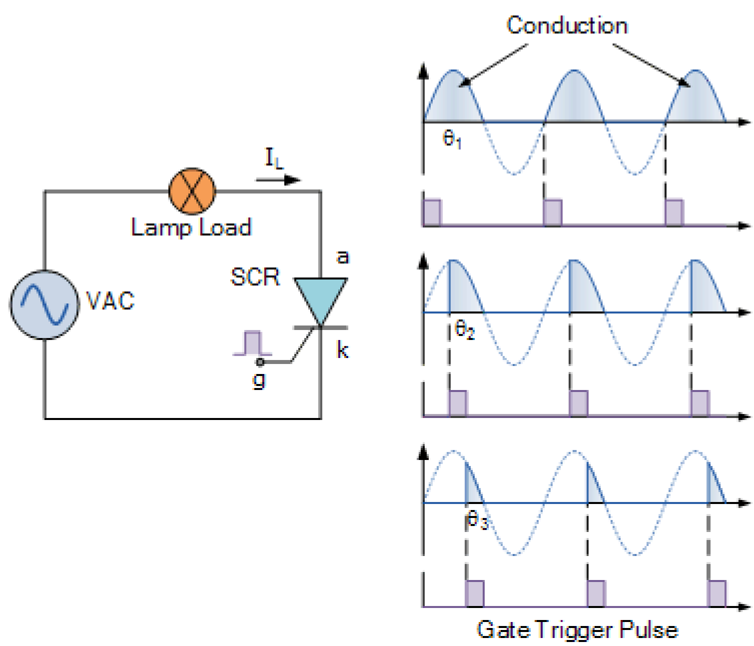
Power Electronics

Learning outcomes
After completion of the chapter 1, students will be able to:
Describe the construction, working principles of SCR, methods of SCR triggering, SCR specifications
VI characteristics of SCR , TRIAC , UJT, DIAC

Chapter 1

1.Introduction

Thyristor is a unidirectional device, that is it will only conduct current in one direction only, but unlike a diode, the thyristor can be made to operate as either an open-circuit switch or as a rectifying diode depending upon how
the thyristors gate is triggered. A thyristor is a solid-state semiconductor device with four layers of alternating P- and N-type materials. It acts exclusively as a bistable switch, conducting when the gate receives a current trigger, and continuing to conduct until the voltage across the device is reversed biased, or until the voltage is removed



Silicon Controlled Rectifier (SCR)

- *The silicon controlled rectifier (SCR) is a three terminal semiconductor switching device which can be used asa controlled switch to perform various functions such as rectification, inversion and regulation of power flow.*
- *An SCR can handle currents upto several thousand amperes and voltages upto more than 1kV.*
- *The SCR has appeared in the market under different names such as thyristor, thyrode transistor.*
- *Like the diode, SCR is a unidirectional device,i.e. it will only conduct current in one direction only, but unlike a diode, the SCR can be made to operate as either an open-circuit switch or as a rectifying diode depending upon how its gate is triggered.*
- *In other words, SCR can operate only in the switching mode and cannot be used for amplification.*
- *Hence, it is extensively used in switching d.c. and a.c., rectifying a.c. to give controlled output, converting d.c. into a.c. etc.*

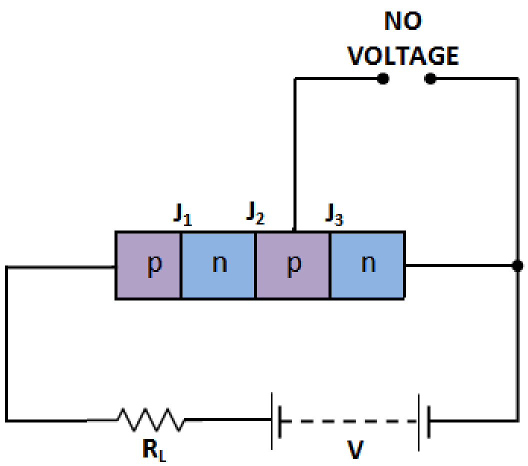
Working of SCR

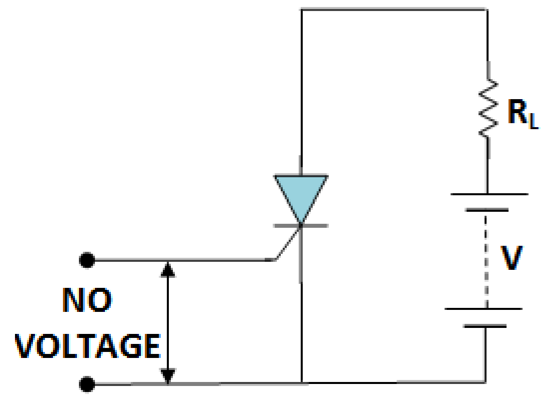
In a silicon controlled rectifier, load is connected in series with anode. The anode is always kept at positive potential w.r.t. cathode.

The working of SCR can be studied under the following two heads:

When Gate is Open

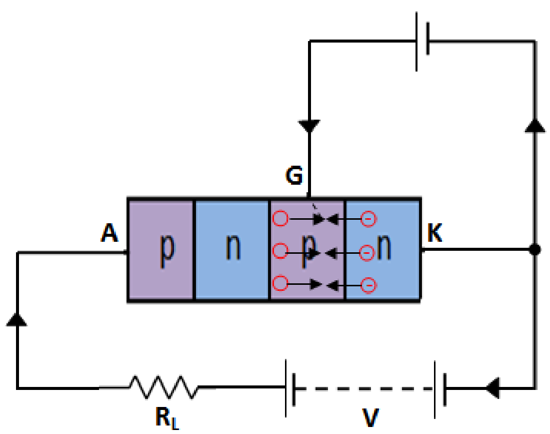
- *Under this condition, junction J2 is reverse biased while junction J1 and J3 are forward biased.*
- *Hence, the situation in the junctions J1 and J3 is just as in a npn transistor with base open.*
- *Consequently, no current flows through the load RL and the SCR is cut off.*
- *However, if the applied voltage is gradually increased, a stage is reached when the reverse biased junction J2 breaks down.*
- *The SCR now conducts heavily and is said to be in the ON state.*
  The applied voltage at which SCR conducts heavily without gate voltage is called Break over voltage Fig.2 shows the SCR circuit with gate open i.e. no voltage applied to the gate.

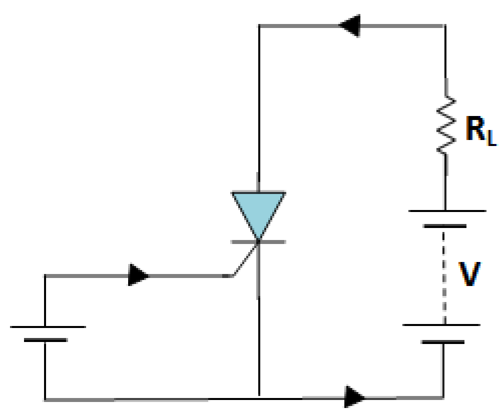




When gate is positive w.r.t. cathode

The SCR can be made to conduct heavily at smaller applied voltage by applying a small positive potential to the gate as shown in fig.3.





- *Now junction J3 is forward biased and junction J2 is reverse biased.*
- *The electrons from n-type material start moving across junction J3 towards left whereas holes from p-type towards the right.*
- *Consequently, the electrons from junction J3 are attracted across the junction J2and gate current starts flowing*

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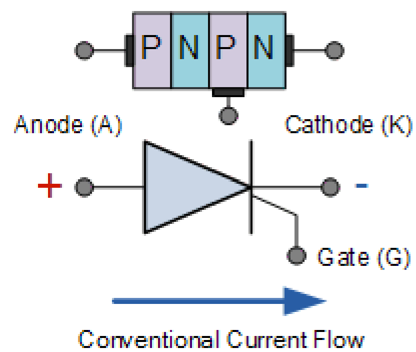
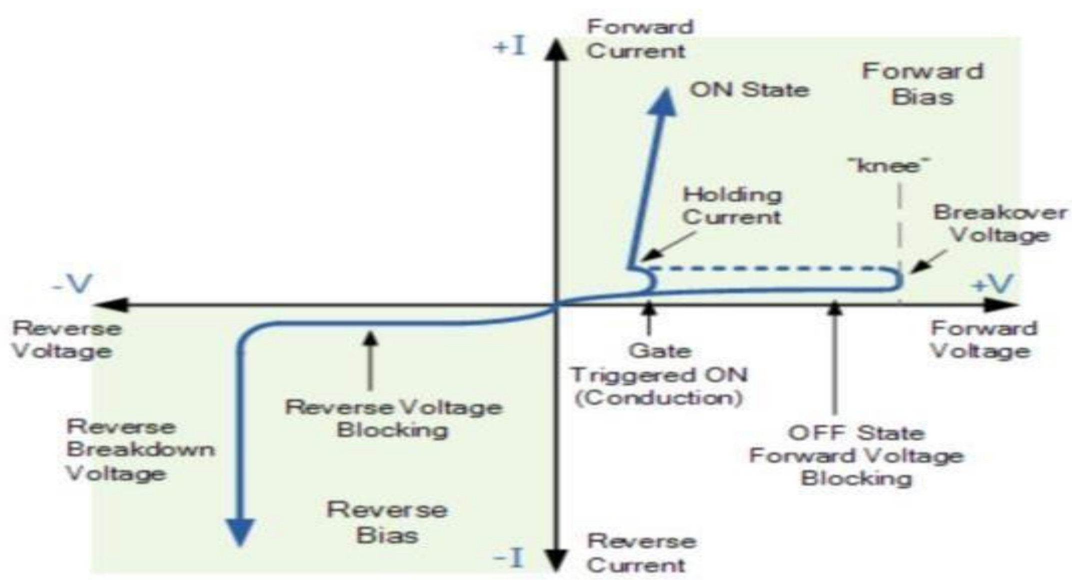
- *As soon as the gate current flows, anode current increases.*
- *The increased current in turn makes more electrons available at junction J2.*
- *This process continues and in an extremely small time, junction J2 breaks down and the SCR starts conducting heavily.*
- *Once SCR starts conducting, the gate loses all control. Even if gate voltage is removed, the anode current does not decrease at all.*
- *The only way to stop conduction i.e. to bring the SCR in off condition, is to reduce the applied voltage to zero.*

V-I Characteristics of SCR

It is the curve between anode-cathode voltage (V) and anode current (I) of an SCR at constant gate current. Fig.1 shows the V-I characteristics of a typical SCR .





Forward Characteristics

- *When anode is positive w.r.t. cathode, the curve between V and I is called the forward characteristics.*
- *In fig.1, OABC is the forward characteristics of SCR at I_G=0.*
- *If the supply voltage is increased from zero, a point reached (point A) when the SCR starts conducting.*
- *Under this condition, the voltage across SCR suddenly drops as shown by dotted curve AB and most of supply*

voltage appears across the load resistance R_L .

- *If proper gate current is made to flow, SCR can close at much smaller supply voltage.*

Reverse Characteristics

- *When anode is negative w.r.t. cathode, the curve between V and I is known as reverse characteristics.*
- *The reverse voltage does come across SCR when it is operated with a.c. supply.*
- *If the reverse voltage is gradually increased, at first the anode current remains small (i.e. leakage current) and at some reverse voltage, avalanche breakdown occurs and the SCR starts conducting heavily in the reverse direction as shown by the curve DE.*
- *This maximum reverse voltage at which SCR starts conducting heavily is known as reverse breakdown voltage.*
- *SCR in Normal Operation*

In order to operate the SCR in normal operation, the following points are kept in view:

a) *The supply voltage is generally much less than breakover voltage.*
b) *The SCR is turned on by passing appropriate amount of gate current (a few mA) and not by breakover voltage.*
c) *When SCR is operated from a.c. supply, the peak reverse voltage which comes during negative half-cycle should not exceed the reverse breakdown voltage..*
d) *When SCR is to be turned OFF from the ON state, anode current should be reduced to holding current.*
e) *If gate current is increased above the required value, the SCR will close at much reduced supply voltage.*

Specifications of SCR

Voltage and Current Rating of SCR

1. *Breakover voltage*
2. *Peak reverse voltage*
3. *Holding current*
4. *Forward current rating*
5. *Circuit fusing rating*

Breakover Voltage

- *It is the minimum forward voltage, gate being open, at which SCR starts conducting heavily i.e. turned on.*
- *Thus, if the breakover voltage of an SCR is 200 V, it means that it can block a forward voltage (i.e. SCR remains open) as long as the supply voltage is less than 200 V. If the supply voltage is more than this value, then SCR will be turned on.*
- *In practice, the SCR is operated with supply voltage less than breakover voltage and it is then turned on by means of a small voltage applied to the gate.*
- *Commercially available SCRs have breakover voltages from about 50 V to 500 V.*

Peak Reverse Voltage (PRV)

- *It is the maximum reverse voltage (cathode positive w.r.t. anode) that can be applied to an SCR without conducting in the reverse direction.*
- *PRV is an important consideration while connecting an SCR in an a.c. circuit. During the negative half of a.c. supply, reverse voltage is applied across SCR. If PRV is exceeded, there may be avalanche breakdown and the SCR will be damaged if the external ciruit does not limit the current.*
- *Commercially available SCRS have PRV ratings upto 2.5 kV.*

Holding Current

- *It is the maximum anode current, gate being open, at which SCR is turned OFF from ON condition.*
- *When SCR is in the conducting state, it can not be turned OFF even if gate voltage is removed.*
- *The only way to turn off or open the SCR is to reduce the supply voltage to almost zero at which point the internal transistor comes out of saturation and opens the SCR.*
- *The anode current under this condition is very small (a few mA) and is called holding current.*
- *Thus, if an SCR has a holding current of 5mA, it means that if anode current is made less than 5 mA, then SCR*

will be turned off.

Forward Current Rating

- *It is the maximum anode current that an SCR is capable of passing without destruction.*
- *Every SCR has a safe value of forward current which it can conduct. If the value of current exceeds this value, the SCR may be destroyed due to intensive heating at the junction.*
- *For example, if an SCR has a forward current rating of 40 A, it means that the SCR can safely carry only 40 A. Any attempt to exceed this value will result in the destruction of the SCR.*
- *Commercially available SCRs have forward current ratings from about 30A to 100A.*

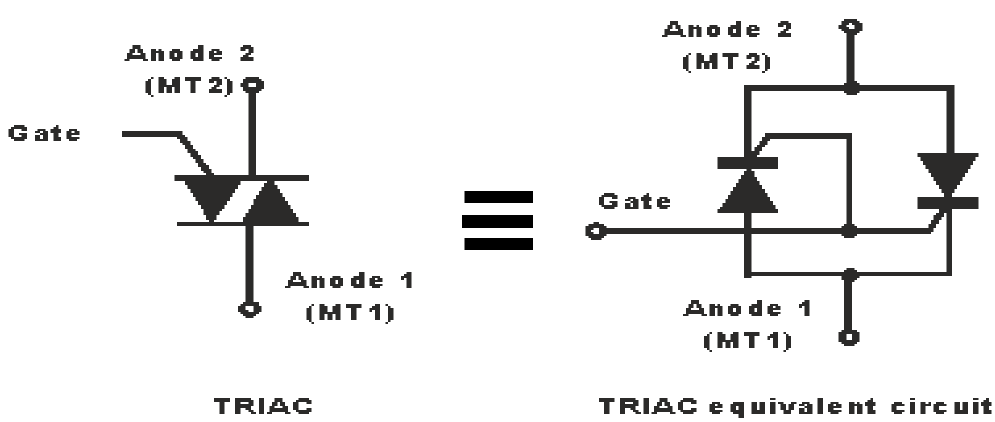
Circuit Fusing (I^2t) Rating

- *It is the product of square forward surge current and the time of duration of the surge i.e.,*
- *Circuit fusing rating =I2t*
- *The circuit fusing rating indicates the maximum forward surge current capability of SCR.*
- *For example, consider an SCR having circuit fusing rating of 90 A2s. If this rating is exceeded in the SCR circuit, the device will be destroyed by excessive power dissipation.*

TRIAC

- *The TRIAC is an ideal device to use for AC switching applications because it can control the current flow over both halves of an alternating cycle. SCR is only able to control them over one half of a cycle. During the remaining half no conduction occurs and accordingly only half the waveform can beutilised.*

- *The fact that the TRIAC can be used to control current switching on both halves of an alternating waveform allows much better power utilisation.*

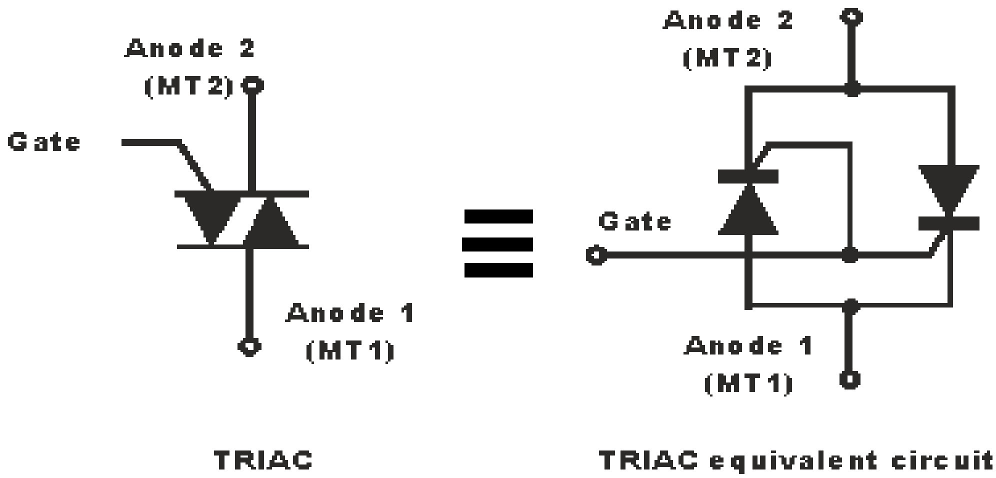


TRIAC symbol for circuit diagrams

- *On the TRIAC symbol there are three terminals. These are the Gate and two other terminals are often referred to as an "Anode" or "Main Terminal". As the TRIAC has two of these they are labelled either Anode 1 and Anode 2 or Main Terminal, MT1 and MT2.*
- *The TRIAC is a component that is effectively based on the thyristor. It provides AC switching for electrical systems.*
- *Like SCR, the TRIACs are used in many electrical switching applications. They find particular use for circuits in light dimmers, etc., where they enable both halves of the AC cycle to be used. This makes them more efficient in terms of the usage of the power available.*

TRIAC equivalent as two thyristors.

- *While it is possible to use two thyristors back to back, this is not always cost effective for low cost and relatively low power applications.*
- *It is possible to view the operation of a TRIAC in terms of two thyristors placed back to back*



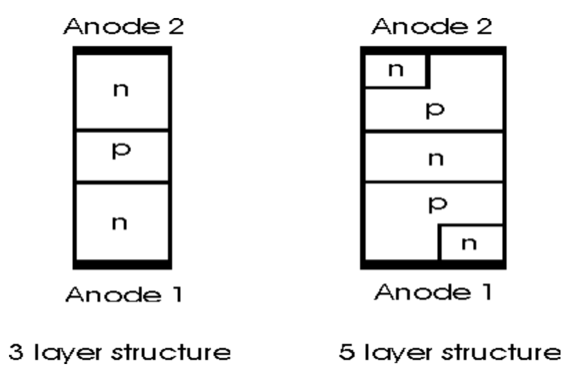
TRAIC Application

TRIACs are still used for many electrical switching applications:

- *Domestic light dimmers*
- *Electric fan speed controls*
- *Small motor controls*
- *Control of small AC powered domestic appliances*

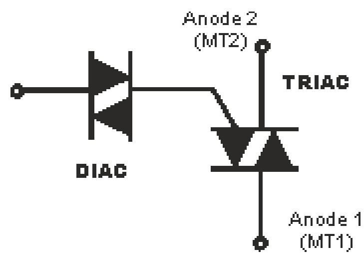
DIAC

- *The DIAC can be fabricated as either a two layer or a five layer structure.*
- *In the three layer structure the switching occurs when the junction that is reverse biased experiences reverse breakdown.*
- *The three layer version of the device is the more common and have a break-over voltage of around 30 V.*
- *Operation is almost symmetrical owing to the symmetry of the device.*
- *A five layer DIAC structure is also available. This does not act in quite the same manner, although it produces an I-V curve that is very similar to the three layer version*



Typical DIAC circuit configuration

- *To help in overcoming this problem, a DIAC is often placed in series with the gate.*
- *This device helps make the switching more even for both halves of the cycle.*
- *This results from the fact that its switching characteristic is far more even than that of the TRIAC.*
- *Since the DIAC prevents any gate current flowing until the trigger voltage has reached a certain voltage in either direction, this makes the firing point of the TRIAC more even in both directions*

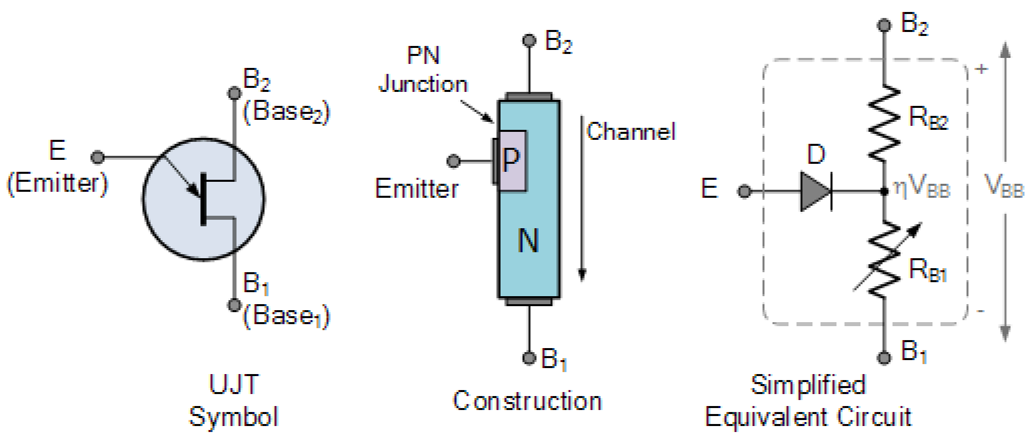


UJT (Unijunction Transistor)

*The **Unijunction Transistor** or **UJT** for short, is another solid state three terminal device that can be used in gate pulse, timing circuits and trigger generator applications to switch and control either thyristors and triac's for AC power control type applications.*
Like diodes, unijunction transistors are constructed from separate P-type and N-type semiconductor materials forming a single (hence its name Uni-Junction) PN-junction within the main conducting N-type channel of the device.

UJT Working

- *Like diodes, unijunction transistors are constructed from separate P-type and N-type semiconductor materials forming a single (hence its name Uni-Junction) PN-junction within the main conducting N-type channel of the device.*
- *Although the* Unijunction Transistor *has the name of a transistor, its switching characteristics are very different from those of a conventional bipolar or field effect transistor as it can not be used to amplify a signal but instead is used as a ON-OFF switching transistor. UJT's have unidirectional conductivity and negative impedance characteristics acting more like a variable voltage divider during breakdown.*
- *Like N-channel FET's, the UJT consists of a single solid piece of N-type semiconductor material forming the main current carrying channel with its two outer connections marked as* Base 2 *(B_2) and* Base 1 *(B_1). The third connection, confusingly marked as the* Emitter *(E) is located along the channel. The emitter terminal is represented by an arrow pointing from the P-type emitter to the N-type base.*
- *The Emitter rectifying p-n junction of the unijunction transistor is formed by fusing the P-type material into the N-type silicon channel. However, P-channel UJT's with an N-type Emitter terminal are also available but these are little used.*
- *The Emitter junction is positioned along the channel so that it is closer to terminal B_2 than B_1. An arrow is used in the UJT symbol which points towards the base indicating that the Emitter terminal is positive and the silicon bar is negative material. Below shows the symbol, construction, and equivalent circuit of the UJT.*



Very Short Answer type Question:

Q1: Define Heat Sink
Q2: What are dual Converters?
Q3: What is UPS?
Q4: Expand TRIAC
Q5: What is Bridge Inverter?
Q6: What is Duty Cycle?
Q7: What UJT Stands for?

Short Answer Type Question:

Q1: Draw V-I Characteristics of SCR
Q2: Explain anyone method of SCR triggering
Q3: What are the application of SCR?
Q4: Explain V-I characteristics of UJT

Long Answer Type Question:

Q1: Give the construction and working principle of TRIAC and V-I characteristics
Q2: Explain the construction and working of Class A Choppers
Q3: Explain the working of single phase half wave controlled rectifier with load
Q4: Explain different methods of SCR triggering
Q5: Write detail note on:

- **a> Cycloinverter Drive**
- **b> UPS**

Fully controlled full wave bridge rectifier

Learning outcomes

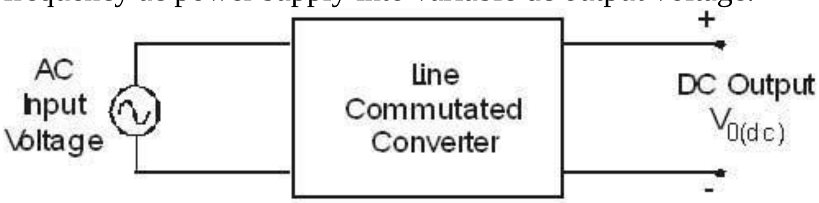
After completion of the chapter 2, students will be able to:

Describe the construction, working principles of controlled rectifier, single phase half wave contolled rectifier with load, single phase half controlled full wave rectifier with load (R,R.L), full controlled full wave bridge rectifier , single phase full wave centre tap rectifier

Chapter 2

1.Introduction

Controlled rectifiers are line commutated ac to dc power converters which are used to convert a fixed voltage, fixed frequency ac power supply into variable dc output voltage.



Type of input: Fixed voltage, fixed frequency ac power supply. Type of output: Variable dc output voltage

The input supply fed to a is ac supply at a fixed rms voltage and at a fixed frequency. We can obtain variable dc output voltage by using **Controlled rectifiers**. By employing phase controlled thyristors in the circuits we can obtain variable dc output voltage and variable dc (average) output current by varying the trigger angle (phase angle) at which the thyristors are triggered. We obtain a uni-directional and pulsating load current waveform, which has a specific average value.

The thyristors are forward biased during the positive half cycle of input supply and can be turned ON by applying suitable gate trigger pulses at the thyristor gate leads. The thyristor current and the load current begin to flow once the thyristors are triggered (turned ON) say at $\omega t = \alpha$. The load current flows when the thyristors conduct from $\omega t = \alpha$ to β . The output voltage across the load follows the input supply voltage through the conducting thyristor. At $\omega t = \beta$, when the load current falls to zero, the thyristors turn off due to AC line (natural) commutation.

In some bridge circuits the conducting thyristor turns off, when the other thyristor is (other group of thyristors are) turned ON.

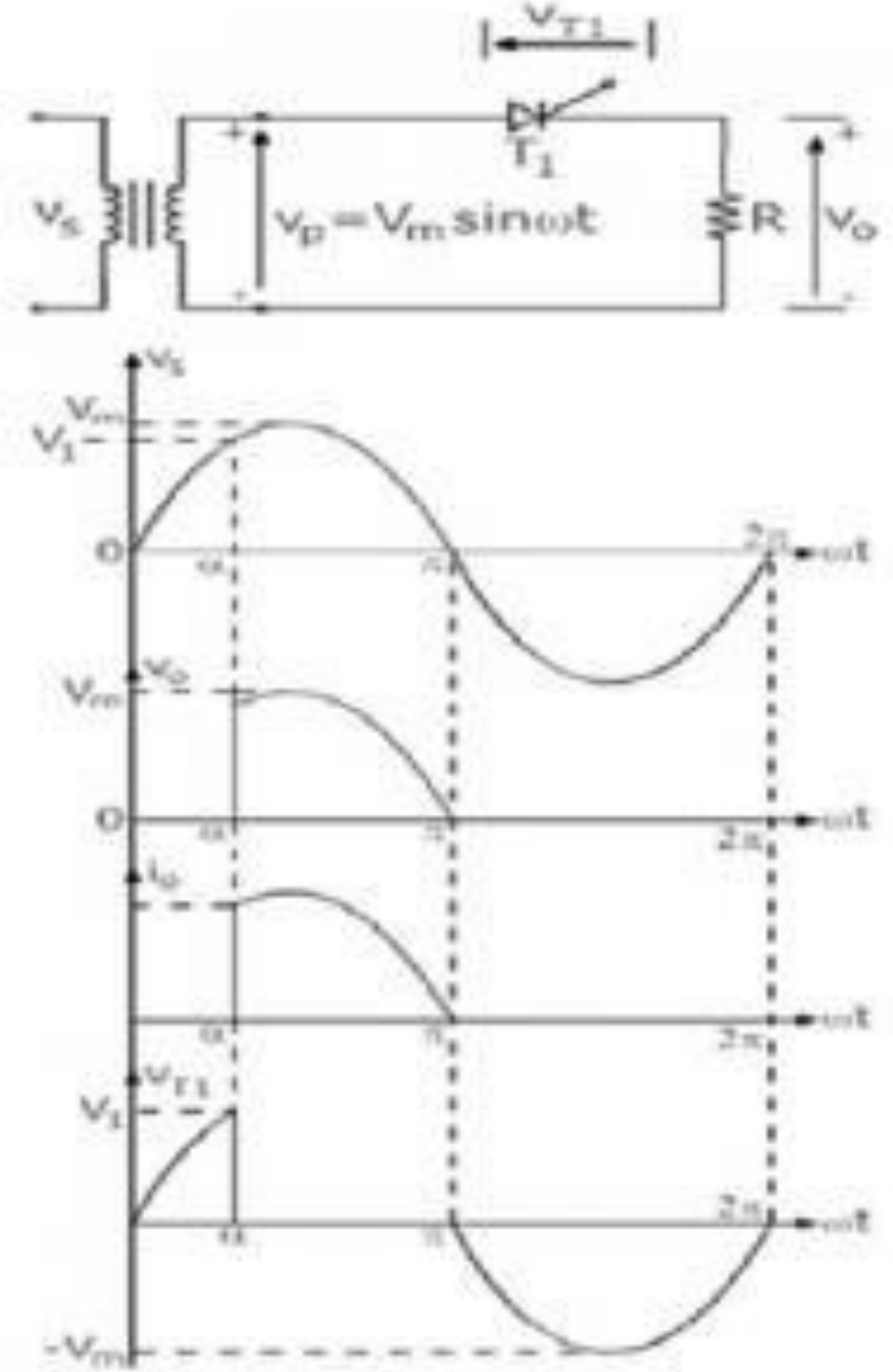
The thyristor remains reverse biased during the negative half cycle of input supply. The type of commutation used in circuits is referred to AC line commutation or Natural commutation or AC phase commutation.

When the input ac supply voltage reverses and becomes negative during the negative half cycle, the thyristor becomes reverse biased and hence turns off. There are several types of power converters which use ac line commutation. These are referred to as line commutated converters.

Single Phase Half Wave Controlled Rectifier

Single Phase Half Wave Controlled Rectifier with 'R' load:

Fully controlled full wave bridge rectifier



Fully controlled full wave bridge rectifier

The load current i0 flows through 'R'
The waveforms for voltage & current are as shown above.
As load is resistive,
Output current is given as,

$$I_0 = \frac{V_0}{R}$$

Hence shape of output current is same as output voltage
As T1 conducts only in positive half cycle as it is reversed bias in negative cycle, the ripple frequency of output voltage is-
fripple= 50 Hz (supply frequency)

Average output voltage is given as,

$$V_0(Avg) = \frac{1}{T}\int_0^T V_0(wt)\,dwt$$

Area under one cycle. Therefore T=2π&Vo(ωt) = Vmsinωt from α to π& for rest of the period Vo(ωt)=0

$$\therefore V_0(Avg) = \frac{1}{2\pi}\int_0^{2\pi} V_m sin(wt)\,dwt$$
$$= \frac{V_m}{2\pi}[-coswt]_\alpha^\pi$$
$$= \frac{V_m}{2\pi}(1+cos\alpha)$$

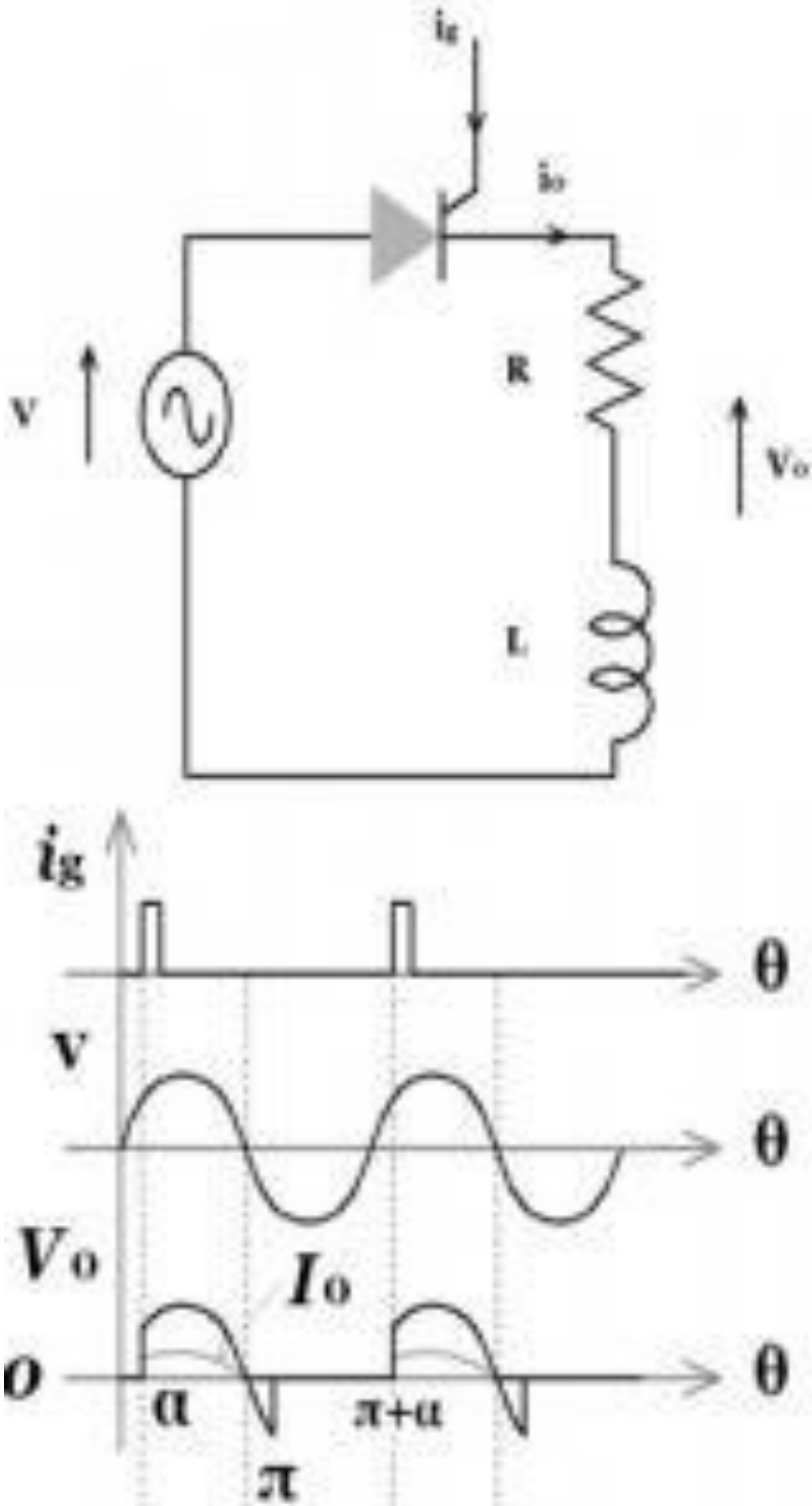
Power transferred to load,

$$P_0(Avg) = \frac{V_0^2(Avg)}{R}$$

Thus, power & voltage can be controlled by firing angle.

<u>Single Phase Half Wave Controlled Rectifier with 'RL' load:</u>

Fully controlled full wave bridge rectifier



Fully controlled full wave bridge rectifier

Figure above shows the single phase half wave rectifier with RL Load.

- *Normally motors are inductive loads*

L= armature of field coil inductance

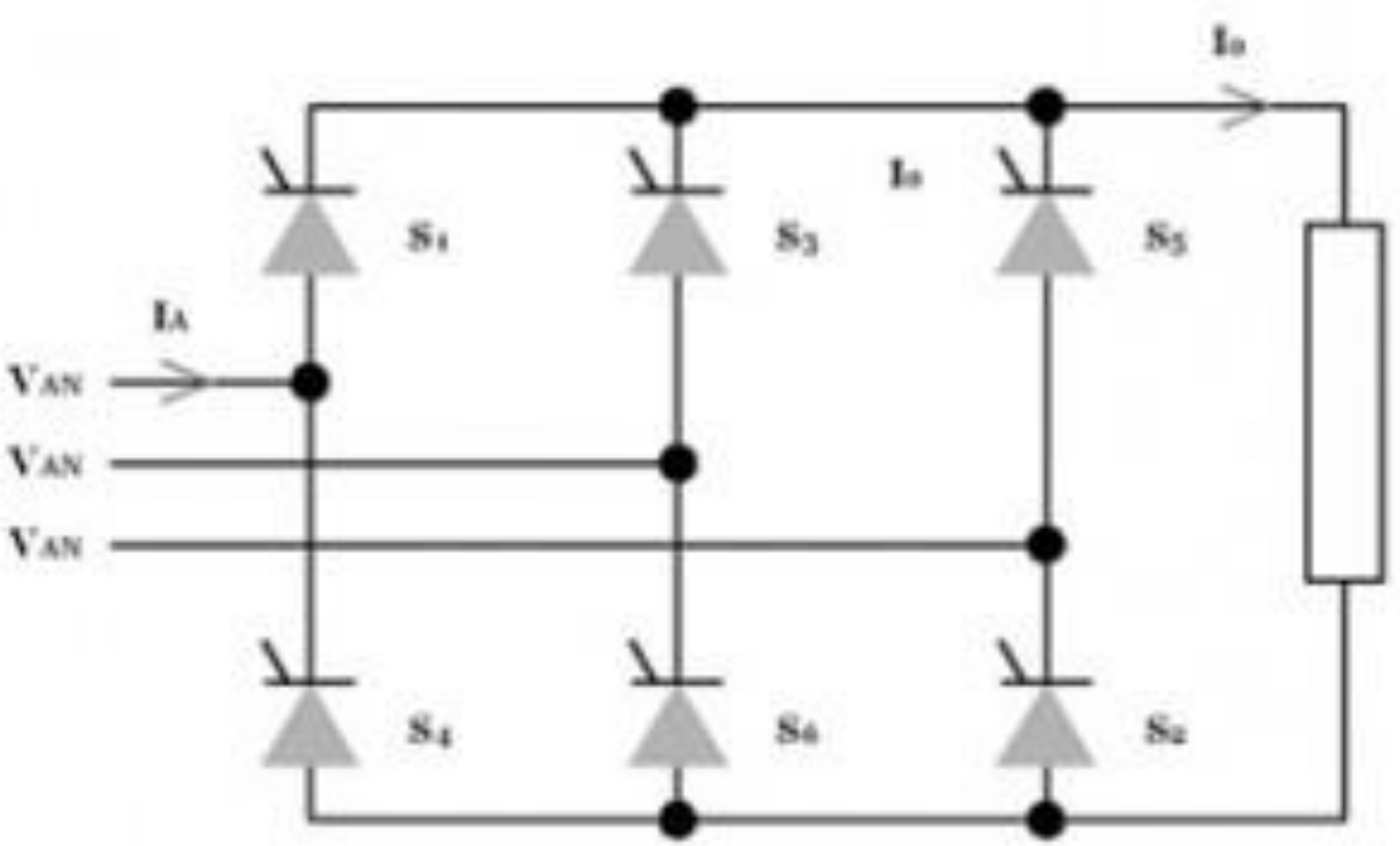
R= Resistance of coil.

- *In positive half cycle, SCR starts conduction at firing angle "α".*
- *Drop across SCR is small & neglected so output voltage is equal to supply voltage.*
- *Due to 'R_L' load, current through SCR increases slowly.*
- *At 'π', supply voltage is at zero where load current is at its max value.*
- *In positive half cycle, inductor stores energy & that generates the voltage.*
- *In negative half cycle, the voltage developed across inductor, forward biases SCR & maintains its conduction.*
- *Basically with the property of inductance it opposes change in current.*
- *Output current & supply current flows in same loop, so all the time i_o=i_s.*
- *After π the energy of inductor is given to mains & there is flow of 'io'. The energy reduces as if gets consumed by circuit so current also reduces.*
- *At 'β' energy stored in inductance is finished, hence 'i_o' becomes zero & 'T1' turns off.*
- *'i_o' becomes zero from 'β' to '2π+α' hence it is discontinuous conduction.*

Three Phase Full Wave Controlled Rectifier

The 3-phase half wave converter combines three single phase half wave controlled rectifiers in one single circuit feeding a common load. The thyristor S1 in series with one of the supply phase windings 'a-n' acts as one half wave controlled rectifier. The second thyristor S2 in series with the supply phase winding 'b-n' acts as the second half wave controlled rectifier. The third thyristor S3 in series with the supply phase winding acts as the third half wave controlled rectifier. Figure bellow shows three phase fully controlled rectifier.

Fully controlled full wave bridge rectifier



• When thyristor S2 is triggered at ωt=(5π/6α), S1 becomes reverse biased and turns-off. The load current flows through the thyristor and through the supply phase winding 'b-n'. When S2 conducts the phase voltage vbnappears across the load until the thyristor S3 is triggered.

• The 3-phase input supply is applied through the star connected supply transformer as shown in the figure. The common neutral point of the supply is connected to one end of the load while the other end of the load connected to the common cathode point.

• When the thyristor S1 is triggered at ωt=(π/6 + α)=(30° + α) , the phase voltage Van appears across the load when S1 conducts. The load current flows through the supply phase winding 'a-n' and through thyristor S1 as long as S1 conducts.

• When the thyristor S3 is triggered at ωt=(3π/2 + α)=(270°+α) , S2 is reversed biased and hence S2 turns-off. The phase voltage Van appears across the load when S3 conducts.

• When S1 is triggered again at the beginning of the next input cycle the thyristor S3 turns off as it is reverse biased naturally as soon as S1 is triggered. The figure shows the 3-phase input supply voltages, the output voltage which appears across the load, and the load current assuming a constant and ripple free load current for a highly inductive load and the current through the thyristor T1.

• For a purely resistive load where the load inductance 'L = 0' and the trigger angle α >(π/6), the load current appears as discontinuous load current and each thyristor is naturally commutated when the polarity of the corresponding phase supply voltage reverses. The frequency of output ripple frequency for a 3-phase half wave converter is fs, where fs is the input supply frequency.The 3-phase half wave converter is not normally used in practical converter systems because of the disadvantage that the supply current waveforms contain dc components.

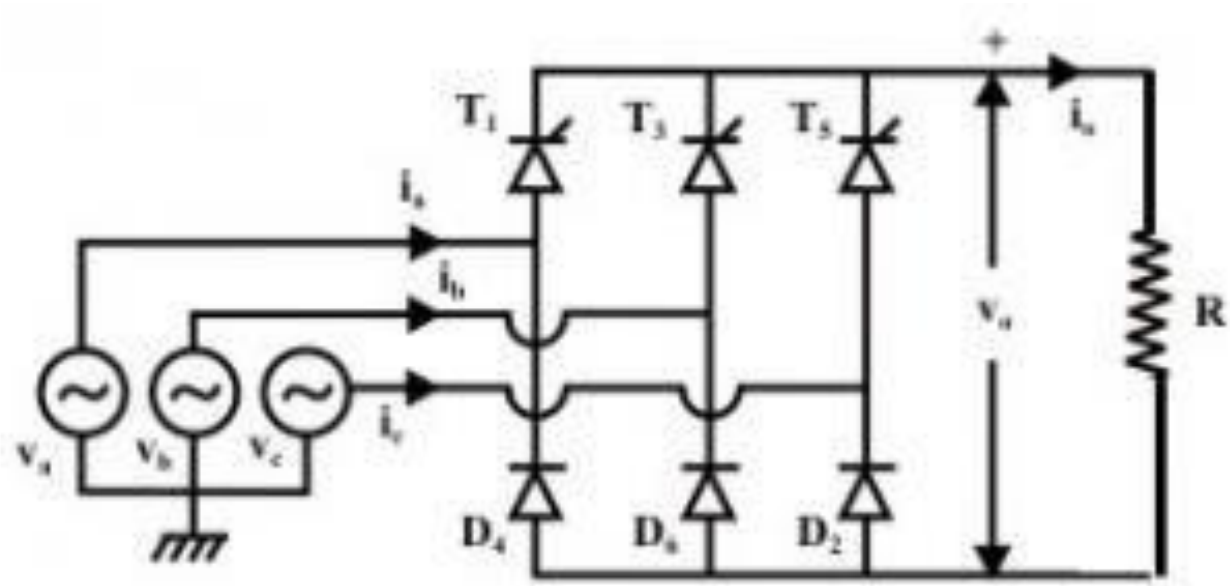
Three phase Half controlled rectifier

Three phase converters

Three phase converters provide higher average output voltage. Frequency of ripples on output voltage is higher compared with that of single phase converter. Thus the filtering requirements for smoothing out load current & load voltage are simpler. For these reasons, three phase converters are extensively used in high power variable speed drivers.

Fully controlled full wave bridge rectifier
Three phase semiconverters

Three single phase half wave converters can be connected to form a three phase half wave converter. Similarly three phase semiconverter uses 3 SCRs T1, T3 & T5 and 3 diodes D2, D4& D6 R,Y,B are phase voltages with respect to 'N'.

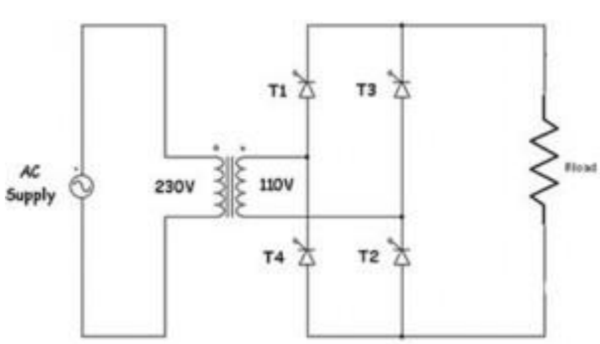


In the circuit shown above when any device conducts,line voltage is applied across load. so line voltage are necessary to draw
Phase shift between two line voltages is 60 degree & between two phase voltages it is 120 degree Each phase & line voltage is sine wave with the frequency of 50 Hz.

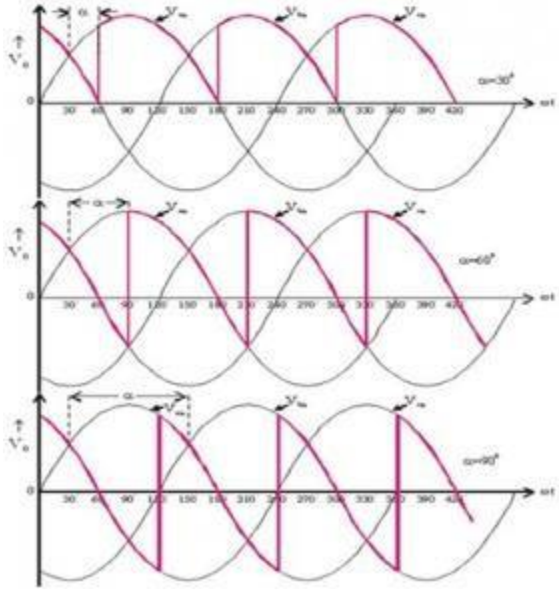
Operation of semiconverters with R load
With purely resistive load current will be in phase with load voltage. Depending on value of firing angle, circuit can operate in two different modes.
Mode1- when $\alpha<60$
T1 is triggered at $\alpha=30$. SCR T1 and D6 conduct and line voltage RY is applied to the load from $(\pi/6+\alpha)$ to $\pi/2$. 60. At $\pi/2$ 'D2' is more positive so conducts. Therefore, line voltage RB is applied to load. This continues up to firing of T3 at $\pi/6+\alpha$
$Vo(avg)=(3\sqrt{3}Vm)/2\pi(1+\cos\alpha)$
For $\alpha\leq60$ the output voltage is continuous so called continuous mode of operation.
For $\alpha>60$ for some duration of time no device conducts so called discontinuous mode of operation.

Single Phase Full Wave Controlled Rectifier
Single Phase Full Wave Controlled Rectifier with 'R' load:

Figure below shows the Single phase Full Wave Controlled Rectifiers with R load



Fully controlled full wave bridge rectifier



• The single phase fully controlled rectifier allows conversion of single phase AC into DC. Normally this is used in various applications such as battery charging, speed control of DC motors and front end of UPS (Uninterruptible Power Supply) and SMPS (Switched Mode Power Supply).

• All four devices used are thyristors. The turn-on instants of these devices are dependent on the firing signals that are given. Turn-off happens when the current through the device reaches zero and it is reverse biased at least for duration equal to the turn-off time of the device specified in the data sheet.

• In positive half cycle thyristors T1 & T2 are fired at an angle α .

• When T1 & T2 conducts

Vo=Vs

IO=is=Vo/R=Vs/R

• In negative half cycle of input voltage, SCR's T3 &T4 are triggered at an angle of (π+α)

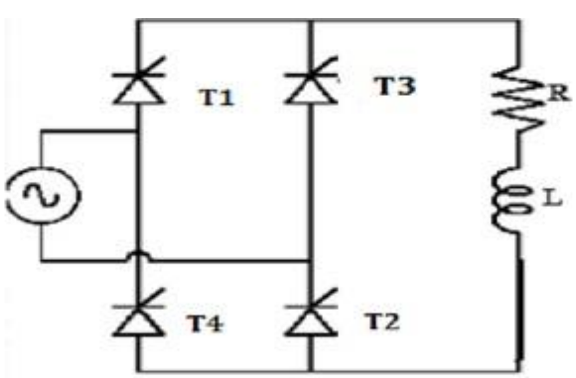
• Here output current & supply current are in opposite direction

∴ is=-io

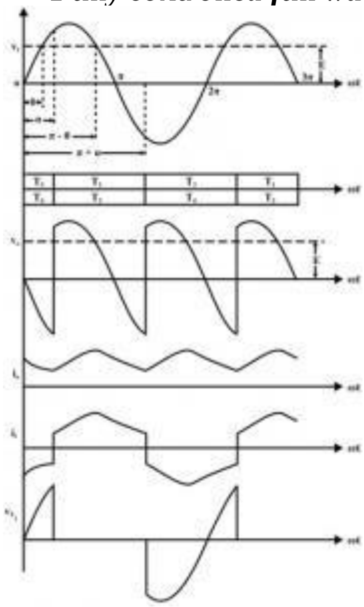
T3 & T4 becomes off at 2π.

Single Phase Full Wave Controlled Rectifier with 'RL' load:

Figure below shows Single phase Full Wave Controlled Rectifiers with RL load.



Fully controlled full wave bridge rectifier



Operation of this mode can be divided between four modes
Mode 1 (α toπ)
• In positive half cycle of applied ac signal, SCR's T1 & T2 are forward bias & can be turned on at an angle α.
• Load voltage is equal to positive instantaneous ac supply voltage. The load current is positive, ripple free, constant and equal to Io.
• Due to positive polarity of load voltage & load current, load inductance will store energy.
Mode 2 (π toπ+α)
• At wt=π, input supply is equal to zero & after π it becomes negative. But inductance opposes any change through it.
• In order to maintain a constant load current & also in same direction. A self inducedemf appears across 'L' as shown.
• Due to this induced voltage, SCR's T1 & T2 are forward bais in spite the negative supply voltage.
• The load voltage is negative & equal to instantaneous ac supply voltage whereas load current
• Thus, load acts as source & stored energy in inductance is returned back to th
• At wt=π+α SCR's T3 & T4 are turned on & T1, T2 are reversed bias.
• Thus , process of conduction is transferred from T1,T2 to T3,T4.
• Load voltage again becomes positive & energy is stored in inductor
• T3, T4 conduct in negative half cycle from (π+α) to 2π
• With positive load voltage & load current energy gets stored

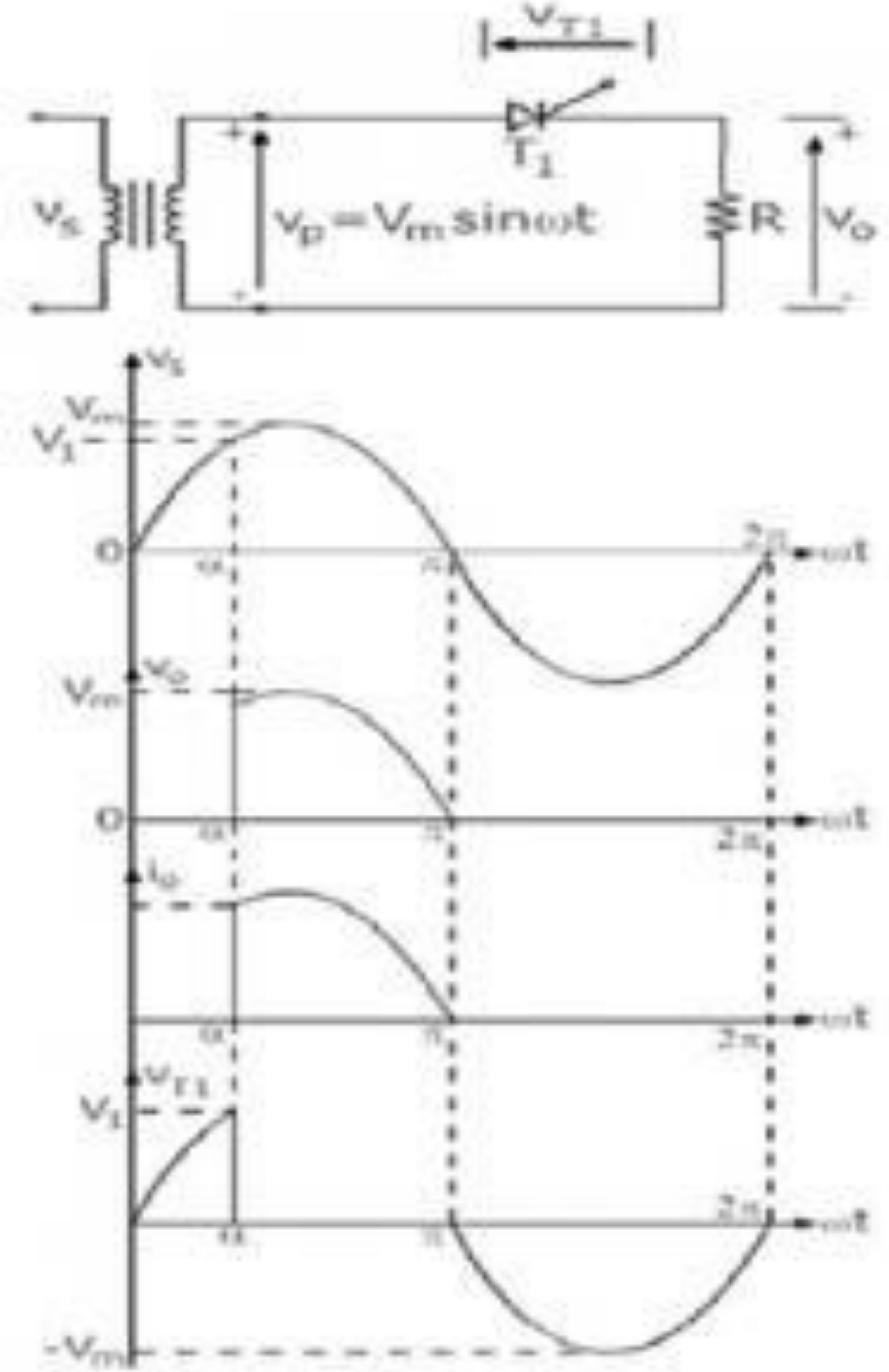
• At wt=2π, input voltage passes through zero.
• Inductive load will try to oppose any change in current if in order to maintain load current constant & in the same direction.
• Induced emf is positive & maintains conducting SCR's T3 & T4 with reverse polarity also.
• Thus VL is negative & equal to instantaneous ac supply voltage. Whereas load current continues to be positive.
• Thus load acts as source & stored energy in inductance is returned back to ac supply
• At wt=α or 2π+α, T3 & T4 are commutated and T1,T2 are turned on

Single Phase Half Wave Controlled Rectifier

Single Phase Half Wave Controlled Rectifier with 'R' load:

As shown in figure below primary of transformer is connected to ac mains supply with which SCR becomes forward bias in positive half cycle. T1 is triggered at an angle α, T1 conducts and voltage is applied across R.

Fully controlled full wave bridge rectifier



Fully controlled full wave bridge rectifier

The load current i0 flows through 'R'
The waveforms for voltage & current are as shown above.
As load is resistive,
Output current is given as,

$$I_0 = \frac{V_0}{R}$$

Hence shape of output current is same as output voltage
As T1 conducts only in positive half cycle as it is reversed bias in negative cycle, the ripple frequency of output voltage is-
fripple= 50 Hz (supply frequency)

Average output voltage is given as,

$$V_0(Avg) = \frac{1}{T}\int_0^T V_0(wt)\,dwt$$

Area under one cycle. Therefore T=2π&Vo(ωt) = Vmsinωt from α to π& for rest of the period Vo(ωt)=0

$$\therefore V_0(Avg) = \frac{1}{2\pi}\int_0^{2\pi} V_m sin(wt)\,dwt$$
$$= \frac{V_m}{2\pi}[-coswt]_\alpha^\pi$$
$$= \frac{V_m}{2\pi}(1+cos\alpha)$$

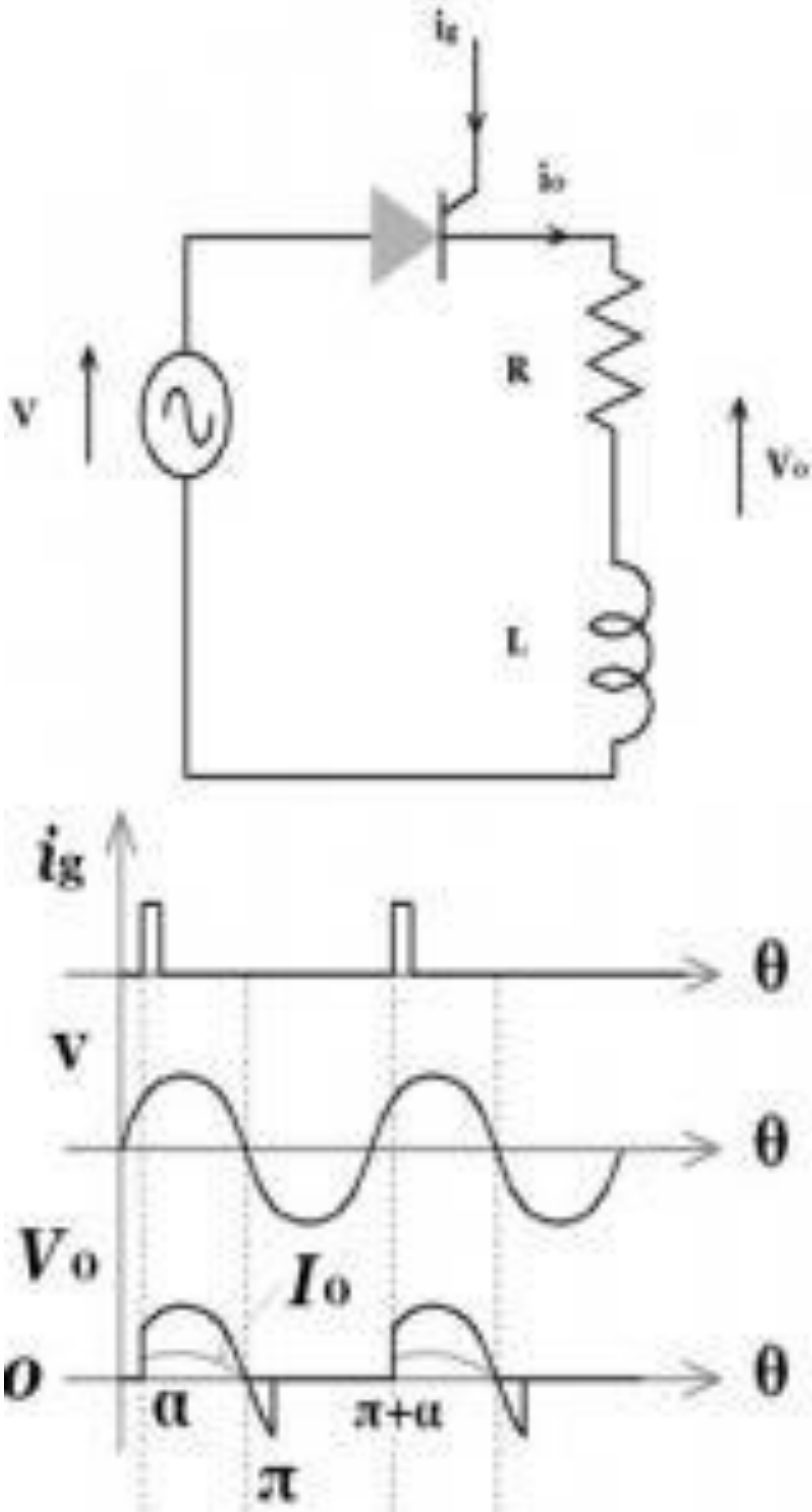
Power transferred to load,

$$P_0(Avg) = \frac{V_0^2(Avg)}{R}$$

Thus, power & voltage can be controlled by firing angle.

<u>Single Phase Half Wave Controlled Rectifier with 'RL' load:</u>

Fully controlled full wave bridge rectifier



Fully controlled full wave bridge rectifier

Figure above shows the single phase half wave rectifier with RL Load.

- *Normally motors are inductive loads*

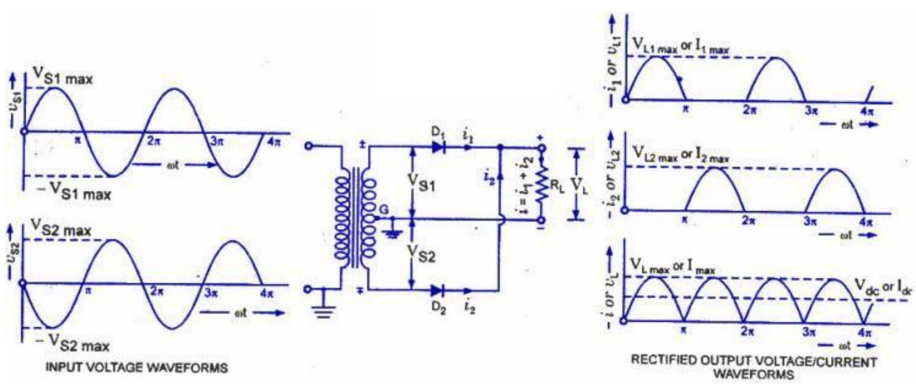
L= armature of field coil inductance

R= Resistance of coil.

- *In positive half cycle, SCR starts conduction at firing angle "α".*
- *Drop across SCR is small & neglected so output voltage is equal to supply voltage.*
- *Due to 'R_L' load, current through SCR increases slowly.*
- *At 'π', supply voltage is at zero where load current is at its max value.*
- *In positive half cycle, inductor stores energy & that generates the voltage.*
- *In negative half cycle, the voltage developed across inductor, forward biases SCR & maintains its conduction.*
- *Basically with the property of inductance it opposes change in current.*
- *Output current & supply current flows in same loop, so all the time $i_o = i_s$.*
- *After π the energy of inductor is given to mains & there is flow of 'io'. The energy reduces as if gets consumed by circuit so current also reduces.*
- *At 'β' energy stored in inductance is finished, hence 'i_o' becomes zero & 'T1' turns off.*
- *'i_o' becomes zero from 'β' to '2π+α' hence it is discontinuous conduction.*

Full Wave Center-tapped Rectifier

This type of rectifier uses two diodes and a transformer with center tapped secondary winding. During the positive half cycle of the input AC diode D1 is forward biased and the current starts flowing to the load through it. During the negative half of the input diode D2 forward biased and D1 becomes reverse biased. Load current start flowing through D2 during this negative peak. Note that the current flow through load has not changed even when the voltage polarity changed.



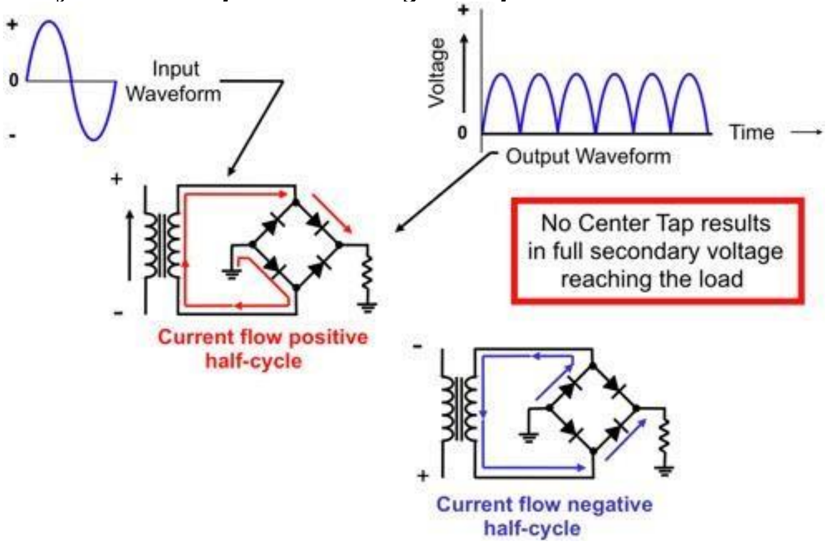
Full Wave Center-tapped Rectifier

Advantages of this rectifier are lower ripple factor and higher efficiency, but the necessity of transformer with center tapping secondary is the main disadvantage and makes a circuit as costlier.

Full Wave Bridge Rectifier

Using the same secondary voltage, this bridge rectifier can produce almost double the output voltage as compared with full wave center-tapped transformer rectifier. During the positive half of the input AC diodes D1 and D2 are forward biased and D3 and D4 are reverse biased. Thus load current flows through D1 and D2 diodes. During the negative half cycle of the input diodes D3&D4 are forward biased and D1&D2 are reverse biased. Therefore load current flows through D3&D4 diodes.

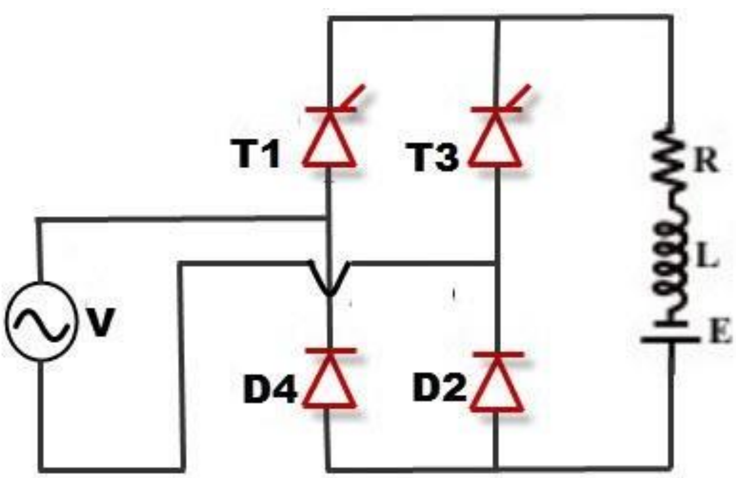
Fully controlled full wave bridge rectifier



Full Wave Bridge Rectifier

Single Phase Half Controlled Rectifiers

Controlled rectifiers use Thyristors in place of diodes to control the output. By adjusting the triggering time of Thyristors (or MOSFETs and IGBTs) we can control the voltage and current through loads and this process is termed as a phase control method of rectification.

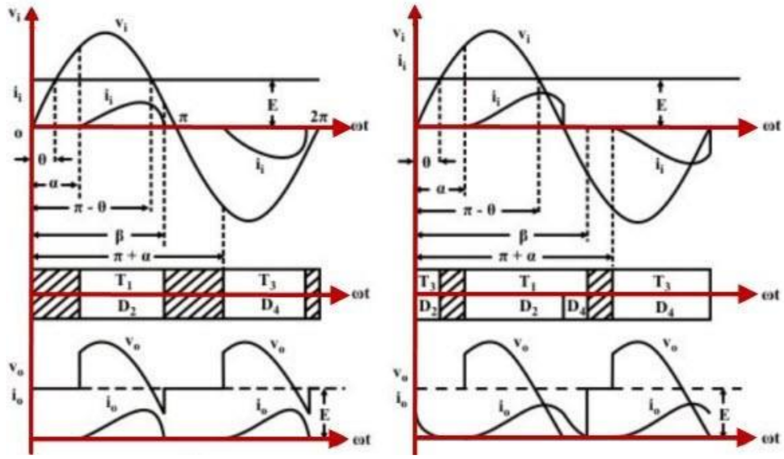


Single Phase Half Controlled Rectifiers

The circuit of single phase half controlled rectifier is shown below where it uses two diodes and two thyristors which are connected across the load. Each leg consists of one thruster and one diode and for every conduction, two leg components are responsible. However thyristors T1 and T3 or diodes D2 and D4 cannot conduct simultaneously .

During the positive half cycle of the input, T1 and D2 are forward biased. When T1 is fired, then the load current flows through T1 and D2. If the voltage passes through negative going zero crossing of the input voltage, D4 comes into conduction by commutating D2 and then the load voltage becomes zero.

Fully controlled full wave bridge rectifier

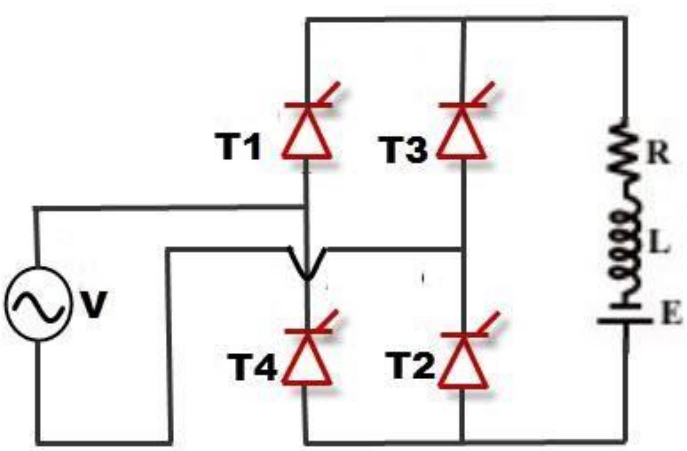


Half Controlled Rectifier Waveforms

During the negative half cycle, T3 and D4 are forward biased and when T3 is triggered load current start flowing through T3 and D4. Similarly, at the zero crossing D2 comes into the conduction by commutating D4. As we can observe in below figure that the load current always remains above zero is termed as the continuous conduction mode of rectifying DC. Also discontinuous mode of operation is shown in figure.

Single Phase Fully Controlled Rectifier

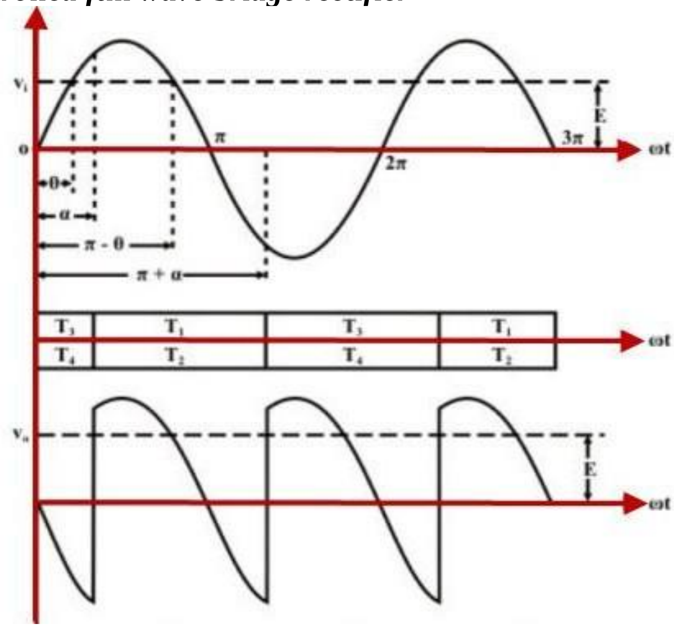
This type of power electronics based rectifier circuit is most popular one and widely used in controlling speed of the DC motors. This circuit is obtained by replacing all the diodes used in uncontrolled or half controlled rectifiers with thyristors as shown in figure. From the circuit, we can observe that one thyristor from a top group (T1, T3) and one thyristor from the bottom group (T2, T4) must conduct for load current flow. However T1T3 or T2T4 cannot conduct simultaneously.



Single Phase Fully Controlled Rectifier

During the positive half cycle of the input signal T1 and T2 are forward biased and when these are triggered or fired these are starts conducting so that load current flow through them. During the negative half cycle of the input AC, T3 and T4 are in the forward blocking state and when a gate pulse is applied to them, they will turn ON and load current starts flowing through them. At the same time, across T1 and T2 a negative voltage causes to the commutation of these thyristors immediately. This process repeats for every cycle as shown in below figure.

Fully controlled full wave bridge rectifier

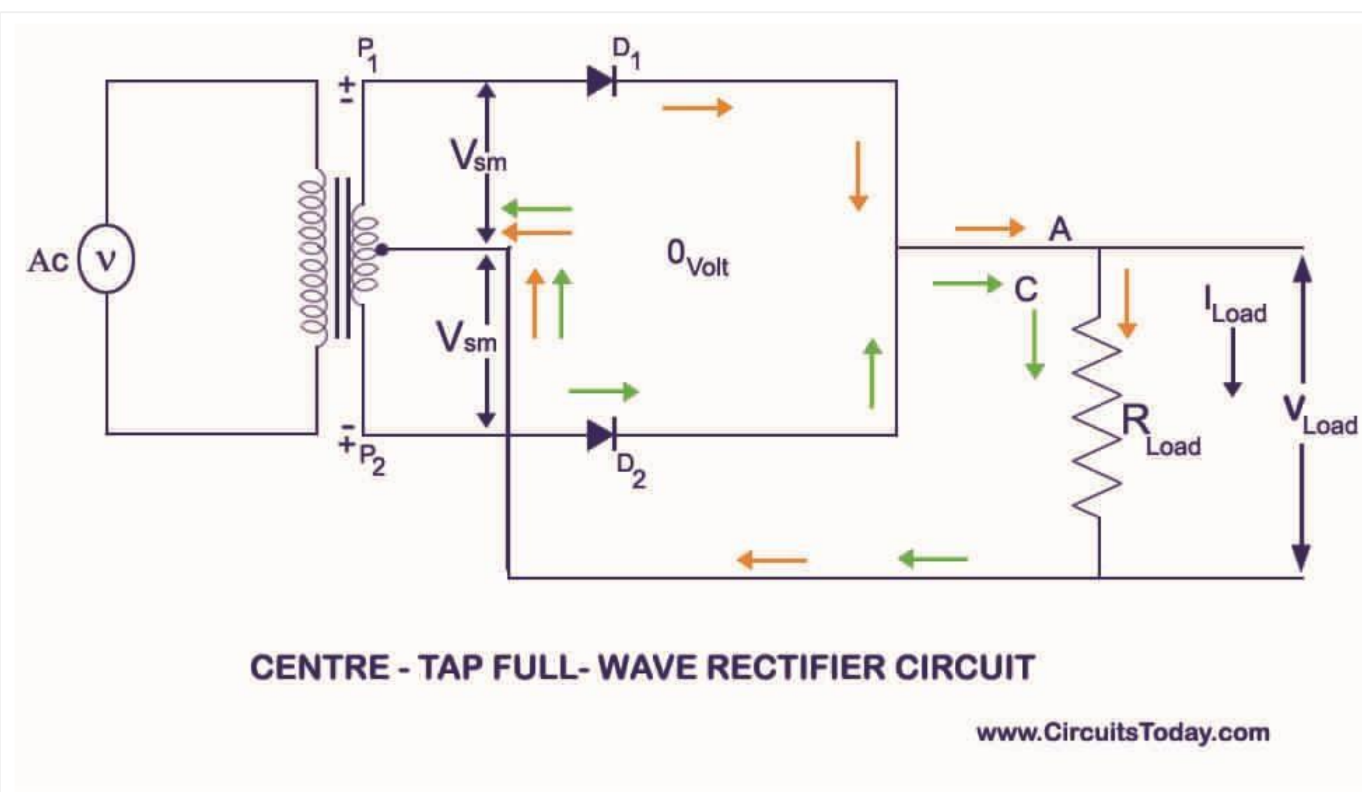


These are the few types of rectifiers used frequently for several applications including all electronic and electrical projects. This article discussed only single phase rectifier for easier understanding and not to make this document as complex one. We hope that readers might have got a better answer for the question what is a rectifier and its types. Any further queries regarding this topic or.

Centre-Tap Full Wave Rectifier

We have already discussed the Full Wave Bridge Rectifier, which uses four diodes, arranged as a bridge, to convert the input alternating current (AC) in both half cycles to direct current (DC).

In the case of centre-tap full wave rectifier, only two diodes are used, and are connected to the opposite ends of a centre-tapped secondary transformer as shown in the figure below. The centre-tap is usually considered as the ground point or the zero voltage reference point.



CENTRE - TAP FULL- WAVE RECTIFIER CIRCUIT

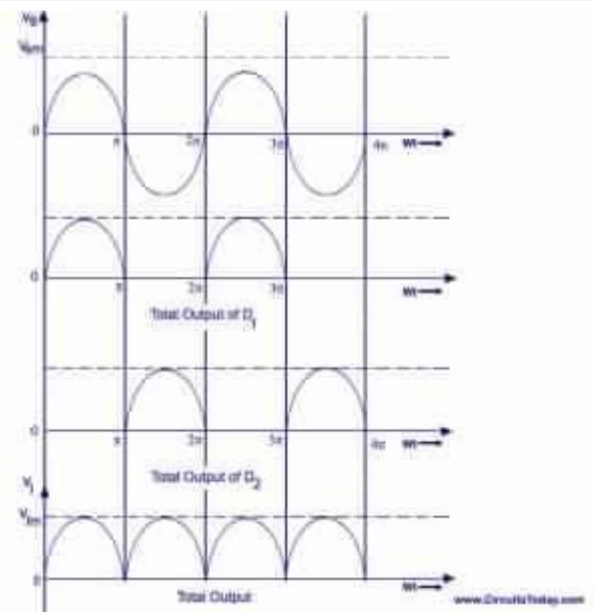
Fully controlled full wave bridge rectifier

Centre Tap Full Wave Rectifier Circuit

Working of Centre-Tap Full Wave Rectifier

As shown in the figure, an ac input is applied to the primary coils of the transformer. This input makes the secondary ends P1 and P2 become positive and negative alternately. For the positive half of the ac signal, the secondary point D1 is positive, GND point will have zero volt and P2 will be negative. At this instant diode D1 will be forward biased and diode D2 will be reverse biased. As explained in the Theory Behind P-N Junction and Characteristics of P-N Junction Diode, the diode D1 will conduct and D2 will not conduct during during the positive half cycle. Thus the current flow will be in the direction P1-D1-C-A-B-GND. Thus, the positive half cycle appears across the load resistance RLOAD.

During the negative half cycle, the secondary ends P1 becomes negative and P2 becomes positive. At this instant, the diode D1 will be negative and D2 will be positive with the zero reference point being the ground, GND. Thus, the diode D2 will be forward biased and D1 will be reverse biased. The diode D2 will conduct and D1 will not conduct during the negative half cycle. The current flow will be in the direction P2-D2-C-A-B-GND.



Centre-tap Full-wave Rectifier-Waveform

When comparing the current flow in the positive and negative half cycles, we can conclude that the direction of the current flow is the same (through load resistance RLOAD). When compared to the Half-Wave Rectifier, both the half cycles are used to produce the corresponding output. The frequency of the rectified output voltage is twice the input frequency. The output that is rectified, consists of a dc component and a lot of ac components of minute amplitudes.

Peak Inverse Voltage (PIV) of Centre-Tap Full Wave Rectifier

PIV is the maximum possible voltage across a diode during its reverse biased period. Let us analyze the PIV of the centre-tapped rectifier from the circuit diagram. During the first half or the positive half of th input ac supply, the diode D1 is positive and thus conducts and provided no resistance at all. Thus, the whole of voltage Vs developed in the upper-half of the ac supply is provided to the load resistance RLOAD. Similar is the case of diode D2 for the lower half of the transformer secondary.

Therefore, PIV of D2 = Vm + Vm = 2Vm

PIV of D1 = 2Vm

Fully controlled full wave bridge rectifier

Centre-Tap Rectifier Circuit Analysis

1. Peak Current

The instantaneous value of the voltage applied to the rectifier can be written as

Vs = Vsm Sinwt

Assuming that the diode has a forward resistance of RFWD ohms and a reverse resistance equal to infinity, the current flowing through the load resistance RLOAD is given as

$Im = Vsm/(R_F + R_{Load})$

2. Output Current

Since the current is the same through the load resistance RL in the two halves of the ac cycle, magnitude od dc current Idc, which is equal to the average value of ac current, can be obtained by integrating the current i1 between 0 and pi or current i2 between pi and 2pi.

$$\text{So } I_{dc} = 1/\pi \int_0^{\pi} i1 \, d(wt) = 1/\pi \, [\int_0^{\pi} I_{max} \text{ Sin wtd(wt)} = 2I_m/\pi$$

Output current of centre Tap rectifier

3. DC Output Voltage

Average or dc value of voltage across the load is given as

$$\text{So } I_{dc} = 1/\pi \int_0^{\pi} i1 \, d(wt) = 1/\pi \, [\int_0^{\pi} I_{max} \text{ Sin wtd(wt)} = 2I_m/\pi$$

DC Output Voltage of centre Tap Rectifier

4. Root Mean Square (RMS) Value of Current

RMS or effective value of current flowing through the load resistance R_L is given as

$$I^2_{rms} = 1/\pi \int_0^{\pi} i12 d(wt) = I^2 m/2 \text{ or } I_{rms} = Im/\sqrt{2}$$

RMS Value of Current of centre Tap Rectifier

5. Root Mean Square (RMS) Value of Output Voltage

RMS value of voltage across the load is given as

$$V_{LOAD}\text{ rms} = Irms\ R_{LOAD} = [I_M/\sqrt{2}]R_{LOAD}$$

Fully controlled full wave bridge rectifier

RMS Value of Output Voltage of Centre Tap Rectifier

6. Rectification Efficiency

Power delivered to load,

$$P_{dc} = I^2_{dc} R_{LOAD} = (2I_M/\pi)^2 R_{LOAD} = (4/\pi^2) I^2_M R_{LOAD}$$

AC power input to the transformer, P_{ac} = Power dissipated in diode junction + Power dissipated in load resisance R_{LOAD}

$$I^2_{rms}R_F + I^2_{rms}R_{LOAD} = \{I^2_M/2\}[R_F + R_{LOAD}]$$

SO, rectification efficiency, $\eta = P_{dc}/P_{ac} = \{(4/\pi^2)I^2_M R_{LOAD}\}/\{I^2_M/2\}[R_F+R_{LOAD}]$

$$=\{0.812/(1=R_F/R_{LOAD})\}$$

In case of bridge rectifier, $\eta = \{0.812/(1+2R_F/R_{LOAD})\}$

Rectification Efficiency of Centre Tap Rectifier

7. Ripple Factor

Form factor of the rectified output voltage of a full wave rectifier is given as

$$K_f = I_{rms} / I_{avg} = (I_m/\sqrt{2})/(2I_M/\pi) = \pi \div 2\sqrt{2} = 1.11$$

Learning outcomes

After completion of the chapter 3, students will be able to:

Describe the construction, working principles of inverter,CHOPPER,DUALCONVERTER

Chapter-3

1.Introduction

INVERER

- An inverter is connected to a DC source and it converts it into AC power in its circuit.

The details on input and output are as under.

- The input is DC power. The value of input voltage depends upon the application. Some applications require 12 V while some may require very high voltages of thousands volts.

Fully controlled full wave bridge rectifier

- The ideal output of an inverter is a sinusoidal waveform. Such a wave gives continuous flow of power. But the output from the circuit is generally not ideal. It gives output in the form of square wave, quasi-square wave or PWM.
- The conversion of DC power to AC power can be done using two approaches. Both do conversion in two steps.
  - In the first approach, a low voltage DC power is converted into high voltage DC power and then in the second step this high voltage DC power is converted to AC power.
  - In the second approach, a low voltage DC power is converted to low voltage AC power and then this output is stepped up to high voltage AC power.
- They are available in different types in market. They exist in different shapes and sizes. They vary from low power to high power functions.

Let's move towards the second section in which I am going to tell you all about the main parts of an inverter's circuit.

TYPES OF INVERTER:

SERIES INVERTER

PARALLEL INVERTER

Series Inverter (Load Commutated Inverter or Self Commutated Inverter **)**

- *The commutating components L and C are connected in series with the load therefore this inverter is called as series inverter.*
- *The value of commutating components is selected such that the circuit becomes under damped.*
- *The anode current itself becomes zero in this inverter resulting the SCRturns off automatically therefore this inverter is also called as self commutated or load commutated inverter.*
- *The power circuit diagram of the series inverter is shown in the figure A.*
- *The SCR T1 and SCR T2 are turned on at regular interval in order to achieve desirable output voltage and output frequency.*
- *The SCR T2 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.*

Fully controlled full wave bridge rectifier

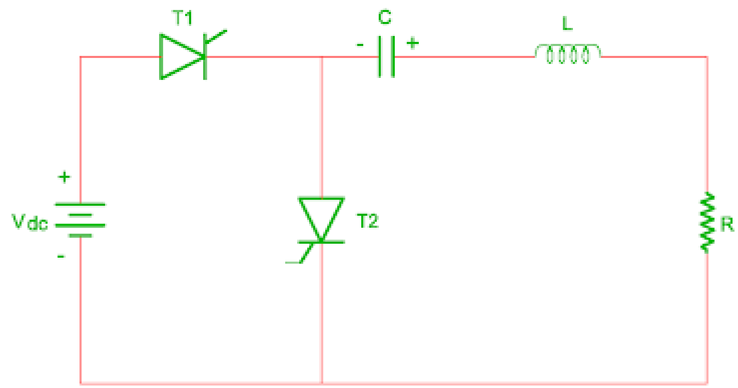


FIGURE A : BASIC SERIES INVERTER

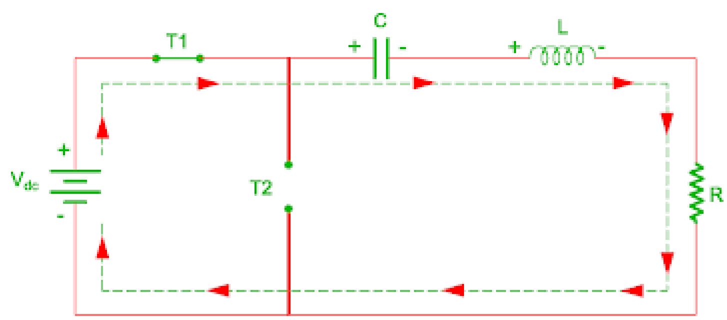


FIGURE B : EQUIVALENT CIRCUIT WHEN SCR T1 'ON'

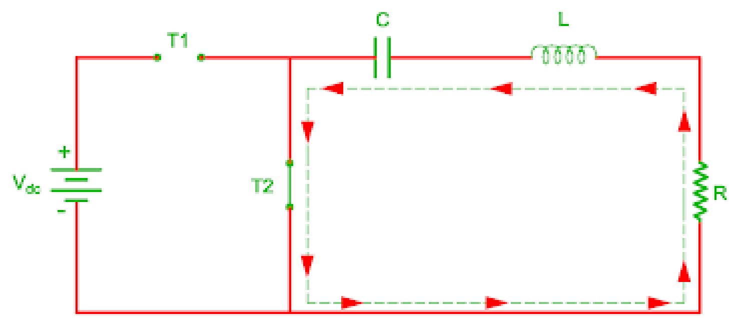


FIGURE C : EQUIVALENT CIRCUIT WHEN SCR T2 'ON'

Mode 1

- *The voltage V_{dc} directly applies to RLC series circuit as soon as the SCR T1 is turned on.*
- *The polarity of capacitor charging is shown in the figure B. The nature of the load current is alternating as there is underdamped circuit of the commutating components.*
- *The voltage across capacitor becomes + V_{dc} when the load current becomes maximum.*
- *The voltage across capacitor becomes +2V_{dc} when the load current becomes zero at point a (figure D). The SCR T1 automatically turns off at point a because the load current becomes zero.*

Mode 2

- *The load current becomes zero from point a to b as the SCR T1 turns off in this time period.*
- *The SCR T1 and SCR T2 are turned off in this time duration and voltage across capacitor becomes equal to +2 V_{dc}.*

Mode 3

- *The SCR T2 is turned on at point b due to it receives positive capacitor voltage. The discharging of capacitor is done through SCR T2 and R – L circuit as shown in the figure C.*
- *The load current becomes zero after it becomes maximum in the negative direction.*

Fully controlled full wave bridge rectifier

- *The capacitor discharges from +2 V_{dc} to – V_{dc} during this time and SCR T2 turns off automatically at point C due to load current becomes zero.*
- *The SCR T2 turns off during point C to D and SCR T1 again turns on.*
- *This way cycle repeat after it complete one turns.*
- *The positive AC output voltage half cycle generates due to DC voltage source whereas negative half cycle generates due to capacitor.*
- *There is always some time delay kept between one SCR turned on time and other SCR turned on time.*
- *The DC output gets short circuited due to continuous conduction of both SCRs if there is no time delay between SCRs.*
- *The time duration ab and cd must be greater than the SCR specific turn off time and it is called as dead zone.*

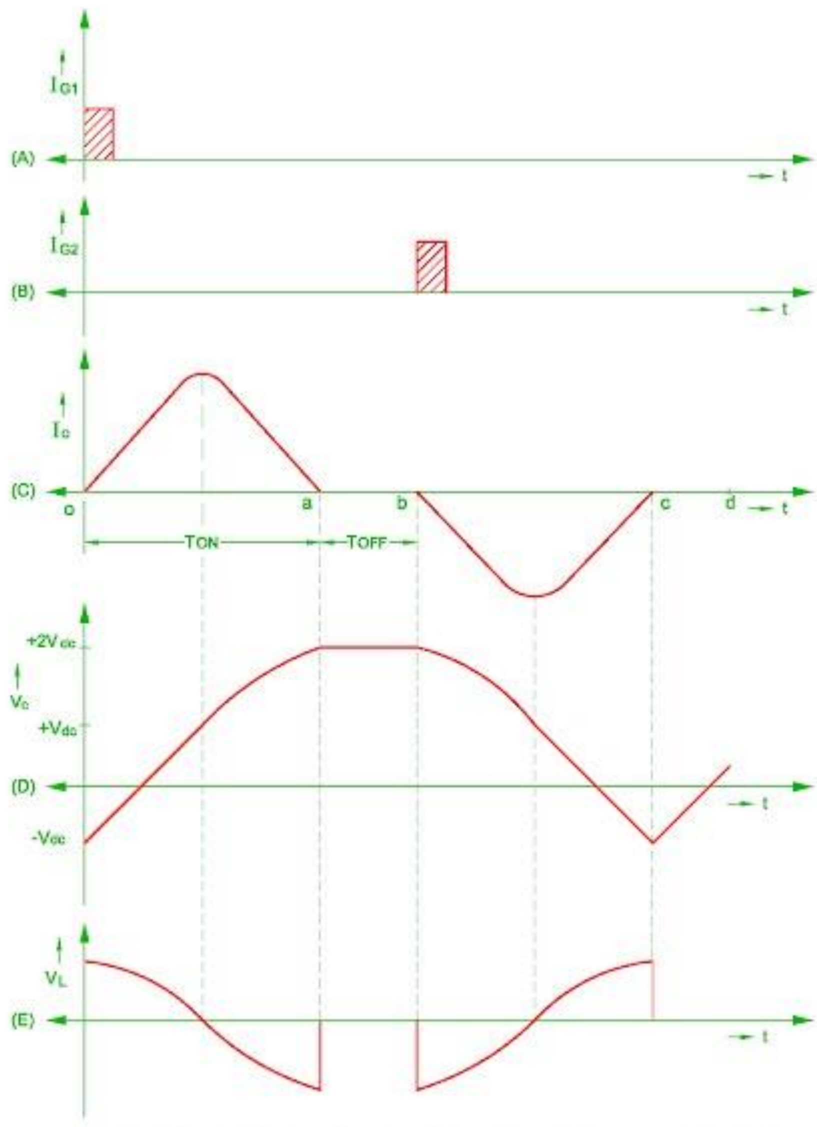


FIGURE D : VOLTAGE AND CURRENT WAVEFORMS OF SERIES INVERTER
(A) Gate pulse for SCR T1 (B) Gate pulse for SCR T2 (C) output current,
(D) Capacitor voltage (E) Load voltage

Limitations of series inverter

The limitation of series inverter is as given below.

- *The load current flows only during positive half cycle from supply source.*
- *The DC supply source gets short circuited if SCR T1 and SCR T2 simultaneously turned on.*

Fully controlled full wave bridge rectifier

- *The rating of commutating components should high because the load current flows through it.*
- *The load voltage waveform gets distorted if the dead zone time or SCR turns on time high.*
- *The maximum output frequency of the inverter should be less than the ringing frequency. The DC supply source is short circuited if the output frequency of the inverter is higher than the ringing frequency.*
- *The maximum current during each half cycle and its time duration depends upon parameter of load this will result in poor regulation of the inverter output.*

Applications

This type of inverter generates sinusoidal waveforms whose output frequency is in the range of 200 Hz to 100 kHz therefore it is applicable for

- *Induction heating*
- *Sonar transmitter*
- *Fluorescent lighting and*
- *Ultrasonic generator*

Parallel Inverter OR Parallel Inverter With Feedback Diodes

- *The power circuit diagram of the single phase parallel inverter is shown in the figure A.*
- *The commutating capacitor C is connected across supply source therefore it is called as parallel inverter.*
- *The turns ratio of half primary winding and secondary winding of the transformer is kept unity.*
- *The SCR T1 and SCR T2 are main SCRs from which load current passes through it.*

Fully controlled full wave bridge rectifier

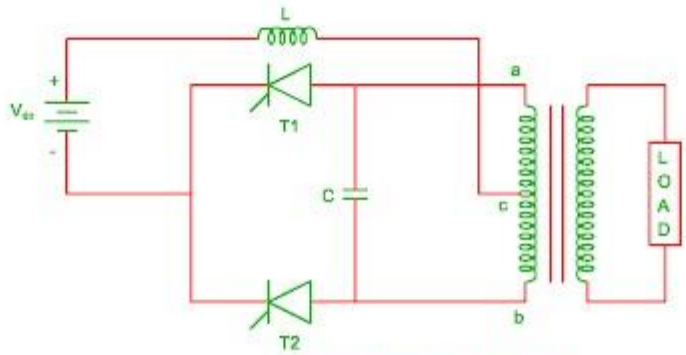


FIGURE A : PARALLEL INVERTER

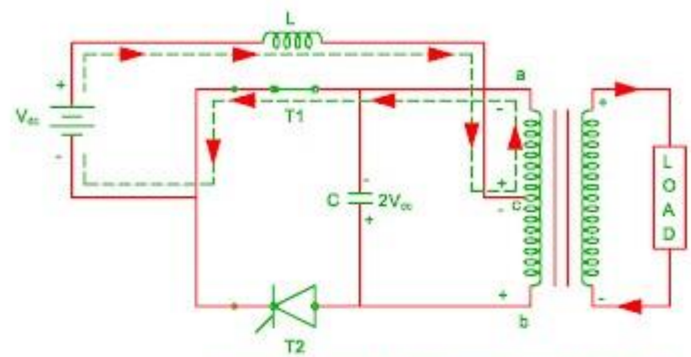


FIGURE B : EQUIVALENT CIRCUIT WHEN SCR T1 'ON'

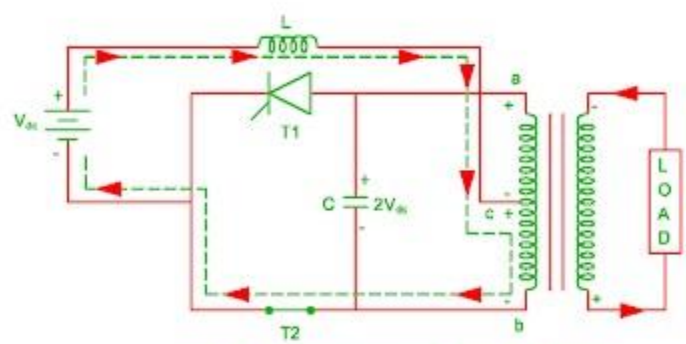


FIGURE C : EQUIVALENT CIRCUIT WHEN SCR T2 'ON'

Mode 1

- *The load current flows through path $+V_{dc} – L – c – a –$ SCR T1 $– V_{dc}$ when the SCR T1 is turned on.*
- *This will generate flux and resulting emf in the transformer primary winding ac and bc.*
- *The charging of capacitor is done up to $2V_{dc}$ voltage due to these induced emf. The polarity of capacitor C is done in the figure B.*
- *The maximum voltage withstand capability of the SCR T2 is $2V_{dc}$.*
- *The induced emf in the transformer secondary is $2V_{dc}$ as there is unity turns ratio between half primary and secondary winding.*
- *This will result flow of current through load.*

Mode 2

- *When the SCR T2 is turned on, the SCR T1 is turned off due to capacitor reverse voltage $2V_{dc}$ applied across it.*
- *As the SCR T2 is turned on, the load current flows through path $+V_{dc} – L – c – b –$ SCR T2 $– V_{dc}$ and discharging of capacitor is done through SCR T2.*
- *The charging of capacitor again done with $– 2V_{dc}$ voltage.*

Fully controlled full wave bridge rectifier

- *The current flows during this interval are in reverse direction as that of when SCR T1 is turned on.*
- *The SCR T1 again turned on when it receives gate pulse and SCR T2 is in off condition during this interval.*
- *The waveforms of the output voltage become rectangular due to alternately switching of SCR T1 and SCR T2.*

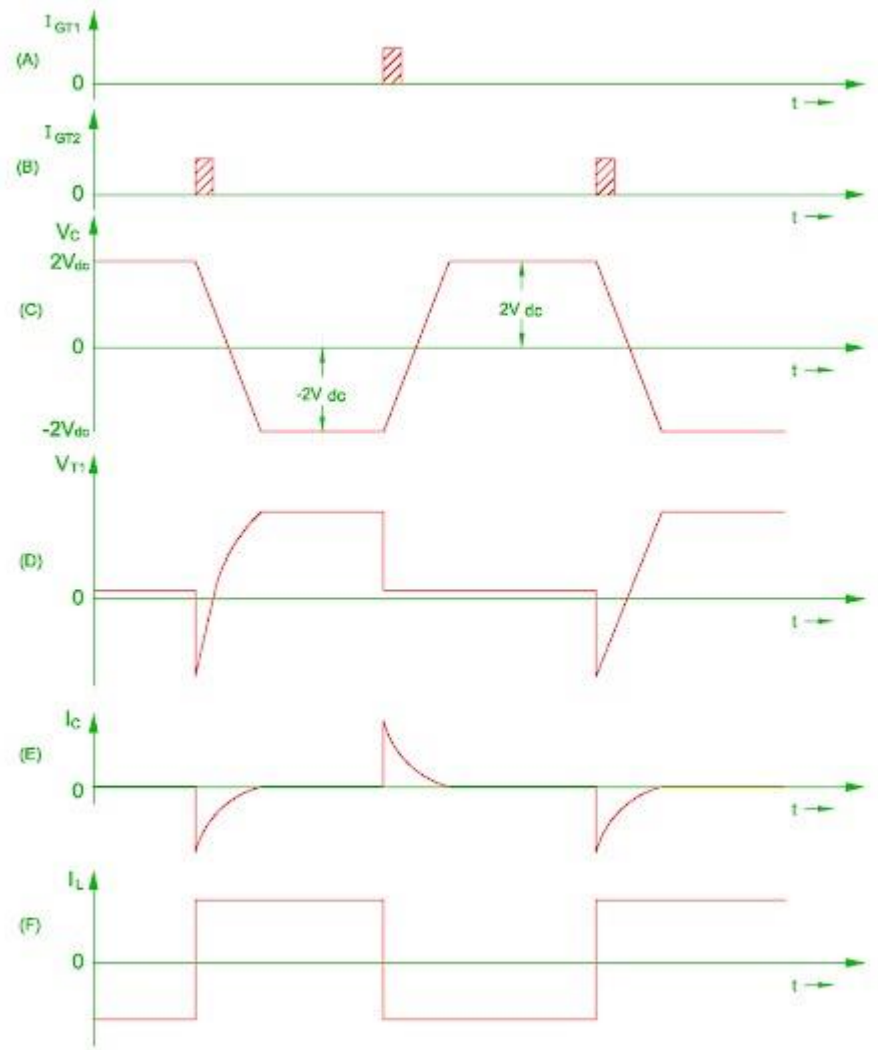


FIGURE D : VOLTAGE AND CURRENT WAVEFORMS FOR PARALLEL INVERTER

(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

Parallel inverter:

- *When load is inductive, the load current becomes out of phase with load voltage and direction of load current reverses with respect to load voltage.*
- *The stored energy during this interval feeds back through diodes D1 and D2. The circuit diagram of parallel inverter with feedback diodes is shown in the figure C.*

Fully controlled full wave bridge rectifier

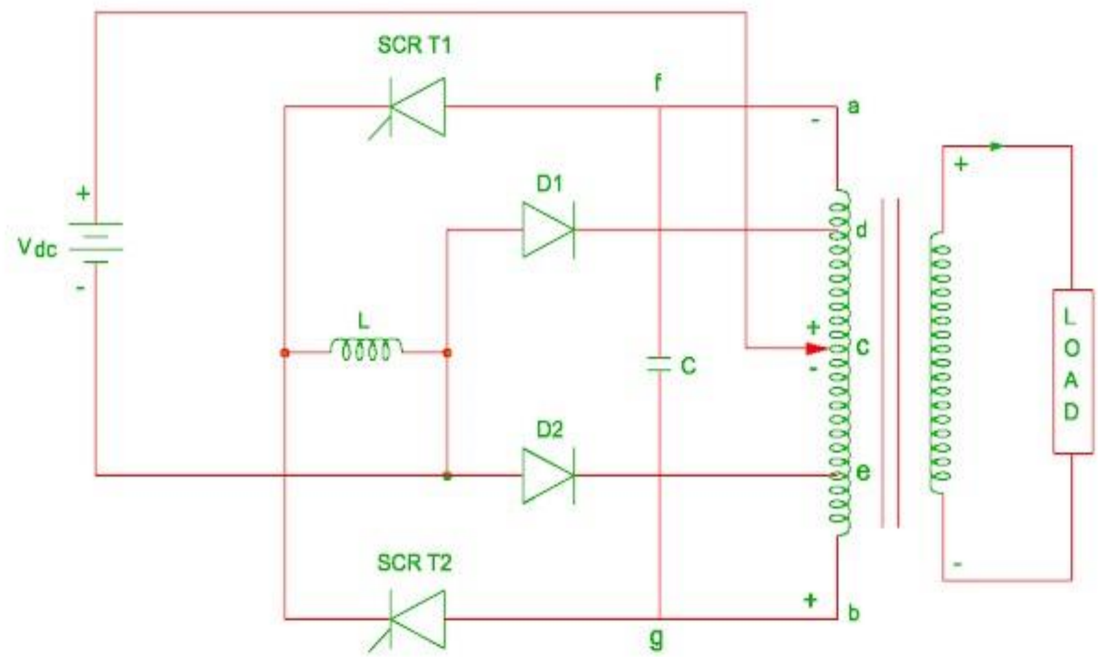


FIGURE E : PARALLEL INVERTER WITH FEEDBACK DIODES

- *When SCR T1 is switched on, the current flows through path + V_{dc} – c – a – SCR T1 – L – V_{dc} (-).*
- *The flux generated in the transformer primary winding ac and bc due to this current.*
- *This will result in 2V_{dc} voltage induced in the transformer primary winding. The charging of capacitor polarity is shown in the figure D.*
- *When SCR T2 is switched on, the SCR T1 is turned off due to reverse voltage of capacitor and capacitor discharges through path C – g – SCR T2 – L – D1 – d – a – f – C.*
- *The stored energy of capacitor transfers to load via transformer upper side primary winding.*
- *When SCR T2 is turned on, the current flows through path + V_{dc} – c – b – SCR T2 – L – V_{dc}(-) and capacitor again charges with voltage – 2V_{dc}.*
- *The capacitor again discharges through path C – f – SCR T1 – L – D2 – e – b – g – C when SCR T1 is again turned on.*
- *This will result in stored energy of capacitor transfer to load via transformer lower side primary winding.*

__Fully controlled full wave bridge rectifier__

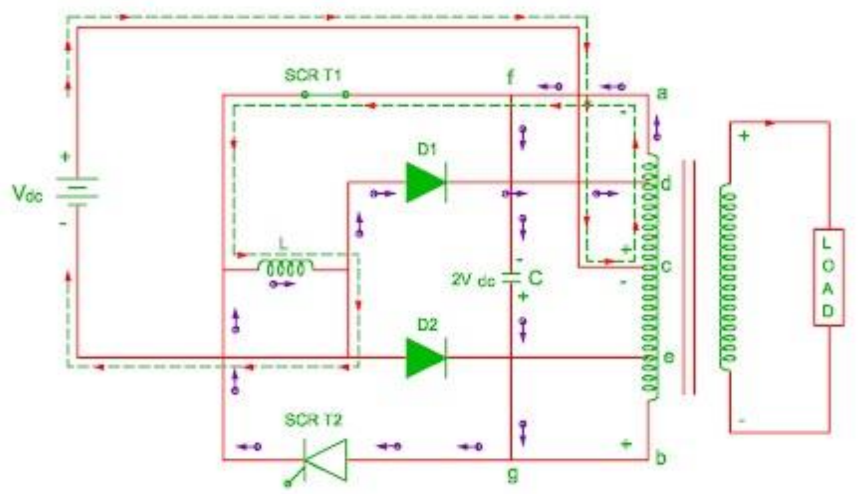


FIGURE F : EQUIVALENT CIRCUIT WHEN SCR T1 'ON'
CAPACITOR CHARGING PATH

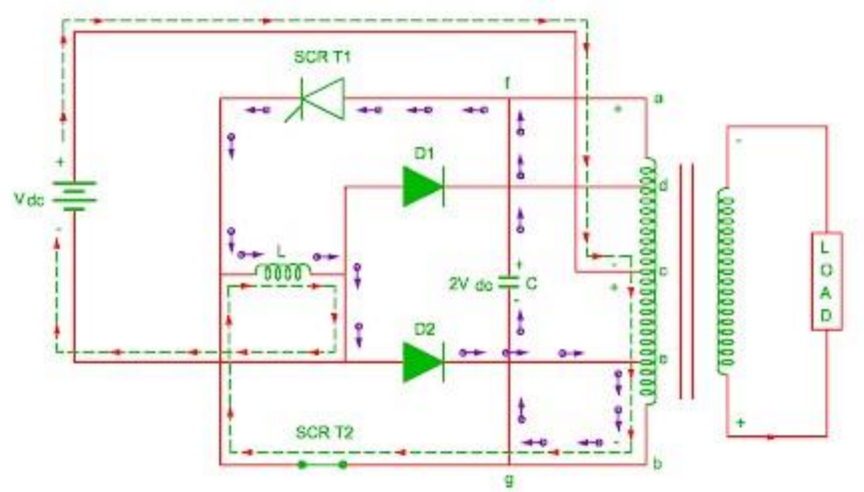


FIGURE G : EQUIVALENT CIRCUIT WHEN SCR T2 'ON'
CAPACITOR DISCHARGING PATH

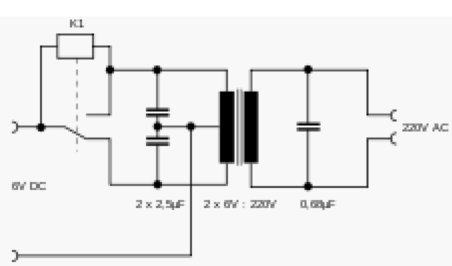
Advantages

- *Simple forced commutation circuit.*
- *Sinusoidal waveform at output is possible by using suitable filter circuit*

Disadvantages

- *The parallel inverter is useful only when load is fixed. (The output waveform changes due to change in load)*
- *The inverter does not useful for higher power for fixed value of inductor L and capacitor C.*

Chopper



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Schematic of an inverter using a vibrator as a chopper.

*In electronics, a **chopper** circuit is used to refer to numerous types of electronic switching devices and circuits used in power control and signal applications. A chopper is a device that converts fixed DC input to a variable DC output voltage directly. Essentially, a chopper is an electronic switch that is used to interrupt one signal under the control of another.*

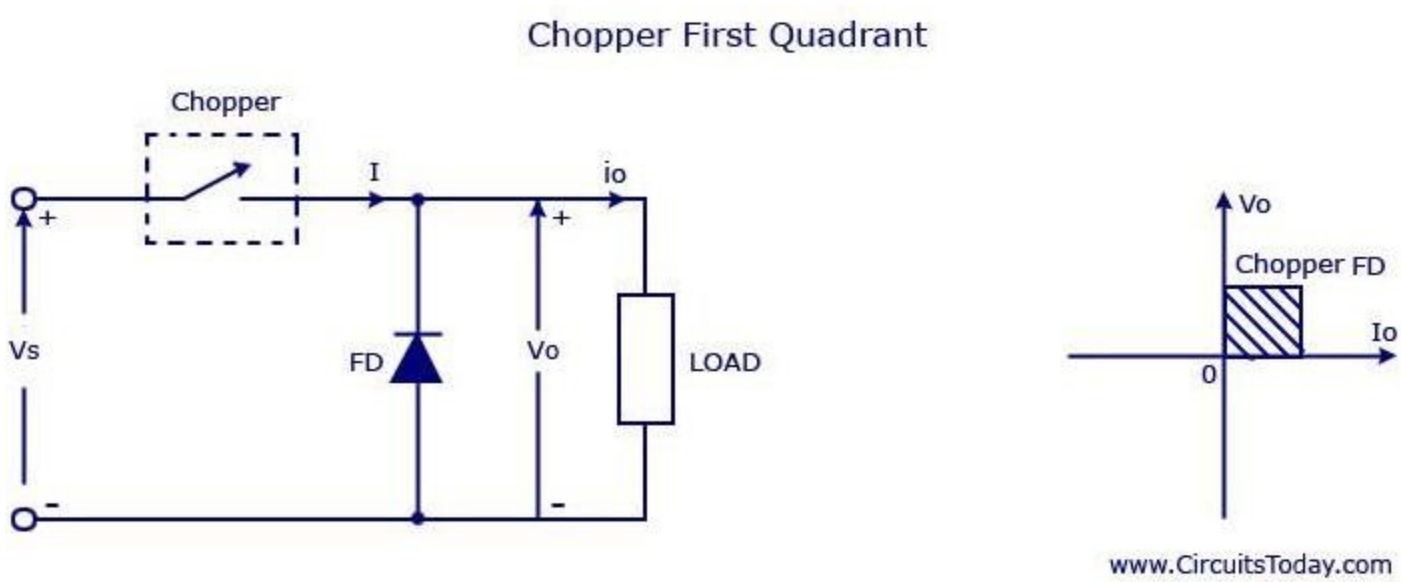
In power electronics applications, since the switching element is either fully on or fully off, its losses are low, and the circuit can provide high efficiency. However, the current supplied to the load is discontinuous and may require smoothing or a high switching frequency to avoid undesirable effects. In signal processing circuits, use of a chopper stabilizes a system against drift of electronic components; the original signal can be recovered after amplification or other processing by a synchronous demodulator that essentially un-doe

Types of Chopper Circuits

In power electronics **chopper circuits**, unidirectional power semiconductors are used. If these semiconductor devices are arranged appropriately, a chopper can work in any of the four quadrants. we can classify chopper circuits according to their working in any of these four quadrants as type A, type B, type C, type D and type E. Let us now take a look of these classifications and the characteristics of various classifications.

Type A Chopper or First–Quadrant Chopper

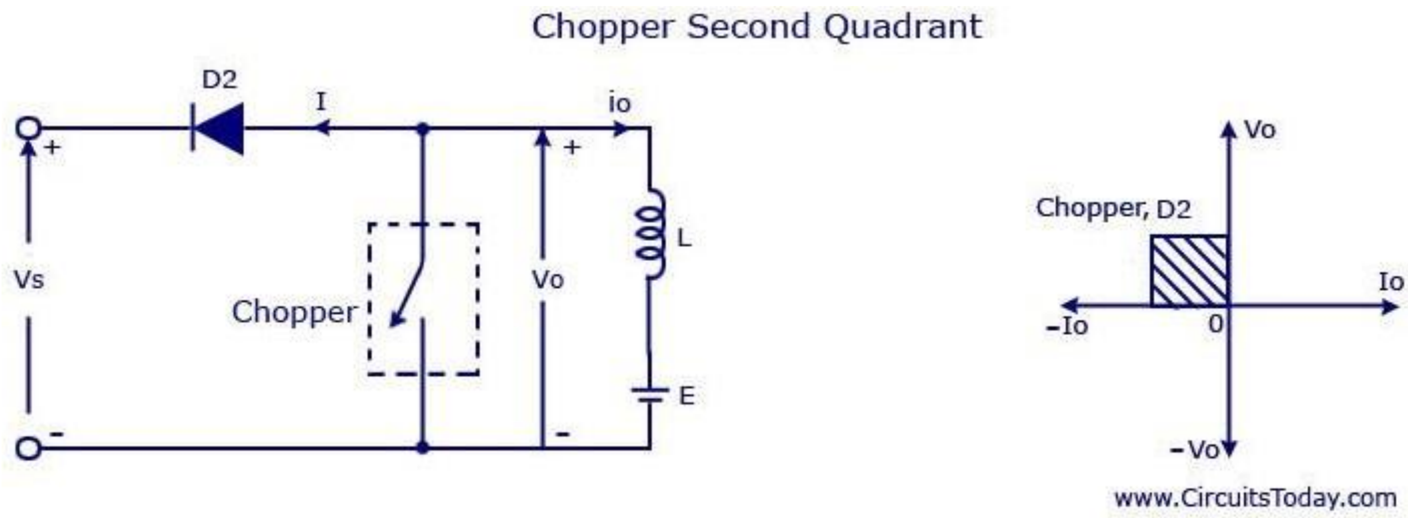
This type of chopper is shown in the figure. It is known as first-quadrant chopper or type A chopper. When the chopper is on, $v_0 = V_S$ as a result and the current flows in the direction of the load. But when the chopper is off v_0 is zero but I_0 continues to flow in the same direction through the 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.



Chopper First Quadrant

In type A chopper the power flow will be always from source to the load. As the average voltage V_0 is less than the dc input voltage V_s -

Fully controlled full wave bridge rectifier
Type B Chopper or Second-Quadrant Chopper



Chopper Second Quadrant

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 D2 will be forward biased and begins conducting and hence the power starts flowing to the source. No matter the chopper is on or off the current 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

Type C chopper is obtained by connecting type –A and type –B choppers in parallel. We will always get a positive output voltage V_0 as the freewheeling diode FD is present across the load. When the chopper is on the freewheeling diode starts conducting and the output voltage v_0 will be equal to V_s . The direction of the load current i_0 will be reversed. The current i_0 will be flowing towards the source and it will be positive regardless the chopper is on or the FD conducts. The load current will be negative if the chopper is or the diode D2 conducts. We can say the chopper and FD operate together as type-A chopper in first quadrant. In the second quadrant, the chopper and D2 will operate together as type –B chopper.

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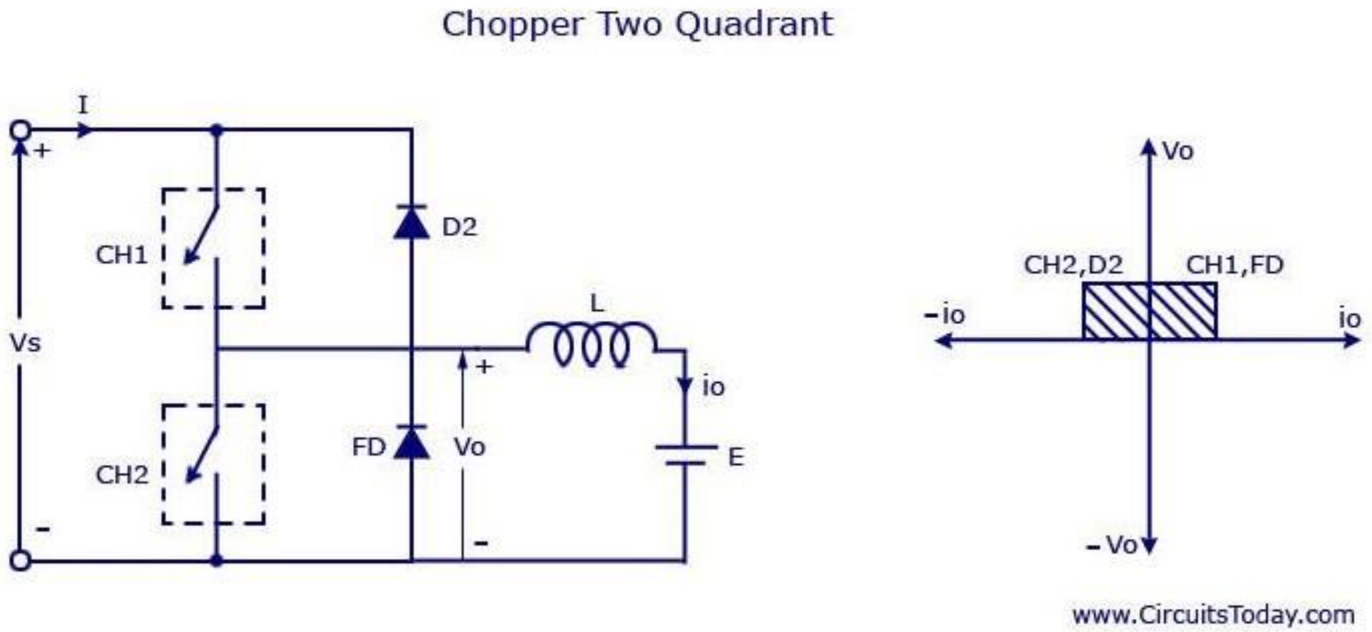
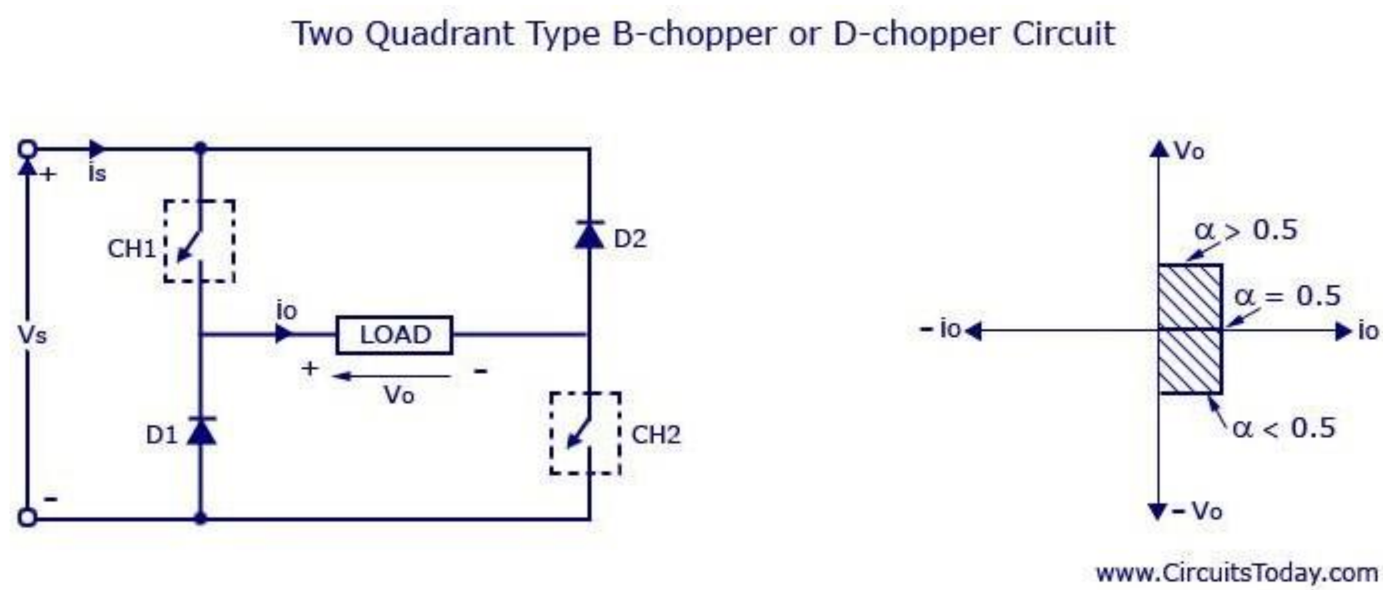


Chopper Two Quadrant

The average voltage will be always positive but the average load current might be positive or negative. The power flow may be life the first quadrant operation ie from source to load or from load to source like the second quadrant operation. The two choppers should not be turned on simultaneously as the combined action my cause a short circuit in supply lines. For regenerative braking and motoring these type of chopper configuration is used.

Type D Chopper or Two-Quadrant Type –B Chopper

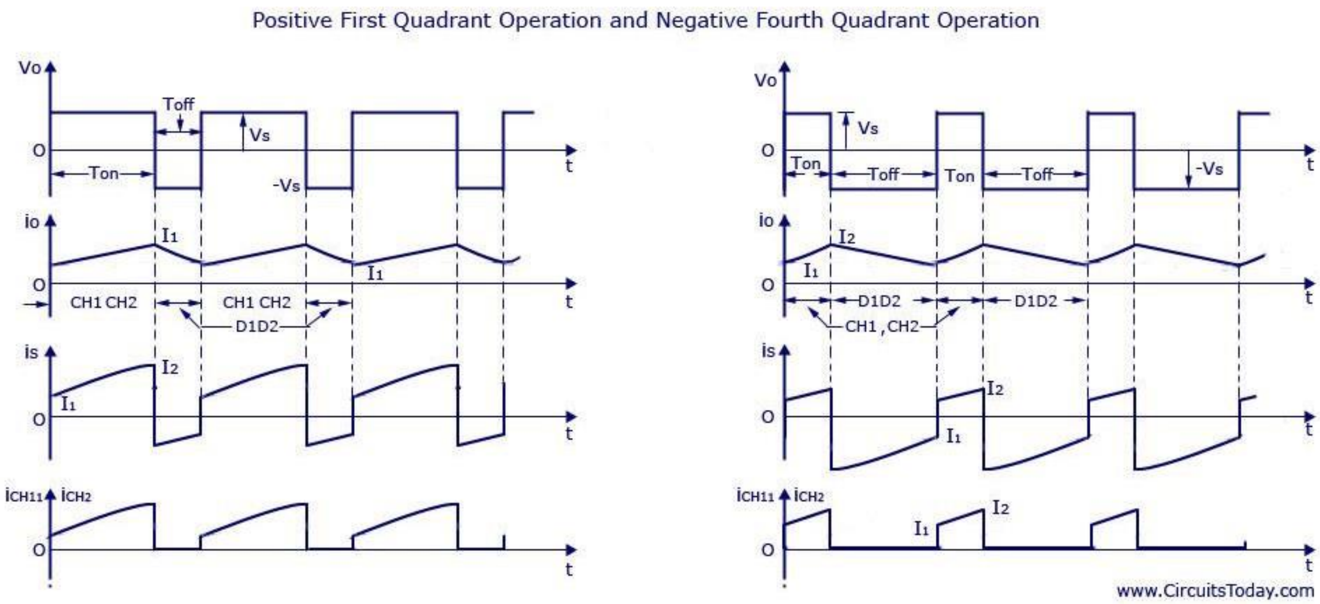


Two Quadrant Type B chopper or D Chopper Circuit

The circuit diagram of the type D chopper is shown in the above figure. When the two choppers are on the output voltage v_0 will be equal to V_s . When $v_0 = – V_s$ the two choppers will be off but both the diodes D1 and D2 will start conducting. V_0 the average output voltage will be positive when the choppers turn-on the time T_{on} will be more than

Fully controlled full wave bridge rectifier

the turn off time T_{off} its shown in the wave form below. As the diodes and choppers conduct current only in one direction the direction of load current will be always positive.



Positive First Quadrant Operation and Negative Fourth Quadrant Operation

The power flows from source to load as the average values of both v_0 and i_0 is positive. From the wave form it is seen that the average value of V_0 is positive thus the forth quadrant operation of type D chopper is obtained.

From the wave forms the Average value of output voltage is given by V0= $(V_s T_{on}-V_sT_{off})/T = V_s.(T_{on}-T_{off})/T$

Type –E chopper or the Fourth-Quadrant Chopper

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

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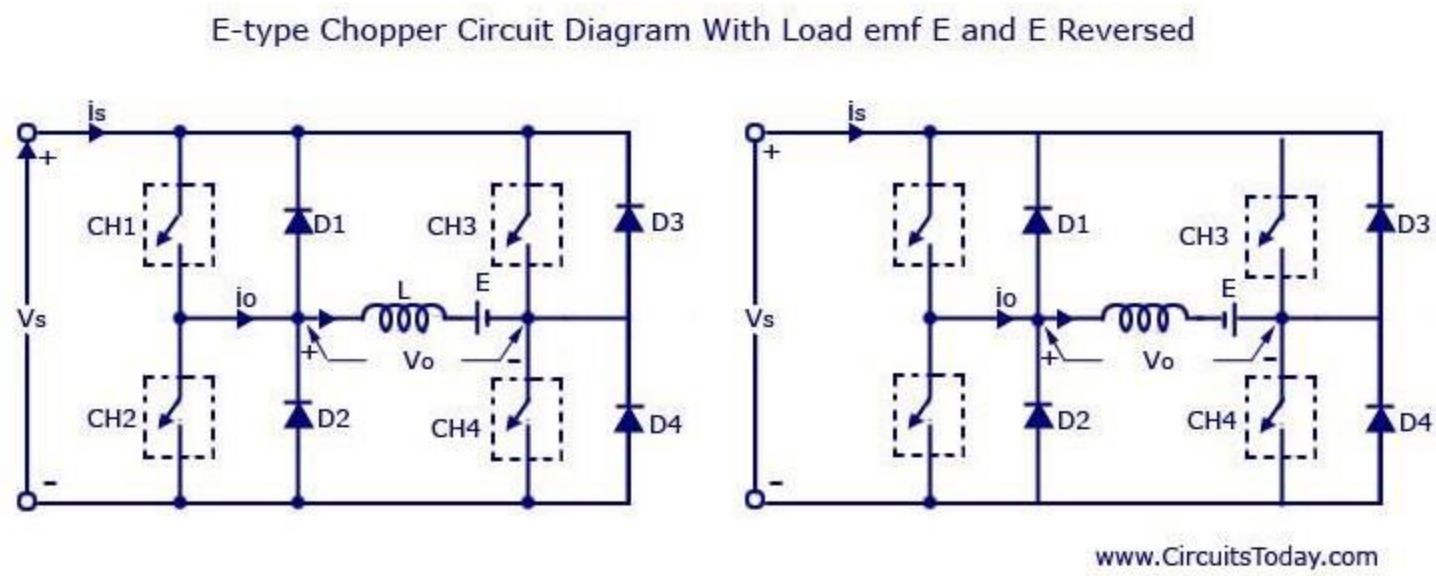

E-type Chopper Circuit diagram with load emf E and E Reversed

First Quadrant

During the first quadrant operation the chopper CH4 will be on . Chopper CH3 will be off and CH1 will be operated. AS the CH1 and CH4 is on the load voltage v_0 will be equal to the source voltage V_s and the load current i_0 will begin to flow . v_0 and i_0 will be positive as the first quadrant operation is taking place. As soon as the chopper CH1 is turned off, the positive current freewheels through CH4 and the diode D2 . The type E chopper acts as a step- down chopper in the first quadrant.

Second Quadrant

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

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

CH4 will be operated and CH1, CH2 and CH3 will be off. When the chopper CH4 is turned on positive current starts to flow through CH4, D2 ,E and the inductor L will store energy. As the CH4 is turned off the current is feedback to the

Fully controlled full wave bridge rectifier

source through the diodes D2 and D3 , the operation will be in fourth quadrant as the load voltage is negative but the load current is positive. The chopper acts as a step up chopper as the power is fed back from load to source.

Step Up Chopper-Boost converter

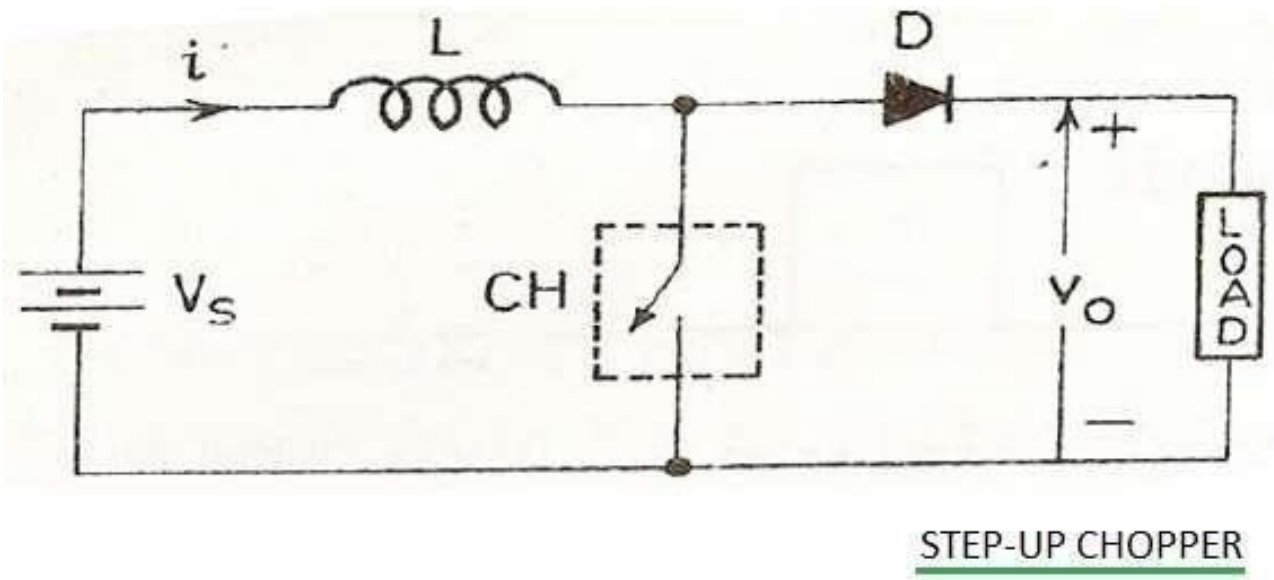

Figure-1 depicts circuit of ***Step Up Chopper****. As it increases input voltage, hence it is also known as boost converter.*

The Operation of the Step Up chopper is as follows:

• When the chopper is in ON state, the switch path is closed and current flows. Hence inductor connected in series stores energy during this ON period.

• When the chopper is in OFF state, the switch path is open. Inductor current does not reduce instantaneously and it flows through the diode and load during this OFF period.

• Due to above, voltage across the load exceeds the source voltage Vs. Hence the circuit is referred as step up chopper.

• The equation for average load voltage for this boost converter is given by following:

$Vo = (T/Toff)* Vs = (1/1-\alpha)*Vs$

Where,

α is duty cycle

$T = Ton + Toff$

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Step Down Chopper-Buck converter

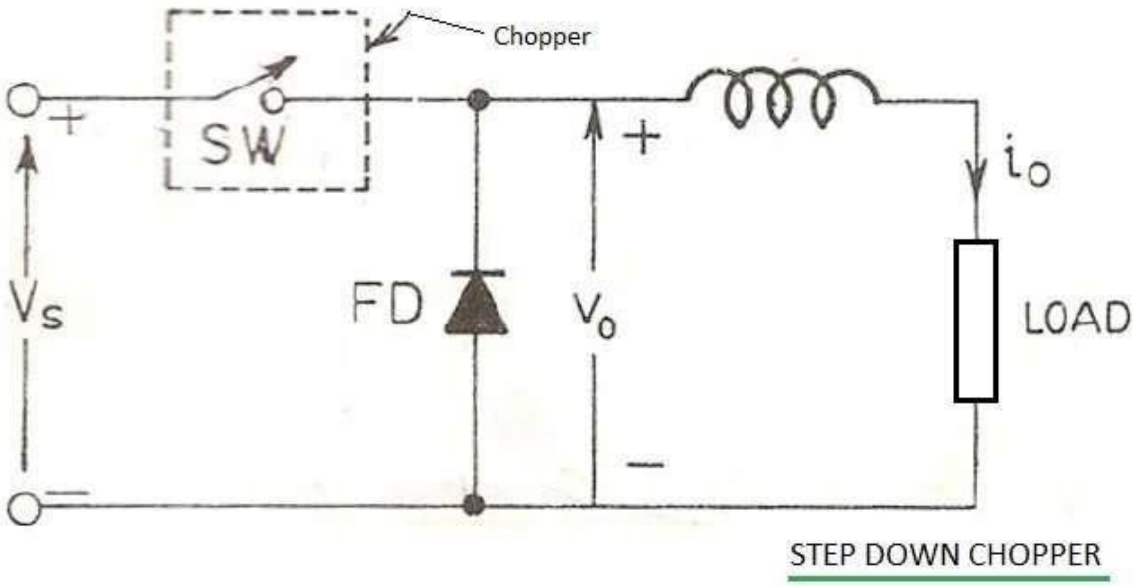


Figure-2 depicts circuit of **Step Down Chopper**. As it decreases input voltage, hence it is also known as buck converter.

The Operation of the Step Down chopper is as follows:

• When the chopper is in ON state, load voltage is equal to the source voltage.

• When the chopper is in OFF state, the load current flows through the diode. As a result load terminals are short circuited by the diode. Hence load voltage is zero during the OFF period.

• Due to above, load current increases during ON period and decreases during OFF period. Hence chopped DC voltage is available at the load. Hence the circuit is referred as step down chopper.

• The equation for average load voltage for this buck converter is given by following:

Vo = { Ton/(Ton+Toff) } Vs = α*Vs*

Where,

α is duty cycle

T =Ton + Toff

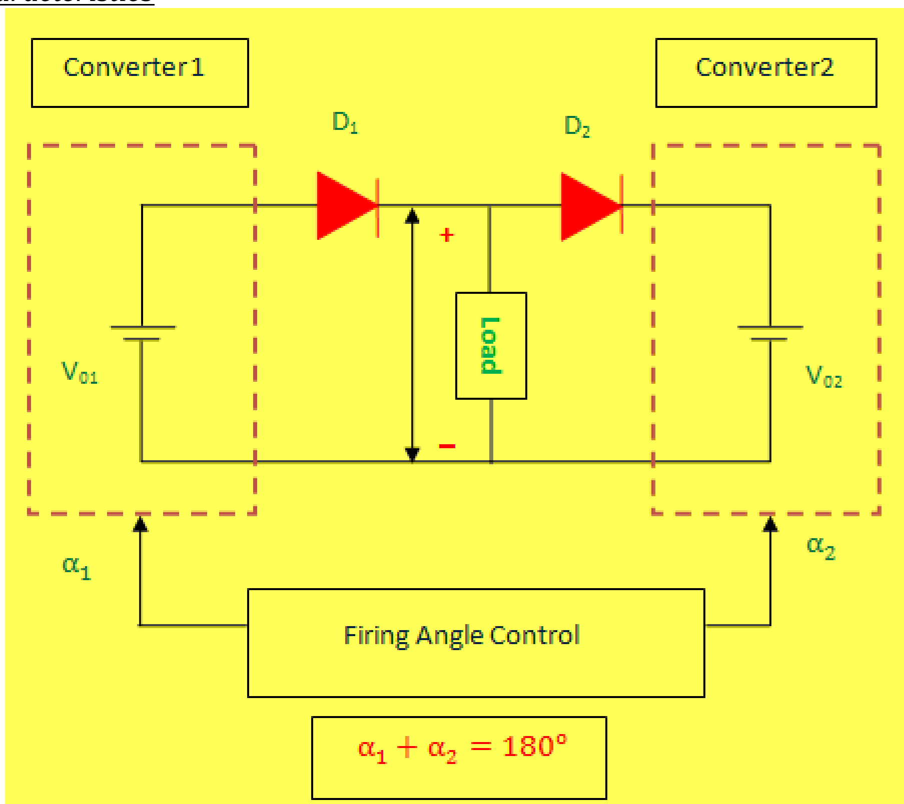
Principle of Dual Converter

The dual converter basic principle of operation can be explained with reference to the simplified equivalent diagram of the DC circuit shown in the figure below. In this simplified representation, two assumptions are made.

- *Dual converters are ideal that means they produce pure DC output terminals without containing any ripples.*
- *Each two-quadrant converter is assumed to be a controllable direct voltage source, connected in series with a diode.*

Here Diode D1 and D2 represent the unidirectional current flow characteristics of the converters. However, the direction of current can be in any way. Let us assume, the average output voltage of the converter 1 is V01 and *converter 2 is V02. To make the output voltage of the two converters in same polarity and magnitude, the firing angles of the thyristors have to be controlled.*

To know more about thyristor, please follow the link: Thyristor or Silicon Controlled Rectifier Tutorial basics and Characteristics



Ideal Dual Converter Simplified Representation

Average output voltage of Single-phase converter = 2Vm COSα/ π

Average output voltage of Three-phase converter = 3Vm COSα/ π

For converter 1, the average output voltage, V01= Vmax COSα1

For converter 2, the average output voltage, V02= Vmax COSα2

The Output voltage is given by,

$$V_0 = V_{01} = -V_{02}$$
$$V_{max}Cos\alpha_1 = -V_{max}Cos\alpha_2$$
$$Cos\alpha_1 = Cos(180^o - \alpha_2)\ or\ Cos\alpha_2 = Cos(180^o + \alpha_2)$$
$$\alpha_1 + \alpha_2 = 180^o\ And\ \alpha_1 - \alpha_2 = 180^o$$

The firing angle can never be greater than 180. So, $\alpha1 + \alpha2 = 180^0$

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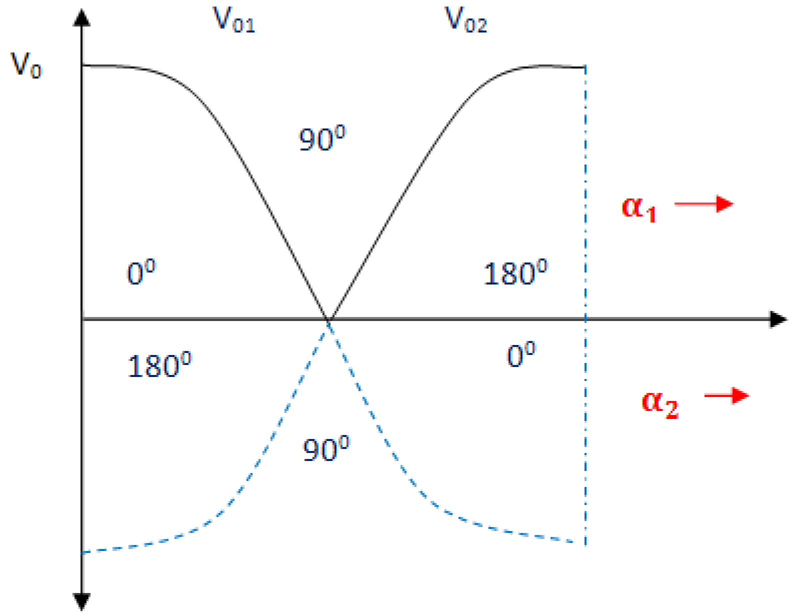

Firing Angle

Modes of Operation of Dual Converter

There are two functional modes: Non-circulating current mode and circulating mode.

Non-Circulating Current Mode

- *One converter will perform at a time. There is no circulating current between the converters.*
- *During the converter 1 operation, the firing angle (α1) will be $0<\alpha 1< 90^0$ (Vdc and Idc are positive)*
- *During the converter 2 operation, firing angle (α2) will be $0<\alpha 2< 90^0$ (Vdc and Idc are negative)*

Circulating Current Mode

- *In this mode, both converters will be in the ON condition at the same time. So circulating current is present.*
- *The firing angles are adjusted such that $\alpha 1+ \alpha 2=180^0$. Firing angle of converter 1 is α1 and firing angle of converter 2 is α2.*
- *In this mode, 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, Vdc and Idc are positive.*
- *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, Vdc and Idc are negative.*

Single Phase Dual Converter

The blow shown figure shows single phase dual converter using thyristors. As explained above, in single phase dual converter we use single phase rectifier circuit for converting single phase AC into steady DC.

The Converter 1 consists of Rectifier. Then the rectified DC fed to a filter which removes pulses from rectified DC and converts it to a pure DC by filtering.

After that, this pure DC is fed to load and from the load, it is given to inverter circuit which converts this DC to AC and finally this AC of inverter taken as the output.

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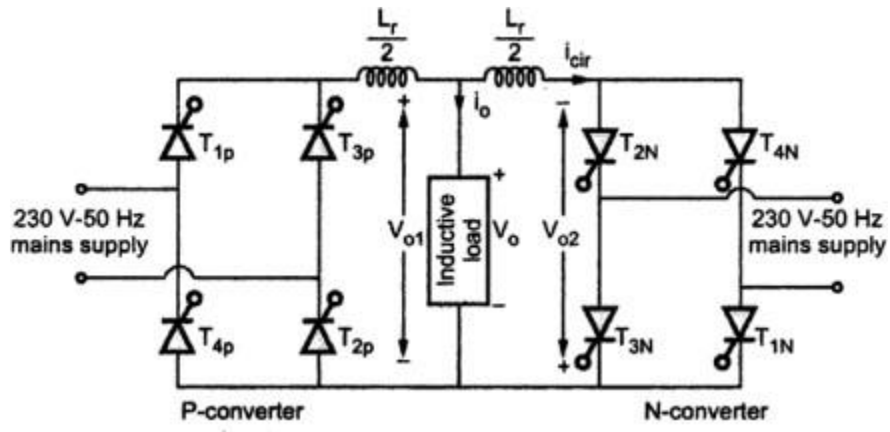
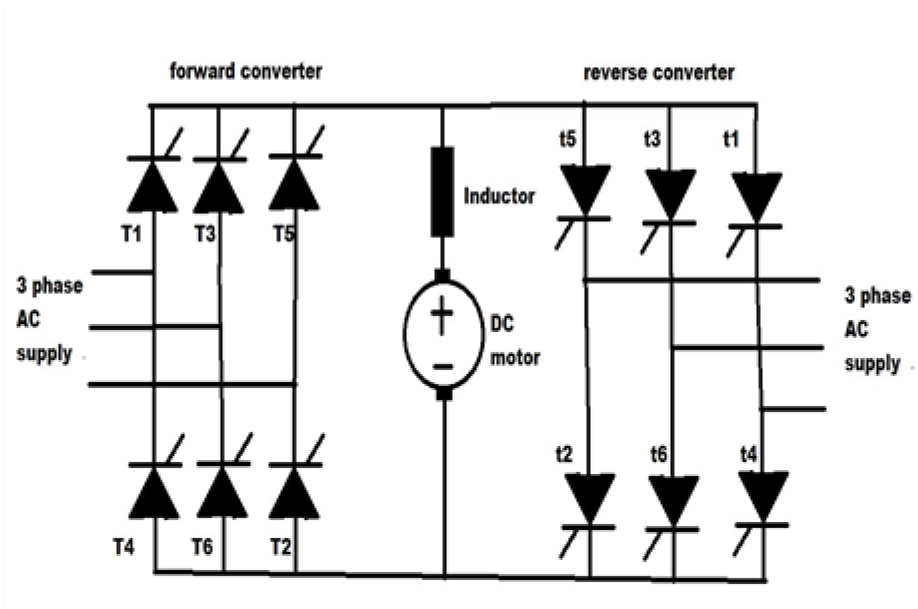


Single Phase Dual Converter

Three Phase Dual Converter

In three phase dual converter, we make use of three phase rectifier which converts 3 phase AC supply to DC. The structure of the converter is same as single phase dual converter.

The output of three phase rectifier is fed to filter and after filtering the pure DC is fed to the load. At last, the supply from the load is given to last bridge that is inverted. It does the Invert process of the rectifier and converts DC into 3 phase AC, which is output.



Three Phase Dual Converter

Applications of Dual Converter

- *Direction and Speed control of DC motors.*
- *Applicable wherever, the reversible DC is required.*
- *Industrial variable speed DC drives.*

Direction and Speed Control of DC Motors using Dual Converter by

The dual converter is a power electronics control system to get either polarity DC from AC rectification by the forward converter and reverse converter. It can run a DC motors in either direction with speed control too.

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This single phase converter is achieved by using a pair of a thyristor controlled bridge (4 SCRs X 2) that enables the DC motor to get reversed polarity for either direction rotation and speed control also lowered in steps by Microcontroller triggering each bridge SCR bank of duly interfaced through Opto-isolators.

A pair of switches is used to input logical signal for the desired output. If the input of 230 volt AC is given to the dual SCR Bridge we can have a 100-watt lamp load and the DC polarity across the lamp is checked or a low power DC motor of 220 volts can be used.

This project uses 12-volt ac at the input and a 12 volt DC motor to verify either direction rotation as the polarity gets reversed.

Further more details about this project please follow the link: Dual Converter using Thyristors.

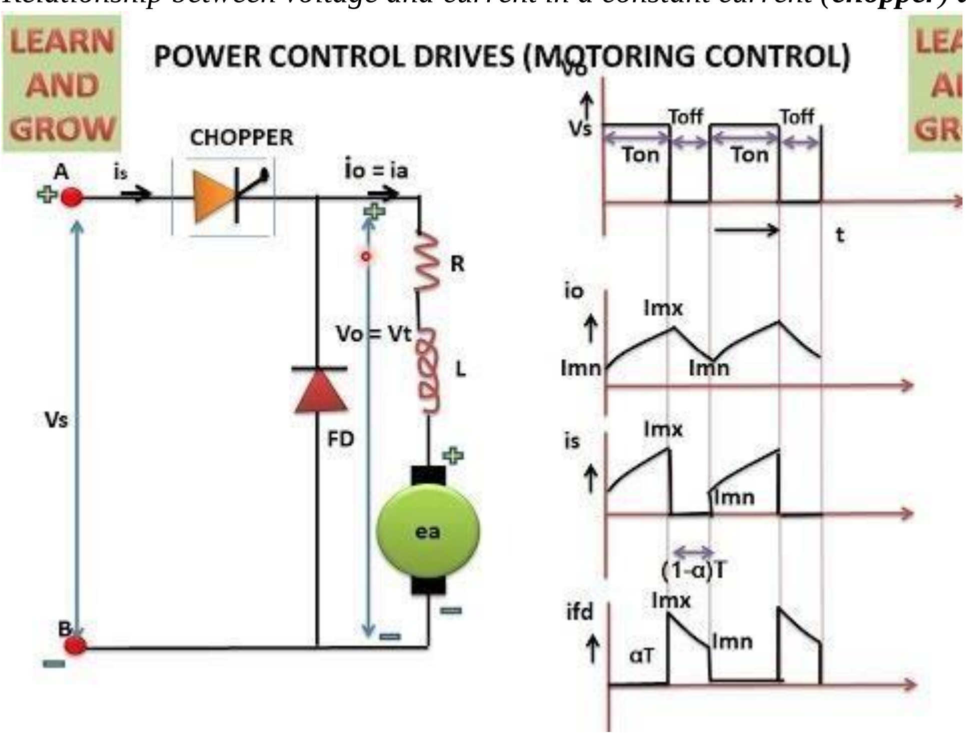
I hope you have clearly understood the topic of the Dual converter, It is a power electronics control system to get either polarity DC from AC rectification by forwarding converter and reverse converter. If any furthermore queries on this topic or on the electrical and electronic projects leave the comments section below.

UNIT-4

THRISTORISED CONTROL OF ELECTRIC DRIVE

Chopper drive

*A **chopper drive** addresses the problem of obtaining high torque at high speed from a stepper motor by turning the output voltage to the motor on and off rapidly (aka "chopping") to control the motor current. Relationship between voltage and current in a constant current (**chopper**) **drive**.*



Single phase controlled rectifier fed DC Drives –

Single phase controlled rectifier fed DC Drives Here AC supply is fed to the phase controlled rectifier circuit.AC supply may be single phase or three phase.Phase controlled rectifier converts fixed AC

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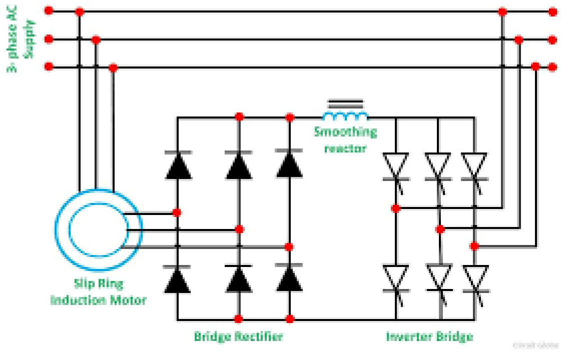
voltage into variable DC voltage . Here the circuit consists of SCR's.By varying the SCR firing angle the output voltage can be controlled. This variable output voltage is fed to the DC motor.

SLIP POWER RECOVERY SYSTEM

***SLIP POWER** RECOVERYSCHEME **Slip power recovery scheme** (SPRS)is a method of speed controlof wound rotor induction motor (WRIM) in which some amount of rotor recovered**power** is feedback to main supply instead of wasting it in the rotor resistance.*



Learning outcomes

After completion of the chapter 5, students will be able to:

Describe the construction, working principles of ups, specification, online ups,offline ups. Smartups.

Chapter-5

1.Introduction

Uninterruptible Power Supply

The Uninterruptible Power Supply (UPS) is an electronics device which supplies power to a load when main supplies or input power source fails. It not only acts as an emergency power source for the appliances, it serves to resolve common power problems too. Any UPS has a power storage element which stores energy in the form of chemical energy like the energy is stored in batteries.

It is like energy is stored in the form of motion in a flywheel. That is why these devices are also called battery backup or flywheel backup. The UPS not only provides emergency power, they also help to sort out common power related issues like providing protection from input power interruptions, protection from overvoltage, output voltage regulation and stabilization.

Uninterruptible Power Supply Circuit Diagram

The circuit diagram of the UPS is shown below, which shows how the batteries in the equipments controls during a power disruption. The input voltage of the primary winding of the transformer (TR1) is 240V. The secondary winding of the transformer (TR2) can be raised up to 15V if the value is at least 12V running 2 amps.The fuse is used to give the protection to the owl circuit from the short circuits. The electricity presence will cause the led1 to glow. The LED glows will set off upon power disruption and the battery of the UPS will take over. This circuit is designed to provide a more flexible pattern where it can be modified by using different batteries and regulators to offer regulated & unregulated voltages. Using two 12V batteries in series and a positive input of 7815 regulators, we can control a 15Volts supply.

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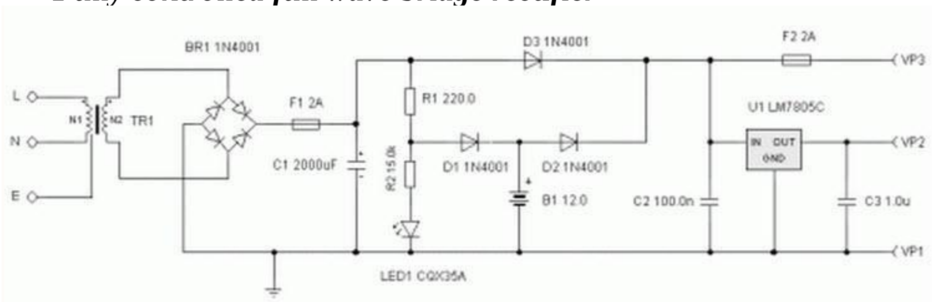

Specifications Of UPS:

UPS Type

Your choices are...	
Single Phase	Single-phase uninterruptible power supplies (UPS) sit between an AC outlet and an electronic device to provide power conditioning, back-up protection, and distribution for electronic equipment loads. They also prevent power disturbances from affecting the performance and life of the electronic device and vital data.
Three Phase	Three-phase uninterruptible power supplies (UPS) operate in conjunction with existing electrical systems to provide power conditioning, back-up protection, and distribution for electronic equipment loads that use three-phase power.
DC Power	DC uninterruptible power suppliers are designed specifically for DC systems. This type of UPS provides continuous back-up for telecommunication, telephone, and other systems that use DC power.
Search Logic:	All products with ANY of the selected attributes will be returned as matches. Leaving all boxes unchecked will not limit the search criteria for this question; products with all attribute options will be returned as matches.

Technology	
Your choices are...	
Delta Conversion	Delta conversion technology delivers a fraction of the input power to the load.
Ferro-Resonant	Ferro-resonant technology enables the UPS to operate like a standby/offline device. The difference, however, is that a ferro-resonant transformer is used to filter the output.
Fuel Cell UPS	This type of UPS uses a fuel cell as the power source. The fuel cell replaces the battery used in other types of units.
Hybrid Topology	Hybrid topology (double conversion on-demand) operates as an offline/standby for a particular preset window of power conditions. When the power conditions are outside of this predefined window, the UPS switches to online/double conversion operation. This type of operation is highly efficient.
Line-Interactive	The inverter works in parallel with conditioned input AC power to supply power to the load (boosting or bucking), and only handles the full load power when the AC input power fails. A line-interactive UPS provides protection from spikes and surges. It also supplies auxiliary power if a voltage sag or blackout occurs. Unlike a standby

	unit, a line-interactive UPS provides an automatic voltage boost (or buck) when the power dips, but without accessing the batteries. This feature provides continuous line conditioning, promotes longer battery life, and eliminates electronic "noise" that can cause minor application errors and loss of data.
On-line (Double-Conversion)	The load is supplied by a continuously-operating power converter that receives its input from a DC supply (a battery) and a large battery charger that are connected in parallel. By using an on-line conversion technique, an on-line UPS provides the highest-quality power protection. The UPS takes the incoming AC power and recreates it by converting the voltage to DC; then conditions the power to eliminate noise, sags, or surges; and, finally, converts the power back to AC before it exits the UPS. Because power runs continuously through the inverter, there is no transfer or switching time to battery mode in the event of a blackout.
Off-line (Standby)	With off-line or standby power supplies, power comes directly from the AC outlet until the voltage sags or the power fails. When such conditions occur, a battery-powered inverter turns on almost immediately and continues the supply of power. Batteries are charged as necessary when direct AC power is available. Even while power comes directly from the AC outlet, an off-line or standby UPS provides protection from voltage spikes and surges.
Rotary	A rotary UPS uses the inertia of a large spinning flywheel to provide short-term power in the event of a power loss.
Other	Other unlisted, specialized, or proprietary technologies.
Search Logic:	All products with ANY of the selected attributes will be returned as matches. Leaving all boxes unchecked will not limit the search criteria for this question; products with all attribute options will be returned as matches.

Protection	
Your choices are...	
Lightning	The device provides protection against lightning.
Over Voltage	The device provides protection against over voltage transients.
Power Failure	The UPS protects when a total loss of power takes place.
Short Circuit	The device provides protection against short-circuits.
Surge	The device provides protection against surge.
Voltage Sags	The device provides protection against voltage sags. Voltage sags are a brief reduction in the voltage on AC power systems.
Under Voltage	The UPS provides protection against low-voltage changes for prolonged periods.
Unbalanced Loads	The device provides protection against unbalanced Loads.
Other	Other unlisted protection types.
Search Logic:	All products with ANY of the selected attributes will be returned as matches. Leaving all boxes unchecked will not limit the search criteria for this question; products with all attribute options will be returned as matches.

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Performance

Volt-Amp	Uninterruptible power supplies (UPS) are rated in volt-amperes (VA) or kilo volt-amperes

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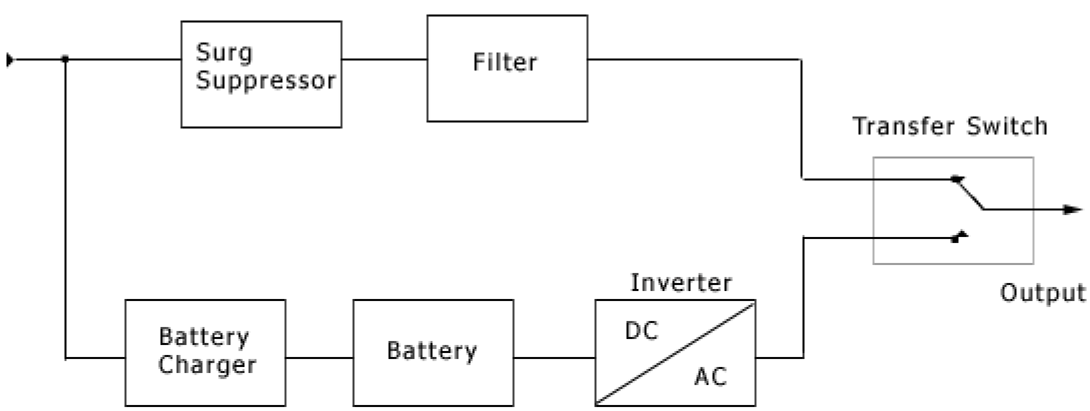
Rating	(kVA). The VA rating is the maximum number of volts * amps that a device can deliver. Note that the VA rating is not necessarily the same as the power drain (in watts) of the equipment.
Search Logic:	User may specify either, both, or neither of the "At Least" and "No More Than" values. Products returned as matches will meet all specified criteria.
Watt Rating	Specify the watt rating only if the volt-amp (VA) rating is unknown. The watt rating is less than or equal to the VA rating.
Search Logic:	User may specify either, both, or neither of the "At Least" and "No More Than" values. Products returned as matches will meet all specified criteria.

Offline UPS

The OFFLINE UPS supplies (or routes) the incoming mains supply directly through to the output usually through a relay contact. Some high frequency noise filtering and surge suppression may be included in this path.The UPS swiches on its inverter as soon as mains supply failure is detected or below the normal load and simultaneously switches the output relay to the inverter side to supply battery sourced power to the load. This transition involves a delay on account of the time to reliably detect mains failure and switch over a relay, and the output is broken for this period (usually for 2 to 12msec). OFF – LINE UPS are usually the least exensive as compared to the other two.

The Block diagram of inverter section of Online ups is shown:



ONLINE UPS:

A ***On-line UPS*** *uses a "double conversion" method of accepting AC input, rectifying to DC for passing through the rechargeable battery (or battery strings), then inverting back to 120V/240V AC for powering the protected equipment.*

Fully controlled full wave bridge rectifier

VERY SHORT ANSWER TYPE QUESTION

1- What is freewheeling diode
2- An inverter converts…..
3- What is online UPS
4- The load circuit of single phase full bridge inverter…..

SHORT ANSWER TYPE QUESTION

1- Write a short notes on series inverter
2- What is single phase full wave center tap rectifier.?
3- Give block diagram of online UPS
4- Write short note on parallel inverter.

- LONG ANSWER TYPE QUESTION
  1- What is chopper? explain in detail.
  2- What is slip recovery system
  3- What is dual converter
  4- Explain single phase full wave rectifier