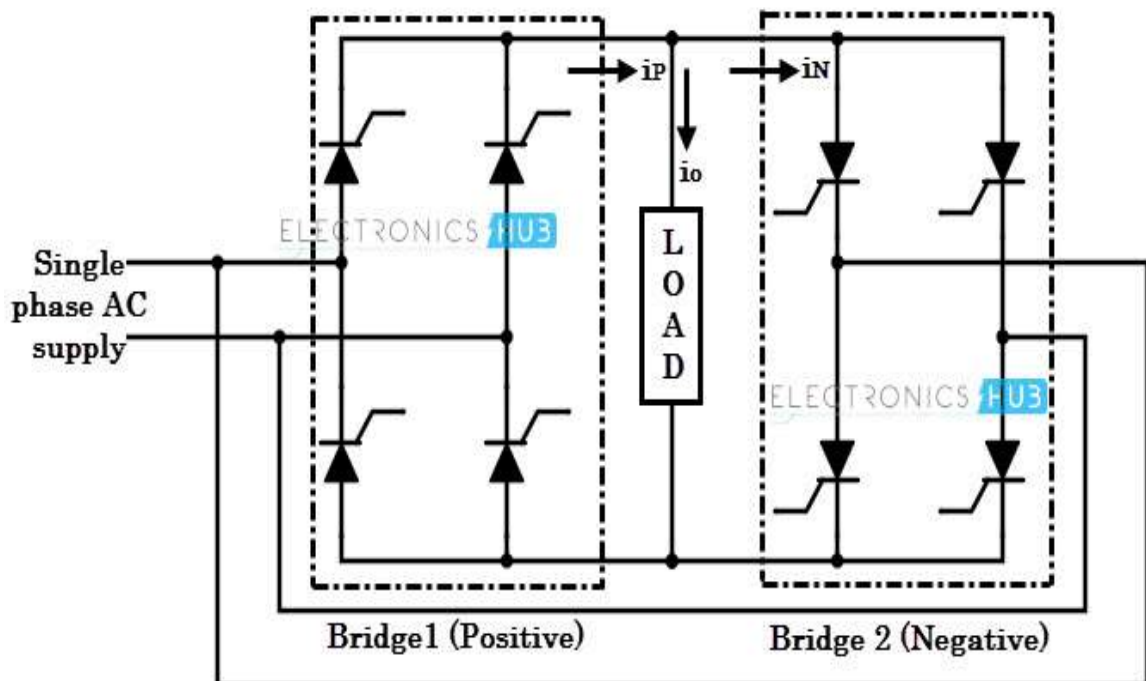
These are most commonly used and work with help of Natural Commutation hence comparatively easy to build and operate.

The Step-Down is further classified into three types :

- a) Single-Phase to Single-Phase Cyclo-converter
- b) Three-Phase to Single-Phase Cyclo-converter
- c) Three-Phase to Three-Phase Cyclo-converter

a) **Single Phase to Single Phase Cyclo-converters:**

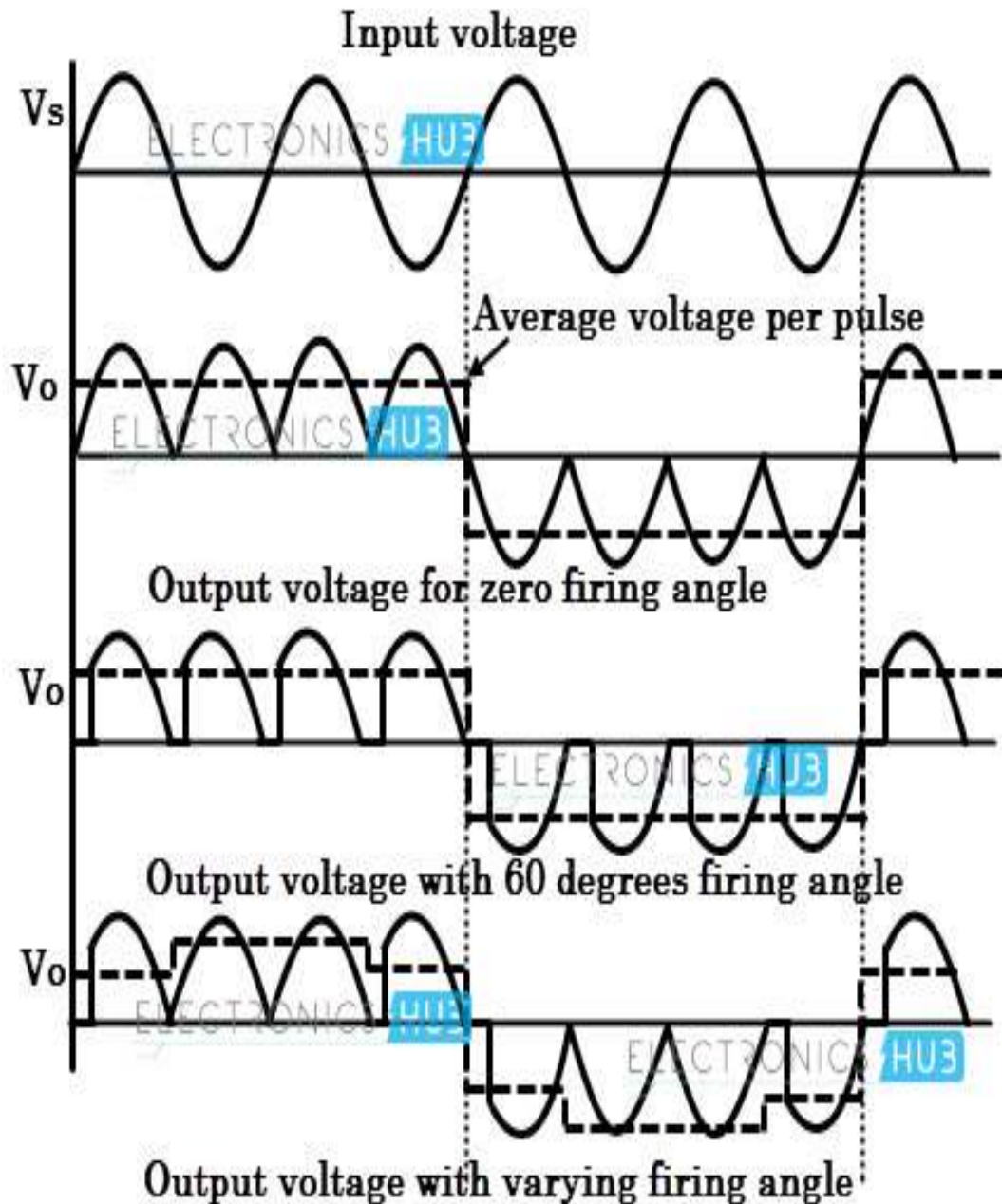
It consists of Two Full-Wave, Fully Controlled Bridge thyristors, where each Bridge has 4 thyristors, and each bridge is connected in opposite direction (back to back) such that both Positive and Negative Voltages can be obtained as shown in figure below. Both these bridges are excited by single phase, 50 Hz AC supply.



During Positive half cycle of the input voltage, Positive converter (Bridge-1) is turned ON and it supplies the load current. During Negative half cycle of the input, Negative converter (Bridge-2) is turned ON and it supplies load current.

Both converters should not conduct together that cause short circuit at the input. To avoid short circuit, triggering to thyristors of bridge-2 is prevented / intercepted during positive half cycle of load current, while triggering is applied to the thyristors of bridge-1 at their gates. During negative half cycle of load current, triggering to positive bridge is prevented / intercepted, while applying triggering to negative bridge.

By controlling the switching period of thyristors, time periods of both positive and negative half cycles are changed and hence the frequency. This frequency of output voltage can be easily reduced in steps, i.e., $1/2$, $1/3$, $1/4$ and so on.



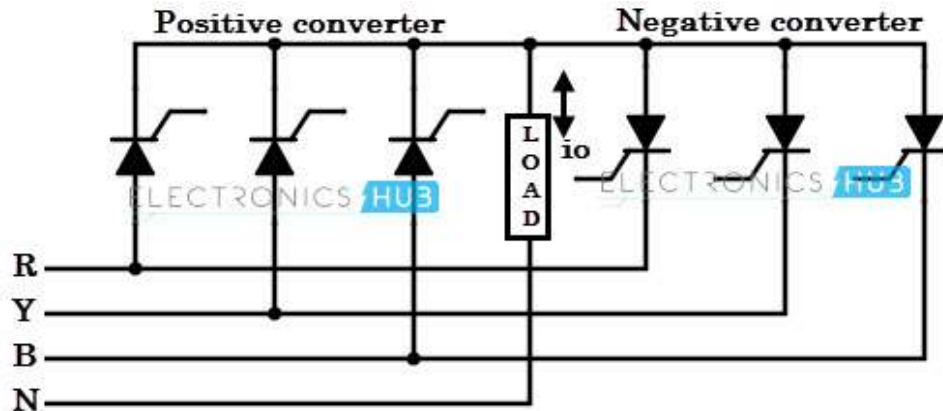
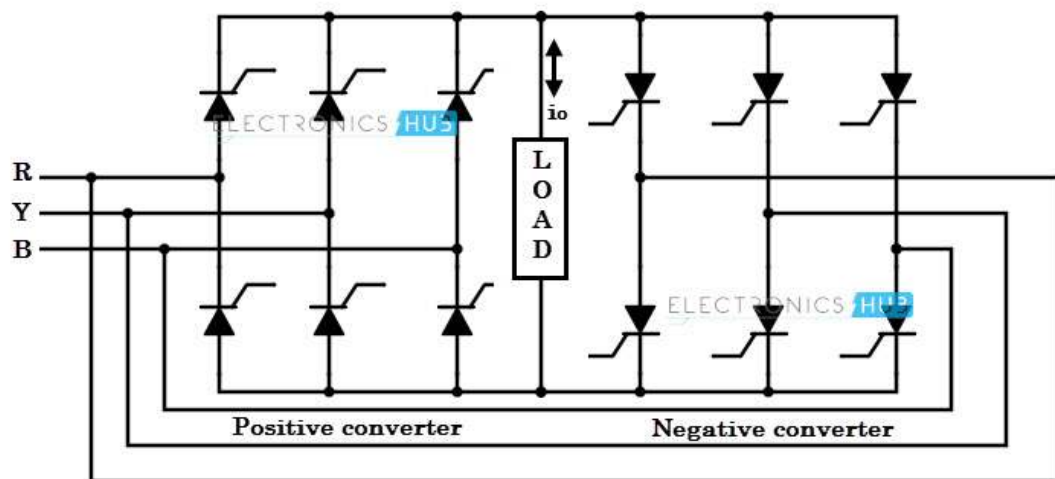
The above figure shows output waveforms of a cyclo-converter that produces one-fourth of the input frequency. Here, for the first two cycles, the positive converter operates and supplies current to the load.

It rectifies the input voltage and produce unidirectional output voltage as we can observe four positive half cycles in the figure. And during next two cycles, the Negative converter operates and supplies load current.

Here one converter is disabled if another one operates, so there is no circulating current between two converters.

b) **Three Phase to Single Phase Cyclo-Converters:**

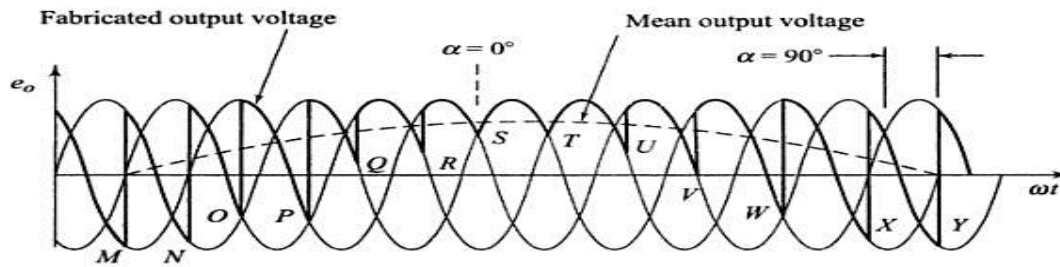
A Three-Phase to Single Phase Cyclo-Converter consists of Positive and Negative Group thyristors. These cyclo-converters can be Half-Wave or Full Wave Bridge converters as shown in figure. Like Single Phase Cyclo-converters, these also produce a rectified voltage at the load terminals by each group of thyristors.

**Half-Wave Cyclo-Converters****Full Wave Bridge Cyclo-converters**

During Positive Half Cycle of the Input, conduction of the Positive Group thyristors is controlled and during Negative Half-Cycle, conduction of Negative group of thyristors is controlled in order to produce an output voltage at desired frequency.

In a Bridge type of Cyclo-converter, both Positive and Negative converters can generate voltages at either polarity, but negative converter only supplies negative current while positive converter supply positive current.

Therefore, the Cyclo-converter can operate in four quadrants, i.e., rectification modes of (+V, +i) and (-V, -i) and inversion modes of (+V, -i) and (-V, +i).



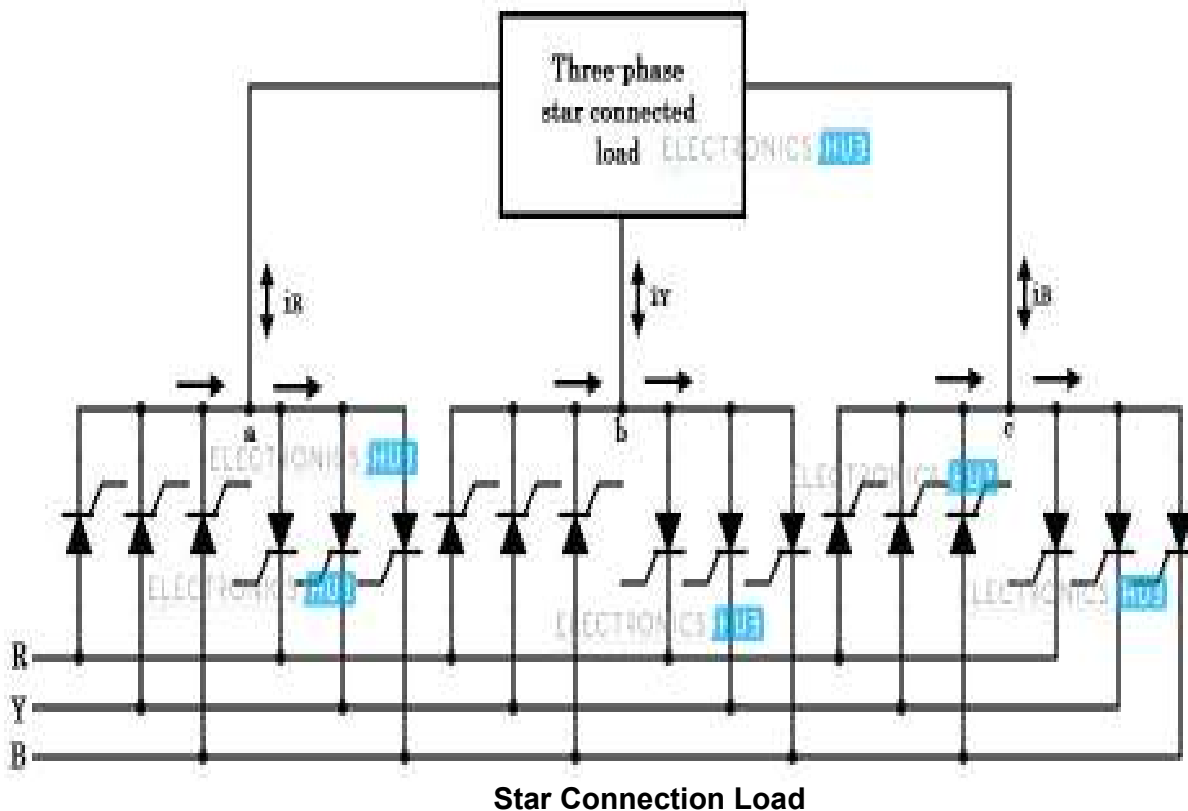
The above figure shows the conversion of three phase supply at one frequency to single phase supply of lower frequency. In this, the firing angle to a positive group of thyristors is varied progressively to produce single phase output voltage.

At point M, the firing angle is 90 degrees and it is reduced till point S where it is zero. Again from point T to Y, the delay angle is progressively increased. This varied triggering signals to the thyristors, varies its conduction time periods and hence the frequency of the output voltage.

C) Three-phase to Three-phase Cyclo-converters:

These are obtained by connecting 3 Three-Phase to Single-Phase Cyclo-Converters to the Load. These converters can be connected in star or delta.

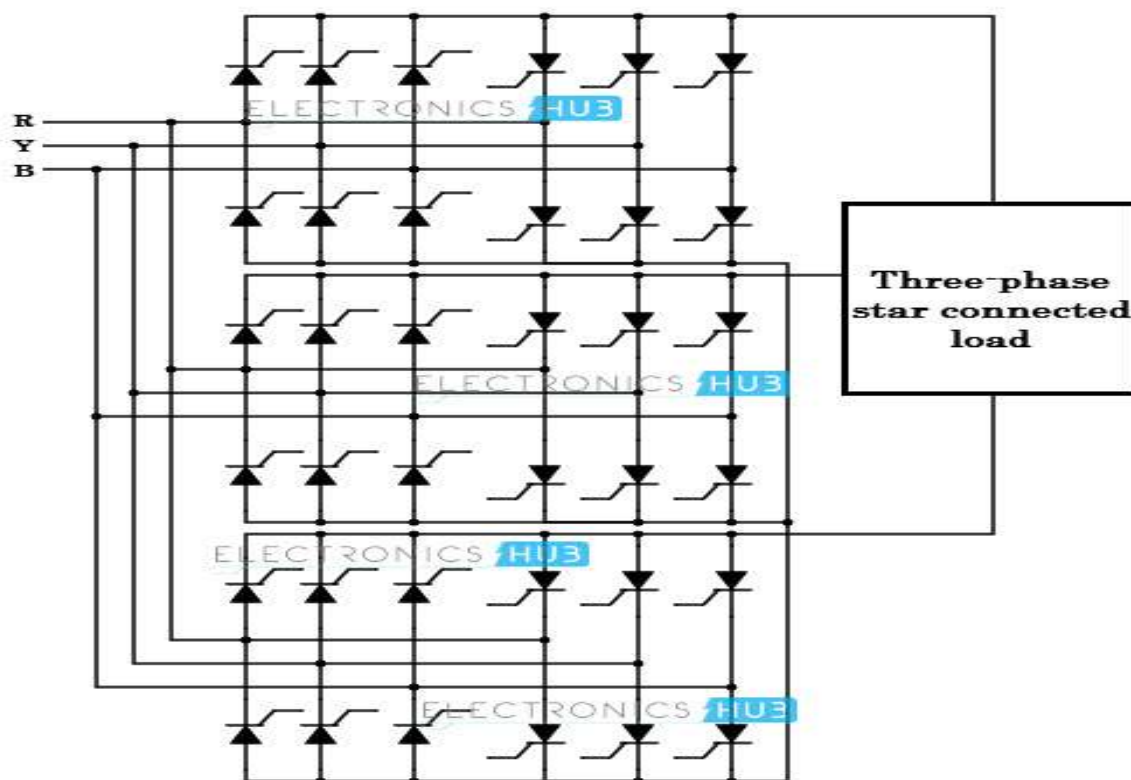
Three Phase Cyclo-converter of both Star Connection Load and Delta Connection Load types are shown in figures below.



Inverters, Choppers, Dual-Converters and Cyclo-Converters

Three-phase to three-phase cyclo-converter is also called as 18-thyristor cyclo-converter or 3-pulse cyclo-converter and three-phase to three-phase bridge type cyclo-converter is called as 6-pulse cyclo-converter or 36-thyristor cyclo-converter.

This converter consists of six groups of converter circuits where three groups are called as positive group while other three are negative group. During each positive half cycle, positive group carries the current and during negative half cycle, negative group carries the current. The duration for conduction of each group of thyristor determines the desired output frequency.



Delta Connection Load

Here average value of output voltage is varied by varying the firing or delay angle of SCRs conduction whereas the output frequency can be varied by changing the sequence of firing the SCRs. The Neutral connection is no longer necessary with a balanced load and hence this connection can be omitted.

Three-phase cyclo converters are more popular than single-phase type as these can handle very large currents and produce smooth output waveform. It is a highly efficient variable frequency drive, because the pulse number is increased due to the large number of thyristors, which causes small ripple content in the output voltage waveform.

Advantages of Cyclo-Converter :

- i. Cyclo-converters are very high efficient as compared to other converters.
- ii. Cyclo-converters can operate in Four, So these are capable to power transfer in both the directions.
- iii. AC power at one frequency is directly converted to a lower frequency in a single conversion
- iv. In Cyclo-converter, Power transfer is possible from supply load and vice versa at any power factor.
- v. Dynamic Response of Cyclo-Converter is good
- vi. Working operation of Cyclo-Converter is Smooth.

Disadvantages of Cyclo-Converter :

- i. Control circuit of Cyclo-Converter becomes complex because there are large numbers of SCRs .
- ii. Power factor is too much poor at large values of Firing Angle (α).
- iii. Cyclo-Converter output will be more distorted at low frequencies.

Applications of Cyclo-converters

Cyclo-converters are mainly used for producing low frequency AC voltage. The main application of such requirement is the electric traction system where low frequencies, typically 25 Hz or 16 2/3 Hz are preferred.

In such systems, three-phase squirrel cage induction motor is controlled by a suitable cyclo-converter circuit. Other applications of Cyclo-converter include

- i. Cyclo-Converters are used in HVDC transmission systems.
- ii. Cyclo-Converters are used in Aircraft or shipboard power supplies.
- iii. Cyclo-Converters are used in Speed control of high power AC drives.
- iv. Cyclo-Converters are used in Grinding and Rolling mills.
- v. Cyclo-Converters are used in Cement mill drives.
- vi. Cyclo-Converters are used in Mine winders.
- vii. Cyclo-Converters are used in Industries.
- viii. Cyclo-Converters are used in Water Pumps.
- ix. Cyclo-Converters are used in Washing Machines.

DUAL-CONVERTERS

DUAL-CONVERTER: Dual converter is a power electronics control system / Device, which have two **conversion processes simultaneously**.

If Both Converters in Rectification mode, It converts A. C. Signal in D. C. Signal by First Converter in one direction (Forward) and then other Converter converts also AC Signal in to DC Signal in reverse direction. Here two conversion processes take place simultaneously, so it is called as a dual converter It can run a DC motors in either direction with speed control too.

If one of the converter works as a rectifier (converts AC to DC), another converter works as an inverter (converts DC to AC) and connected commonly to a DC load. Here two conversion processes also take place simultaneously, so it is also called as a dual converter.

Modes of Operation of Dual Converter: There are two functional modes of Operations of Dual Converter:

- i. Non-Circulating Current Mode
- ii. Circulating Current Mode.

i. **Non-Circulating Current Mode Dual-Converter:** In Non-Circulating current mode, one converter will work / perform at a time and there is no circulating current between the converters.

During Converter-1 Operation:

Firing angle (α_1) will be $0 < \alpha_1 < 90^\circ$ (V_{dc} and I_{dc} are positive)

During Converter-2 Operation:

Firing angle (α_2) will be $0 < \alpha_2 < 90^\circ$ (V_{dc} and I_{dc} are negative)

In this type of Dual Converter, only one Converter is in conduction and another Converter is temporarily Blocked. So, at a time one Converter operates and the **Reactor is not required between the converters**. At a particular instant, let say Converter-1 acts as a Rectifier and supplying the Load current. At this instant, Converter-2 is blocked by removing the Firing Angle.

For Inversion operation, Converter-1 is Blocked and Converter-2 is supplying the Load current.

The pulses to the converter-2 are applied after a delay time. The delay time is around **10 to 20 msec**. It ensures reliable operation of thyristors. If converter-2 trigger before the converter-1 has completely turned off, a large amount of

Inverters, Choppers, Dual-Converters and Cyclo-Converters circulating current will flow between converters which can be controlled by very sophisticated control system and the load current is not continuous.

Here, at a time only one Converter is in conduction. Therefore, it is possible to use only one firing angle unit.

Advantages of Non-Circulating Current Mode Dual Converter:

1. In Non-Circulating Current Mode Dual Converter, the Size and Cost of Reactor is Low.
2. The Power Factor and Efficiency of Non-Circulating Current Mode Dual Converter are High.
3. In Non-Circulating Current Mode Dual Converter, the Thyristors are of low Current Ratings.

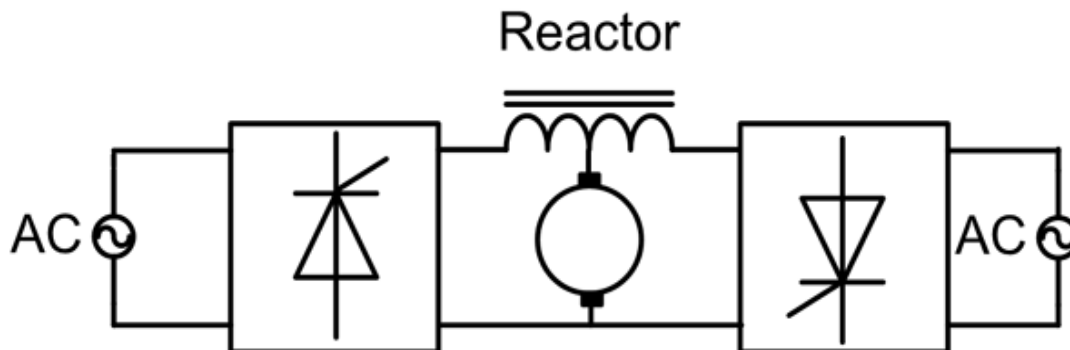
Disadvantages of Non-Circulating Current Mode Dual Converter:

1. Operation of Both Convertors stopped at the time of Inversion.
2. Time Response is very slow. The delay time is around **10 to 20 msec.**
3. When One Converter conducted, the other one required blocked.

- ii. **Circulating Current Mode Dual-Converter:** In Circulating current mode, both converters will be in the ON condition at the same time. So circulating current is present.

A Dual Converter can operate with the Circulating Current Mode by connecting Current Limiting Reactor between the DC terminals of both Converters. The firing angle of both Converters is set in such a way that the minimum amount of Circulating Current flow through the Reactor.

In Circulating Mode, the Firing Angles are adjusted such that $\alpha_1 + \alpha_2 = 180^\circ$. Firing angle of converter 1 is α_1 and firing angle of converter 2 is α_2 .



Let say the Firing Angle of Converter-1 is 60° then Firing Angle of Converter-2 must be maintained at 120° . In this operation, Converter-1 will operate as a Rectifier and Converter-2 will operate as an Inverter. Thus, in this type of operation, at a time both Converters are in Conducting State. If the Load current is reversed, the Converter which is operated as a Rectifier is now operating as an Inverter, while the Converter which is operated as an Inverter is now operating as a Rectifier. In this scheme, both Converters conduct at the same time. So, it requires two firing angle generator unit.

The Converter 1 works as a Controlled Rectifier when the firing angle is $0 < \alpha_1 < 90^\circ$ and Converter 2 works as an Inverter when the firing angle is $90^\circ < \alpha_2 < 180^\circ$. In this condition, V_{dc} and I_{dc} are Positive.

The Converter 1 works as an Inverter when firing angle be $90^\circ < \alpha_1 < 180^\circ$ and Converter 2 works as a Controlled Rectifier when the firing angle is $0 < \alpha_2 < 90^\circ$. In this condition, V_{dc} and I_{dc} are Negative.

Advantages of Circulating Current Mode Dual Convertor:

1. Operation of Both Convertors is smooth at the time of Inversion.
2. Time Response is very fast.

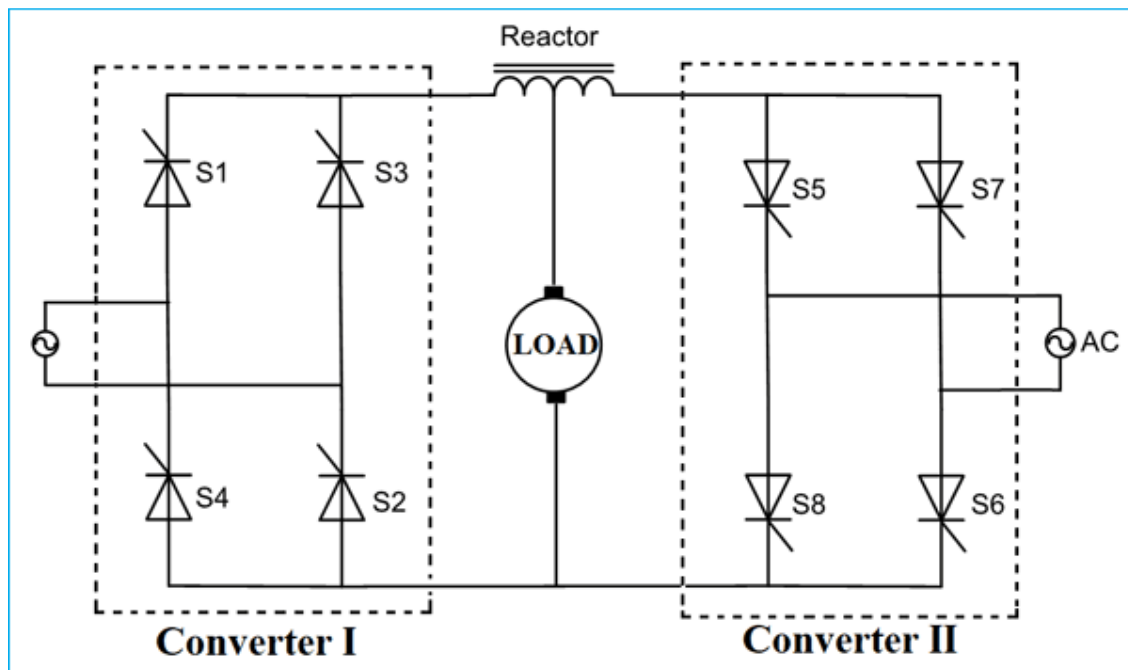
Disadvantages of Circulating Current Mode Dual Convertor:

1. In Circulating Current Mode Dual Convertor, the Size and Cost of Reactor is very High.
2. The Power Factor and Efficiency of Circulating Current Mode Dual Convertor are low Because of the circulating current,.
3. In Circulating Current Mode Dual Convertor, the Thyristors with High Current Ratings are required for handling the Circulating Current.

According to the type of load, single-phase and three-phase dual converters are used.

1. Single-Phase Dual Converter

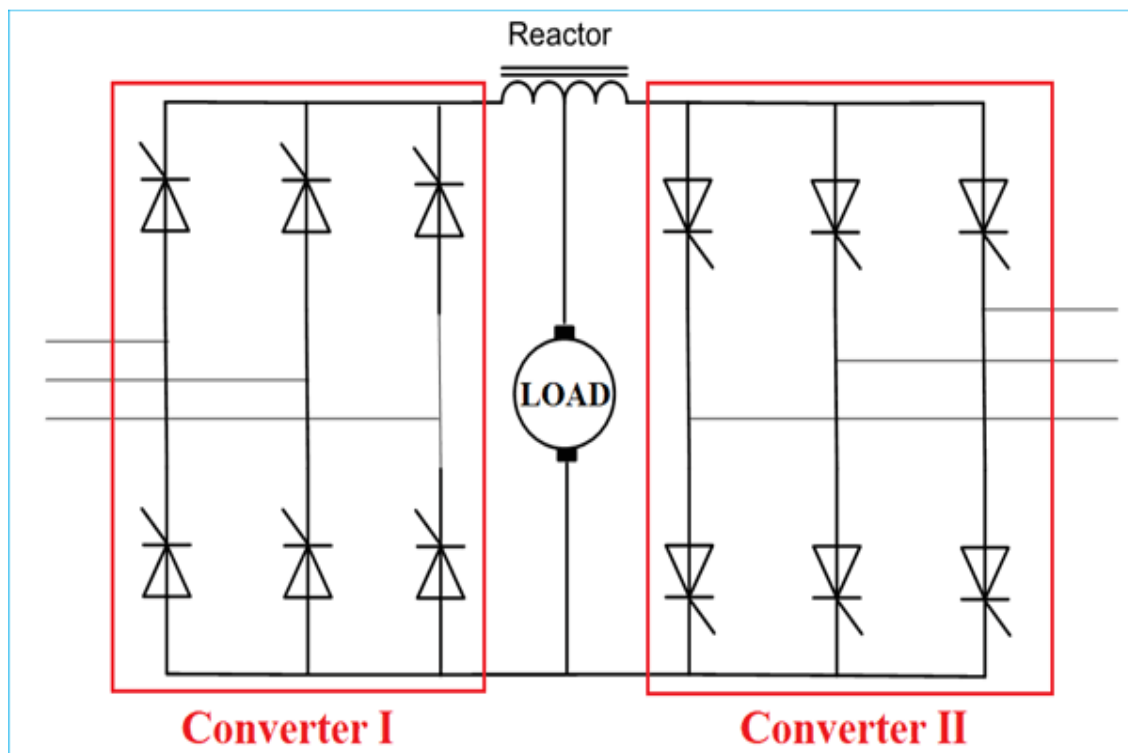
The Circuit Diagram of the dual converter is shown in the below figure. A separately excited DC Motor is used as a Load. The DC terminals of Both the Converters are connected with the terminals of the Armature Winding. Here, two Single-Phase Full Converters are connected back to back. Both Converters Supply a common Load.



1. **The Firing Angle of Converter - 1 is α_1 and α_1 is less than 90° .** Hence, the Converter-1 act as a Rectifier. For Positive Half Cycle ($0 < t < \pi$), SCRs S_1 and S_2 will conduct and for a Negative Half Cycle ($\pi < t < 2\pi$), SCRs S_3 and S_4 will conduct. In this operation, Output Voltage and Current both are Positive. **So, this operation is known as Forward Motoring Operation and the Converter works in the First quadrant.**
2. **The firing angle of converter-2 is $180 - \alpha_1 = \alpha_2$ and α_2 is greater than 90° .** So, Converter-2 act as an Inverter. In this operation, the Load Current remains in the same direction. The polarity of the Output Voltage is Negative. **Therefore, the Converter works in the Fourth quadrant. This operation is known as regenerative braking.**

3. **For reverse rotation of DC Motor, Converter-2 act as Rectifier and Converter-1 act as an Inverter.** The firing angle of Converter-2 α_2 is less than 90° . The alternative voltage source supplies the Load. In this operation, the Load Current is Negative and the Output Average Voltage is also Negative. **Therefore, the Converter-2 works in the Third quadrant. This operation is known as the Reverse Motoring.**
4. **In Reverse operation, the firing angle of Converter-1 is less than 90° and firing angle of Converter-2 is greater than 90° .** So, in this operation, the Load Current is Negative but the Average Output Voltage is Positive. **So, the Converter-2 works in the Second quadrant. This operation is known as the reverse regenerative braking.**
2. **Three-Phase Dual Converter**

The Circuit Diagram of the Three-Phase Dual Converter is as shown in the below figure. Here, Two Three-Phase Converters are connected back to back. The Principle of operation is the same as a Single-Phase Dual Converter.



1. **The Firing Angle of Converter - 1 is α_1 and α_1 is less than 90° .** Hence, the Converter-1 act as a Rectifier. For Positive Half Cycle ($0 < t < \pi$), SCRs S_1 and S_2 will conduct and for a Negative Half Cycle ($\pi < t < 2\pi$), SCRs S_3 and S_4 will conduct. In this operation, Output Voltage and Current both are Positive. **So, this operation is known as Forward Motoring Operation and the Converter works in the First quadrant.**

2. **The firing angle of converter-2 is $180 - \alpha_1 = \alpha_2$ and α_2 is greater than 90° .** So, Converter-2 act as an Inverter. In this operation, the Load Current remains in the same direction. The polarity of the Output Voltage is Negative. **Therefore, the Converter works in the Fourth quadrant. This operation is known as regenerative braking.**

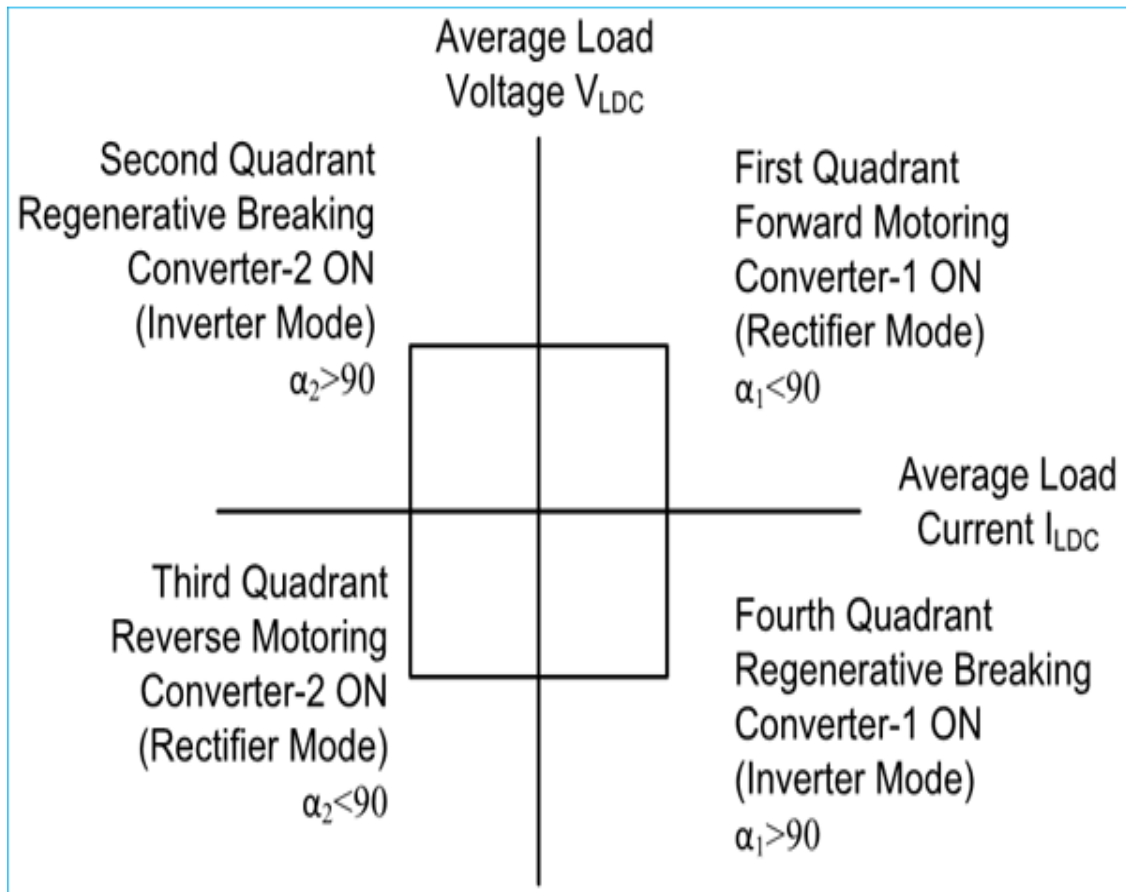
3. **For reverse rotation of DC Motor, Converter-2 act as Rectifier and Converter-1 act as an Inverter.** The firing angle of Converter-2 α_2 is less than 90° . The alternative voltage source supplies the Load. In this operation, the Load Current is Negative and the Output Average Voltage is also Negative. **Therefore, the Converter-2 works in the Third quadrant. This operation is known as the Reverse Motoring.**

4. **In Reverse operation, the firing angle of Converter-1 is less than 90° and firing angle of Converter-2 is greater than 90° .** So, in this operation, the Load Current is Negative but the Average Output Voltage is Positive. **So, the Converter-2 works in the Second quadrant. This operation is known as the reverse regenerative braking.**

Applications of Dual Converter:

- i. Dual Converters are used for Direction and Speed control of DC motors.
- ii. Dual Converters are used in the circuit where the reversible DC is required.
- iii. Industrial variable speed DC drives.

The Dual Converter can provide Four quadrant operations. The four quadrant operation is shown below.



Dual Converter Four Quadrant Operations

FILL IN THE BLANKS:

1. In a Dual Converter, Converter-1 and Converter-2 works as.....&
2. Duty Cycle of a Chopper is expressed by
3. A Chopper is a Switch.
4. A is a direct frequency changer.
5. A Converter can operate in four quadrants.
6. In Inverter, the commutating components L, C, & R are connected in series.
7. Series Inverters are also known as
8. Main advantage of bridge Inverter is that it does not use any at the output.
9. The output voltage waveform of ideal Inverter should be
10. The heart of Inverter is the
11. An Inverter Converts into
12. A converter having one positive converter and other the negative converter, together is called
13. A Chopper converts into
14. A Step-Up Chopper produces voltages at the load.
15. In Parallel Inverter, the Commutation Capacitor is effectively in with the Load.
16. The Series Inverters uses type of Commutation.
17. The output frequency of Cyclo-Converter should be of the input frequency.
18. The maximum frequency of Series Inverter is bounded to the

Answers:

- | | | |
|-----------------------------------|-------------------------|------------------------|
| 1) Inverter, Rectifier | 2) T_{ON} / T_{TOTAL} | 3) Thyristorised |
| 4) Cyclo-Converter | 5) Dual | 6) Series |
| 7) Fixed output | 8) Transformer | 9) Sinusoidal |
| 10) Switching Devices/ Thyristors | 11) DC , AC | 12) Dual-Converter |
| 13) DC, Variable DC | 14) Higher | 15) Parallel |
| 16) Class-A | 17) Sub Multiple | 18) Resonant Frequency |

FILL IN THE BLANKS:

19. One of the converter is called the Converter and the other the Converter and together they constitute a Dual-Converter.
20. The Device which converts DC into AC is called
21. The resonant Components in an Inverter are called as..... components.
22. A Class-D Chopper operates in Quadrants.
23. A is a device which converts AC signal into AC Signal of other frequency
24. A Cyclo-Converter consist of and.....Group of thyristors.
25. A Dual Converter consists of Two Fully Controlled Converters connected in
26. The output frequency of the Inverter depends upon Components.
27. is a device that converts DC into variable DC.
28. The output voltage of Chopper is lower than the Input Voltage.
29. Class / Type Chopper operate in 2nd Quadrant.
30. Class –E Choppers operate in , ... , ... & Quadrants.
31. Class Choppers operate only in the First Quadrant..
32. In Cyclo- Converters, Input is AC Signal and output..... Signal.
33. An Converts D. C. into A. C.
34. A Class-C Chopper operates in Quadrants.
35. The output of Chopper is Higher than the Input Voltage.
36. Output voltage and current, both are in Class – A Chopper.

Answers:

- | | | |
|--|----------------------------|--|
| 19) Positive, Negative | 20) Inverter | 21) Commutating |
| 22) 1st & 4th | 23) Cyclo-Converter | 24) Positive, Negative |
| 25) Anti-Parallel | 26) Resonant | 27) Chopper |
| 28) Step Down | 29) B | 30) 1st, 2nd, 3rd 4th |
| 31) A | 32) A. C. | 33) Inverter |
| 34) 1st & 2nd | 35) Step-Up | 36) Positive |

TRUE / FALSE Statement:

1. The ratio of output to input frequency affects the waveform of the AC output in case of Cyclo-Converter using centre tapped Transformer.
2. As the value of firing angle is decreased, output wave form of Cyclo-Converter is more distorted.
3. As input Transformer is required for Bridge configuration of Cyclo-Converter.
4. Minimum firing angle will produce the best possible waveform for a Cyclo-Converter.
5. Step-Up Chopper require forced commutation.
6. A Cyclo-Converter converts AC at one frequency to AC of other frequency.
7. The output frequency of Cyclo-Converter can be changed by changing the firing angle.
8. A Cyclo-Converter is Group of Controlled converters.
9. A Dual Converter consists of two fully controlled converters connected in anti-parallel.
10. In a Dual Converter α_1 & α_2 are the firing angle of Converter 1 and Converter 2. Then $\alpha_1 + \alpha_2 = \Omega / 2$
11. A Cyclo-Converter can be Step-down or Step-Up
12. Series Inverter is also known as Self Commutated Inverter.
13. In Parallel Inverter, the Capacitor is connected in series with the Load.
14. In a chopper circuit, the average output voltage across the load can be varied by varying the supply voltage level.
15. Inverter is device that convert DC into AC Power.
16. Parallel Inverters are used for low frequency applications.
17. Choppers are used to convert the DC input to a controlled DC output with a desired voltage level.
18. MOSFETs are used as a switching device in high voltage applications.
19. Type- A Choppers are also known as the second quadrant Chopper.
20. Type – B Choppers are also known as the second quadrant Chopper .

Answers:

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

TRUE / FALSE Statement:

21. Type – C Choppers are also known as Two Quadrant Chopper.
22. The direction of Load current in Class – D Chopper circuit is restricted to be always negative.
23. Class – A Chopper configuration may be used for both motoring and regenerative braking of DC Motors.
24. In Step UP Choppers, the output voltage is lower than the input voltage.
25. Step-Down Choppers are also known as boost Choppers.
26. Step-Down are also known as buck Choppers.
27. Boost Chopper is power converter with an output DC voltage greater than its input DC voltage.
28. A Dual Converter consists of two converters (Both either fully controlled or half controlled) connected to the different loads.
29. With a step-up Chopper, four quadrant operations are possible.
30. In a Cyclo-Converter, AC Power at one frequency is converted directly to a lower frequency in a single conversion stage.
31. Series Inverter is a forced commutation Type Inverter.
32. Parallel Inverter is a self Commutation Type Inverter.
33. In Step Down Chopper , Load Voltage is more than the source voltage.
34. Type- E Chopper is a four quadrant Chopper.
35. A Cyclo-Converter is an AC power converter.
36. Class – A Choppers operate only in the First Quadrant..
37. A Class-D Chopper operates in 3rd Quadrant.
38. Inverter is a device that converts DC into variable DC
39. The output voltage waveform of ideal Inverter should be sinusoidal.
40. The Device which converts DC into AC is called Rectifier.

Answers:

- | | | | | |
|------------------|------------------|------------------|------------------|------------------|
| 21) TRUE | 22) FALSE | 23) FALSE | 24) FALSE | 25) FALSE |
| 26) TRUE | 27) TRUE | 28) FALSE | 29) FALSE | 30) TRUE |
| 31) FALSE | 32) FALSE | 33) FALSE | 34) TRUE | 35) TRUE |
| 36) TRUE | 37) FALSE | 38) FALSE | 39) TRUE | 40) FALSE |

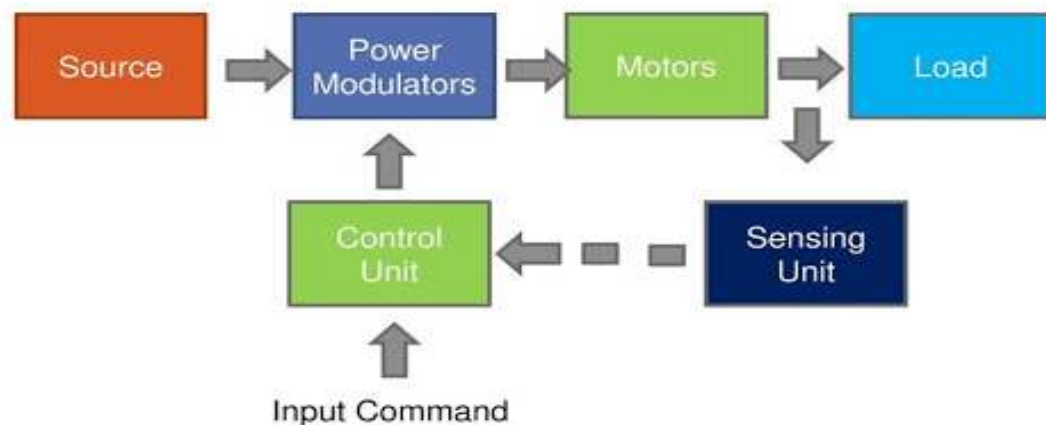
THYRISTORISED CONTROL OF ELECTRIC DRIVES

Electric Drives : Electrical Drive is an Electromechanical Device which converts Electrical Energy into mechanical energy and provide electrical control on the processes.

This system (Electric Drives) are used for motion control of electrical Machine .

Block Diagram of Electrical Drive

The block diagram of the electrical drive is shown in the figure below:



The main parts of the electrical drives are power modulator, motor, controlling unit and sensing units. These parts are explained below in details:

- i. **Source**: The Power Source in the above Block Diagram provide the necessary Energy for the System and can be AC or DC. Single Phase or Three Phase (50 Hz) AC Sources are mostly used in the drive system. Lower power drives are generally fed from the single phase supply and high power drives are generally fed from the 3 phase supply. Some of the drives are also fed from the battery source.
- ii. **Power Modulator** – The Power Modulator converts the Energy according to the requirement of the Motor e.g. if the Source is DC and an Induction Motor is used then Power Modulator convert DC into AC. The Power Modulator also regulates the Output Power of the Source. It controls the Power from the Source to the Motor in such a manner that motor transmits the speed-torque characteristic required by the Load.

THYRISTORISED CONTROL OF ELECTRIC DRIVES

During the transient operations like starting, braking and speed reversing the excessive current drawn from the source. This excessive current drawn from the source may overload it or may cause a voltage drop. Hence the Power Modulator controls the Source and Motor Current.

It also selects the mode of operation of the Motor, i.e., Motoring or Braking.

- iii. **Motor:** Motors are generally used in the System to convert Electrical Energy into Mechanical Energy. Motors used in electric drives may be Induction Motors, Synchronous Motors, DC Motors, Stepper Motors and also Reluctance Motors.
- iv. **Load:** Load can be any machinery, such as fans, blowers, pumps, robots and machines which consumes Power and performs a given task.
- v. **Control Unit** – The Control Unit generates commands for the protection of Power Modulator and Motor as per input command signal received to the control unit.
- vi. **Sensing Unit** – It senses the certain Drive Parameter like Motor Current and Speed of Motor and the information will be provided to Control Unit for issuing necessary command. It mainly required either for protection or for closed loop operation.

Advantages of electrical drives

1. The electric drive are available in wide range of Torque, Speed and Power.
2. Working of Electric Drive is independent of the environmental conditions.
3. Electric Drives have a longer life than other Drives Systems.
4. Electric Drives are Air Pollution Free as there are no flue gases.
5. Electric Drives are more economical and reliable source of Power.
6. No need of any fuel storage and transportation.
7. Electric Drive has High efficiency.
8. Electric Drives have various speed control methods.
9. Electric Drive require less Space.
10. Electric Drives can be remotely controlled.
11. Available in wide range of various parameters like speed, torque, and power.

Disadvantages of Electrical Drive

1. The Application of the Drive is limited because it cannot use in a place where the Power Supply is not available.
2. It can cause noise Pollution.
3. On the failure of Electrical Supply, the Electrical Drive System cannot work.
4. The initial Cost of the System is high.
5. It has a Poor dynamic Response.
6. The Output Power obtained from the Drive is low.
7. During the breakdown of Conductors are short circuit, the System may get damaged due to which several problems occur.

Application of Electric Drive

Electric Drives are used in a large number of industrial and domestic applications as below:

1. Electric drives are used in boats.
2. Electric Drive are used in lifts.
3. Electric Drive are used in cranes.
4. Electric Drive are used in electric car.
5. Electric Drive are used in traction systems.
6. Electric Drive are used in transportation systems.
7. Electric Drive are used in rolling mills.
8. Electric Drive are used in paper machines.
9. Electric Drive are used in textile mills.
10. Electric Drive are used in fans, pumps, robots and washing etc.

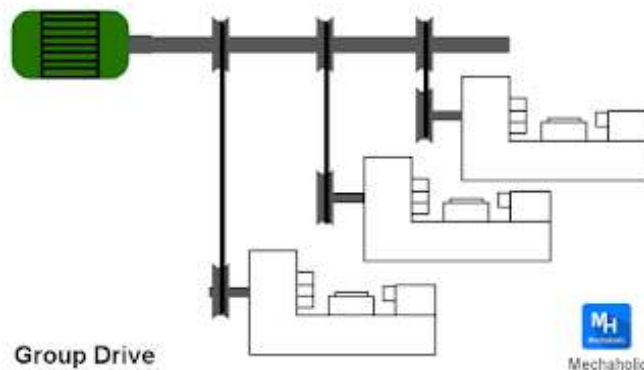
CLASSIFICATION OF ELECTRIC DRIVES WITH BASED ON DEVELOPEMENT FACTOR

There are three Type of Electric Drives

1. Group Electric Drive
2. Individual Electric Drive
3. Multi-motor Electric Drive

THYRISTORISED CONTROL OF ELECTRIC DRIVES

1. **Group Electric Drive:** Group Electric Drive are those Electric Drives in which One motor is used as a drive for two or more than two motors are used as machines. The motor is connected to a long shaft. All the other machines are connected to this shaft through belt and pulleys and shaft of the driven machine, serves to vary their speed. Hence Group Electric Drive is also called "line shaft drive"



Group drive is economical in consideration for the Cost of Motor and Control Gear. A Single Motor of large capacity Costs less than that of the Total Cost of number of small Motors for same Total capacity namely, a Single Motor of 100KW costs less than that of ten Motors of 10KW each. Since all the Motors may not operate on full load at the same time, the KW rating of motor of group drive is often less than the aggregate KW output rating of the individual Motor and further cause reduction in Cost.

Advantages:

- i. Group Electric Drive are most economical.
- ii. Group Electric Drive reduces the initial Cost of installing a particular Industry.
- iii. Group Electric Drive Cost is less because of investment in one Motor which is lesser in HP rating.

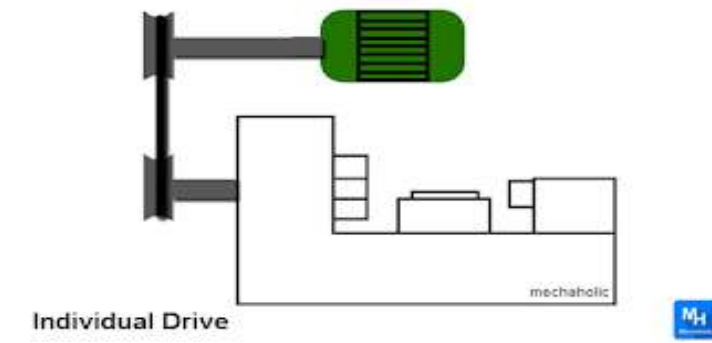
Disadvantages:

- i. It is not possible to install any machine as per our requirement. so, flexibility of lay out is lost.
- ii. The possibility of installation of additional machines in an existing Industry is limited.

THYRISTORISED CONTROL OF ELECTRIC DRIVES

- iii. In case of any fault to the main driving Motor, all the other Motors will be stopped immediately.
- iv. Level of noise produced at the Site is high.
- v. Since all the motors has to be connected through belts and pulleys, large amount of energy is wasted in transmitting mechanisms. Therefore, Power loss is high.

2. **Individual Electric Drive** Individual Electric Drive are those Electric Drives in which there will be a separate driving motor for each process (Machine) equipment. One motor is used for transmitting motion to various parts or mechanisms belonging to signal (Machine) equipment.



In individual Electric Drive, the Energy is transmitted to different parts of same mechanism by means of mechanical parts like Gear, Pulley, etc. hence occurs some power loss

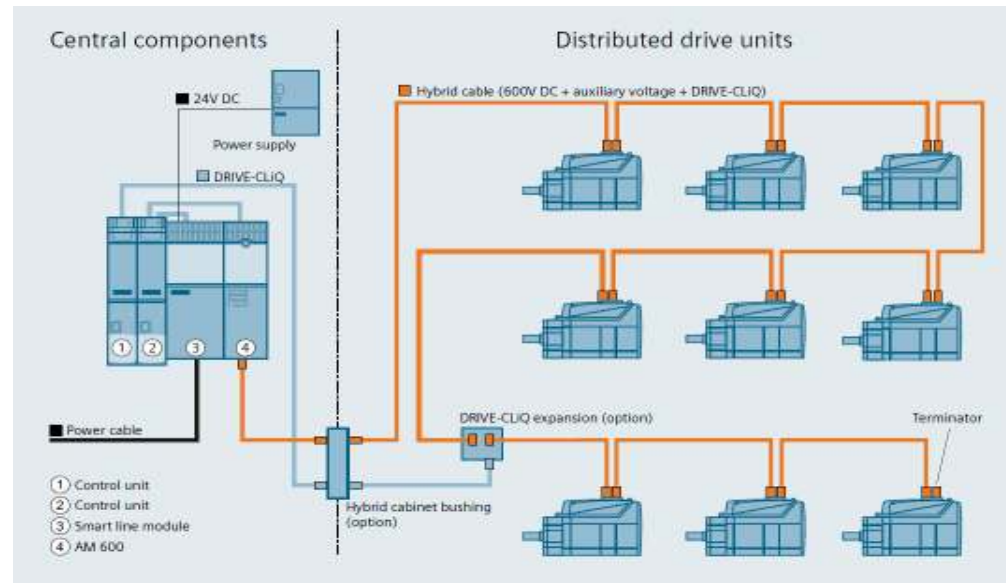
Advantages:

- i. Machines can be located at convenient places.
- ii. Continuity in the production of the processing Industry is ensured to a high level of reliability.
- iii. If there is a fault in one Motor, the effect on the production or output of the industry will not be appreciable.

Disadvantages:

- i. Initial cost of Individual Electric Drive is very high.

3. **Multi-motor Electric Drive:** Multi-Motor Electric Drives are those Electric Drives in which separate motors are provided for actuating different parts of the driven (Machine) mechanism.



The Multi-Motor Electric Drive consist of several individual Motors which serve to one of many motions or mechanism (Machine) in some Production Unit.

For example, in Travelling Crane, there are three Motors used. One for hoisting, other for long travel motion and third for cross travel motion. Such Drives are used in Metal cutting Machine, Paper making Machine, Rolling Mills, Rotary Printing Machine, etc.

The use of multi-motor electric drive is expanding in modern industries due to their advantage outweighs increase in capital cost compared to the group drive.

Advantages :

1. In Multi-Motor Electric Drives, Automatic control methods can be employed.
2. In Multi-Motor Electric Drives, each operation can be executed under optimum conditions.

CLASSIFICATION OF ELECTRICAL DRIVES AS PER SOURCE OF POWER AVAILABLE & LOAD REQUIREMENT

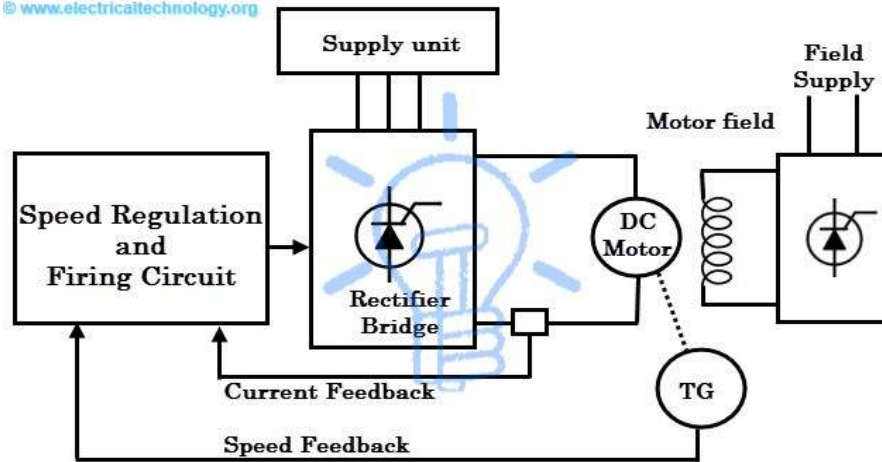
Basically, there are two types of Electric Drives:

1. D. C. Electric Drives
2. A. C. Electric Drive

1. **D. C. Electric Drive:** DC Electric Drive is basically a DC Motor Speed Control System that supplies the D. C. Voltage to the Motor to operate for desired speed. Nowadays, the thyristor family of devices are used widely to control the speed of the DC Motor.

The main components of a DC drive system are shown in figure below:

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COMPONENTS OF A DC DRIVE SYSTEM

- i. **DC Drive Input (Supply Unit) :** Mostly Available Supply Unit is Single Phase AC Supply for DC Drives. This Supply to be converted into Controlled DC through Full Wave Fully Controlled Rectifier.
- ii. **Rectifier Bridge:** The Power Component of a Controlled DC drive is a Full Wave Bridge Rectifier which can be driven by AC Power Supply. The Thyristors Controlled Full Wave Bridge Rectifier convert incoming AC Supply into Controlled DC Supply and supply to the motor armature. By changing the Firing angle of these Thyristors, the Voltage varies to the Motor.
- iii. **Field Supply Unit:** A Separate Thyristor Bridge or Diode Rectifier is used for supplying the Power to the Field Winding of the Motor. The function of the Field Supply Unit is to provide a Constant Voltage to the Field Winding to create a constant field or flux in the Motor.

THYRISTORISED CONTROL OF ELECTRIC DRIVES

In some cases, this Unit with Thyristors reduce the voltage applied to the field so as to Control the Speed of the Motor above the base Speed.

In case of permanent magnet DC Motors, the Field Supply Unit is not included in the Drive.

- iv. **Speed Regulation unit:** It compares the desired Speed with feedback Signals and sends appropriate Signals to the Firing Circuit. This Unit consists of both Voltage and Current Regulators. The Voltage Regulator accepts the Speed error as Input and produces the Voltage Output which is then applied to the Current Regulator.

The Current Regulator then produces required Firing Current to the Firing Circuit. If more Speed is required, additional Current is called from the Voltage Regulator and hence thyristors conducts for more periods. The Field Current Regulator is also provided where Speed greater than the Base Speed is required.

- v. **Firing Circuit:** It supplies the Gate Pulses to Thyristors so that they turned ON for particular periods to produce Variable Armature Voltage.

Advantages of DC Drives over AC Drives:

- i) DC Drive technology is efficient.
- ii) DC Drives are more reliable.
- iii) This cost of DC Drives is less.
- iv) The DC Drive have regenerative and high power applications.
- v) DC drives are widely used in industrial drive applications in order to offer very precise control.

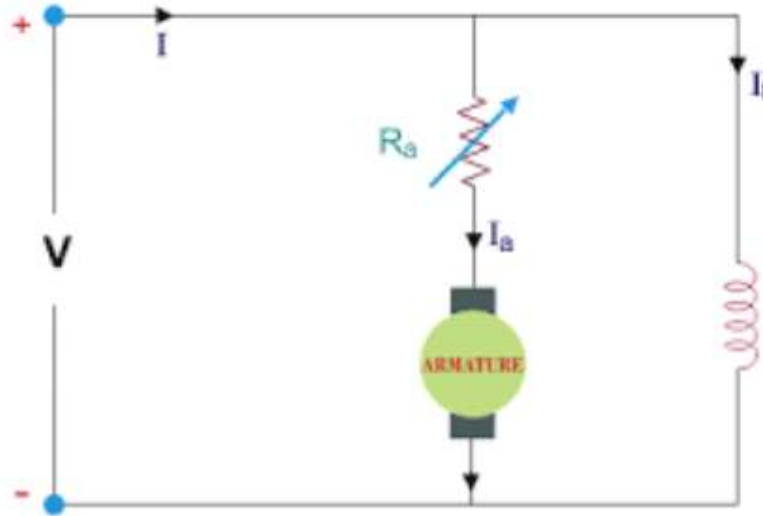
Speed Control of DC Motor By D. C. Drives :

In DC motors, the speed is proportional to the Armature Voltage and inversely proportional to the Field Current. And also, the Armature Current is proportional to the Motor Torque. Therefore, by increasing or reducing the applied Voltage, the Speed of the Motor is varied. However, it is possible up to the Rated Voltage. If the speed greater than the Base Speed is required, the Field Current of the Motor has to be reduced. By reducing the Field Current, the flux in the Motor reduces. The reduction of Field Current reduces the Armature counter EMF. The more Armature Current flows if there is less counter armature EMF. Further, this Armature Current increases the Motor Torque and hence the Speed.

There are the two basic DC drives to control the speed of the motor.

1. Armature Controlled DC Drive:
2. Field Controlled DC Drive:

- 1) **Armature Controlled DC Drive:** In Armature Controlled DC Drive, the Voltage is varied using Armature Resistance. In this method, a Variable Resistance is connected in series to the Armature. Once resistance increased, the current flow through this circuit is reduced and the Armature Voltage drop is less than the Line Voltage. This will reduce the Motor Speed in proportion to the Voltage that's being applied.



The armature resistance control method is used in applications that require Speed variation for shorter periods of time, not continuously.

In the Armature Control Method, the Speed of the DC motor is directly proportional to the back EMF (E_b)

And $E_b = V - I_a \cdot R_a$.

When Supply Voltage (V) and Armature Resistance R_a are kept Constant, then the speed is directly proportional to Armature Current I_a . Thus, if we add resistance in series with the Armature, I_a decreases and, hence, the speed also decreases. Greater the resistance in series with the armature, greater the decrease in Speed.

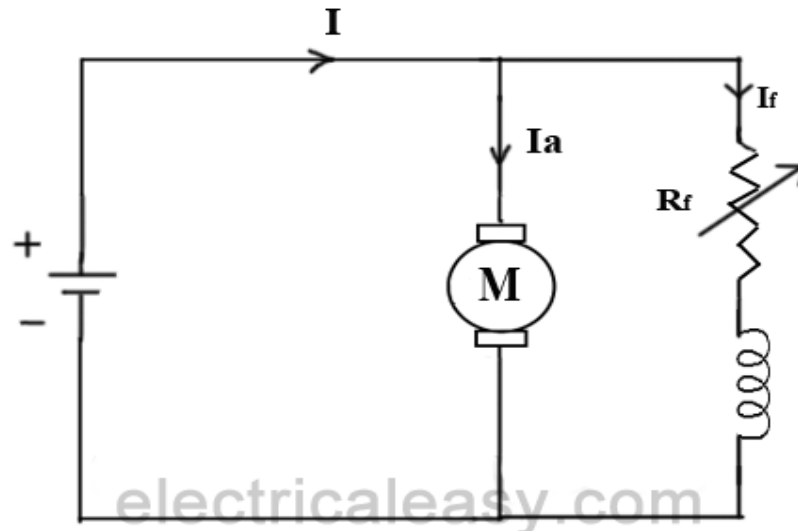
Advantages of Armature Controlled of DC Motor

- i. In Armature Controlled DC Motor, Very fine Speed Control over Whole range in both directions.
- ii. In Armature Controlled DC Motor, Uniform acceleration is obtained
- iii. In Armature Controlled DC Motor, Speed Regulation is Good.
- iv. It has regenerative braking capacity.

Disadvantages of Armature Controlled of DC Motor

- i. Armature Controlled DC Motor arrangement is Costly
- ii. It require more floor space.
- iii. It has Low efficiency at light loads
- iv. This Drive produce more noise.

- 2) **Field Controlled DC Drive:** In Field Controlled DC Drive, the speed of a DC Motor controlled by the Flux in the Field of the Poles. The Speed of Motor is inversely proportional to the Flux per Pole. Thus by decreasing the Flux, Speed can be increased and vice versa.



For controlling the flux, a rheostat (Variable resistance) is connected in series with the Field Winding, as shown in the above Circuit Diagram.

By increase the resistance in series with the Field Winding, it will increase the Speed as it decreases the Flux. In Shunt Motors, as Field Current is relatively very small, $I_{sh}^2 R$ loss is Small. Therefore, this method is quite efficient.

THYRISTORISED CONTROL OF ELECTRIC DRIVES

Though speed can be increased above the rated value by reducing Flux with this method, it puts a limit to maximum Speed as weakening of Field Flux beyond a limit will adversely affect the commutation.

Advantages of Field Controlled of DC Motor:

- i. This method of speed control is independent of Load on the Motor.
- ii. In this method, Power wasted in controlling resistance is very less as Field Current is a small value.

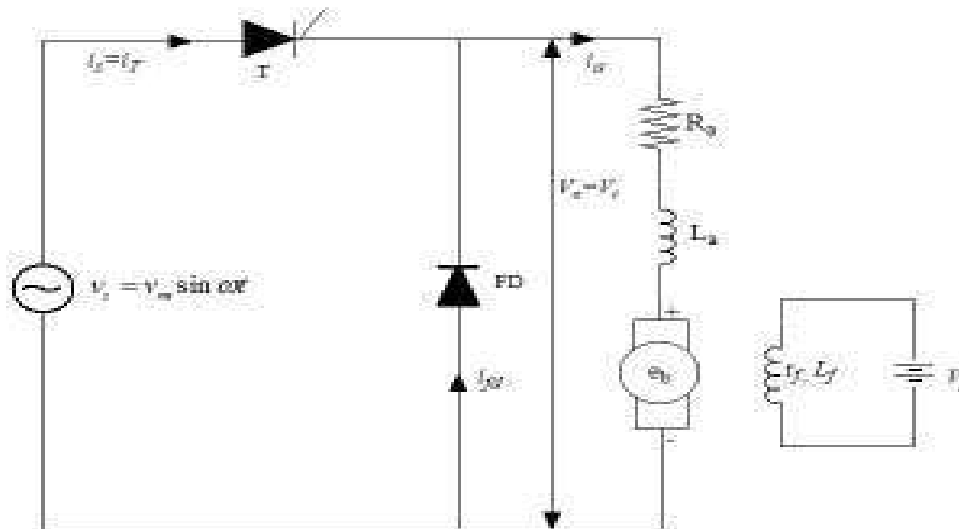
Disadvantages of Field Controlled of DC Motor

- i. Creeping (Constant / Continuous) speeds cannot be obtained.
- ii. Top speeds only obtained at reduced torque.

Depending Upon Source of Power Supply is available for DC Load, DC Electric Drive are classified as under:

I) Single Phase Half-Wave DC Drive Control:

Figure shows a single phase half-wave DC Drive for controlling a separately excited dc motor.



It needs a Single Thyristor (T) and a Freewheeling Diode (D_{FD}). The Freewheeling Diode is also known as Bypass Diode, which is used to improve the wave-shape of Load Current and Power Factor. Freewheeling diode is connected across the Motor terminals to allow for dissipation of Energy stored in the Motor Inductance and to provide for continuity of Motor Current when the Thyristors are blocked. It also provides protection against transient over-voltages.

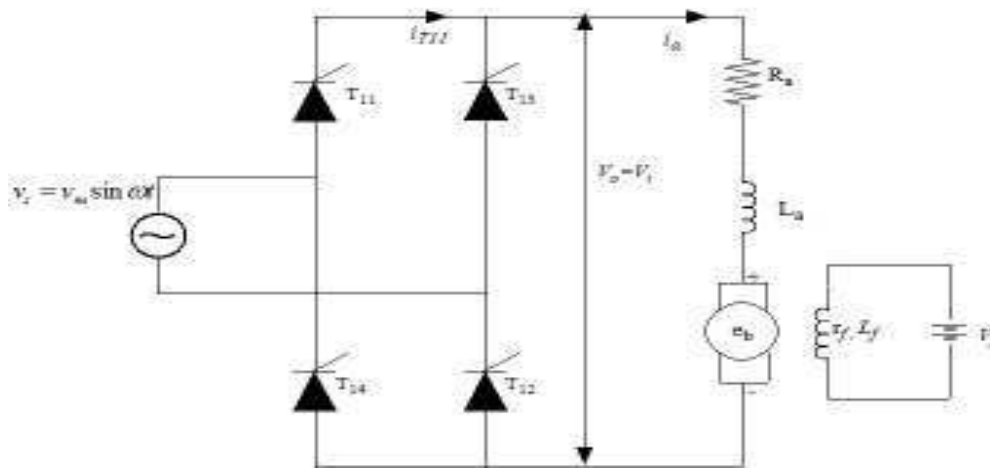
THYRISTORISED CONTROL OF ELECTRIC DRIVES

The Half Wave Rectifier is used for Supply to Field Circuit of the DC Motor. Because of inductance of the Field and Armature, the Thyristor would not turn OFF at $\omega t = \pi$. Therefore it is desirable to have Freewheeling Diode (D_{FD}) in the circuit.

In Half Wave Rectifier / DC Drives, the Load Current is always discontinuous, resulting in poor performance. This type of drive is used only for small DC Motors of rating up to 500 W.

II) Single Phase Full-Wave DC Drives Control:

Figure shows a Single Phase Full-Wave DC Drive for controlling a separately excited DC Motor. A full-DC Drive / Rectifier needs four Thyristors. In Full Wave Rectification, Two quadrants operation is possible as the rectifier in the armature circuit provides $+V_a$ or $-V_a$. Thus allowing operation in first and fourth quadrants.



Current remains unidirectional because of the unidirectional thyristors. When operating in the fourth quadrant regenerative braking is possible and motor feeds back energy to the source. This drive is also employed for motors of rating up to 15 kW.

III) Chopper Control of Separately Excited DC Motor Drive:

The chopper converts the fixed DC voltage to variable DC voltage. Self-commutated devices are used for making choppers because they can be commutated by low power control signal and do not need commutation circuit.

The chopper was operated at high frequency due to which it upgrade the motor performances by decreasing the ripple and removing the discontinuous conduction. The most important feature of chopper control is that the regenerative braking is carried out at very low generating speed when the drive is fed from a fixed voltage to low DC voltage.

Chopper drives can be operated in the following modes:

1. Motoring mode.
2. Regenerative braking mode.

1. Motoring Mode:

Figure (a) Shows Motoring Mode of the Chopper, this mode of operation with a one quadrant Chopper feeding the Motor from DC Supply of Voltage V , the Field being excited from a separate Source. Figure (b) shows the quadrant of operation.

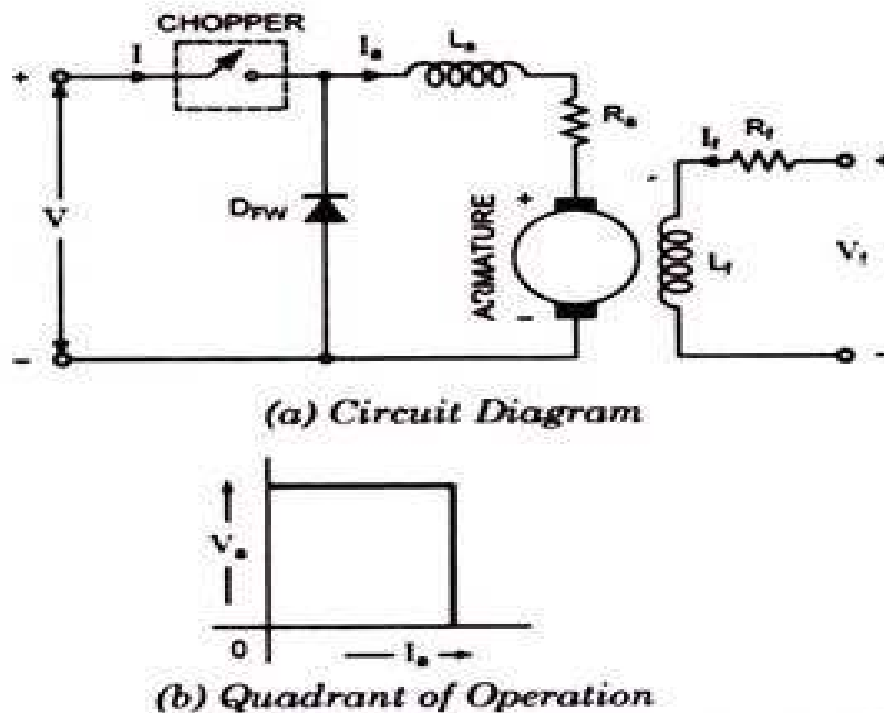


Fig. 3.24. Separately Excited DC Motor Supplied by a Chopper

When the Chopper conducts, Voltage across the Motor Armature is Supply voltage V , and when it blocks, Voltage across the Motor Armature is zero. Therefore, both average voltage and current are Positive and Power can flow from Supply Source to the Load, and thus, represents Motoring operation.

Freewheeling diode D_{FW} is necessary so that the Armature Current may flow when the Chopper is OFF. By varying the Duty cycle α , the Speed of the Motor can be controlled.

2. Regenerative Braking Mode:

When the Motor is to be stopped, brakes are to be applied. In Regenerative braking the Motor is made to operate as a generator and the kinetic energy of the Motor is converted into electrical energy and returned to the Supply.

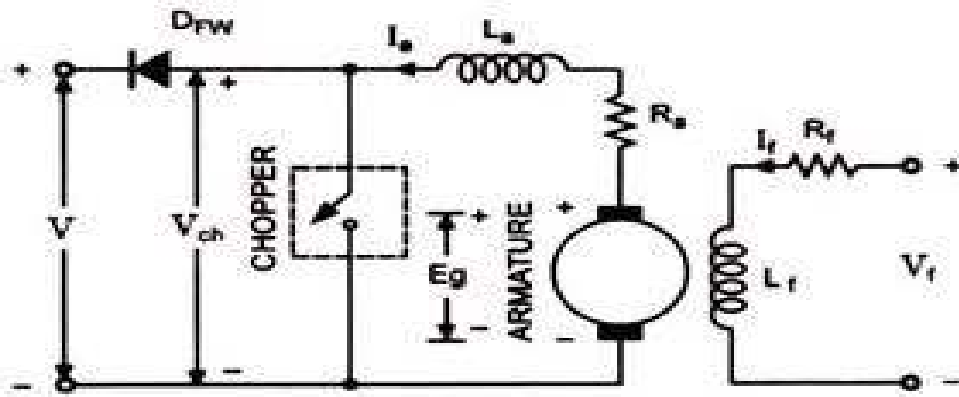
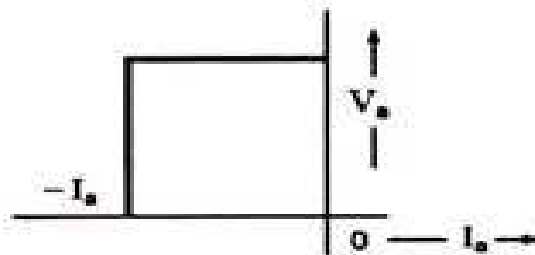
*(a) Circuit Diagram**(b) Quadrant of Operation***Fig. 3.25. Regenerative Braking of Separately Excited DC Motor**

Fig. (a) shows the Circuit Diagram for this mode of operation. During Regenerative braking mode, When the Chopper is Triggered so that the Motor Armature is short circuited through the Chopper. Kinetic energy of the Motor is partly dissipated in Armature Resistance R_a and partly stored in Inductance L_a . When chopper is turned OFF, Freewheeling Diode D_{FW} , is turned ON and the energy stored in Inductance L_a is returned to the Supply Source. The operation is in Second quadrant, as shown in Fig. (b).

D. C. Drive are further classified into two types:

- i. **Non-Regenerative D. C. Motors C Drives:** Non-regenerative DC Drives are those Drives that rotates only in one direction and hence also called single quadrant drive. The non-regenerative DC motor drive does not have any braking capability. The motor is terminated only by removing the supply. Such type of drive is used in a place where high friction load or strong natural brake requires. In their most basic form, they are able to control motor speed and torque in one direction.
- ii. **Regenerative DC drives:** Regenerative D. C. Drive are those Drives which are capable to control the speed of DC Motors as well as direction of motor rotations. Regenerative DC Drive are used as adjustable speed and direction drives, also known as four-quadrant drives.

2. **A. C. Electric Drive:** An AC Drive is a drive which Control the Speed of an AC electric Motor. In this Drive, the speed of the Motor is controlled by changing the Frequency and Voltage of the Electrical Supply to the AC Motor.

The speed of the AC (induction) motor can be controlled by ;

- I. By changing frequency. (VFD)
- II. By Changing Voltage (VVD) / Phase Control AC Drive
- III. By Changing the slip of the motor (only possible in slip ring motors)
- IV. By Changing number of poles

Classification of AC Drives

AC Drive are Basically of Two Types:

- i. Variable Frequency Drive (VFD)
 - ii. Variable Voltage Drive (VVD)
- i. **Variable Frequency Drive (VFD)** A variable-frequency drive (VFD) is an adjustable-Speed Drive which used in electro-mechanical drive systems to control Speed & Torque of AC Motor by varying Motor Input Signal Frequency.

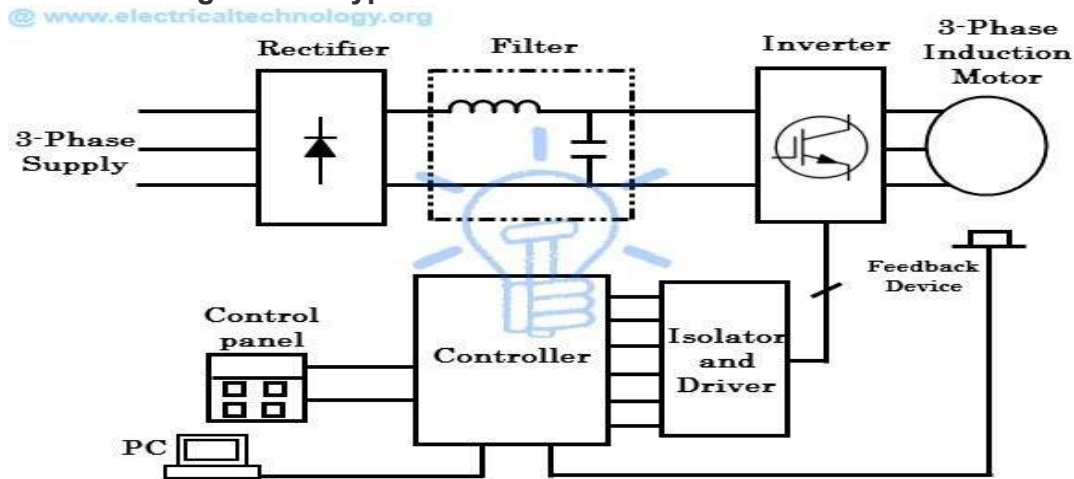
We know that the speed of an Induction Motor is proportional to the frequency of the supply ($N = 120 f / p$)

THYRISTORISED CONTROL OF ELECTRIC DRIVES

Where N is Speed of Induction Motor, f is the Frequency of the Power Supply and p are the numbers of Magnetic Poles

By varying the Frequency we can obtain the Variable Speed. When the Frequency of Power Supply is decreased, the Speed of Induction Motor also decreased and vice versa.

The block diagram of a typical VFD is shown below:

**BLOCK DIAGRAM OF TYPICAL VFD (AC DRIVE)**

- i. **Rectifier:** The Rectifier is made with diodes that Converts AC in to Pulsating DC output with negligible Ripples .
- ii. **Filter:** The Filter Section removes Ripples and produces the fixed DC from pulsating DC and gives the pure DC at the Output.
- iii. **Inverter:** The **inverter** takes the DC power from the rectifier / Filter section and then converts back to the AC Power of Variable Frequency under the control of microprocessor or microcontroller. This section is turned ON/OFF by the Signals from the Controller.
- iv. **Controller:** The controller is made with microprocessor or microcontroller and it takes the input from Sensor (as speed reference) and Speed reference from the user and accordingly Triggers the Power electronic components in order to vary the Frequency of the Supply.

It also performs Overvoltage and Under voltage Trip, Power Factor Correction, Temperature Control and PC connectivity for real time monitoring.

THYRISTORISED CONTROL OF ELECTRIC DRIVES

- v. **AC motor:** The AC Motor converts AC Electrical Energy into Mechanical Rotations which drive the Load.

The AC electric Motor used in a Variable Frequency Drive System is usually a Three-Phase Induction Motor. Some types of Single-Phase Motors or Synchronous Motors can be advantageous in some situations, but generally Three-Phase Induction Motors are preferred as the most economical.

ii) **Variable Voltage Drive (VVD):** A variable-Voltage Drive (VVD) is a type of adjustable-Speed Drive used in electro-mechanical drive systems to control AC motor Speed and Torque by varying Motor Input Signal Voltage through Thyristors by controlling of Firing Angle..

Voltage Control is a method used to control the speed of an Induction Motor. The Speed of a Induction Motor can be varied by varying the Supply Voltage. When Supply Voltage decreases, the Speed of Induction Motor also decreased and vice versa.

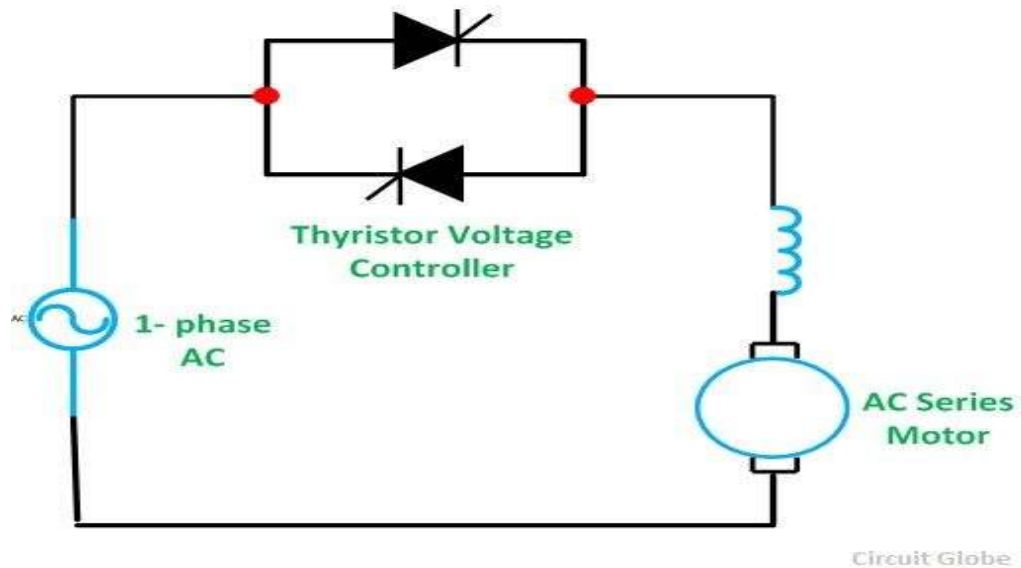
This method gives a speed control below the normal rated speed and suitable for the Fan and Pump Drives. As in Fan and Pump, the Load Torque Varies as the square of the speed. These types of drives required Low Torque at Lower Speeds. This condition can be obtained by applying Lower Voltage without exceeding the Motor Current.

The Variable Voltage for Speed control of Small Size Motors mainly for Single Phase can be obtained by using a Thyristor (SCRs / TRIAC) voltage controller.

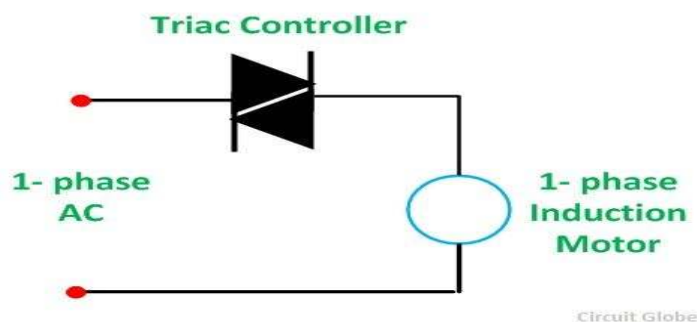
Single Phase Variable Voltage AC Drives:

For a single phase supply, Two SCRs are connected back to back Voltage Controller as shown in the figure below.

The Upper Thyristor will provide the controlled output during Positive half Cycle and Lower Thyristor will provide the controlled output during Negative Half Cycle.



For a Single Phase AC Supply, Two SCRs can be replaced by a Single Phase TRIAC Voltage Controller / DRIVE as shown in the figure below.

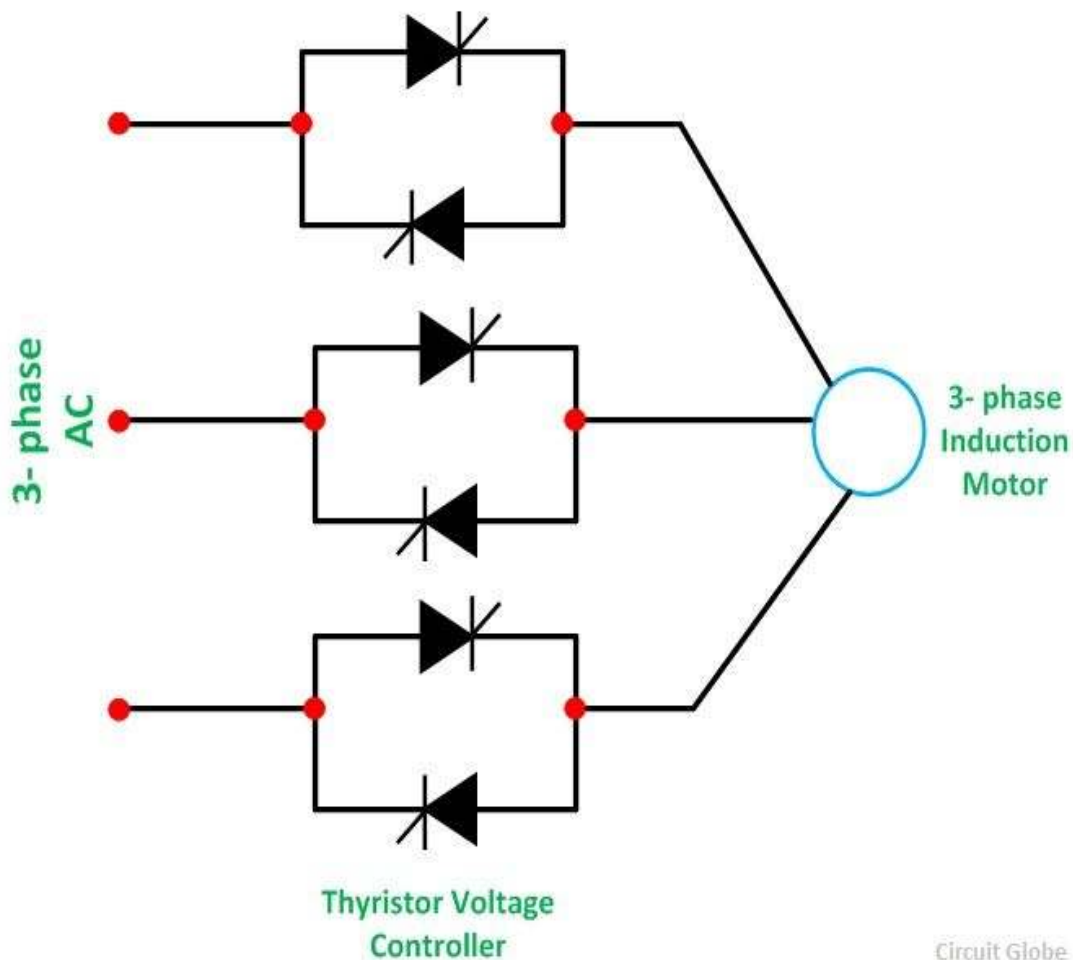


Speed control can be obtained by varying the Firing Angle of the SCRs / TRIAC. These controllers are known as Solid State Fan Regulators. As the solid state Regulators are more compact and efficient as compared to the conventional variable Regulator. Thus, This controller is preferred over the normal regulator.

Three Phase Variable Voltage AC Drives

In case of a Three Phase Induction Motor, Three Pairs of Thyristors are required which are connected back to back. Each pair consists of Two Thyristor. The diagram below shows the Stator Voltage Control of the three phase induction motors by Thyristor Voltage Controller.

The Upper Set of Thyristors will provide the controlled output during Positive half Cycle and Lower Set of Thyristors will provide the controlled output during Negative Half Cycle.



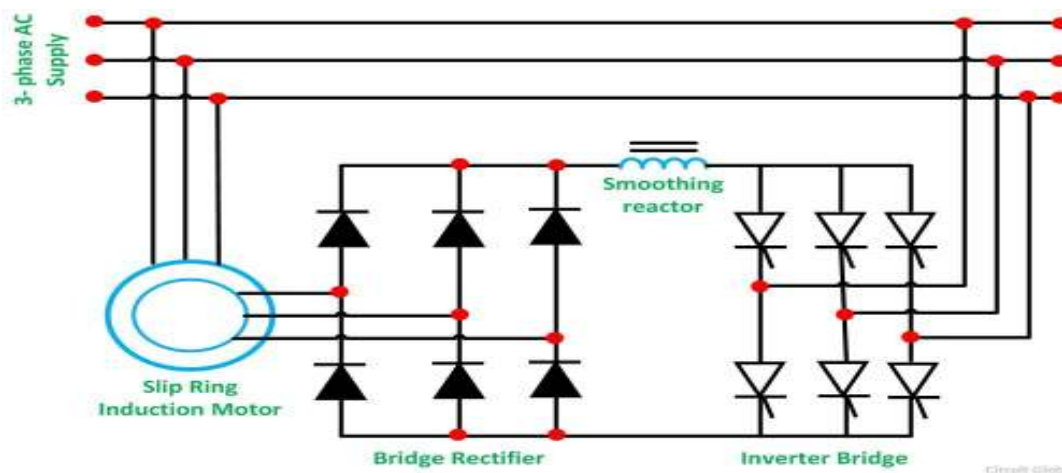
Circuit Globe

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 is replaced by TRIAC.

THYRISTORISED CONTROL OF ELECTRIC DRIVES

iii) **Slip Energy Recovery of an Induction (Slip Ring) Motor:** Slip Energy Recovery is one of the methods of controlling the Speed of an Induction (Slip Ring) motor. In the Rotor Circuit, the Slip Power is wasted as I^2R losses during the Low-Speed operation. The efficiency is also reduced. The Slip Power from the Rotor Circuit can be recovered and fed back to the AC Source so as to utilize it outside the Motor. Thus, the Overall Efficiency of the Drive System can be increased and control can be obtained on the Speed also.

The figure below shows the connection and method for recovering the Slip Energy and Power recovery of an Induction Motor.



The Basic Principle of the Slip Power recovery is to connect an external Source of the EMF of the Slip frequency of the Rotor Circuit. The Slip Energy recovery method provides the Speed control of a Slip Ring Induction Motor below its Synchronous Speed.

A portion of Rotor AC Power (Slip Power) is converted into DC by a diode bridge. The smoothing reactor is provided to smoothen the rectified current. The output of the rectifier is then connected to the DC terminals of the Inverter. The Inverter converts the DC Power to the AC Power and feeds it back to the AC Source.

This method of Speed control is used in large Power applications where the variation of Speed over a wide range involves a large amount of Slip Power.

iv) Pole Changing Method to Control Speed of Induction

Motor: In Pole Changing Method for controlling the Speed of Induction Motor, The speed of Induction Motor is inversely proportional to the number of Magnetic Poles.

Therefore, Motor Speed can be changed by changing the number of Poles. Provision for changing the number of Poles has to be incorporated at the manufacturing Stage and such machines are called, '**Pole Changing Motors**' or '**Multi-Speed Motors**'.

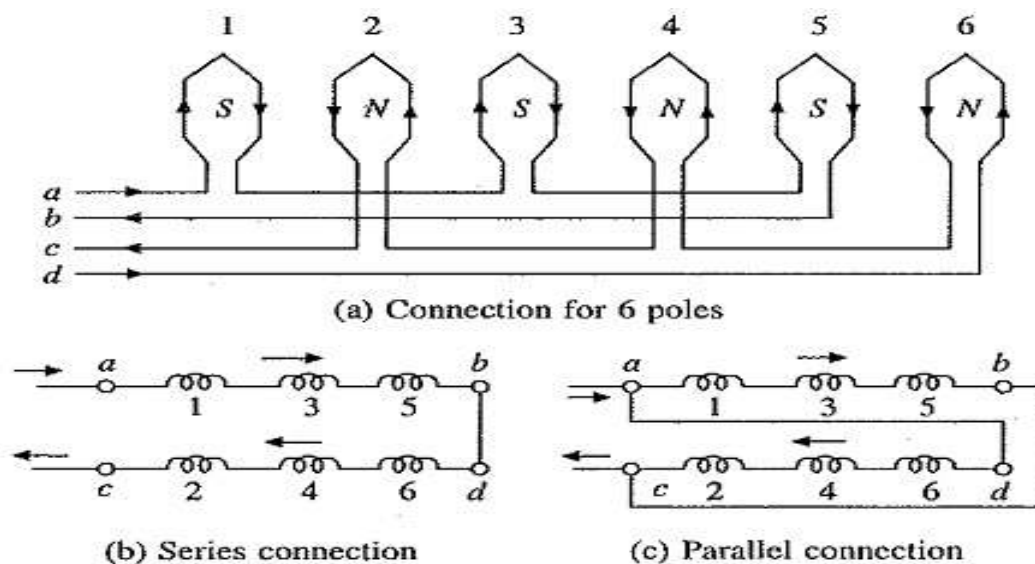


Fig. 6.24 Stator phase connection for 6-poles

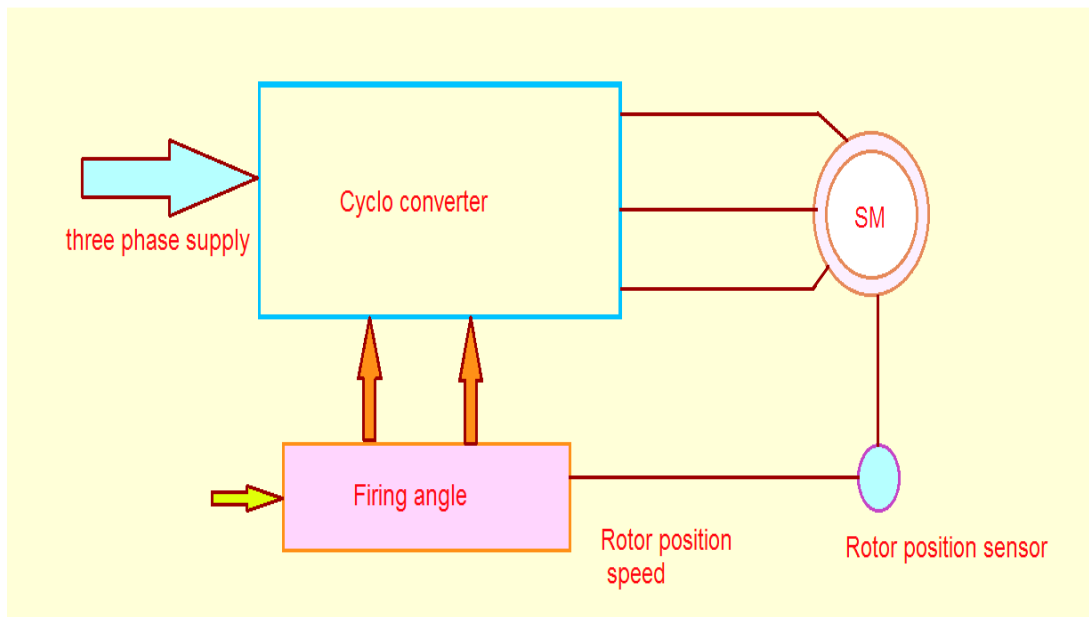
Squirrel-Cage Rotor is not wound for any specific number of poles. It produces the same number of poles as stator winding has. Therefore, in a Squirrel-Cage Motor, an arrangement is required only for changing the number of poles in stator. In wound-rotor motor, arrangement for changing the number of Poles in Rotor is also required, which complicates the machine. Therefore, this Pole Changing of Induction Motor method of Speed Control is only used with Squirrel-Cage Motors.

A simple but expensive arrangement for changing the number of Stator Poles is to use Two separate Stator winding which are wound for two different Pole numbers. An economical and common alternative is to use a Single Stator winding divided into few Coil Groups.

Number of poles is changed by changing the connections of these coil groups. Theoretically by dividing winding into a number of coil groups and bringing out terminals of all these groups, a number of pole numbers can be obtained by reconnecting these groups. In practice, for simplicity, winding is divided only in two coil groups. This allows the change in pole number by a factor 2.

- v) **Cyclo-Converter AC Drive:** In this Drive, A Cyclo-Converter is used to control the speed of a single phase induction motor.

A Cyclo-Converter is a Frequency Changer that converts AC (alternating current) Power of a certain frequency to AC Power of another frequency without the help of any intermediate DC (direct current) link.



Cyclo-Converter control has the advantages of smooth Low Speed operation, four-quadrant operation with regenerative braking and good dynamic response. But it has low speed range.

These Drives are used in Low Speed gearless Drives for Ball Mills in cement Plants, Mine hoists, Reversing Rolling mills requiring fast dynamic response and in ships equipped with diesel generator etc.

Advantages of AC drives:

- i. AC drives have the lowest starting current of any starter type.
- ii. AC drives reduce Thermal and Mechanical stresses on Motors and Belts.
- iii. AC drives installation is Simple as connecting the power supply to the AC Drive.
- iv. AC Drives save large Energy at Lower Speed.
- v. AC Drives increase the life of rotating components, as operating speed of rotating components is Slower.
- vi. AC Drives reduce the Noise and vibration level.
- vii. AC Drives provide High Power Factor.
- viii. AC Drives provide lower KVA, helping to reduce voltage sags and power outages.

Difference between AC Drives and DC Drives

CHARACTERISTICS	AC DRIVES	DC DRIVES
Maintenance	Requires less maintenance.	Requires comparatively more and frequent maintenance.
Use/ Application	Are generally used for AC motors.	Are used for DC motors normally.
Locational use	Are used in almost all the locations.	are used in very few locations
Breaking Mechanism	Breaking and accelerating when supply frequency (F_s) changes	Breaking occurs when resistance is applied at rotor.
Power & Control Circuitry	Power and control circuits are difficult and quite complex in design.	Power and control circuits are simple to design and less expensive as compared to their counter-parts.

CHARACTERISTICS	AC DRIVES	DC DRIVES
Size in terms of Power Rating	Power to Weight ratio is very large.	Power to Weight ratio is considerably small.
Commutation	There is no commutation which makes AC Drives less bulky and inexpensive.	Because of commutation, they are more heavy and costly.
Rectifier	There is no need of rectifier circuit	Rectifying circuit is necessary
Speed Control	Speed control is achieved by changing the frequency	Speed control is achieved by armature and field control
Cost	In AC Drives, motors are less expensive especially squirrel cage motors.	In DC Drives, motors are significantly expensive.
Speed limit	There is no upper limit for speed.	Speed is limited because of commutation process.
Harmonics	Converters produce harmonics in supply as well as in load	Converters do not produce harmonics
Motor speed	Can reach up to 10000 RPM	Can reach up to 2500 RPM
Starting torque	Do not produce high starting torque	Produces high starting torque
Noise	Operation is noisy which is highly unfavorable in certain applications	They are not noisy as compared to AC Drives
Power consumption	Consume less power	Consume more power
Circuit complexity	More complex as it involves inverter (DC $\rightarrow$ AC) and converter (AC $\rightarrow$ DC)	Less complex because of single power conversion process from AC to DC

FILL IN THE BLANKS:

1. Speed of Motor with the increase in firing angle of Thyristor Bridge.
2. DC Motors provide starting torque.
3. Speed of AC Motor can be controlled by AC Drive by changing of of Input signal.
4. For wide range speed control, ...drives are used.
5. Power conversion efficiency of AC to DC converter is
6. The speed of Motor increases with the increase in armature.....
7. Cyclo-Converter is used for Drives.
8. The Drive in which a single thyristor is used to control input power is called drive.
9. AC Motors are better suited for speed of operation.
10. For DC Motors, Dual Converter is used to obtain speed control.
11. For Controlling speed of 3 phase Induction Motor, the scheme generally used is variable voltage and variable..... scheme.
12. Armature control method is used in DC Motors to get the speeds.....Normal speed.
13. Field control method is used in DC Motors to get the speeds.....Normal speed.
14. DC Chopper Drive controls the voltage across DC Motor by continuously switching ON and OFF the Motor for duration of T_{ON} and T_{OFF} .
15. Cyclo-Converters Drives can be used for speed control of Motors.
16. Single Phase DC Drive converts AC signal in to Signal.
17. Chopper drive are used for controlling the speed of Motor.
18. Control method is used to control the speed above normal speed.
19. Control method is used to control the speed above normal speed.
20. Power Modulator controls the of power from source to Motor.

Answers:

- | | | | |
|-------------|----------------|---------------|--------------|
| 1) Decrease | 2) High | 3) Frequency | 4) AC |
| 5) High | 6) Voltage | 7) AC | 8) Half Wave |
| 9) High | 10) Reversible | 11) Frequency | 12) Below |
| 13) Above | 14) Fixed | 15) AC | 16) DC |
| 17) DC | 18) Field | 19) Armature | 20) Flow |

TRUE / FALSE Statements:

1. DC Motors provide High starting torque.
2. Armature control method is used in DC Motors to get the speeds above Normal speed.
3. For wide range speed control, AC drives are used.
4. Cyclo-Converters Drives can be used for speed control of DC Motors.
5. Speed of Motor increases with the increase in firing angle of Thyristor Bridge.
6. Field control method is used in DC Motors to get the speeds above Normal speed.
7. Chopper drive can be used in regenerative braking mode.
8. Output frequency of Cyclo-Converter Drive can be $1/3^{\text{rd}}$ of input frequency.
9. Chopper drive are used for controlling the speed of AC Motor.
10. Cyclo-Converter Drive can be used for speed control of three phase Induction Motors.
11. The Drive in which a single thyristor is used to control input power is called Full Wave drive.
12. Chopper drive cannot be used in regenerative braking mode.
13. Power Modulator controls the flow of power from source to Motor.
14. DC Chopper Drive controls the voltage across DC Motor by continuously switching ON and OFF the Motor for Fixed duration of T_{ON} and T_{OFF} .
15. DC Motors provide very low starting torque.

Answers:

- | | | | |
|----------|----------|-----------|-----------|
| 1) TRUE | 2) FALSE | 3) TRUE | 4) FALSE |
| 5) FALSE | 6) FALSE | 7) TRUE | 8) TRUE |
| 9) FALSE | 10) TRUE | 11) FALSE | 12) FALSE |
| 13) TRUE | 14) TRUE | 15) FALSE | |

Uninterrupted Power Supply

Uninterrupted Power Supply: Uninterruptible power supply (UPS) is a type of power supply system that provide interrupts (Power outage, power blackout, Brownout, surge, spike, sag) free power supply to the load.

An Uninterruptible Power Supply system generally offers multiple outlets, allowing to maintain battery back-up power to more than one device and will also include additional outlets for surge protection.

Important Interrupts

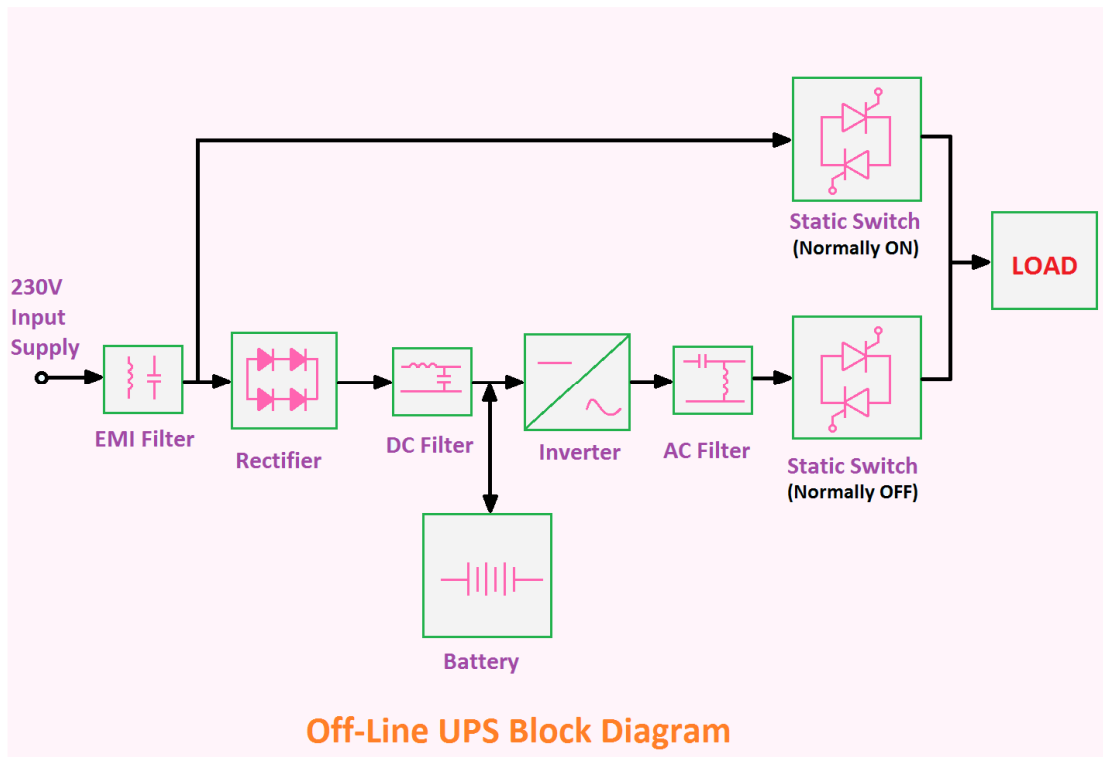
- i. **Surges:-** Oversupply of voltage from the electrical supply voltage (or current or both) for a very short period (less than a second) from power grids
- ii. **Spike:-** Electrical spike is increase in the electrical supply voltage (or current or both) for a very short period (less than a second),. Another name for an electrical spike is an electrical surge.
- iii. **Power outage:-** (also called a power cut, a power blackout, power failure or a Brownout) is a short-term or a long-term loss of the electric power to a particular area. There are many causes of power failures in an electricity network. Blackouts is due caused by bad weather. Brownouts is due to an overloaded power grid.
- iv. **Voltage Sag:-** A voltage **sag** is a short duration reduction in r. m. s. voltage which can be caused by a short circuit, overload or starting of electric motors.

Types of UPS

There are three types of UPS

- i. OFF Line UPS
 - ii. Online UPS
 - iii. Line Interactive UPS
1. **OFF Line UPS:** OFF-Line UPS are those UPS which passes the AC Mains Supply directly to the output load if the AC Mains Supply is present. Only in the case of power failure, it switches to inverter within few milliseconds to give power to load until mains supply returns. The off line UPS is also called as standby Uninterruptible Power.

The Block Diagram of Offline UPS is given below.



1. **EMI Filter:** It is made using inductors and capacitor. The main function of this EMI filter circuit is to reduce or filter the electromagnetic interferences.
2. **Rectifier Circuit:** The rectifier circuit is used to convert AC to DC. As the UPS has the battery inside it, and the battery can store only DC that is why we need to convert input AC supply into DC.
3. **DC Filter Circuit:** The DC filter circuit is used to filter the impure DC comes from the rectifier circuit. The DC output from the rectifier has some AC component. So the filter circuit is used to remove those AC components from the DC supply.
4. **Battery:** The battery is connected with the output of the DC filter circuit. When the UPS is connected to the power supply the battery will charge.
5. **Inverter Circuit:** Now we have DC supply but, we need AC supply as output to drive the load. So the inverter circuit is used to convert the DC to AC. The inverter Circuit is made high-speed solid state switches such as MOSFET, SCR, etc. If your load required DC supply then the Inverter Circuit is not required.

6. **AC Filter Circuit:** The AC filter circuit is used to filter the impure AC coming from the inverter circuit.
7. **Static Switch:** A static switch is connected between the AC filter Circuit and the Critical Load. Which allow or disallow the power flow from the UPS to load according to the given condition.

Another static switch is connected between the critical load and the main power supply after the EMI filter Supply. This switch allows or disallows the power flow from the main supply to the load.

In the case of Offline UPS, the upper static switch is normally ON and lower static switch is normally OFF. So in normal condition, the power directly flows from the main supply to the load. At the same time, the battery will charge. When the main power supply is not available, the upper static switch will be OFF and the lower static switch will be ON. So the load takes power from the battery.

This kind of UPS system offers a small size, high degree of efficiency, & pretty low costs, making of this UPS is easy.

Advantages of Offline UPS:

- i. Offline UPS has high efficiencies, since charger is not continuously on.
- ii. The power handling capacity of charger is reduced.
- iii. Cost of Offline UPS is low..
- iv. Internal control is simpler in offline UPS.
- v. Operation of Off-Line UPS is Silent when in standby mode.

Disadvantages of OFF-Line UPS:

- i. Since offline UPS provides mains supply when it is present, the output contains voltage spikes, brownouts, blackouts.
- ii. There is finite transfer time from mains to inverter when mains supply fails.
- iii. Output of offline Uninterruptible Power Supply is not perfectly reliable.
- iv. Minimal power protection - only protects against a small percentage of problems.
- v. Output voltage regulation is poor- sags and surges will be passed straight to the load.

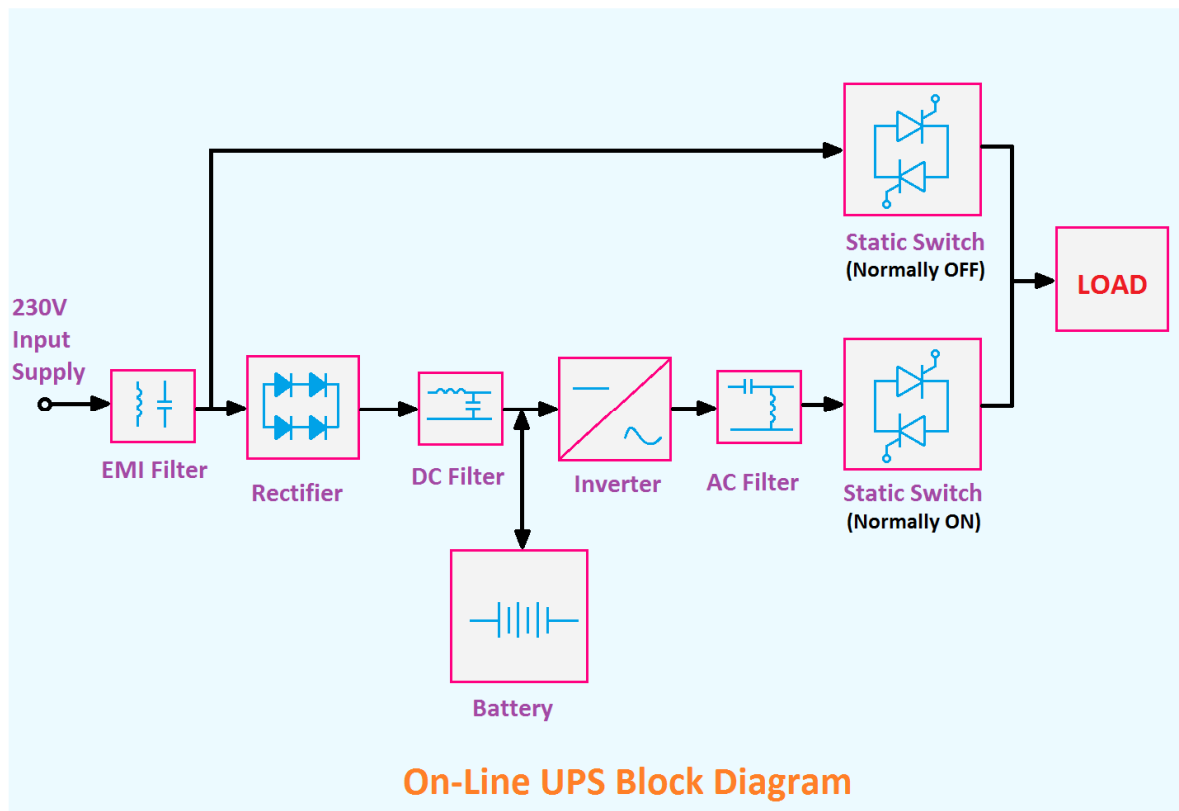
Applications of OFF-Line UPS:

- i. Off-Line UPS are used in Computers, printers, scanners etc.
- ii. Off-Line UPS are used in Emergency power supplies, EPABX.

2. **ON-Line UPS:** ON-Line UPS are those UPS which supplies power to load via the inverter. Even if the mains supply fails, there is no interruption to the output load at all and always charges battery from incoming AC mains supply.

In this UPS, the total load power flow through both the inverter and the battery charger, resulting in reduced efficiency with its associated increased heat generation.

The block diagram of ON-Line UPS is shown below :-



1. **EMI Filter:** It is made using inductors and capacitor. The main function of this EMI filter circuit is to reduce or filter the electromagnetic interferences.
2. **Rectifier Circuit:** The rectifier circuit is used to convert AC to DC. As the UPS has the battery inside it, and the battery can store only DC that is why we need to convert input AC supply into DC.
3. **DC Filter Circuit:** The DC filter circuit is used to filter the impure DC comes from the rectifier circuit. The DC output from the rectifier has some AC component. So the filter circuit is used to remove those AC components from the DC supply.

4. **Battery:** The battery is connected with the output of the DC filter circuit. When the UPS is connected to the power supply the battery will charge.
5. **Inverter Circuit:** Now we have DC supply but, we need AC supply as output to drive the load. So the inverter circuit is used to convert the DC to AC. The inverter Circuit is made high-speed solid state switches such as MOSFET, SCR, etc. If your load required DC supply then the Inverter Circuit is not required.
6. **AC Filter Circuit:** The AC filter circuit is used to filter the impure AC coming from the inverter circuit.
7. **Static Switch:** A static switch is connected between the AC filter Circuit and the Critical Load. Which allow or disallow the power flow from the UPS to load according to the given condition.

Another static switch is connected between the critical load and the main power supply after the EMI filter Supply. This switch allows or disallows the power flow from the main supply to the load.

In the case of Online UPS, the lower static switch is normally ON and the upper static is normally OFF. So in normal condition the power flow from the main supply to the load through the total UPS circuitry. When the main power supply is not available, then the load takes power from the battery.

If the UPS is unable to deliver power to the load then the upper static switch will be ON and the lower Switch will be OFF. So in this case, the power will directly flow from the main supply to the load.

Online UPSs provide full protection from major power problems, such as surges, spikes, sags, blackouts and brownouts.

Advantages of Online UPS:

- i. It provides isolation between main supply and load.
- ii. Since inverter is always ON, the quality of load voltage is free from distortion.
- iii. All the disturbances of supply such as blackout, brownouts, spikes etc are absent in the output.
- iv. Voltage regulation of On-Line UPS is better.
- v. Transfer time is practically zero since inverter is always ON.

Disadvantages of Online UPS:

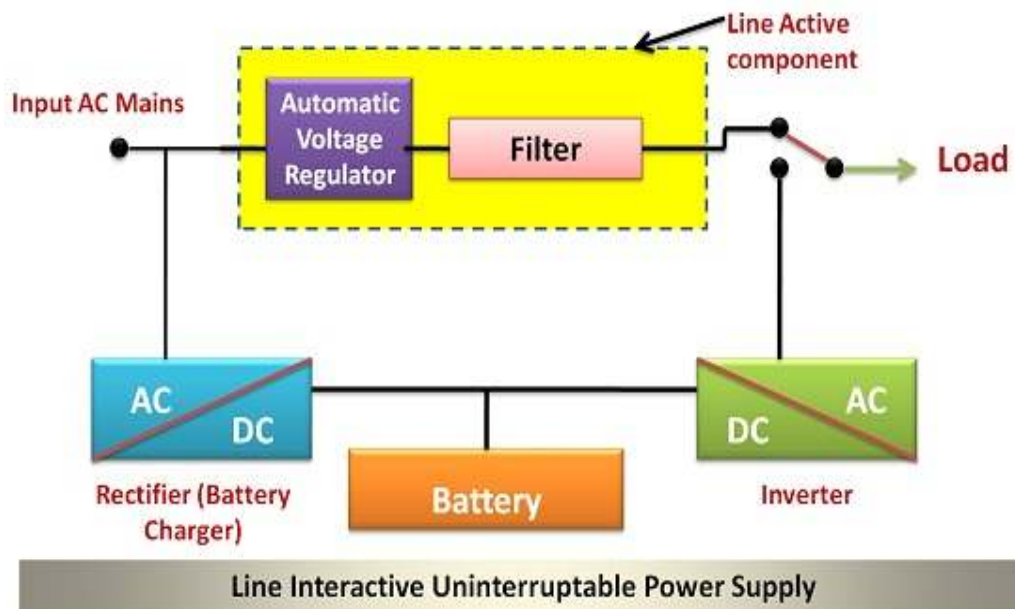
- i. Overall efficiency of UPS is reduced since inverter is always ON.
- ii. The wattage of the rectifier is increased since it has to supply power to inverter as well as charge battery.
- iii. Online UPS is costlier than other Uninterruptible Power Supply Systems.

Applications of Online UPS:

- i. ON-Line UPS are used in Induction motor drives and similar other motor control applications.
- ii. ON-Line UPS are used in Intensive care units, medical equipments.
- iii. ON-Line UPS are used in Computers, Data Centres, Server rooms, Search Data Centres
- iv. ON-Line UPS are used in Network Operation Centres
- v. ON-Line UPS are used in Process Industries

3. Line Interactive UPS : Line-interactive UPS is one type of Uninterruptible Power Source that can regulate voltage automatically. Line-Interactive technology is an incorporates technology that allows the UPS to correct minor power fluctuations (under and over voltages) without switching to battery.

Line Interactive UPSs provide full protection from major power problems, such as surges, spikes, sags, blackouts and brownouts..



1. **Automatic Voltage Regulator (AVR)** : An automatic voltage regulator (AVR) is a electronic device for automatically maintaining output voltage at a set value under varying load and operating temperature. It controls output by sensing the voltage V_{out} .
2. **Filter** : It is made using inductors and capacitor. The main function of this EMI filter circuit is to reduce or filter the electromagnetic interferences.
3. **Rectifier (Battery Charger)** : The rectifier circuit is used to convert AC to DC. As the UPS has the battery inside it, and the battery can store only DC that is why we need to convert input AC supply into DC.
4. **Battery**: The battery is connected with the output of the Rectifier. When the UPS is connected to the power supply the battery will charge.
5. **Inverter**: Now we have DC supply but, we need AC supply as output to drive the load. So the inverter circuit is used to convert the DC to AC. The inverter Circuit is made high-speed solid state switches such as MOSFET, SCR, etc.
6. **Static Switch**: A static switch is connected between the AC filter Circuit and Inverter Circuit to connect with the Critical Load. Which allow or disallow the power flow from the UPS to load according to the given condition.

The designing of line interactive UPS is like as Offline (standby) UPS, in addition the design Line Interactive generally includes an automatic voltage regulator(AVR). This AVR provide the regulation of input main supply voltage. The Voltage regulation is a significant feature when the conditions of a low voltage exist, otherwise the UPS would transfer to battery & then finally down the load.

.A good line-interactive UPS, Inverter will supply a sine wave output to the load. Upon the return of mains power, the output is switched back onto mains supply and the inverter will be turned off. In Line Interactive UPS, Electronic Switching to and from battery is faster than an offline UPS.

Advantages:

- i. The cost of Line interactive UPS is lower than online UPS
- ii. It gives better protection than offline UPS.
- iii. The operation of Line Interactive UPS is Silent when in standby mode.

Disadvantages:

- i. In Line Interactive UPS, Fluctuations, such as spikes, can still be passed straight to the load
- ii. There is finite transfer time from mains to inverter when mains supply fails
- iii. Line Interactive UPS has No failsafe - UPS will drop the load if there is a high start-up current, overload or inverter failure.

Simply put, an **on-line UPS** offers a higher level of protection than a **line interactive** at a higher cost.

Comparison between Online, Offline UPS and Line-interactive UPS :

Sr. No	Parameter	Online UPS	Offline UPS	Line-interactive UPS
1	Inverter	Always ON	Turned On when mains fails	Turned On when mains fails
2	Rectifier cum charger	Supplies power to inverter as well as charges battery	Charges only battery	Charges only battery
3	Output waveform	Sine wave	Quasi square wave	Sine wave & Quasi square wave
4	Harmonic distortion	Low	High	Low
5	Efficiency	Low	High	High
6	Load	Isolated from supply	Not isolated from Supply	Not isolated from Supply but regulated by AVR
7	Cost	High	Low	Medium

High Voltage Direct Current Transmission (HVDC Transmission):

A High-Voltage Direct Current (HVDC) electric power transmission system is a Transmission system which uses direct current for the bulk transmission of electrical power.

The bulk transmission of electricity in the form of DC over long distances by means of overhead transmission line is the high voltage direct current transmission.

This type of transmission is preferred over HVAC transmission for very long distance when considering the cost, losses and many other factors.

HVDC Transmission System

We know that AC power is generated in the generating station. This should first be converted into DC. The conversion is done with the help of rectifier. The DC power will flow through the overhead lines. At the user end, this DC has to be converted into AC. For that purpose, an inverter is placed at the receiving end.

Thus, there will be a rectifier terminal in one end of HVDC substation and an inverter terminal in the other end. The power of the sending end and user end will be always equal.

$$(\text{Input Power} = \text{Output Power})$$

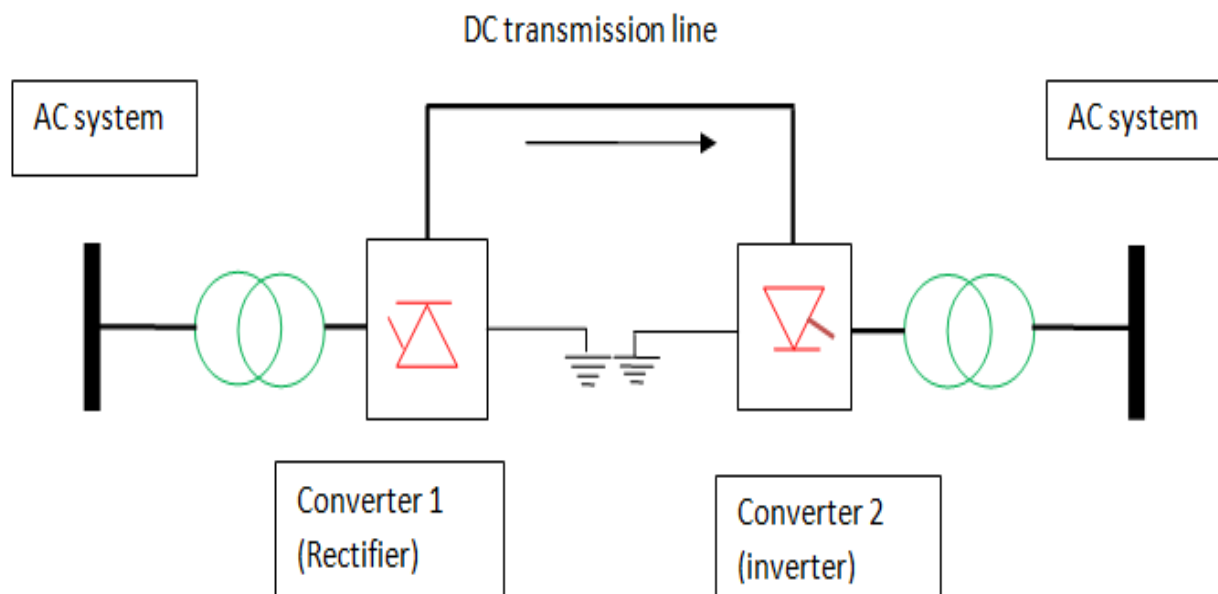


Figure 3: Mono Polar Link

The components of the **HVDC Transmission** system and its function are explained below:

- i. **A. C. System** : AC power Generating System at the generating station will generate A. C. Power.
- ii. **Converter 1 (Rectifier)**: The Rectifier Converter at the transmitting end converts AC Power in to DC Power before Transmission.
- iii. **DC Transmission Lines**: It can be cables or overhead lines which transfer High Voltage Direct Current to the destination / receiving end.
- iv. **Converter 2 (Inverter)**: The Inverter Converter at the receiving end converts DC Power in to AC Power after receiving at the destination.

Advantages of HVDC Transmission:

- i. HVDC Transmission System have Low losses.
- ii. HVDC Transmission System have Better Voltage regulation and Control ability.
- iii. HVDC Transmission System Transmit more power over a longer distance.
- iv. HVDC Transmission System need Less insulation.
- v. Reliability of HVDC Transmission System is high.
- vi. HVDC Transmission System Reduced line cost due to fewer conductors.

Disadvantages of HVDC Transmission

- i. In HVDC, Converters with small overload capacity are used.
- ii. In HVDC, Circuit Breakers, Converters and AC filters are expensive especially for small distance transmission.
- iii. HVDC link is extremely complicated.
- iv. In HVDC, power flow is uncontrollable.

Application of HVDC Transmission

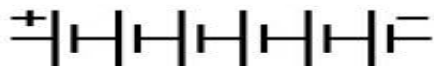
- i. HVDC Transmissions are used in Undersea and underground cables.
- ii. HVDC Transmissions are used in AC network interconnections
- iii. HVDC Transmissions are used in Interconnecting Asynchronous system.

Comparison of both HVAC and HVDC Transmission System

HVDC Transmission System	HVAC Transmission System
i. Low losses.	i. Losses are high due to the skin effect and corona discharge
ii. Better Voltage regulation and Control ability.	ii. Voltage regulation and Control ability is low.
iii. Transmit more power over a longer distance.	iii. Transmit less power compared to a HVDC system.
iv. Less insulation is needed.	iv. More insulation is required.
v. Reliability is high.	v. Low Reliability.
vi. Asynchronous interconnection is possible.	vi. Asynchronous interconnection is not possible.
vii. Reduced line cost due to fewer conductors.	vii. Line cost is high.
viii. Towers are cheaper, simple and narrow.	viii. Towers are bigger compared to HVDC.

Battery: A battery is a device consisting of one or more electrochemical cells with external connections provided to power electrical devices such as flashlights, mobile phones, and electric cars. When a battery is supplying electric power, its positive terminal is the Anode and its negative terminal is the Cathode.

Symbol:



Types of Batteries

Batteries generally are of two major types;

- i. Primary Batteries
- ii. Secondary Batteries
- i. **Primary Batteries:** Primary batteries are batteries that cannot be recharged once depleted. Primary batteries are made of electrochemical cells whose electrochemical reaction cannot be reversed.

The most popular type of primary batteries are **alkaline batteries** Pace makers, Animal trackers, Wrist watches, remote controls and children toys.

- ii. **Secondary Batteries:** Secondary batteries are batteries with electrochemical cells whose chemical reactions can be reversed by applying a certain voltage to the battery in the reversed direction. Also referred to as rechargeable batteries, secondary cells unlike primary cells can be recharged after the energy on the battery has been used up.

The Secondary batteries can be further classified into several other types based on their chemistry. There are basically four major chemistries for rechargeable batteries;

- i. Nickel Cadmium(Ni-Cd)
- ii. Nickel-Metal Hydride(Ni-MH)
- iii. Lead-Acid
- i. **Nickel-Cadmium Batteries:** The nickel–cadmium battery (Ni-Cd battery or Ni-Cad battery) is a type of rechargeable battery which is developed using nickel oxide hydroxide and metallic cadmium as electrodes. Ni-Cd batteries excel at maintaining voltage and holding charge when not in use. However, NI-Cd batteries easily fall a victim of the dreaded “memory” effect when a partially charged battery is recharged, lowering the future capacity of the battery.



Nickel – Cadmium battery

In comparison with other types of rechargeable cells, Ni-Cd batteries offer good life cycle and performance at low temperatures with a fair capacity but their most significant advantage will be their ability to deliver their full rated capacity at high discharge rates. They are available in different sizes including the sizes used for alkaline batteries, A to D. Ni-Cd cells are used individual or assembled in packs of two or more cells. The small packs are used in portable devices, electronics and toys while the bigger ones find application in aircraft starting batteries, Electric vehicles and standby power supply.

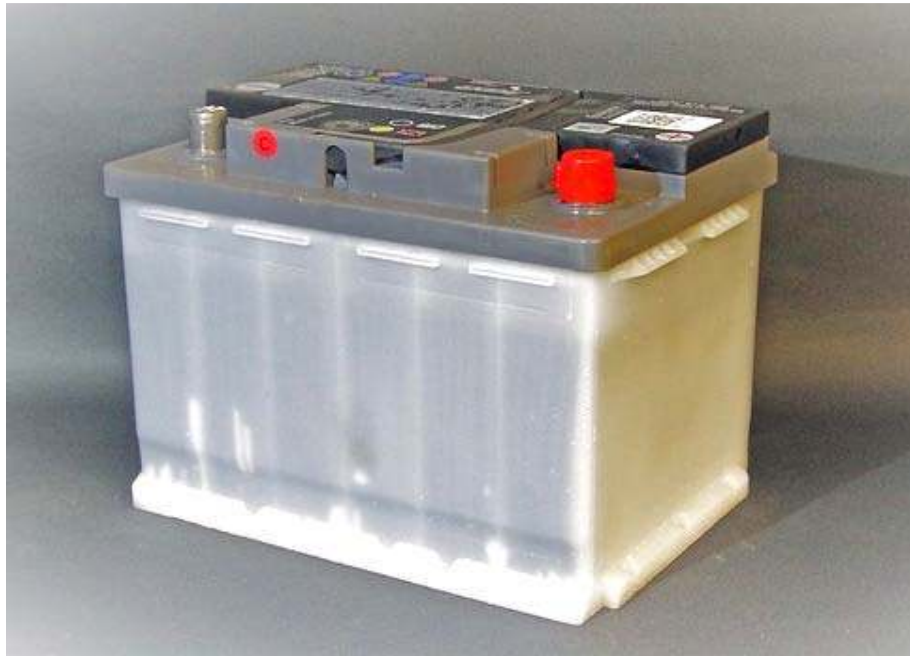
- ii. **Nickel-Metal Hydride Batteries:** Nickel metal hydride (Ni-MH) is another type of chemical configuration used for rechargeable batteries. The chemical reaction at the positive electrode of batteries is similar to that of the nickel–cadmium cell (Ni-Cd), with both battery type using the same nickel oxide hydroxide (NiOOH). However, the negative electrodes in Nickel-Metal Hydride use a hydrogen-absorbing alloy instead of cadmium which is used in NiCd batteries



Ni-MH Battery

NiMH batteries find application in high drain devices because of their high capacity and energy density. A NiMH battery can possess two to three times the capacity of a NiCd battery of the same size, and its energy density can approach that of a lithium-ion battery.

- iii. **Lead-Acid Batteries:** Lead acid batteries are a low-cost reliable power workhorse used in heavy duty applications. They are usually very large and because of their weight, they're always used in non-portable applications such as solar-panel energy storage, vehicle ignition and lights, backup power and load leveling in power generation/distribution. The lead-acid is the oldest type of rechargeable battery and still very relevant and important into today's world. Lead acid batteries have very low energy to volume and energy to weight ratios but it has a relatively large power to weight ratio and as a result can supply huge surge currents when needed. These attributes alongside its low cost makes these batteries attractive for use in several high current applications like powering automobile starter motors and for storage in backup power supplies.



Lead Acid Batteries

Selecting the right battery for your application

One of the main problems hindering technology revolutions like IoT is power, battery life affects the successful deployment of devices that require long battery life and even though several power management techniques are being adopted to make the battery last longer, a compatible battery must still be selected to achieve the desired outcome.

Below are some factors to consider when selecting the right type of battery for your project.:

- i. **Size of Load:** It means the total KVA requirement of load to be connected.
- ii. **Energy Density:** The energy density is the total amount of energy that can be stored per unit mass or volume. This determines how long your device stays on before it needs a recharge.
- iii. **Power Density:** Maximum rate of energy discharge per unit mass or volume. Low power: laptop, i-pod. High power: power tools.
- iv. **Safety:** It is important to consider the temperature at which the device you are building will work. At high temperatures, certain battery components will breakdown and can undergo exothermic reactions. High temperatures generally reduces the performance of most batteries.
- v. **Life cycle durability:** The stability of energy density and power density of a battery with repeated cycling (charging and discharging) is needed for the long battery life required by most applications.
- vi. **Cost:** Cost is an important part of any engineering decisions you will be making. It is important that the cost of your battery choice is commensurate with its performance and will not increase the overall cost of the project abnormally.

FILL IN THE BLANKS:

1. UPS stands for
2. UPS in which Inverter is even the main power is ON is called ON-Line UPS.
3. The Online UPS provides an Between the Load and AC supply.
4. On-Line UPS System is Reliable than OFF Line UPS.
5. The back-up Time depends on the of the Battery and the of Inverter.
6. UPS in which Inverter is when the main Power is ON is called OFF-Line UPS.
7. UPS also called Double Conversion UPS.
8. In UPS, the primary power source is mains line power, and secondary power source is battery.
9. The UPS is also called Backup UPS.
10. In an UPS is one where the Inverter is running 100% of Time interacting continuously with the changing state of the Input AC Utility Line.
11. In an UPS, the batteries are always connected to the Inverter, so that No Power Transfer Switches are necessary.
12. In ON-Line UPS, the Inverter is all the time.
13. HVDC Stand for
14. For charging of Battery supply is required.
15. HVAC System are economical only for transmission.
16. System has full control over the Transmission Line.
17. SMF stand for
18. In OFF-Line UPS, the Inverter is when the main supply is present.
19. A Switching Mode Power Supply is a multistage supply.
20. Sealed Maintenance Free Batteries (SMF) than Lead Acid Batteries.

Answers:

- | | | | |
|----------------------------------|---------------------------------|-------------------------------------|-------------|
| 1) Un-Interruptable Power Supply | 2) ON | 3) Isolation | 4) more |
| 5) Capacity, Efficiency | 6) OFF | 7) ON-Line | 8) OFF-Line |
| 9) OFF-Line | 10) Line Interactive | 11) ON-Line | |
| 12) ON | 13) High Voltage Direct Current | 14) DC | |
| 15) Short Distance | 16) HVDC | 17) Sealed Maintenance Free Battery | |
| 18) DC | 19) DC | 20) Costlier | |

TRUE / FALSE Statements:

1. In ON-Line UPS, the Inverter is ON all the time.
2. Sealed Maintenance Free Batteries (SMF) Cheaper than Lead Acid Batteries.
3. ON-Line UPS also called Double Conversion UPS.
4. The ON-Line UPS is also called Backup UPS.
5. UPS are never used in street light.
6. Sealed Maintenance Free Batteries (SMF) costlier than Lead Acid Batteries.
7. The output of a regulated power supply changes when input AC Supply Changes.
8. In an OFF-Line UPS, the batteries are always connected to the Inverter, so that No Power Transfer Switches are necessary.
9. In OFF-Line UPS, the primary power source is mains line power, and secondary power source is battery.
10. A HVDC Transmission Line are Cheaper than HVAC Line.
11. A Switching Mode Power Supply is a multistage DC supply.
12. UPS in which Inverter is OFF when the main Power is ON is called OFF-Line UPS.

Answers:

- | | | | | |
|----------|-----------|----------|----------|-----------|
| 1) TRUE | 2) FALSE | 3) TRUE | 4) FALSE | 5) TRUE |
| 6) TRUE | 7) FALSE | 8) FALSE | 9) TRUE | 10) FALSE |
| 11) TRUE | 12) FALSE | | | |