Inverters

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An inverter is a circuit which converts a dc power into an ac power at desired output voltage and frequency.

Note: ....

For low and medium power output, we use BJTs, MOSFET, IGTB, GTO. But for high power output, thyristor should be used.

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Types of Inverter

1. Voltage Source Inverter (VSI)

VSI is one in which dc source has small impedance. Because of a low internal impedance, the terminal voltage of a voltage source inverter remains substantially constant with variation in load.

2. Current Source Inverter (CSI)

Current source inverter is supplied with a controlled current from a dc source of high impedance. Typically, a phase controlled thyristor rectifier feeds the inverter with a regulated current through a large series inductor. Thus, load current is controlled.

Remember: ....

- CSI does not required any feedback diodes whereas, these are required in a VSI.
- To make input current almost ripple free ,L-filter is used before CSI.
- CSI may be load or force commutated. Load commutation is possible when load p.f. is leading. For lagging p.f. loads, force commutation is essential.

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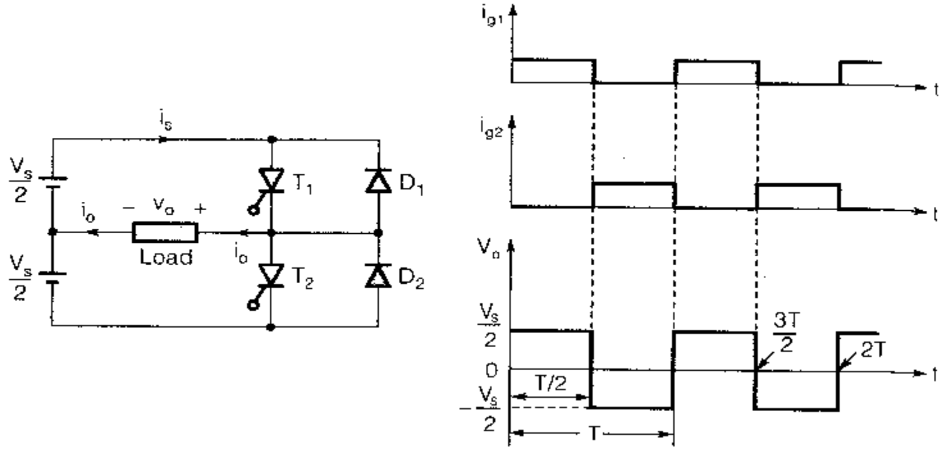
Single Phase Bridge Inverter

1. Single-Phase Half Bridge Inverter



For R load

- RMS output voltage

$$V_{or} = \frac{V_s}{2}$$

- n^{th} harmonic output voltage

$$V_{on} = \frac{2V_s}{n\pi} \sin n\omega t$$

- n^{th} harmonic current

$$I_{on} = \frac{2V_s}{n\pi R} \sin n\omega t$$

- Fundamental output voltage

$$V_{01} = \frac{2V_s}{\pi} \sin \omega t$$

- RMS fundamental output voltage

$$(V_{01})_{RMS} = \frac{\sqrt{2}\, V_s}{\pi}$$

- Fundamental distortion factor (FDF)

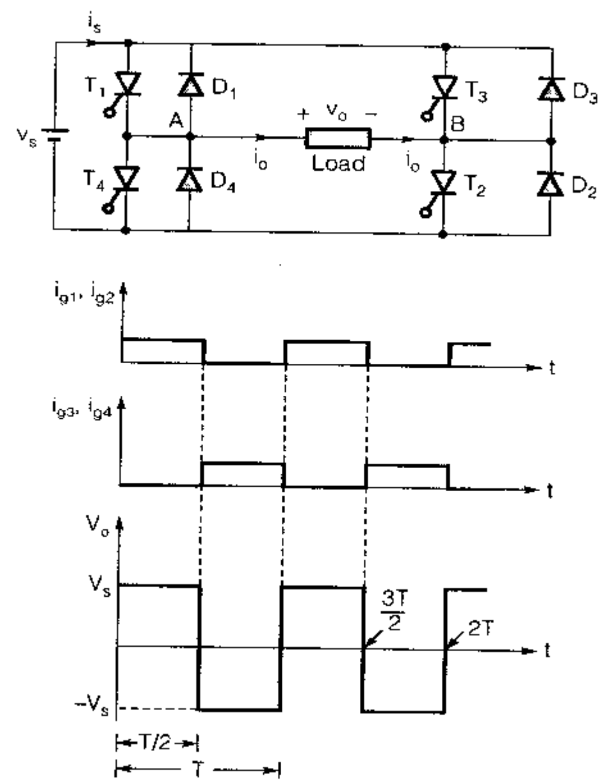
$$g = \frac{(V_{01})_{RMS}}{V_{or}} = \frac{2\sqrt{2}}{\pi}$$

- Total harmonic distortion (THD)

$$THD = \left(\frac{1}{g^2} - 1\right)^{1/2}$$

$$THD = 48.34\%$$

2. Single Phase-Full Bridge Inverter



For R load

- RMS output voltage

$$V_{or} = V_s$$

- n^{th} harmonic output voltage

$$V_{on} = \frac{4V_s}{n\pi}\sin n\omega t$$

- Fundamental output voltage

$$V_{01} = \frac{4V_s}{\pi}\sin \omega t$$

- RMS fundamental output voltage

$$(V_{01})_{RMS} = \frac{2\sqrt{2}}{\pi}V_s$$

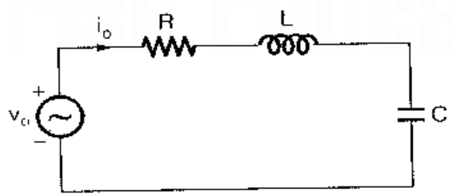
- Fundamental distortion factor (FDF)

$$g = \frac{2\sqrt{2}}{\pi}$$

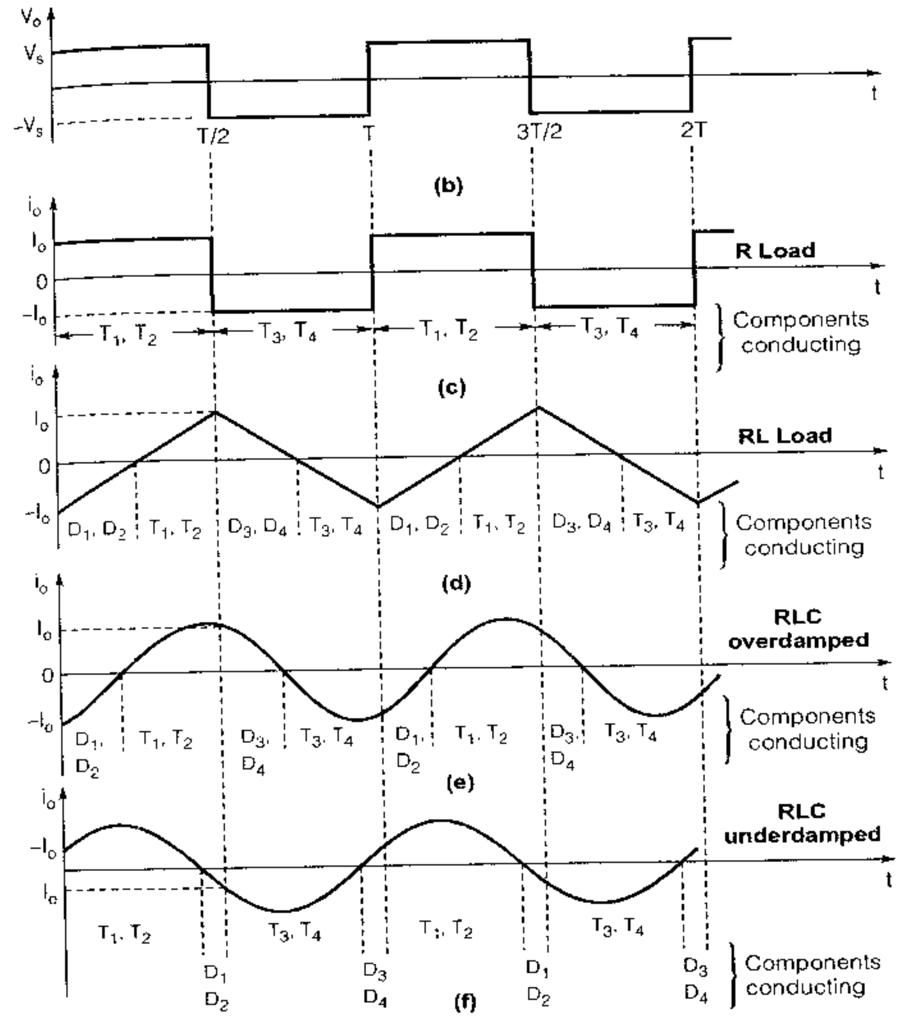
- Total harmonic distortion (THD)

$$THD = 48.34\%$$

Single Phase VSI for Different Loads



(a)



- Load impedance at frequency (nf)

$$Z_n = \left[R^2 + \left(n\omega L - \frac{1}{n\omega C}\right)^2\right]^{1/2}$$

- Phase angle

$$\phi_n = \tan^{-1}\frac{\left[n\omega L - \frac{1}{n\omega C}\right]}{R}\ \text{rad}$$

- ❑ Output current at the instant of commutation

$$I_o = \left.\frac{V_o}{Z_n}\right|_{\omega t = \pi}$$

- ❑ Fundamental load power

$$P_{o1} = I_{o1}^2 R = V_{o1} I_{o1} \cos\theta_1$$

where, I_{o1} = RMS value of fundamental output current

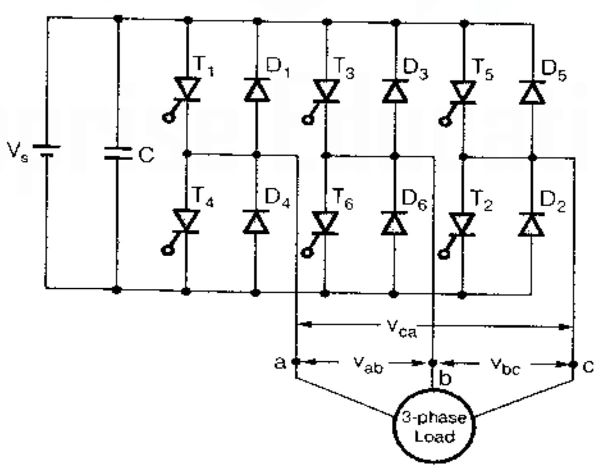
V_{o1} = RMS value of fundamental output voltage

Note:

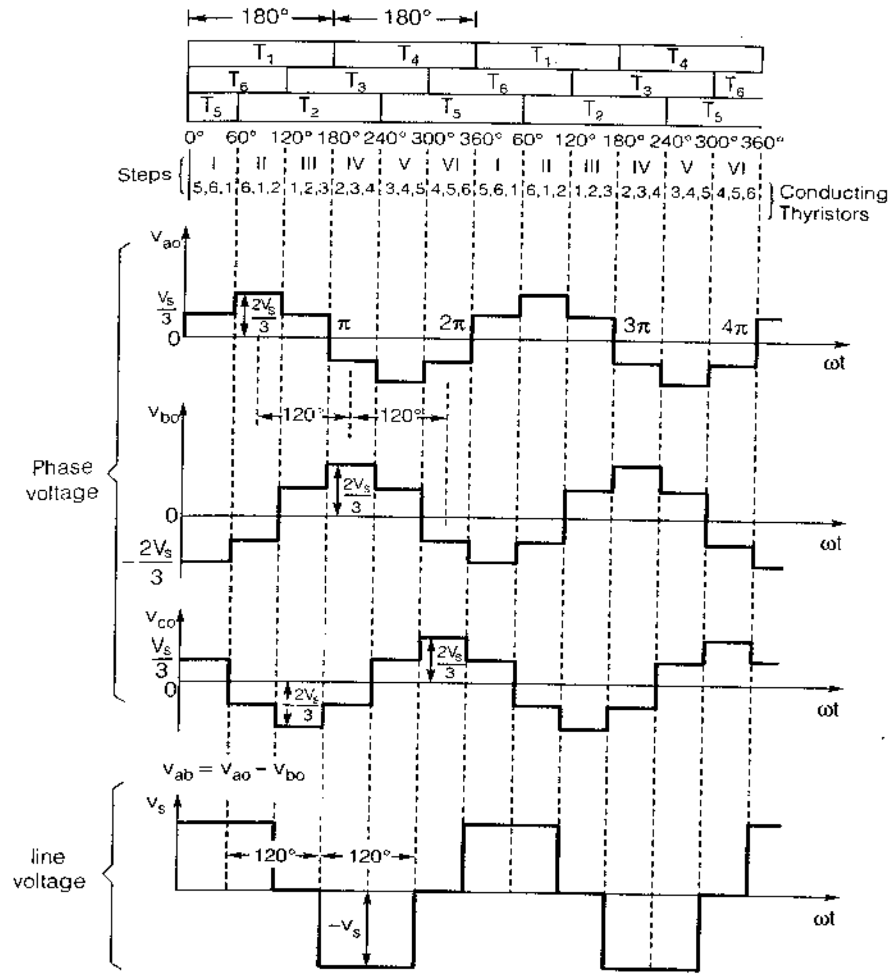
- If circuit turn-off time (t_c) is more than device turn-off time (t_q) then it does not require force commutation.
- If $t_q > t_c$ then force commutation required.
- The fundamental output power P_{o1} does the useful work and the output power associated with harmonic current is dissipated as heat, leading to rise in load temperature.
- Feedback diode (D) conducts only when there is presence of energy storing element L and C in load.

Three Phase Bridge Inverter

For providing adjustable frequency power to industrial application, 3ϕ bridge inverter are used. A large capacitor is connected at the input terminals tend to make the input DC voltage constant.



1. 3ϕ 180° Mode VSI



- ❑ Phase RMS voltage

$$(V_{ph})_{RMS} = \frac{\sqrt{2}}{3} V_s$$

- ❑ Line RMS voltage

$$(V_L)_{RMS} = \sqrt{\frac{2}{3}} V_s$$

- nth harmonic output voltage for phase "a"

$$V_{an} = \frac{2V_s}{n\pi}\sin n\omega t$$

- Fundamental phase RMS voltage

$$(V_{a1}) = \frac{\sqrt{2}\,V_s}{\pi}$$

- $$\text{FDF (g)} = \frac{3}{\pi}$$

- $$\text{THD} = 31\%$$

- nth harmonic line output voltage

$$(V_{ab})_n = \frac{4V_s}{n\pi}\cos\frac{n\pi}{6}\sin n\left(\omega t + \frac{\pi}{6}\right)$$

- Fundamental RMS line value

$$(V_{ab})_{RMS} = \frac{2\sqrt{2}}{\pi}\cos\frac{\pi}{6} = \frac{\sqrt{6}}{\pi}V_s$$

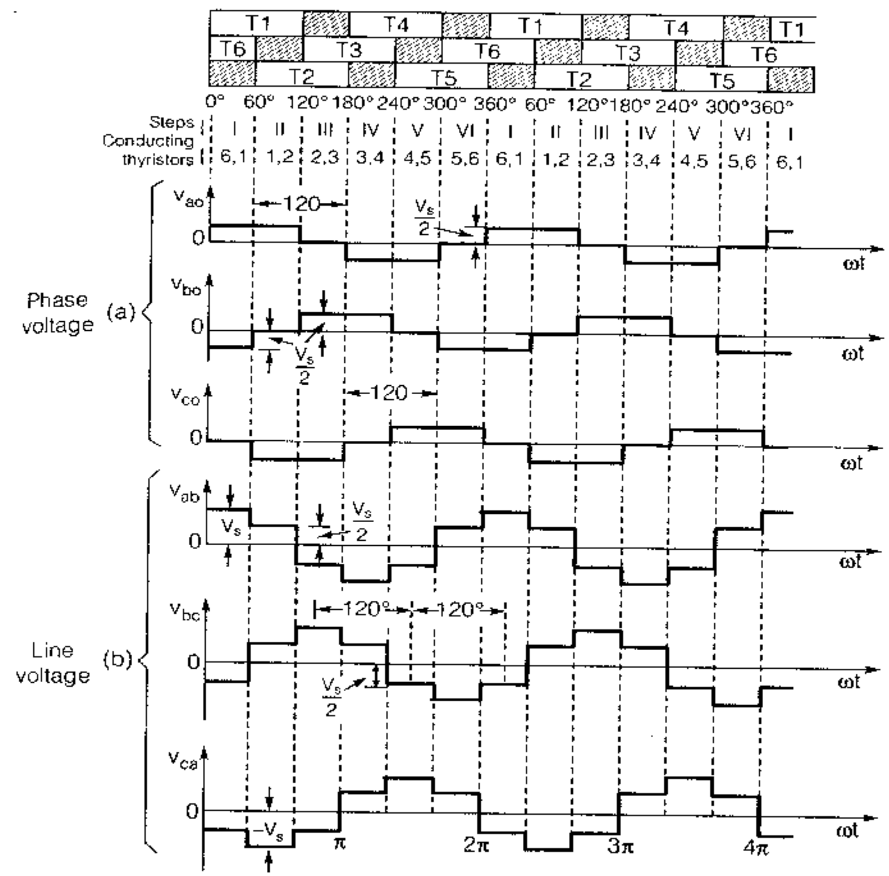
- $$\text{FDF (g)} = \frac{3}{\pi}$$

- $$\text{THD} = 31\%$$

Remember:

- The phase as well as line voltage are out of phase by 120°.
- For n = 3, all triplen harmonics are absent from the line voltage.

2. 3ϕ 120° Mode VSI



- **Line voltage**

$$V_{ab} = \sum_{n=6k\pm1}^{\infty} \frac{3V_s}{n\pi}\sin n\left(\omega t + \frac{\pi}{3}\right)$$

where, k = 0, 1, 2 ...

- **Phase voltage**

$$V_{a0} = \sum_{n=1,3,5..}^{\infty} \frac{2V_s}{n\pi}\cos\frac{n\pi}{6}\sin n\left(\omega t + \frac{\pi}{6}\right)$$

- RMS value of phase voltage

$$V_P = \frac{V_s}{\sqrt{6}} = 0.4082\ V_s$$

- RMS value of line voltage

$$V_L = \frac{V_s}{\sqrt{2}} = 0.7071\ V_s$$

For both line and phase voltage:

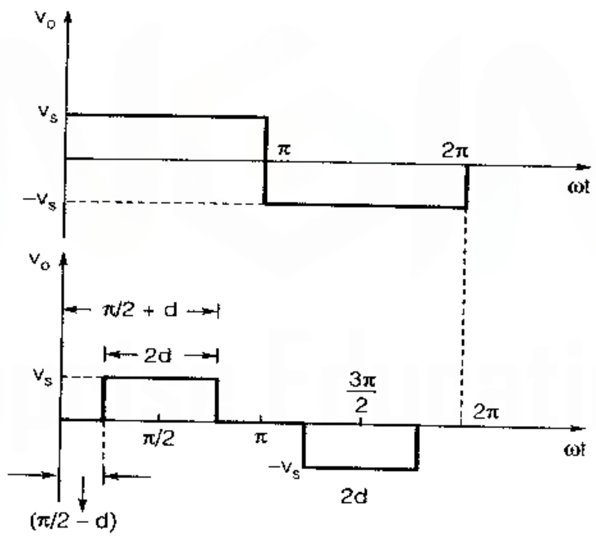
- $FDF = \frac{3}{\pi}$ and THD = 31%

Remember:

- Generally we used IGBT in 1ϕ and 3ϕ inverter.

Pulse Width Modulated Inverters

1. Single-pulse Modulation



- Output voltage

$$V_0 = \sum_{n=1,3,5...}^{\infty} \frac{4V_s}{n\pi} \cdot \sin\frac{n\pi}{2} \sin nd \cdot \sin n\omega t$$

- Pulse width

$$\text{Pulse width} = 2d$$

- Peak value of n^{th} harmonic

$$V_{o\,nm} = \frac{4V_s}{n\pi} \sin nd$$

- RMS value of output voltage

$$V_{or} = V_s \left[\frac{2d}{\pi}\right]^{1/2}$$

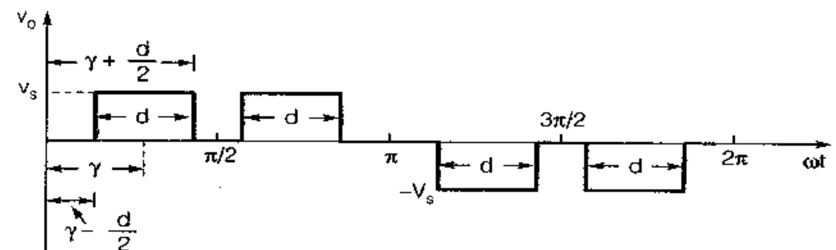
$$FDF\,(g) = \frac{2\sqrt{2}\sin d}{\sqrt{\pi \cdot 2d}}$$

$$THD = \sqrt{\frac{1}{g^2} - 1}$$

Remember:

When pulse width $2d = \frac{2\pi}{n}$, then nth harmonic eliminated.

2. Multiple Pulse Width Modulation



- Output voltage

$$V_0 = \sum_{n=1,3,5...}^{\infty} \frac{8V_s}{n\pi} \cdot \sin n\gamma \cdot \sin\frac{nd}{2} \cdot \sin n\omega t$$

$$\gamma = \frac{\pi - 2d}{N+1} + \frac{d}{N}$$

where, N = Number of pulses per half cycle.

- Amplitude of the n^{th} harmonic of the two pulse wave form

$$V_n = \frac{8V_s}{n\pi} \sin n\gamma \cdot \sin \frac{nd}{2}$$

- Condition to eliminate n^{th} harmonic

(i) $\gamma = \frac{\pi}{n}$ (ii) $2d = \frac{4\pi}{n}$

Remember:

- By using PWM technique, we can get variable voltage and frequency within inverter itself by eliminating some of the lower order harmonics.
- In PWM inverter, force commutation is essential.

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