What we have studied so far

With Prof Lianping Hou

- Electric Circuits
- Power Switches
- Uncontrolled and Controllable Switches
- Heatsinks

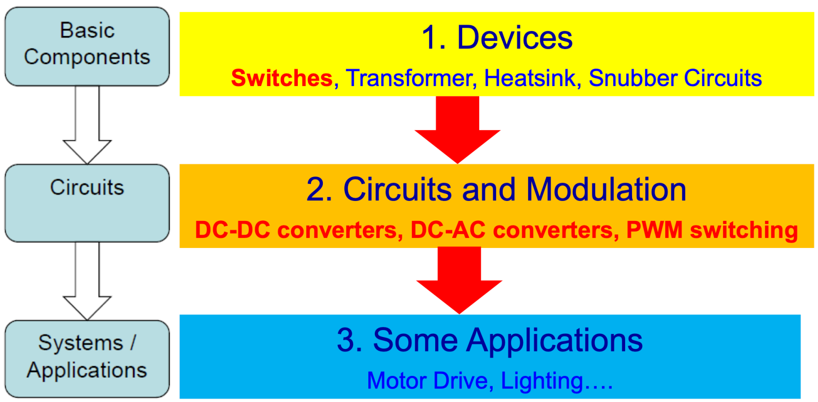
Since Week-8

- Snubber Circuits
- Switched Mode Power Supplies (DC converters)

To do

- DC-AC converters (Inverters)
- PWM Inverters
- Applications and Systems
- Revision

Course Structure



Today's Lecture

- Quiz on SMPS
- Q&A on SMPS
- DC-AC Inverter

Power Electronics

DC-AC Converters (Inverters)

逆变器

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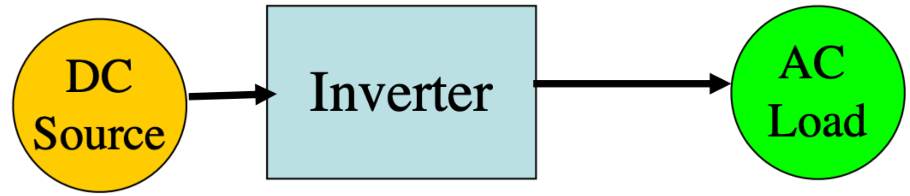
Please read Chapter 8 in the textbook

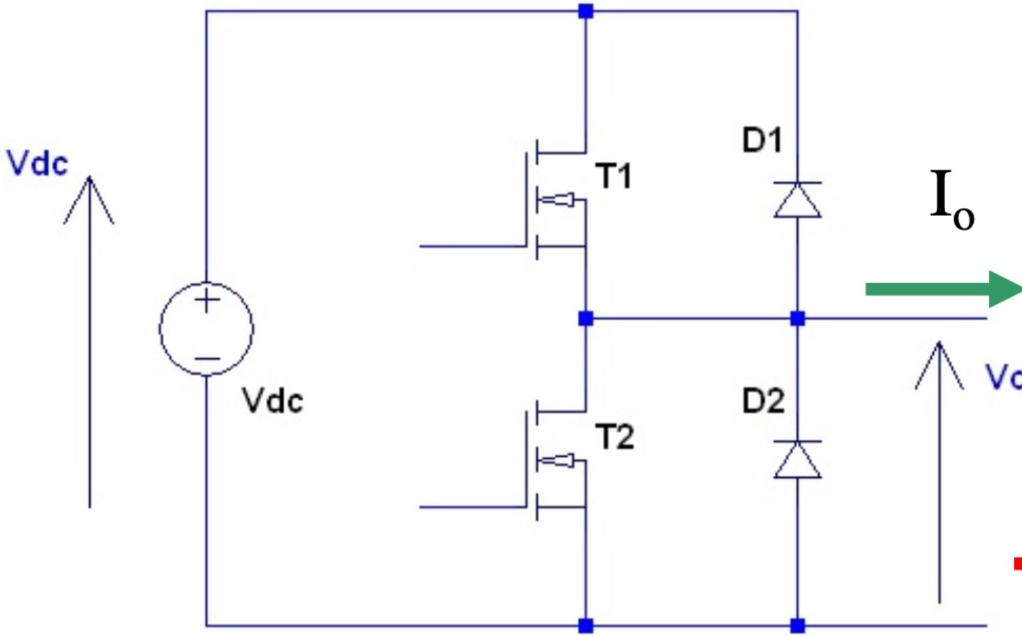
Fundamentals



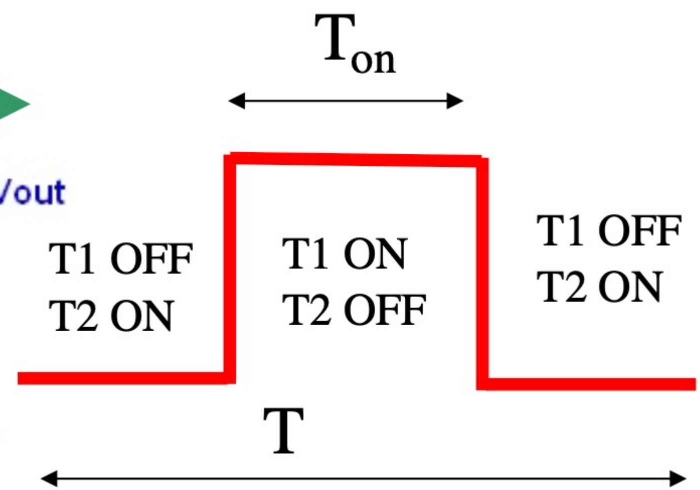
- DC-AC Converters are known as inverters
- Role is to convert a DC signal to AC
- Ideally, output should be sinusoidal.
- In reality, they are non-sinusoidal and contain harmonics
- This is fine for low and medium power applications
- Divided into two main types
  - Single Phase
  - Three Phase
- Semiconductor devices typically used
- The basic building block is the two ‘Bridge’ circuit

https://www.youtube.com/watch?v=qVeERT4nyz8

Bridge Circuit



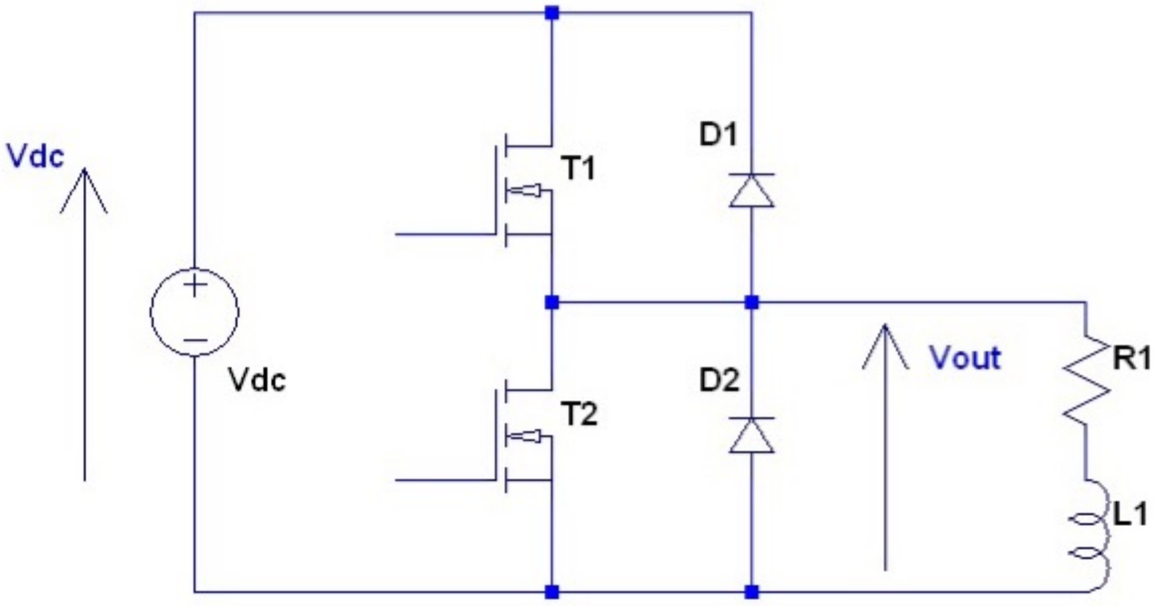
$$V_{out} = V_{dc}\frac{t_{1,on}}{T_s}$$



I_0>0 T1 and D2 are active

I_o< 0 D1 and T2 are active

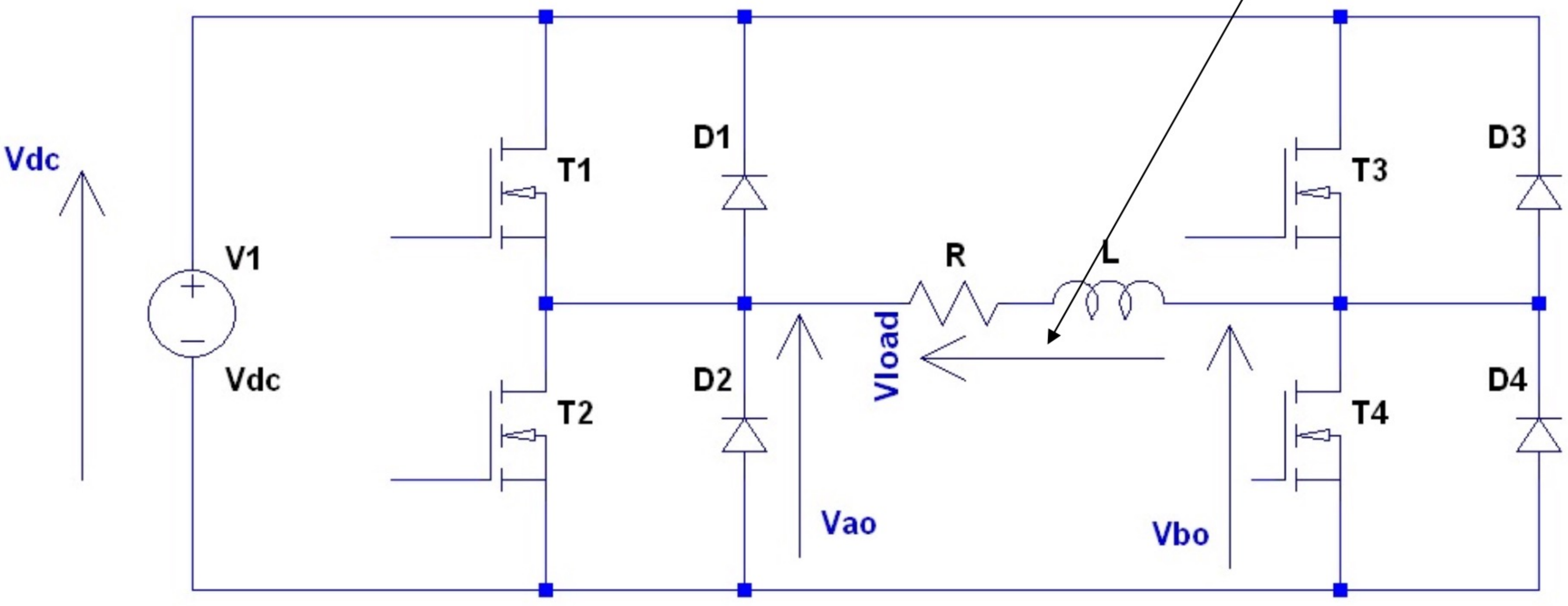
Current Flow



Single-phase H-bridge

- Two inverter legs connected in parallel.
- Bi-directional load voltage and current.

$$V_{load} = V_a - V_b$$

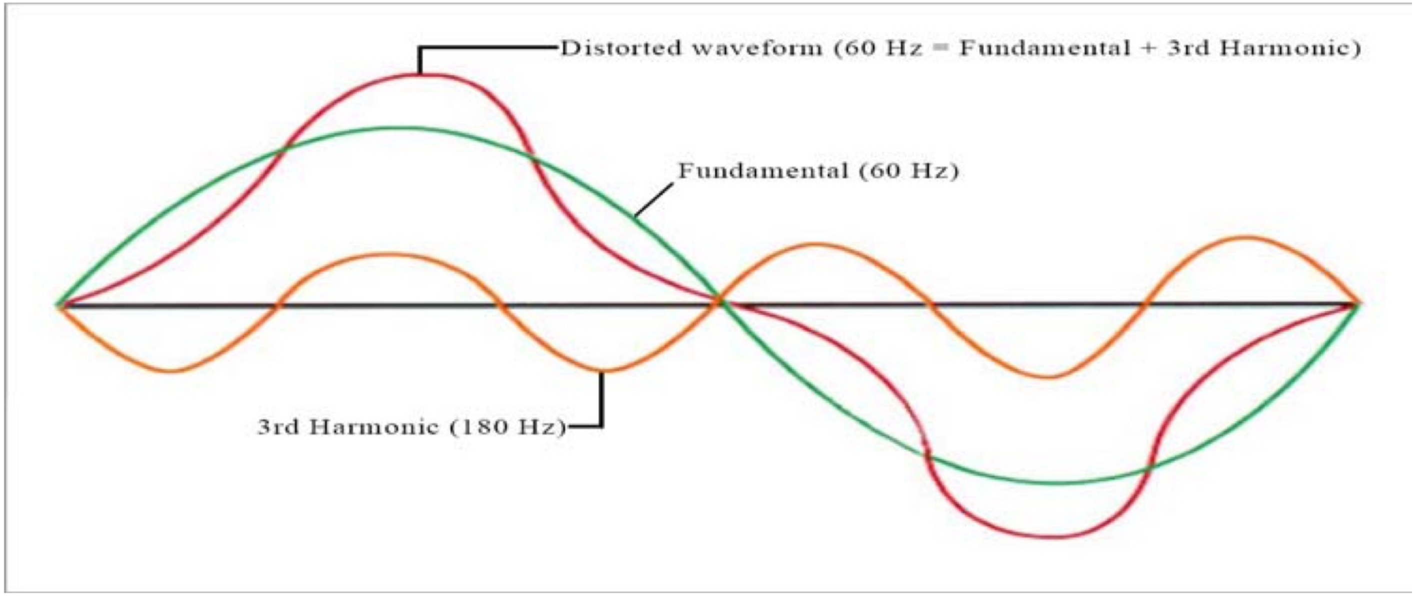


- For low- and medium-power applications, square-wave or quasi- square-wave voltages may be acceptable; and for high-power applications, low distorted sinusoidal waveforms are required.

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

What are Harmonics?

Harmonics are the result of nonlinear loads that convert AC line voltage to DC. Harmonics flow into the electrical system because of nonlinear electronic switching devices, such as variable frequency drives (VFDs), computer power supplies and energy-efficient lighting.

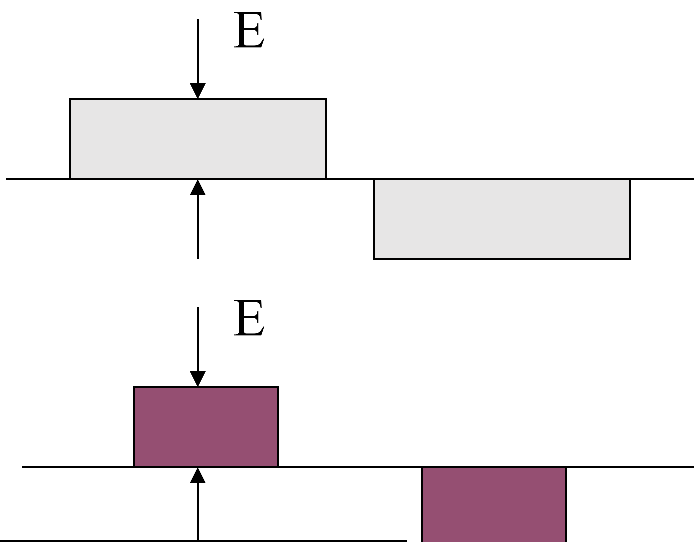


Inverter Control Techniques

- 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

Quasi-Square

E = fixed dc input voltage to inverter



High AC voltage (r.m.s.)

Low AC voltage (r.m.s.)

Significant Low Frequency Harmonic Content !!

Voltage control by varying width of +/- pulse

Notching

Can be used for voltage control !

Still has harmonic issues

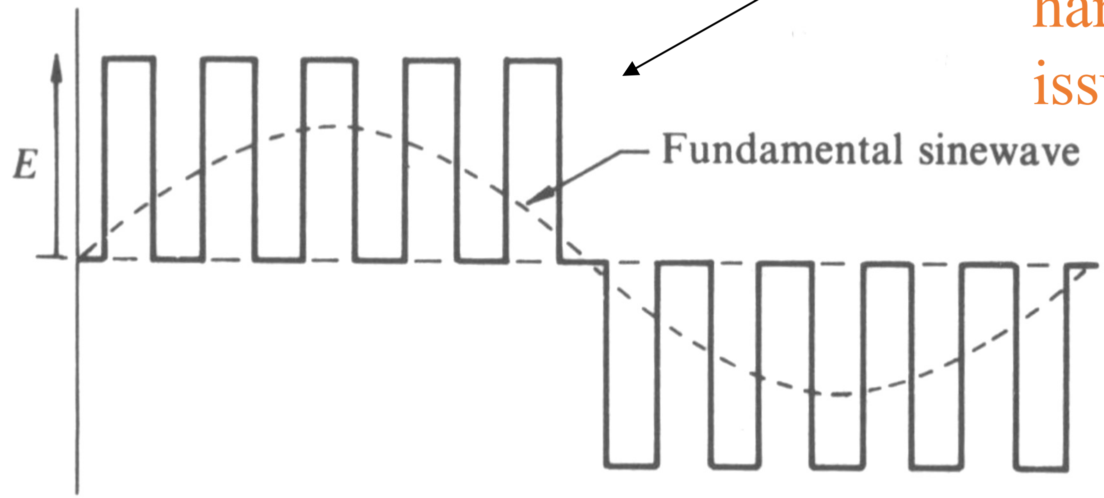


Figure 5-22 Inverter controlled to give notched waveform.

PWM

Minimise Harmonics

Voltage and Frequency Control

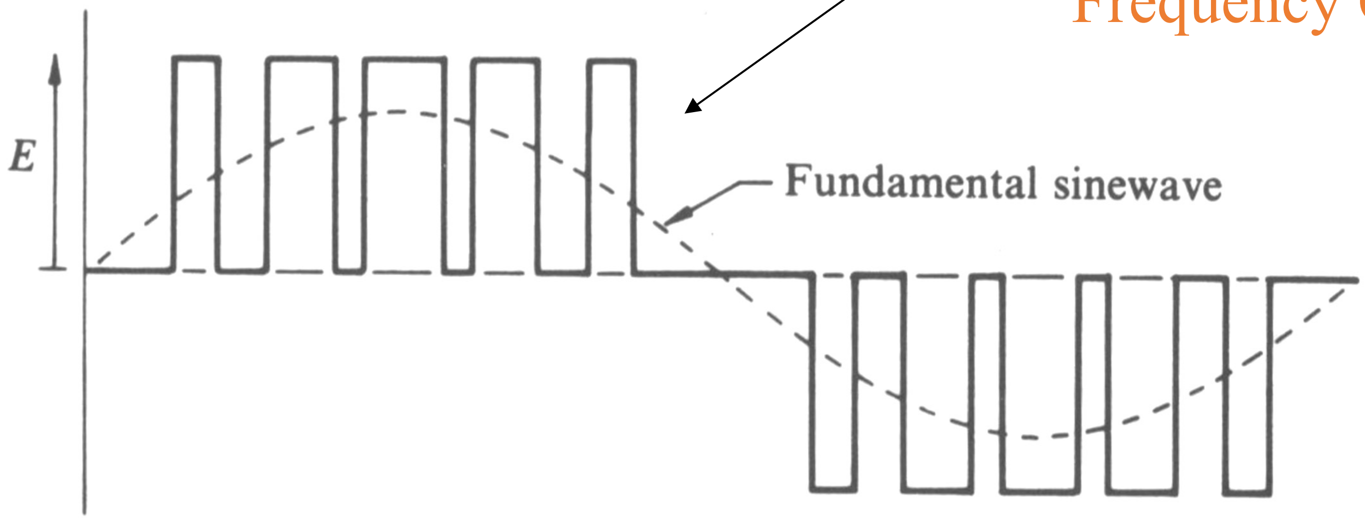


Figure 5-23 Inverter controlled to give pulse-width-modulated waveform.

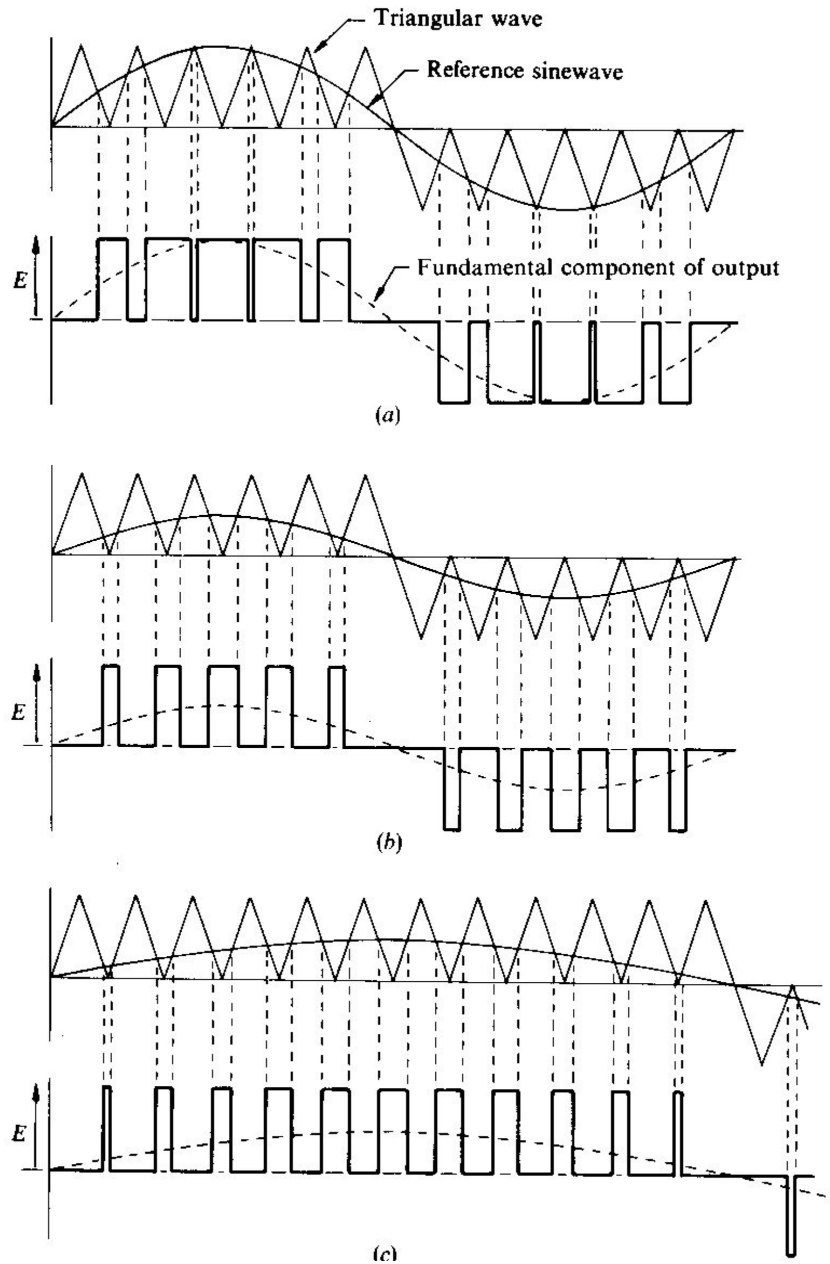
Application of PWM

Reduce
Voltage

Frequency
Unchanged

Voltage
Unchanged

Reduce
Frequency



Covered in more detail in next lectures

Single Phase AC Output

Basic AC Waveform Generation

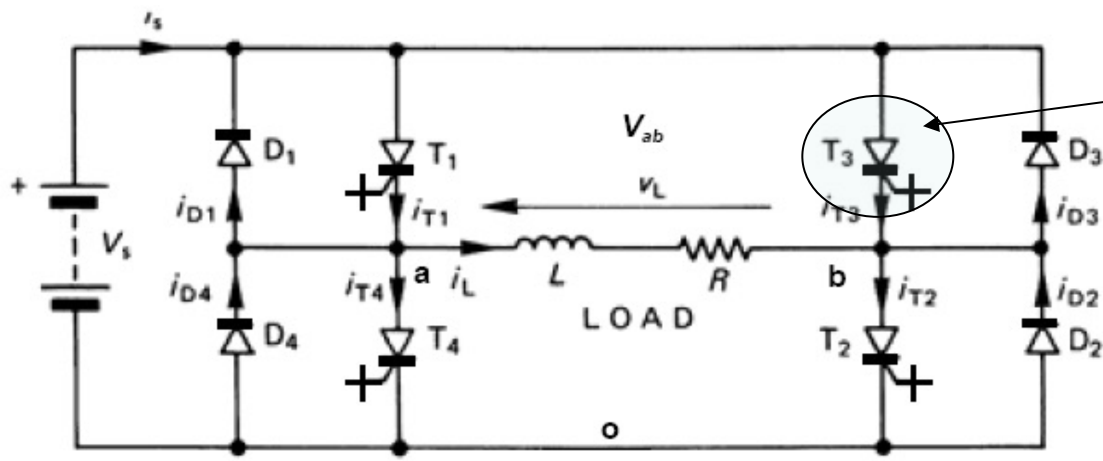
A simple AC waveform may be generated by switching the bridge legs at the fundamental frequency.

The converter gives square wave output at the desired power frequency.

The maximum output corresponds to a $-V_{dc}$ to $+V_{dc}$ square-wave.

It is possible to vary the magnitude of the fundamental component of the AC output by introducing zero output voltage regions where $V_a=V_b$

Single Phase H-Bridge **Inverter**

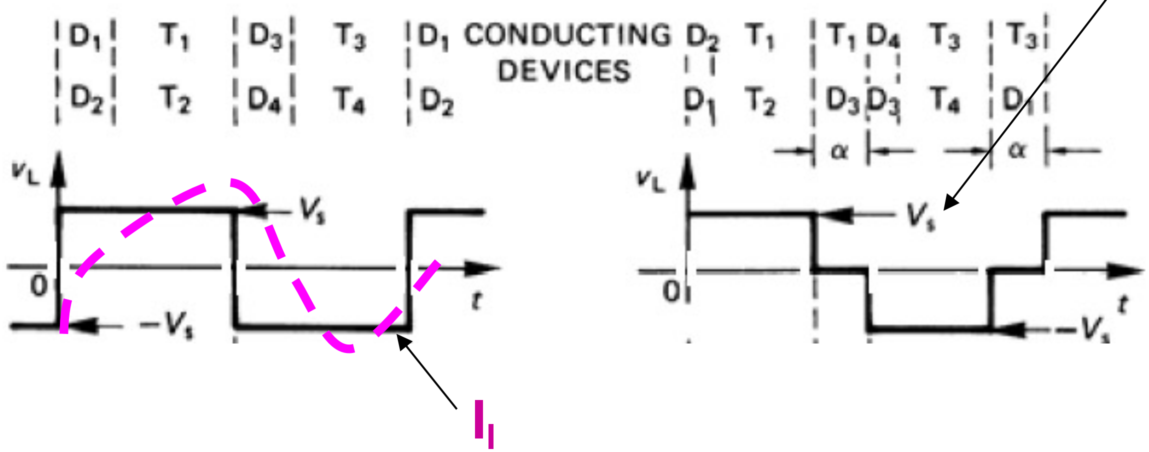


GTO switch

(a)

Fundamental frequency switching

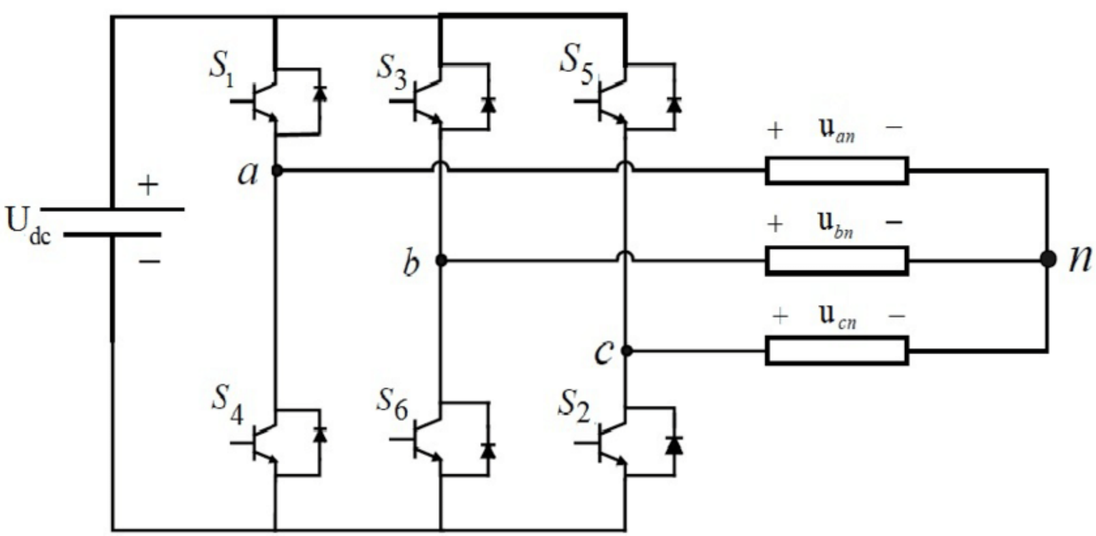
Magnitude of Fundamental can be controlled



Load Voltage

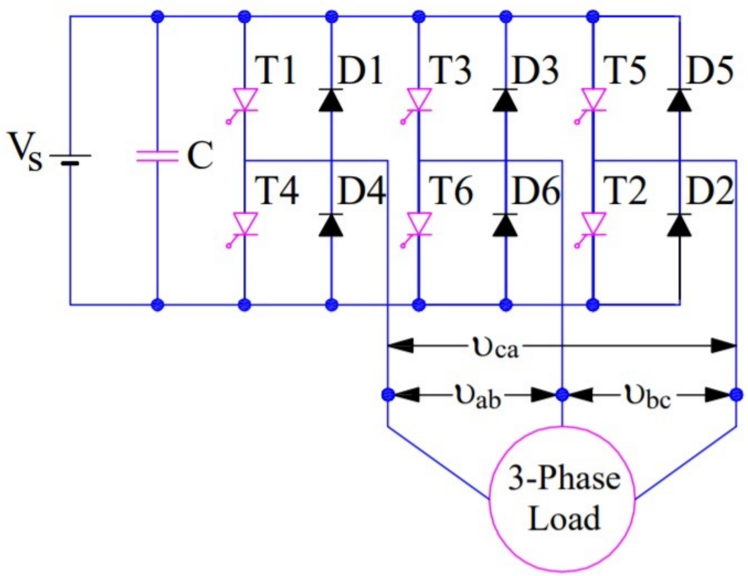
Three Phase Output

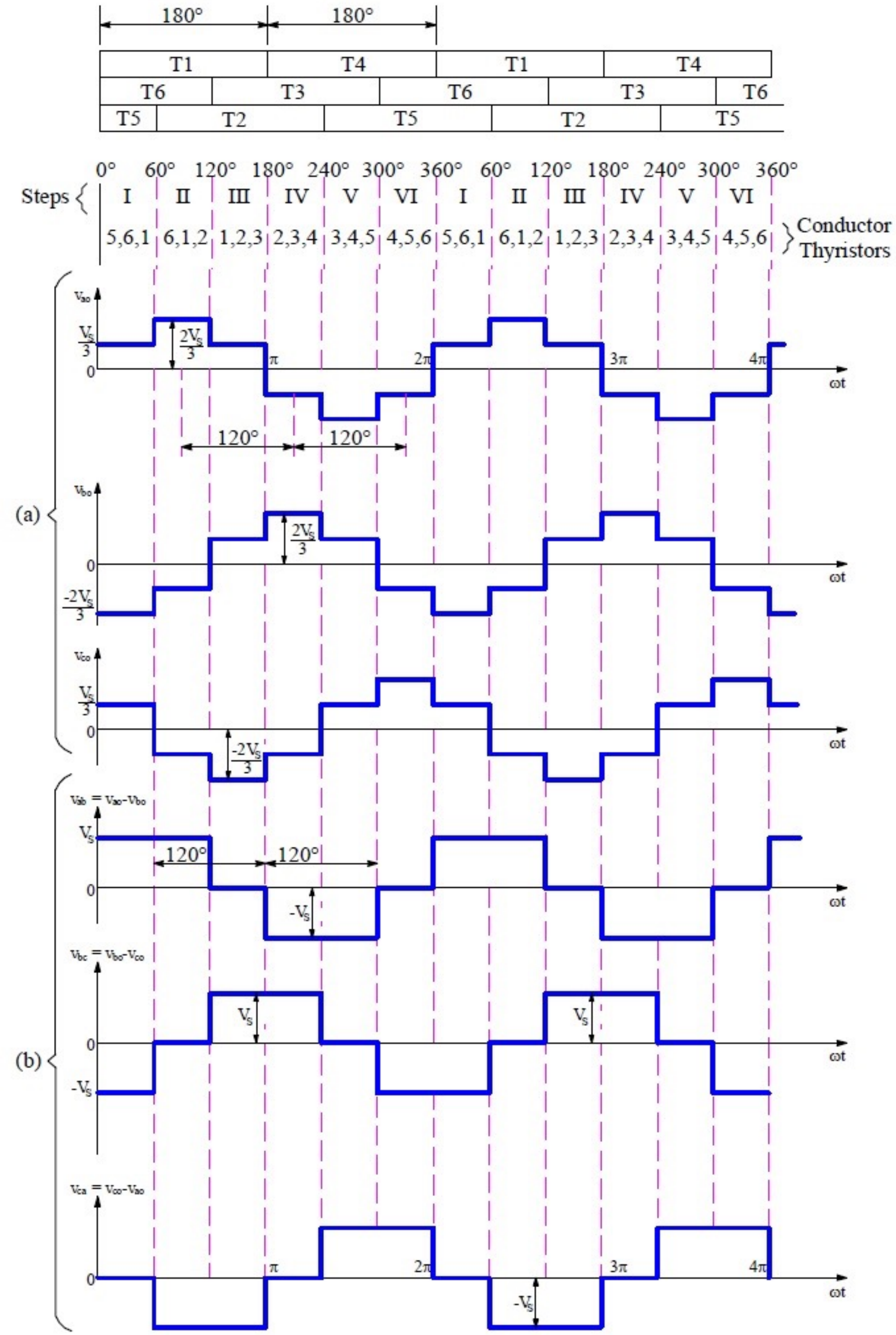
Three Phase Inverters



Three bridge leg circuits can be modulated with a 120deg phase shift

Simple fundamental frequency switching exhibits three phases


V_S
C
T1
D1
T3
D3
T5
D5
T4
D4
T6
D6
T2
D2
υca
υab
υbc
3-Phase Load


180°
180°
T1
T4
T1
T4
T6
T3
T6
T3
T6
T5
T2
T5
T2
T5
Steps
0° 60° 120° 180° 240° 300° 360° 60° 120° 180° 240° 300° 360°
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)
Vao
Vs/3
2Vs/3
0
π
2π
3π
4π
ωt
120°
120°
Vbo
-2Vs/3
Vco
Vab = Vao-Vbo
Vs
-Vs
Vbc = Vbo-Vco
Vca = Vco-Vao

Six-step Line Voltages

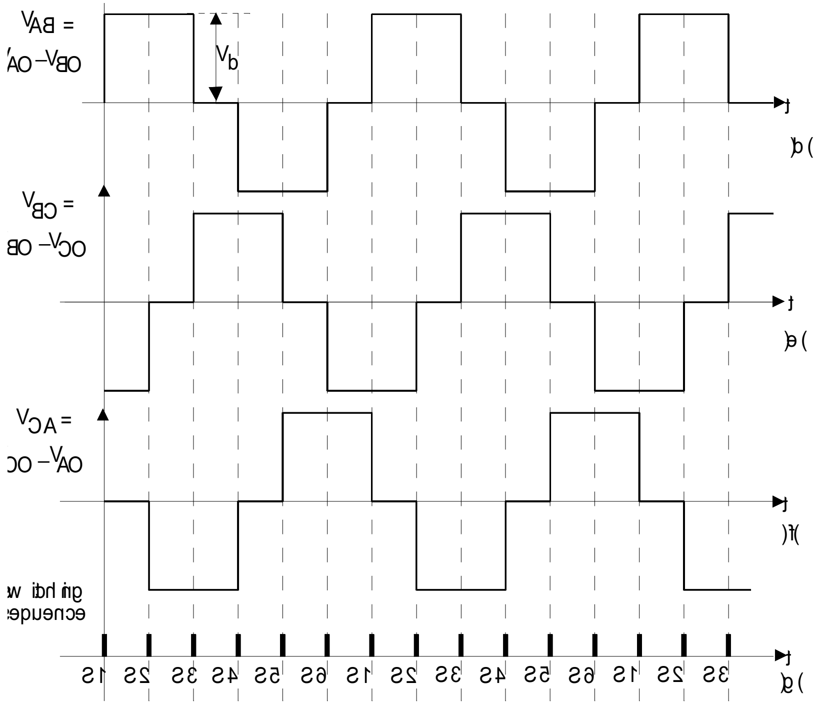
Line Voltage

- Line voltages are stepped
- Fourier analysis of output voltages gives

$$V_{AO} = \frac{4}{\pi}.\frac{V_d}{2}\left[\sin\omega t + \frac{1}{3}\sin 3\omega t + \frac{1}{5}\sin 5\omega t + ...\right]$$

- and line voltages

$$V_{AB} = \frac{2\sqrt{3}}{\pi}V_d\left[\sin\omega t + \frac{1}{5}\sin 5\omega t - \frac{1}{7}\sin 7\omega t + \frac{1}{11}\sin 11\omega t + ...\right]$$



Six-step Inverter Currents

- Inverter currents are obviously non-sinusoidal. (Note: this load is inductive)
- Result from the harmonic voltages in the output line voltage.
- Harmonic currents causes additional loss components.
- And also torque ripple if the load is a machine.