Power Electronics Lab

Single phase controlled rectifier

Eng :Eman Abu Hany

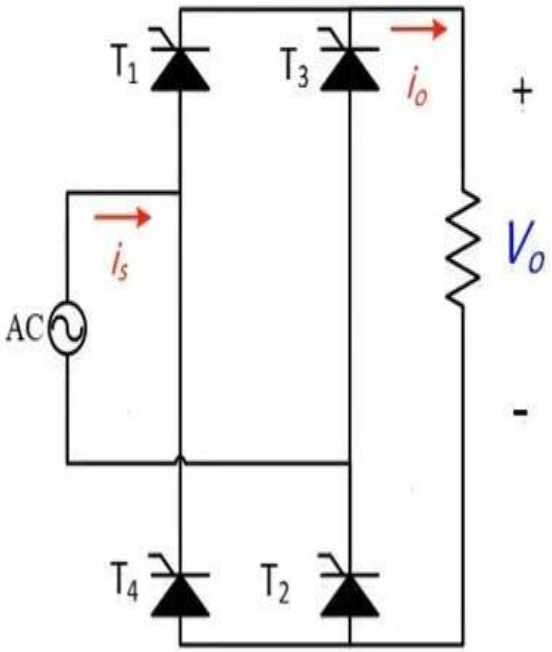
Single Phase controlled Rectifier

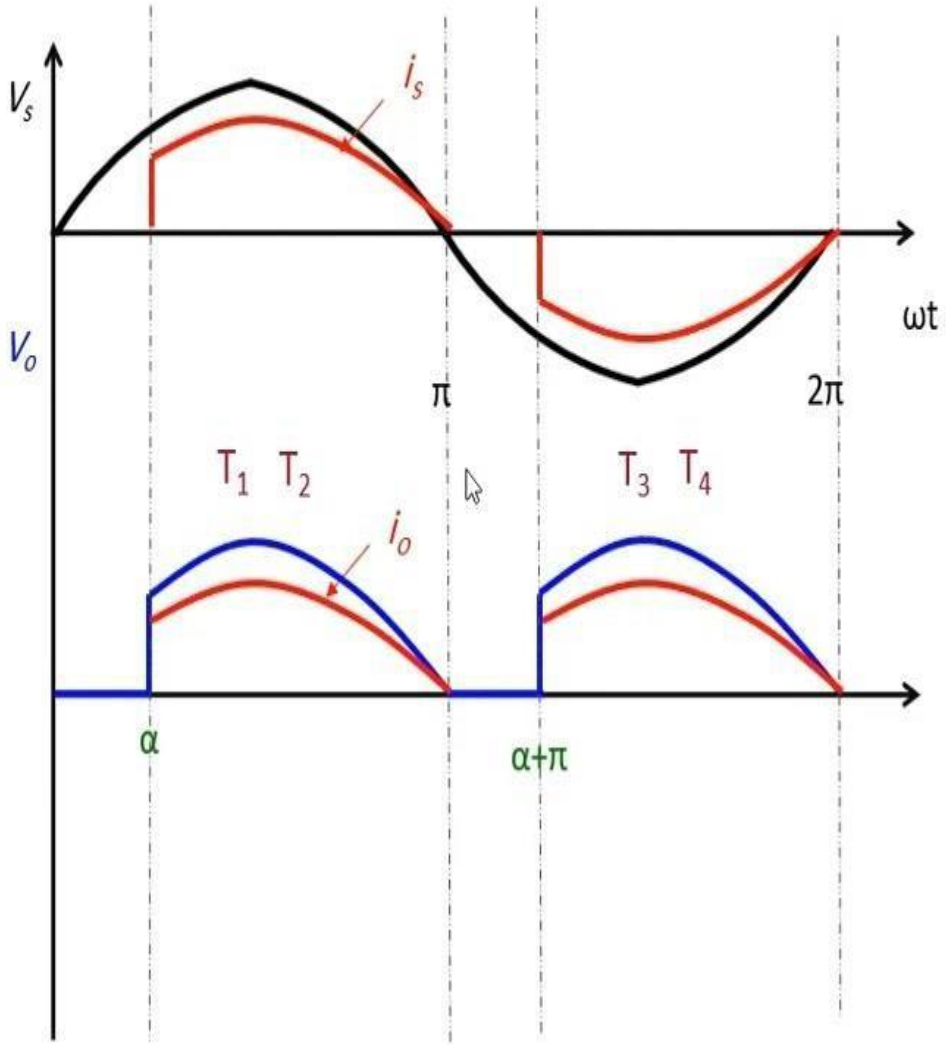
1- the controlled single - pulse Mid – point circuit M1C

2- the controlled Double - pulse Bridge Circuit B2C

Full Wave Controlled Rectifier

R Load





Full Wave Controlled Rectifier

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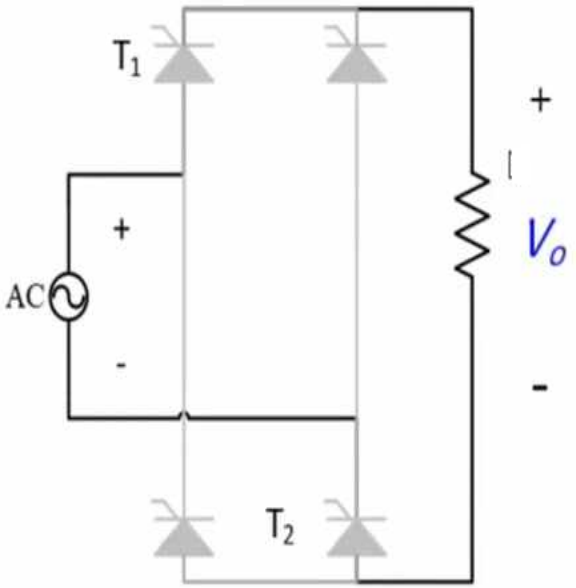
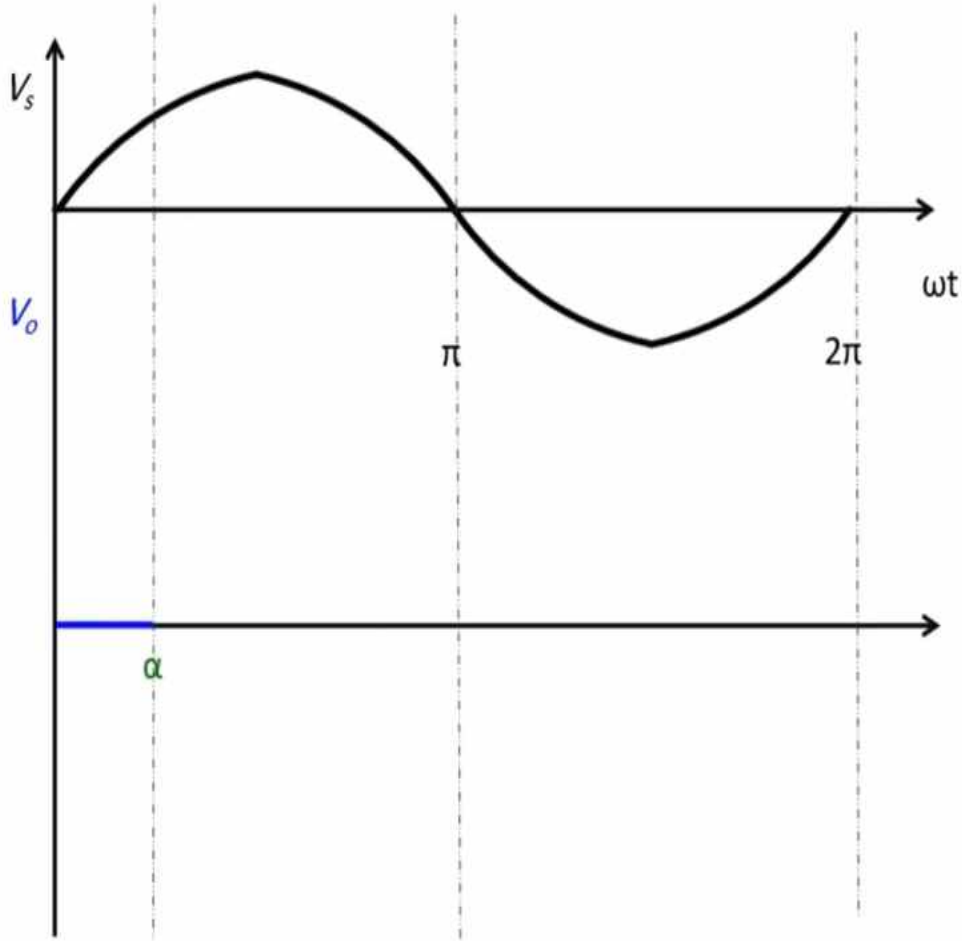


$0 \leq \omega t \leq \alpha$



Full Wave Controlled Rectifier

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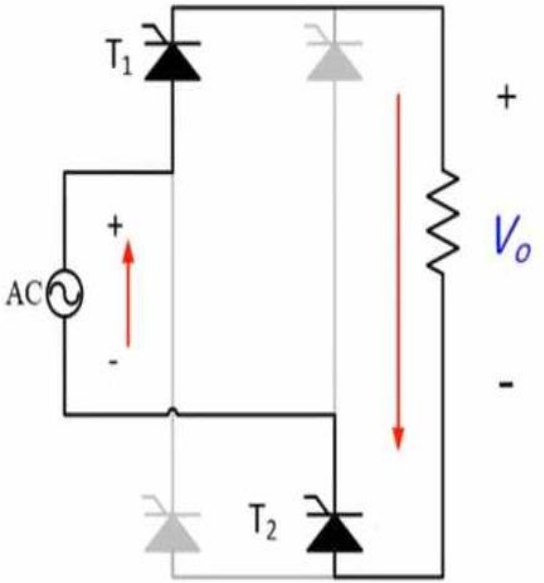
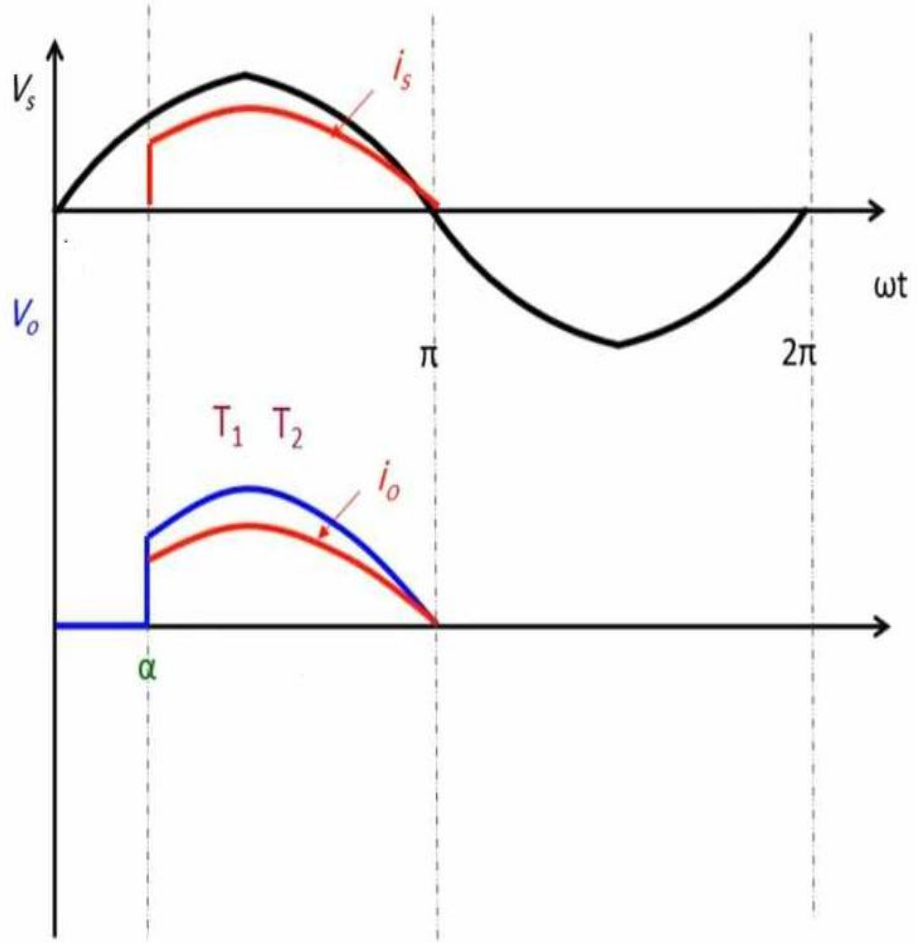


$\alpha \leq \omega t \leq \pi$



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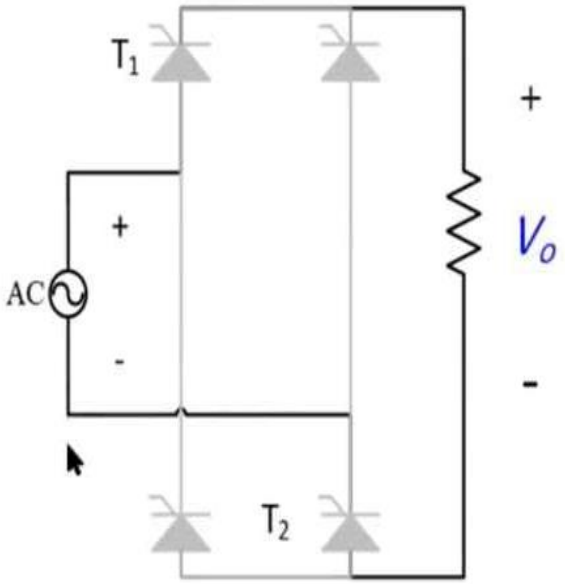
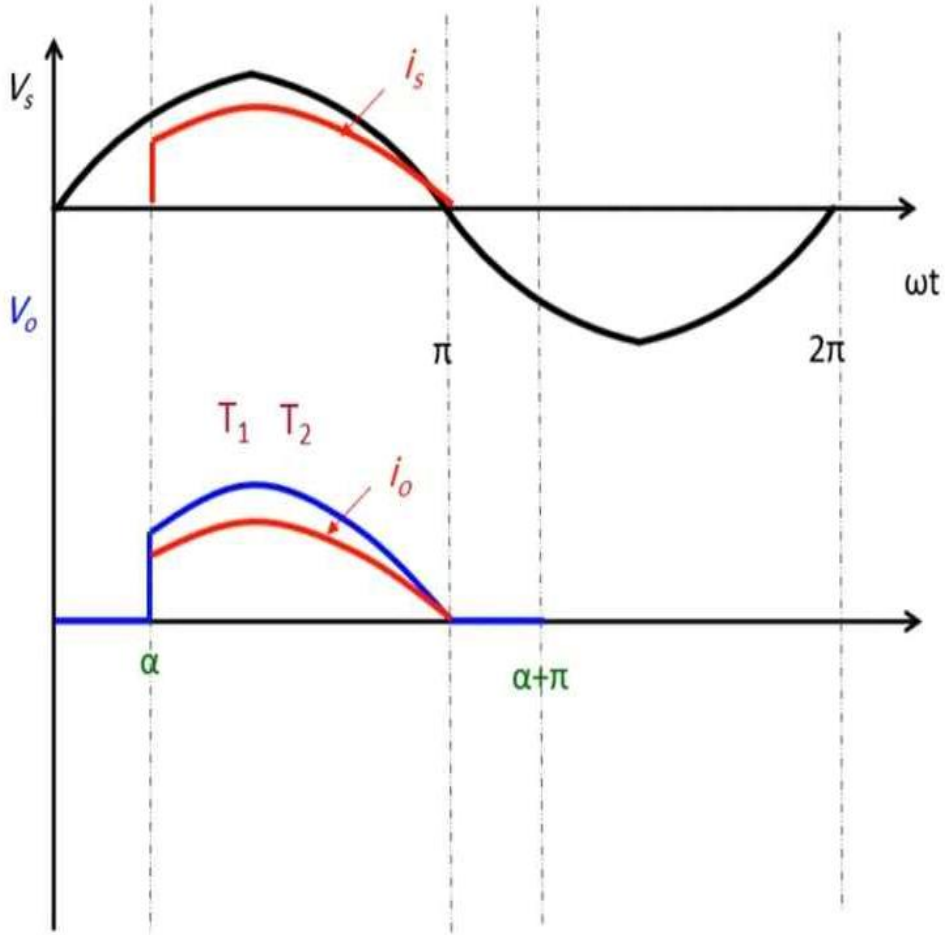


$\pi \leq \omega t \leq \alpha + \pi$



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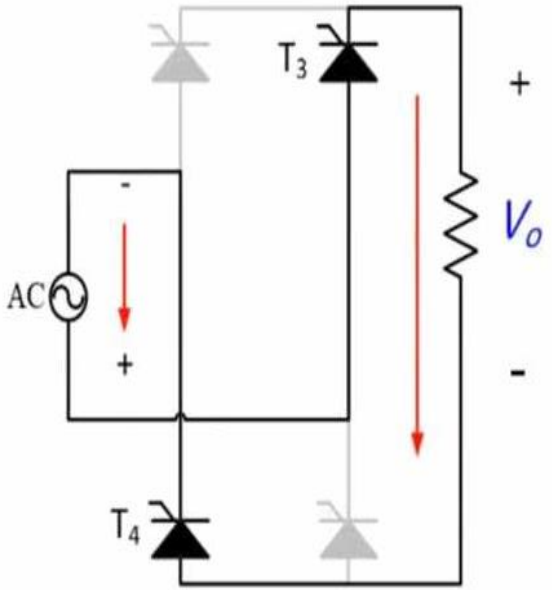
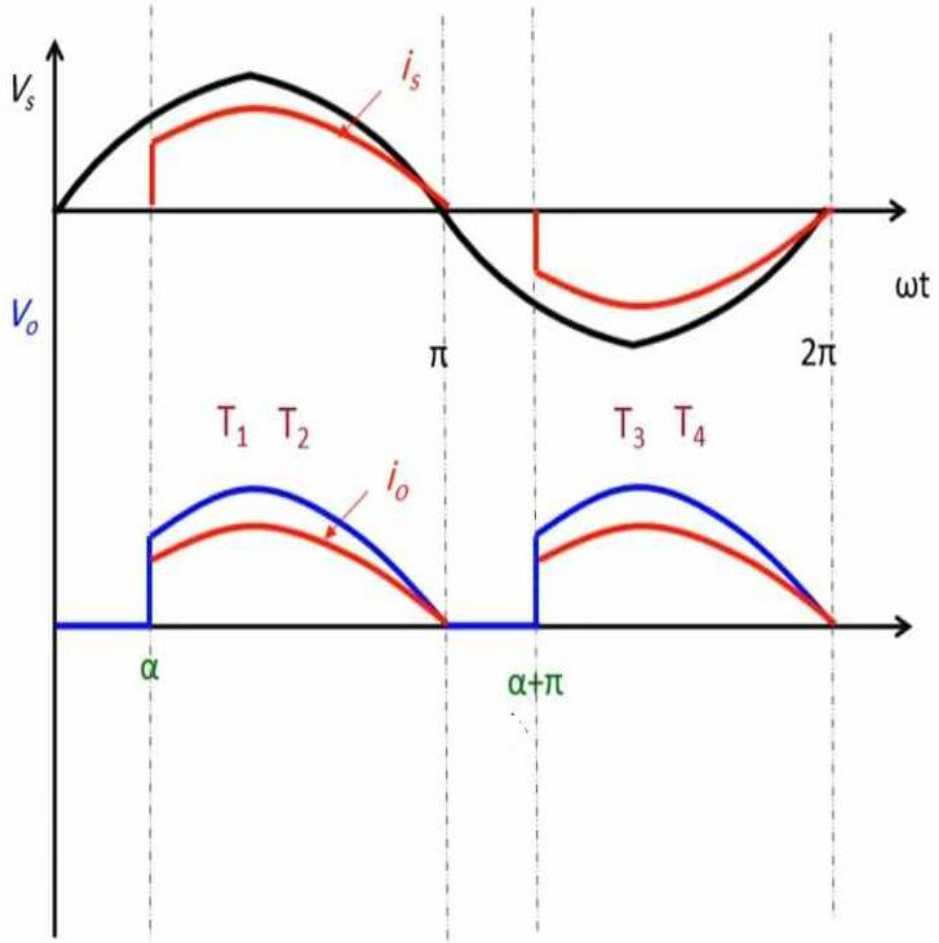


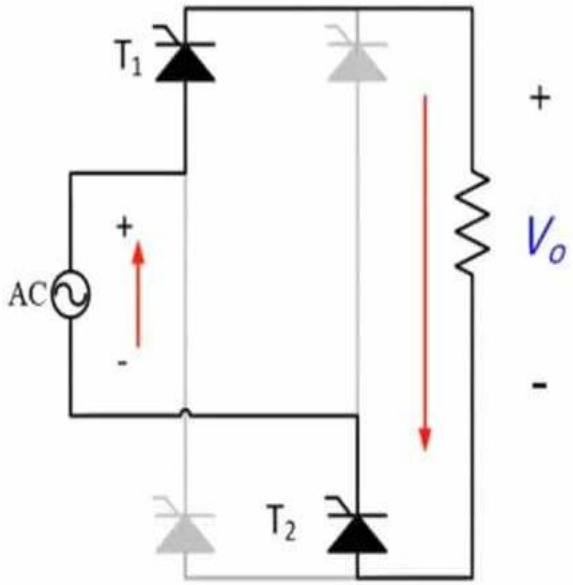
$\alpha + \pi \leq \omega t \leq 2\pi$

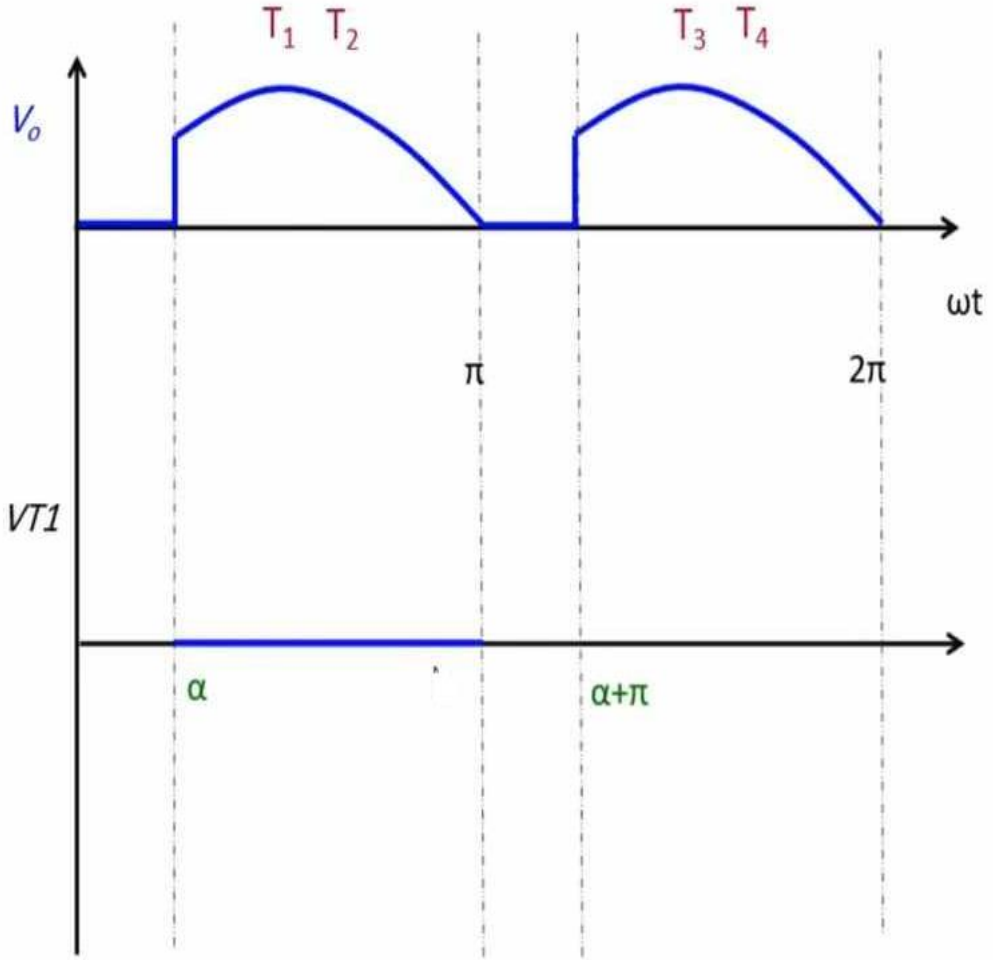


Full Wave Controlled Rectifier

R Load

Thyristor Voltage

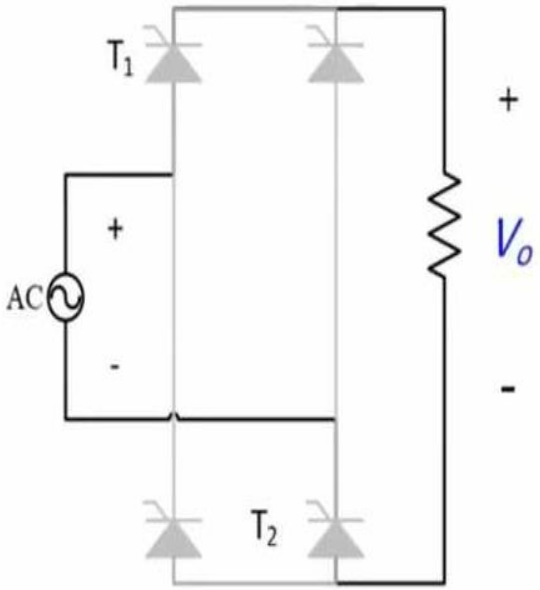


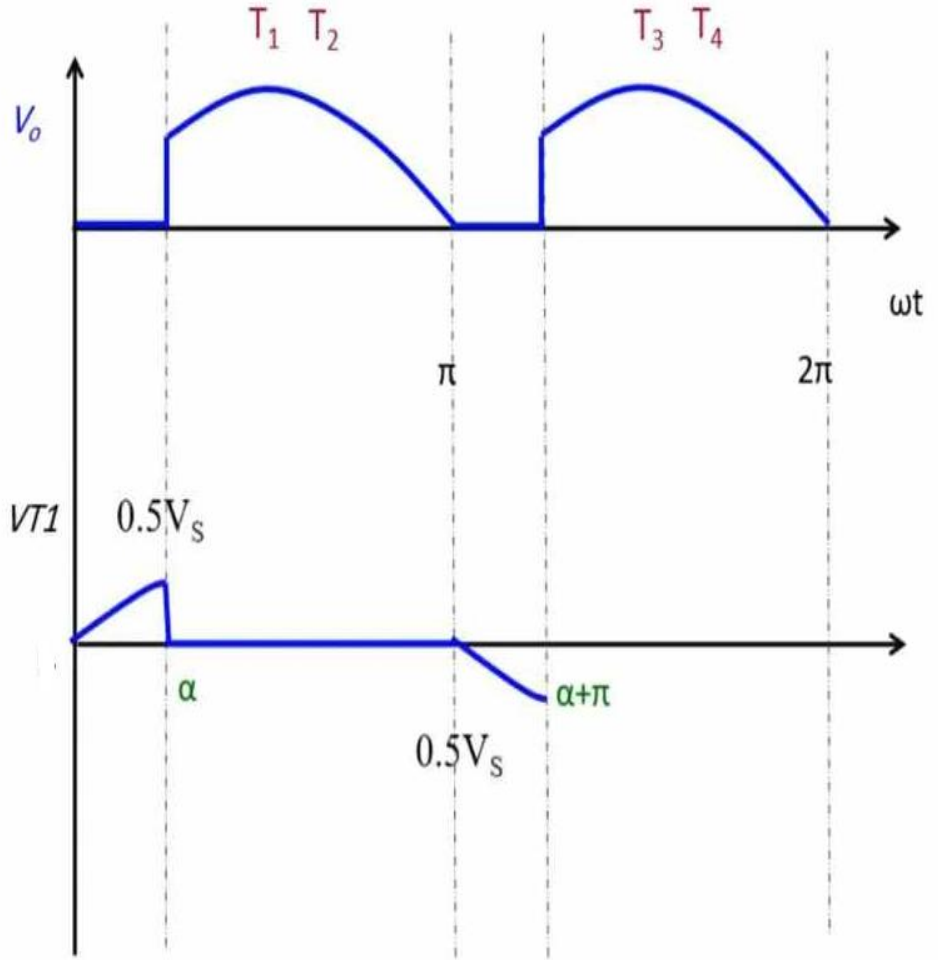


Full Wave Controlled Rectifier

R Load

Thyristor Voltage





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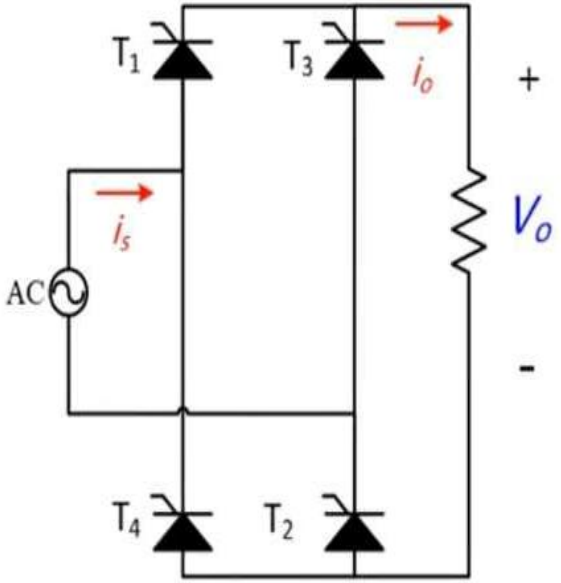

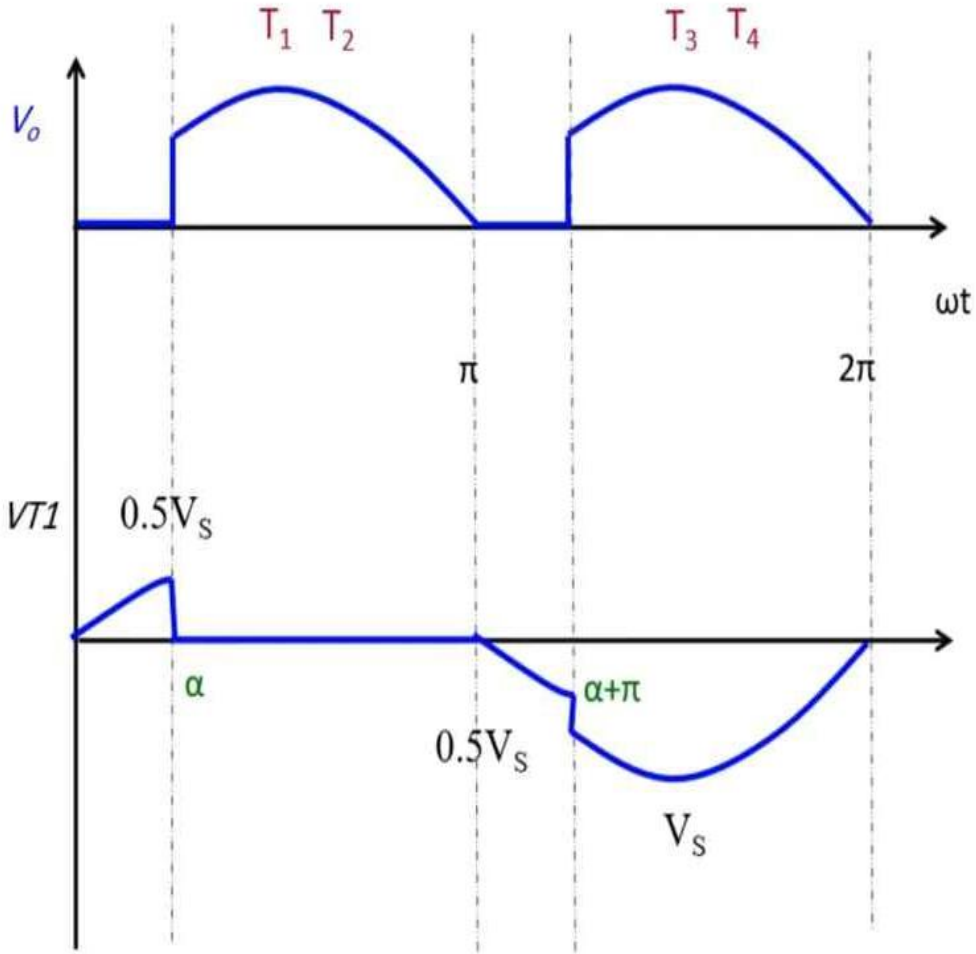

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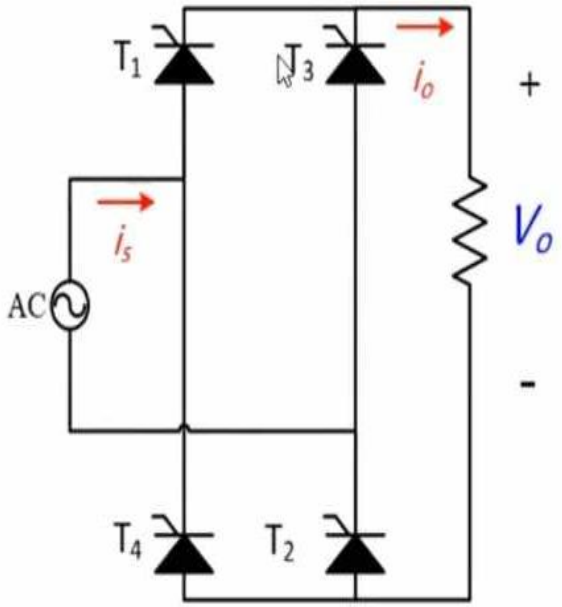
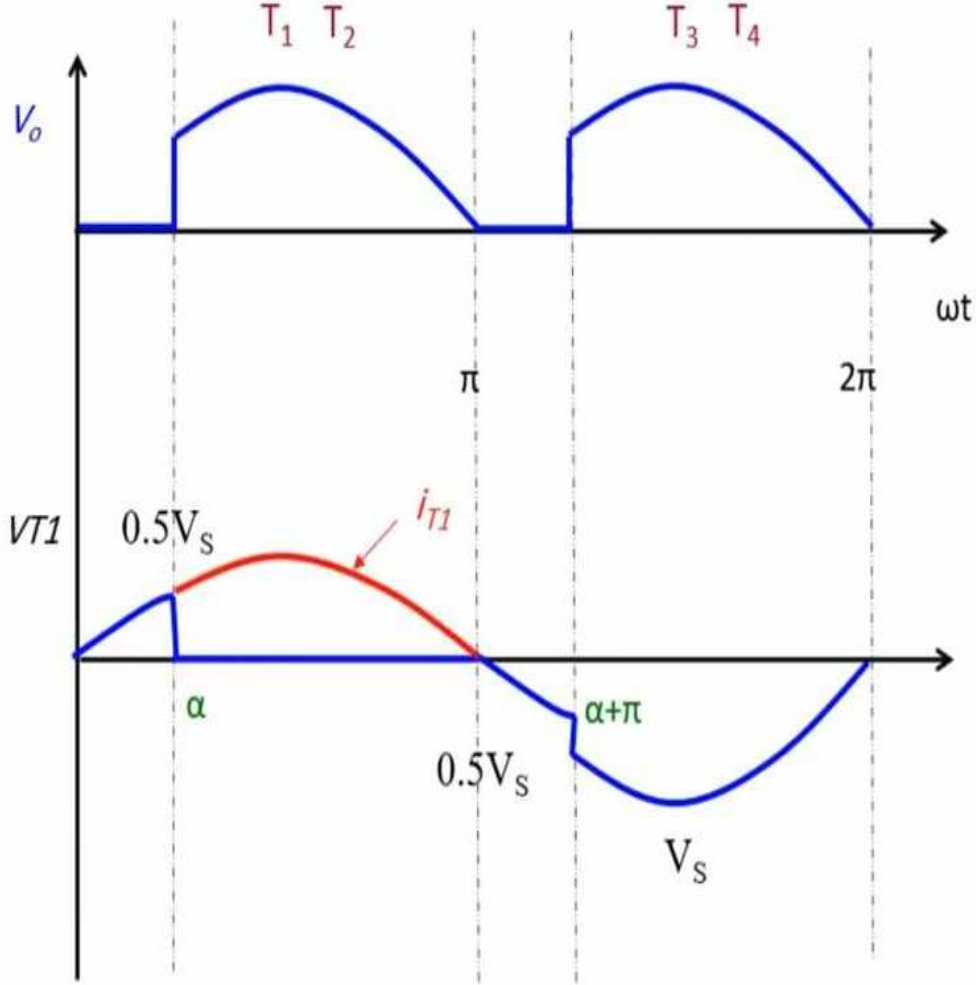
Thyristor Voltage





Output voltage and output current

The average output voltage

$$v_{o,avg} = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin(\omega t)\, d\omega t = \frac{V_m}{\pi}[\cos(\alpha)+1]$$

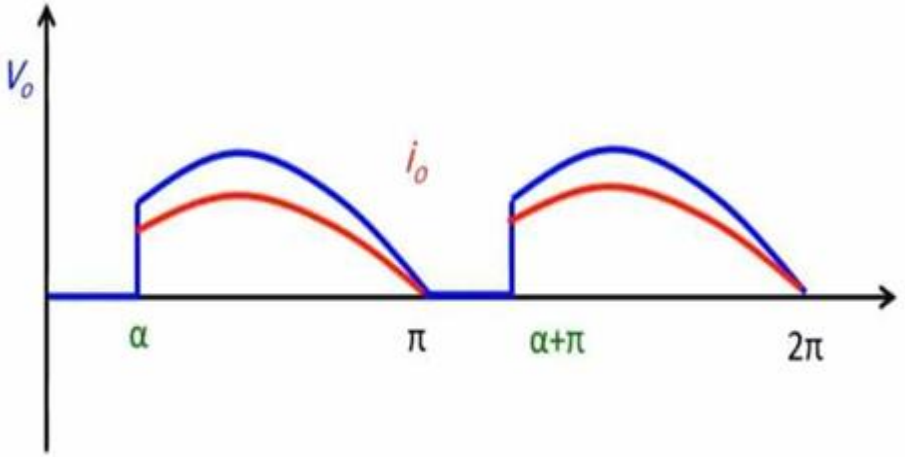
The average output current

$$I_{o,avg} = \frac{V_{o,avg}}{R}$$

The rms output voltage

$$v_{o,rms} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi} \left(V_m \sin(\omega t)\right)^2 d\omega t}$$

$$= \frac{V_m}{\sqrt{2}}\sqrt{1 - \frac{\alpha}{\pi} - \frac{\sin(2\alpha)}{2\pi}}$$



The rms output current/Supply current

$$I_{o,rms} = \frac{V_{o,rms}}{R} = I_{S,rms}$$

The rms switch current $I_{T,rms} = \frac{I_{o,rms}}{\sqrt{2}}$

The average switch current $I_{T,avg} = \frac{I_{o,avg}}{2}$

Output power and power factor

The output power

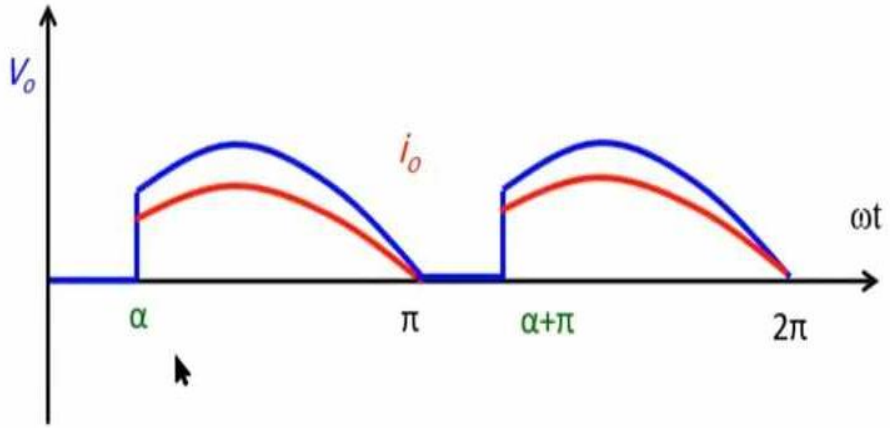
$$P_o = I_{o,rms}{}^2 R$$

The apparent power

$$S = V_{s,rms} I_{s,rms}$$

The supply power factor

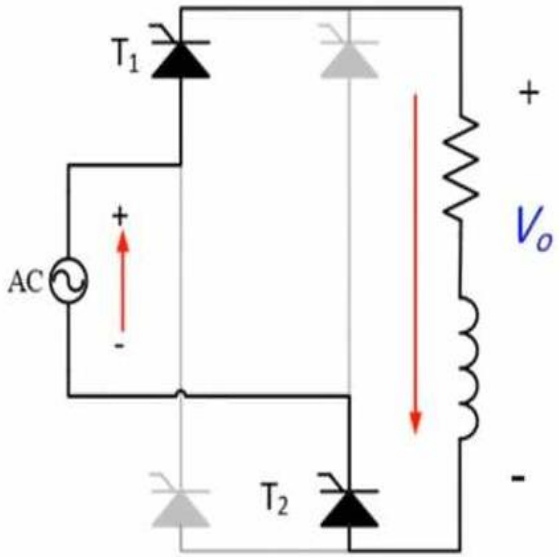
$$pf = \frac{P_o}{S}$$



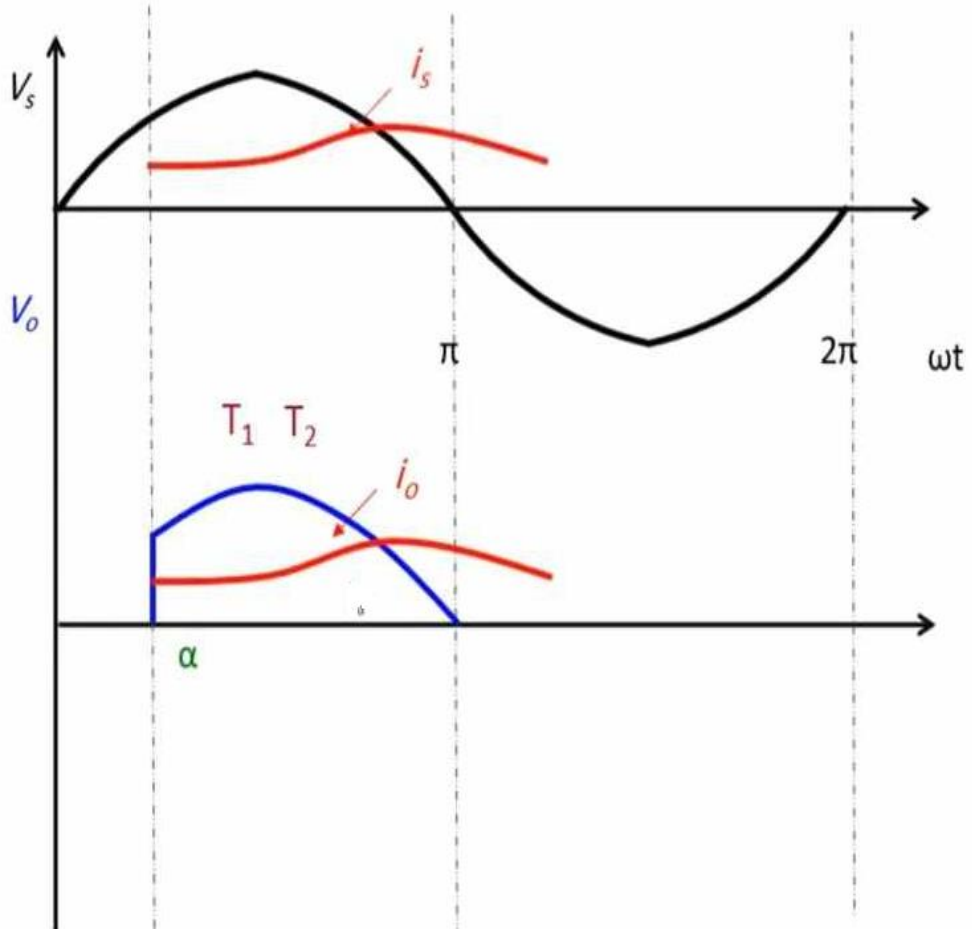
The supply power factor depends on the firing angle

Full Wave Controlled Rectifier

RL Load

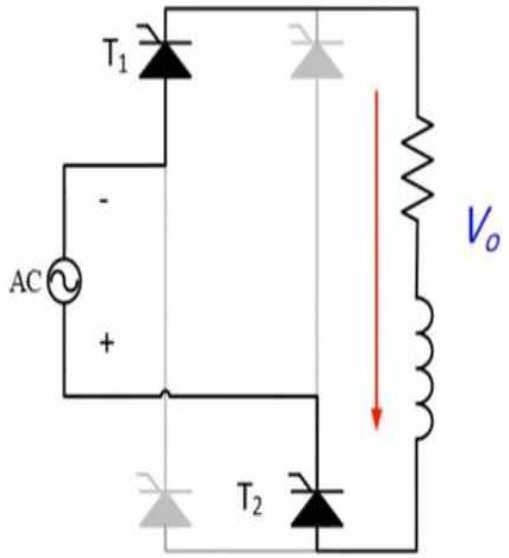


$\alpha \leq \omega t \leq \pi$

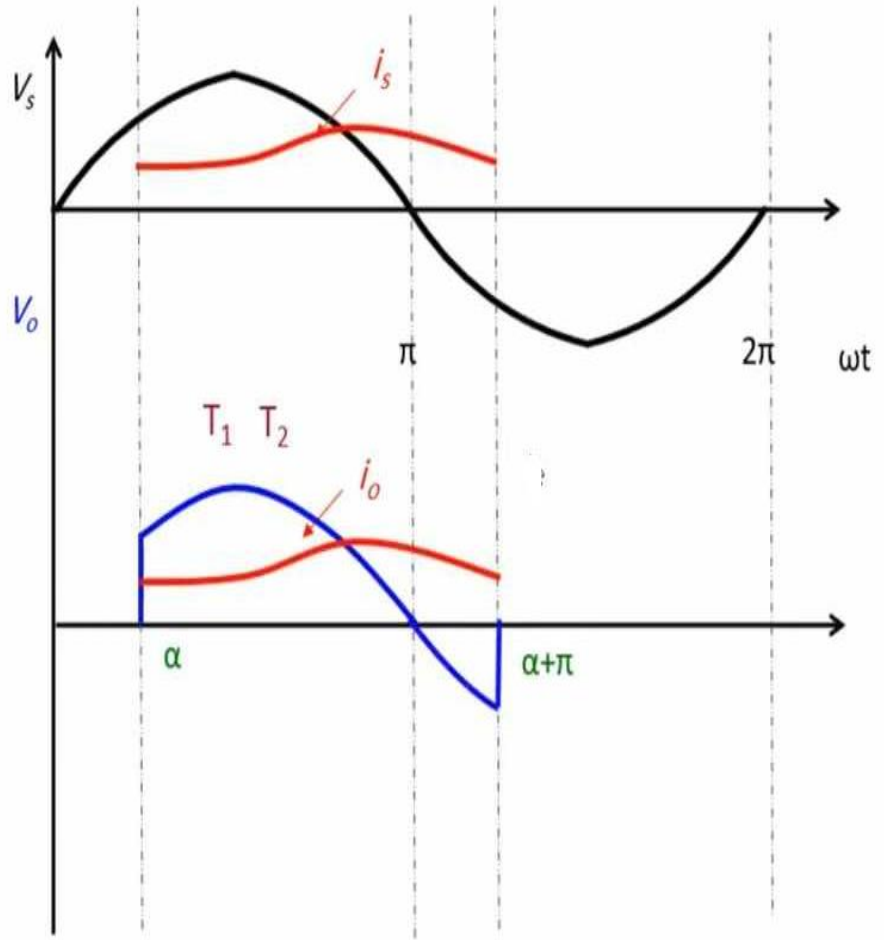


Full Wave Controlled Rectifier

RL Load

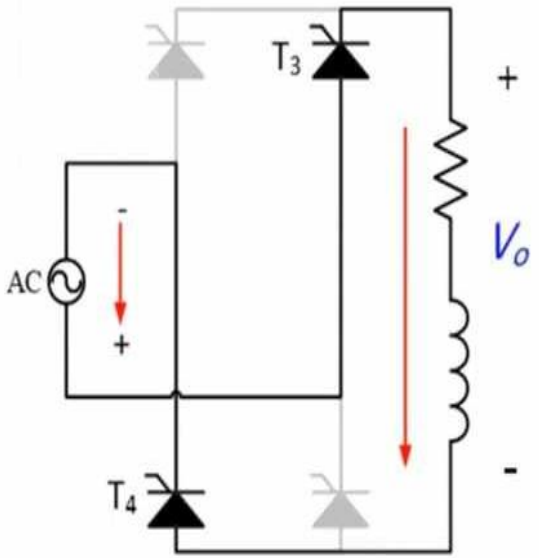


$\pi \leq \omega t \leq \alpha + \pi$

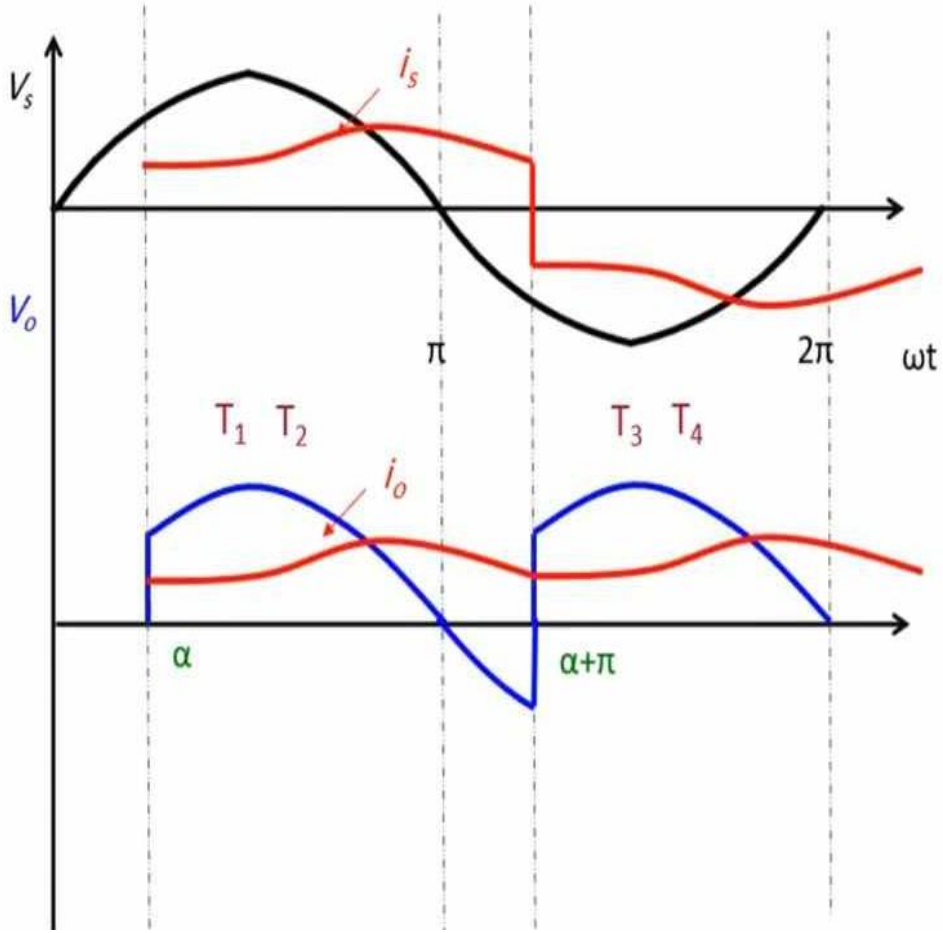


Full Wave Controlled Rectifier

RL Load

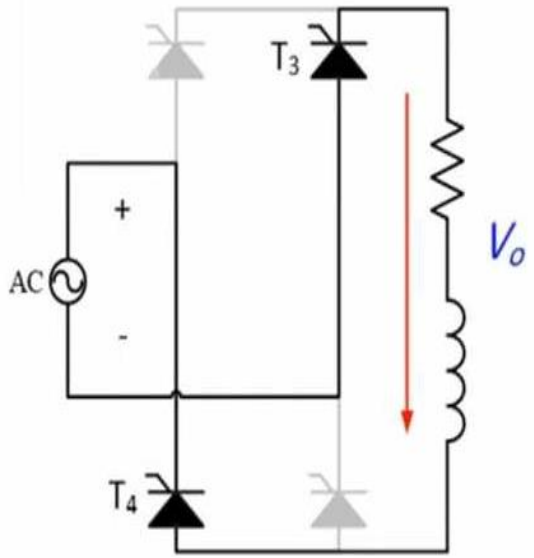


$\alpha + \pi \leq \omega t \leq 2\pi$

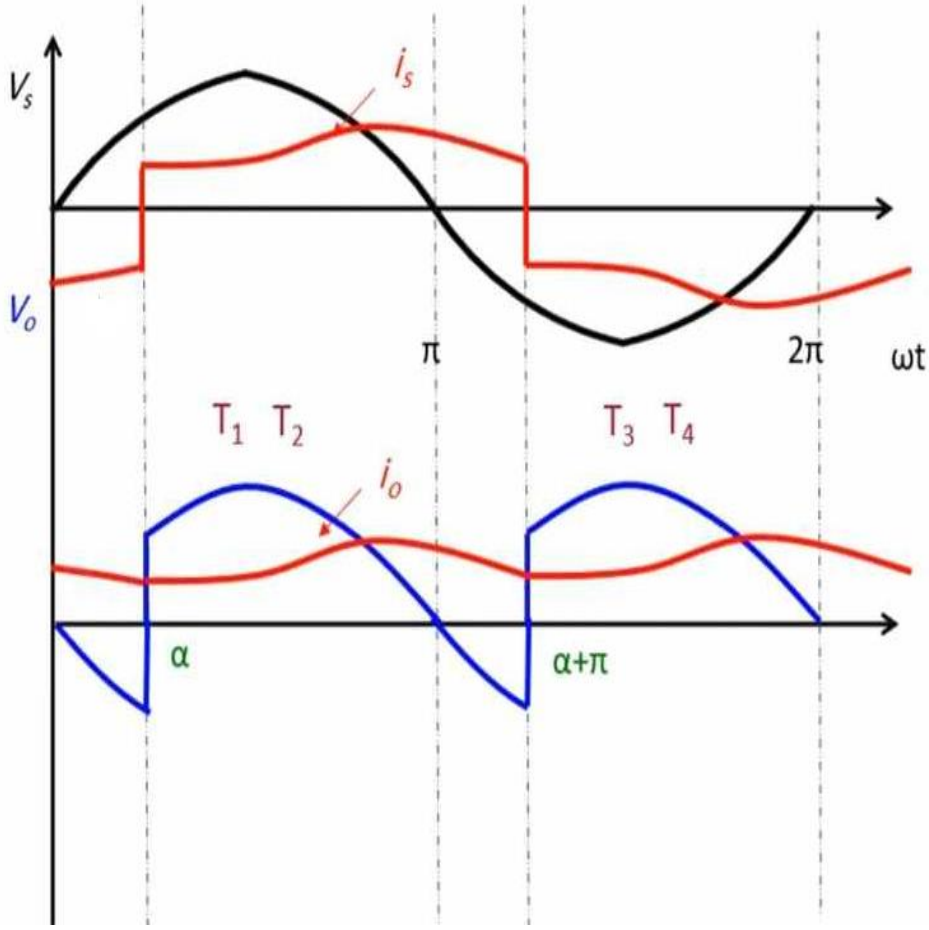


Full Wave Controlled Rectifier

RL Load



$0 \leq \omega t \leq \alpha$



Full Wave Controlled Rectifier

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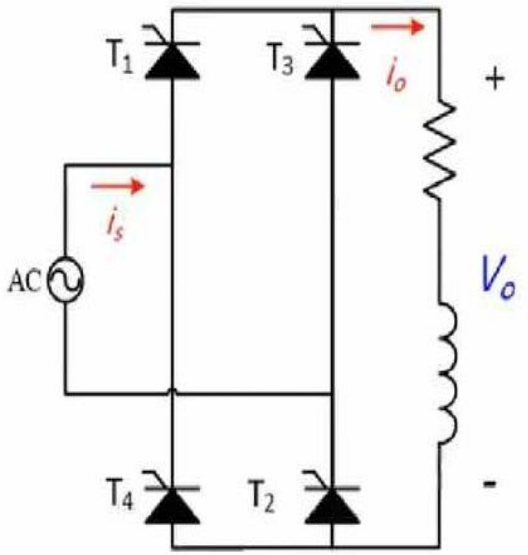
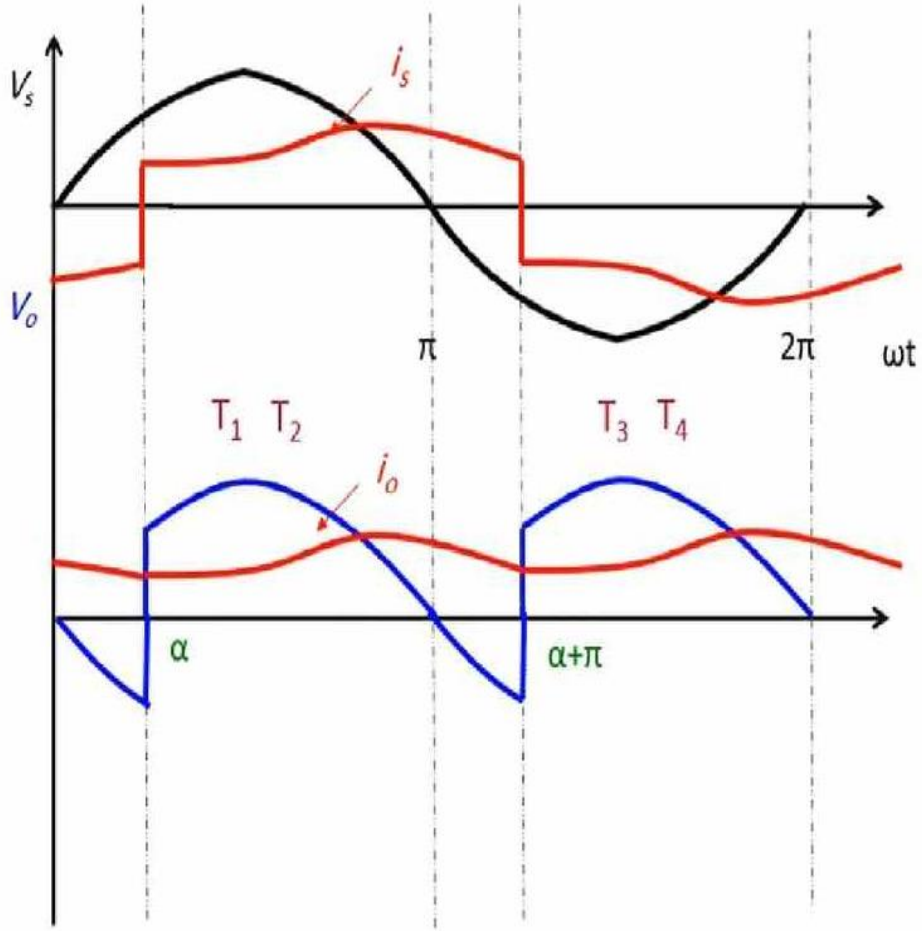


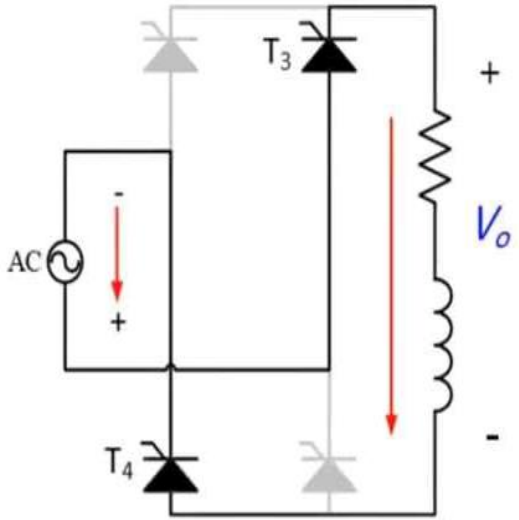


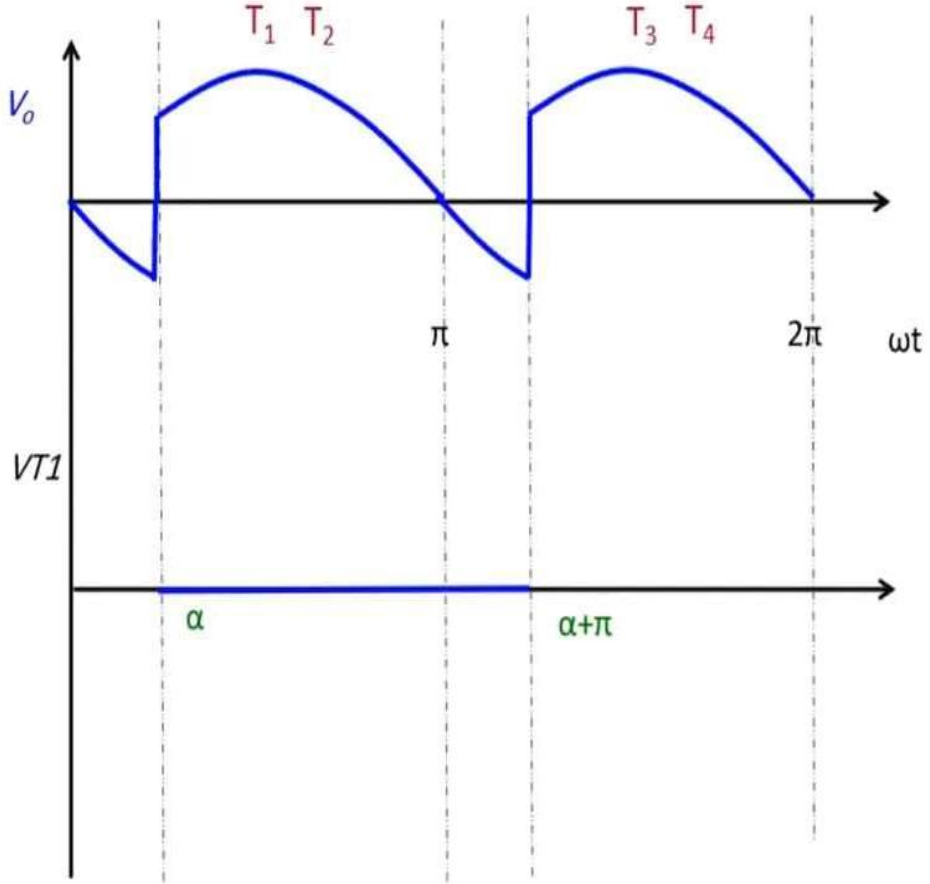
CCM

Full Wave Controlled Rectifier

RL Load

Thyristor Voltage

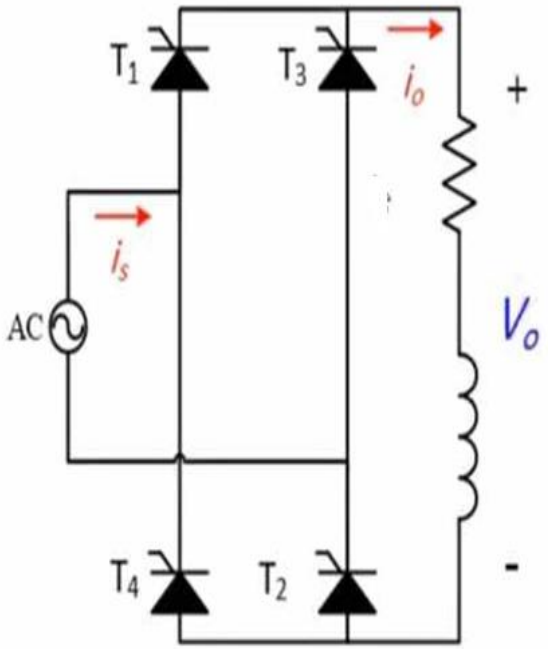


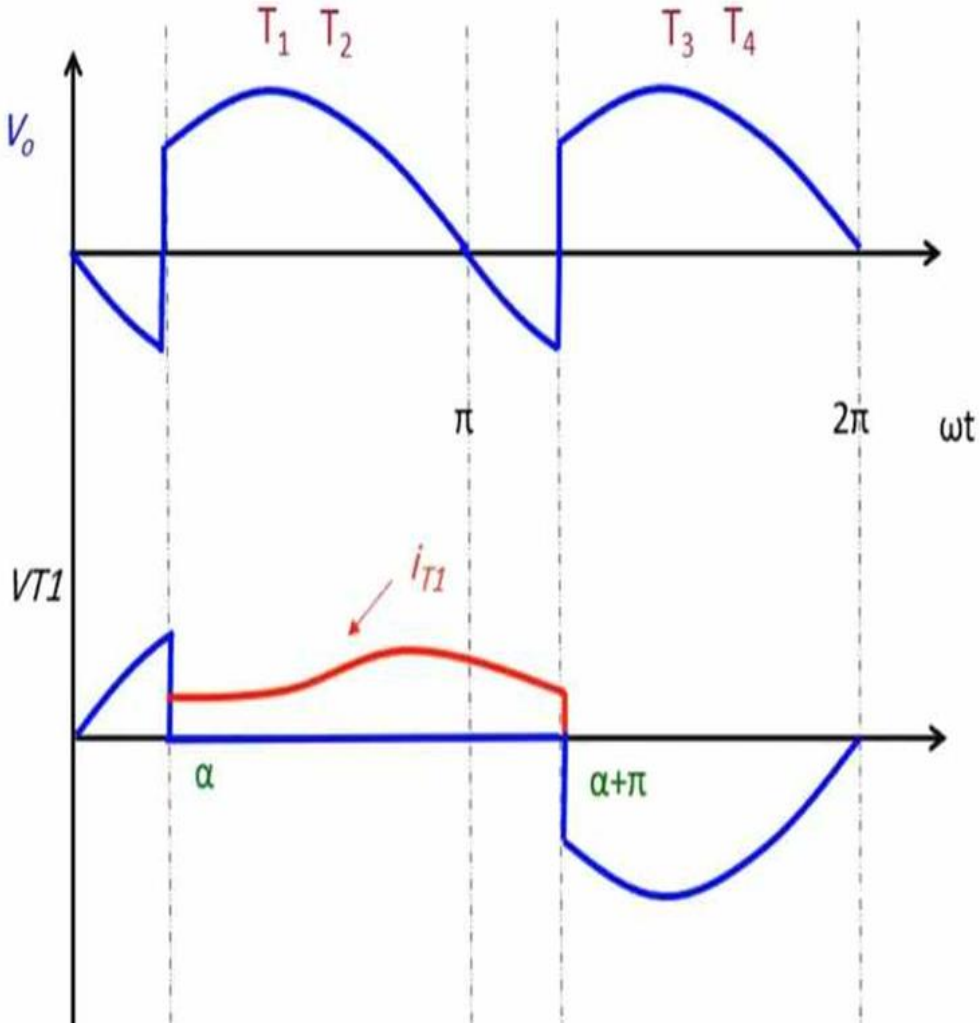


Full Wave Controlled Rectifier

RL Load

Thyristor Voltage





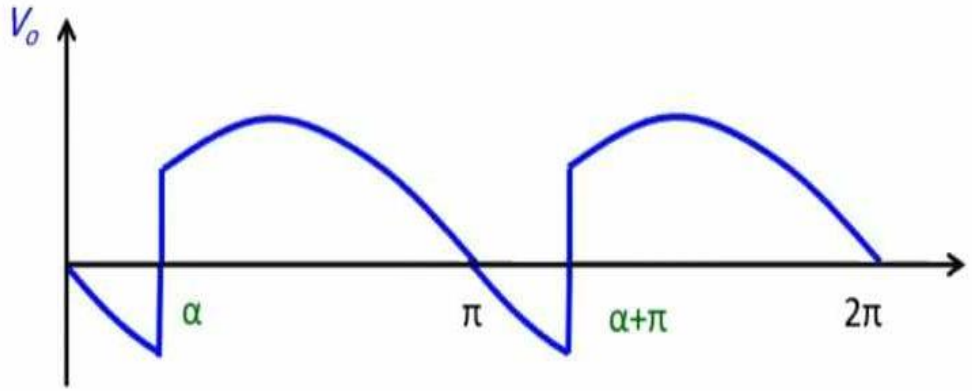
Output voltage and output current

The average output voltage

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

The average output current

$$I_{o,avg} = \frac{V_{o,avg}}{R}$$



The rms output voltage

$$v_{o,rms} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\alpha+\pi} \left(V_m \sin(\omega t)\right)^2 d\omega t} = \frac{V_m}{\sqrt{2}}$$

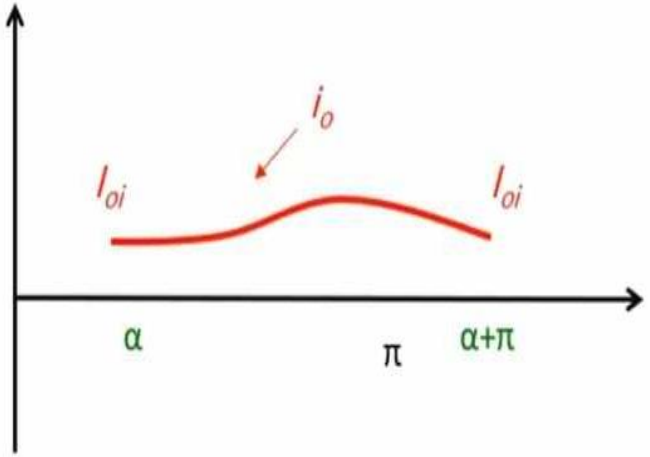
The rms output current/Supply current

$$I_{o,rms} = ??$$

Current Expression

$$\alpha \le \omega t \le \alpha + \pi$$

$$V_s = i_o R + L\frac{di_o}{dt} \qquad i_o(t) = i_{ss} + i_{tr}$$



$$i_o(t) = \frac{Vm}{Z}\sin(\omega t - \phi) + Ae^{\frac{-t}{\tau}}$$

$$i_o(t) = \frac{Vm}{Z}\sin(\omega t - \phi) + Ae^{\frac{-\omega t}{\tan(\phi)}}$$

where

$$Z = \sqrt{R^2 + (\omega L)^2}$$

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

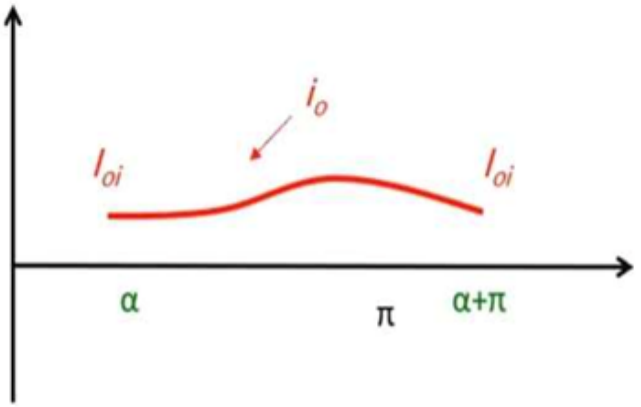
$$\tau = \frac{L}{R}$$

From initial value $\omega t = \alpha \quad i_o = I_{oi}$

$$A = I_{oi} + \frac{Vm}{Z}\sin(\phi - \alpha)e^{\frac{\alpha}{\tan(\phi)}}$$

Current Expression and Initial Current

$$i_o(t) = \frac{V_m}{Z}\left[\sin(\omega t - \phi) + \sin(\phi - \alpha)e^{\frac{\alpha - \omega t}{\tan(\phi)}}\right] + I_{oi}e^{\frac{\alpha - \omega t}{\tan(\phi)}}$$



Initial Current

$$\omega t = \alpha + \pi \quad i_o = I_{oi}$$

$$I_{oi} = \frac{V_m \sin(\phi - \alpha)}{Z}\frac{1 + e^{\frac{-\pi}{\tan(\phi)}}}{1 - e^{\frac{-\pi}{\tan(\phi)}}}$$

Output power and power factor

The output power

$$P_o = I_{o,rms}^{\,2} R$$

The rms output current/Supply current

The apparent power

$$S = V_{s,rms} I_{s,rms}$$

$$I_{o,rms} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\alpha+\pi}\left(\frac{V_m}{Z}\left[\sin(\omega t-\phi)+\sin(\phi-\alpha)e^{\frac{\alpha-\omega t}{\tan(\phi)}}\right]+I_{ot}e^{\frac{\alpha-\omega t}{\tan(\phi)}}\right)^2 d\omega t}$$

By calculator

The supply power factor

The rms switch current

$$I_{T,rms} = \frac{I_{o,rms}}{\sqrt{2}}$$

$$pf = \frac{P_o}{S}$$

Check Continuity of the Load Current

$$I_{oi} = \frac{V_m \sin(\phi - \alpha)}{Z} \frac{1 + e^{\frac{-\pi}{\tan(\phi)}}}{1 - e^{\frac{-\pi}{\tan(\phi)}}} \longrightarrow I_{oi} \begin{cases} \geq 0 & Continuous \\ < 0 & discontinuous \end{cases}$$

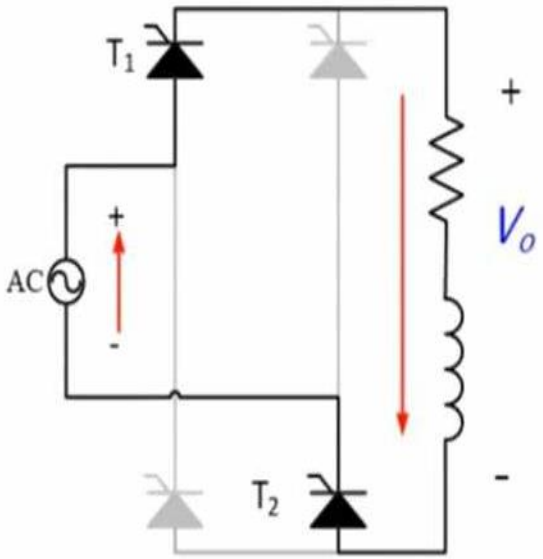
Another check

$\phi \geq \alpha$ *Continuous*

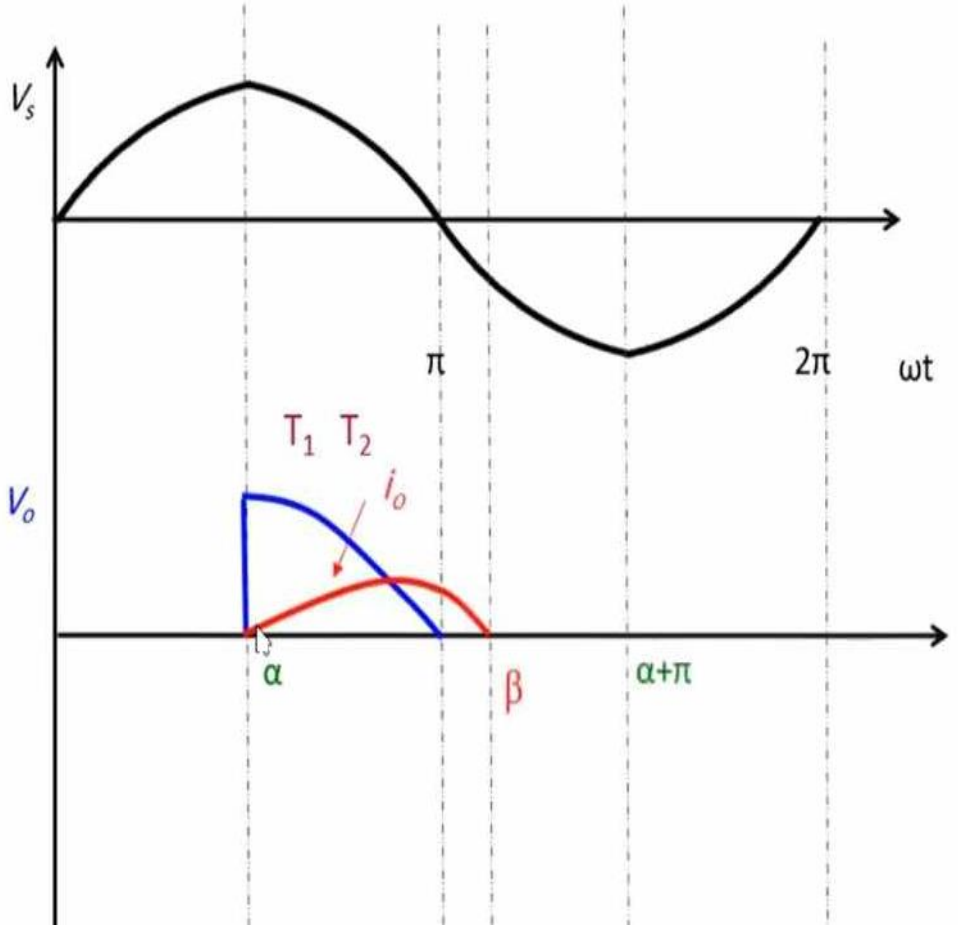
$\phi < \alpha$ *discontinuous*

Full Wave Controlled Rectifier

RL Load



$\alpha \leq \omega t \leq \pi$



Full Wave Controlled Rectifier

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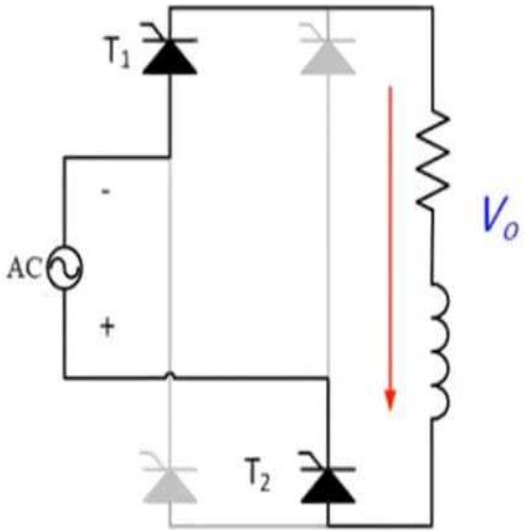
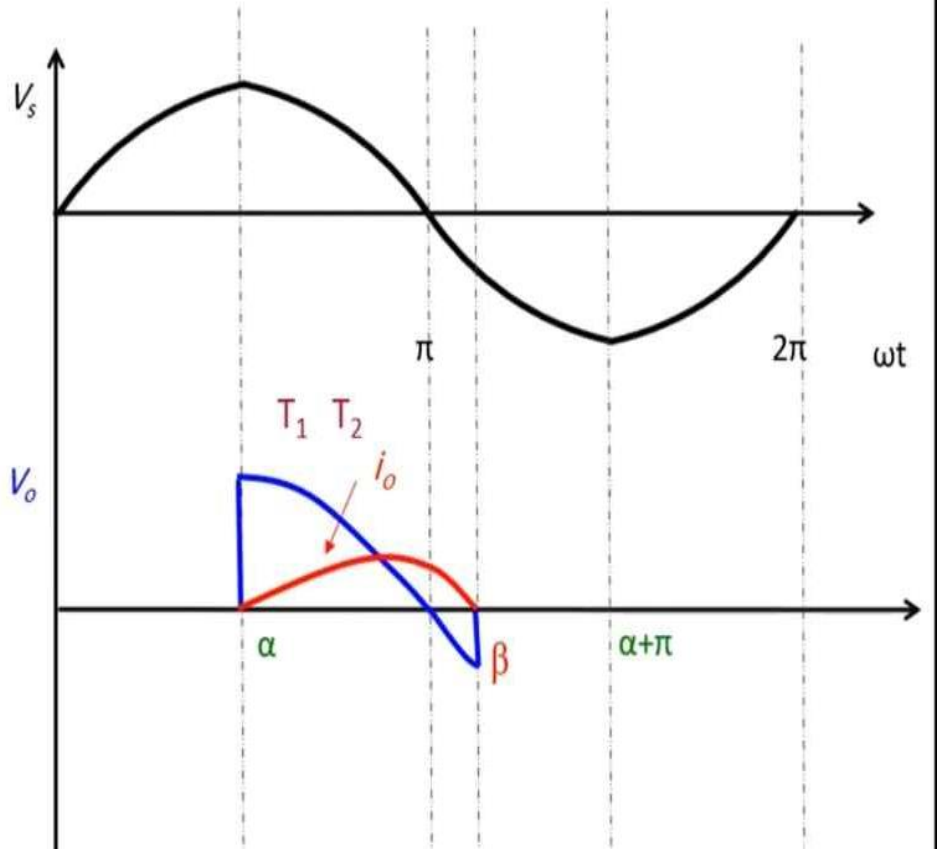
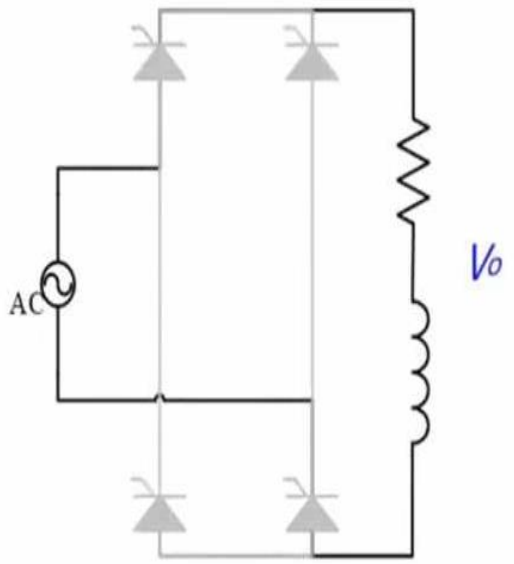


$\pi \leq \omega t \leq \beta$

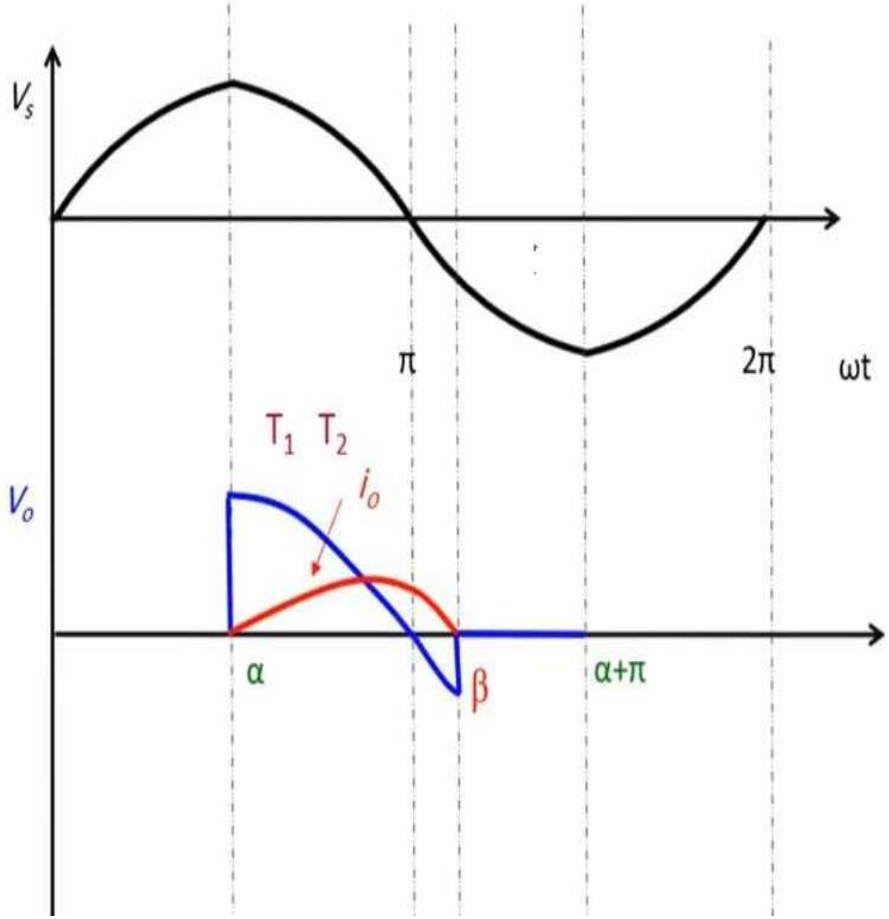


Full Wave Controlled Rectifier

RL Load



$\beta \leq \omega t \leq \alpha + \pi$



Full Wave Controlled Rectifier

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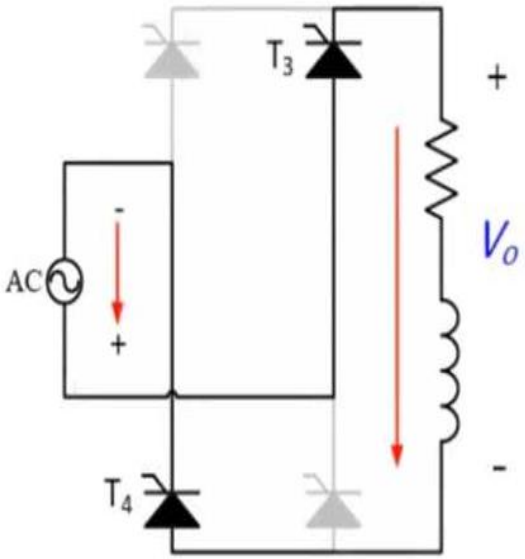
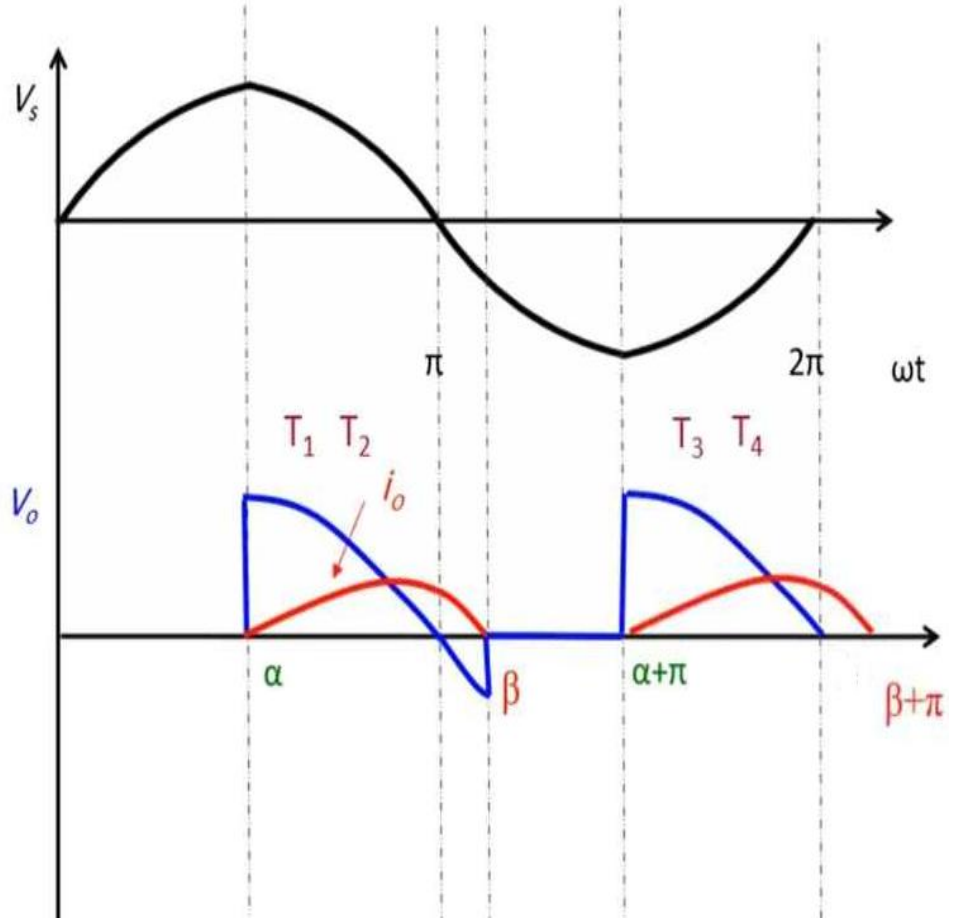


$\alpha + \pi \leq \omega t \leq 2\pi$



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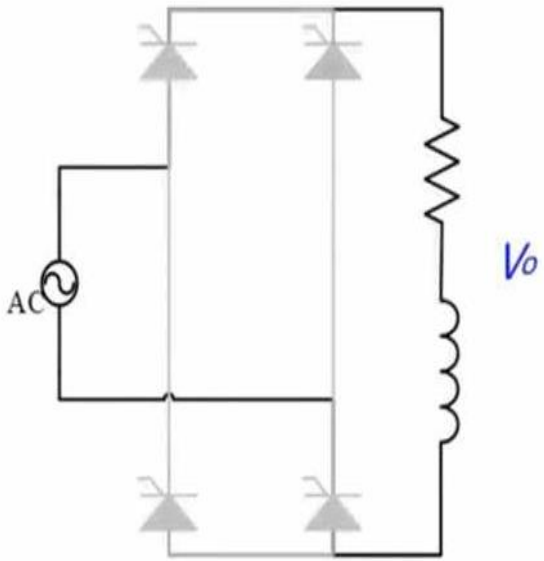
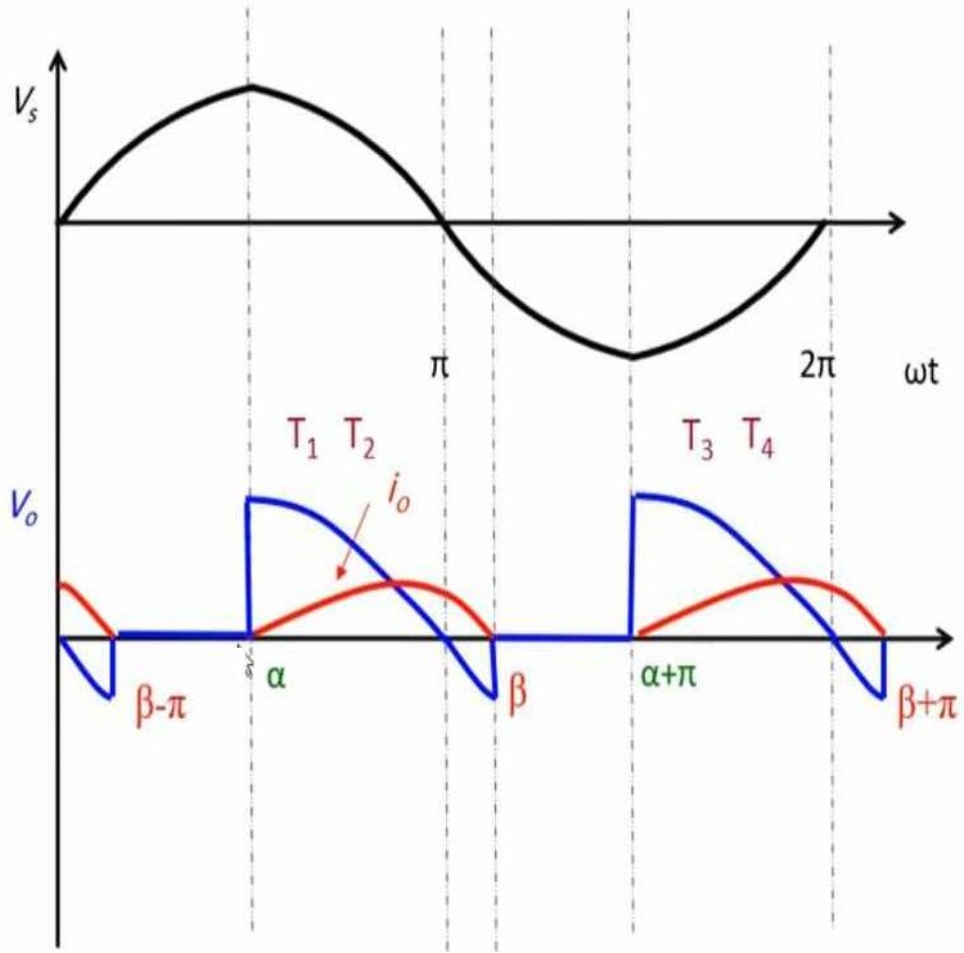


$$\beta - \pi \leq \omega t \leq \alpha$$



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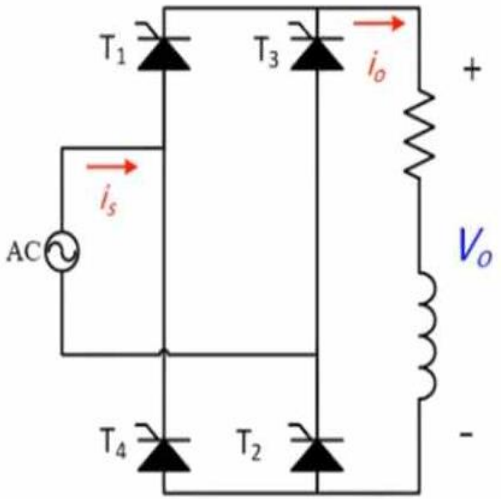
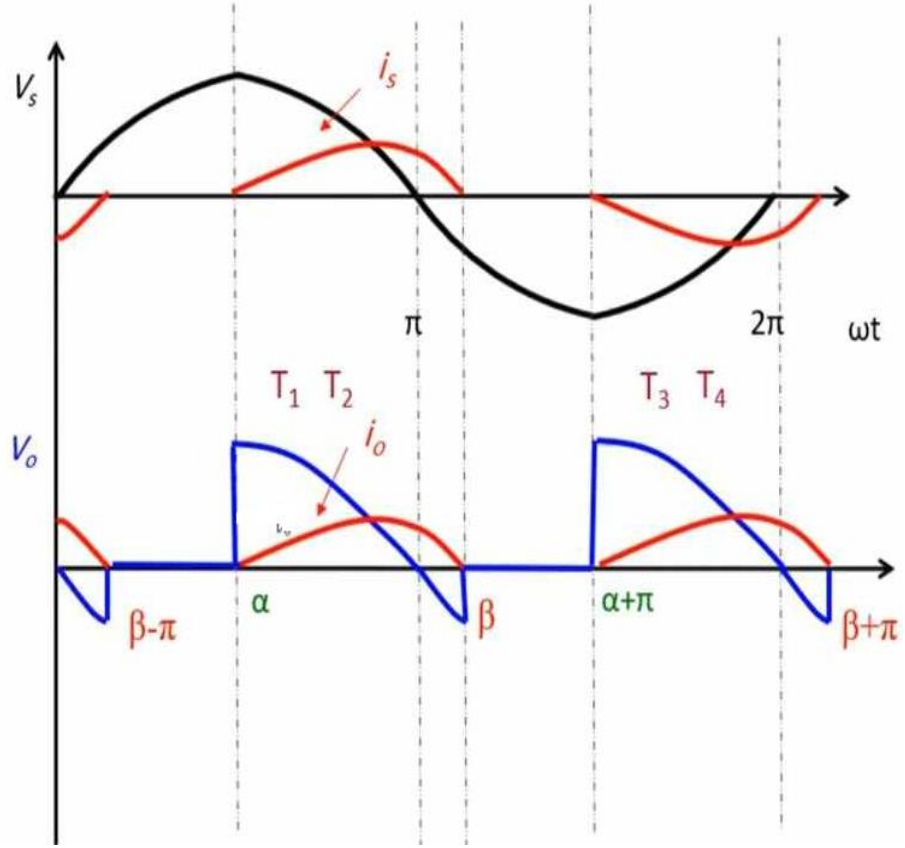
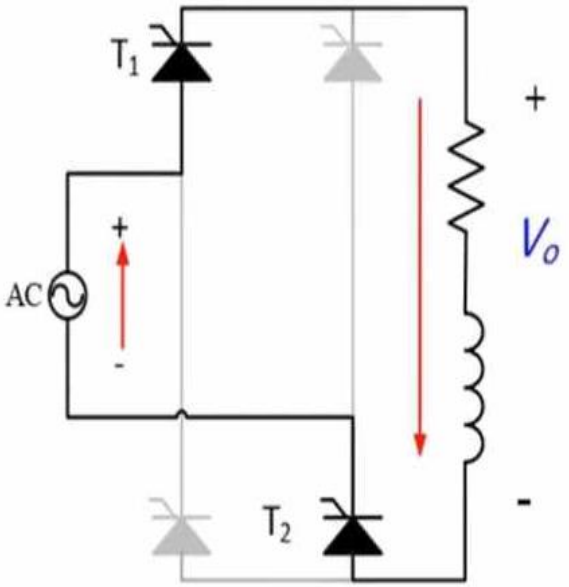


DCM

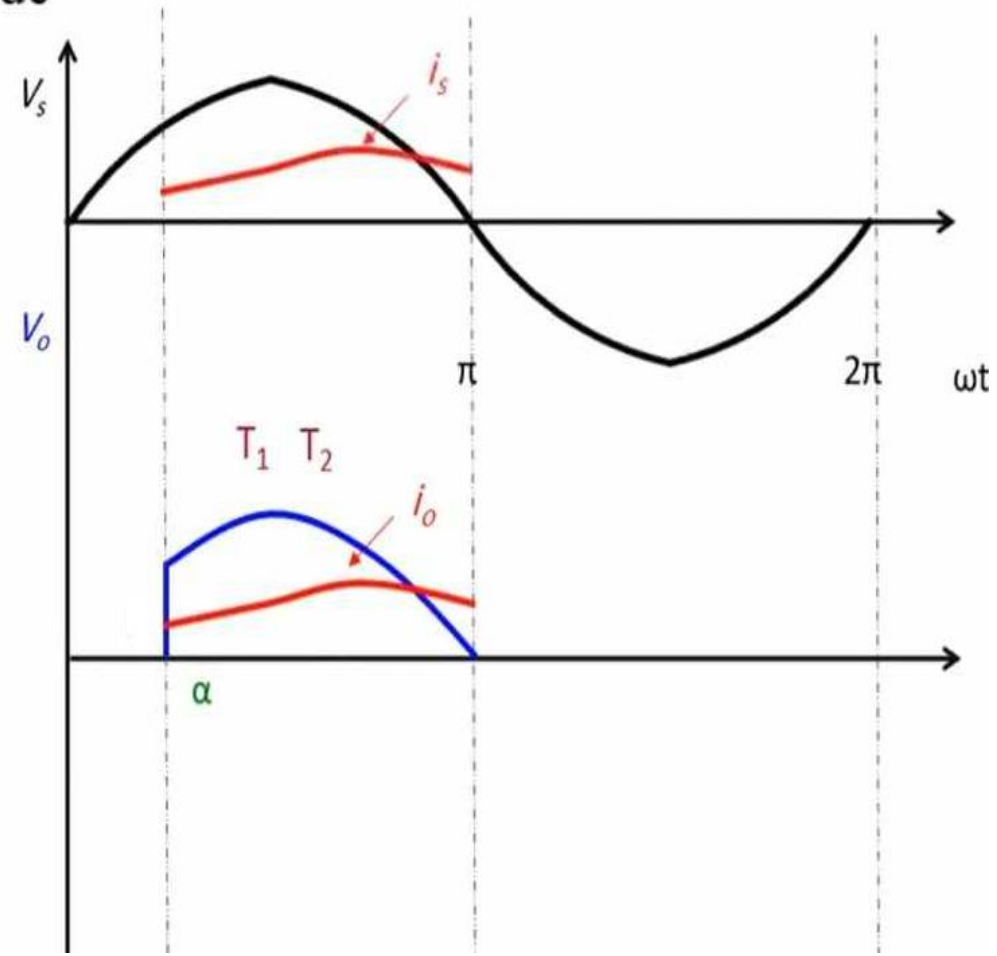


Full Wave Controlled Rectifier

RL Load with Free-Wheeling Diode

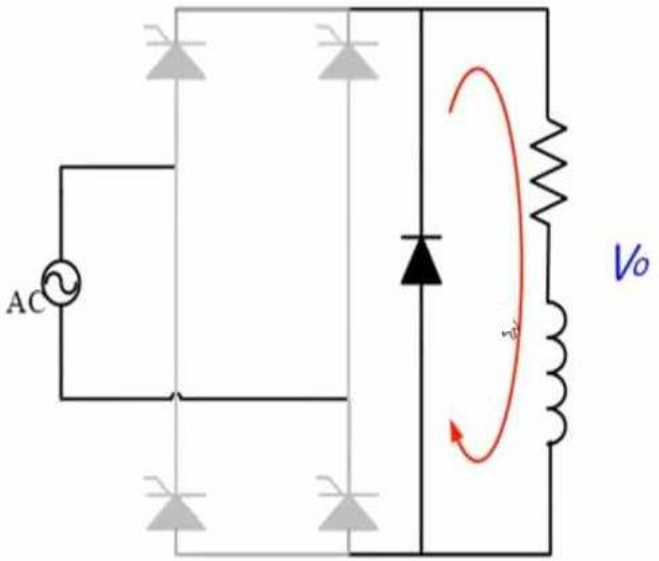


$\alpha \leq \omega t \leq \pi$

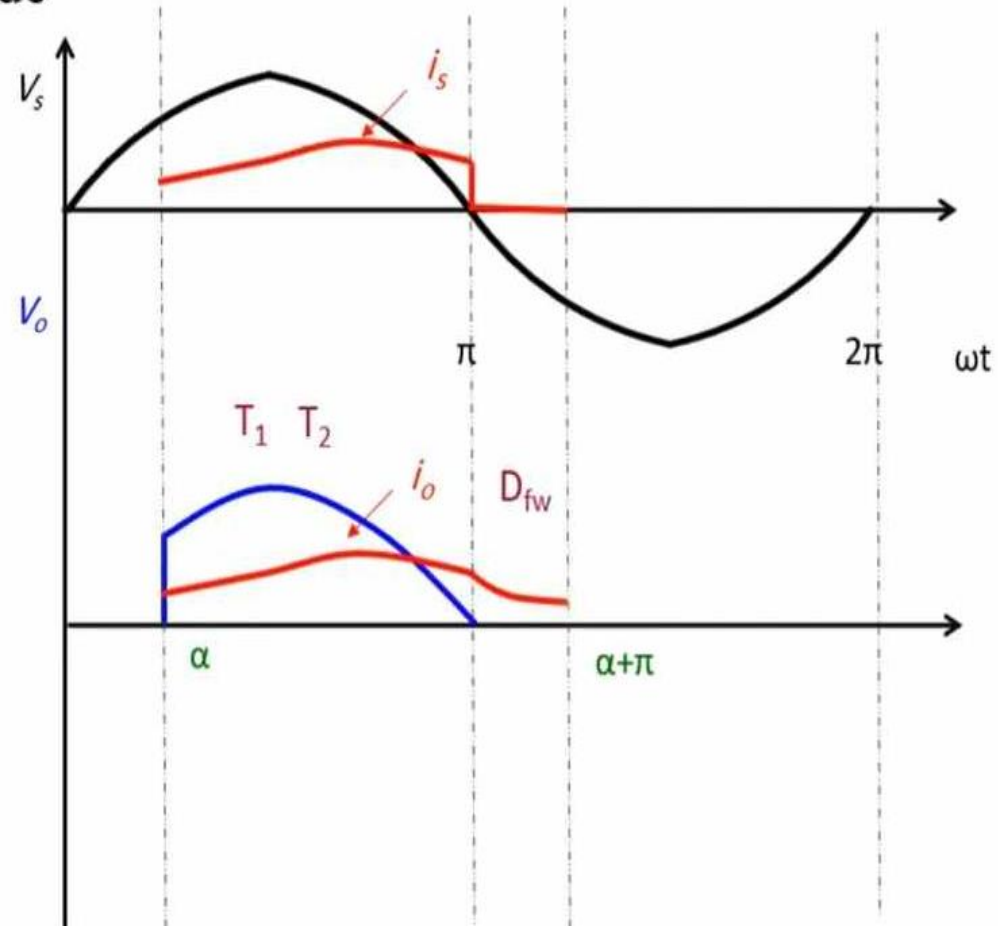


Full Wave Controlled Rectifier

RL Load with Free-Wheeling Diode

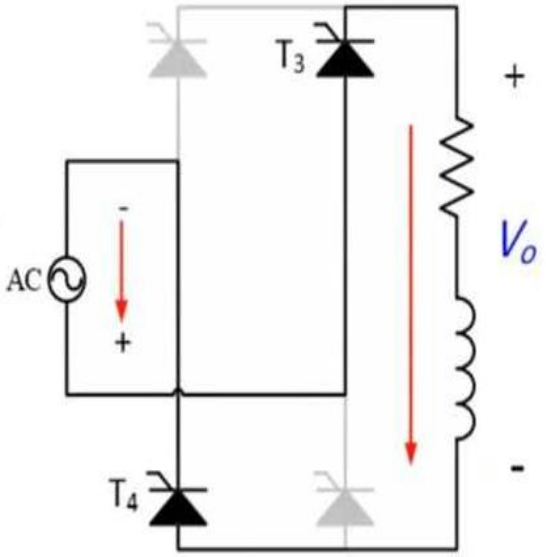


$\pi \leq \omega t \leq \alpha + \pi$

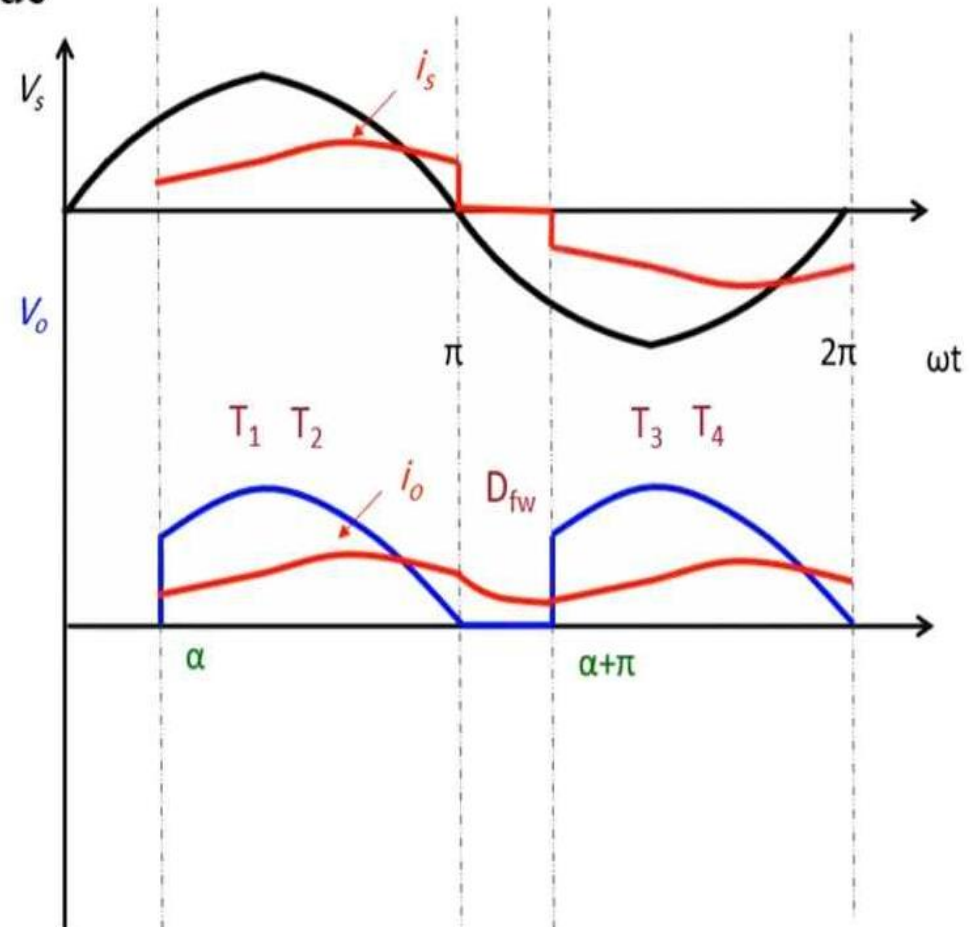


Full Wave Controlled Rectifier

RL Load with Free-Wheeling Diode

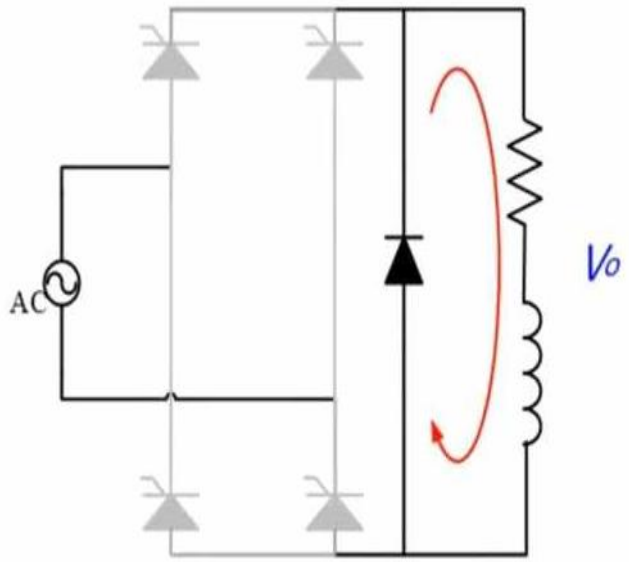


$$\alpha + \pi \leq \omega t \leq 2\pi$$



Full Wave Controlled Rectifier

RL Load with Free-Wheeling Diode



$0 \leq \omega t \leq \alpha$