EEE213 Power Electronics and Electromechanism

Assignment 1

Deadline: ~~21st April,~~ 12th May2019. Time: 23.55.

Assignment 2

Deadline: 19th May 2019. Time: 23.55.

ALL Tutorial questions (week11 &12)

TA (PhD student) : room EE511

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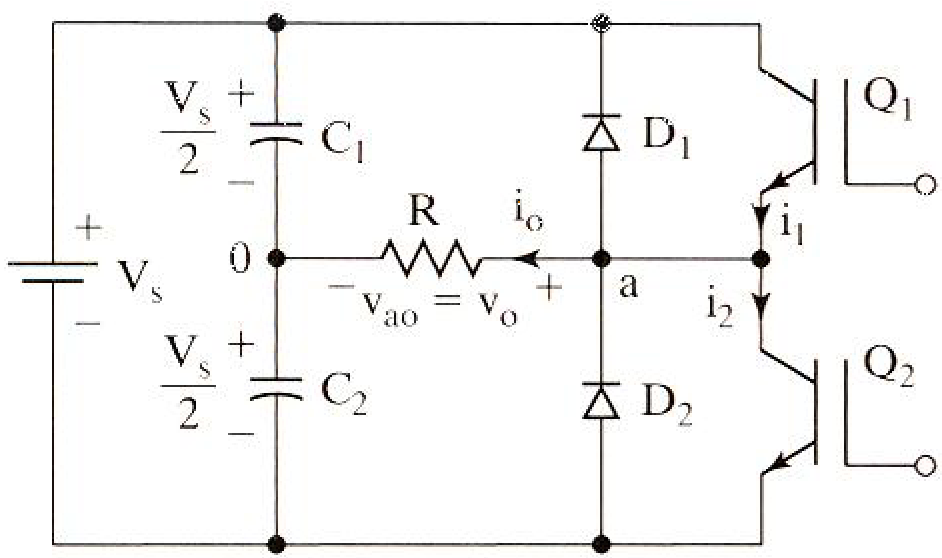
EEE213 Power Electronics and Electromechanism

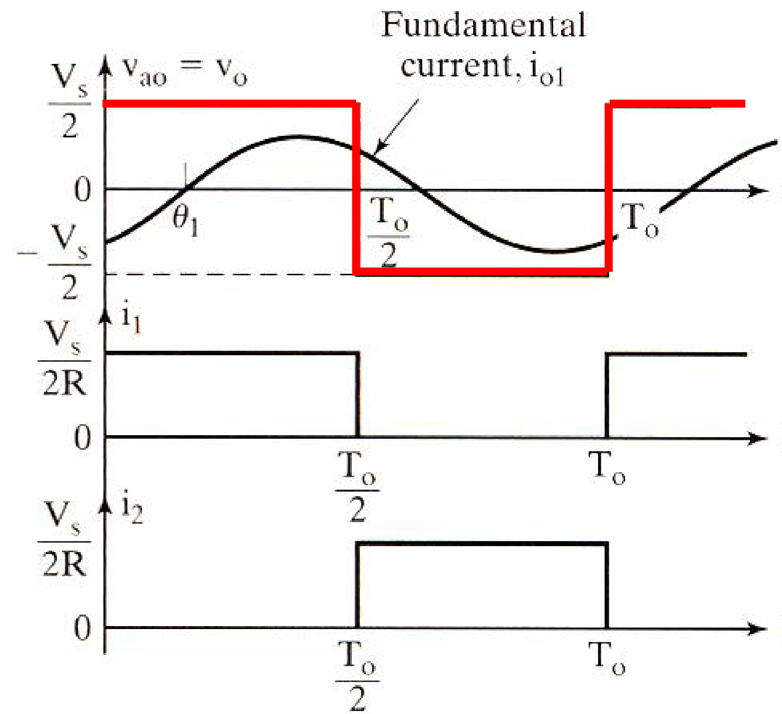
9. DC-AC Converters

Outline

- Principle of single phase DC-AC inverters
  - Half bridge voltage source inverter (VSI)
  - Full bridge VSI
- PWM Technique
  - The equal-area theorem
  - SPWM – Sinusoidal PWM
- Motors
  - DC motor
  - AC motor (induction motor)

1.1 Single-phase half-bridge VSI





- DC side is constant voltage, low impedance
- The current conducting path is determined by the polarity of load voltage and load current.
- The magnitude of output square-wave voltage is $V_s/2$.

Quantitative analysis 1

- The rms output voltage can be found:

$$V_0 = \sqrt{\frac{2}{T_0}\int_0^{T_0/2}\frac{V_S^2}{4}dt} = \frac{V_S}{2}$$

- The instantaneous output voltage in Fourier series form:

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

  - Due to the symmetry, all a_n (including a_0) are 0
  - b_n are calculated as

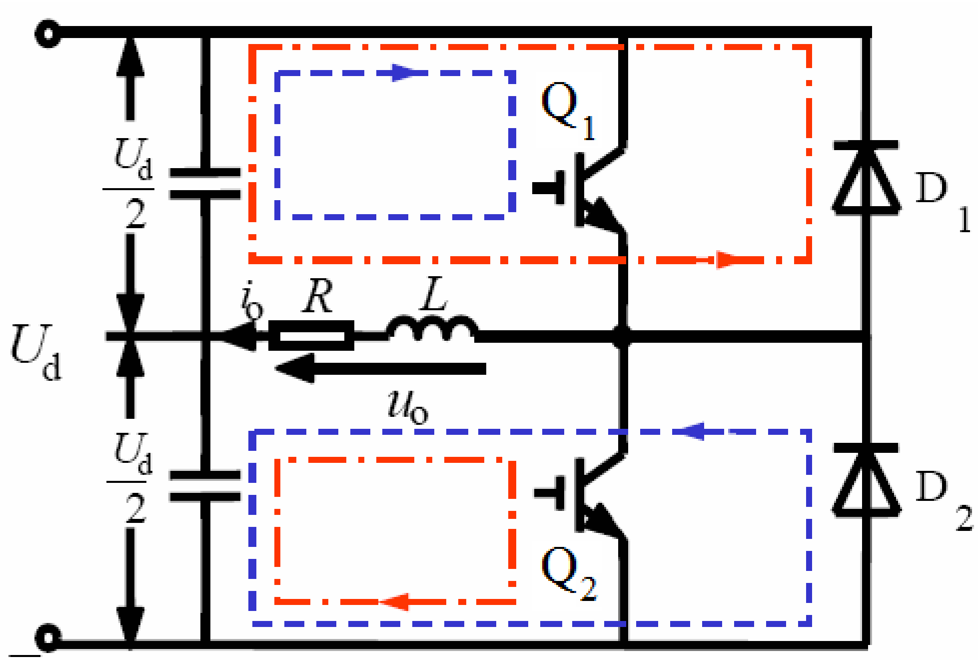
$$b_n = \frac{1}{\pi}\left[\int_{-\pi}^{0}\frac{-V_S}{2}\sin n\omega t d\omega t + \int_0^{\pi}\frac{V_S}{2}\sin n\omega t d\omega t\right] = \frac{V_S\left(1-\cos n\pi\right)}{n\pi} = \begin{cases}\frac{2V_S}{n\pi}, & n = 1,3,5,\ldots \\ 0, & n = 2,4,6,\ldots\end{cases}$$

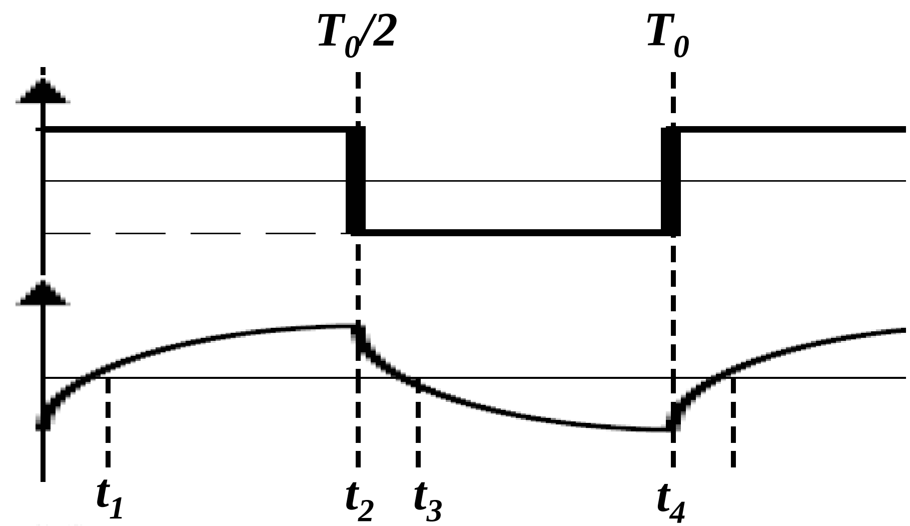
$$\Rightarrow v_0 = \sum_{n=1,3,5,\ldots}^{\infty}\frac{2V_S}{n\pi}\sin n\omega t$$

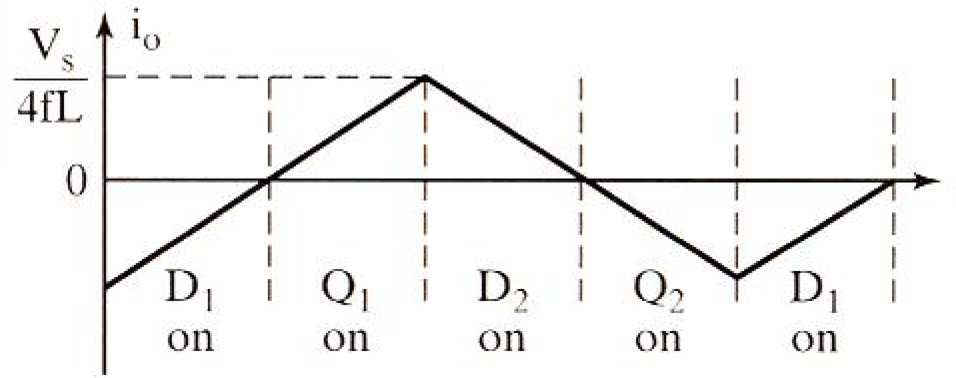
- The rms value of fundamental component of output is

$$v_{o1} = \frac{2V_S}{\sqrt{2}\pi} = 0.45V_S$$

Inductive load







(c) Load current with highly inductive load

- For inductive load, the load current cannot change immediately with the output voltage.
- Feedback / freewheeling diodes

Quantitative analysis 2

- For an RL load, the instantaneous load current i_0 can be found by dividing the instantaneous output voltage by the load impedance ***Z=R+jnωL***, so

$$i_0 = \sum_{n=1,3,5,\ldots}^{\infty} \frac{2V_S}{n\pi\sqrt{R^2+(n\omega L)^2}} \sin(n\omega t - \theta_n)$$

- where $\theta_n = \tan^{-1}(n\omega L / R)$ is the phase of the load impedance
- The rms fundamental load current (n=1) is:

$$I_{o1} = \frac{2V_S}{\sqrt{2}\pi\sqrt{R^2+(\omega L)^2}}$$

- The fundamental output power (n=1) is

$$P_{o1} = V_{o1} I_{o1} \cos\theta_1 = I_{o1}^2 R = \frac{2V_S^2 R}{\pi^2\left(R^2+(\omega L)^2\right)}$$

Performance parameters

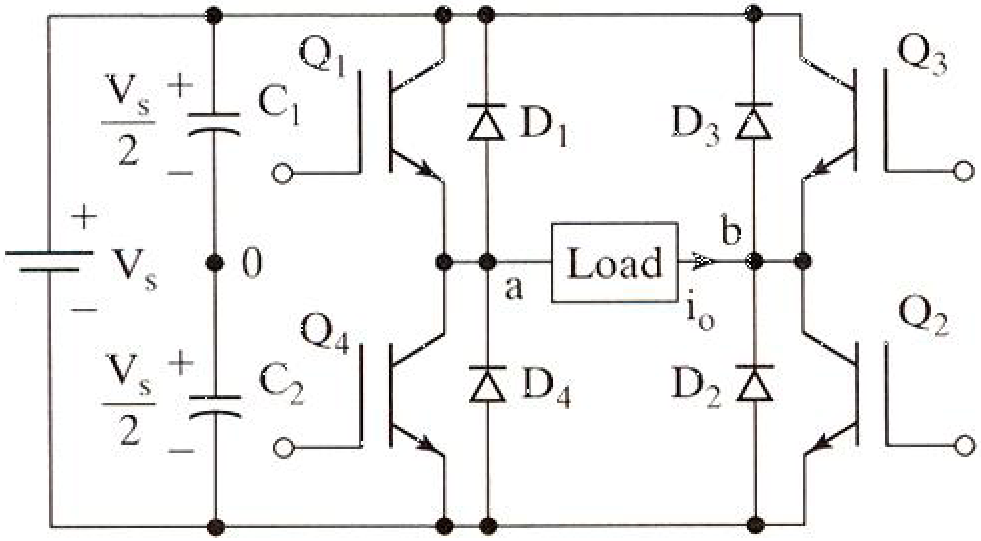
- The output of practical inverters contain harmonics and the quality of an inverter is normally evaluated in terms of these performance parameters:
  - Harmonic factor of nth harmonic (HF_n)
    - a measure of individual harmonic contribution

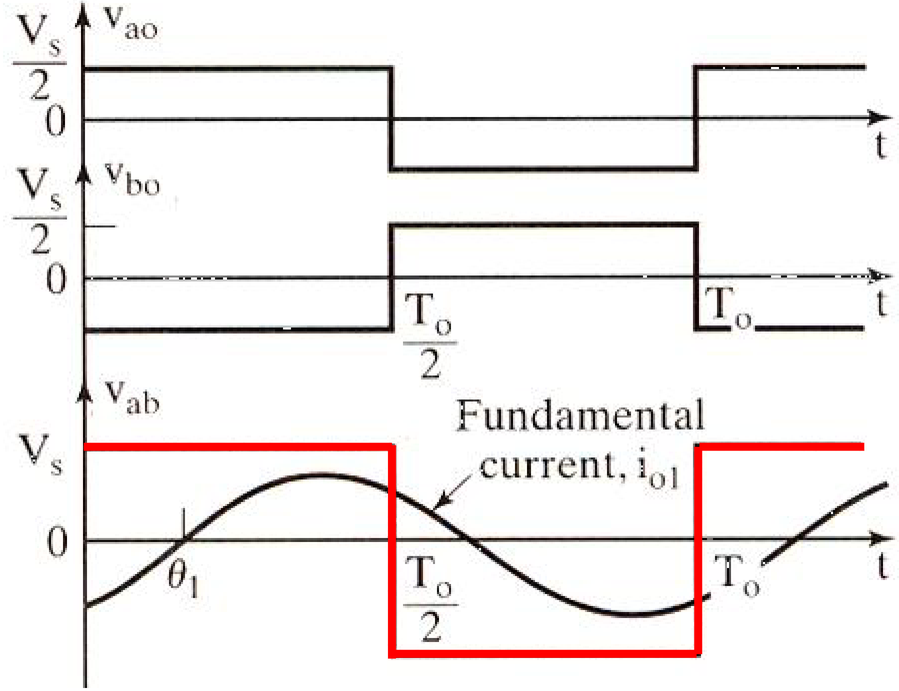
$$HF_n = \frac{V_{on}}{V_{o1}}$$

    - where V_{on} is the rms value of the nth harmonic component
  - Total harmonic distortion (THD) of output voltage
    - a measure of closeness in shape between a waveform and its fundamental components

$$THD = \sqrt{\frac{\sum_{n=2,3,\ldots}^{\infty} V_{on}^2}{V_{o1}^2}} = \sqrt{\frac{V_0^2 - V_{o1}^2}{V_{o1}^2}}$$

1.2 Single-phase full-bridge VSI





- C1 and C2 are used for DC-link filtering
- When the load is highly inductive, the current waveform is triangular.
- The magnitude of output square-wave voltage is V_S.

- There are four states available in the H-bridge, as shown at right.

- The voltages that can be applied to the load are $+V_{DC}$, $-V_{DC}$, and 0.

- Notice that switches 1 and 4 should never be turned "on" simultaneously, and the same for switches 2 and 3.

- Such a condition would be called a ***<u>shoot-through</u>***.
  - To prevent shoot-through, a very short time interval called *the blanking time* must be inserted between the turning "off" of switch 1 and the turning "on" of switch 4.

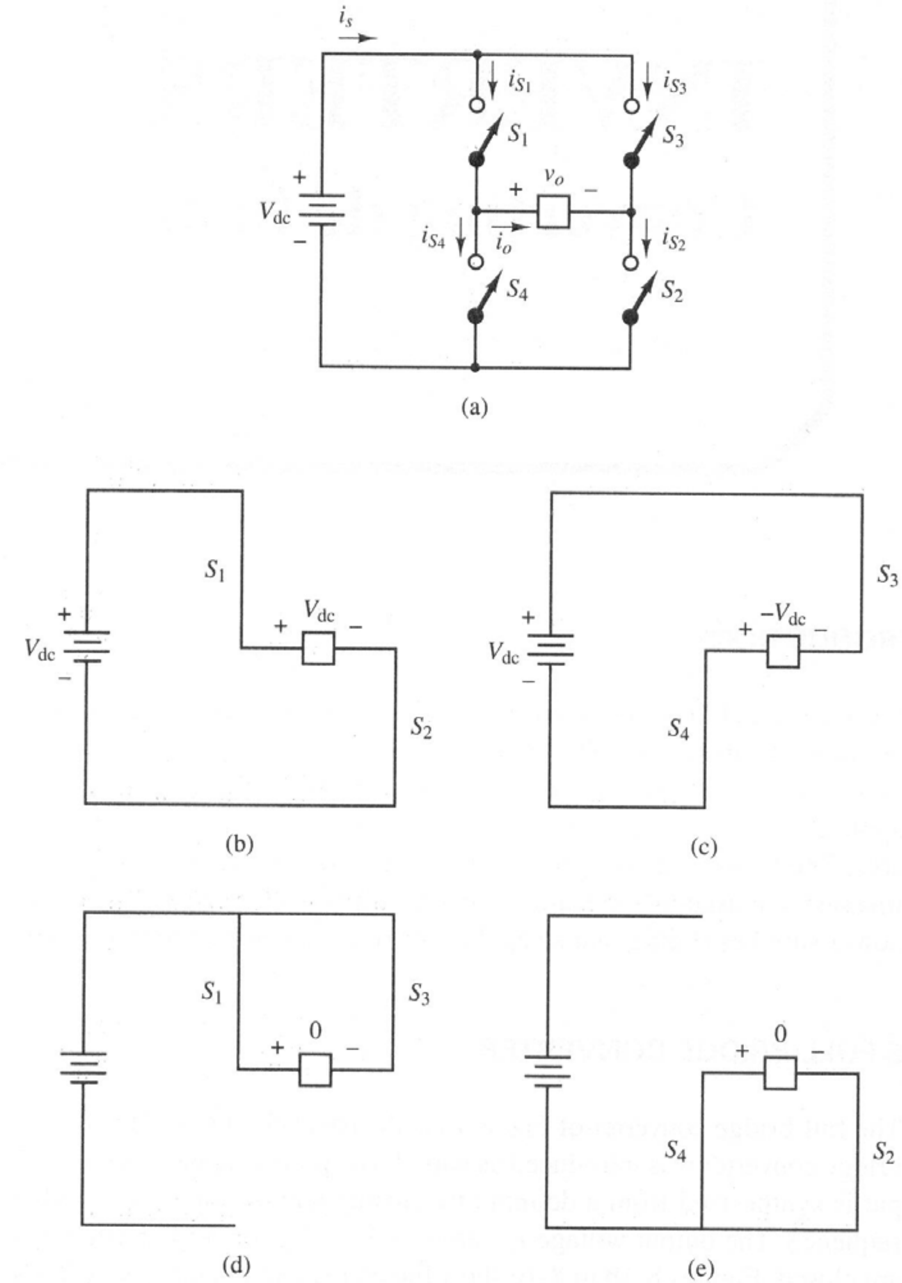
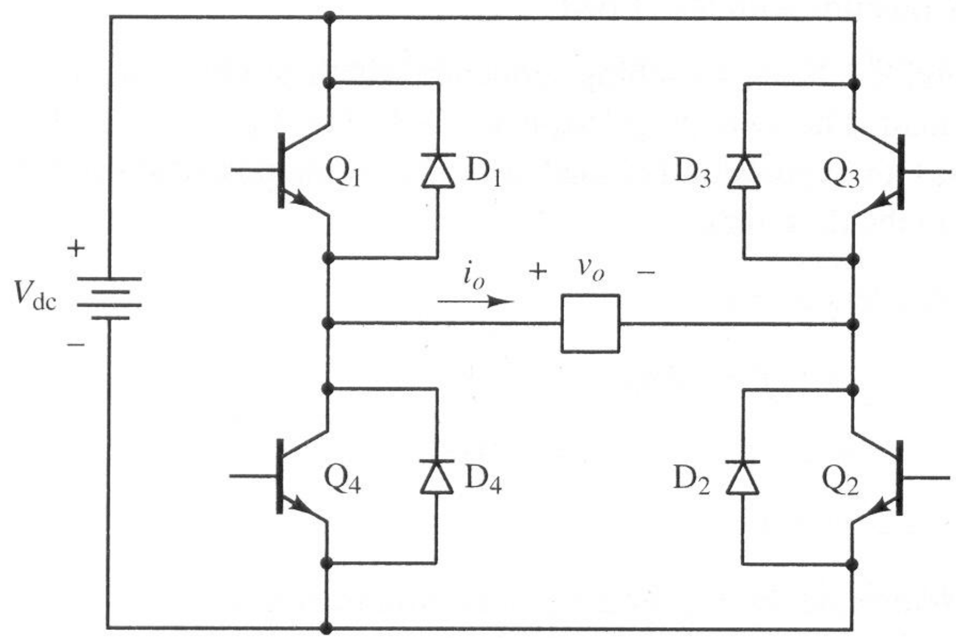


Figure 8.1 (a) Full-bridge converter. (b) S_1 and S_2 closed. (c) S_3 and S_4 closed. (d) S_1 and S_3 closed. (e) S_2 and S_4 closed.

Why use diodes?

- They appear in case the load is not purely resistive. If it's inductive, which it usually is, then when switch 1 (for example) turns off, the inductive load current can commutate over to the diode D4 until it goes to zero and reverses direction. Then switch Q4 can pick it up.



(a)

Quantitative analysis

- The rms output voltage can be found:

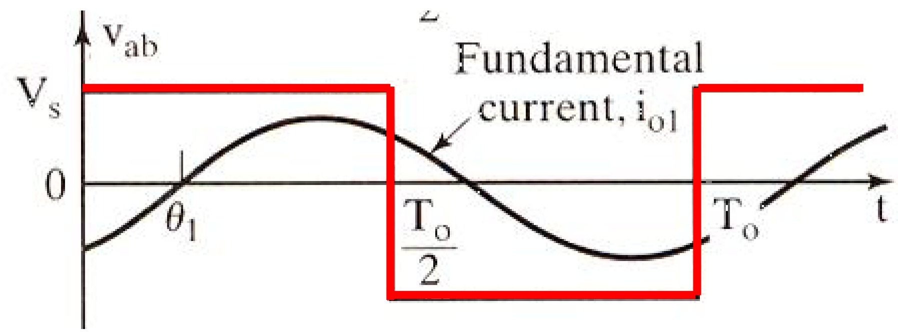
$$V_0 = \sqrt{\frac{2}{T_0}\int_0^{T_0/2} V_S^2 dt} = V_S$$

- The instantaneous output voltage in Fourier series form:

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

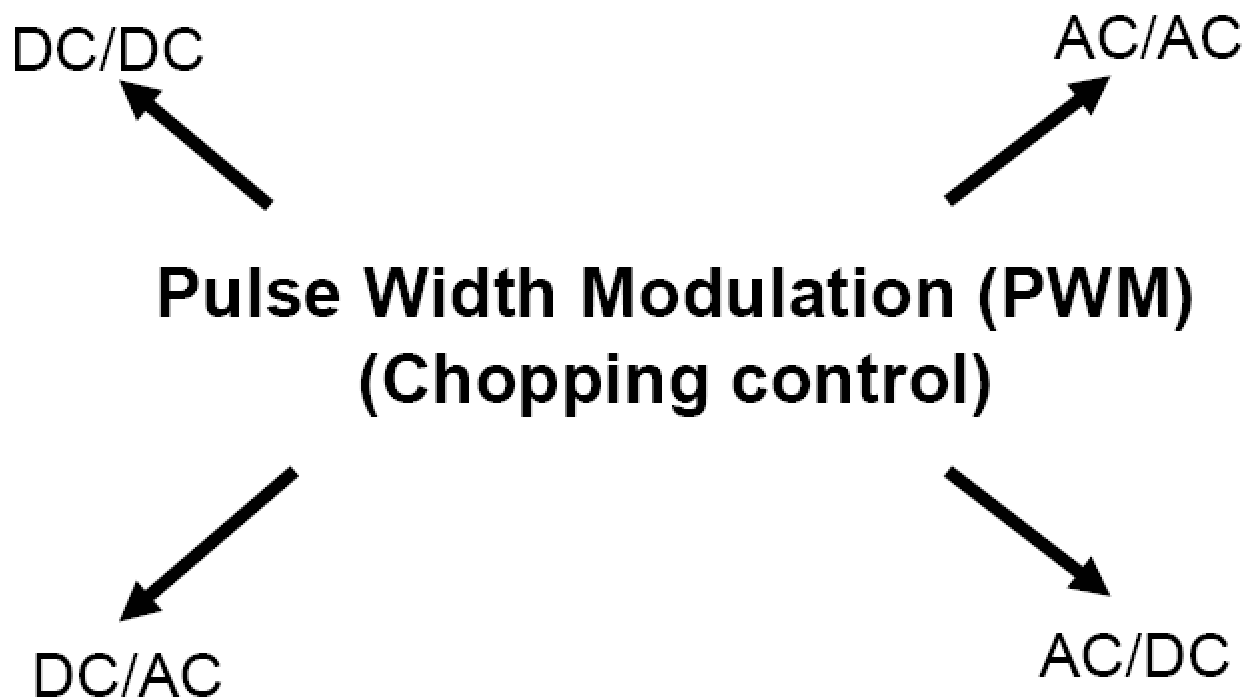
- The rms value of fundamental component of output is

$$v_{o1} = \frac{4V_S}{\sqrt{2}\pi} = 0.9V_S$$



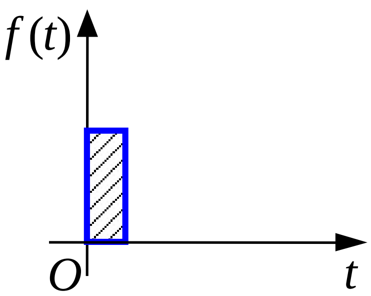
2. PWM Technique

- Pulse Width Modulation (PWM)
  - is a commonly used technique for controlling power to inertial electrical devices, made practical by modern electronic power switches.

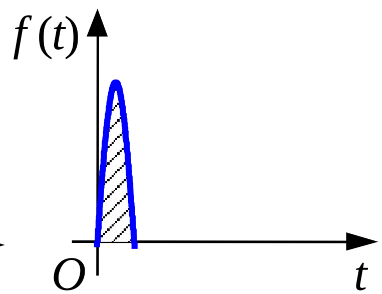


2.1 The equal-area theorem

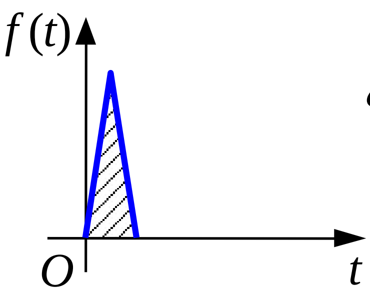
- The equal-area theorem: Responses tend to be identical when input signals have same area and time durations of input impulses become very small.



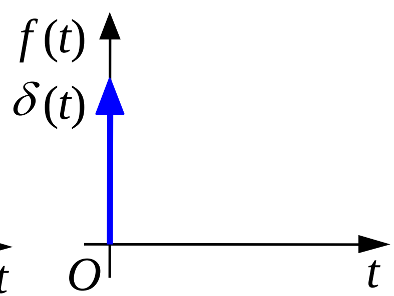
a) Square pulse



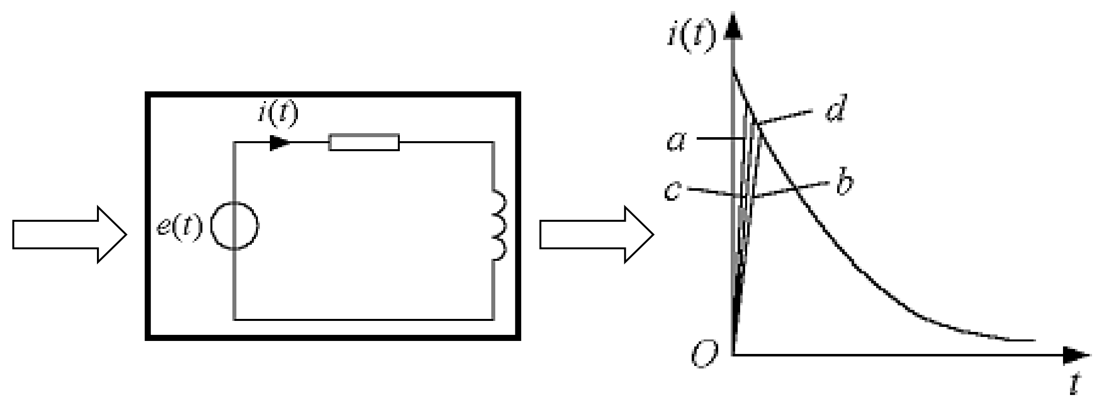
c) Half-sin pulse



b) Triangular pulse



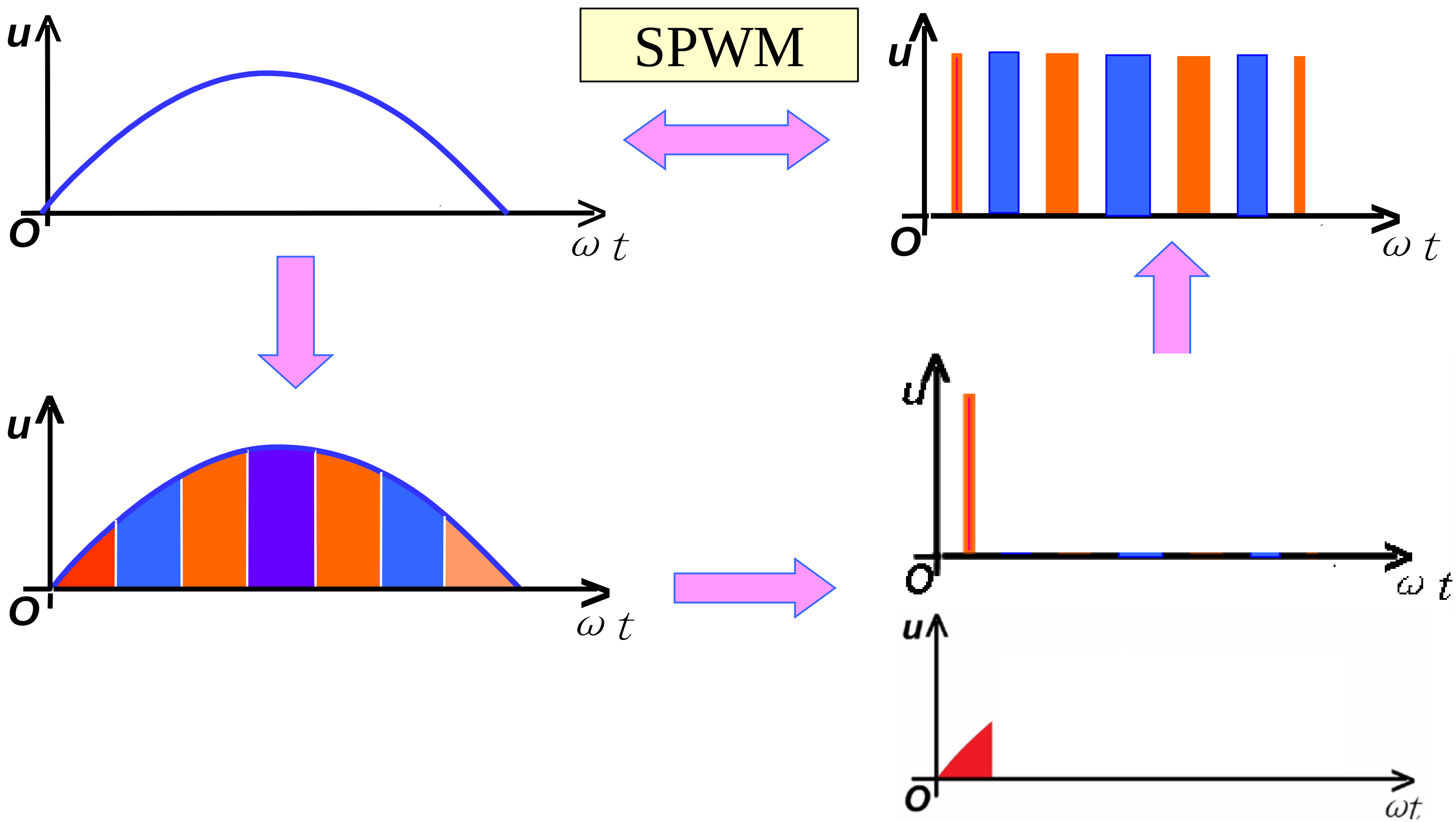
d) Ideal pulse



Similar response to different shape of impulse input

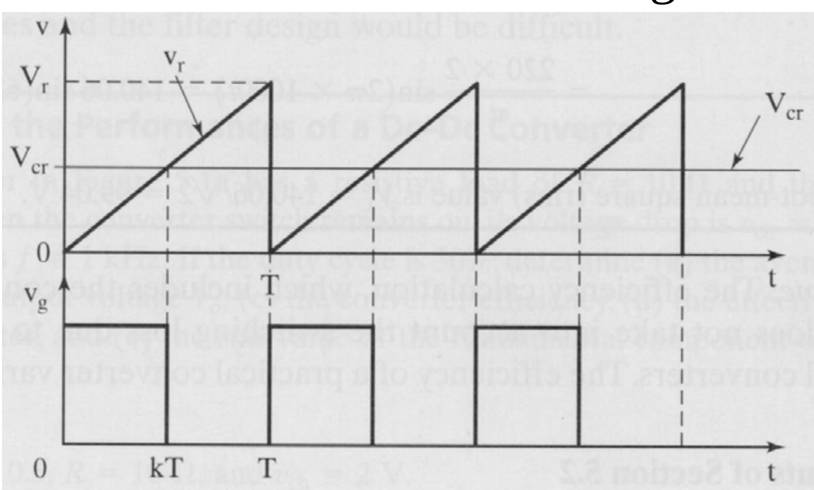
2.1 The equal-area theorem

- Application of the equal-area theorem

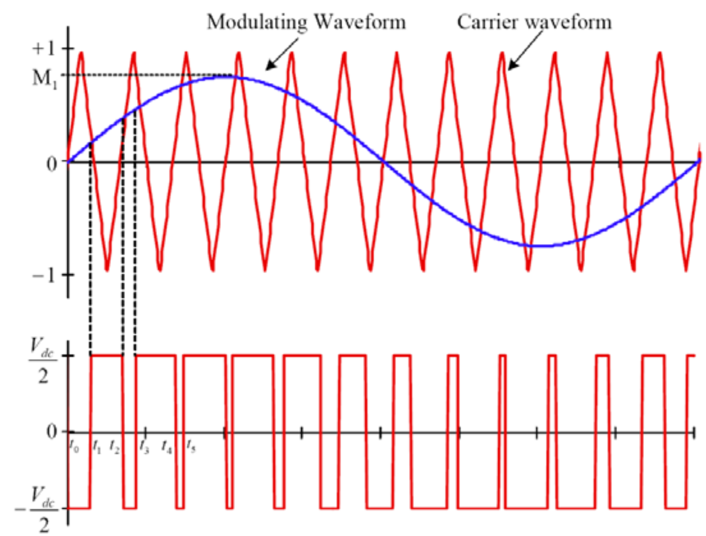


2.2 Sinusoidal PWM

- Most of the DC-AC inverters are required to provide a clean sinusoidal voltage supply with a fixed or varying frequency, which is normally much lower than the switching frequency
- Solution: sinusoidal PWM.
  - Instead of having a DC voltage V_{cr}, a reference sinusoidal V_{cr} is used for PWM.
  - It is possible to change the amplitude and frequency of the output: just change those of the reference voltage.



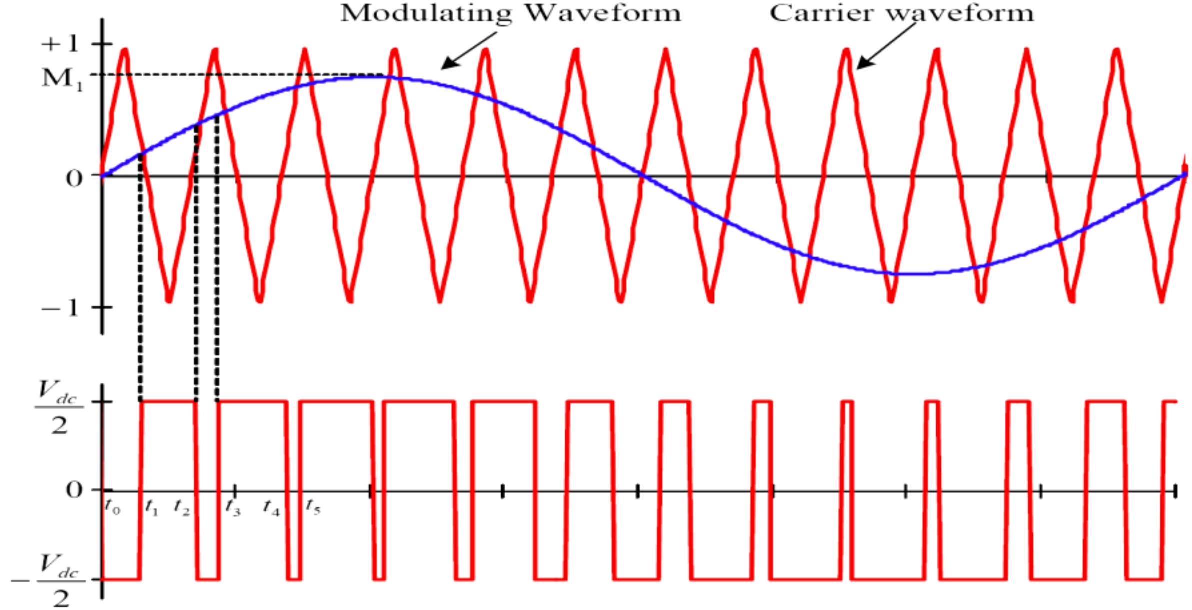
Conventional PWM



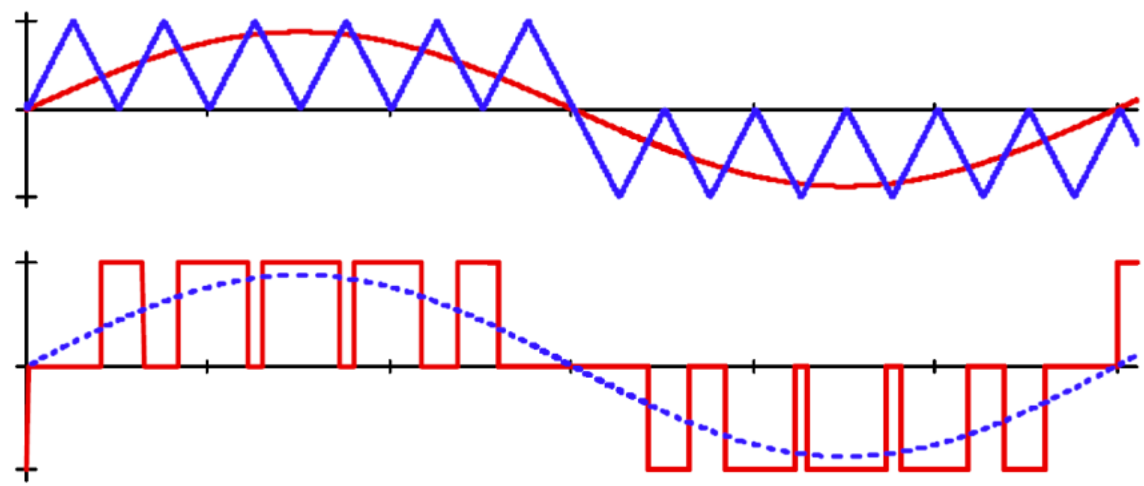
Sinusoidal PWM

Bipolar or unipolar

- Bipolar:
  - easy to generate/use



- Unipolar:
  - better THD
  - but difficult to generate



Other PWM techniques

- Optimised PWM
  - PWM waveform are constructed based on certain performance criteria, e.g. THD.
- Harmonic elimination/minimisation PWM
  - PWM waveforms are constructed to eliminate some undesirable harmonics from the output waveform spectra.
  - Highly mathematical in nature
- Space-vector PWM
  - Using vectors to approximate a circle
  - Easy to generate and very commonly used

Single-phase SPWM bridge inverters

- The gate-driven signals are SPWM signals.
- For bipolar PWM signals, positive pulses to drive Q1 and Q2 and negative pulses to drive Q3 and Q4.

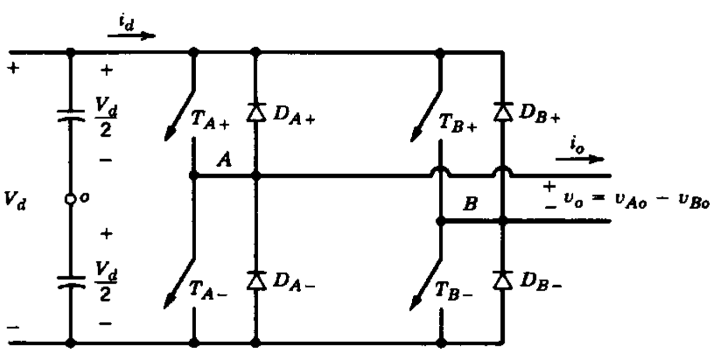
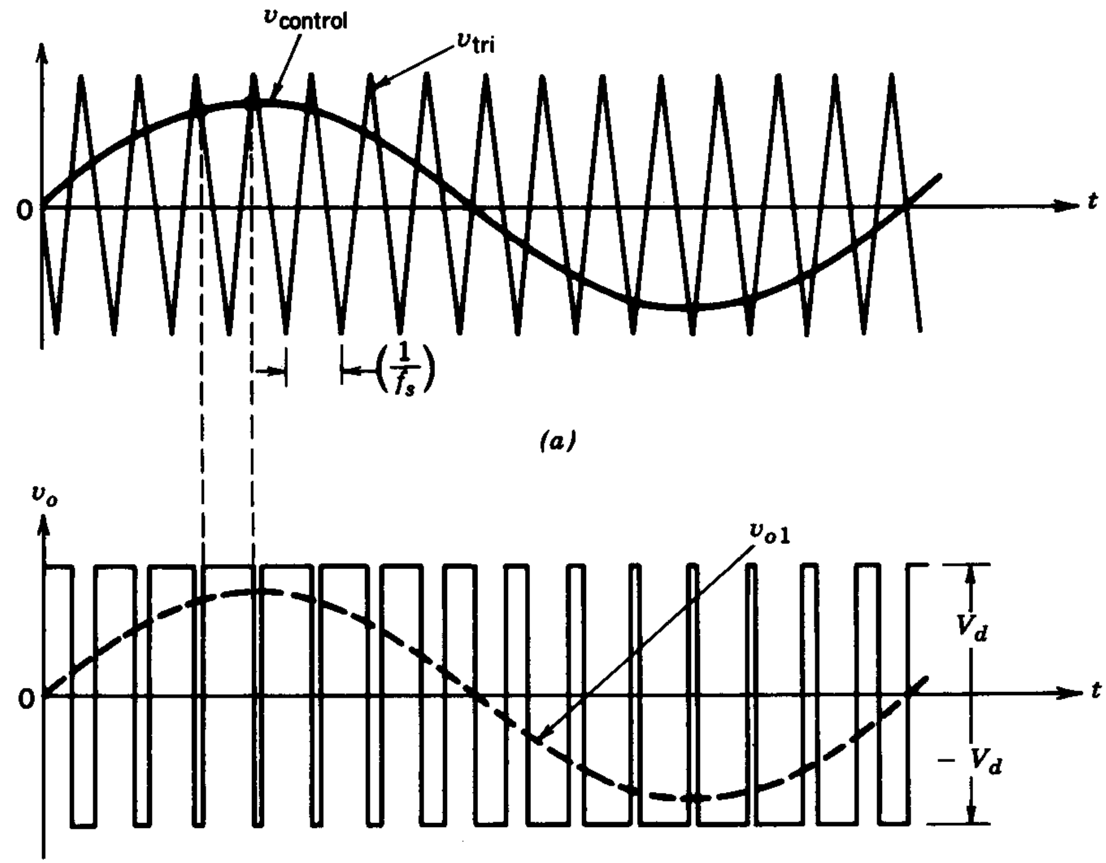


Figure 8-11 Single-phase full-bridge inverter.



Single-phase SPWM bridge inverters

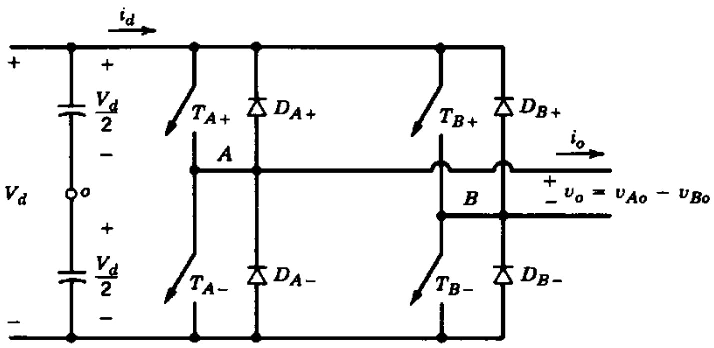
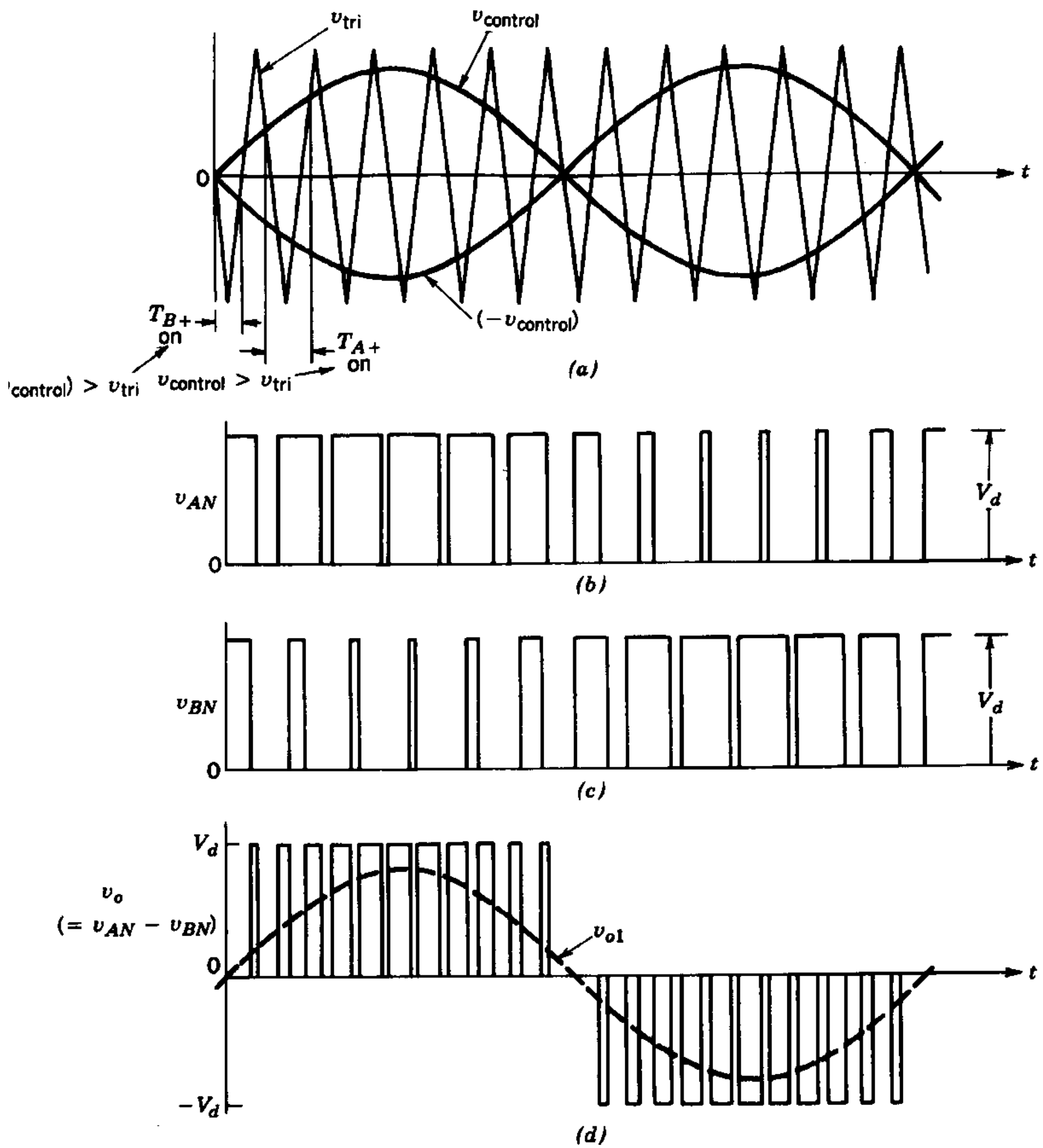


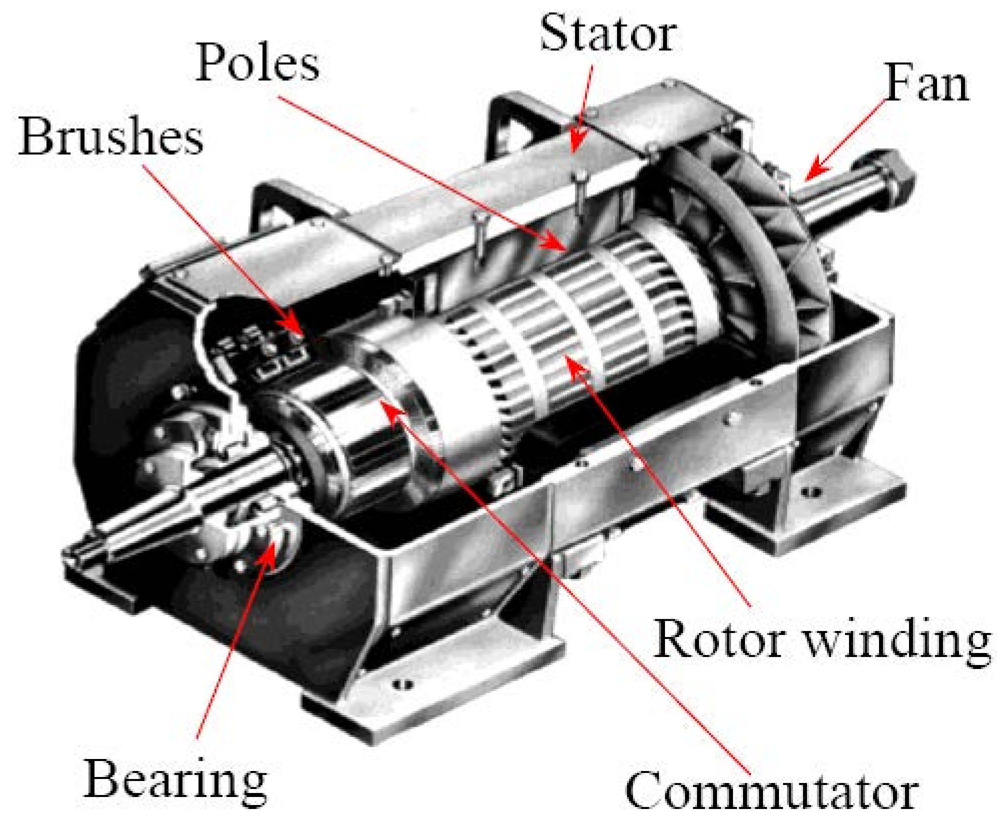
Figure 8-11 Single-phase full-bridge inverter.



- For unipolar PWM
  - Legs A and B are controlled separately by comparing Vcr with positive and negative carrier waves.

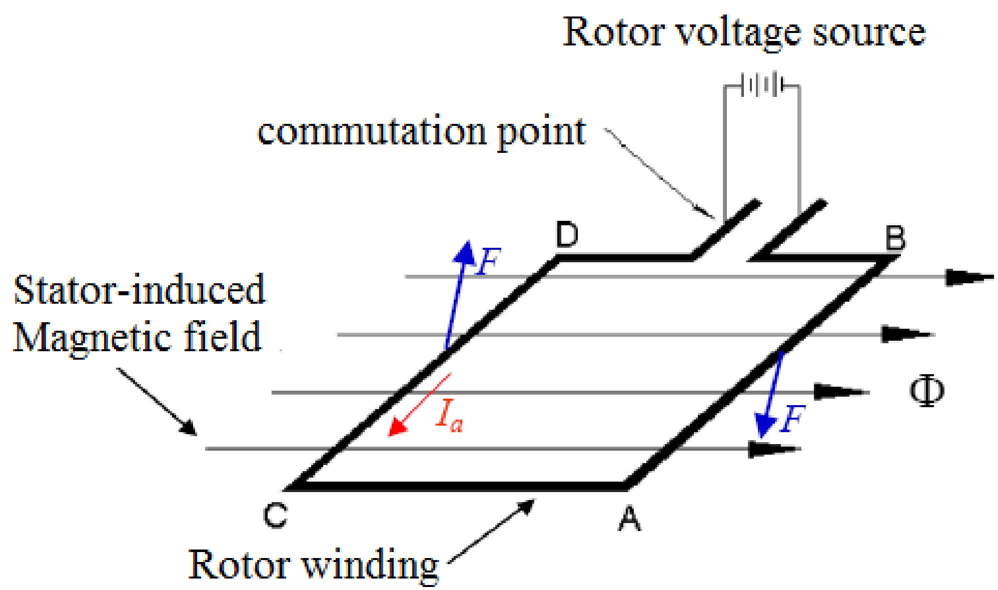
3.1 DC motors

- Three parts:
  - Rotor (Armature) –The rotating centre portion.
  - Stator–The static (stationary) windings around the rotor. In many small motors, the stator can be replaced with permanent magnets.
  - Commutator–The brush connection to the winding on the rotor.



A simplified DC motor

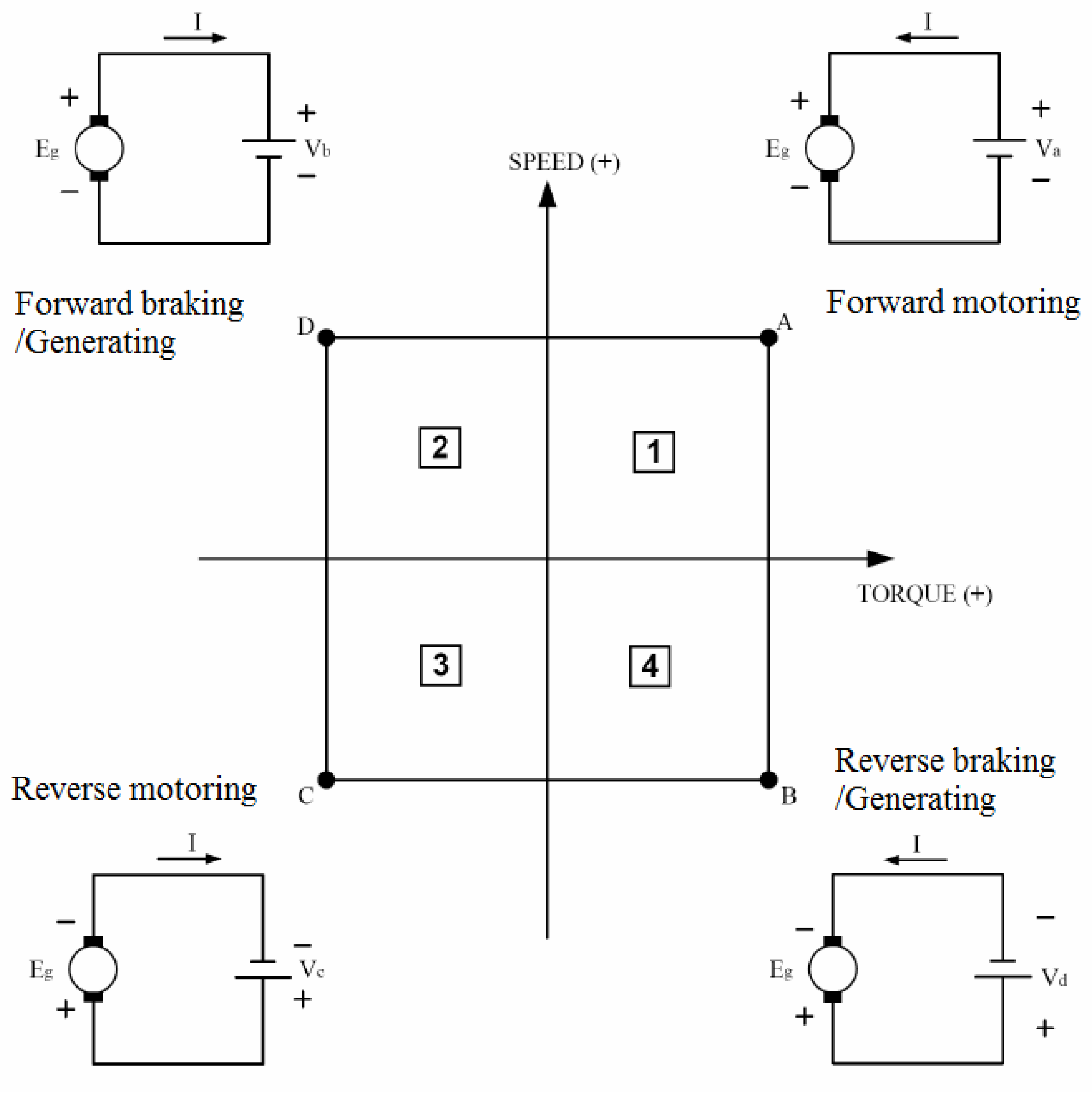
- Operated by DC voltage sources
- Easy to control the speed by controlling the voltage source
- Easy to reverse



Operation modes of a DC motor

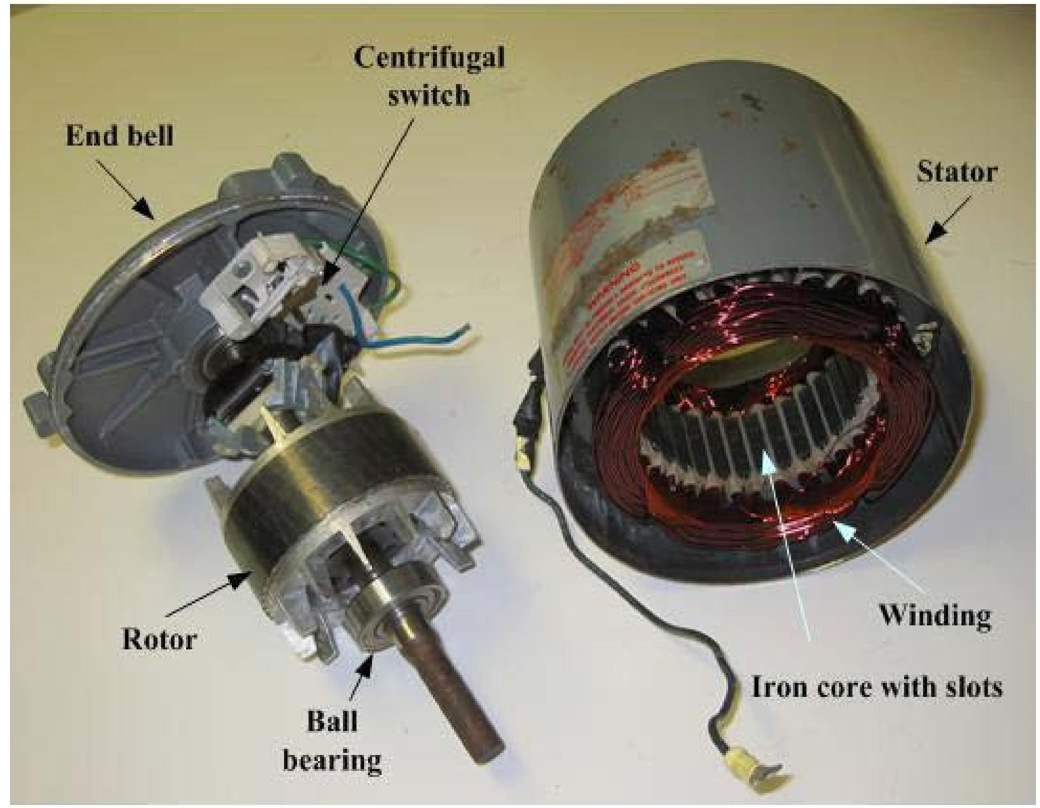
- Motoring: E_a is less than V_a and the motor drives the mechanical load
- Generating: the motor is driven by a rotating machine.
- Braking (short-period operation):
  - Dynamic braking: re-connecting the motor as a generator by temporarily replacing the supply with a braking resistance R, and dissipating the generated power into a resistive load.
  - Regenerating braking: an extension of dynamic braking. The kinetic energy of the motor is converted into electricity and returned to the supply, which means E_a is greater than V_a
  - Plugging: another type of braking by temporarily reversing the armature terminals to forcefully stop it.

Four-quadrant operation



3.2 Induction motors

- The single-phase induction motor is the most frequently used motor in the world
- Highly reliable and economical
- For industrial applications, three-phase induction motors are used.



Construction

- An induction motor consists of
  - Stator
  - Rotor
  - Housing
- The motor housing consists of
  - Shaft: the cylindrical middle piece that holds the stator iron core;
  - End bell: the two bell-shaped end covers holding the ball bearings.

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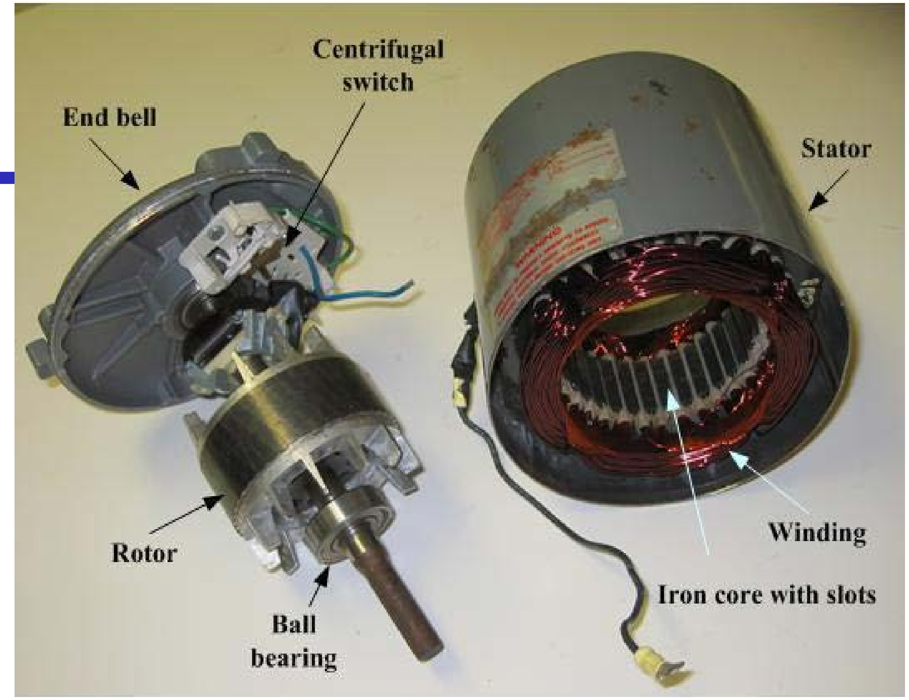

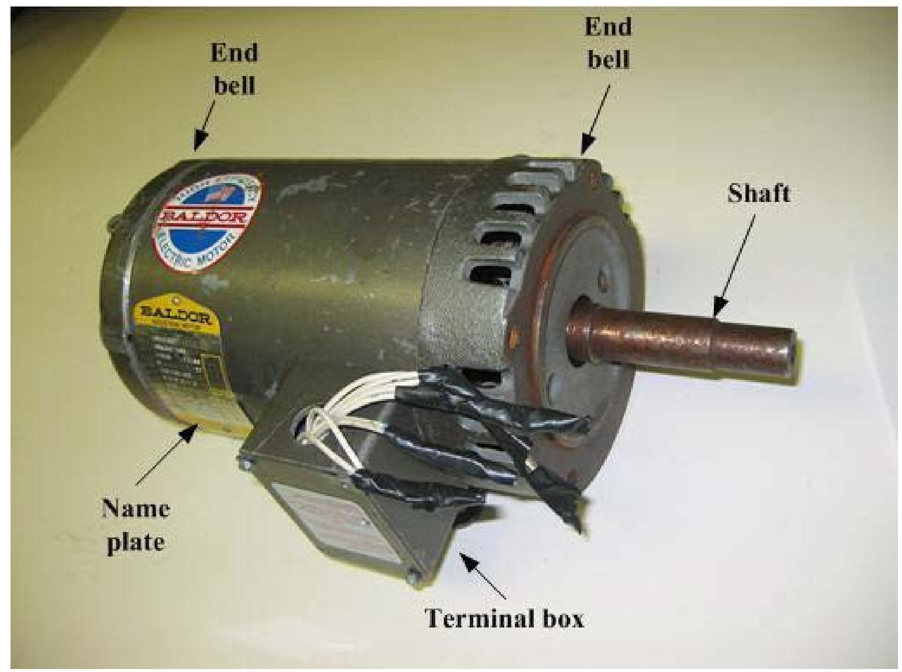

Problem 9.1

- The half-bridge inverter has an RC load with R=10ohm and C=112uF. The inverter frequency is f_0=60Hz and DC input voltage is V_s=220V.
  - a) Express the instantaneous load current in Fourier series;
  - b) Calculate the rms load current at the fundamental frequency;
  - c) the THD of the load current;
  - d) the power absorbed by the load P_0.