Electronics and
Computer Science

ELEC2208 Power Electronics and Drives

Inverter

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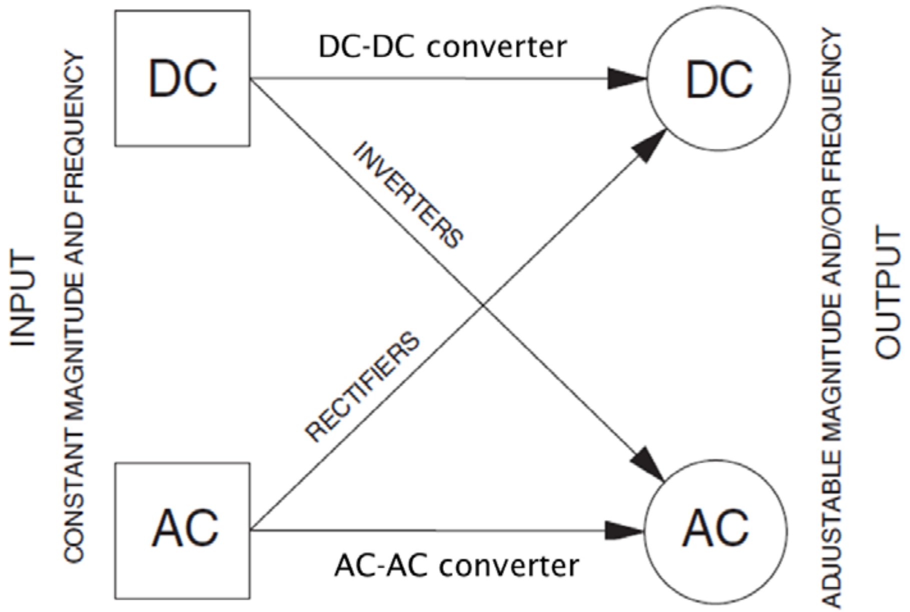
Classification

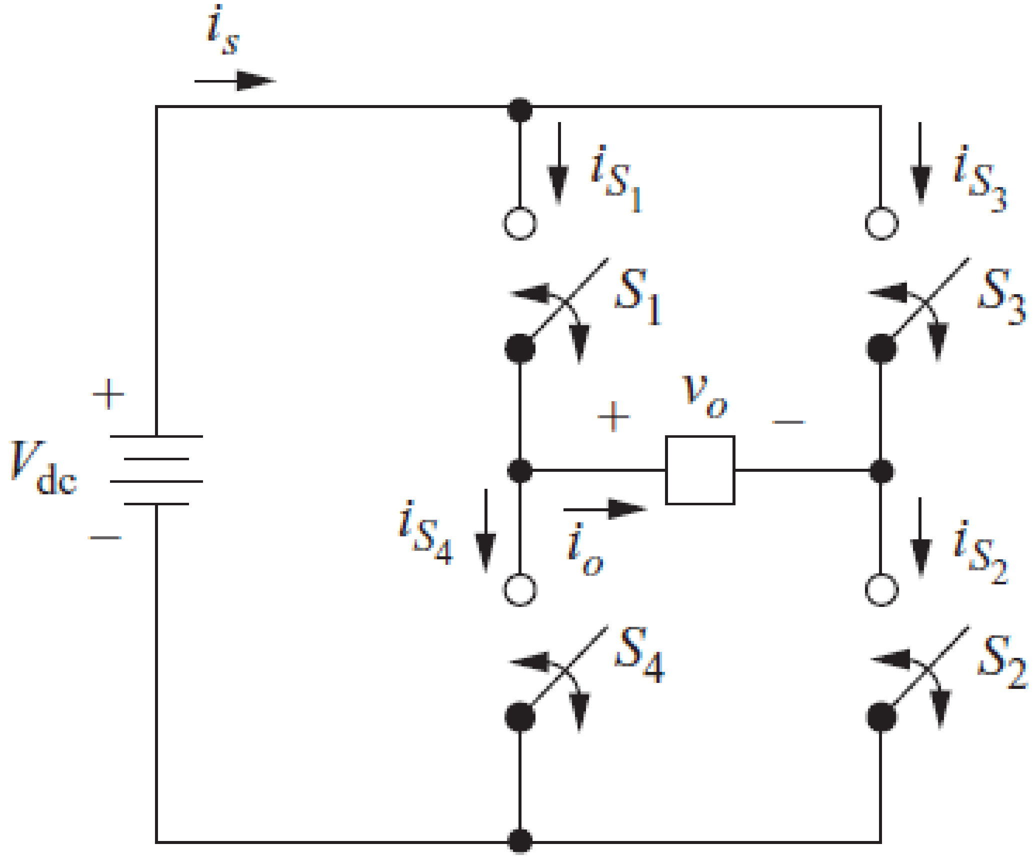
- Phase-Controlled Thyristor Converter **AC-AC, Voltage**
- Rectifier **AC-DC**
- Cycloconverter **AC-AC, Frequency**
- Inverter **DC-AC**
- DC-to-DC Converter **DC-DC**



What is Inverter?

- Converts DC to AC.
- Inverters transfer power from a DC source to an AC load.
- Synthesize a sinusoidal voltage waveform (fundamental component) that has a controlled frequency and magnitude from a dc supply.
- Applications: adjustable-speed ac motor drives, uninterruptable power supplies (UPS), running ac appliances from dc power source such as automobile battery.

Single-Phase Full-Bridge Inverter

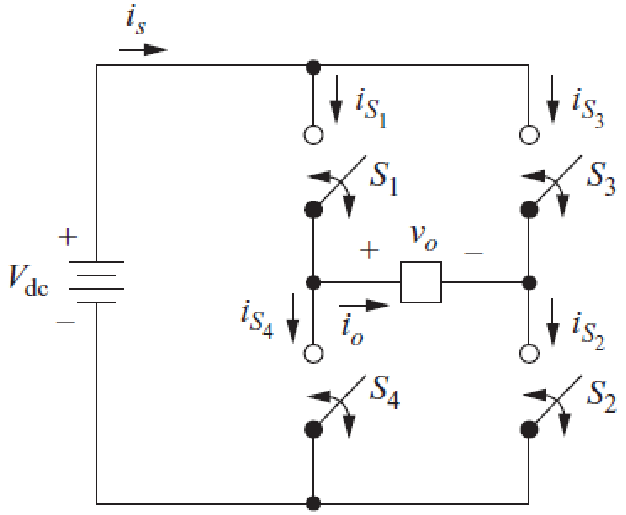


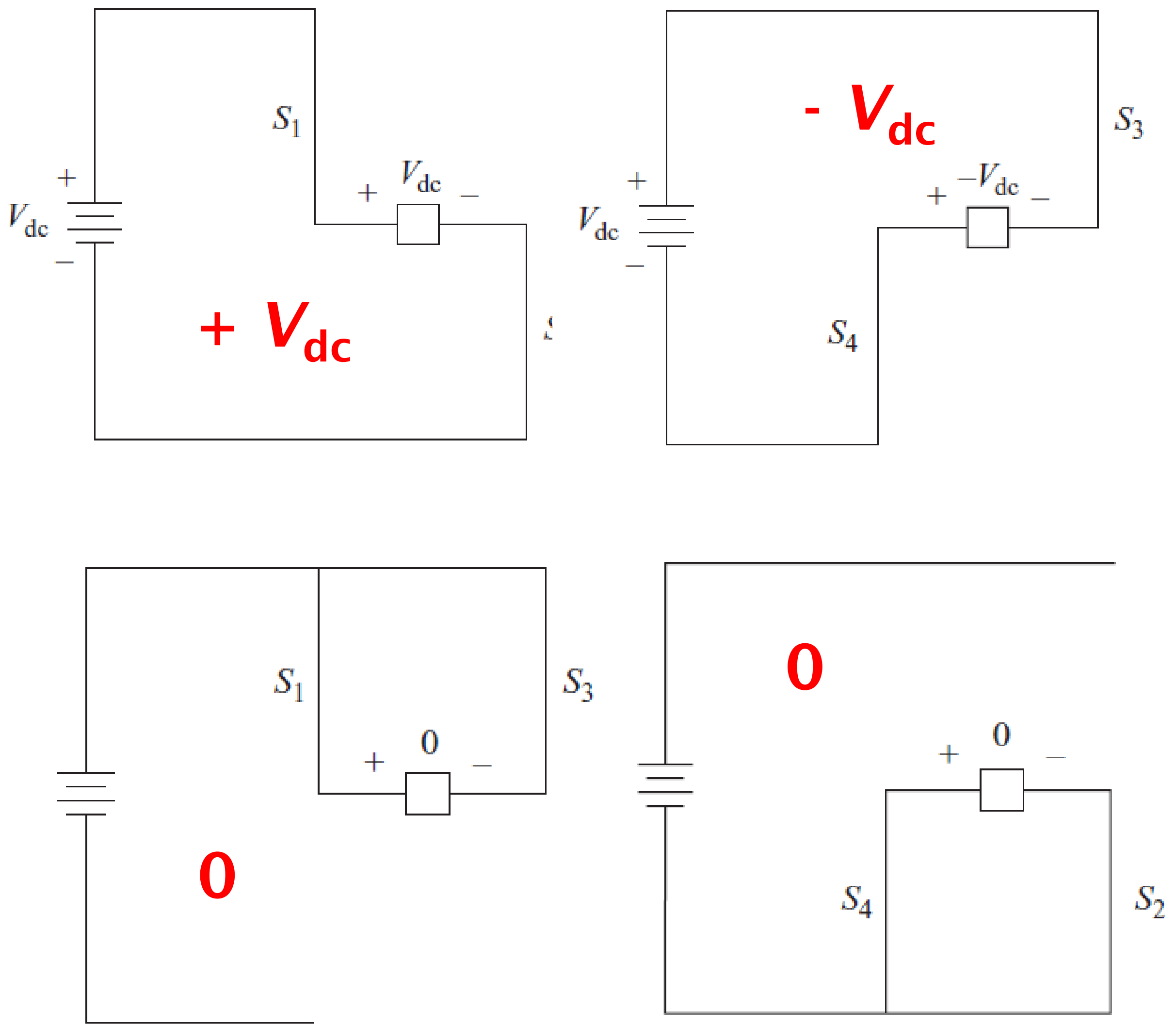
Power switches: MOSFET or IGBT

Only one switch in each leg closed at a time.

Neither S_1 & S_4 nor S_2 & S_3 should be closed at the same to avoid the source short-circuited.

Single-Phase Full-Bridge Inverter - Operation

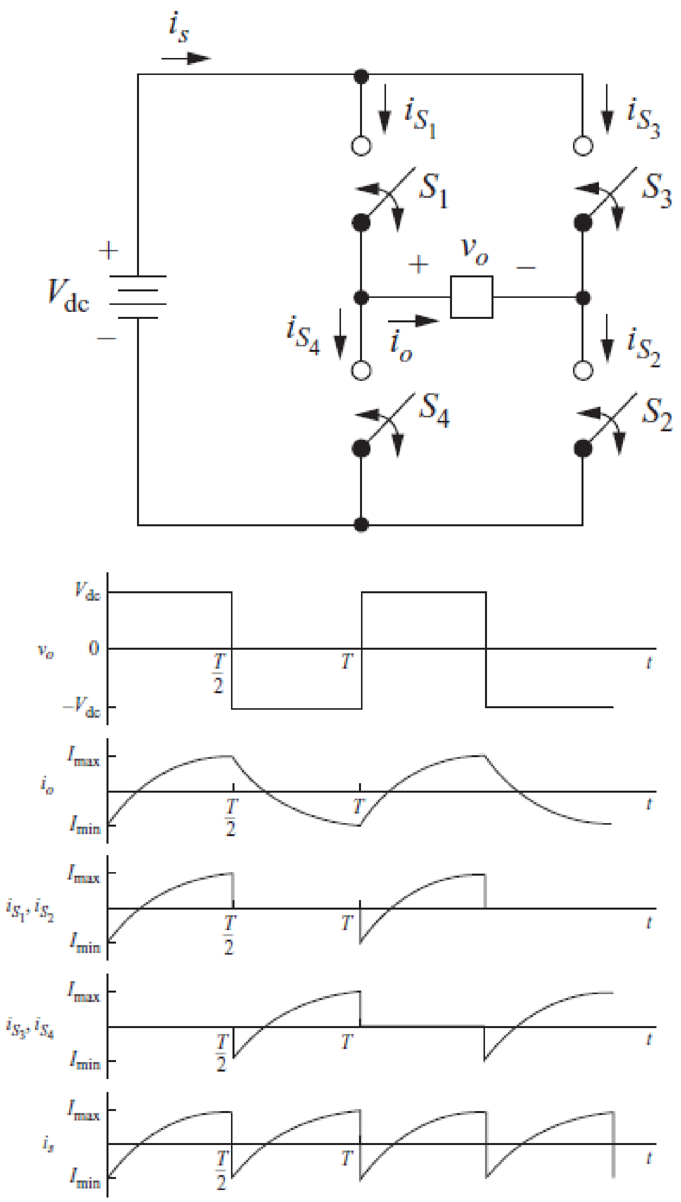




Switches Closed	Output voltage v_o
S_1 & S_2	+ V_{dc}
S_3 & S_4	- V_{dc}
S_1 & S_3	0
S_2 & S_4	0

Square Wave Inverter

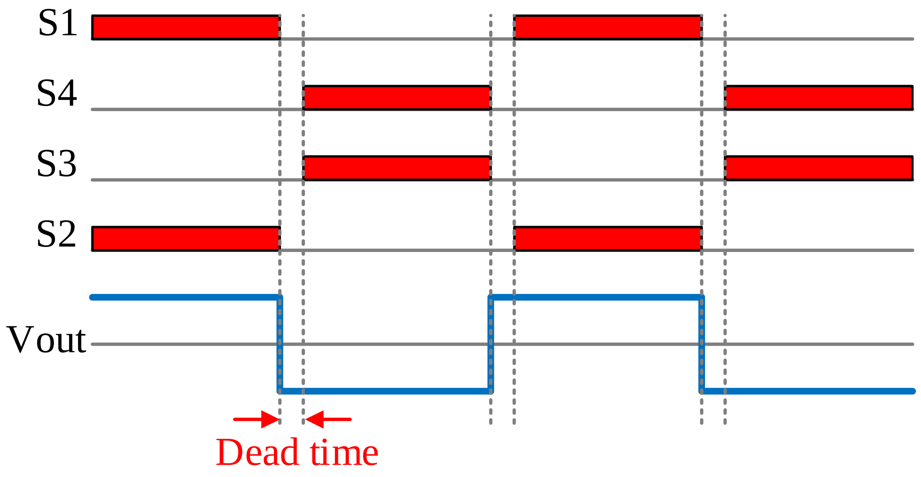
- Simplest switching scheme that produces square wave output voltage.
- The current waveform in the load depends on the load components.
- Resistive load - the current waveform matches the shape of the output voltage.
- Inductive load - current that has more of a sinusoidal quality than the voltage because of the filtering property of the inductance. The switch current is bidirectional.



RL load

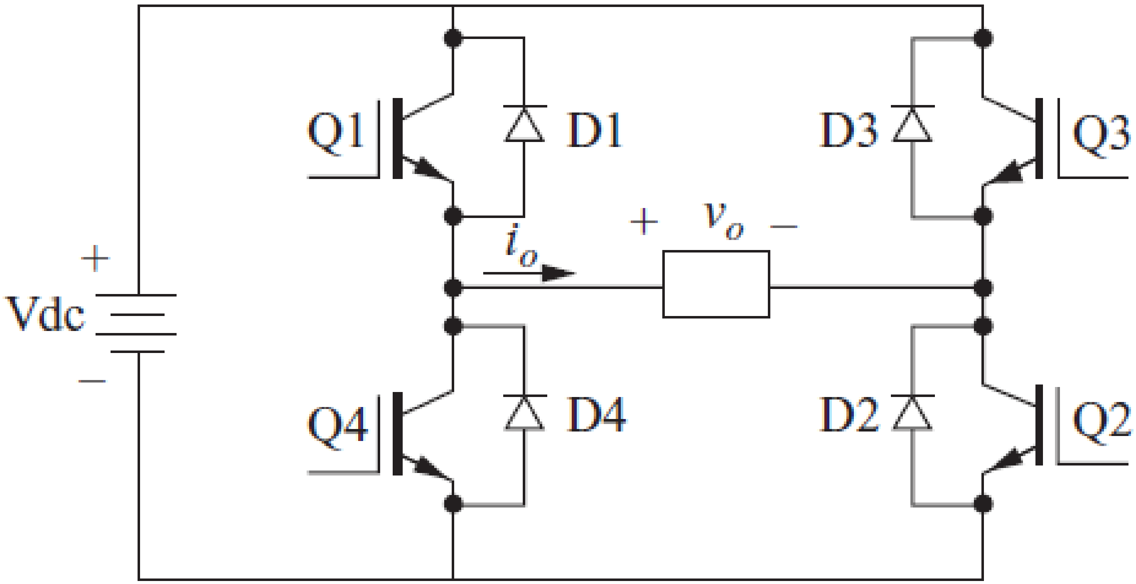
Square Wave Inverter – Dead time

- Real switches do not turn on or off instantaneously.
- Therefore, switching transition times must be accommodated in the control of the switches.
- Overlap of switch “on” times will result in a short circuit, sometimes called a shoot-through fault, across the dc voltage source.
- The time allowed for switching is called blanking time or dead time.

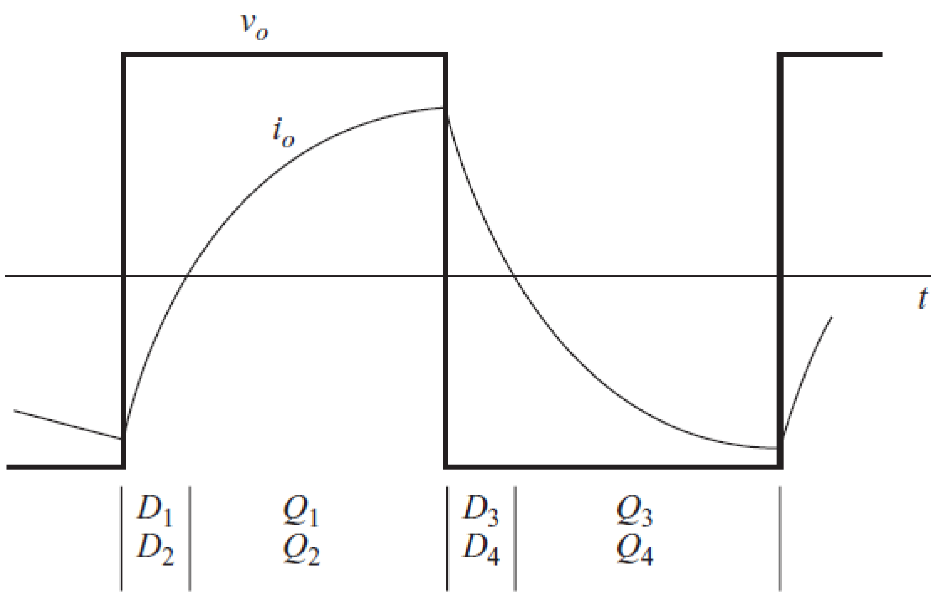


Square Wave Inverter – feedback diodes

For Inductive loads, the switches must be capable of both positive and negative currents.



Inductive *RL* load



Inductive load current freewheels through antiparallel diode of switches.

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Total Harmonic Distortion (THD)

THD expresses the quality of nonsinusoidal wave

Voltage

$$v_o(t) = \sum_{n=1}^{\infty} V_n \sin(n\omega_o t + \theta_n)$$

$$\mathrm{THD} = \frac{\sqrt{\sum_{n=2}^{\infty}\left(V_{n,rms}\right)^2}}{V_{1,rms}} = \frac{\sqrt{V_{rms}^2 - V_{1,rms}^2}}{V_{1,rms}}$$

Current

$$i_o(t) = \sum_{n=1}^{\infty} I_n \sin(n\omega_o t + \phi_n)$$

$$\mathrm{THD} = \frac{\sqrt{\sum_{n=2}^{\infty}\left(I_{n,rms}\right)^2}}{I_{1,rms}} = \frac{\sqrt{I_{rms}^2 - I_{1,rms}^2}}{I_{1,rms}}$$

Pure sinusoidal: THD = 0 %
High THD: More higher-order components

Square Wave Inverter - THD

The output voltage of square wave inverter consists of odd harmonics.

$$v_o(t) = \sum_{n\,\text{odd}} \frac{4V_{\text{dc}}}{n\pi} \sin n\omega_0 t$$

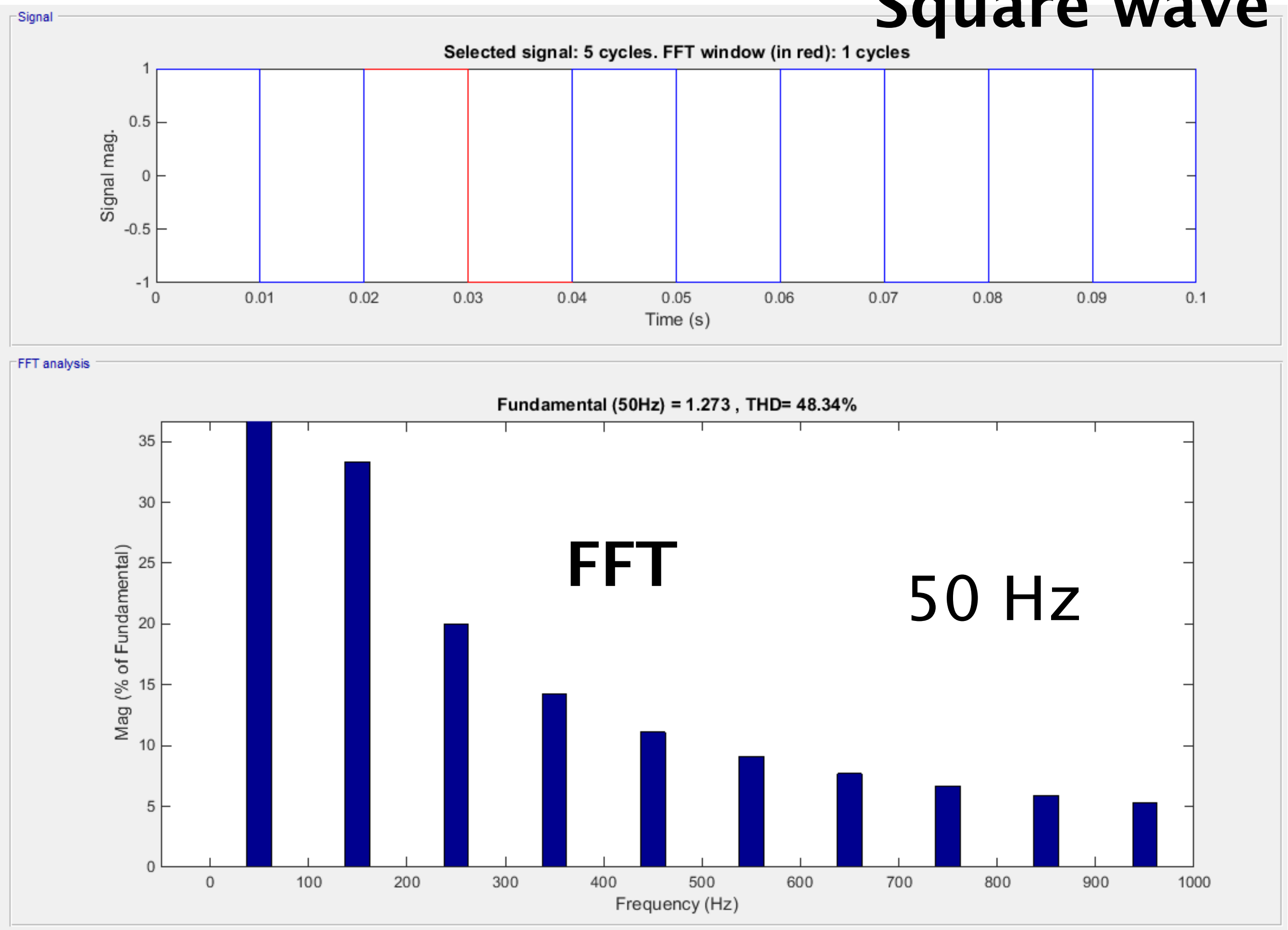
$$V_{rms} = V_{dc} \qquad V_{1,rms} = \frac{4V_{dc}}{\sqrt{2}\pi}$$

Total Harmonic Distortion

$$\text{THD} = \frac{\sqrt{V_{rms}^2 - V_{1,rms}^2}}{V_{1,rms}} = 48.3\%$$

Square wave $\longrightarrow$ High THD

Square wave



Pulse-Width Modulation (PWM)

- PWM provides a way to decrease the total harmonic distortion (THD) of load current.
- A PWM inverter output, with some filtering, can generally meet THD requirements more easily than the square wave switching scheme.
- The amplitude of the output voltage can be controlled with the modulating waveforms.
- Advantages of PWM: (1) decrease harmonics to reduce filter requirements. (2) control of the output voltage amplitude.

Sinusoidal Pulse-Width Modulation (SPWM)

Control of the switches for sinusoidal PWM (SPWM) output requires:

(1) Reference signal, sometimes called a modulating or control signal, which is a sinusoid in this case
(2) Carrier signal, which is a triangular wave that controls the switching frequency.

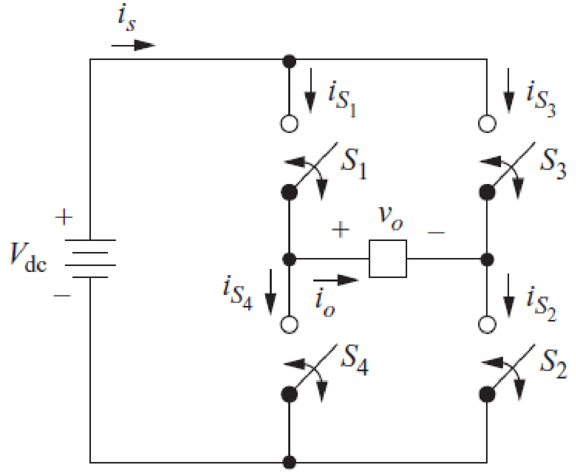
Two types of SPWM switching schemes

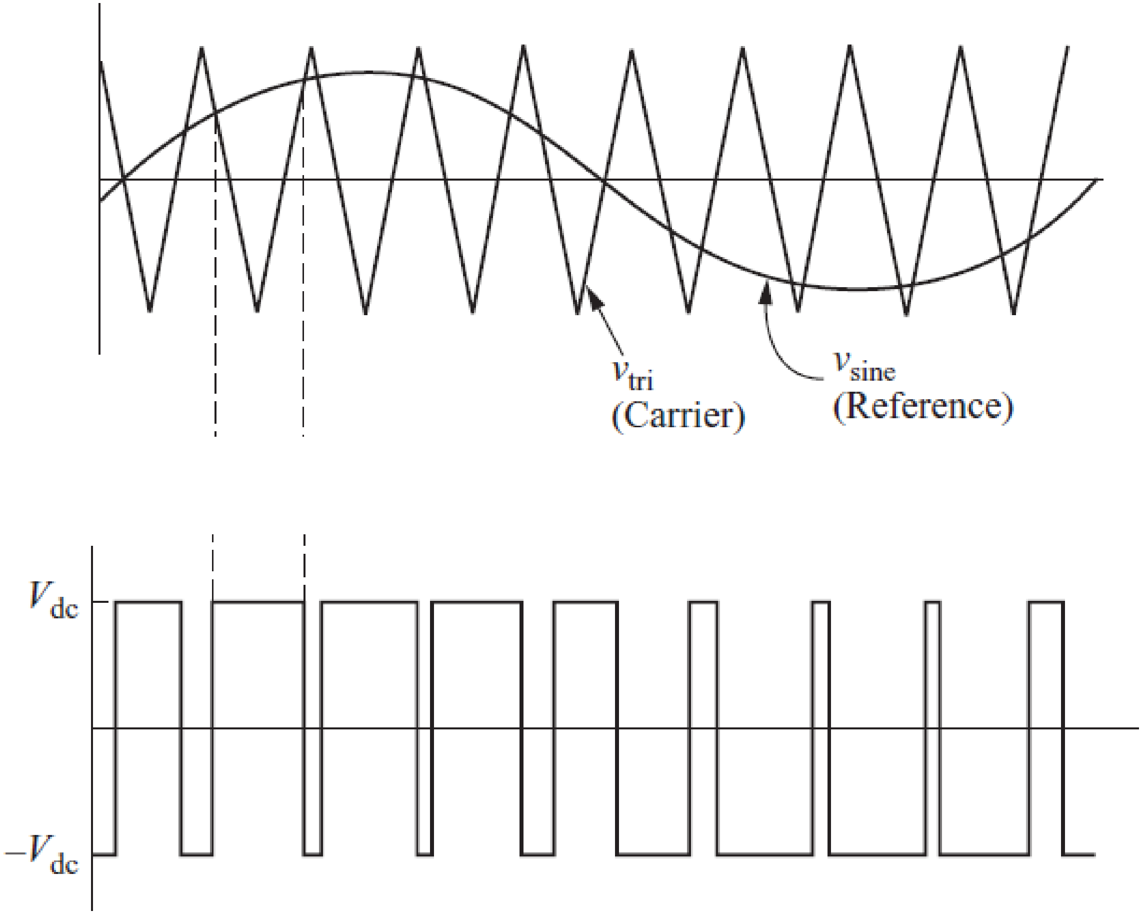
a. Bipolar switching

b. Unipolar switching

SPWM - Bipolar switching

One reference signal and one carrier signal for full-bridge.





S_1 and S_2 are on when $v_{sine} > v_{tri}$

$$(v_o = +V_{dc})$$

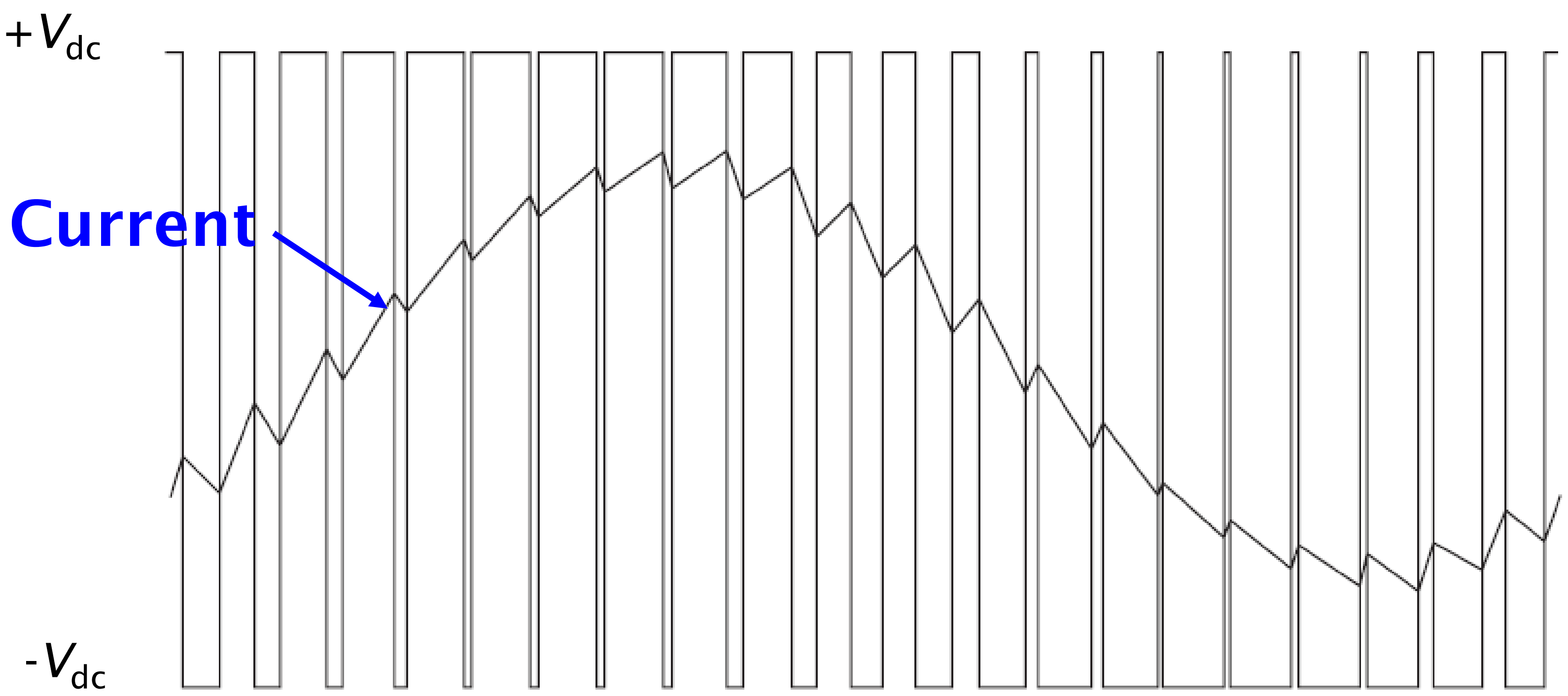
S_3 and S_4 are on when $v_{sine} < v_{tri.}$

$$(v_o = -V_{dc})$$

SPWM - Bipolar switching

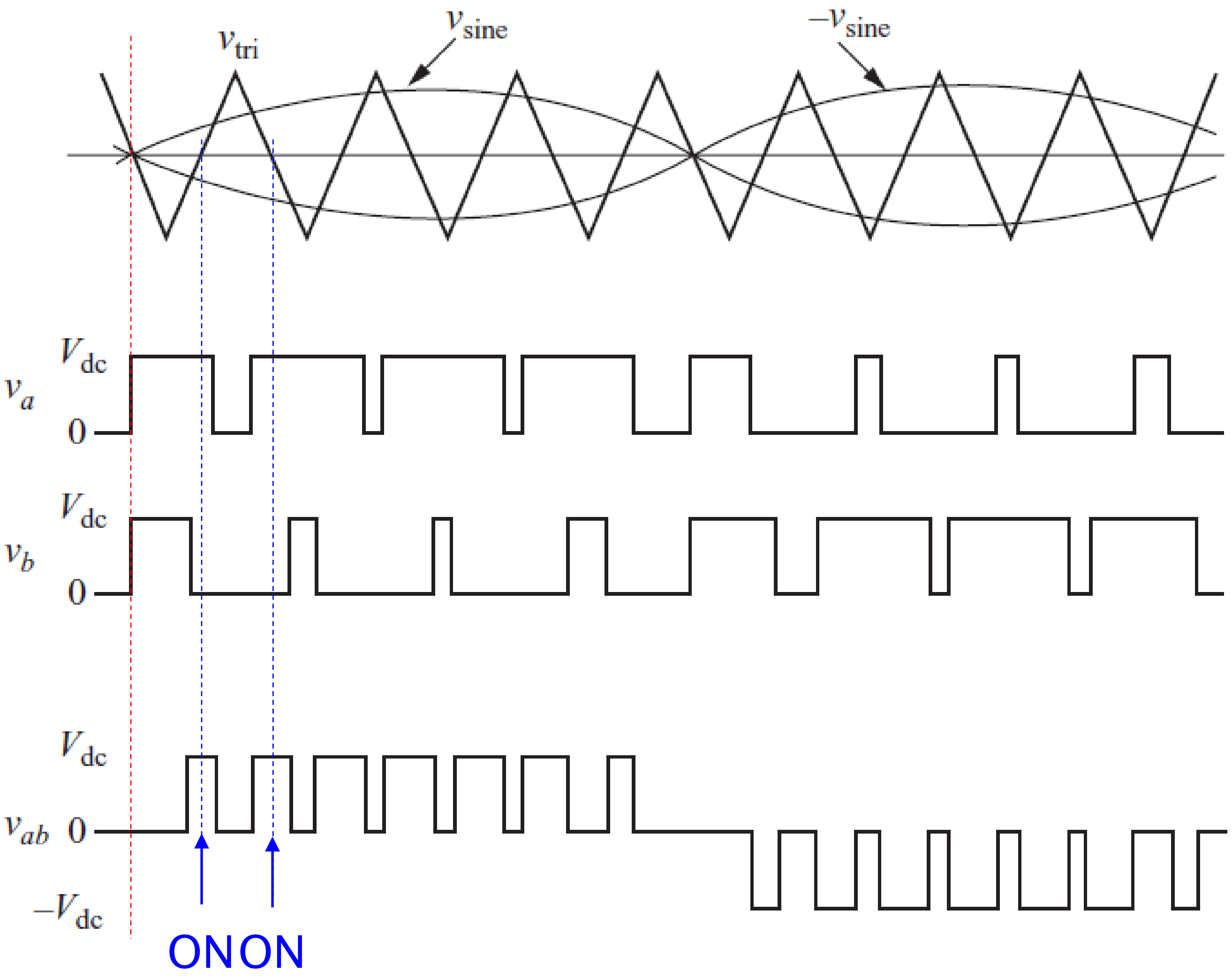
The inductive load current rises and falls linearly with time at a constant rate as the applied voltage is either $+V_{dc}$ or $-V_{dc}$.

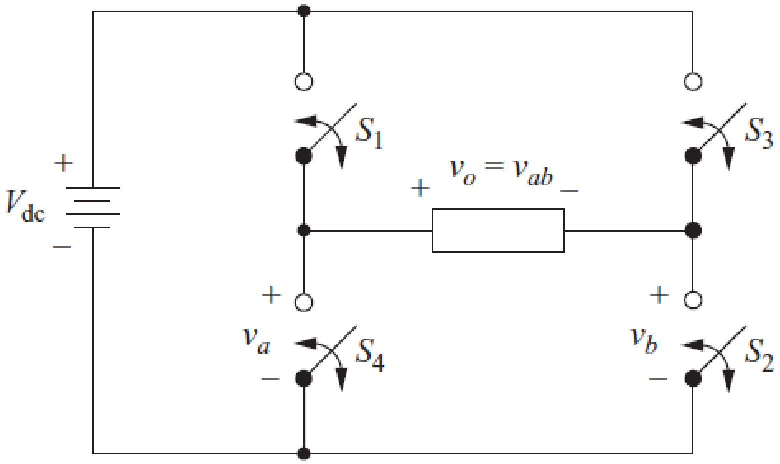
$$di/dt=v_o/L$$



SPWM - Unipolar switching

Two reference signal and one carrier signal.





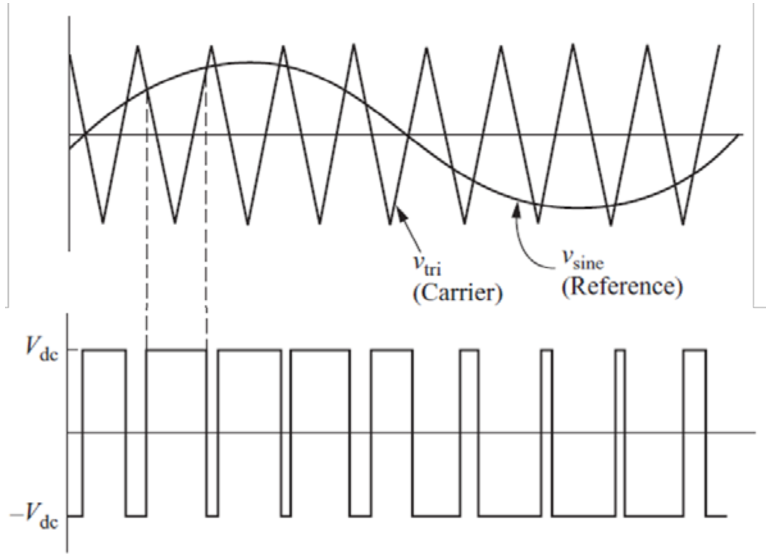
- v_{sine} for controlling S_1 & S_4, and $-v_{sine}$ for controlling S_2 & S_3.

S_1 is on when $v_{sine} > v_{tri}$
S_4 is on when $v_{sine} < v_{tri}$
S_3 is on when $-v_{sine} > v_{tri}$
S_2 is on when $-v_{sine} < v_{tri}$

PWM – Modulation ratio

Frequency modulation ratio m_f

$$m_f = \frac{f_{\text{carrier}}}{f_{\text{reference}}} = \frac{f_{\text{tri}}}{f_{\text{sine}}}$$



Increasing m_f increases the frequencies at which the harmonics occur.

→ A simple low-pass filter is enough to remove, but switching losses are high.

Amplitude modulation ratio m_a

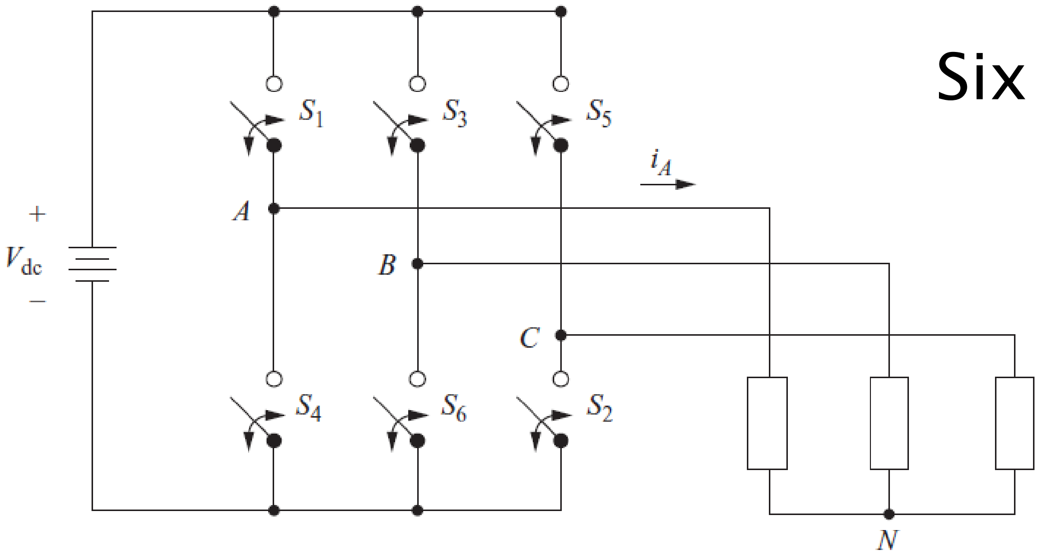
$$m_a = \frac{V_{m,\text{reference}}}{V_{m,\text{carrier}}} = \frac{V_{m,\text{sine}}}{V_{m,\text{tri}}}$$

If $m_a \leq 1$ $\quad V_1 = m_a V_{\text{dc}}$

The amplitude of the fundamental component is thus controlled by m_a.

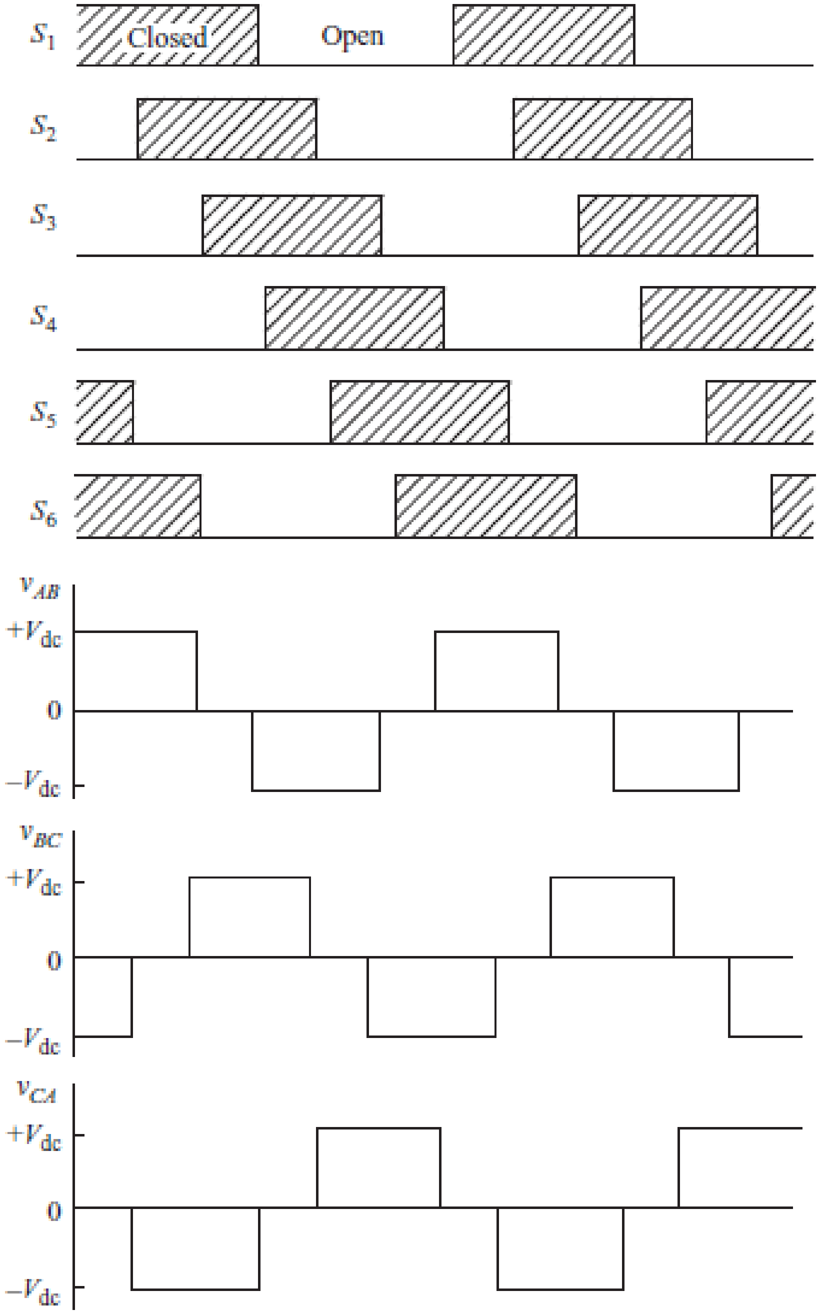
→
- Good to compensate unregulated dc supply voltage.
- m_a can be varied to change the amplitude of the output.

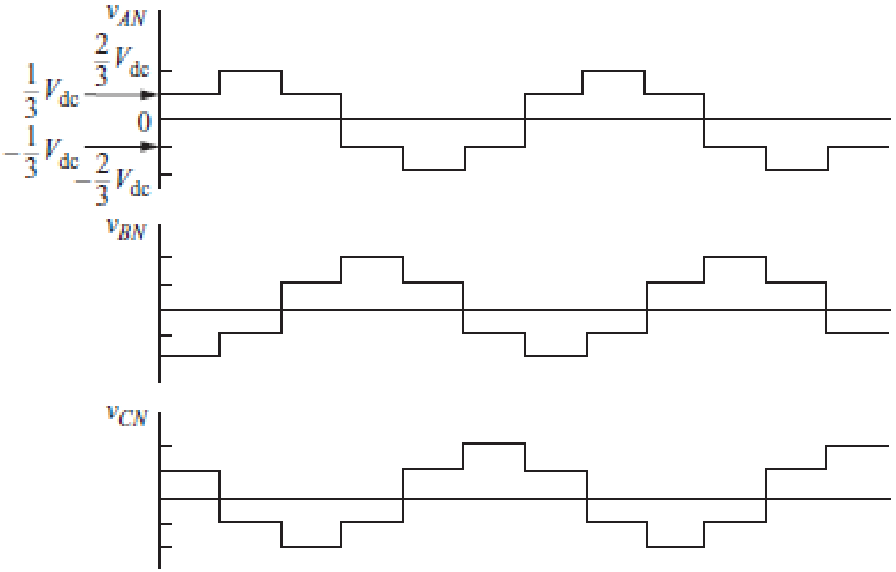
Three-phase Inverter



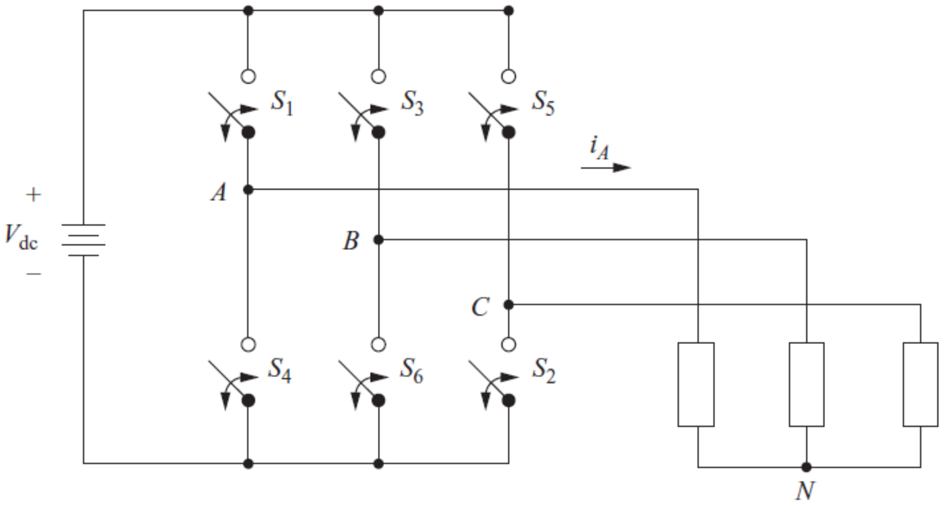
Six step operation

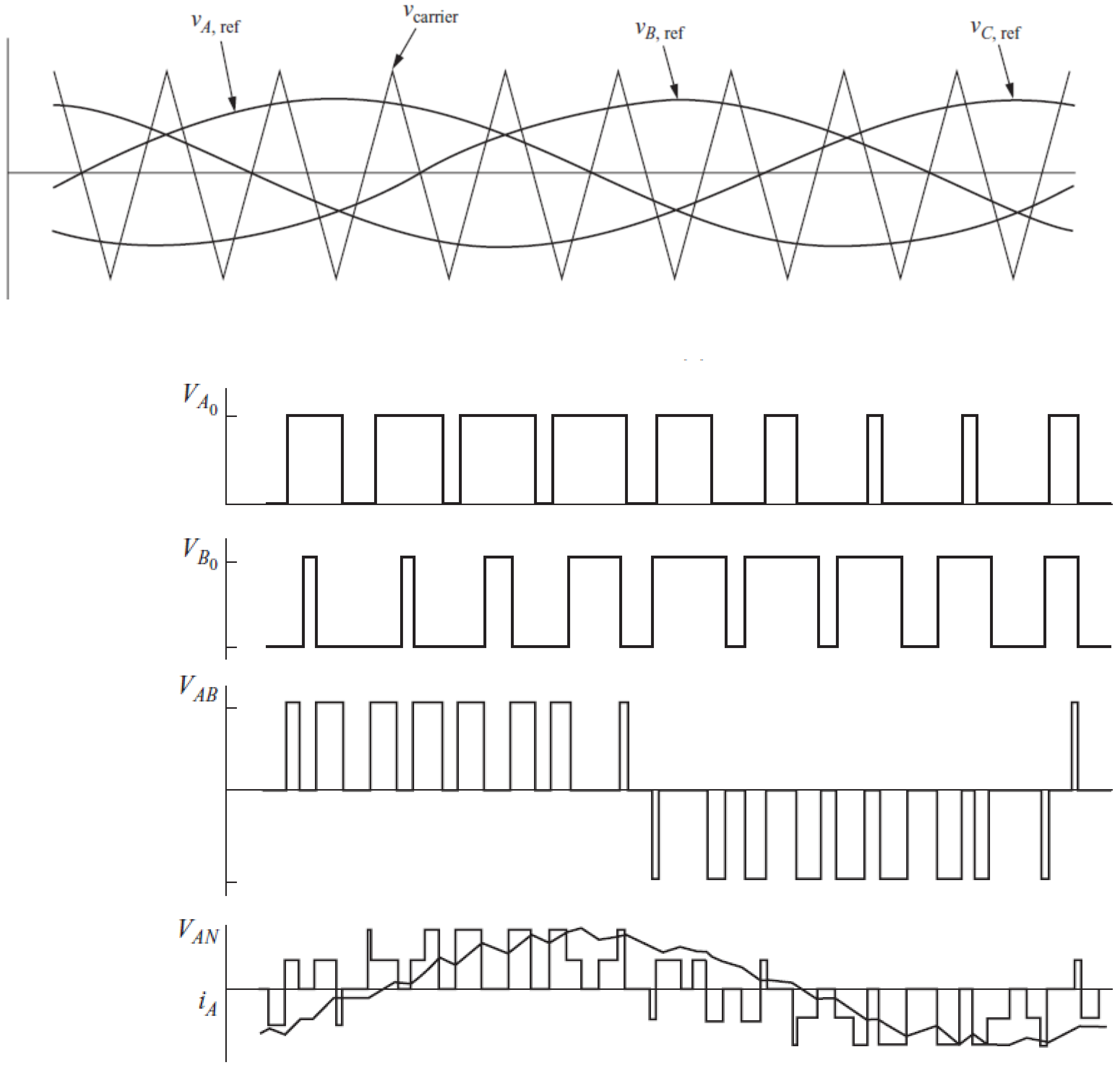
Each switch has a duty ratio of 50%.





Three-phase SPWM





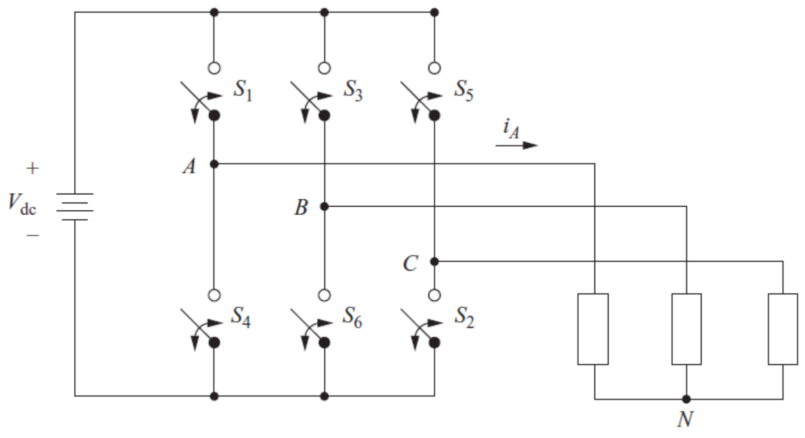
S_1 is on when $v_a > v_{tri}$
S_4 is on when $v_a < v_{tri}$
S_3 is on when $v_b > v_{tri}$
S_6 is on when $v_b < v_{tri}$
S_5 is on when $v_c > v_{tri}$
S_2 is on when $v_c < v_{tri}$

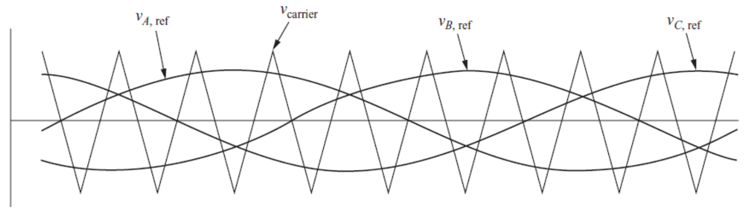
Three-phase SPWM

- Each switch is controlled by comparing a sinusoidal reference wave with a triangular carrier wave.

- The three reference sinusoids are 120 apart to produce a balanced three-phase output.

- The fundamental frequency of the output is the same as that of the reference wave, and the amplitude of the output is determined by the modulation index, m_a.





Summary - Inverter

- Inverters convert a DC voltage supply to an AC voltage.

- Single-Phase Full-Bridge Inverter consists of 4 power switches to generate square waveform.

- Pulse-width modulation (PWM) can decrease the total harmonic distortion (THD) of load current.

- Three phase Inverter consists of 6 power switches to convert DC to three phase AC power.