4.1 Single Phase Inverter

The inverter is a power electronic converter that converts direct power to alternating power.

- By using this inverter device, we can convert fixed dc into variable ac power which as a variable frequency and voltage.
- Secondly from this inverter, we can vary the frequency i.e we will be able to generate the 40HZ, 50HZ, 60HZ frequencies as of our requirement.
- If the dc input is a voltage source then the inverter is known asVSI (Voltage Source Inverter).
- The bridge inverters are of two types they are **half-bridge inverter and full-bridge inverter.**

- The full bridge inverters need four switching devices whereas half- bridge inverter needs two switching devices.

SINGLE PHASE HALF BRIDGE INVERTER WITH R,RL and RLC LOAD

The circuit diagram of a single-phase half-bridge inverter with resistiveload is shown in the below figure.

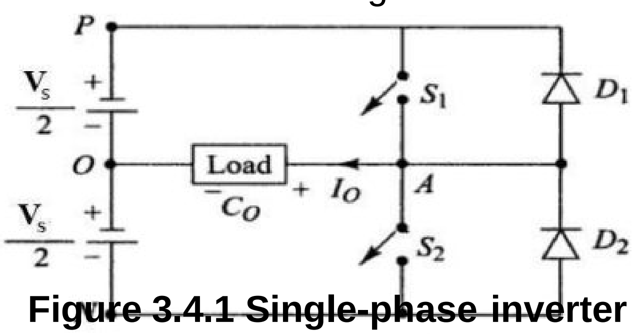


Figure 3.4.1 Single-phase inverter

[Source: "Power Electronics" *by* P.S.Bimbra, Khanna Publishers *Page: 310]*

❖ Vs/2 is the voltage source, S1 and S2 are the two switches, i0 is the current. Where each switch is connected to diodes D1 and D2 parallelly.

❖ In the above figure 4, the switches S1 and S2 are the self-commutating switches.The switch S1 will conduct when the voltage is positive and current is negative, switch S2 will conduct when the voltage is negative,and the current is negative. The diode D1 will conduct when the voltage is positive and current is negative, diode D2 will conduct when the voltage is negative, and the current is positive.

Case 1 (when switch S1 is ON and S2 is OFF):

- When switch S1 is ON from a time period of 0 to T/2, the diode D1 andD2 are in reverse bias condition and S2 switch is OFF.

- Where output voltage V0= Vs/2
- Where output current i0 = V0/R= Vs/2R
- In case of supply current or switch current, the current iS1 = i0 =Vs/2R, iS2 = 0 and the diode current iD1 = iD2 = 0.
- **Case 2 (when switch S2 is ON and S1 is OFF):**
- When switch S2 is ON from a time period of T/2 to T, the diode D1and D2 are in reverse bias condition and S1 switch is OFF.
- Applying KVL (Kirchhoff's Voltage Law)Vs/2+V0=0
- Where output voltage V0= -Vs/2
- Where output current i0 = V0/R= -Vs/2R

- In case of supply current or switch current, the current $i_{S1} = 0, i_{S2} = i_0 = -V_s/2R$ and the diode current $i_{D1} = i_{D2} = 0$.

- The single-phase half-bridge inverter output voltage waveform is shown in the below figure.

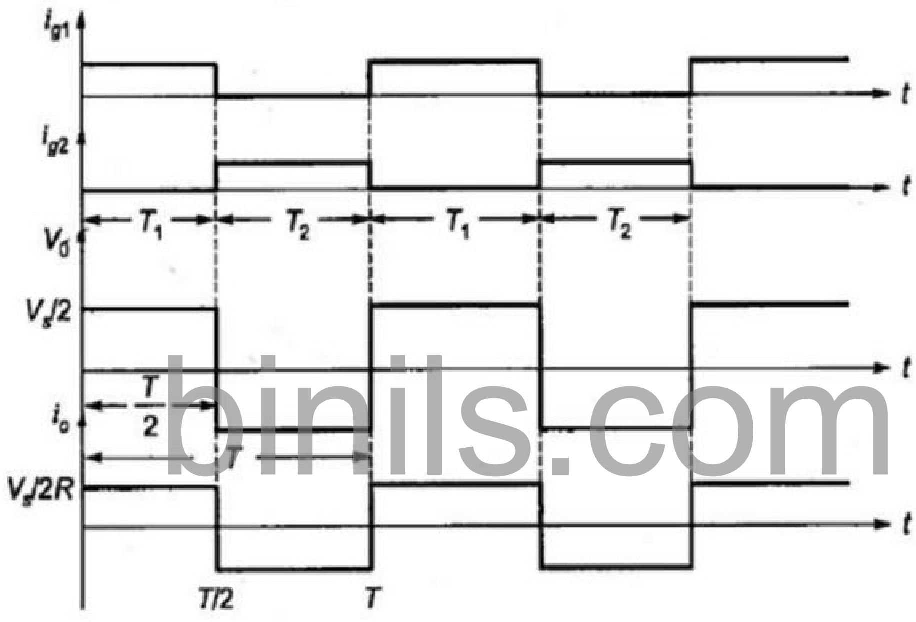


Figure 4.1.2 Single-phase inverter Waveform

4.2 Three Single Phase Inverter

- A three-phase inverter converts a DC input into a three-phase AC output.
- Its three arms are normally delayed by an angle of 120° so as to generate a three-phase AC supply.

The inverter switches each has a ratio of 50% and switching occurs after every T/6 of the time T and for 60°angle interval.

- The switches S1 and S4, the switches S2 and S5 and switches S3and S6 complement each other.
- The figure below shows a circuit for a three phase inverter. It is nothingbut three single phase inverters put across the same DC source.
- The pole voltages in a three phase inverter are equal to the pole voltagesin single phase half bridge inverter.
- Three-phase inverters are normally used for high power applications.
- The advantages of a three-phase inverter are:
- The frequency of the output voltage waveform depends on the switching rate of the switches and hence can be varied over a wide range.
- The direction of rotation of the motor can be reversed by changingthe output phase sequence of the inverter.

Types of control signals can be applied to the switches:

1. 180° conduction
2. 120° conduction

180 DEGREE CONDUCTION MODE

- In this mode of conduction, every device is in conduction state for 180° where they are switched ON at 60° intervals. The terminals A, B and C are the output terminals of the bridge that are connected to the three-phase delta or star connection of the load.
- The operation of a balanced star connected load is explained in the diagram below. For the period 0° − 60° the points S1, S5 and S6 are in conduction mode.
- The terminals A and C of the load are connected to the source at its positive point. The terminal B is connected to the source at its negative point.
- In addition, resistances R/2 is between the neutral and the positive end while resistance R is between the neutral and the negative terminal.
- Output voltage can be controlled by varying the dc-link voltage.

In the three-phase inverter, each SCR conducts for 180° of a cycle. Thyristor pair in each arm, i.e. Tl , T4 ; T3, T6 and T5 , T2 are turned on with a time interval of180°.T1 conducts for 180°and T4 for the next 180° of a cycle.Thyristors in the upper group, i.e. T1, T3, T5 conduct at an interval of 120°. It implies that if T1 is fired at wt = 0°, then T3 must be fired at wt =120° and T5 at wt =240°.

Similarly for lower group of SCRs. On the basis of this firing scheme, a table is prepared .In this table, first row shows that T1 from upper group conducts for 180°, T4 for the next 180° and then again T1 for 180 ° and so on.

In the second row, T3 from the upper group is shown to start conducting 120° after T1 starts conducting. After T3 conduction for 180°,T6 conducts for the next 180 ° and again T3 for the next 180 ° and so on.

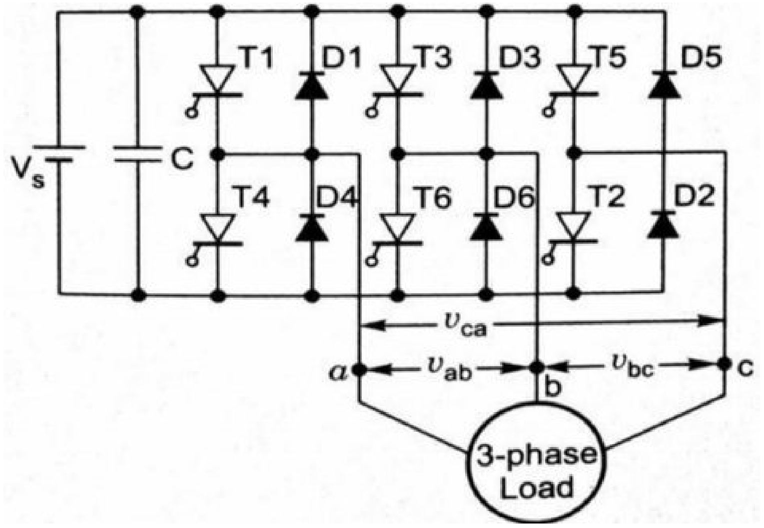
In the third row, T5 from the upper group starts conducting 120° after T3 or 240° after T1. After T5 conduction for 180°, T2 conducts for the next 180°,T5 for the next 180° and so on.

The table shows that T5, T6, T1 should be gated for step I ; T6, T1, T2 for step II T1, T2, T3 for step III; T2, T3, T4 for step IV and so on. Thus the sequence of firing the thyristors is T1, T2, T3, T4, T5, T6 ; T1, T2 It is seen

from the table that in every step of 60° duration, only three SCRs are conducting-one from upper group and two from the lower group or two from the upper group and one from the lower group.

The load voltage is vab =vcb= Vs in magnitude

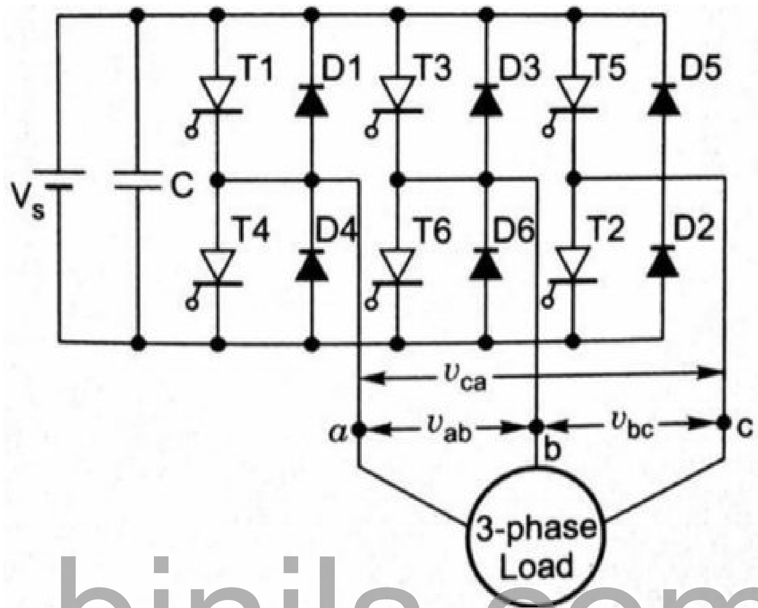
THREE PHASE INVERTER- 180 DEGREE CONDUCTION



- In the three phase inverter of each switch conduct 180° of cycle, thyristor pair in each arm i.e. S1, S4; S3, S6 and S5, S2 are turned on with a time interval of 180°. It means that S1 conduct for 180° and S4 for the next 180° of a cycle.

- Switch in the upper group i.e. S1, S3, S5 conduct at an interval of 120°. It implies that if S1 is fired at ωt=0°, then S3 must be fired at ωt=120° and S5 at ωt=240°. Same is proved lower group of switches.

Three Single Phase Inverter (120° conduction)



The power circuit diagram of this inverter is the same as that 180 ° mode.

- For the 120-degree mode VSI, each thyristor conducts for 120° of a cycle.
- Like 180° mode, 120° mode inverter also requires six steps, each of 60° duration, for completing one cycle of the output ac voltage.
- For this inverter a table giving the sequence of firing the six thyristors is prepared as shown in the top of Fig.
- In 120-degree mode VSI, each thyristor conducts for 120° of a cycle. Like 180° mode, 120° mode inverter also requires six steps, each of 60° duration, for completing one cycle of the output ac voltage.

- Tl conducts for 120° and for the next 60°, neither T1 nor T4 conducts. Now T4 is turned on at wt =180 ° and it further conducts for 120°, i.e. from wt =180° to wt =300°. This means that for 60° interval from wt =120° to wt = 180°, series connected SCRs T1, T4 do not conduct. At wt = 300°, T4 is turned off, then 60° interval elapses before T1 is turnedon again at wt =360°.

- In the second row, T3 is turned on at wt =120° as in 180° mode inverter. Now T3 conducts for 120°, then 60° interval elapses during which neither T3 nor T6 conducts. At wt =300°, T6 is turned on, it conducts for 120° and then 60° interval elapses after which T3 is turned on again.

- The third row- is also completed similarly. This table shows that T6, Tl should be gated for step I;T1, T2 for step II ; T2, T3 for step III and so on.

- The sequence of firing the six thyristors is the same as for the 180° mode inverter.

- During each step, only two thyristors conduct for this inverter - one from the upper group and one from the lower group ; but in 180° mode inverter, three thyristors conduct in each step.

- Load is assumed to be resistive and star connected.

- During step I, thyristors 6, 1 are conducting and as such load terminal a is connected to the positive bus of dc source whereas terminal b is connected to negative bus of dc source, Fig. 8.23 (a). Load terminal c is not connected to dc bus.

- It is seen from Fig. that phase voltages have one positive pulse and one negative pulse (each of 120 ° duration) for one cycle of output alternating voltage. The line voltages, however, if,. have six steps per cycle of output alternating voltage.

4.3 VOLTAGE CONTROL OF INVERTERS

- The various methods for the control of output voltage of inverters can be classified as:

  (a) External control of ac output voltage

  (b) External control of dc input voltage

  (c) Internal control of the inverter.

External Control of ac Output Voltage

In this type of control as shown in Figure, an ac voltage controller is used to control the output of inverter . Through the firing angle control of ac voltage controller the voltage input to the ac load is regulated.

Fig 4.4.1. External Control of Output Voltage

External Control of dc Input Voltage

- When the available voltage souecr is ac then the dc voltage input to the inverter can be controlled through fully controlled rectifier, uncontrolled rectifier and chopper, ac voltage controller and uncontrolled rectifier as shown in Figure .

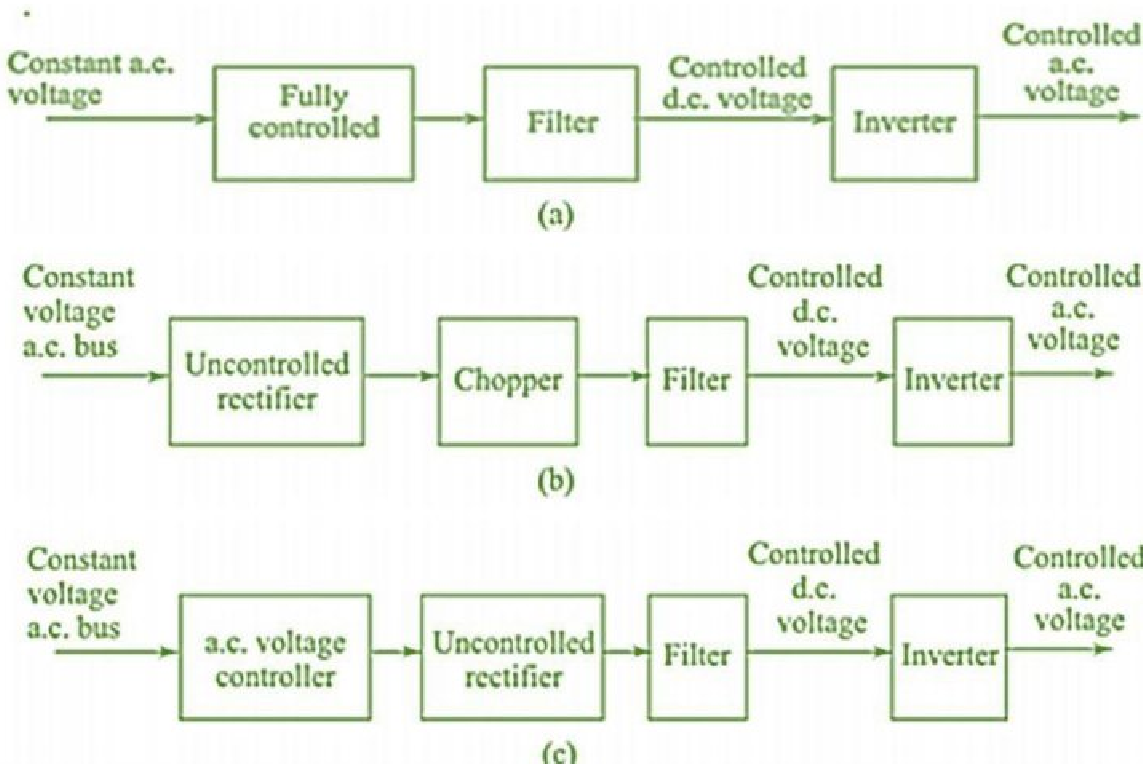


Fig 4.4.2. External Control of Input Voltage

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers Page: 348]

Internal Control of Inverter

- The first method require the use of peripheral components whereas the second method requires no external components.
- Output voltage from an inverter can also be adjusted by exercising a control within the inverter itself. The most efficient method of doing is by pulse- width modulation control used within an inverter. This method is called the internal voltage control of the inverter.

4.4 PWM CONTROL: Multiple pulse width modulation (MPWM)

Pulse width modulation is the most commonly used technique to control the output voltage of inverter. In pulse Width Modulation method, a fixed dc input voltage is given to the inverters and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. PWM is a technique that is used to reduce the overall harmonic distortion THD in a load current. It uses a pulse wave in square form that results in a variable average waveform value, after its pulse width has been modulated.

DIFFERENT TYPES OF PWM CONTROL TECHNIQUE

1. Single pulse width modulation (Single PWM)
2. Multiple pulse width modulation (MPWM)
3. Sinusoidal pulse width modulation (SPWM)
4. Modified Sinusoidal pulse width modulation (MSPWM)
5. Phase displacement control

Multiple Pulse Width Modulation (MPWM)

- The main drawback of single PWM technique is high harmonic content. In order to reduce the harmonic content, the multiple PWM technique is used, in which several pulses are given in each half cycle of output voltage. The generation of gating signal is achieved by comparing the reference signal of the amplitude (Ar) with a triangular carrier wave (Ac) as shown Figure below.

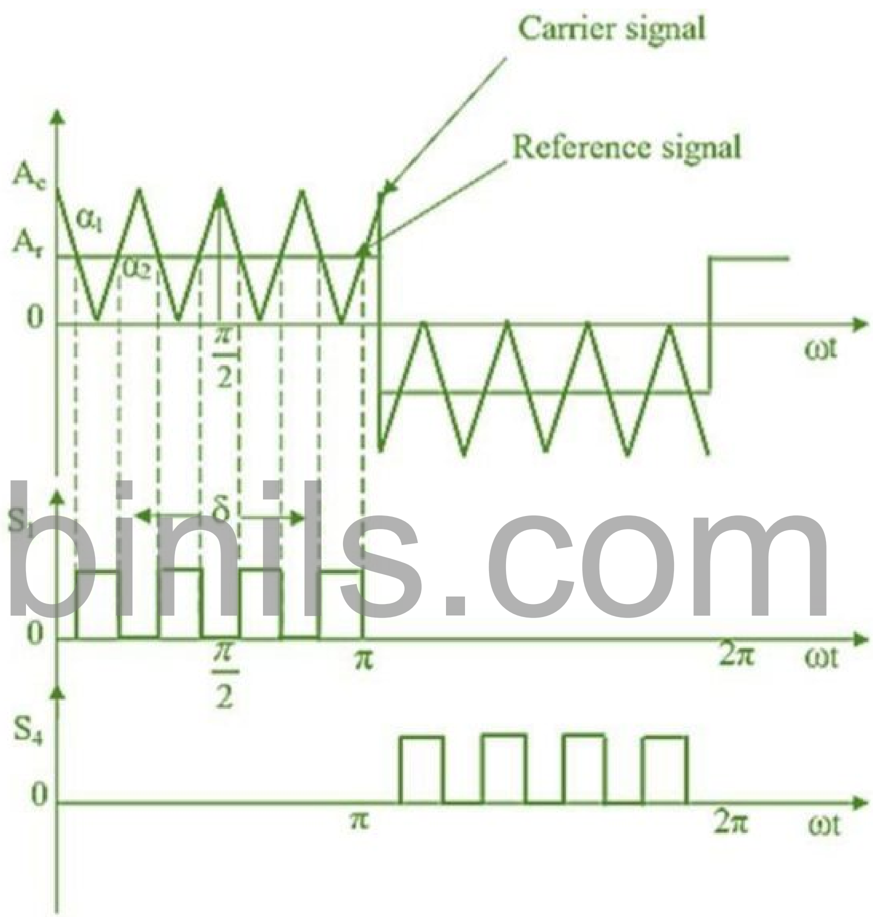


Figure 4.5.1 Multiple pulse width modulation

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers Page: 352]

- The output frequency (fo) is determined by the frequency of the reference signal.The output voltage can be controlled by modulation index.

4.5 PWM CONTROL: Sinusoidal pulse width modulation (SPWM)

In Sinusoidal Pulse Width Modulation triangular carrier signal is compared with sine wave. Figure below explains the generation of a sinusoidal PWM signal, which finds more applications in industries. The gating signal can be generated by comparing a sinusoidal reference signal with a triangular carrier wave and the width of each pulse varied proportionally to the amplitude of a sine wave evaluated at the center of the same pulse. The output frequency (fo) of the inverter can be found by using the frequency of the reference signal (fr). The rms output voltage (vo) can be controlled by modulation index M and in turn modulation index is controlled by peak amplitude (Ar). The voltage can be calculated by VO =Vs (S1- S4) . The number of pulses per half cycle depends on the carrier frequency. The gating signal can be produced by using the unidirectional triangular carrier wave.

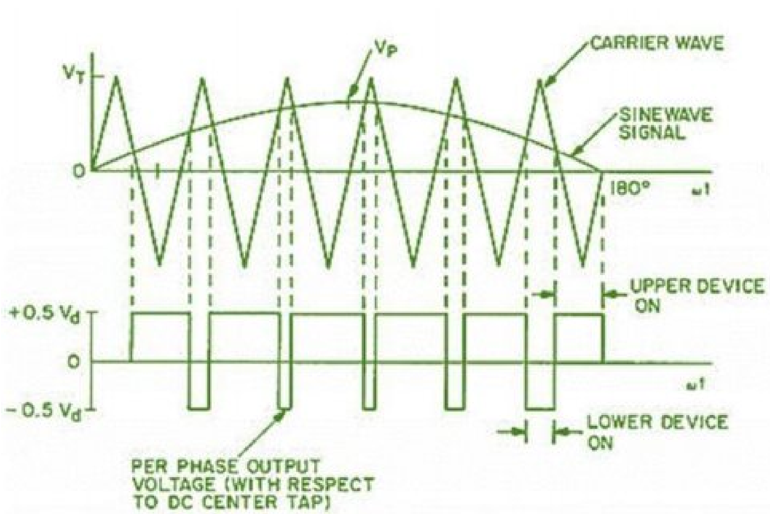


Figure 4.6.1. Multiple pulse width

The frequency of control signal or the modulating signal sets the inverter output frequency (fo) and the peak magnitude of control signal controls the modulation index ma which in turn controls the rms output voltage. The area of each pulse corresponds approximately to the area under the sine wave between the adjacent midpoints of off periods on the gating signals. If ton is the width of nth pulse, the rms output voltage can be determined by:

$$V_o = V_s \left(\sum_{n=1}^{2p} \frac{2t_{on}}{T} \right)^{1/2}$$

Pulse width modulation is the most commonly used technique to control the output voltage of inverter. In pulse Width Modulation method, a fixed dc input voltage is given to the inverters and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components.

PWM is a technique that is used to reduce the overall harmonic distortion THD in a load current. It uses a pulse wave in square form that results in a variable average waveform value, after its pulse width has been modulated.

4.6 PWM CONTROL: MODIFIED Sinusoidal Pulse Width Modulation

When considering sinusoidal PWM waveform, the pulse width does not change significantly with the variation of modulation index. The reason is due to the characteristics of the sine wave. Hence this sinusoidal PWM technique is modified so that the carrier signal is applied during the first and last 600 intervals per half cycle as shown in Figure 5.4. The fundamental component is increased and its harmonic characteristics are improved. The main advantages of this technique is increased fundamental component, improved harmonic characteristics, reduced number of switching power devices and decreased switching losses.

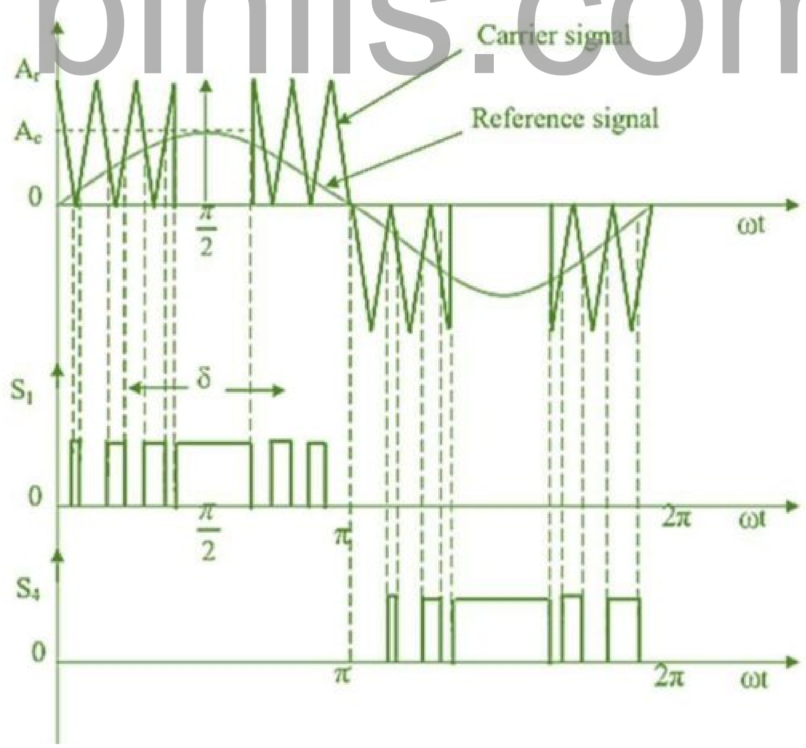


Figure 4.7.1 Modified Sinusoidal

Advantages of PWM

1. The output voltage control with method can be obtained without any additional components.

With this method, lower order harmonic can be eliminated or minimizedalong with it's output voltage control. It reduces the filtering requirements.

4.7 INTRODUCTION TO SPACE VECTOR MODULATION

❖ SVM is another direct digital PWM technique

❖ It has become a basic power processing technique in three-phase converters.

❖ SVM based converter can have a higher output voltage output.

❖ The output voltage is about 15% more in case of SVPWM .

❖ The current and torque harmonics produced are much less .

❖ The maximum peak fundamental magnitude of the SVPWM technique is about 90.6% of the inverter capacity

❖ SVPWM is accomplished by rotating a reference vector around the state diagram, which is composed of six basic nonzero vectors forming a hexagon. The reference is sampled at fixed interval and is formed using the voltage vectors of the particular sector in which reference lies along with zero vectors.

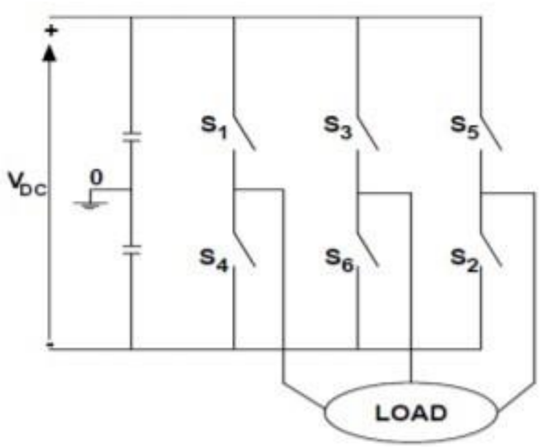


Figure 4.8.1 Basic diagram of two level three phase inverter

[Source: "Power Electronics" *by* P.S.Bimbra, Khanna Publishers *Page: 358]*

From fig.It has six switches (S1-S6) and each of these is represented with an IGBT switching device. A, B and C represents the output for the phase shifted sinusoidal signals. Depending on the switching combination the inverter will produce different outputs, creating the two-level signal (+Vdc and -Vdc).

The switches 1,3 and 5 are the upper switches and if these are 1 (separately or together) it turns the upper inverter leg ON and the terminal voltage (Va, Vb, Vc)is positive (+Vdc). If the upper switches are zero, then the terminal voltage iszero.

The lower switches are complementary to the upper switches, so the only possible combinations are the switching states: 000, 001, 010, 011, 100,
110, 110, and 111.

This means that there are 8 possible switching states, for which two of them are zero switching states and six of them are active switching states. These are represented by active (V1-V6) and zero (V0) vectors . The zero vectors are placed in the axis origin.

Next step is to calculate the dwell times or time for which we have to provide voltage vectors, so as to generate the Vref at that particular point of time. Vref can be found with two active and one zero vector. For sector 1 (0 to pi/3), Vref can be generated with V0, V1 and V2 as shown in fig.3. Vref in terms of the duration time can be considered as:

Vref *Ts= V1*T1+V2*T2+ V0*T0 ,Where Ts is the sampling time (3.3 *104sec) and T1, T2 andT0 are the time periods for which V1, V2 andV0 are applied for particular sample.

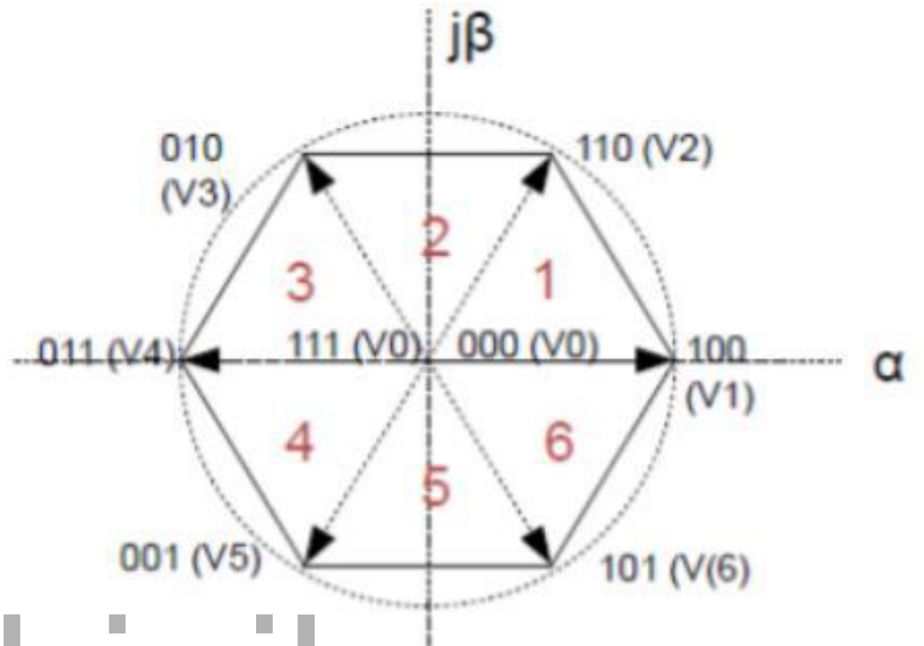


Figure 4.8.2 Space vector diagram of two level three phase inverter

[Source: "Power Electronics" *by* P.S.Bimbra, Khanna Publishers *Page: 359]*

4.8 SINGLE-PHASE CURRENT SOURCE INVERTER

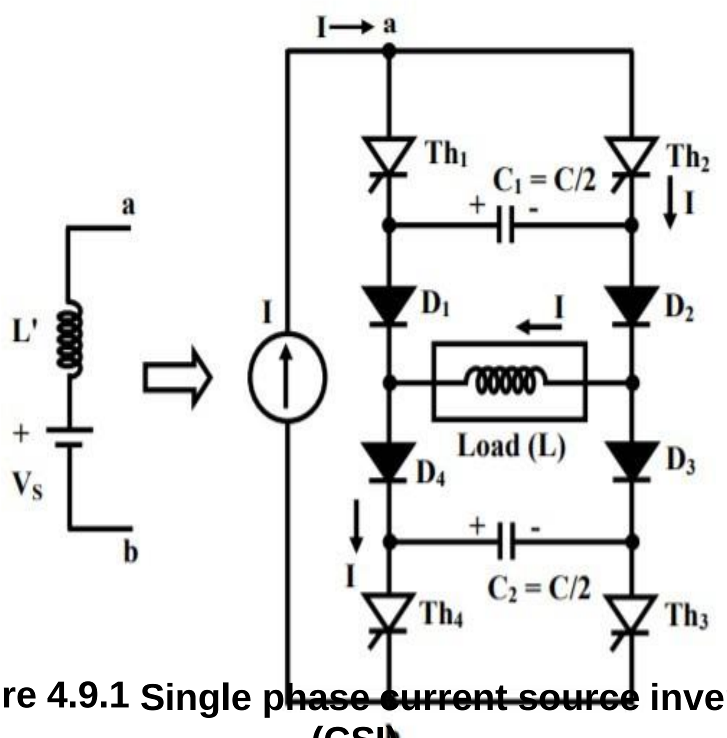


Figure 4.9.1 Single phase current source inverter (CSI)

[Source: "Power Electronics" *by* P.S.Bimbra, Khanna Publishers *Page: 364]*

The circuit of a Single-phase Current Source Inverter (CSI) is shown in Fig. The type of operation is termed as Auto-Sequential Commutated Inverter (ASCI). A constant current source is assumed here, which may be realized by using an inductance of suitable value, which must be high, in series with the current limited dc voltage source. The thyristor pairs, Th1 & Th3, and Th2 & Th4, are alternatively turned ON to obtain a nearly square wave current waveform. Two commutating capacitors − C1 in the upper half, and C2 in the lower half, are used. Four diodes, D1–D4 are connected in series with each thyristor to prevent the commutating capacitors from discharging into the load. The output frequency of the inverter is controlled in the usual way, i.e., by varying the half time period, (T/2), at which the thyristors in pair are triggered by pulses being fed to the respective gates by the control circuit, to turn them ON, as can be observed from the waveforms. The inductance (L) is taken as the load in this case, the reason(s) for which need not be stated, being well known. The operation is explained by two modes.

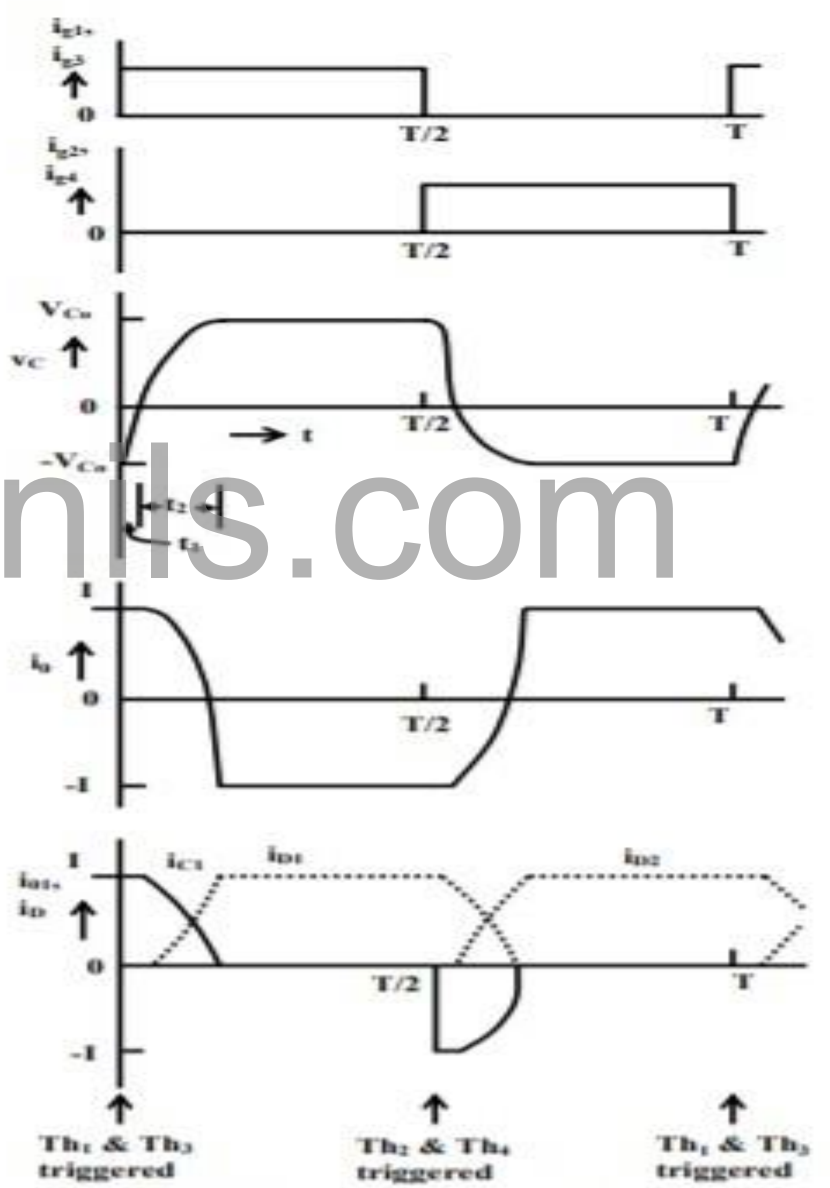


Figure 4.9.2 wave forms of Single phase current source

Mode I: The circuit for this mode is shown in Fig. The following are the assumptions. Starting from the instant ,t= 0 , the thyristor pair, Th 2 & Th4, is conducting (ON), and the current (I) flows through the path, Th2, D2, load (L), D4, Th4, and source, I. The commutating capacitors are initially charged equally with the polarity as given, i.e., . This mans that both capacitors have right hand plate positive and left hand plate negative. If two capacitors are not charged initially, they have to pre-charged.

At time, t = 0, thyristor pair, Th1 & Th3, is triggered by pulses at the gates. The conducting thyristor pair, Th2 & Th4, is turned OFF by application of reverse capacitor voltages. Now, thyristor pair, Th1 & Th3, conducts current (I). The current path is through Th1, C1, D2, L, D4,C2, Th3, and source, I. Both capacitors will now begin charging linearly from –Vco by the constant current, I. The diodes, D2& D4, remain reverse biased initially. As the capacitor gets charged, the voltage vD1 across D1, increases linearly. At some time, say t1, the reverse bias across D1 becomes zero (0), the diode, D1.starts conducting. This means that the voltages across C1 & C2, varies linearly from –Vco to zero in time, t1. Mode I ends, whent=t1, and vc= 0 . Note that t1 is the circuit turn-off time for the thyristors.

Mode II: The circuit for this mode is shown in Fig. 39.4a. Diodes, D2 & D4, are already conducting, but at t = t1 , diodes, D1 & D3, get forward biased, and start conducting. Thus, at the end of time t1, all four diodes, D1–D4 conduct. As a result, the commutating capacitors now get connected in parallel with the load (L).At the end of the process, constant current flows in the path, Th1, D1, load (L), D3, Th3, and source, I. This continues till the next commutation process is initiated by the triggering of the thyristor pair, Th2 & Th4.

4.9 Induction Heating

The working principle of the induction heating process is a combined recipe of Electromagnetic induction and Joule heating. Induction heating process is the non- contact process of heating an electrically conductive metal by generating eddy currents within the metal, using electromagnetic induction principle. As the generated eddy current flows against the resistivity of the metal, by the principle of Joule heating, heat is generated in the metal.

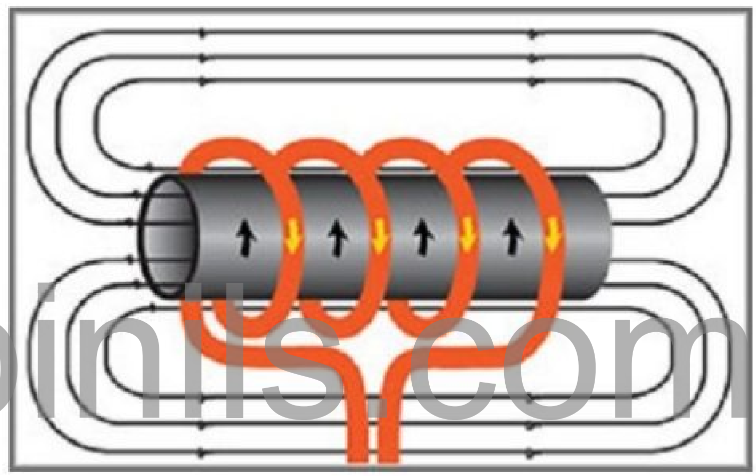


Figure 4.10.1 Induction Heating

[Source: “Power Electronics” by P.S.Bimbra, Khanna Publishers Page: 436]

Principle of Induction Heating

Knowing the Faraday's law is very useful for understanding the working of induction heating. According to Faraday's law of electromagnetic induction, changing the electric field in the conductor gives rise to an alternating magnetic field around it, whose strength depends on the magnitude of the applied electric field. This principle also works vice-versa when the magnetic field is changed in the conductor. So, the above principle is used in the inductive heating process. Here a solid state RF frequency power supply is applied to an inductor coil and the material to be heated is placed inside the coil. When Alternating current is passed through the coil, an alternating magnetic field is generated around it as per Faraday's law. When the material placed inside the inductor comes in the range of this alternating magnetic field, eddy current is generated within the material.

Induction Heating Circuit Diagram

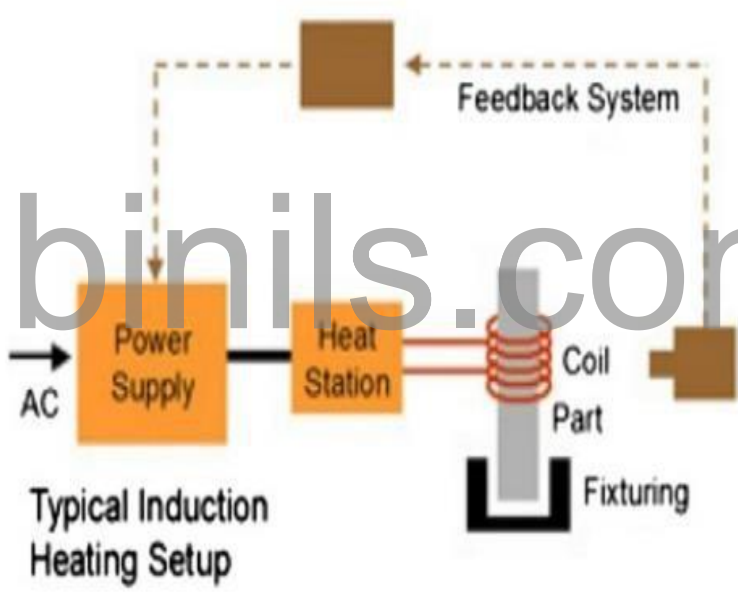


Figure 4.10.2 CIRCUIT DIAGRAM

The setup used for the induction heating process consists of an RF power supply to provide the alternating current to the circuit. A copper coil is used as inductor and current is applied to it. The material to be heated is placed inside the copper coil.

By altering the strength of the applied current, we can control the heating temperature. As the eddy current produced inside the material flows opposite to the electrical resistivity of the material, precise and localized heating is observed in this process.

Besides eddy current, heat is also generated due to hysteresis in magnetic parts. The electrical resistance offered by a magnetic material, towards the changing magnetic field within the inductor, cause internalfriction. This internal friction creates heat.

As the induction heating process is a non-contact heating process, the material to be heated can be present away from the power supply or submerged in a liquid or in any gaseous environments or in a vacuum. This type of heating process doesn't require any combustion gases.

4.10 UPS – UNINTERRUPTIBLE POWER SUPPLY

A UPS is an uninterruptible power supply. It is a device which maintains a continuous supply of electrical power, even in the event of failure of the mains (utility) supply. A UPS is installed between the mains supply and the equipment to be protected.

UPS are used to safeguard various types of equipment. One of the common uses is computers, particularly in data centres and the critical equipment of large organizations.

A UPS works by converting the mains alternating current (a.c.) supply to a direct current (d.c.) voltage. The part of the UPS which does this is called the rectifier. Output from the rectifier is then used to charge batteries, which can supply power during a mains failure. The d.c. voltage from the rectifier (or batteries during mains failure) is the converted back to a.c. by the UPS inverter and supplies power to the equipment.

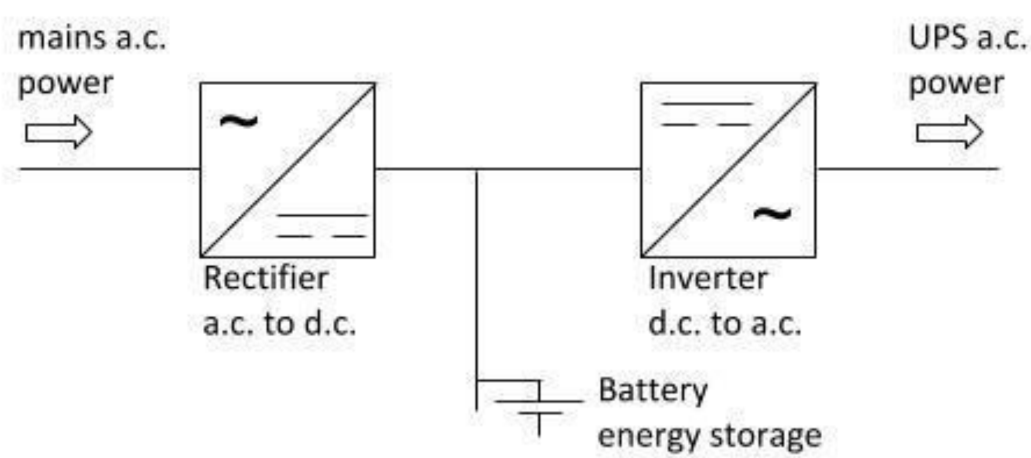


Figure 4.11.1 CIRCUIT DIAGRAM

In addition to protecting equipment in the event of mains failure, because the first convert the a.c. to d.c, a UPS has the added benefit of being able to solve other problems related to power supply quality. These include voltage dips, harmonics,frequency variations, etc.

UPS units and systems come in various sizes, from 1 or 2 kVA all they way to the MVA range. On of the problems and limiting factors with how large a UPS can be is the amount of batteries required. These can become substantial, costing a lot and taking up significant amounts of space. For smaller UPS the batteries are normally internal to the device, while for larger systems the batteries are mounted externally on racks or in cabinets.

Another element to batteries is the discharge time. Any battery backed UPS will only be rated for a certain period (5 minutes, 15 minutes, 30 minutes, etc.). For this reason, most UPS applications are centred around providing sufficient power for a limited time to enable any necessary actions - safely shut down the equipment, change over to generator power, etc.

UPS Configurations

The arrangement of rectifier, inverter, battery and other components can be carried out in different ways. Each arrangement has advantagesand disadvantages.Normally the more robust the configuration, the more expensive the UPS.

UPS are classified in two basic ways - standby and on-line. In a standby UPS, power is normally supplied directly from the mains and the inverter only switched in if the mains fails. This can have the advantages of cheaper cost and higher efficiencies. On-line UPS always supply the load via the inverter. These are more expensive, but because the inverter is always used they can resolve many power quality issues.