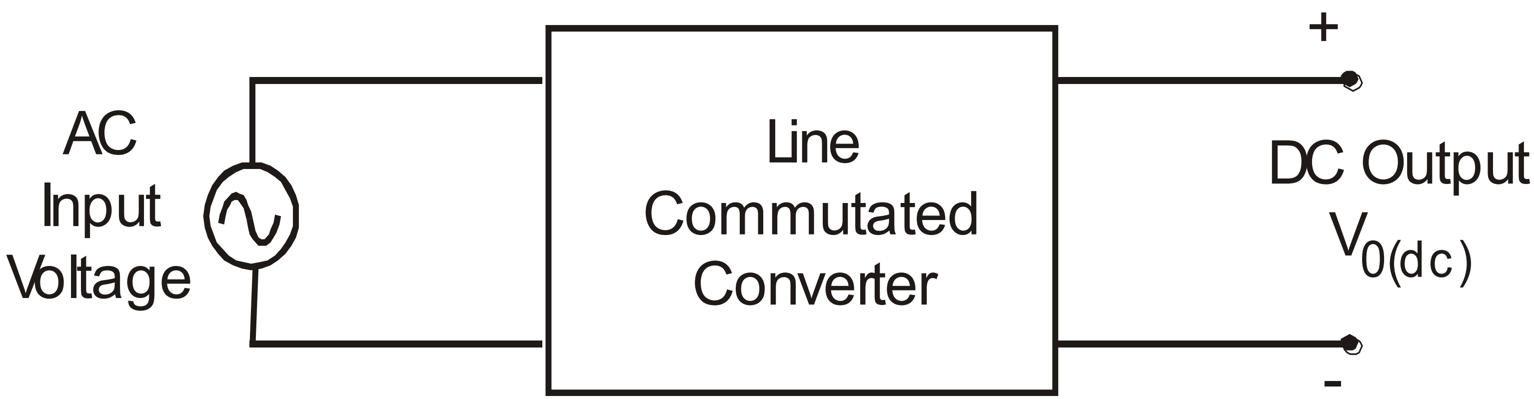
Controlled Rectifiers

(Line Commutated AC to DC converters)



- Type of input: Fixed voltage, fixed frequency ac power supply.
- Type of output: Variable dc output voltage
- Type of commutation: Natural / AC line commutation.

Different types of Line Commutated Converters

- AC to DC Converters (Phase controlled rectifiers)
- AC to AC converters (AC voltage controllers)
- AC to AC converters (Cyclo converters) at low output frequency.

Differences Between Diode Rectifiers & Phase Controlled Rectifiers

- The diode rectifiers are referred to as uncontrolled rectifiers .
- The diode rectifiers give a fixed dc output voltage .
- Each diode conducts for one half cycle.
- Diode conduction angle = 180^0 or π radians.
- We can not control the dc output voltage or the average dc load current in a diode rectifier circuit.

Single phase half wave diode rectifier gives an

Average dc output voltage $V_{O(dc)} = \dfrac{V_m}{\pi}$

Single phase full wave diode rectifier gives an

Average dc output voltage $V_{O(dc)} = \dfrac{2V_m}{\pi}$

Applications of Phase Controlled Rectifiers

- DC motor control in steel mills, paper and textile mills employing dc motor drives.
- AC fed traction system using dc traction motor.
- Electro-chemical and electro-metallurgical processes.
- Magnet power supplies.
- Portable hand tool drives.

Classification of Phase Controlled Rectifiers

- Single Phase Controlled Rectifiers.
- Three Phase Controlled Rectifiers.

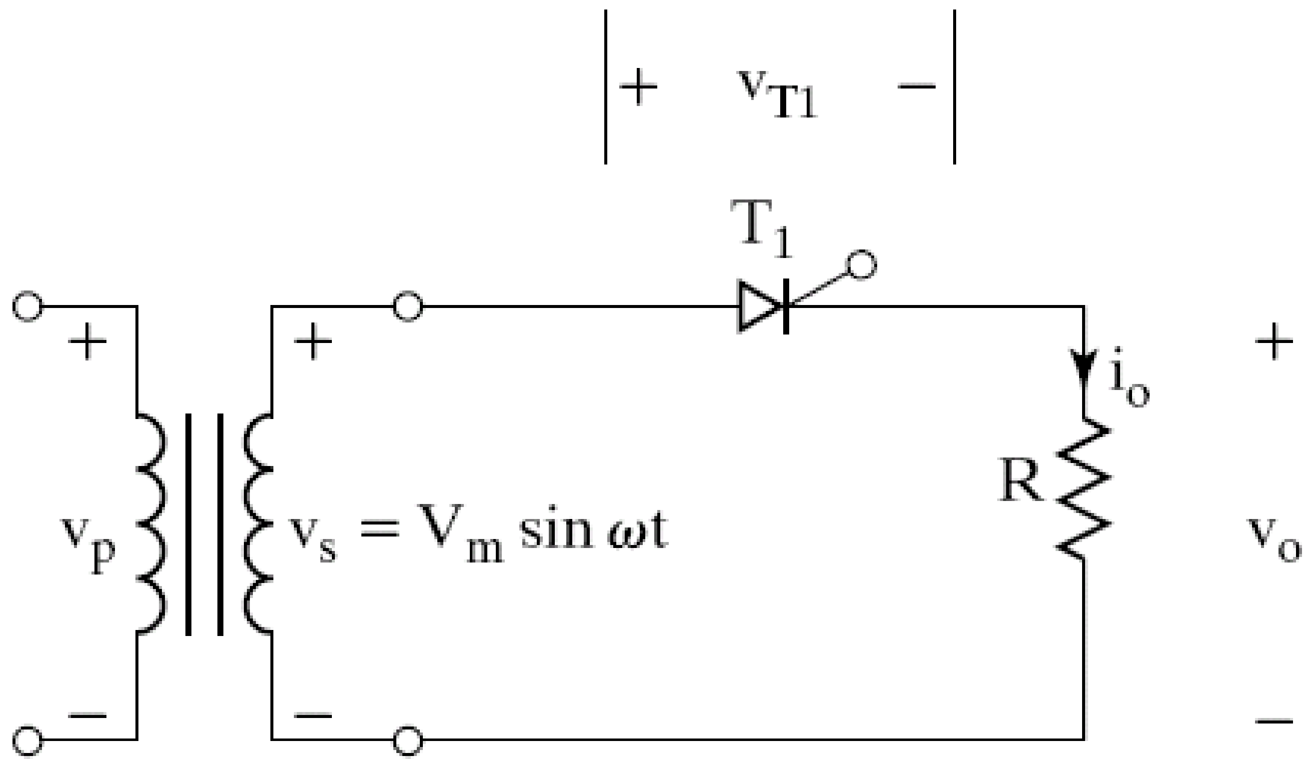
Different types of Single Phase Controlled Rectifiers.

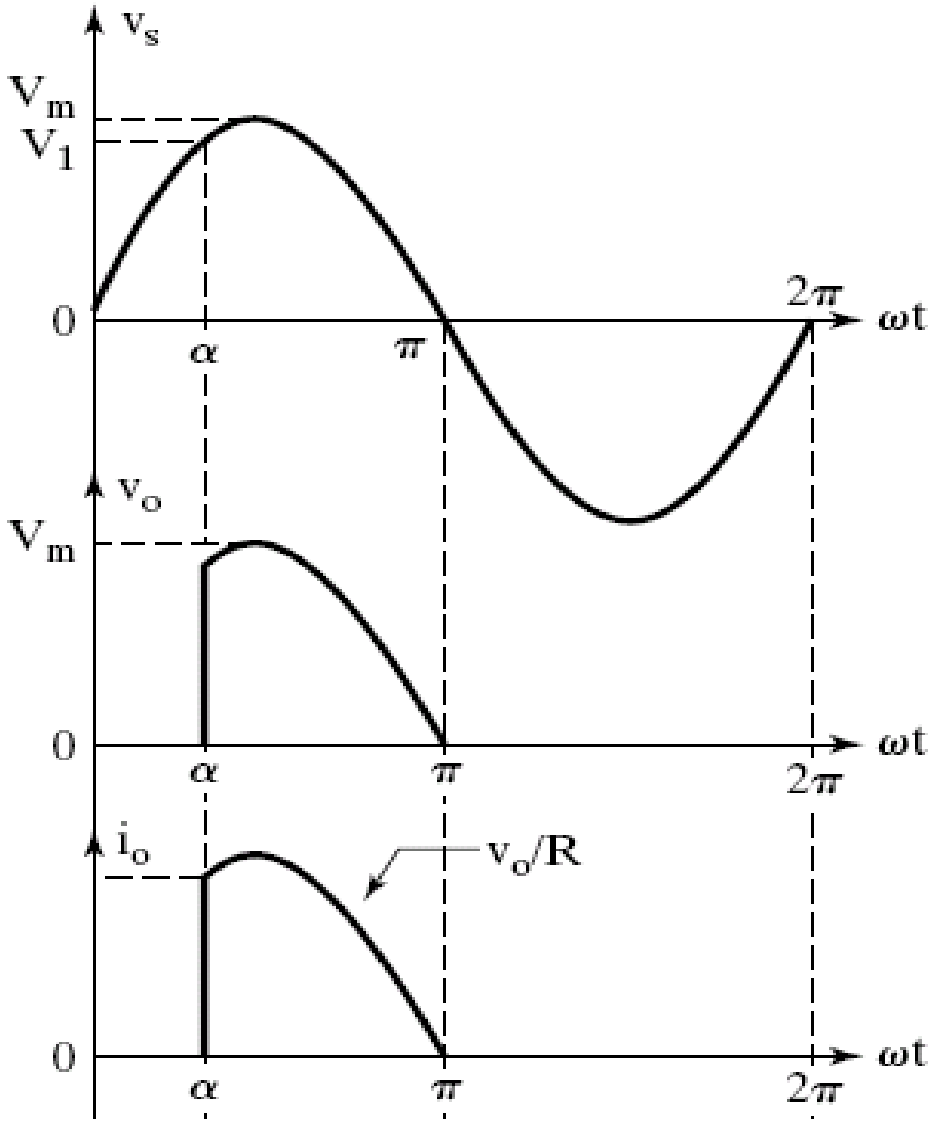
- Half wave controlled rectifiers.
- Full wave controlled rectifiers.
  - Using a center tapped transformer.
  - Full wave bridge circuit.
    - Semi converter.
    - Full converter.

Different Types of Three Phase Controlled Rectifiers

- Half wave controlled rectifiers.
- Full wave controlled rectifiers.
    - Semi converter (half controlled bridge converter).
    - Full converter (fully controlled bridge converter).

Single Phase Half-Wave Thyristor Converter with a Resistive Load

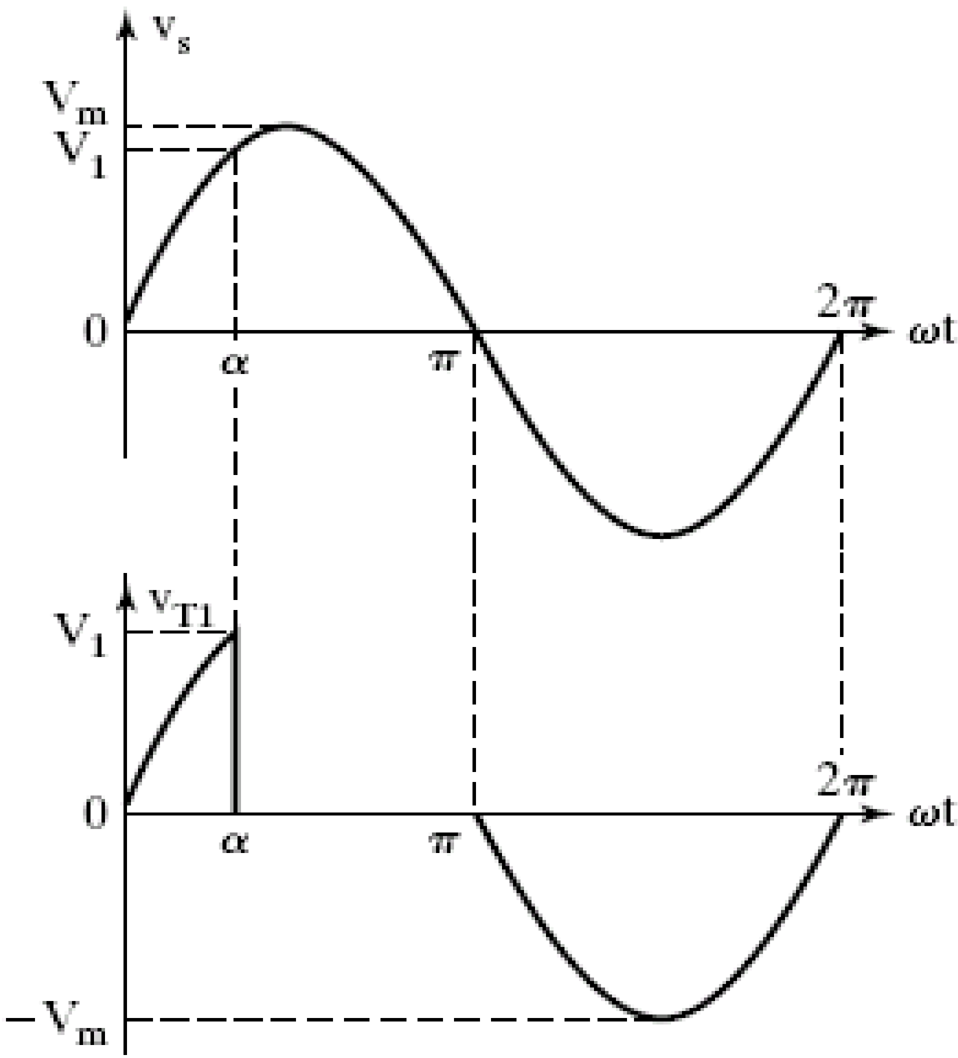




Supply Voltage

Output Voltage

Output (load) Current



Supply Voltage

Thyristor Voltage

Equations

$$v_s = V_m \sin \omega t = \text{ i/p ac supply voltage}$$

$$V_m = \text{max. value of i/p ac supply voltage}$$

$$V_S = \frac{V_m}{\sqrt{2}} = \text{RMS value of i/p ac supply voltage}$$

$$v_O = v_L = \text{ output voltage across the load}$$

When the thyristor is triggered at $\omega t = \alpha$

$$v_O = v_L = V_m \sin \omega t; \ \ \omega t = \alpha \text{ to } \pi$$

$$i_O = i_L = \frac{v_O}{R} = \text{Load current}; \ \ \omega t = \alpha \text{ to } \pi$$

$$i_O = i_L = \frac{V_m \sin \omega t}{R} = I_m \sin \omega t; \omega t = \alpha \text{ to } \pi$$

Where $I_m = \frac{V_m}{R} =$ max. value of load current

To Derive an Expression for the Average (DC) Output Voltage Across The Load

$$V_{O(dc)} = V_{dc} = \frac{1}{2\pi}\int_{0}^{2\pi} v_O . d\left(\omega t\right);$$

$$v_O = V_m \sin\omega t \ for \ \ \omega t = \alpha \ \ to \ \ \pi$$

$$V_{O(dc)} = V_{dc} = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin\omega t . d\left(\omega t\right)$$

$$V_{O(dc)} = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin\omega t . d\left(\omega t\right)$$

$$V_{O(dc)} = \frac{V_m}{2\pi} \int_{\alpha}^{\pi} \sin \omega t . d(\omega t)$$

$$V_{O(dc)} = \frac{V_m}{2\pi} \left[-\cos \omega t \Big/_{\alpha}^{\pi} \right]$$

$$V_{O(dc)} = \frac{V_m}{2\pi} \left[-\cos \pi + \cos \alpha \right]; \quad \cos \pi = -1$$

$$V_{O(dc)} = \frac{V_m}{2\pi} \left[1 + \cos \alpha \right] \; ; \; V_m = \sqrt{2} V_S$$

Maximum average (dc) o/p voltage is obtained when $\alpha = 0$ and the maximum dc output voltage

$$V_{dc(\max)} = V_{dm} = \frac{V_m}{2\pi}\left(1+\cos 0\right); \ \cos\left(0\right)=1$$

$$\therefore V_{dc(\max)} = V_{dm} = \frac{V_m}{\pi}$$

$$V_{O(dc)} = \frac{V_m}{2\pi}\left[1+\cos\alpha\right] \; ; \; V_m = \sqrt{2}V_S$$

The average dc output voltage can be varied by varying the trigger angle α from 0 to a maximum of $180^0 \left(\pi \text{ radians}\right)$

We can plot the control characteristic $\left(V_{O(dc)} \text{ vs } \alpha\right)$ by using the equation for $V_{O(dc)}$

Control Characteristic
of
Single Phase Half Wave Phase Controlled Rectifier
with
Resistive Load

The average dc output voltage is given by the expression

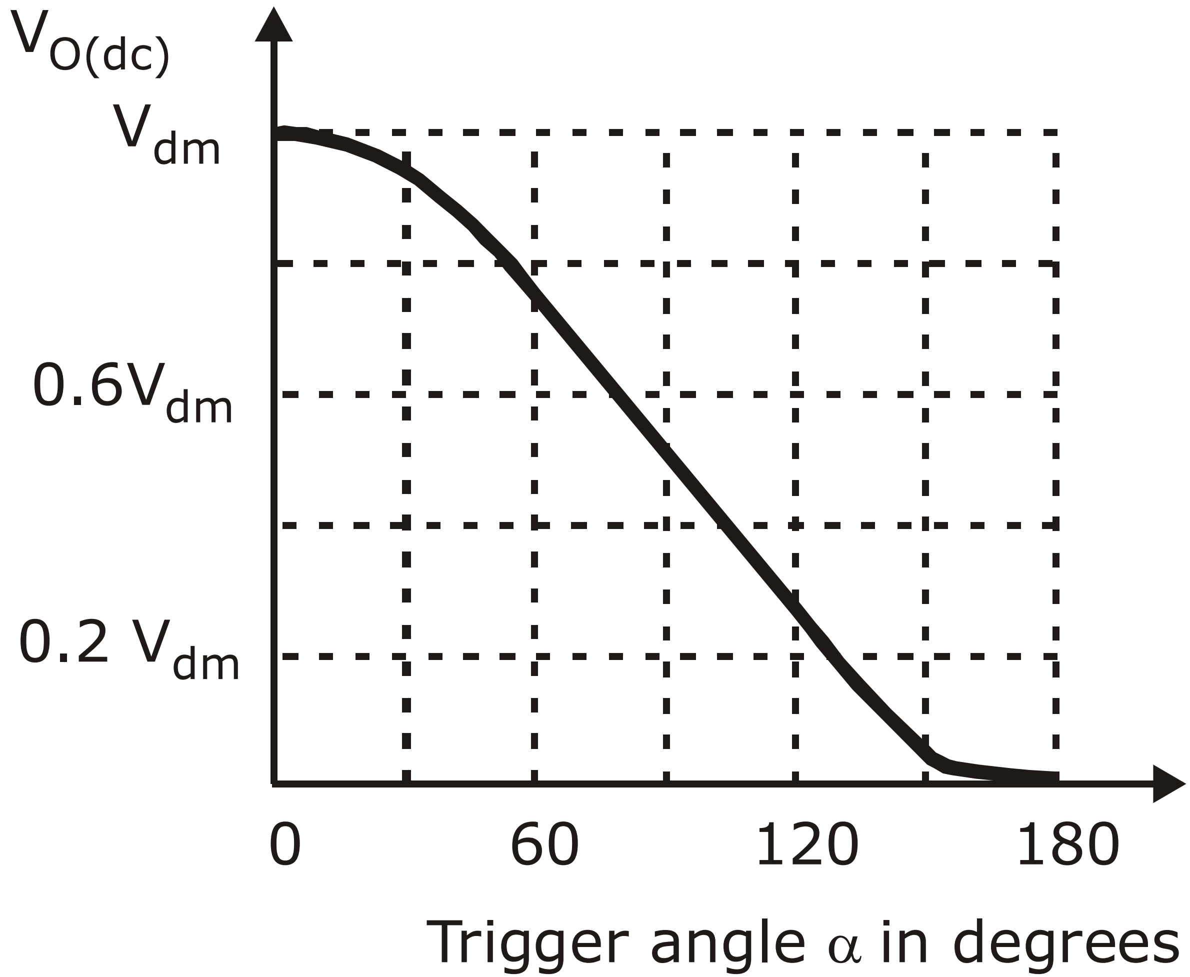
$$V_{O(dc)} = \frac{V_m}{2\pi}\left[1+\cos\alpha\right]$$

We can obtain the control characteristic by plotting the expression for the dc output voltage as a function of trigger angle α

Trigger angle α in degrees	$V_{O(dc)}$	**%**
0	$V_{dm} = \frac{V_m}{\pi}$	100% V_{dm}
30^0	0.933 V_{dm}	93.3 % V_{dm}
60^0	0.75 V_{dm}	75 % V_{dm}
90^0	0.5 V_{dm}	50 % V_{dm}
120^0	0.25 V_{dm}	25 % V_{dm}
150^0	0.06698 V_{dm}	6.69 % V_{dm}
180^0	0	0

$$V_{dm} = \frac{V_m}{\pi} = V_{dc(\max)}$$

Control Characteristic



Normalizing the dc output voltage with respect to V_{dm}, the Normalized output voltage

$$V_n = \frac{V_{dc}}{V_{dm}} = \frac{\frac{V_m}{2\pi}\left(1+\cos\alpha\right)}{\frac{V_m}{\pi}}$$

$$V_n = \frac{V_{dc}}{V_{dm}} = \frac{1}{2}\left(1+\cos\alpha\right) = V_{dcn}$$

To Derive An Expression for the RMS Value of Output Voltage of a Single Phase Half Wave Controlled Rectifier With Resistive Load

The RMS output voltage is given by

$$V_{O(RMS)} = \left[\frac{1}{2\pi} \int_{0}^{2\pi} v_O^2 . d(\omega t) \right]$$

Output voltage $v_O = V_m \sin \omega t$; for $\omega t = \alpha$ to π

$$V_{O(RMS)} = \left[\frac{1}{2\pi} \int_{\alpha}^{\pi} V_m^2 \sin^2 \omega t . d(\omega t) \right]^{\frac{1}{2}}$$

By substituting $\sin^2 \omega t = \dfrac{1-\cos 2\omega t}{2}$, we get

$$V_{O(RMS)} = \left[\frac{1}{2\pi} \int_{\alpha}^{\pi} V_m^2 \frac{\left(1-\cos 2\omega t\right)}{2} .d\left(\omega t\right) \right]^{\frac{1}{2}}$$

$$V_{O(RMS)} = \left[\frac{V_m^2}{4\pi} \int_{\alpha}^{\pi} \left(1-\cos 2\omega t\right) .d\left(\omega t\right) \right]^{\frac{1}{2}}$$

$$V_{O(RMS)} = \left[\frac{V_m^2}{4\pi} \left\{ \int_{\alpha}^{\pi} d\left(\omega t\right) - \int_{\alpha}^{\pi} \cos 2\omega t .d\left(\omega t\right) \right\} \right]^{\frac{1}{2}}$$

$$V_{O(RMS)} = \frac{V_m}{2}\left[\frac{1}{\pi}\left\{\left(\omega t\right)\Big/_{\alpha}^{\pi} - \left(\frac{\sin 2\omega t}{2}\right)\Big/_{\alpha}^{\pi}\right\}\right]^{\frac{1}{2}}$$

$$V_{O(RMS)} = \frac{V_m}{2}\left[\frac{1}{\pi}\left(\left(\pi - \alpha\right) - \frac{\left(\sin 2\pi - \sin 2\alpha\right)}{2}\right)\right]^{\frac{1}{2}} ; \sin 2\pi = 0$$

$$V_{O(RMS)} = \frac{V_m}{2}\left[\frac{1}{\pi}\left(\left(\pi - \alpha\right) + \frac{\sin 2\alpha}{2}\right)\right]^{\frac{1}{2}}$$

$$V_{O(RMS)} = \frac{V_m}{2\sqrt{\pi}}\left(\left(\pi - \alpha\right) + \frac{\sin 2\alpha}{2}\right)^{\frac{1}{2}}$$