Electronics and
Computer Science

ELEC2208 Power Electronics and Drives

Rectifier (1)

- Single Phase Rectifier -

Yoshi Tsuchiya
Smart Electronic Materials and Systems (SEMS) Group
yt2@ecs.soton.ac.uk
59/4219

Smart Electronic Materials and Systems

University of Southampton

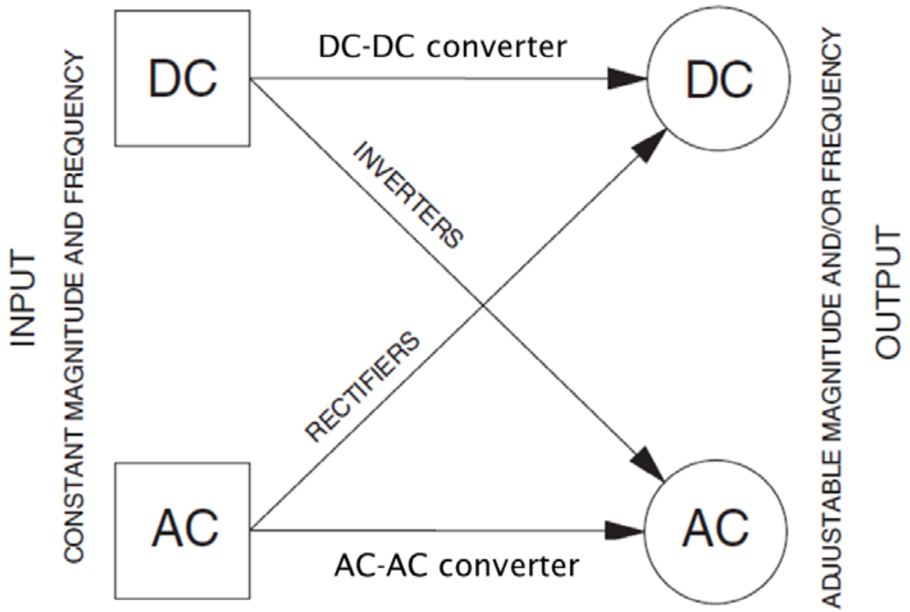
Classification

- Phase-Controlled Thyristor Converter

  AC-AC, Voltage

- Rectifier **AC-DC**

- Cycloconverter **AC-AC, Frequency**
- Inverter **DC-AC**
- DC-to-DC Converter **DC-DC**



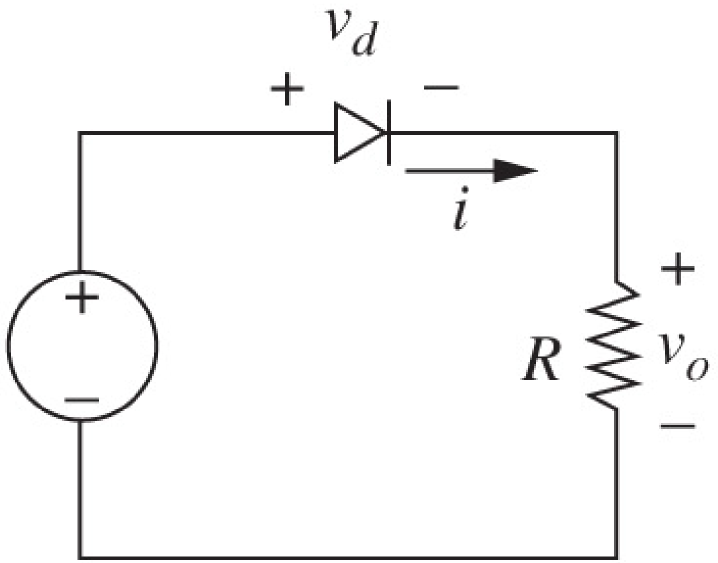
Rectifier - Classification

Rectifier converts AC voltage to DC voltage

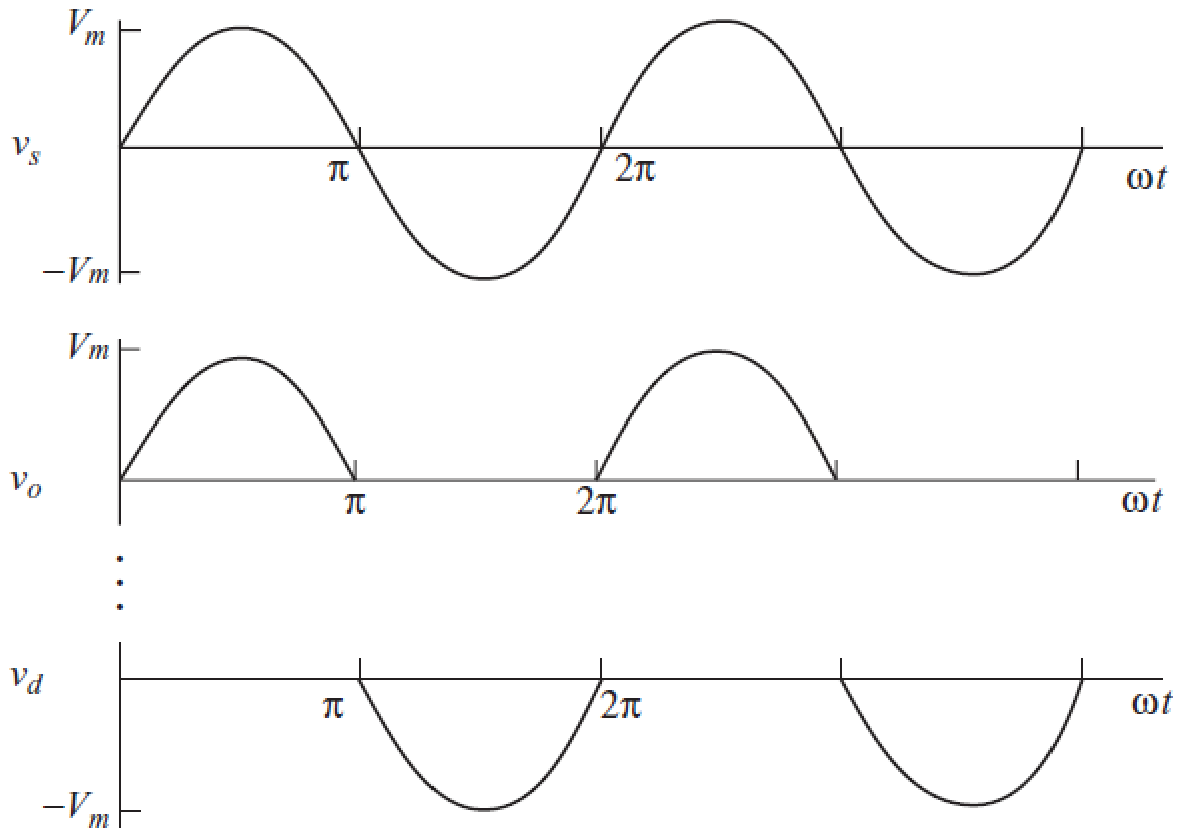
Functionality
- Half wave rectifier
- Full wave rectifier

Rectifier
- Single phase
  - Uncontrolled with diodes
  - Controlled with thyristors
- Three phase
  - Uncontrolled with diodes
  - Controlled with thyristors

Half wave rectifier



$v_s = V_m \sin(\omega t)$



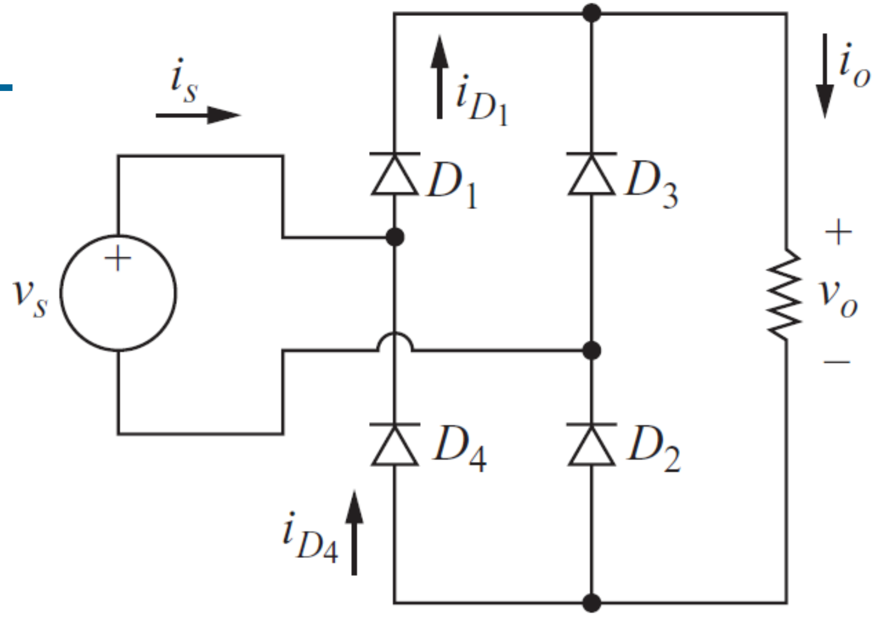
Practically limited to used for low power.

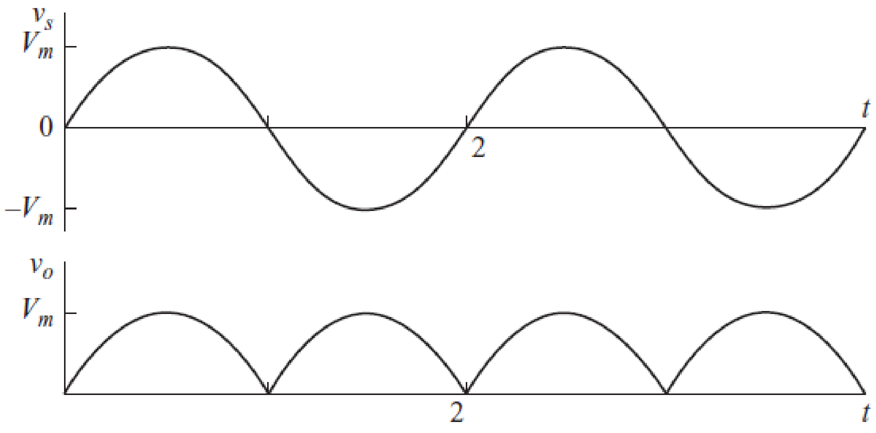
Full wave rectifier

Full wave rectifier is preferred due to following advantages:

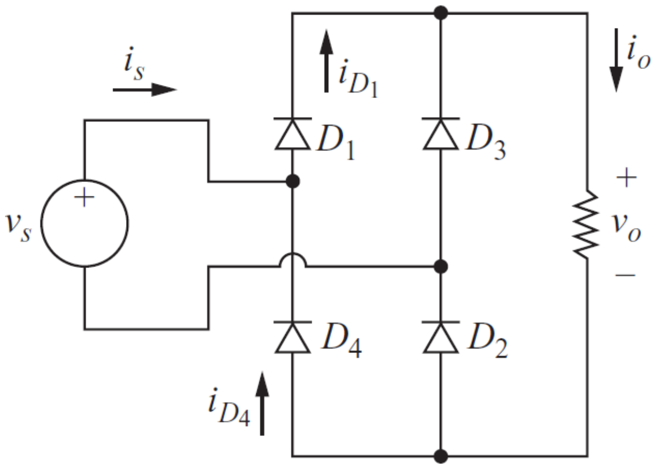
- The average current in the ac source is zero.
- The output of the full-wave rectifier has inherently less ripple than the half-wave rectifier.

Single phase rectifier and three phase rectifier are to be analysed.





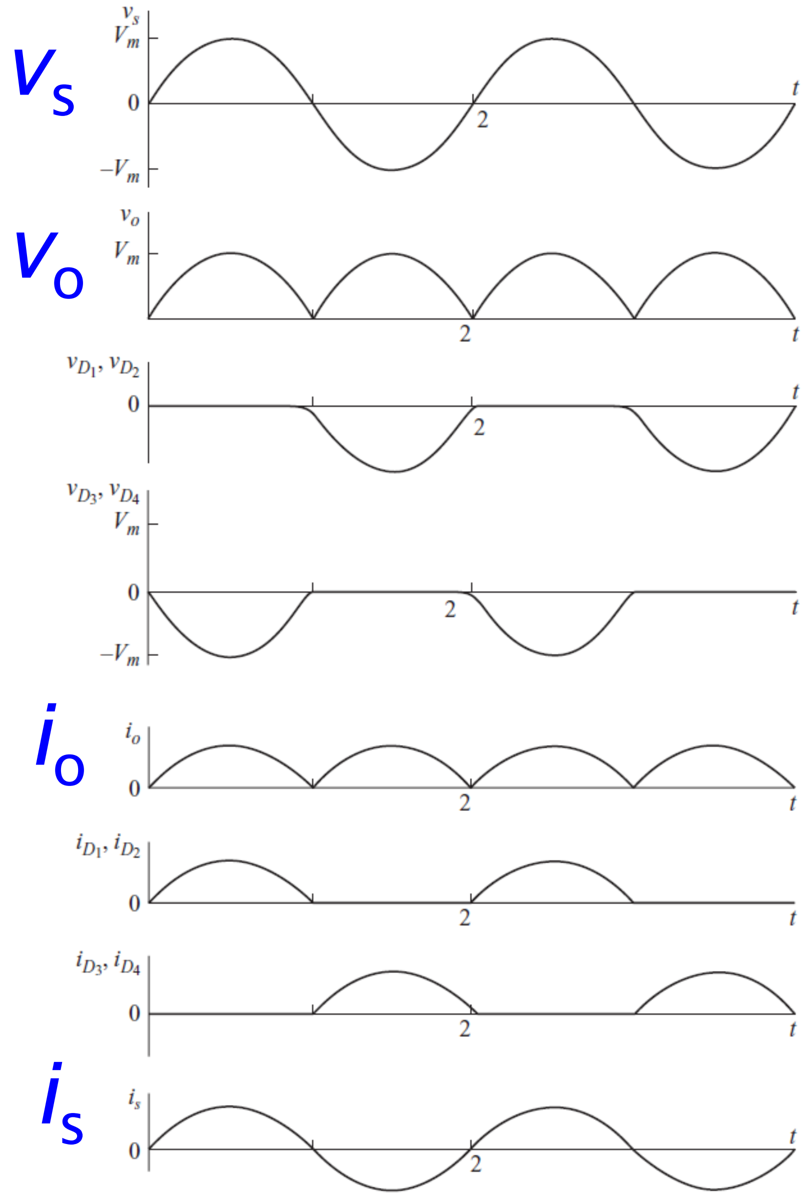
Single phase full wave rectifier



Full wave rectifier with 4 diodes (uncontrolled), Resistive load

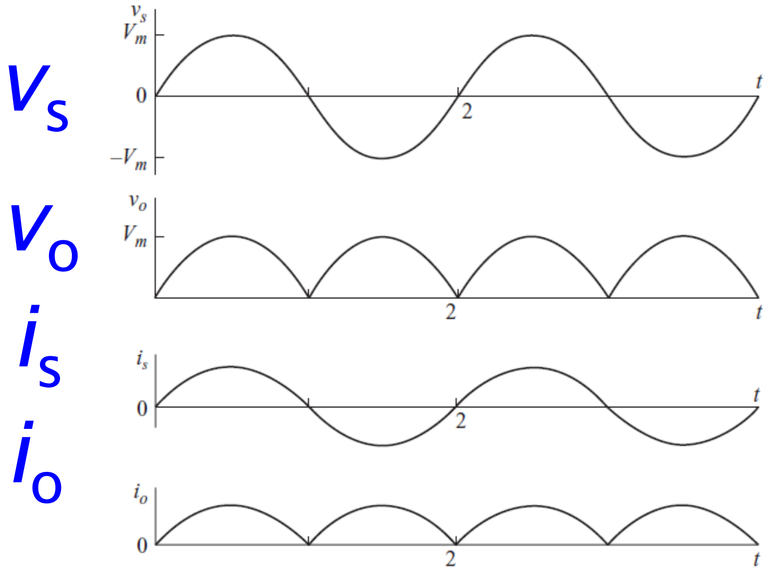
Operation

- Output voltage is $+v_s$ when D1 and D2 are on.
- Output voltage is $-v_s$ when D3 and D4 are on.
- The load current can be positive or zero but can never be negative.
- D1 & D3 and D2 & D4 cannot conduct simultaneously.



University of Southampton

Single phase full wave rectifier



Output voltage v_o

$$v_o(t) = \begin{cases} V_m \sin(\omega t) & \text{for } 0 \le \omega t \le \pi \\ -V_m \sin(\omega t) & \text{for } \pi \le \omega t \le 2\pi \end{cases}$$

DC component of output voltage and current

$$V_o = \frac{1}{\pi}\int_0^{\pi} V_m \sin(\omega t)\, d\,(\omega t)$$

$$= \frac{V_m}{\pi}[-\cos\theta]_0^{\pi} = \frac{2V_m}{\pi}$$

$$I_o = \frac{V_o}{R} = \frac{2V_m}{\pi R}$$

(Resistive load)

Power absorbed by the load

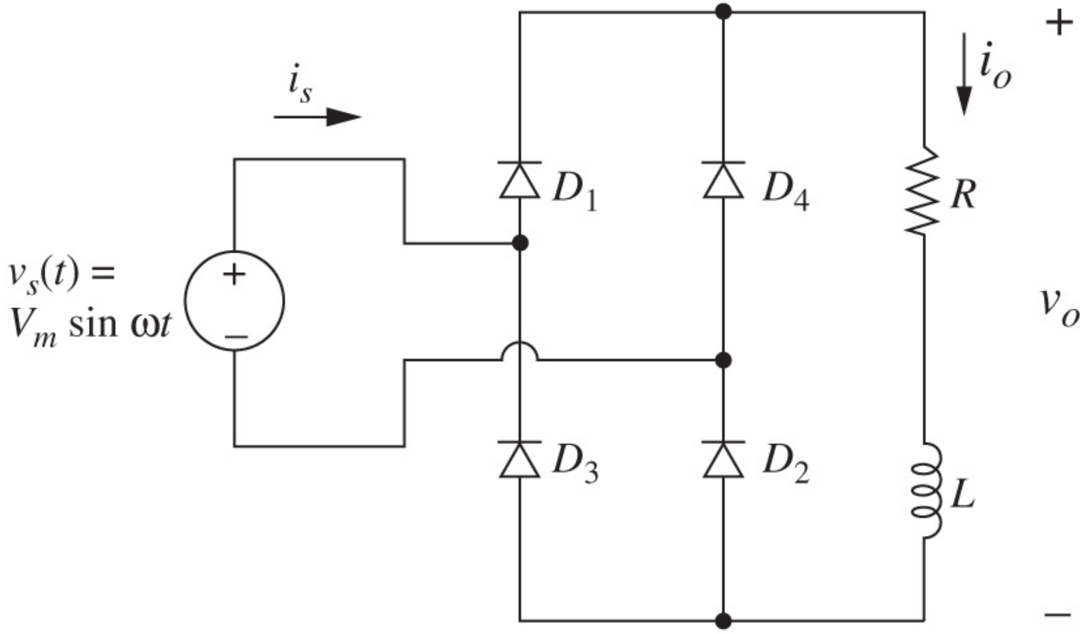
$$P = I_{rms}^2 R$$

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

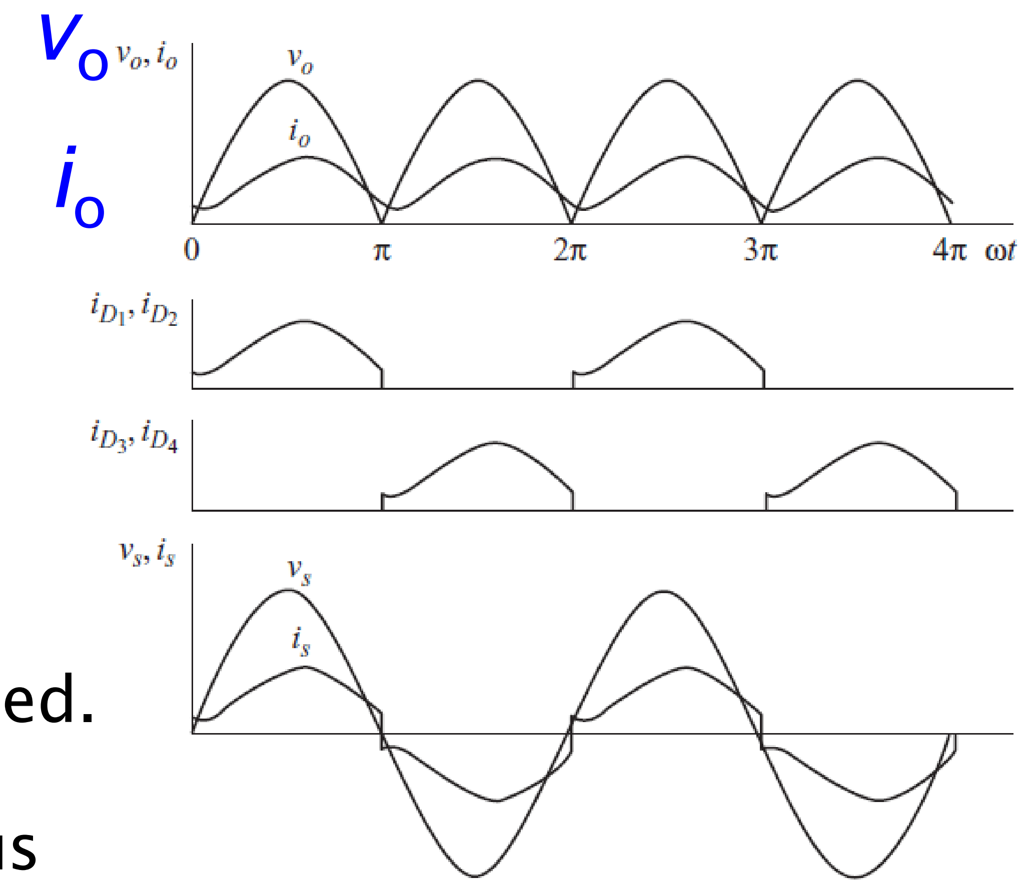
(same as RMS of source)

The fundamental frequency of the output voltage is $2f_{\text{source}}$.

Single phase full wave rectifier – *RL* load



Voltages and currents



- Phase of the output current is shifted.
- Output current becomes continuous

Single phase full wave rectifier – *RL* load

Output voltage (Fourier series)

$$v_o(t) = V_o + \sum_{n=2,4\ldots}^{\infty} V_n \cos(n\omega t + \pi)$$

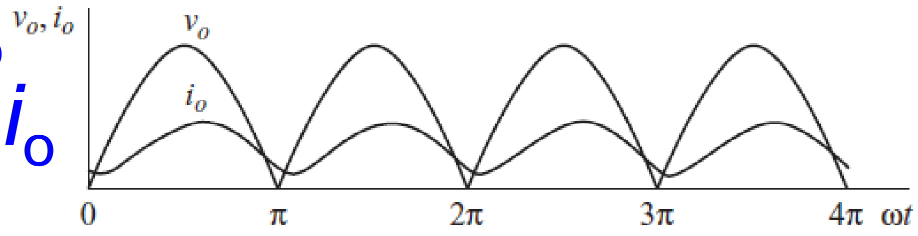
$$\text{where } V_o = \frac{2V_m}{\pi} \text{ and } V_n = \frac{2V_m}{\pi}\left(\frac{1}{n-1} - \frac{1}{n+1}\right)$$

- Voltage amplitude decreases as the harmonic number, n increases.
- The dc current and current amplitude at each frequency are given by

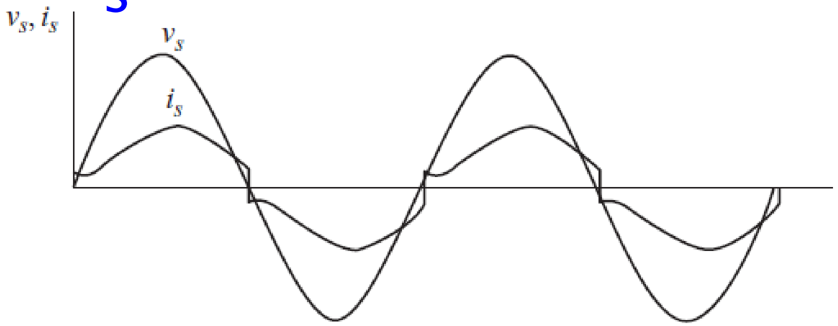
$$I_o = \frac{V_o}{R} \qquad I_n = \frac{V_n}{Z_n} = \frac{V_n}{|R + jn\omega L|}$$

- **If $\omega L >> R$, $I_o >> I_n$ $\longrightarrow$ $i(t) \sim I_o$ (dc only)**

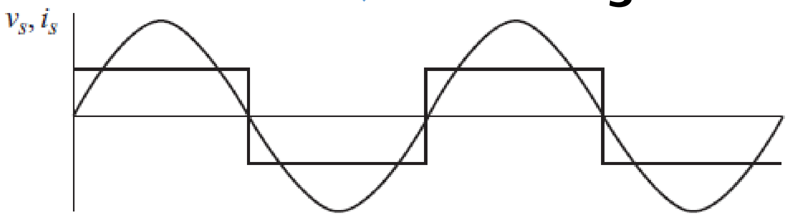
V_o i_o



V_s i_s

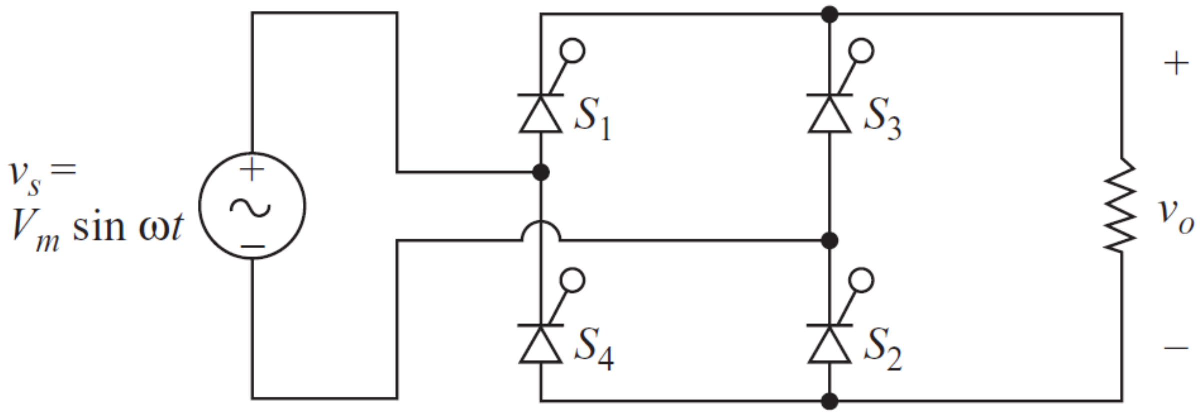


Pure DC current for larger *L*

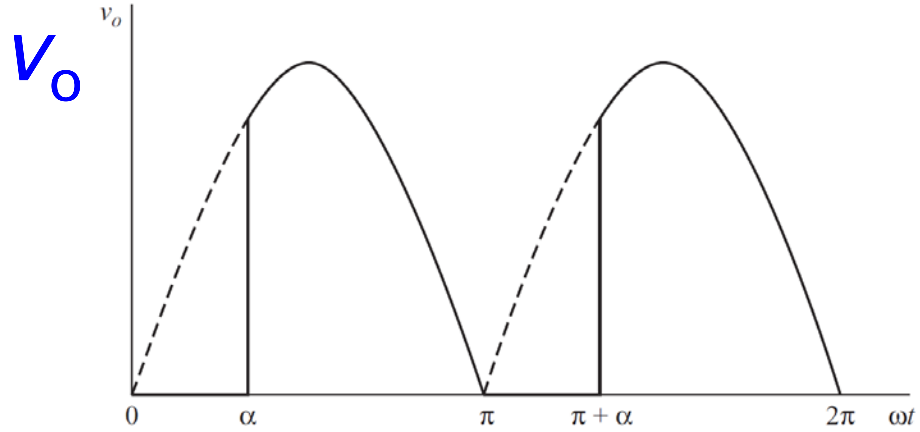


Single Phase Controlled Rectifier

Thyristors are used for rectification.

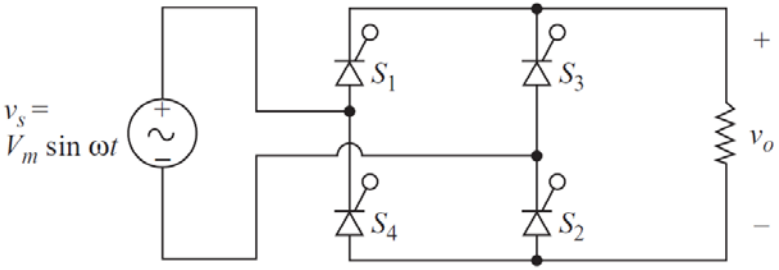


Output voltage



Replacing the diodes with thyristors allow for voltage and hence the power control by controlling the firing/delay angle.

Single Phase Controlled Rectifier



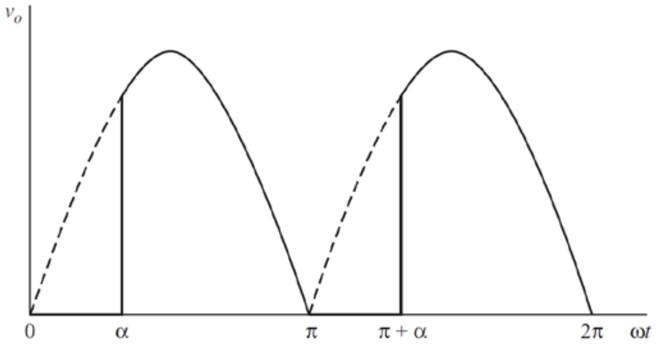
Resistive load

$$V_o = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin(\omega t)\, d(\omega t) = \frac{V_m}{\pi}(1 + \cos\alpha)$$

$$I_o = \frac{V_o}{R} = \frac{V_m}{\pi R}(1 + \cos\alpha)$$

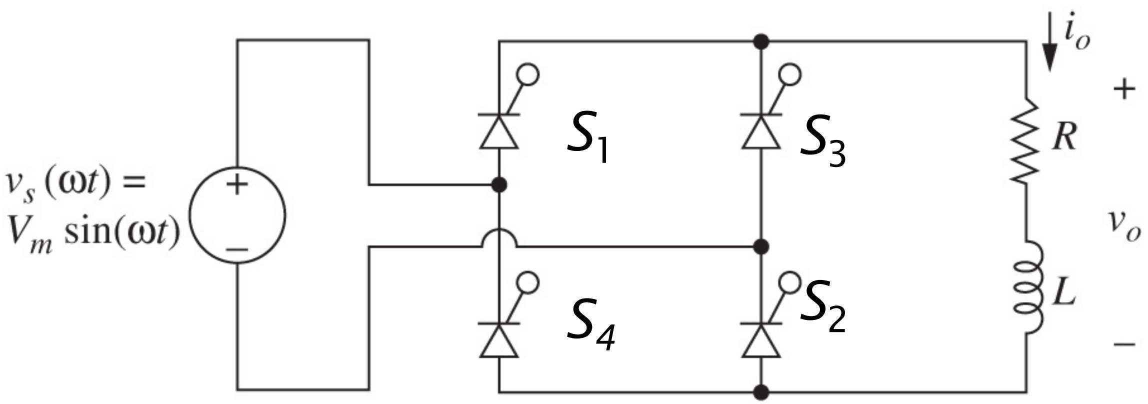
$$I_{rms} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi}\left(\frac{V_m}{R}\sin\omega t\right)^2 d(\omega t)} = \frac{V_m}{R}\sqrt{\frac{1}{2} - \frac{\alpha}{2\pi} + \frac{\sin(2\alpha)}{4\pi}}$$

V_o



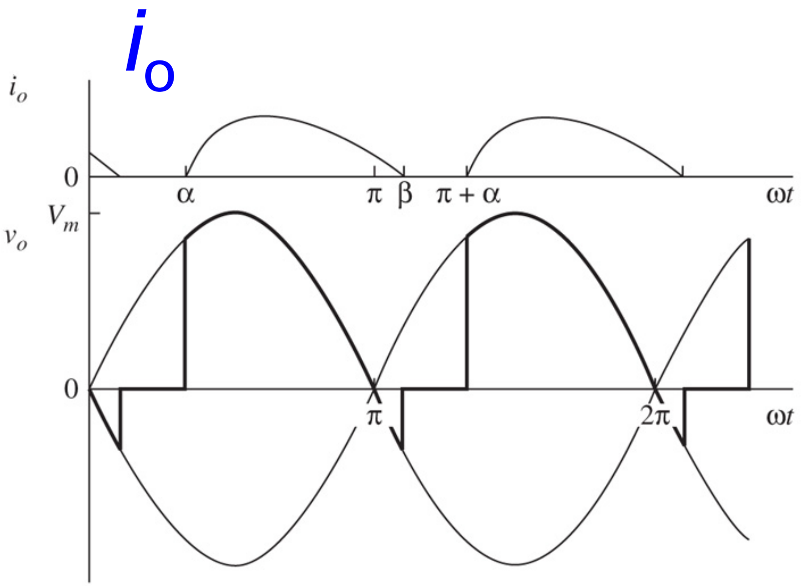
Single phase controlled rectifier

RL load

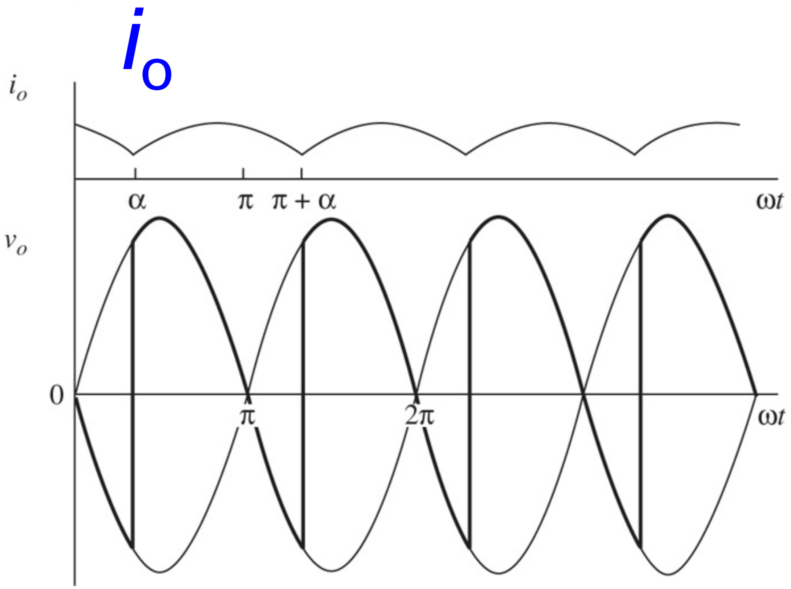


Load current can be continuous or discontinuous depending on the inductance.

Discontinuous current



Continuous current (large *L*)



University of Southampton

Single phase controlled rectifier

RL Load, Continuous Current

Condition

$$\alpha \le \tan^{-1}\left(\frac{\omega L}{R}\right)$$

Output voltage

$$v_o(t) = V_o + \sum_{n=1}^{\infty} V_n \cos(n\omega t + \theta_n)$$

DC average

$$V_o = \frac{1}{\pi}\int_{\alpha}^{\alpha+\pi} V_m \sin(\omega t)\, d(\omega t) = \frac{2V_m}{\pi}\cos\alpha$$

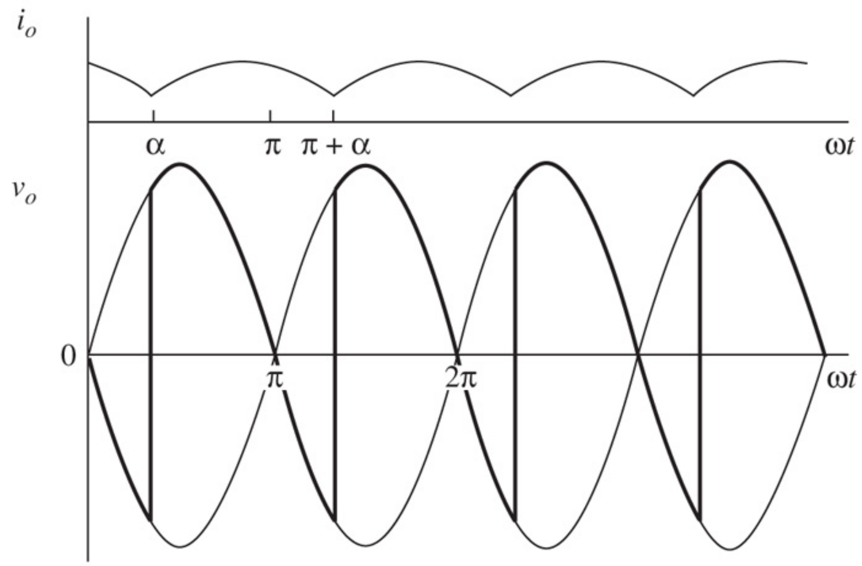
AC components

$$V_n = \sqrt{a_n^2 + b_n^2}$$

$$a_n = \frac{2V_m}{\pi}\left[\frac{\cos(n+1)\alpha}{n+1} - \frac{\cos(n-1)\alpha}{n-1}\right]$$

$$b_n = \frac{2V_m}{\pi}\left[\frac{\sin(n+1)\alpha}{n+1} - \frac{\sin(n-1)\alpha}{n-1}\right]$$

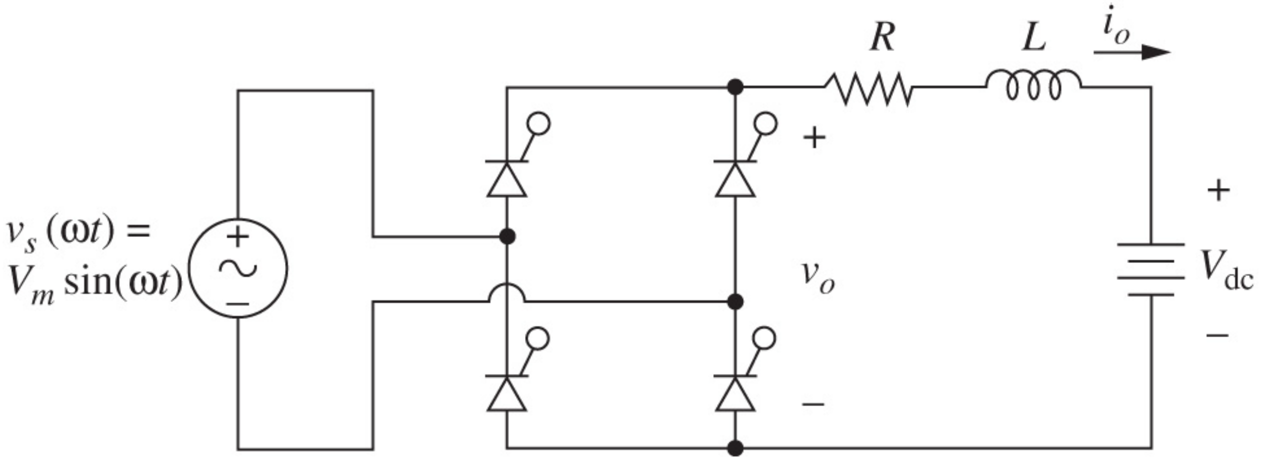
$n = 2,4,6\ldots$



University of Southampton

Single phase controlled rectifier

RL-Source load



Common model in application (DC motor, battery etc)

Minimum firing angle

$$\alpha \geq \sin^{-1}\left(\frac{V_{dc}}{V_m}\right)$$

For continuous current case

Average output voltage $$V_o = \frac{2V_m}{\pi}\cos\alpha$$

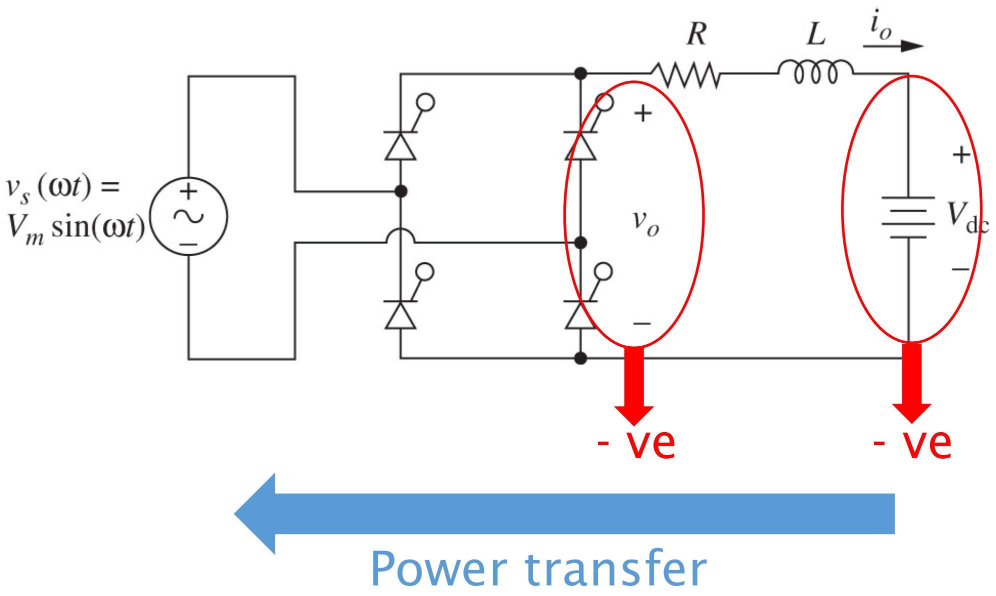
Average load current $$I_o = \frac{V_o - V_{dc}}{R}$$

Power adsorbed by dc voltage $$P_{dc} = I_o V_{dc}$$

Rectifier operating as Inverter

- It is also possible for power to flow from the load to the ac source, which classifies the circuit as an inverter.
- By referring to the equation, $V_o = (2V_m/\pi)\cos\alpha$, the output voltage reduces with firing angle.
- At 0.5π, the average output voltage is zero.
- The output voltage becomes negative (while the load current is remain positive) when α is greater than 0.5π.
- The average power is negative (positive current x negative voltage) indicates that the direction of power flow is reversed; from output (dc power source at load terminal) to input alternating supply.
- V_{dc} must be negative.

Rectifier operating as Inverter



$0 < \alpha < 90° \rightarrow V_o > 0,$
rectifier operation

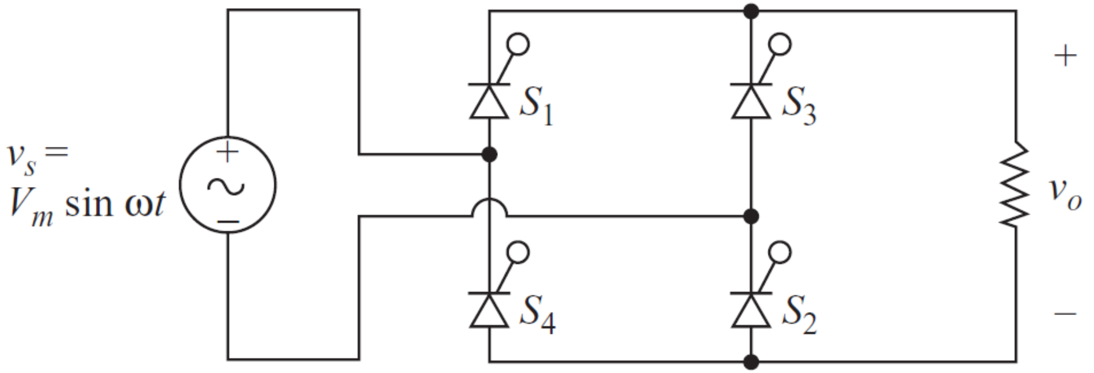
$90° < \alpha < 180° \rightarrow V_o < 0,$
inverter operation

- Output current flows in +ve direction in both rectification and inversion mode.
- The load (battery) now supplies power (during inversion mode) hence the polarity must be reversed.
- Power is transferred from dc load terminal (battery) to ac supply terminal: DC to AC.

University of Southampton

Summary - Single phase rectifier

- 4 diodes/thyristors are used for full-wave rectification.



- The thyristors allow for voltage and hence the power control by controlling the firing/delay angle.

- If the power flows from the load to the ac source, the circuit is classified as an inverter, suggesting a rectifier can be operated as an inverter.