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UNIT-IV

AC-DC Inverters

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Inverter

- Single phase half bridge
- Single phase full bridge
- Inverter Control
  - Frequency Control
  - Voltage Control
  - Harmonic Control (minimisation)

DC-to-AC converters are known as *inverters*. The function of an inverter is to change a dc input voltage to a symmetrical ac output voltage of desired magnitude and frequency.

•The output voltage could be fixed or variable at a fixed or variable frequency.

• A variable output voltage can be obtained by varying the input dc voltage and maintaining the gain of the inverter constant.

•For low- and medium-power applications, square-wave or quasi- square-wave voltages may be acceptable; and for high-power applications, low distorted sinusoidal waveforms are required.

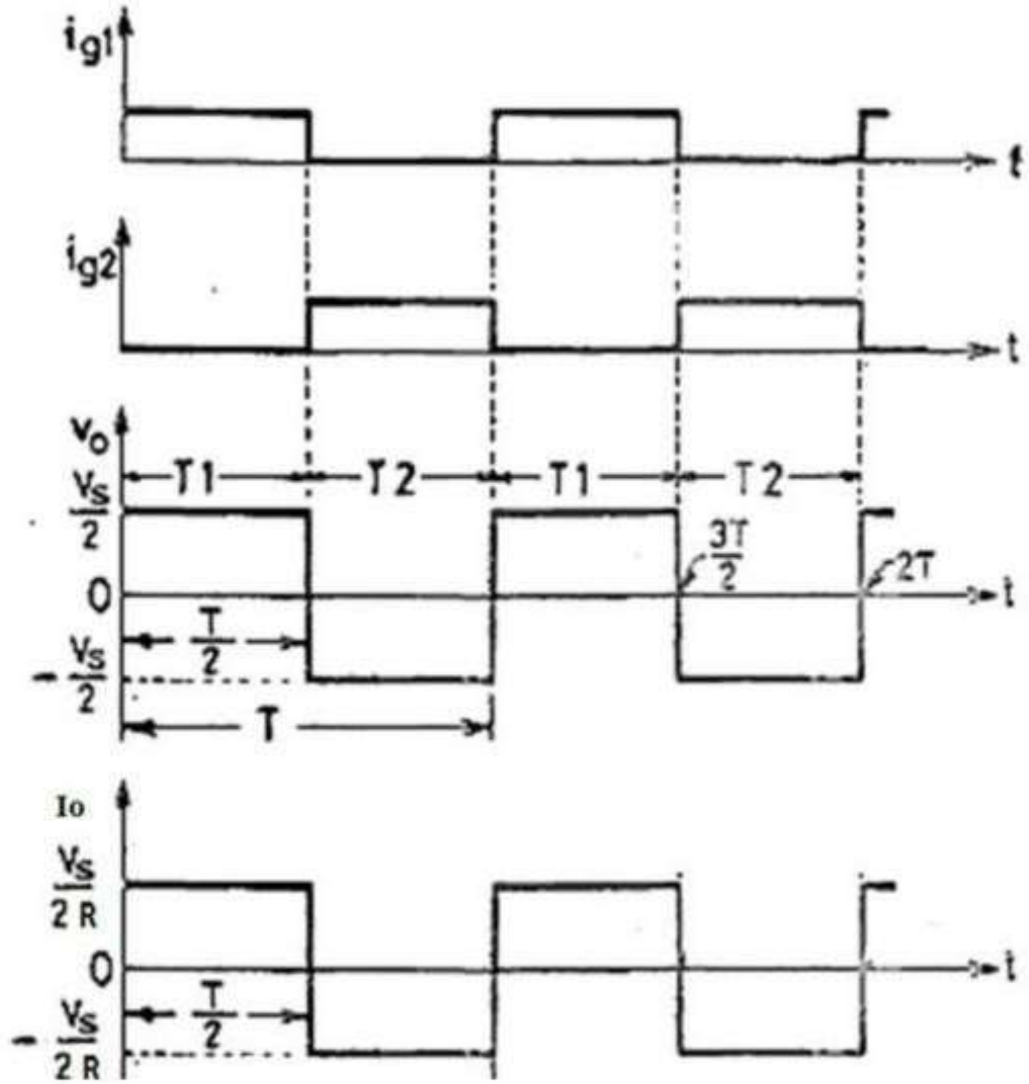
•With the availability of high-speed power semiconductor devices, the harmonic contents of output voltage can be minimized or reduced significantly by switching techniques.

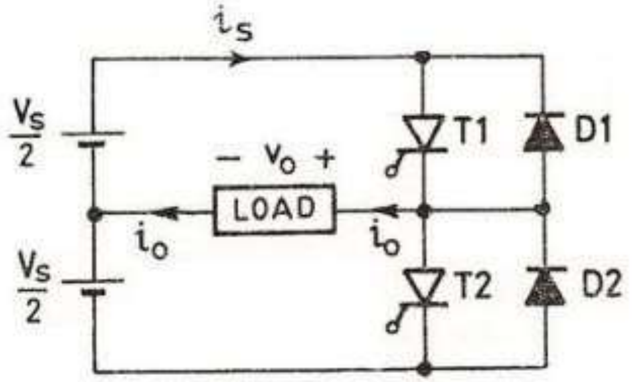
Inverters can be broadly classified into two types:
(I) Single-phase Inverters
(2) Three-phase Inverters

•Each type can use controlled turn-on and turn-off devices (e.g., BJTs, MOSFETs, IGBTs, GTOs) or forced-commutated thyristors depending on applications.

•These inverters generally use PWM control signals for producing an ac output voltage. An inverter is called a ***voltage- Source inverter*** **(VSI)** if the input voltage remains constant, **a *current-Source inverter*** **(CSI)** if the input current is maintained constant, and a ***variable dc linked inverter*** if the input voltage is controllable.

Single Phase Half-Bridge Inverter with R-load-Waveforms





Single Phase Half-Bridge Inverter with R-load-
Modes of operation

T1 is turned on upto t= T/2

Load voltage$V_0 = V_s/2$

T2 is turned on upto t= T

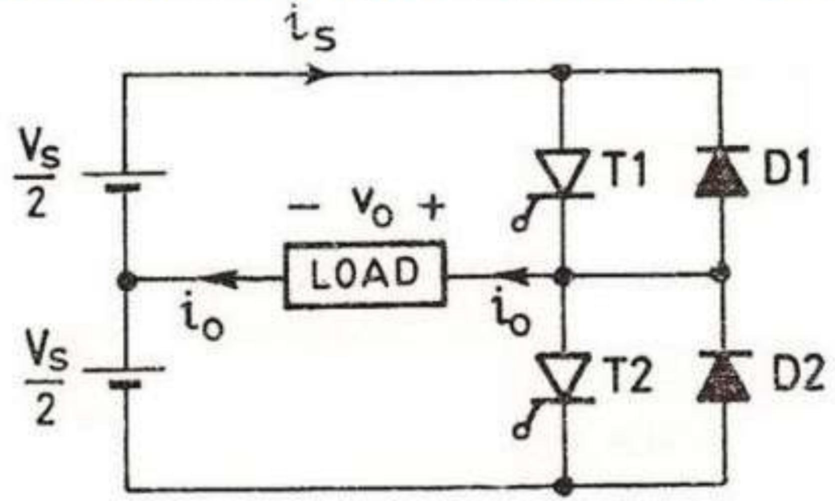
Load Voltage $V_0 = -V_s/2$

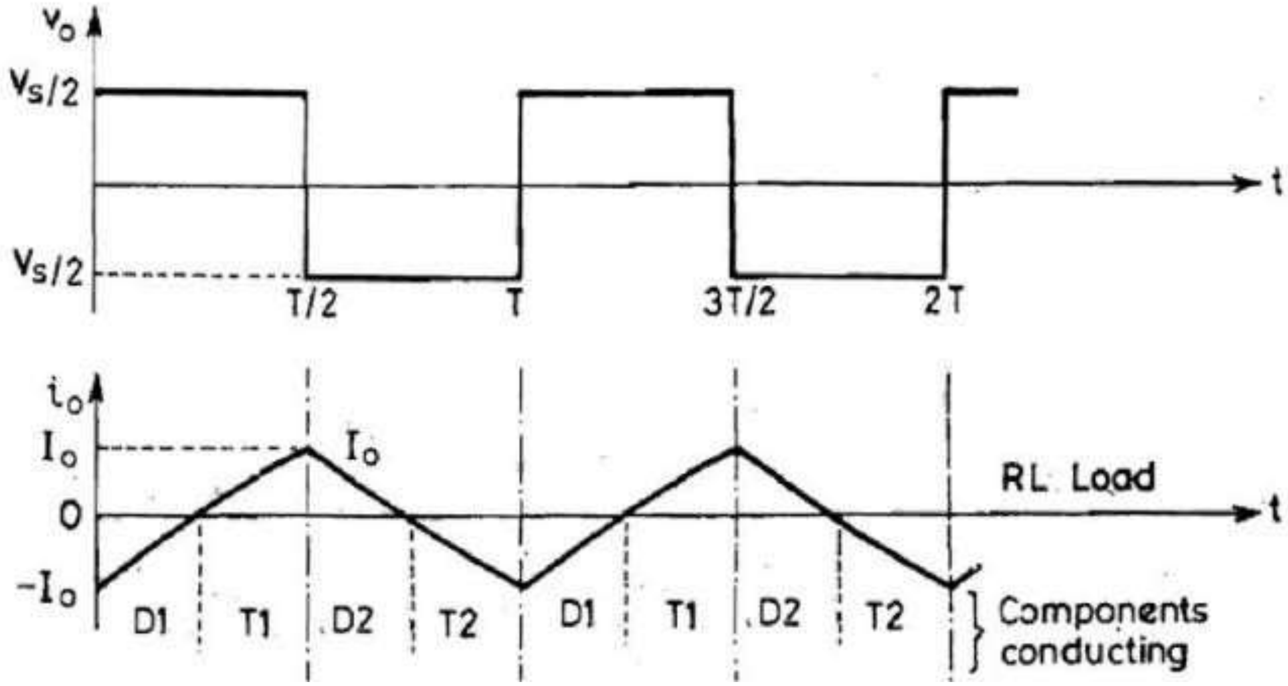
T1 and **T2** are switched complementary

The rms output voltage

$$V_o = \left(\frac{2}{T}\int_0^{T/2} \frac{V_s^2}{4}\, dt\right)^{1/2} = \frac{V_s}{2}$$

Single-phase half-bridge inverter –RL load





Single Phase Half-Bridge Inverter with RL load-
Modes of operation

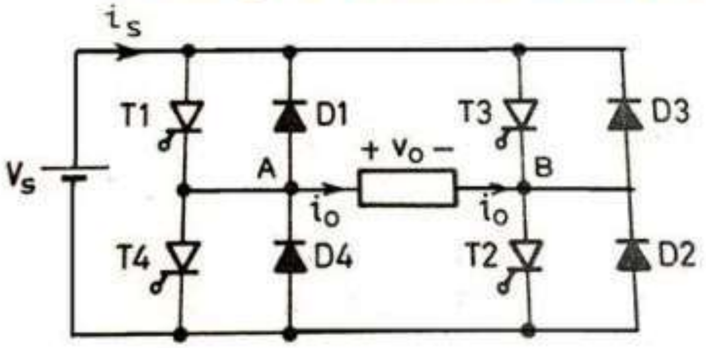
- **For an inductive load**, the load current cannot change immediately with the output voltage.

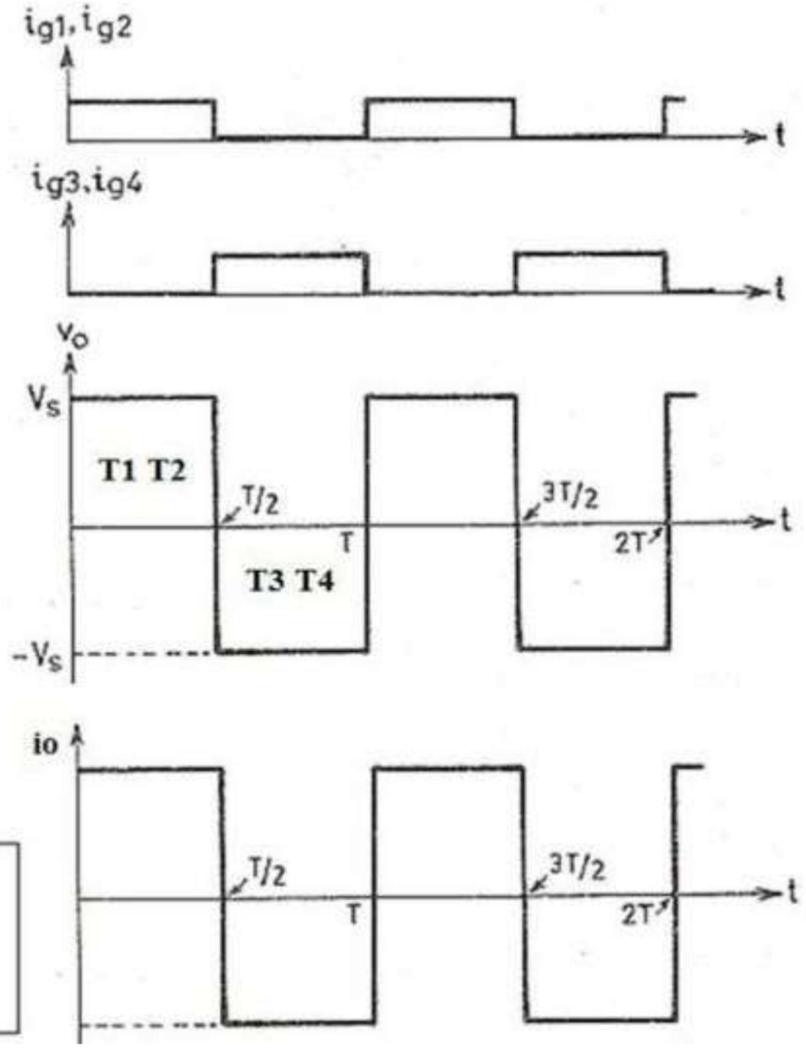
- When *T1* is turned off at $t = T/2$, the load current would continue to flow through D_2, load, and the lower half of the dc source until the current falls to zero.

- when T_2 is turned off at $t = T$, the load current flows through *D1,* load, and the upper half of the dc source.

- When diode *D1* or D_2 conducts, energy is fed back to the dc source and these diodes are known as *feedback diodes.*

Single Phase Full-Bridge Inverter with R-load





At t=T/2

T1 and T2 are ON then Vo= Vs

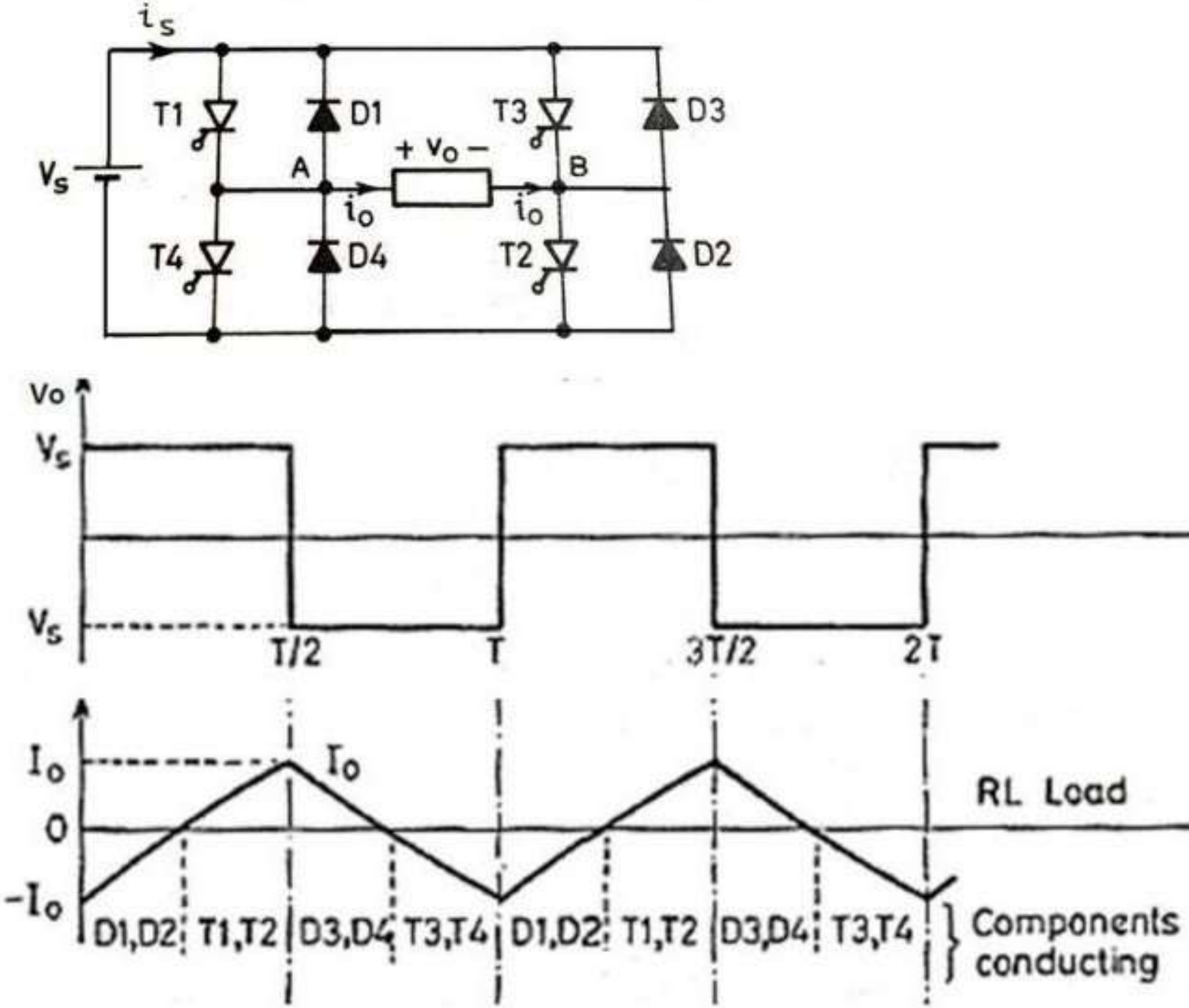
At t=T

T3 and T4 are ON then Vo=-Vs

The rms output voltage

$$V_o = \left(\frac{2}{T}\int_0^{T/2} V_s^2\,dt\right)^{1/2} = V_s$$

Single Phase Full-Bridge Inverter with RL load



Single Phase Full-Bridge Inverter with RL load

- In the waveform of io, Before $t = 0$, thyristors T3,T4 are conducting and load current *io* is flowing from *B* to *A*, *i.e* . in the re versed direction, This current is shown as - Io at $t = 0$.
- After T3, T4 are turned off at $t = 0$, current *i o* cannot change its direction immediately because of the nature of load. As a result, diodes D1, D2 start conducting after $t = 0$ and allow *io* to flow against the supply voltage *Vs* . As soon as D1, D2 begin to conduct, load is subjected to *Vs* as shown.
- Though T1, T2 are gated at $t = 0$, these SCRs will not turn on as these are reverse biased by voltage drops across diodes D1 and D2.
- When load current through *D1, D2* falls to zero, T1 and T2 become forward biased by source voltage *VS* , T1 and T2 therefore get turned on as these are gated for a period $T/2$ sec .
- Now load current *io* flows in the positive direction from *A* to *B* .
- At $t = T/2$; T1, T2 are turned off by forced commutation and as load current cannot reverse immediately, diodes D3, D4 come into conduction to allow the flow of current *io* after $T/2$.
- Thyristors T3, T4, though gated, will not turn on as these are reverse biased by the voltage drop in diodes D3, D4. When current in diodes D3, D4 drops to zero; T3, T4 are turned on as these are already gated.

Fourier Analysis Of Single-phase Inverter Output Voltage

Output Voltage waves can be resolved into Fourier series equation a follows:

$$v_0 = \sum_{n=1,3,5,\ldots}^{\infty} \frac{2V_s}{n\pi} \sin n\omega t \text{ volts}$$

Single-phase half-bridge inverter

$$v_0 = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4\,V_s}{n\pi} \sin n\omega t \text{ volts}$$

Single-phase Full-bridge inverter

n is the order of the harmonic and $\omega = 2\pi f$ is the frequency of the output voltage

- The instantaneous output voltage can be expressed in Fourier series as

$$v_0 = \sum_{n=1,3,5,\ldots}^{\infty} \frac{2V_s}{n\pi} \sin n\omega t$$
$$= 0 \qquad \text{for } n = 2, 4, \ldots \tag{2}$$

is frequency of output voltage.

For n=1 the eq(2) gives the rms of fundamental component.

$$V_1 = \frac{2V_s}{\sqrt{2}\,\pi} = 0.45V_s \tag{3}$$

PERFORMANCE PARAMETERS

The output of practical inverters contain harmonics and the quality of an inverter is normally evaluated in terms of the following performance parameters.

Harmonic factor of nth harmonic- HF_n

The harmonic factor (of the nth harmonic), which is a measure of individual harmonic contribution, is defined as

$$\boxed{HF_n = \frac{V_n}{V_1}} \qquad (4)$$

where *V1* is the rms value of the fundamental component and V_n is the rms value of the nth harmonic component.

Total harmonic distortion THD

The total harmonic distortion, which is a measure of closeness in shape between a waveform and its fundamental component, is defined as

$$\text{THD}=\frac{\sqrt{V_0^2-V_1^2}}{V_1} \qquad (5)$$

THD gives the total harmonic content, but it does not indicate the level of each harmonic component. If a filter is used at the output of inverters, the higher-order harmonics would be attenuated more effectively. Therefore, a knowledge of both the frequency and magnitude of each harmonic is important.

Distortion factor DF

The distortion factor indicates the amount of harmonic distortion that remains in a particular waveform after the harmonics that waveform have been subjected to a second-order attenuation (i.e., divided by n^2).

DF is a measure of effectiveness in reducing unwanted harmonics.

$$\mathrm{DF} = \frac{1}{V_1}\sqrt{\sum_{n=3,5,7}^{\infty}\left(\frac{V_n}{n^2}\right)^2} \qquad (6)$$

DF of nth harmonics component is defined as

$$\boxed{\mathrm{DF}_n = \frac{V_n}{V_1 n^2}} \qquad (7)$$

Inverter Control Techniques

- Control Techniques (frequency, voltage and harmonics)
  - Frequency Control
    - Determined by frequency of fundamental switching pattern
  - Voltage Control (consequential harmonics)
    - Vary d.c. input voltage
    - Quasi-square
    - Notching
    - Pulse Width Modulation (PWM) – variable width notching

4.4 Three Phase DC-AC Converters

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 swtiches and hence

can be varied over a wide range.

- The direction of rotation of the motor can be reversed by changing the

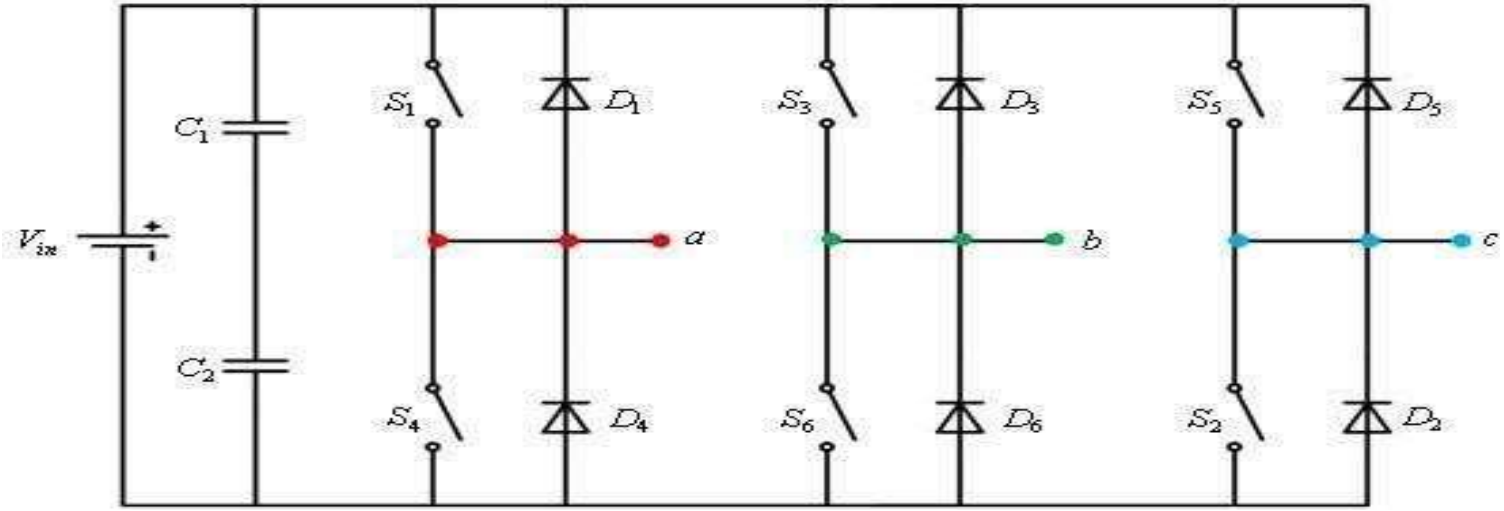
  output phase sequence of theinverter.

The ac output voltage can be controlled by varying the dc link voltage.

The general configuration of a three phase DC-AC inverter is shown in **Figure** Two types of control signals can be applied to the switches:

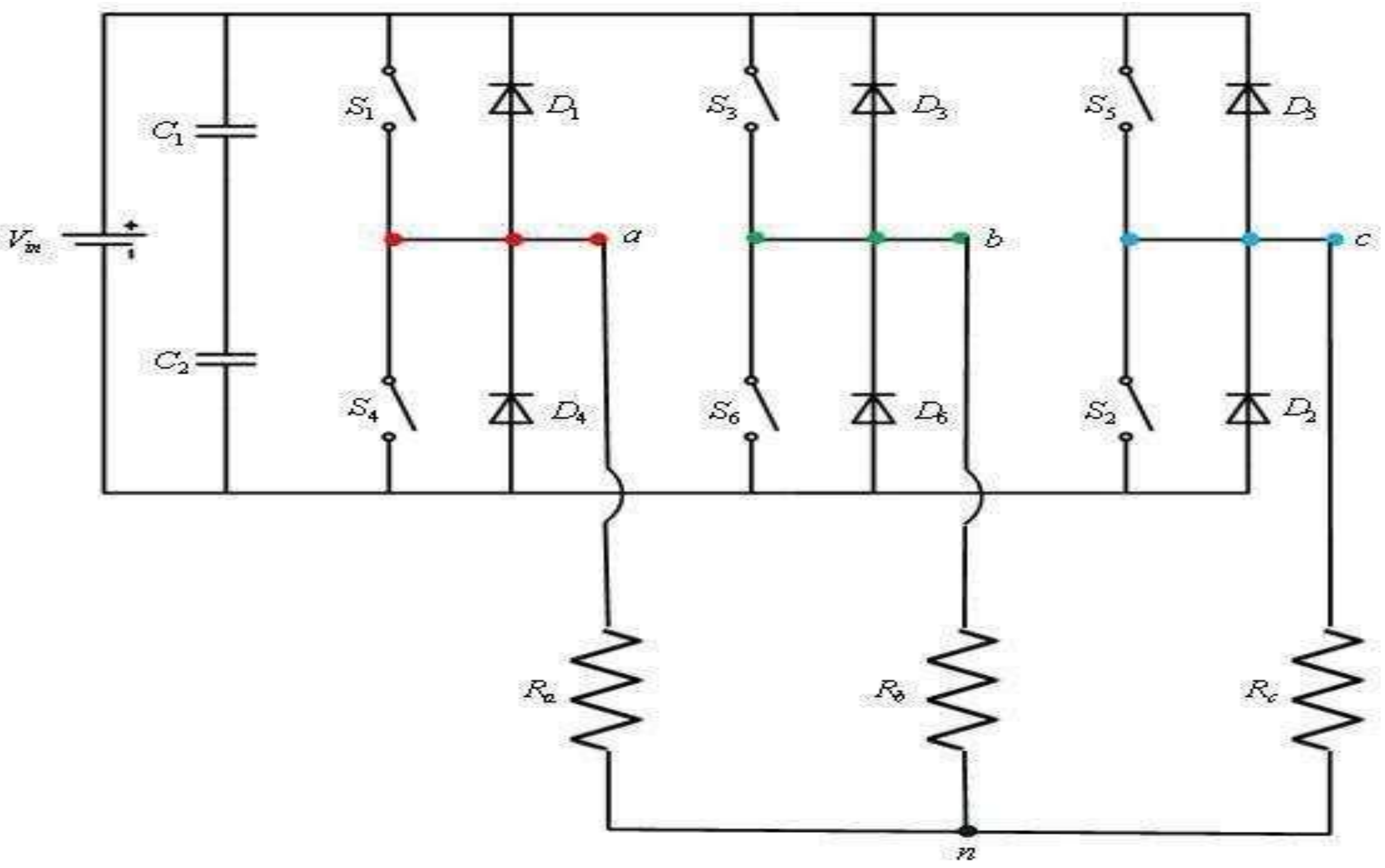
- 180° conduction

120° conduction

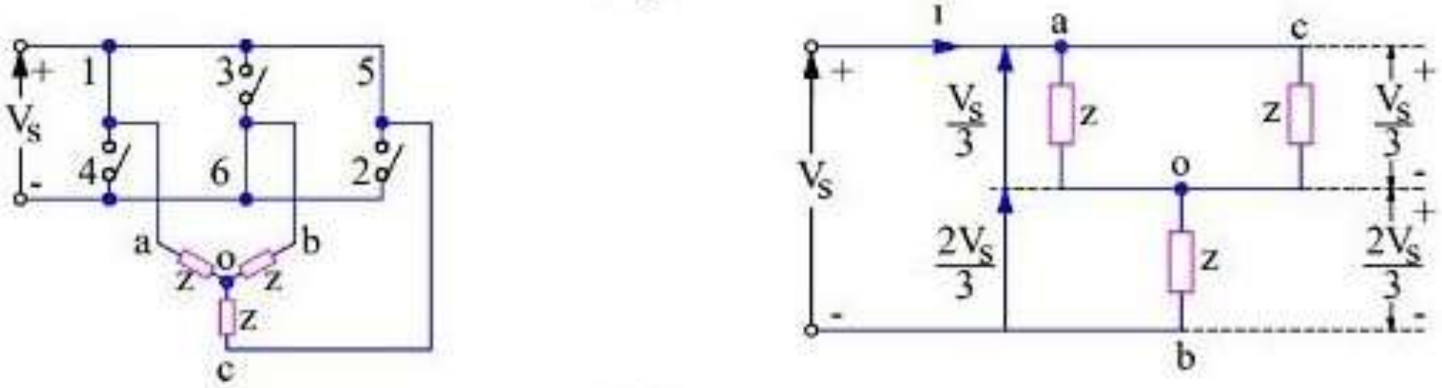


Circuit diagram of three phase bridge inverter

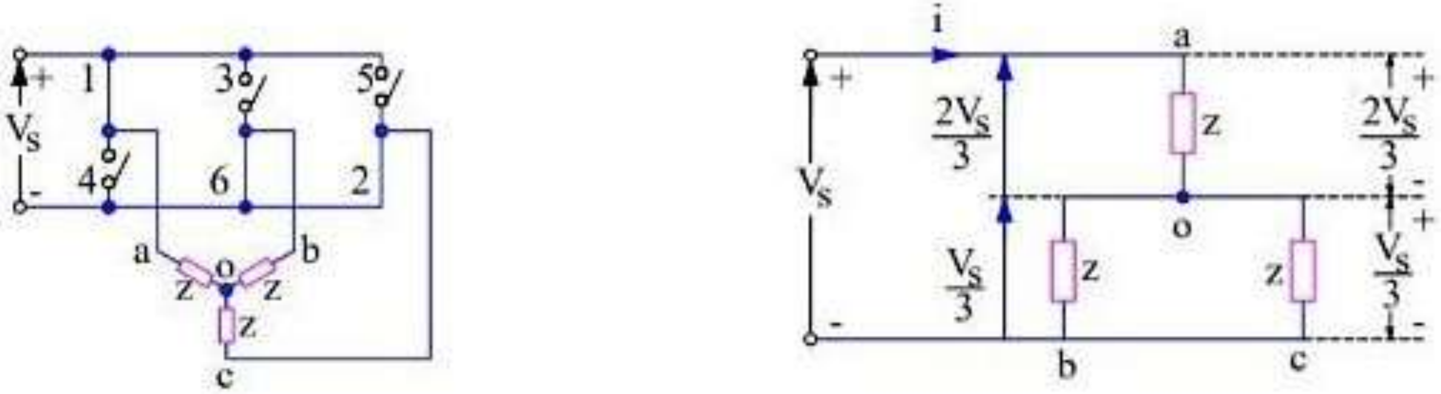
180-Degree Conduction with Star Connected Resistive Load



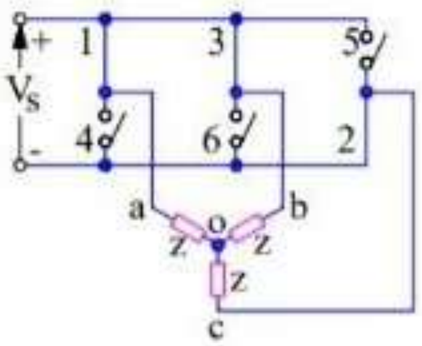
Step-I

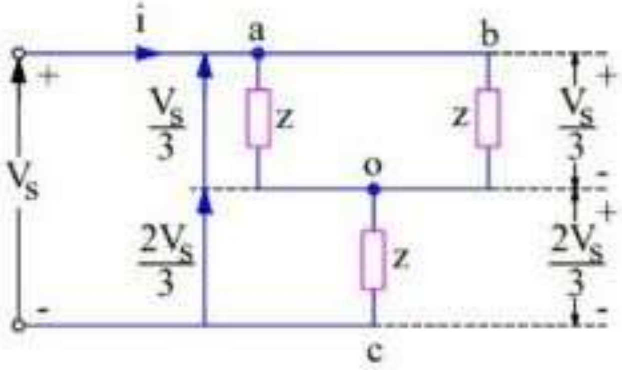


Step-II

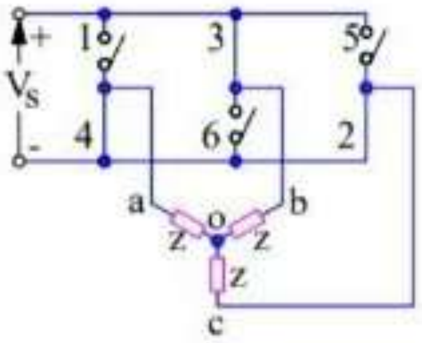


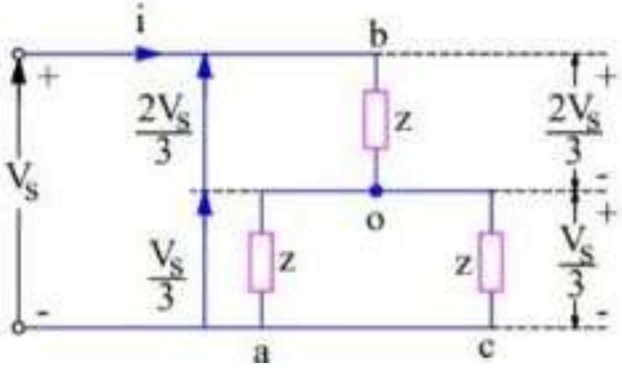
Step-III

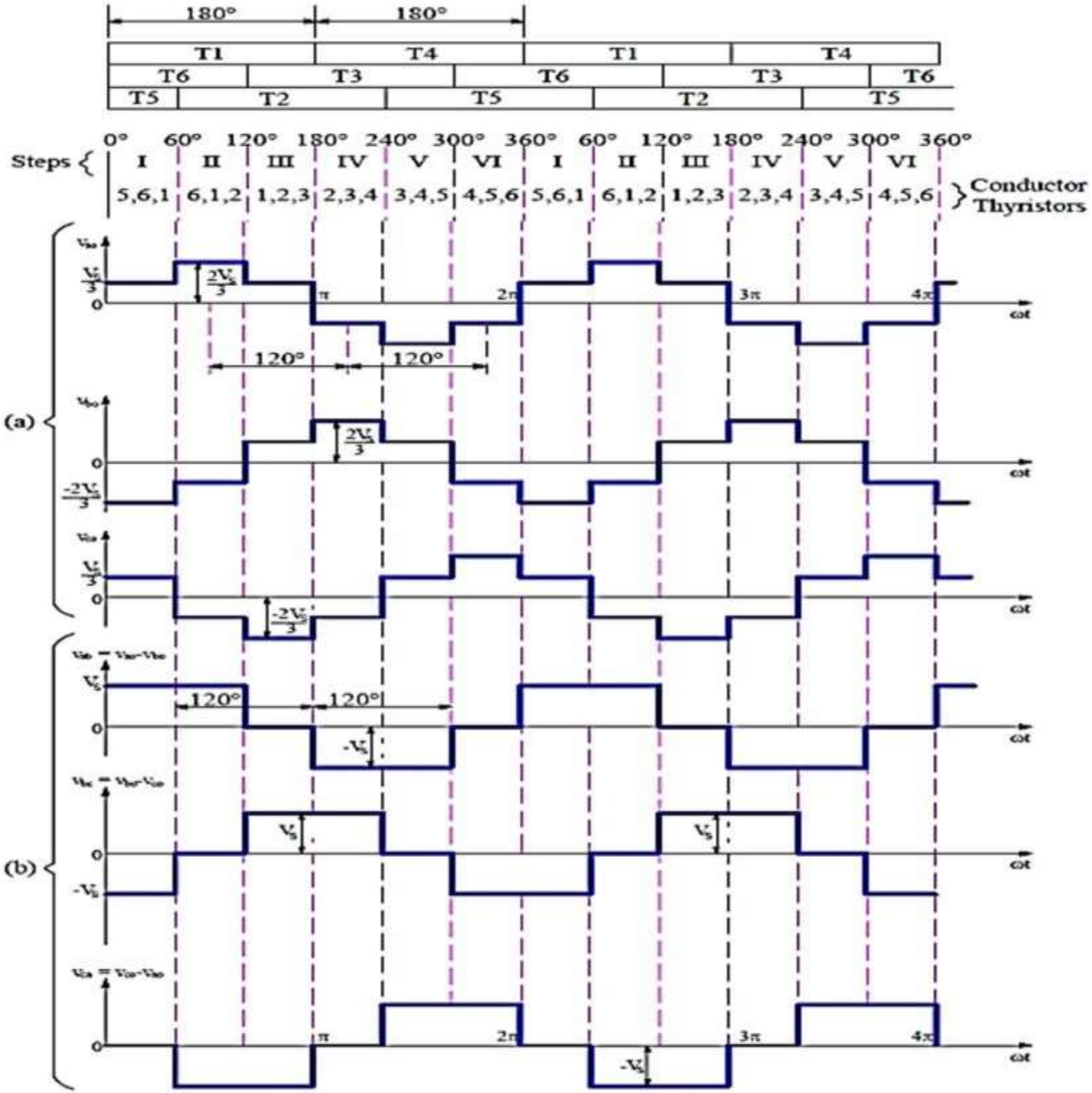




Step-IV



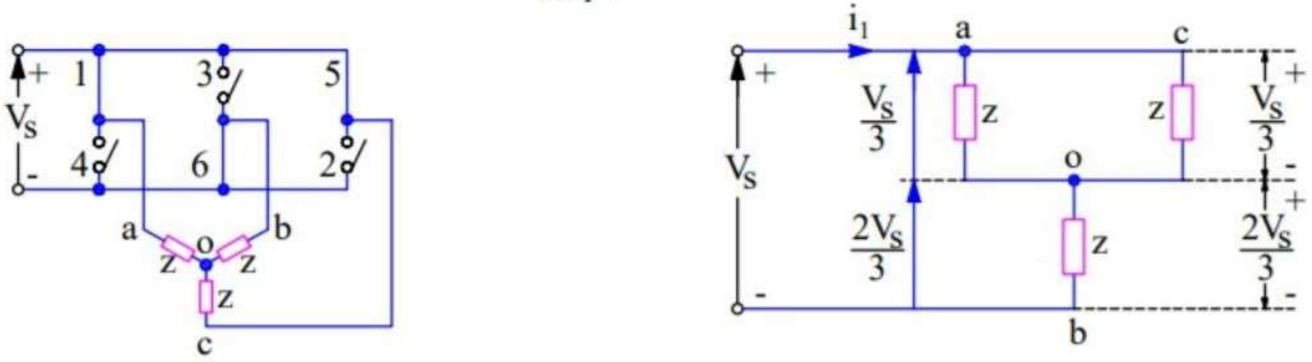




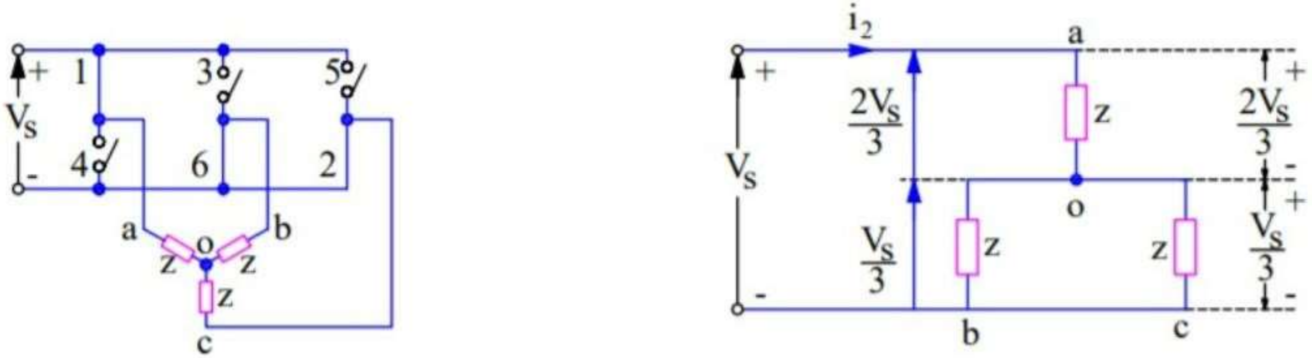
180°
180°
T1
T4
T1
T4
T6
T3
T6
T3
T6
T5
T2
T5
T2
T5
0° 60° 120° 180° 240° 300° 360° 60° 120° 180° 240° 300° 360°
Steps
I II III IV V VI I II III IV V VI
5,6,1 6,1,2 1,2,3 2,3,4 3,4,5 4,5,6 5,6,1 6,1,2 1,2,3 2,3,4 3,4,5 4,5,6
Conductor Thyristors
(a)
(b)
120°
120°
ωt

Three Phase DC-AC Converters with 120 degree conduction mode

Step-I

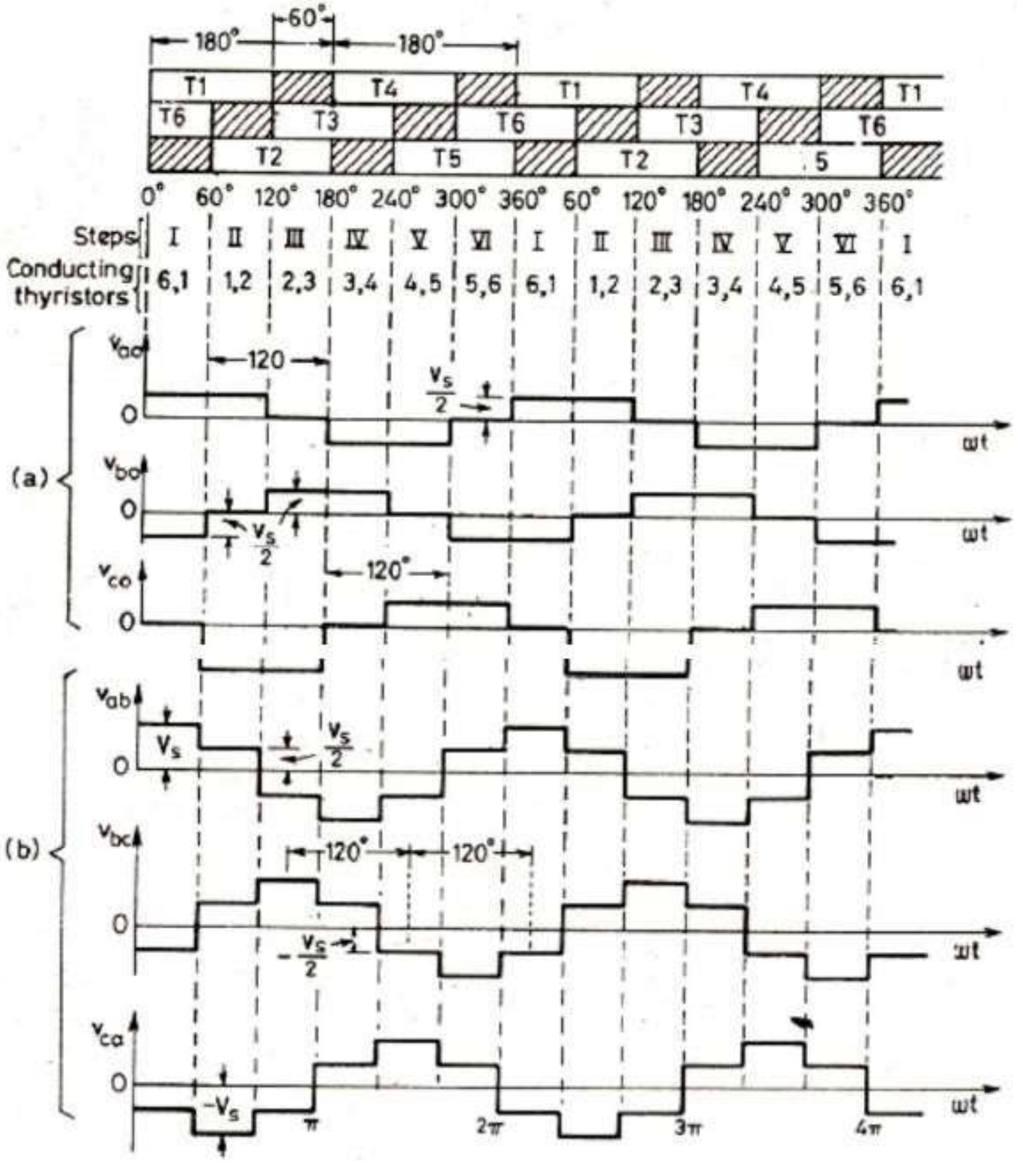


Step-II



120-degree conduction

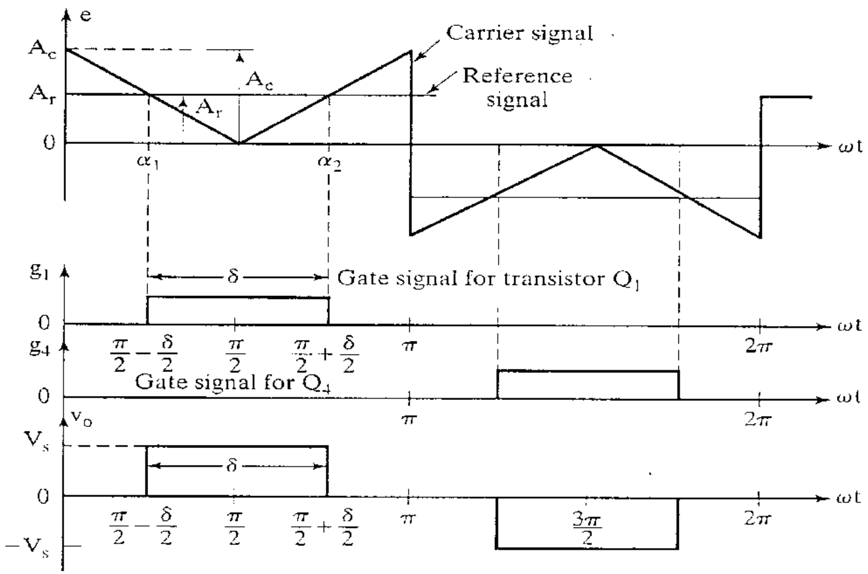
Step	Thyristor conducting	V_{Rn}	V_{Yn}	V_{Bn}	$\vec{v}$
1	6,1	$V_s/_2$	$-V_s/_2$	0	$\frac{\sqrt{3}V_S}{2}(-30^0)$
2	1,2	$V_s/_2$	0	$-V_s/_2$	$\frac{\sqrt{3}V_S}{2}(30^0)$
3	2,3	0	$V_s/_2$	$-V_s/_2$	$\frac{\sqrt{3}V_S}{2}(90^0)$
4	3,4	$-V_s/_2$	$V_s/_2$	0	$\frac{\sqrt{3}V_S}{2}(150^0)$
5	4,5	$-V_s/_2$	0	$V_s/_2$	$\frac{\sqrt{3}V}{2}(210^0)$
6	5,6	0	$-V_s/_2$	$V_s/_2$	$\frac{\sqrt{3}V}{2}(-30^0)$



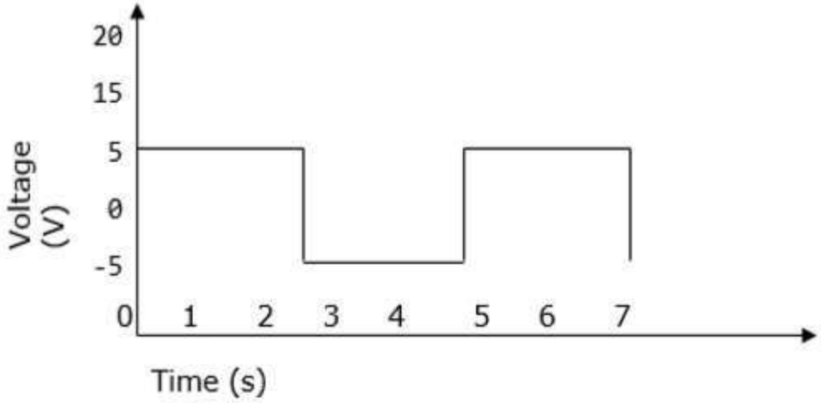
180°
60°
180°
T1
T4
T1
T4
T1
T6
T3
T6
T3
T6
T2
T5
T2
5
0° 60° 120° 180° 240° 300° 360° 60° 120° 180° 240° 300° 360°
Steps
I II III IV V VI I II III IV V VI I
Conducting thyristors
6,1 1,2 2,3 3,4 4,5 5,6 6,1 1,2 2,3 3,4 4,5 5,6 6,1
(a)
(b)
120
120°
Vs/2
-Vs/2
Vs
-Vs
ωt
π
2π
3π
4π

Voltage control techniques for inverters

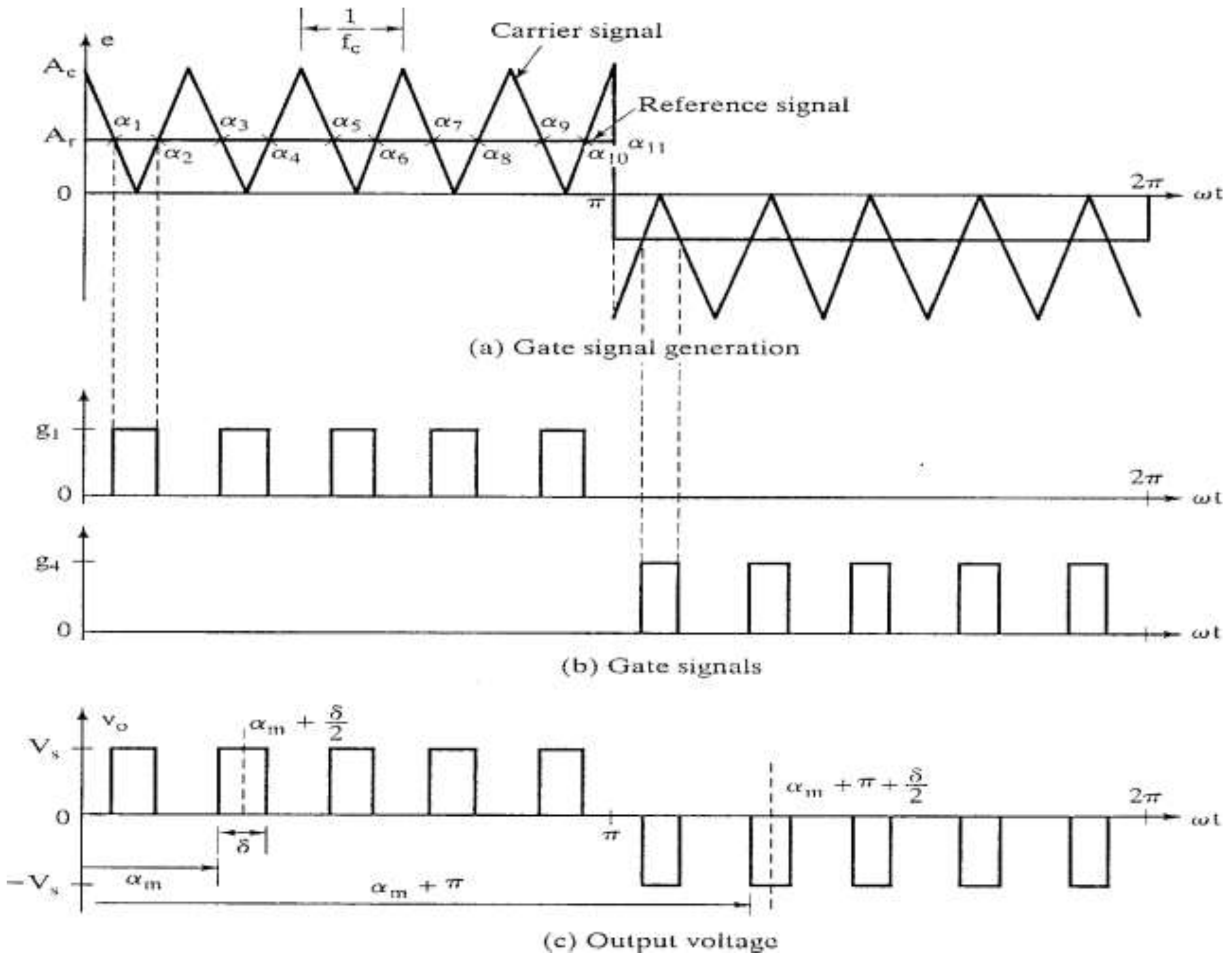
Single Pulse width modulation techniques

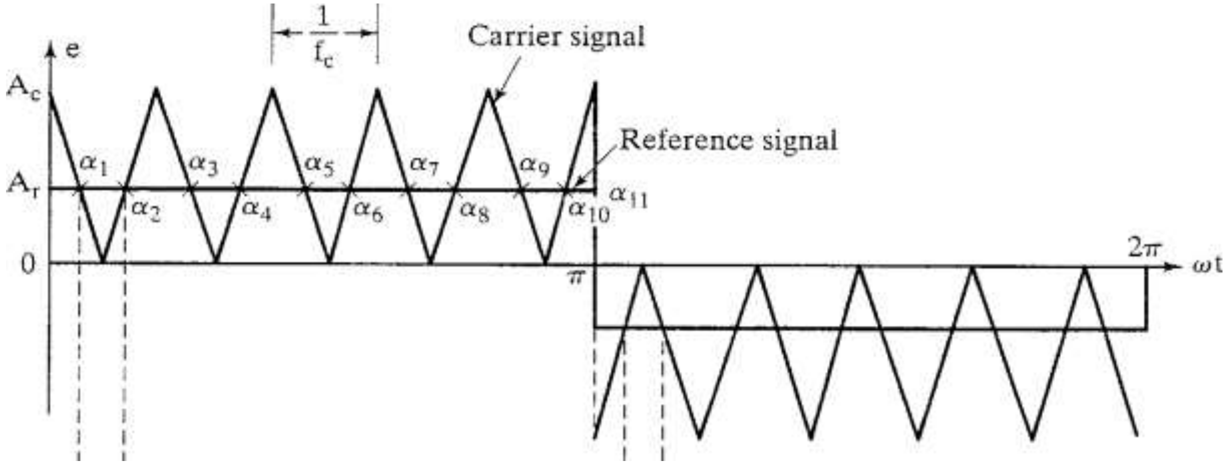


$$v_o(t) = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4V_s}{n\pi} \sin\frac{n\delta}{2} \sin n\omega t$$



Multiple Pulse Width Modulation



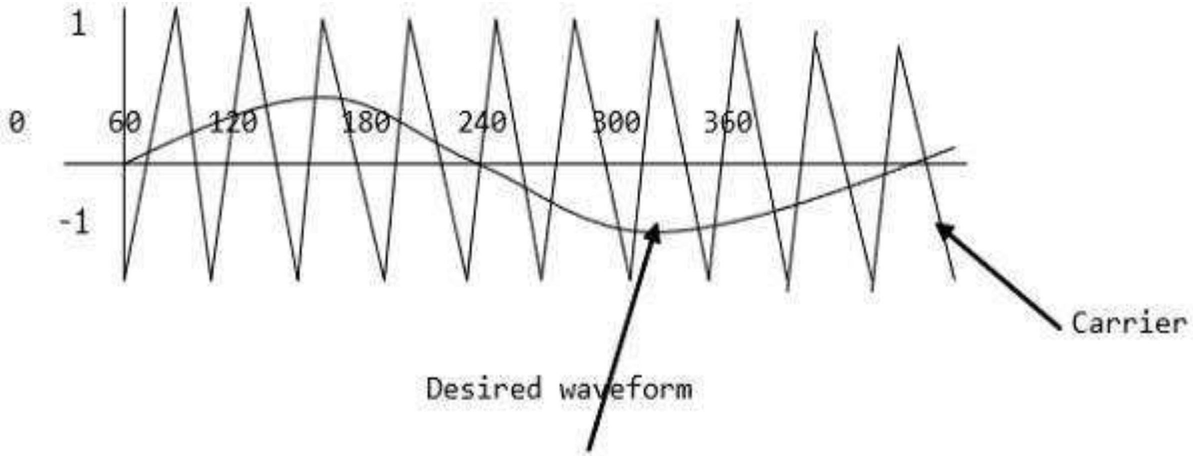


- Compare the Reference Signal with the Carrier
- Frequency of the Reference Signal determines the Output Voltage Frequency
- Frequency of the Carrier determines the number of pulses per half-cycle
- Modulation Index controls the Output Voltage

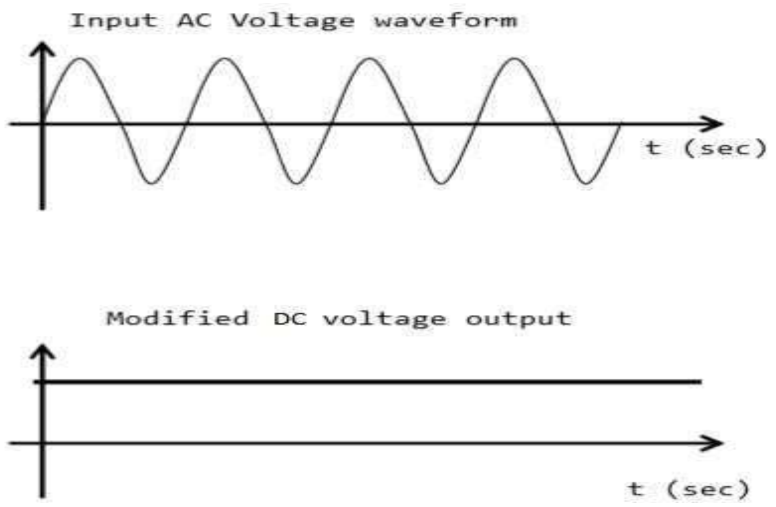
Sinusoidal Pulse Width Modulation

In a simple source voltage inverter, the switches can be turned ON and OFF as needed. During each cycle, the switch is turned on or off once. This results in a square waveform. However, if the switch is turned on for a number of times, a harmonic profile that is improved waveform is obtained.

The sinusoidal PWM waveform is obtained by comparing the desired modulated waveform with a triangular waveform of high frequency. Regardless of whether the voltage of the signal is smaller or larger than that of the carrier waveform, the resulting output voltage of the DC bus is either negative or positive.


1
0
60
120
180
240
300
360
-1
Carrier
Desired waveform

Modified Sinusoidal Waveform PWM



Voltage and Harmonic Control

A periodic waveform that has frequency, which is a multiple integral of the fundamental power with frequency of 60Hz is known as a harmonic. Total harmonic distortion (THD) on the other hand refers to the total contribution of all the harmonic current frequencies.

Harmonics are characterized by the pulse that represents the number of rectifiers used in a given circuit.

It is calculated as follows

$$h=(n\times P)+1 or -1$$

Where **n** − is an integer 1, 2, 3, 4….n

P − Number of rectifiers