CHAPTER 3 (POWER ELECTRONICS)

INVERTERS

1. Introduction

- The word 'inverter' in the context of power-electronics denotes a class of power conversion (or power conditioning) circuits that operates from a dc voltage source or a dc current source and converts it into ac voltage or current. The 'inverter' does reverse of what ac-to-dc converter (rectifier) does.
- In any dc to ac conversion there has to be a ac-dc converter (rectifier)

2. Types of Inverters

a) Voltage Source Inverter (VSI)

- Input voltage to the inverter is constant
- The voltage can't reverse but the current can reverse. (i.e. it can supply or sink current)
- Anti parallel diodes are essential components of VSI
- Dead time is required
- Fast Devices are used

b) Current Source Inverter (CSI)

- Input current to the inverter remains constant
- Input voltage can reverse but the current can't reverse
- Easier to protect the device against any **shoot through** fault
- Circuit is rugged and reliable

3. Single Phase Half-Bridge Inverter

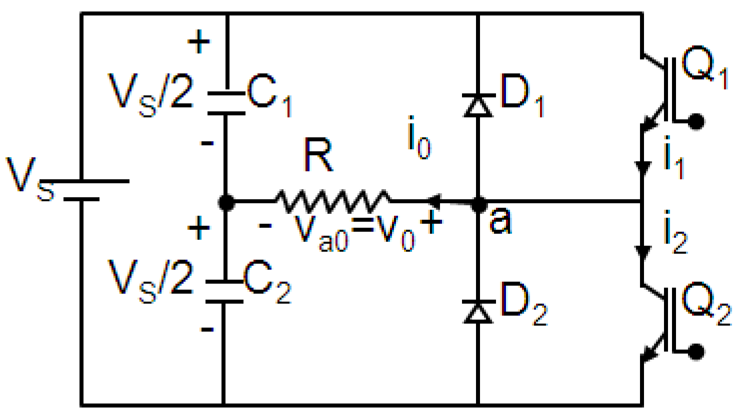
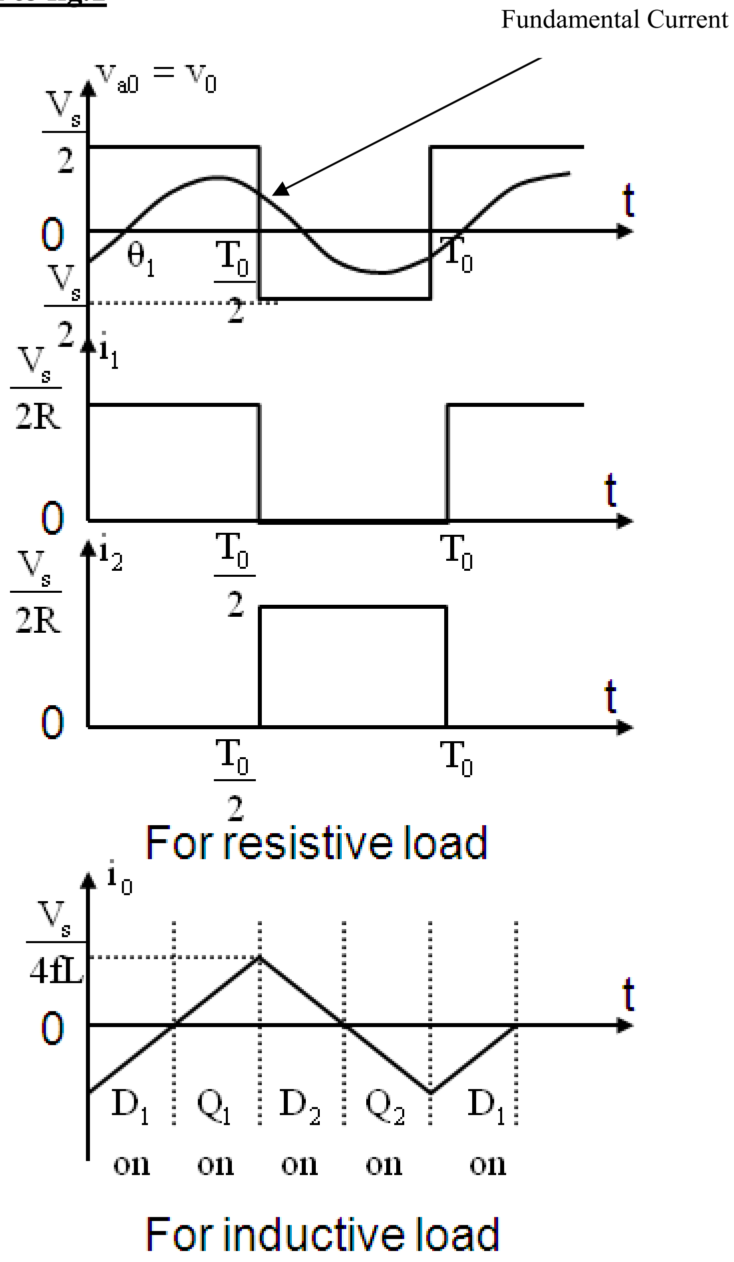


Fig. 1 Single Phase Half bridge Inverter

- Transistors Q1 and Q2 are operated as switch

- If transistor Q1 is on , Q2 is off
- Q1 and Q2 shouldn't be turned on at the same time
- Diodes D1 and D2 which are connected parallel carry negative current for inductive loads

Waveforms related to fig.1



Harmonic Analysis of Single Phase Half Bridge Inverter:

The rms output voltage is given as,

$$V_0 = \left(\frac{2}{T_0} \int_0^{T_0/2} \left(\frac{V_s}{2} \right)^2 dt \right)^{\frac{1}{2}} = \frac{V_s}{2}$$

The instantaneous voltage can be expressed as,

$$v_0 = \frac{a_0}{2} + \sum_{n=1}^{\infty}\left(a_n \cos n\omega t + b_n \sin n\omega t\right)$$

Due to quarter wave symmetry along the x-axis, $a_0 = a_n = 0$

After Fourier series analysis, we obtain

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

- Even order harmonics are absent due to quarter wave symmetry of output voltage along x-axis
- for n=1 the rms value of fundamental component is $v_0 = \frac{2V_s}{\sqrt{2}\pi}$
- For inductive load current cannot change immediately with output voltage (phase difference)
- When Q_1 is OFF at $t=T_0/2$ load current still flows through diode D_2 and lower half of the DC source
- When Q_2 is OFF at $t=T_0$ load current still flows through diode D_1 and upper half of the DC source
- When D1 & D2 conducts energy is fed back to the source therefore called feedback diodes
- For purely inductive load transistor conducts only for $T_0/2$ (90^0), depending upon load conduction period varies from 90^0 to 180^0
- If t_{off} is the off time, a minimum delay $t_d=t_{off}$ must exist outgoing device and triggering of the next incoming device to prevent short circuit condition
- Maximum conduction time of a device is $t_{on}=T_0/1-t_d$
- Assuming lossless inverter, average power absorbed by load is equal to average power supplied $\int_0^T v_s(t)i_s(t)dt = \int_0^T v_0(t)i_0(t)dt \quad T \equiv$ period of ac output voltage
- $\int_0^T i_s(t)dt = \frac{1}{V_s}\int_0^T \sqrt{2}V_{01}\sin(\omega t)\sqrt{2}I_0\sin(\omega t - \theta_1)dt = I_s$ (For inductive load and high switching frequency)
- Where, V_{01}=fundamental rms output voltage, I_0=rms load current θ_1=load angle at fundamental frequency, DC supply current I_s is $I_s = \frac{V_{01}}{V_s} I_0 \cos\theta_1$

4. Performance Parameters of Inverters

a. Harmonics factor of nth harmonic (HF_n): It's the measure of individual harmonic contribution.

$$HF_n = \frac{V_{0n}}{V_{01}} \text{ for } n > 1$$

$V_{01} \equiv$ rms value of fundamental component

$V_{0n} \equiv$ rms value of nth harmonic component

b. Total Harmonic Distortion (THD): It's the measure of measure of closeness in shape between a waveform and its fundamental component.

$$THD = \frac{1}{V_{01}} \left(\sum_{n=2,3,4...}^{\infty} V_{0n}^2 \right)^2$$

c. Lowest Order Harmonic (LOH): Harmonic component whose frequency is closest to fundamental and amplitude greater or equal to 3% of fundamental

d. Distortion Factor (DF): THD gives total harmonic content but does not indicate individual harmonics level. In practice, the Knowledge of both frequency and magnitude of individual harmonic component is required. DF indicates amount of harmonic distortion remaining after the harmonics of that waveform is subjected to second order attenuation (divide by n^2) DF measures effectiveness in reducing unwanted harmonics without specifying values of second order load filter.

$$DF = \frac{1}{V_{01}} \left[\sum_{n=2,3...}^{\infty} \left(\frac{V_{0n}}{n^2} \right)^2 \right]^{1/2}$$

For individual (nth component)

$$DF_n = \frac{V_{0n}}{V_{01} n^2} \text{ for } n > 1$$

5. Single Phase Bridge Inverter

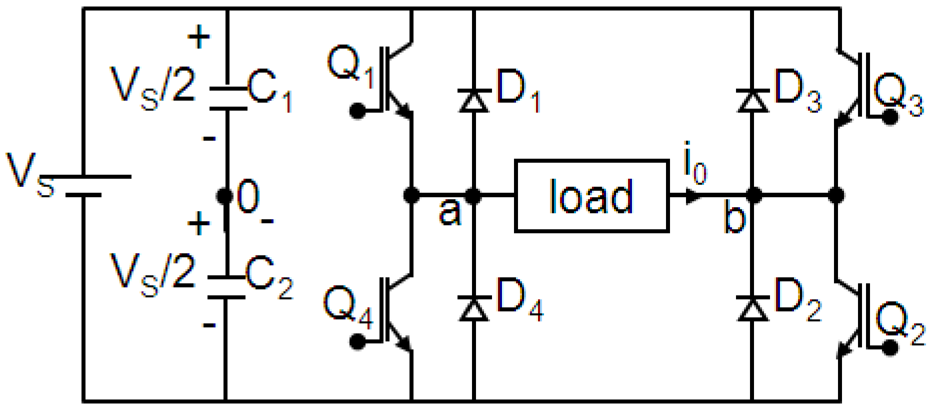


Fig. 2 Single Phase Bridge Inverter

Waveforms

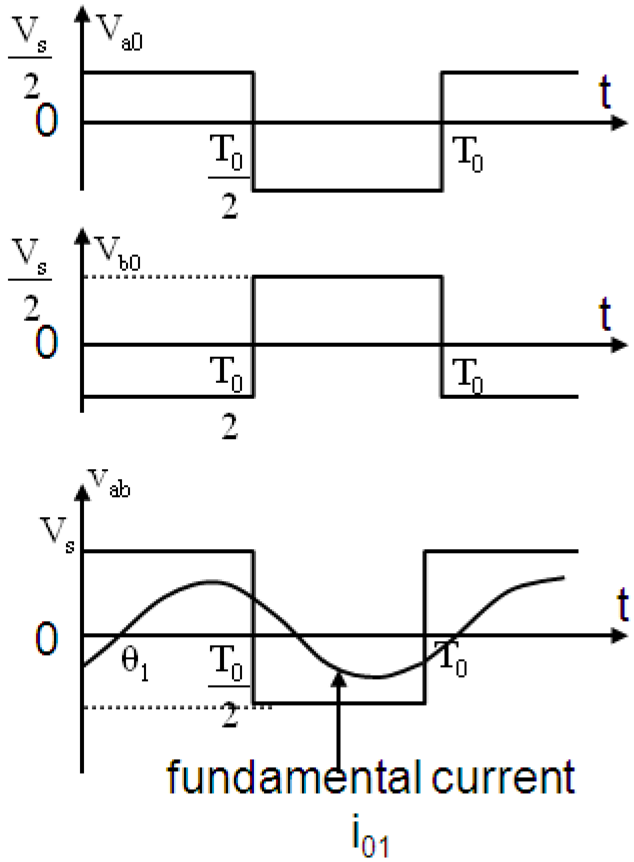


Fig. 3 Waveforms for highly resistive load

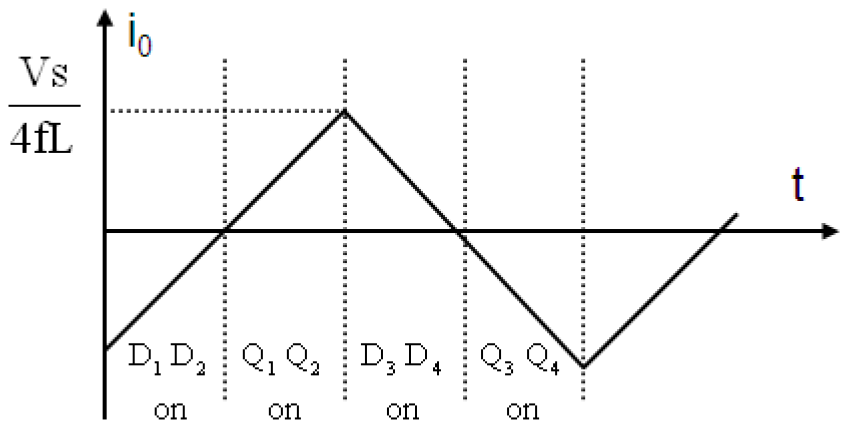


Fig. 4 Waveform for Highly inductive load

Description

- It consists of four switching devices
- When Q_1 & Q_2 is ON instantaneous voltage across load is V_s
- When Q_3 & Q_4 is ON instantaneous voltage across load $-V_s$
- If two switches, one upper & on lower be turned ON at the same time output voltage is $\pm V_s$ the switch is at state 1
- If two switches be turned OFF at the same time the switch is at state 0

Harmonic Analysis of Single Phase Bridge Inverters

The rms output voltage is given as,

$$V_0 = \left(\frac{2}{T_0} \int_0^{T_0/2} (V_s)^2 \, dt \right)^{\frac{1}{2}} = V_s$$

The instantaneous output voltage can be expressed in terms of Fourier series as,

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

$V_o = 0$ for n=2, 4, 6

For n=1 the rms value of the fundamental component is,

$$V_{01} = \frac{2V_s}{\sqrt{2}\pi} = 0.9V_s$$

- For highly inductive loading and relatively high switching frequency, I_0 & output voltage is nearly sinusoidal. Only the fundamental component ac voltage provides power to the load. The dc supply remains constant vs(t)=Vs

$$i_s(t) = \frac{1}{V_s} V_{01}\sin(\omega t)\sqrt{2} I_0 \sin(\omega t - \theta_1)$$

$$i_s(t) = \frac{V_{01}}{V_s} I_0 cos(\theta_1) - \frac{V_{01}}{V_s} I_0 cos(2wt - \theta_1)$$

6. Numerical Problems (Important)

Refer Example 6.1 (page 231), Example 6.2 & 6.3 (page 234) from M.H.Rashid's Power Electronics (3rd Edition)