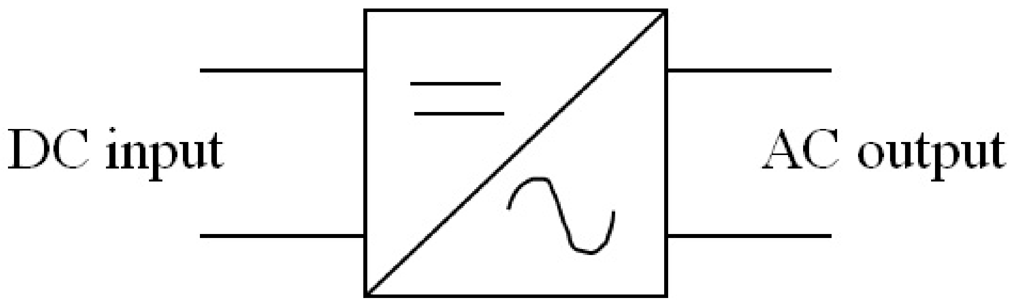
Inverters, Choppers, Dual-Converters and Cyclo-Converters

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 :

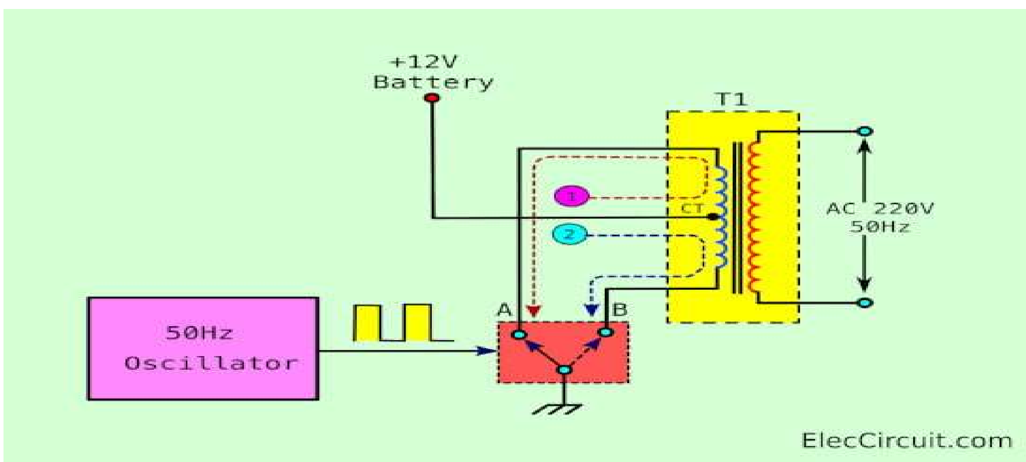


Figure shows the basic circuit of Inverter circuit. The Inverter circuit consist of Battery, centre tapped Transformer, Electronics Switch controlled by Oscillator.

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).

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 selects 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.

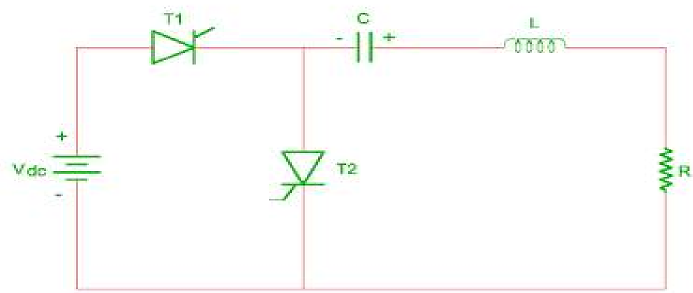


FIGURE A : BASIC SERIES INVERTER

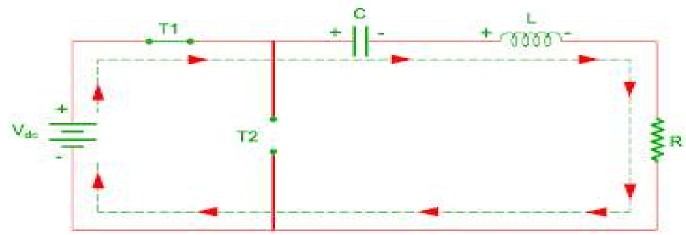


FIGURE B : EQUIVALENT CIRCUIT WHEN SCR T1 'ON'

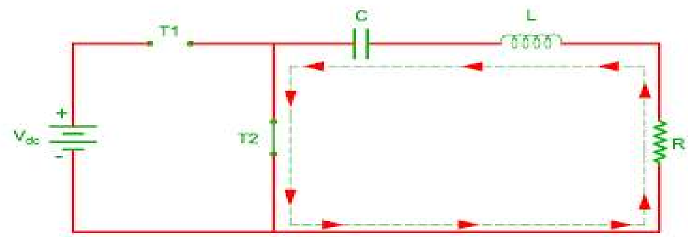


FIGURE C : EQUIVALENT CIRCUIT WHEN SCR T2 'ON'

<u>The Operation of the Series Inverter is explained as follows.</u>

Mode 1

i. When SCR T_1 Triggered, It will Turned ON and the voltage V_{dc} directly applies to RLC series circuit.

ii. The Capacitor will charge with the polarity + C - as shown in the figure B.

iii. The voltage across capacitor becomes + V_{dc} when the load current becomes maximum.

iv. 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

i. 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 +2 V_{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.

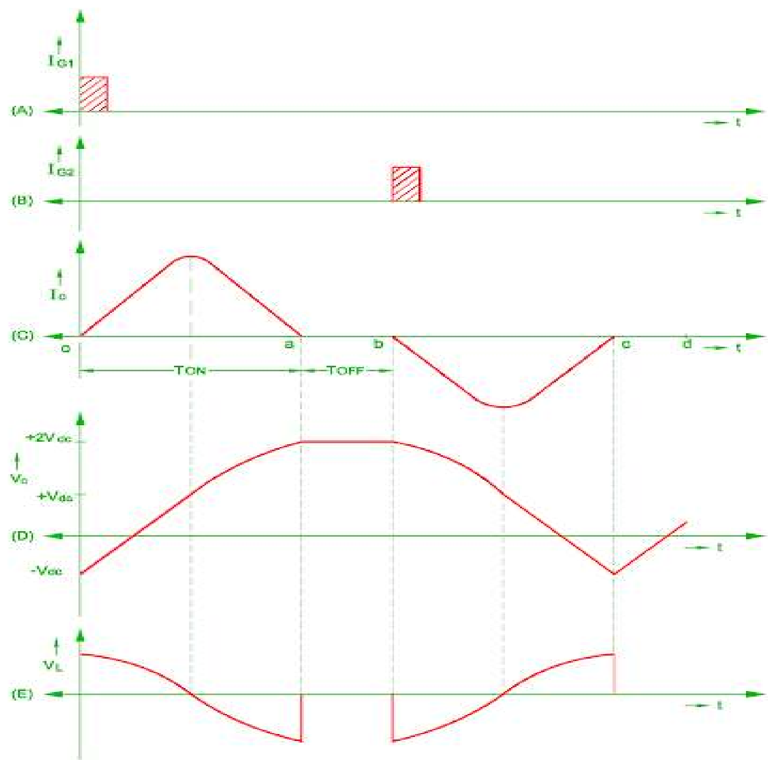


FIGURE D : VOLTAGE AND CURRENT WAVEFORMS OF SERIES INVERTER
(A) Gate pulse for SCR T1 (B) Gate pulse for SCR T2 (C) output current,
(D) Capacitor voltage (E) Load voltage

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.

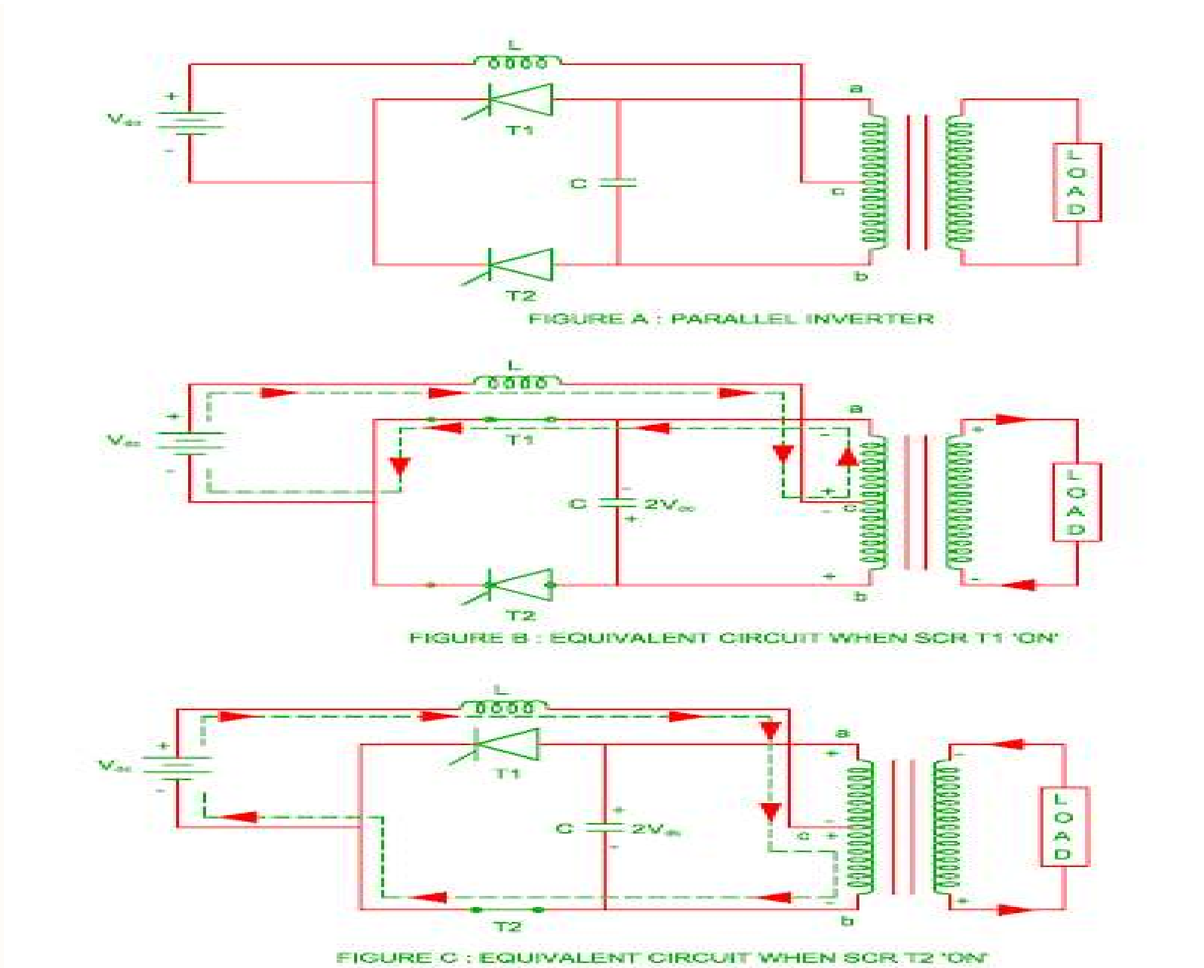
2. **Parallel inverter**: Parallel Inverters are those Inverters in which commutating components are connected parallel with the load.

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 T_1 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.



.

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 – 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.

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

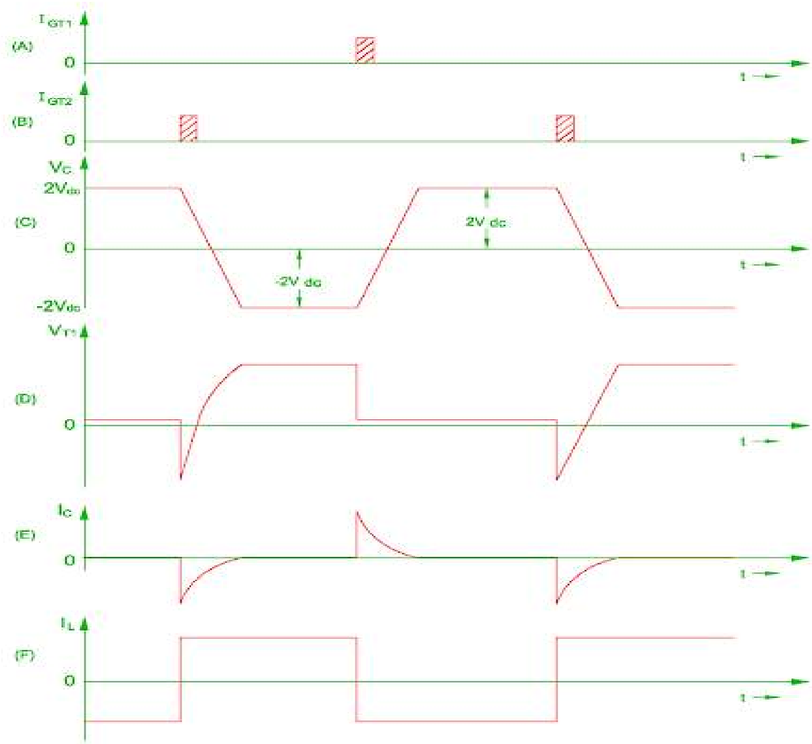


FIGURE D : VOLTAGE AND CURRENT WAVEFORMS FOR PARALLEL INVERTER
(A) GATE PULSE FOR SCR T1 (B) GATE PULSE FOR SCR T2 (C) VOLTAGE ACROSS CAPACITOR (D) VOLTAGE ACROSS SCR T1 (E) CAPACITOR CURRENT (F) LOAD CURRENT

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:

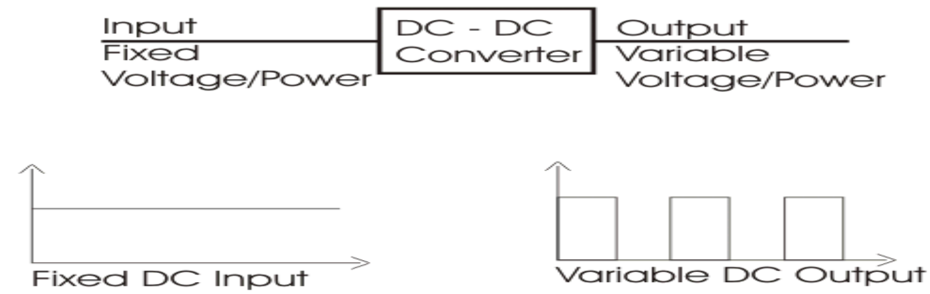
I. The parallel inverter is useful only when load is fixed.
II. The parallel inverter does not useful for higher power for fixed value of inductor L and capacitor C.
III. The design of inverter for fixed voltage is possible.

UNIT - III

Inverters, Choppers, Dual-Converters and Cyclo-Converters

CHOPPERS

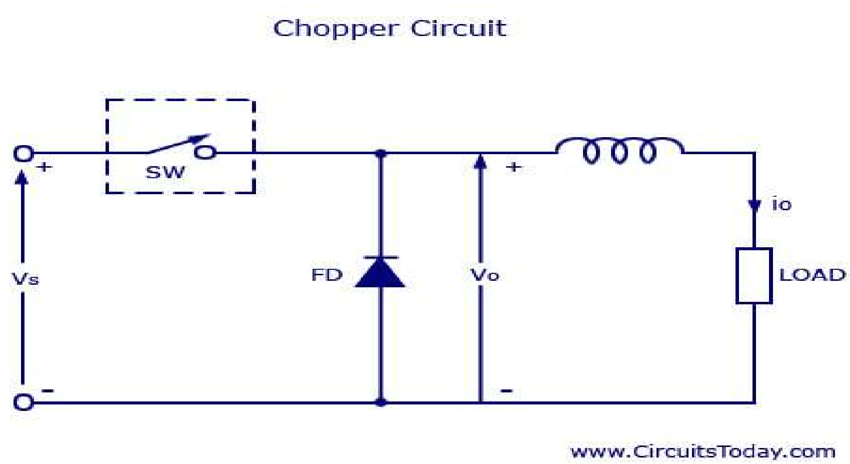
Chopper: A chopper is a device that converts fixed DC input to a variable DC output voltage directly.



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

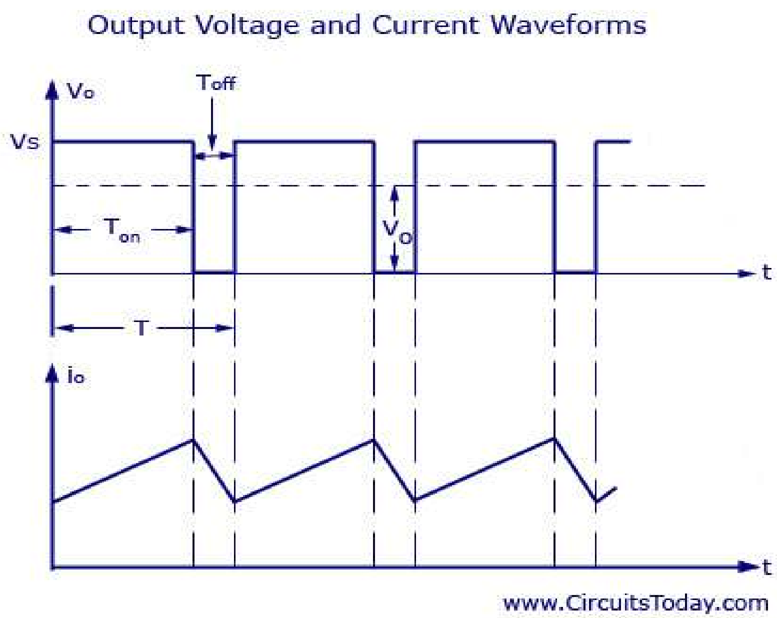
The Principle of operation of chopper can be understood from the circuit diagram below.



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 (Vs) give continuous power supply to the chopper and chopped DC is obtained across the load as V_0.

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 though 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

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

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

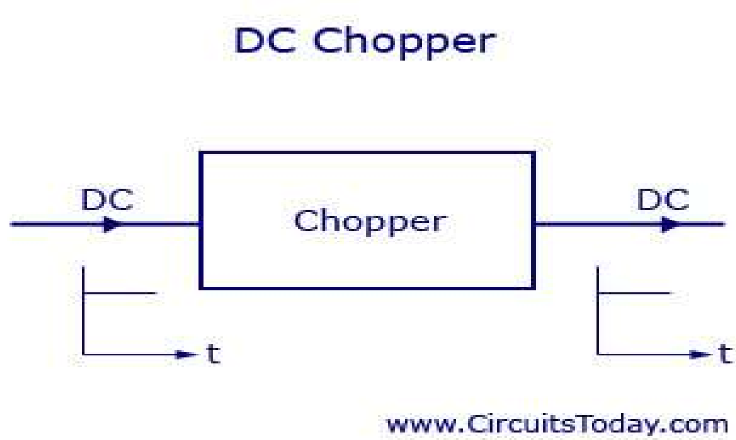
Classification of Choppers:

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

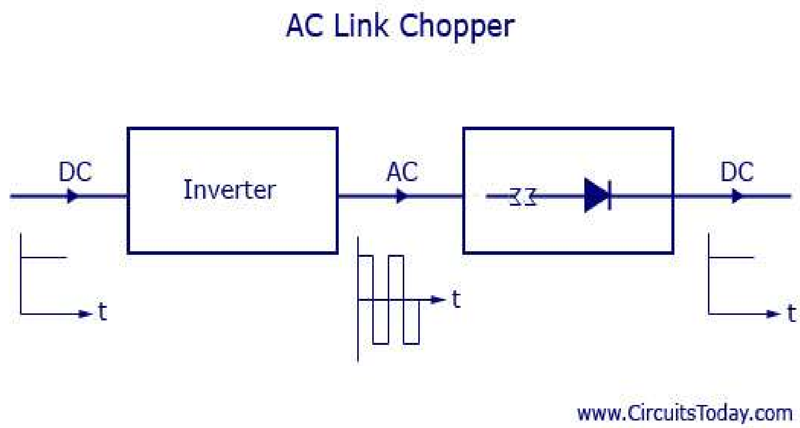
1. **Based on their operation principle and type of source voltage**

   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.



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.



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

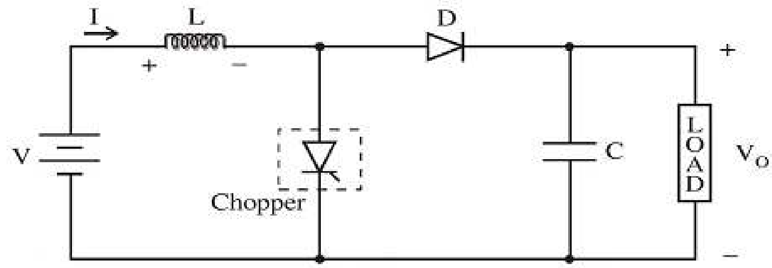
i. **Natural Commutated Chopper**: The Choppers which are commutated naturally are called Natural Commutated Chopper. A. C. based Choppers are naturally commutated Chopper.

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:**

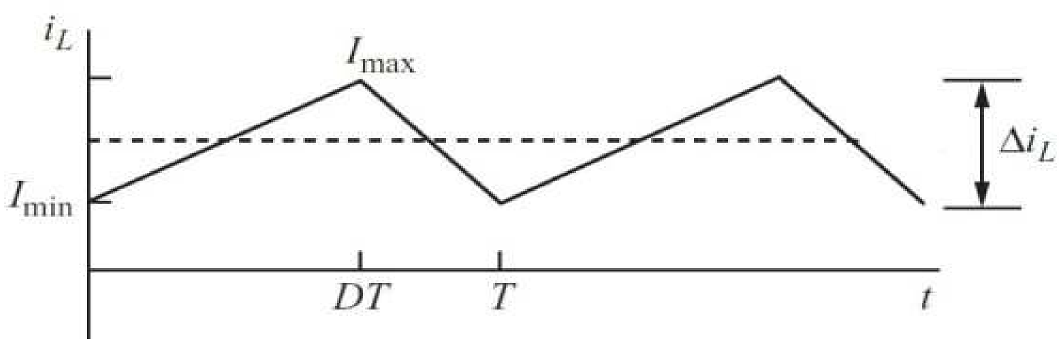
i. **Step-Up Chopper:** Step-Up Choppers are those Choppers which gives Output Voltage is greater than input voltage. The increase in output voltage depends on the frequency of switching. While switch is OFF the output voltage almost same as input. While switch is ON, it is assumed as short and hence 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 – 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 $V_0 = V_S + L\ di / dt$ which is greater than the input voltage. Current changes from I_{max} to $I_{min.}$

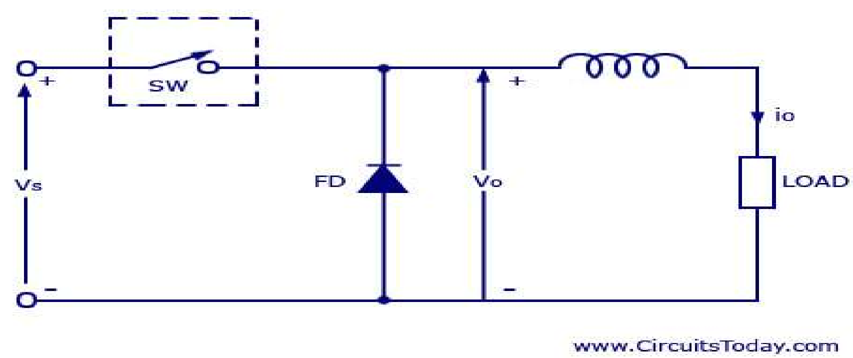
Step–up chopper is also known as Boost choppers.

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.

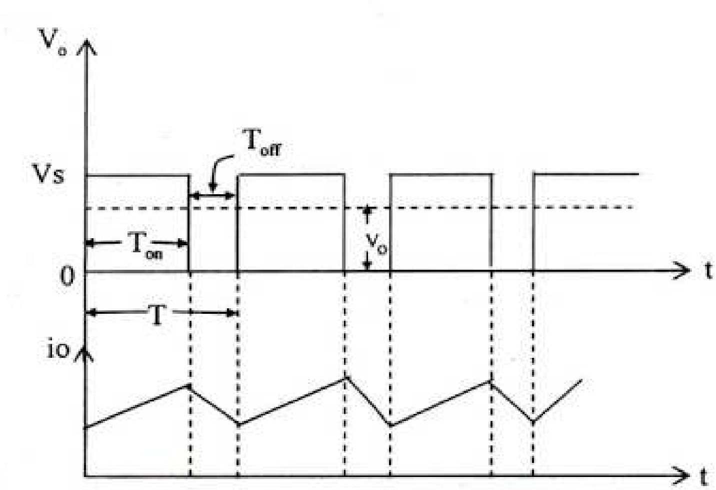
Output (V_0) or the average output voltage of Step Down Choppers is always less than the input voltage V_s.

Chopper Circuit



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 (Vs) give continuous power supply to the chopper and chopped DC is obtained across the load as V_0.



Step Down Chopper waveform

During the period T_{on}, chopper is on and load voltage V_O is equal to source voltage Vs. 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 Ton, load current rises where as during turn off Toff load current decays.

Average load Voltage is given by

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

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.

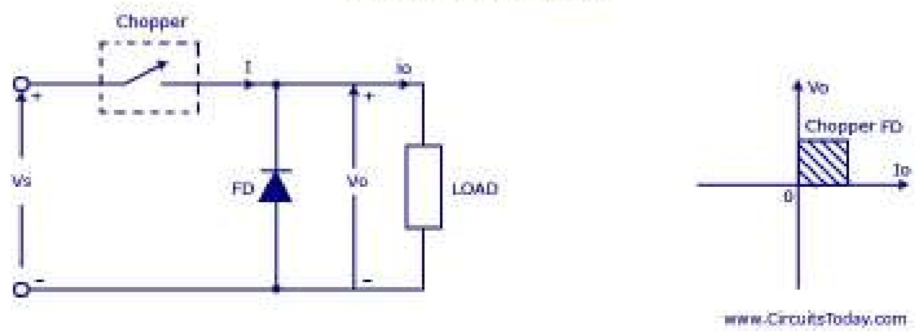
1. Based on the quadrant of operation

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.

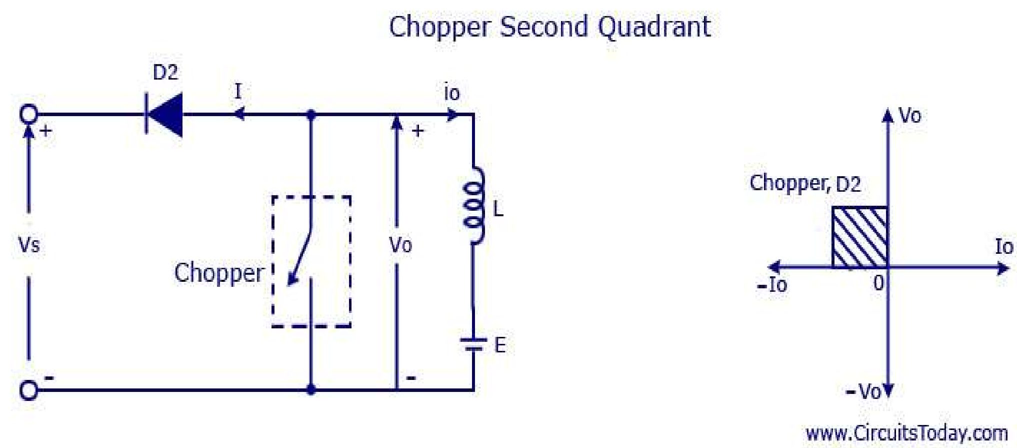
Chopper First Quadrant



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 .

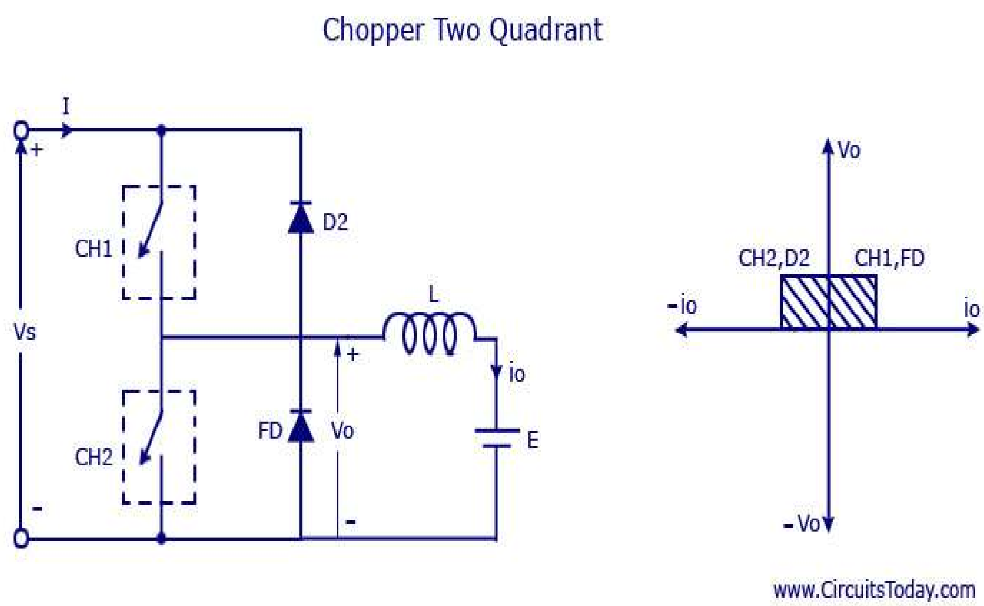
When the chopper is ON, V_0 is zero but the load voltage E drives the current through the inductor L and the chopper, L stores the energy during the time T_{on} of the Chopper .

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_O is Positive and the current I_0 is Negative , the direction of power flow will be from load to source. The load voltage $V_0 = (E+L\,.di/dt)$ 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:



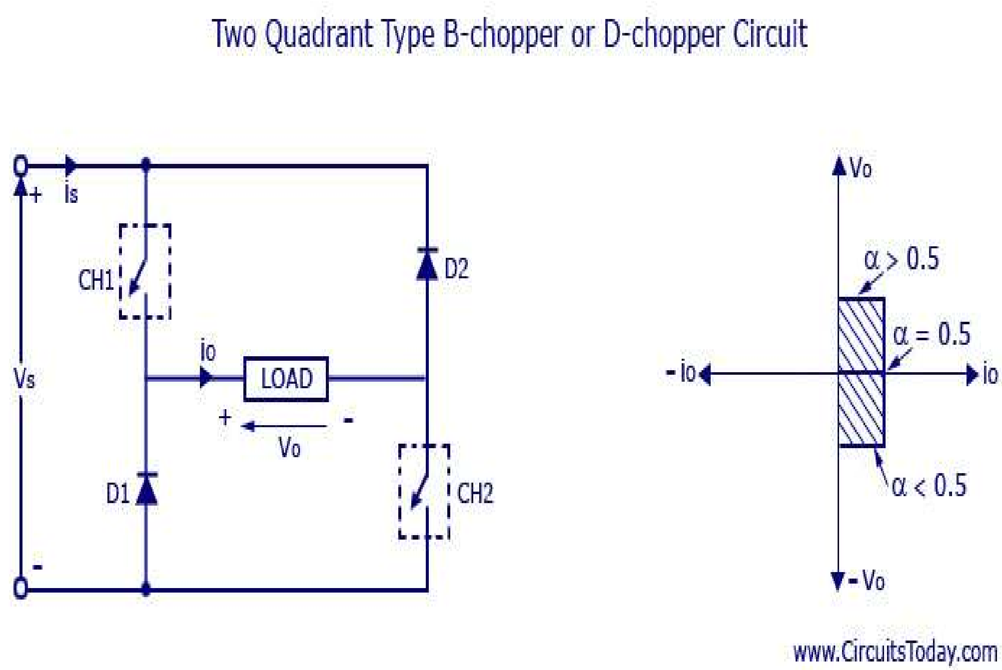
Output voltage V_0 will always Positive in both Quadrant (1 & 2), as the Freewheeling diode FD is present across the load. When any chopper (CH_1 or CH_2) is ON, the Freewheeling Diode starts conducting and the output voltage V_0 will be equal to V_s .

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 D2 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 D2 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

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_0 will be equal to + V_s . When both V_0 and I_0 are positive, the circuit operate in First quadrant and in rectifying. The energy is fed from source to load

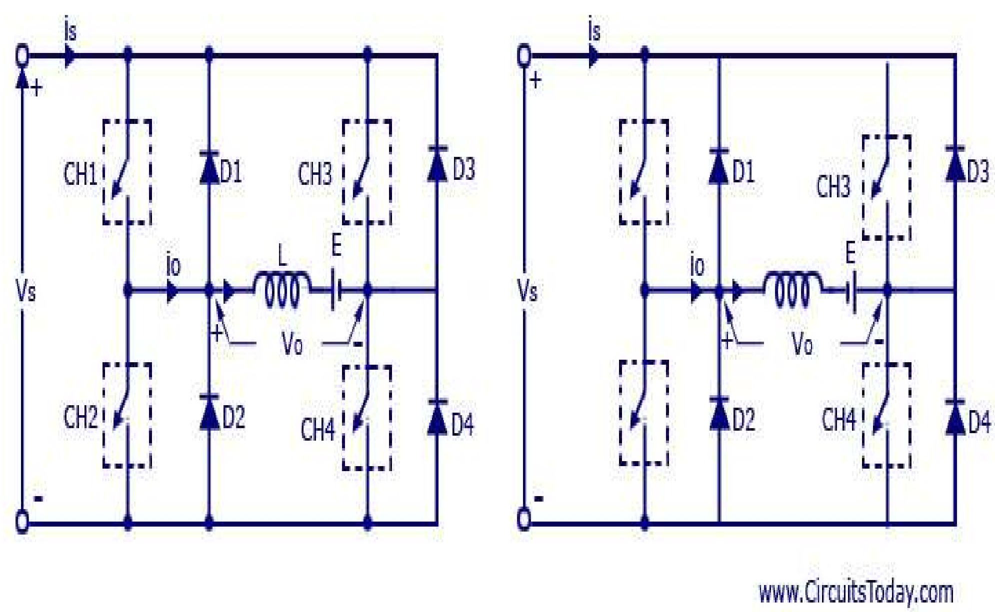
When the both choppers (CH_1 & CH_2) are OFF and both diodes (D_1 & D_2) are ON, the output voltage $V_0 = -V_s$. When V_O is Negative & I_O is Positive, the circuit operate in Fourth Quadrant and in Inverting Mode. The Energy is fed from Load to Source.

The average output voltage V_0 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



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_0 will be equal to the source voltage + V_s and the load current I_0 will begin to flow from source to load . Both V_0 and I_0 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. 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:

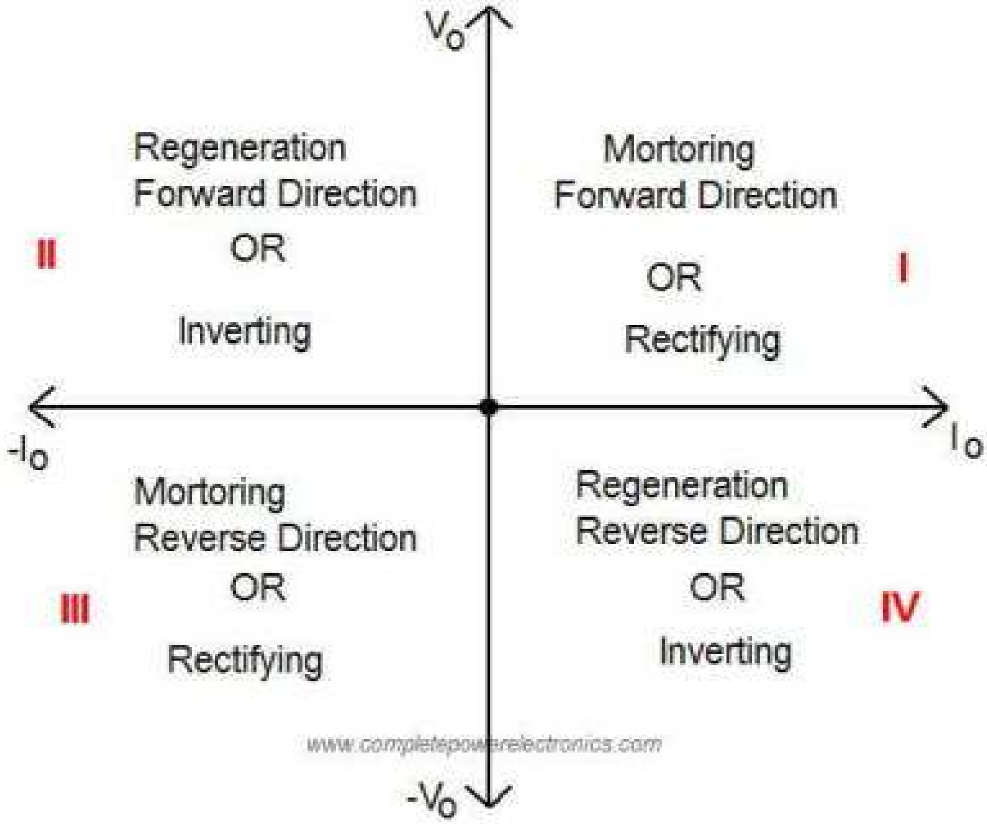
In third quadrant operation, CH_2 will be ON & CH_3 will be in operational and other both Choppers (CH_1 & CH_4) kept OFF. In this quadrant working the polarity of the load should be reversed. As the chopper CH_3 is ON, the load gets connected to the source V_s and V_0 and I_0 will be negative and the 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.

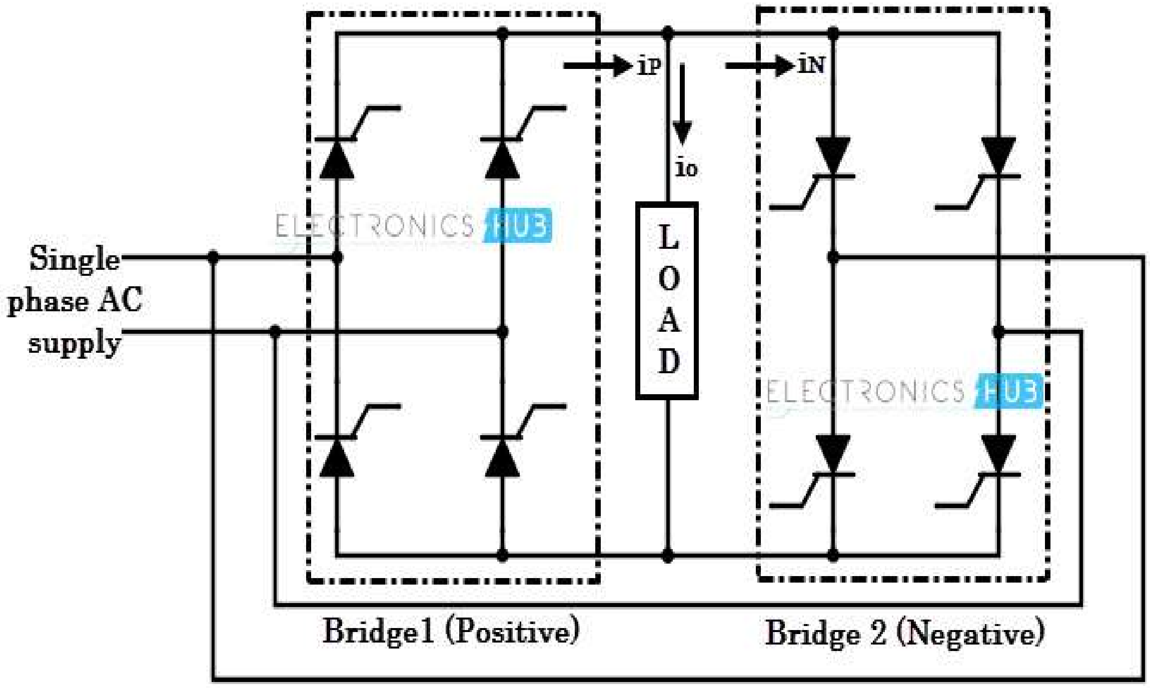
These are most commonly used and work with help of Natural Commutation hence comparatively easy to build and operate.

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**:

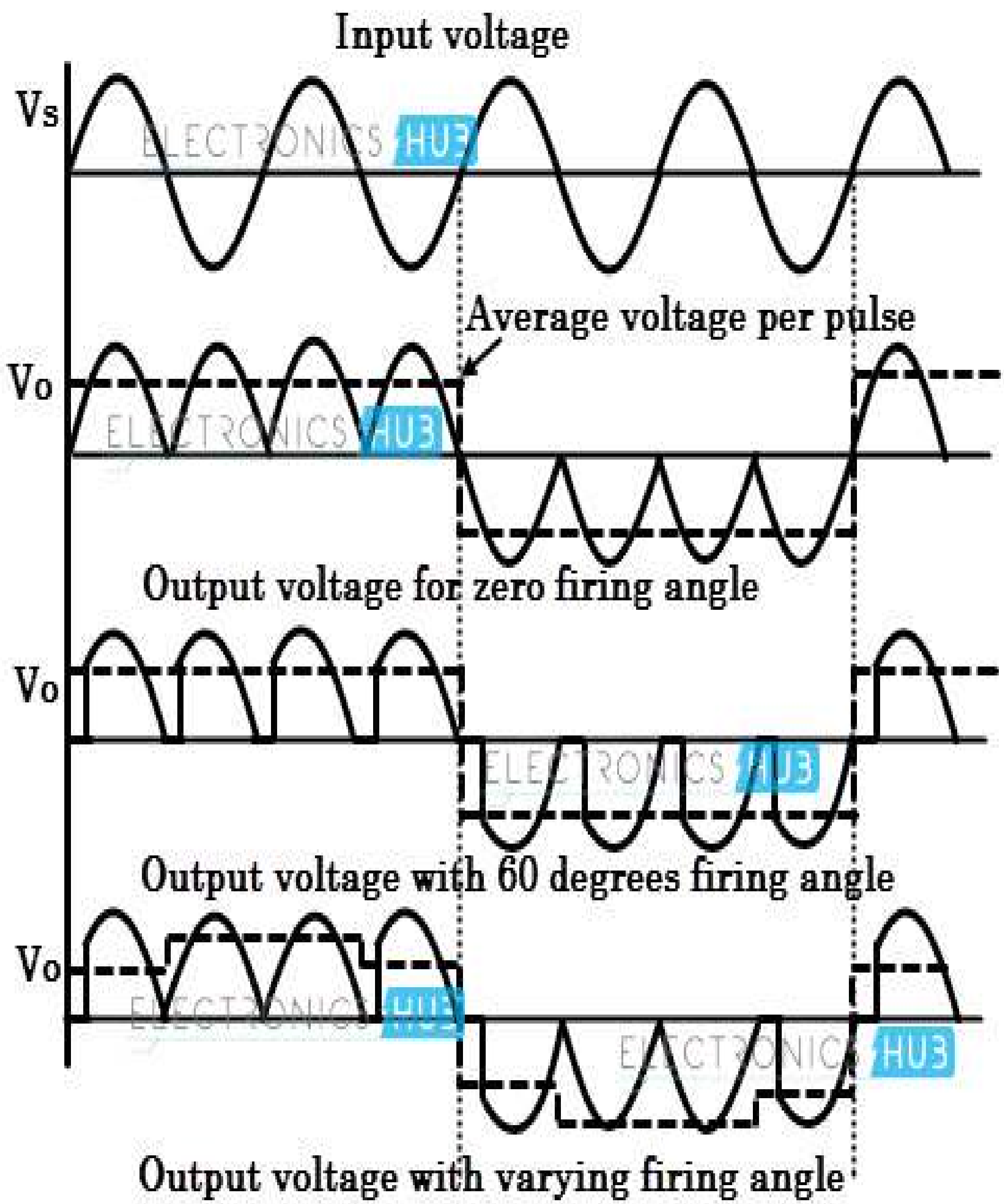
It consists of Two Full-Wave, Fully Controlled Bridge thyristors, where each Bridge has 4 thyristors, and each bridge is connected in opposite direction (back to back) such that both Positive and Negative Voltages can be obtained as shown in figure below. Both these bridges are excited by single phase,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



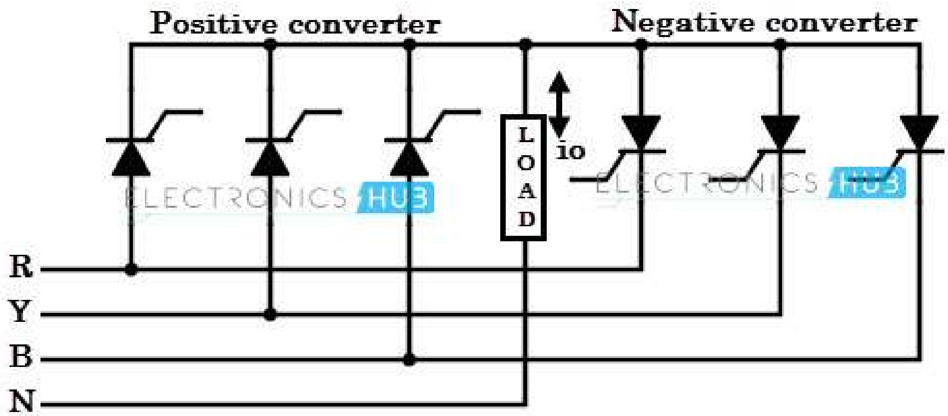
The above figure shows output waveforms of a cyclo-converter that produces one-fourth of the input frequency. Here, for the first two cycles, the positive converter operates and supplies current to the load.

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.

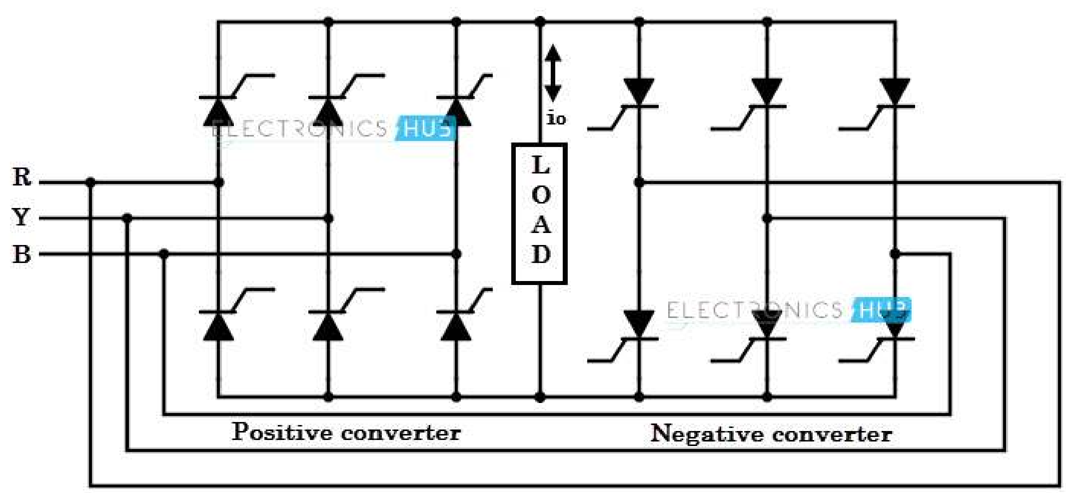
Here one converter is disabled if another one operates, so there is no circulating current between two converters.

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

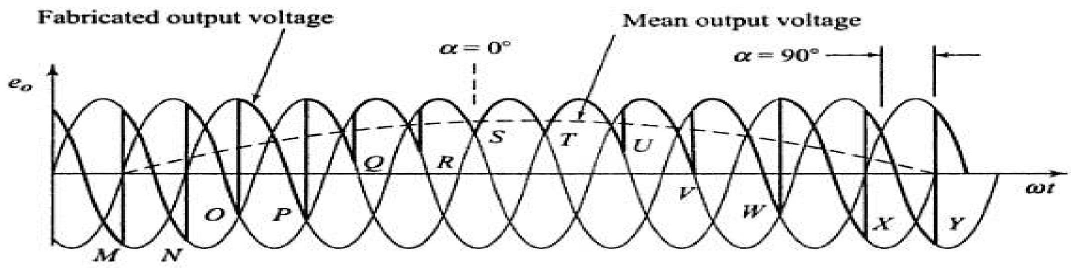
During Positive Half Cycle of the Input, conduction of the Positive Group thyristors is controlled and during Negative Half-Cycle, conduction of Negative group of thyristors is controlled in order to produce an output voltage at desired frequency.

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).

UNIT - III

Inverters, Choppers, Dual-Converters and Cyclo-Converters



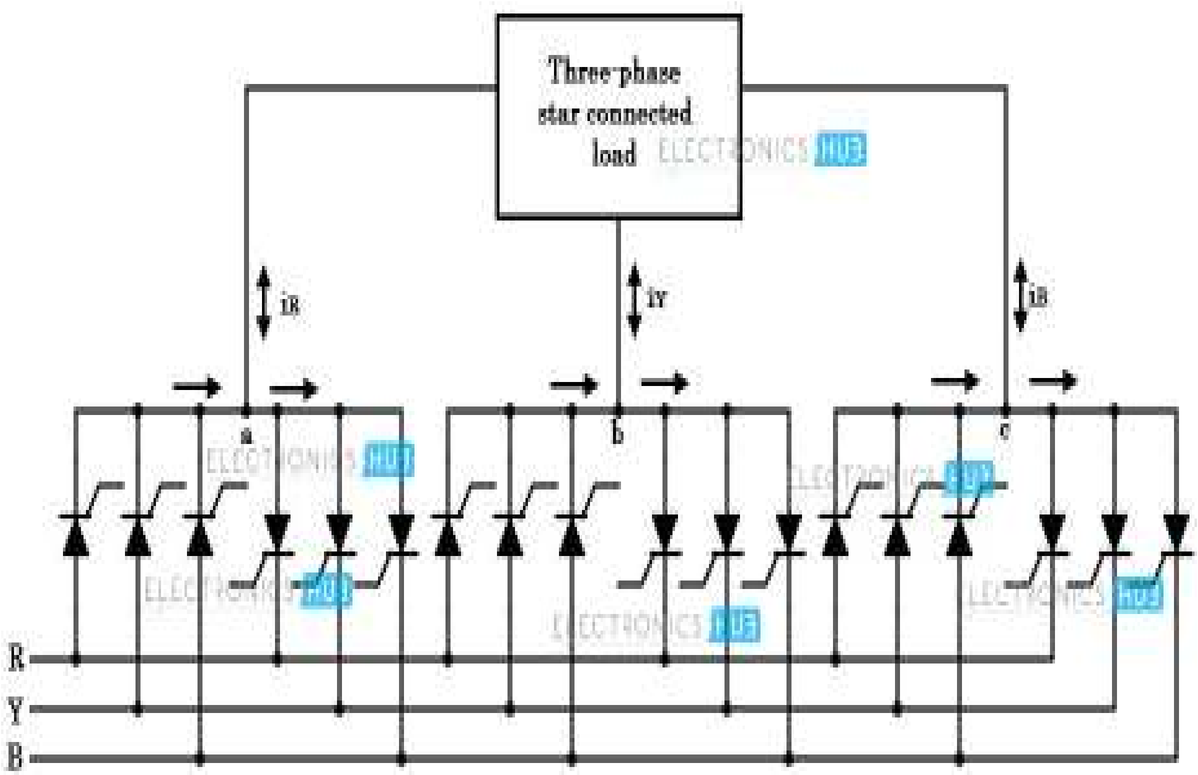
The above figure shows the conversion of three phase supply at one frequency to single phase supply of lower frequency. In this, the firing angle to a positive group of thyristors is varied progressively to produce single phase output voltage.

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.

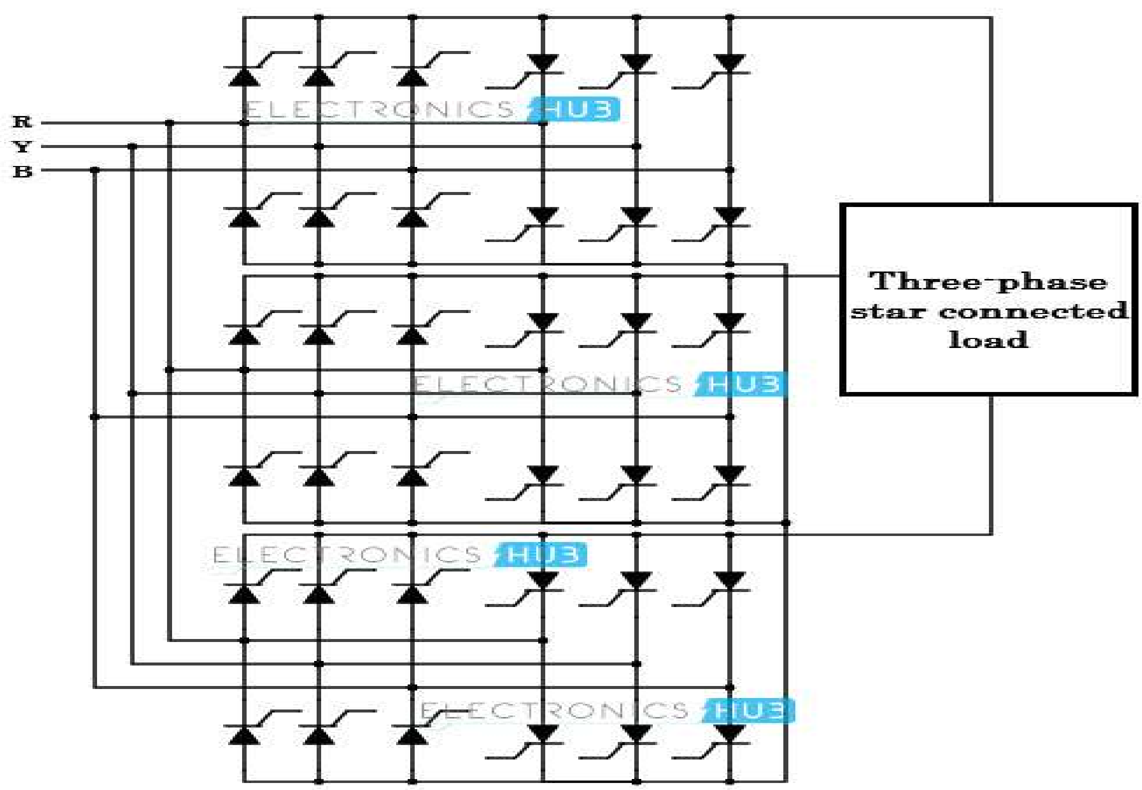
Three Phase Cyclo-converter of both Star Connection Load and Delta Connection Load types are shown in figures below.



Star Connection Load

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-convers 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.

UNIT - III

Inverters, Choppers, Dual-Converters and Cyclo-Converters

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 ($\alpha 1$) will be $0 < \alpha\ 1 < 90^0$ (V_{dc} and I_{dc} are positive)

During Converter-2 Operation:

Firing angle ($\alpha\ 2$) will be $0 < \alpha\ 2 < 90^0$ (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 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 Convertor:

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

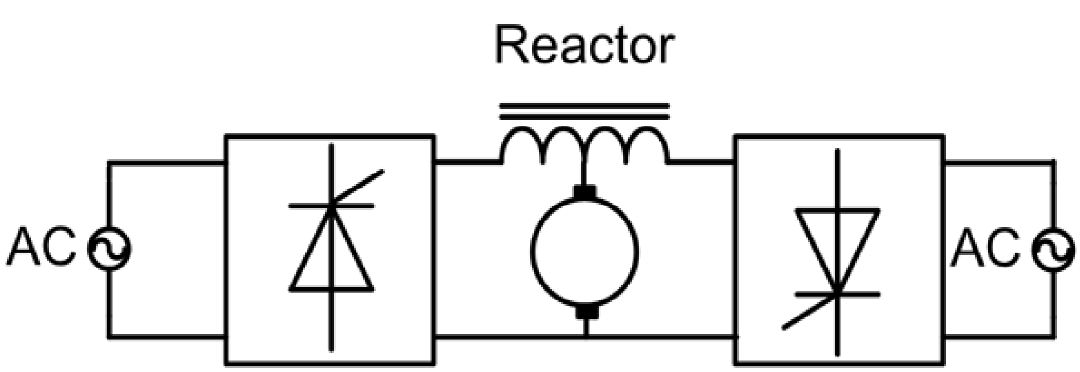
Disadvantages of Non-Circulating Current Mode Dual Convertor:

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 Convertor 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 $\alpha_1 + \alpha_2 = 180^0$. 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 $0 < \alpha\ 1 < 90^0$ and Converter 2 works as an Inverter when the firing angle is $90^0 < \alpha\ 2 < 180^0$. In this condition, V_{dc} and I_{dc} are Positive.

The Converter 1 works as an Inverter when firing angle be $90^0 < \alpha\ 1 < 180^0$and Converter 2 works as a Controlled Rectifier when the firing angle is $0 < \alpha\ 2 < 90^0$. 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.

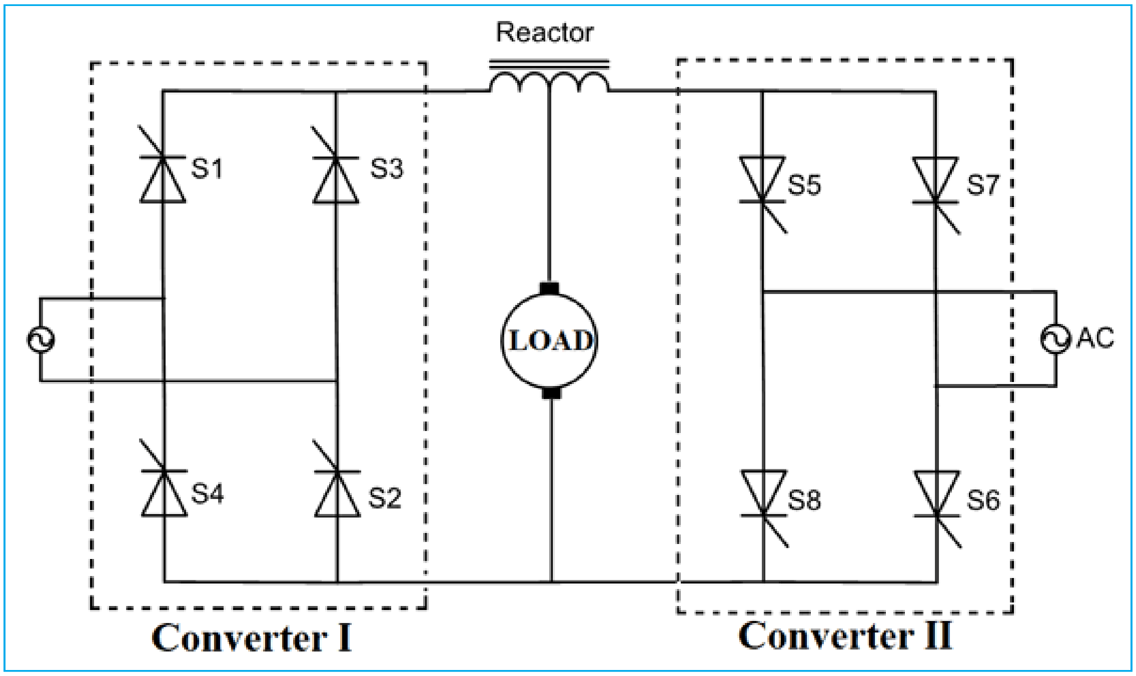
UNIT - III

Inverters, Choppers, Dual-Converters and Cyclo-Converters

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.



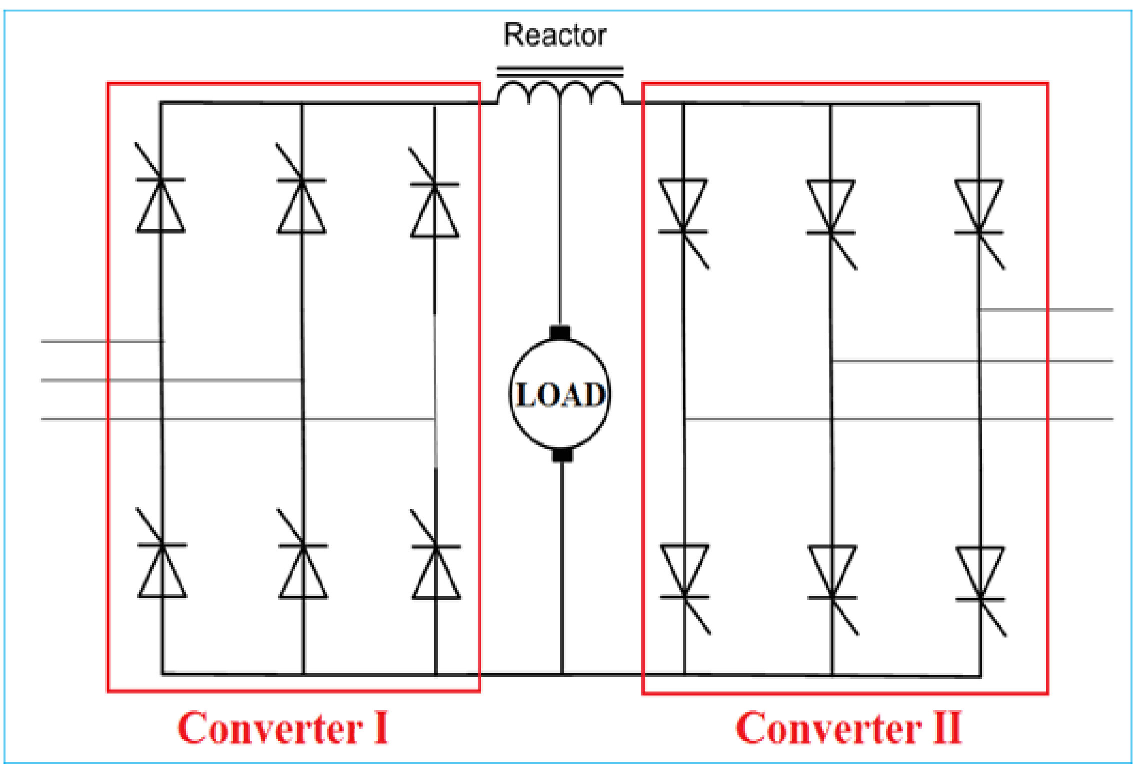
1. **The Firing Angle of Converter - 1 is α_1 and α_1 is less than 90˚**. Hence, the Converter-1 act as a Rectifier. For Positive Half Cycle ($0 < t < \pi$), SCRs S_1 and S_2 will conduct and for a Negative Half Cycle ($\pi < t < 2\pi$),SCRs S_3 and S_4 will conduct. In this operation, Output Voltage 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 - α_1 = α_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 - α_1 = α_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.**

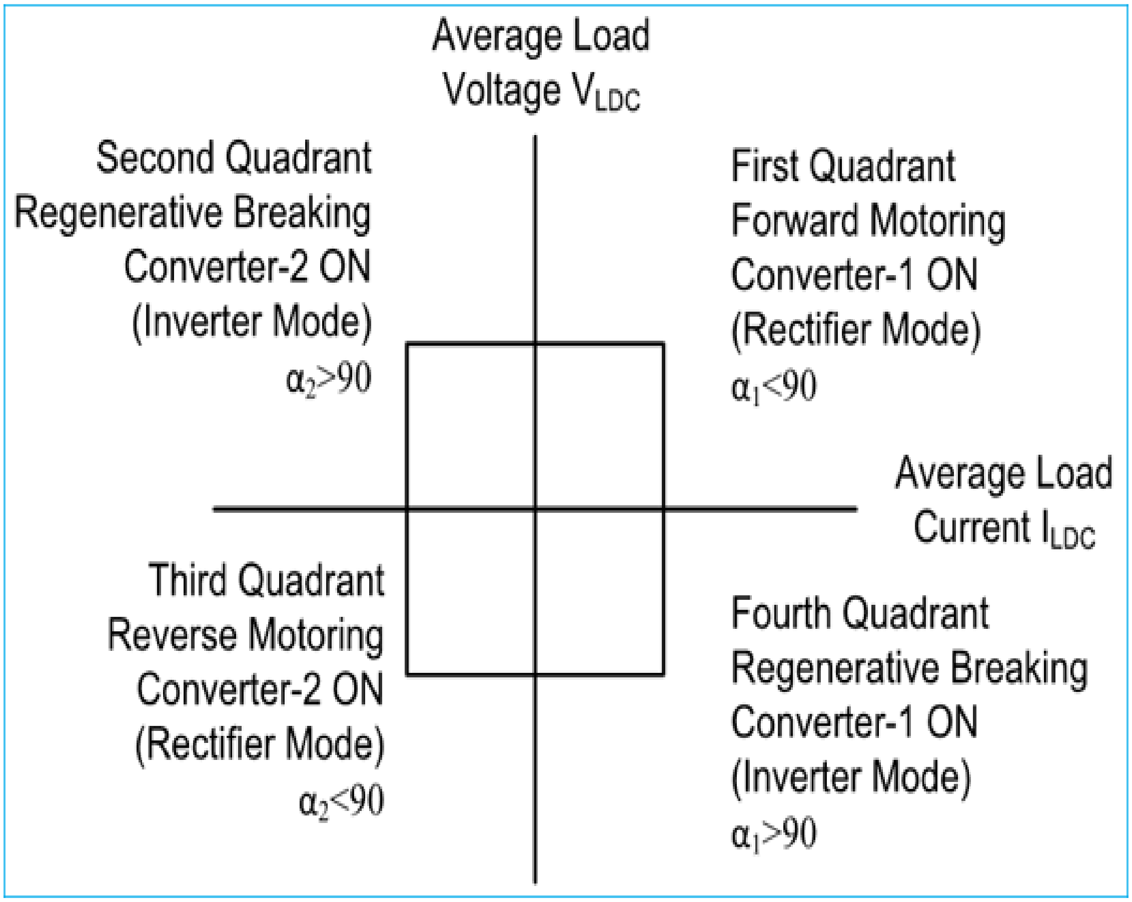
3. **For reverse rotation of DC Motor, Converter-2 act as Rectifier and Converter-1 act as an Inverter.** The firing angle of Converter-2 α_2 is less than 90˚. The alternative voltage source supplies the Load. In this operation, the Load Current is Negative and the Output Average Voltage is also Negative. **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

.

UNIT - III

Inverters, Choppers, Dual-Converters and Cyclo-Converters

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**

UNIT - III

Inverters, Choppers, Dual-Converters and Cyclo-Converters

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**

UNIT - III

Inverters, Choppers, Dual-Converters and Cyclo-Converters

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**

UNIT - III

Inverters, Choppers, Dual-Converters and Cyclo-Converters

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 3^{rd} 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**