EE-463 STATIC POWER CONVERSION-I

Controlled Rectifiers

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Thyristor Rectifiers

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- HVDC Transmission Systems

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- DC Motor Drives

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- Traction Applications

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- HVDC Transmission Systems
- DC Motor Drives
- Traction Applications
- Industrial Loads (Welding, Heating etc)

Thyristor Rectifiers

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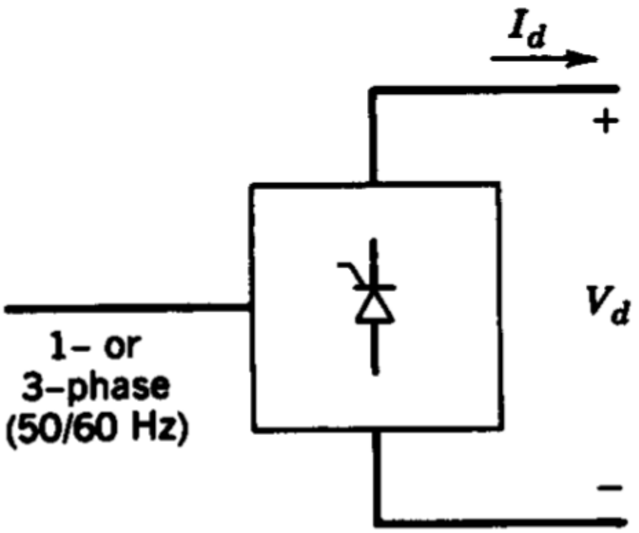
General Schematic



Thyristor Rectifiers

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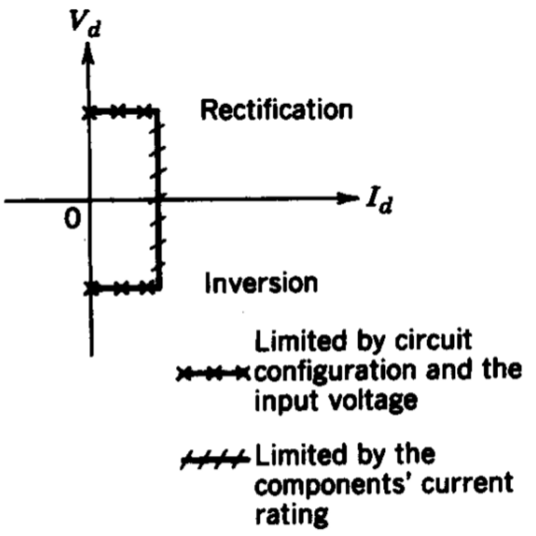
Operating Quadrants

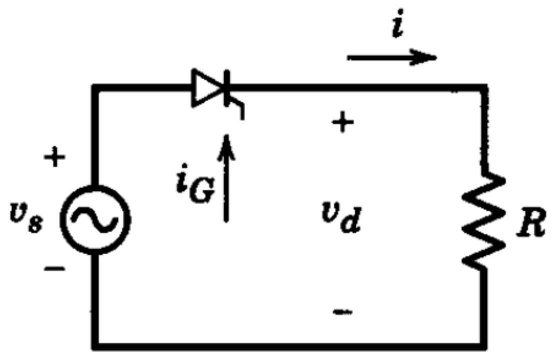


Capable of supplying negative Vd (Q4, Inversion)

Simple Circuits

Simple Circuits

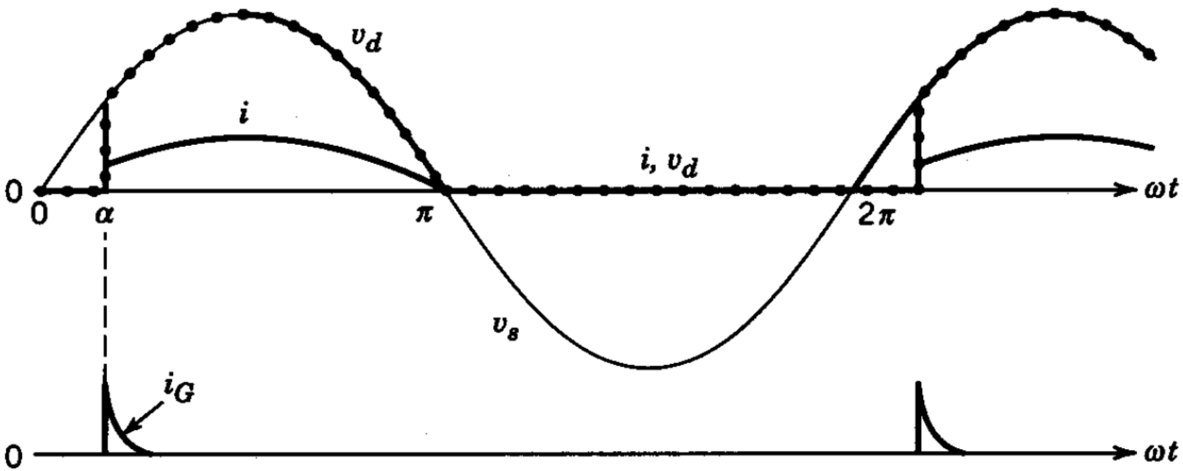
Thyristor with R load



Can you plot the voltage output?

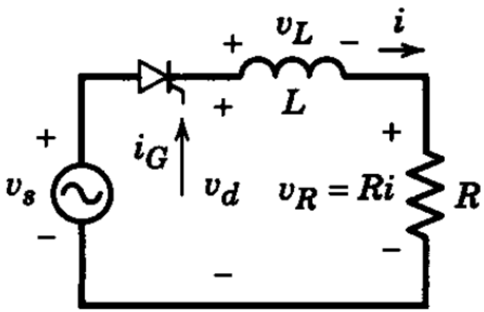
Simple Circuits

Thyristor with R load



Simple Circuits

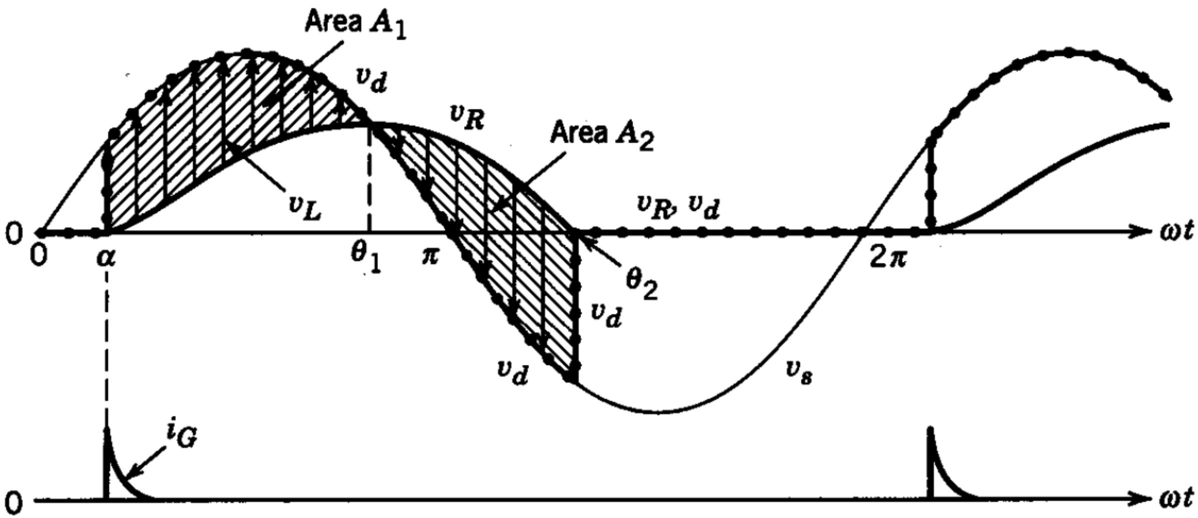
Thyristor with RL load



Can you plot the voltage output?

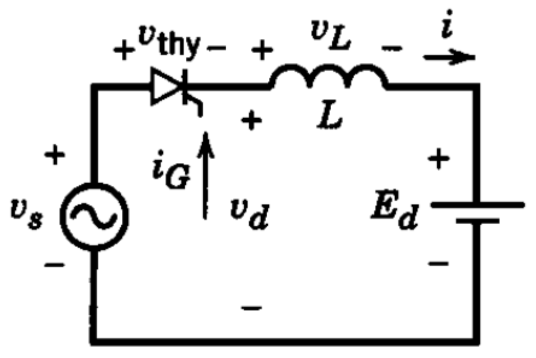
Simple Circuits

Thyristor with RL load



Simple Circuits

Load with DC Source



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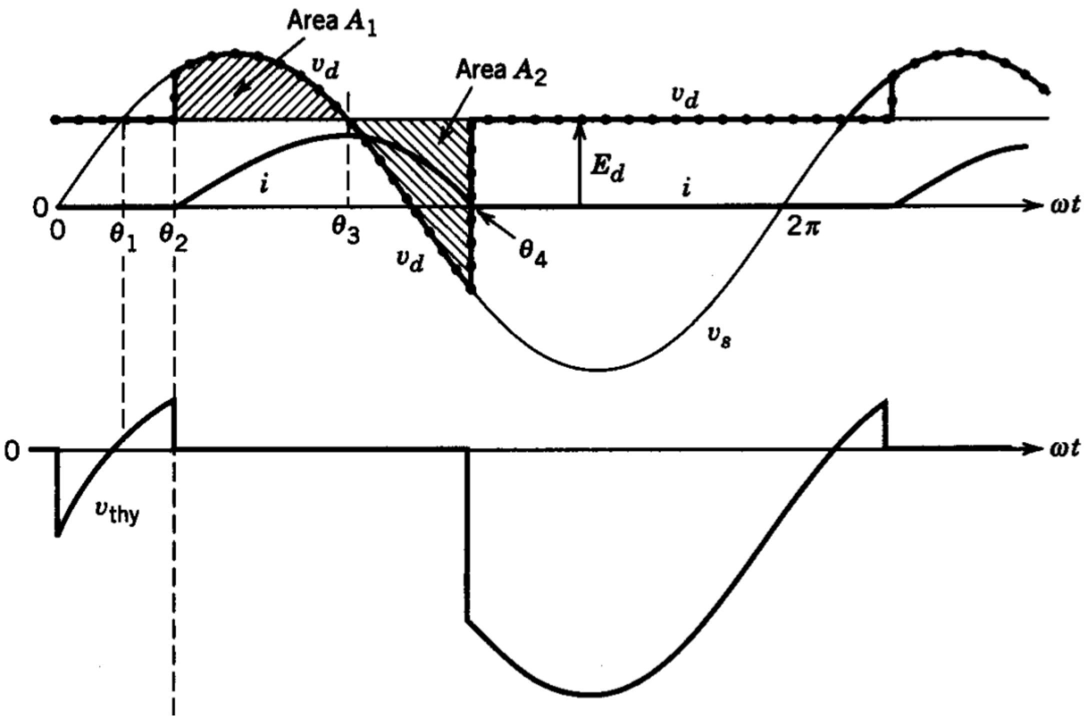
Load with DC Source



Thyristor with RL load

but let's add a freewheeling diode

Thyristor with RL load

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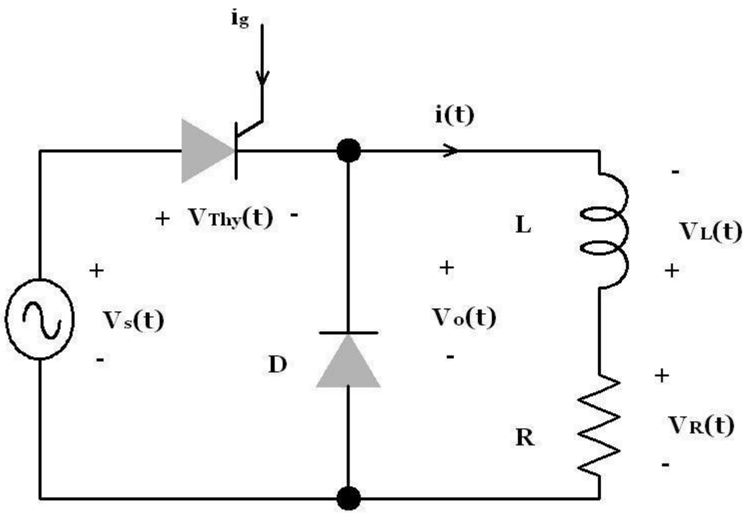
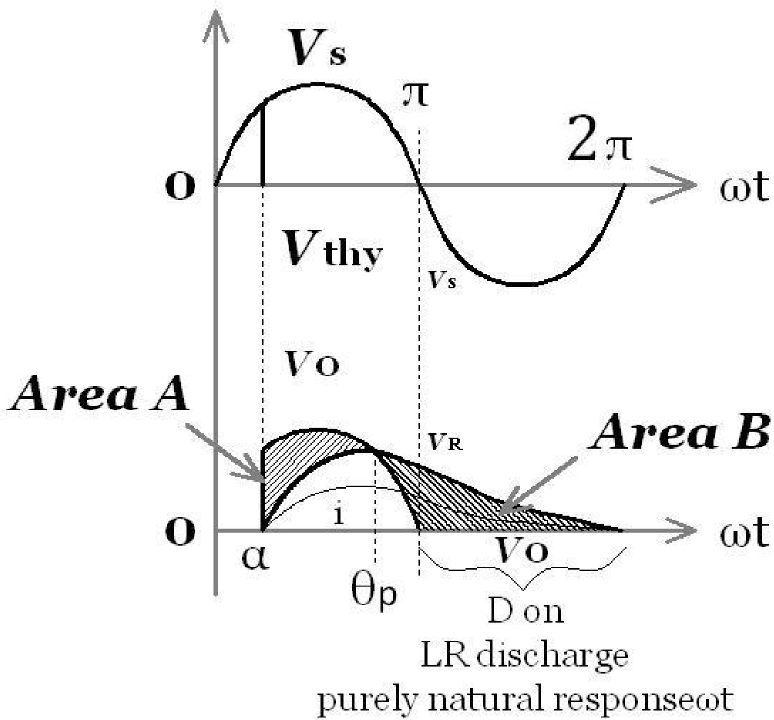


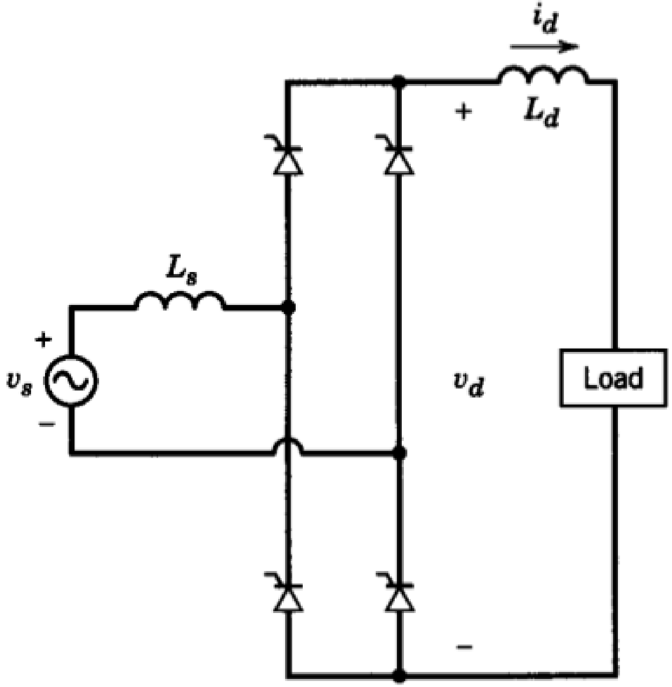
Thyristor with freewheeling diode

Thyristor with freewheeling diode



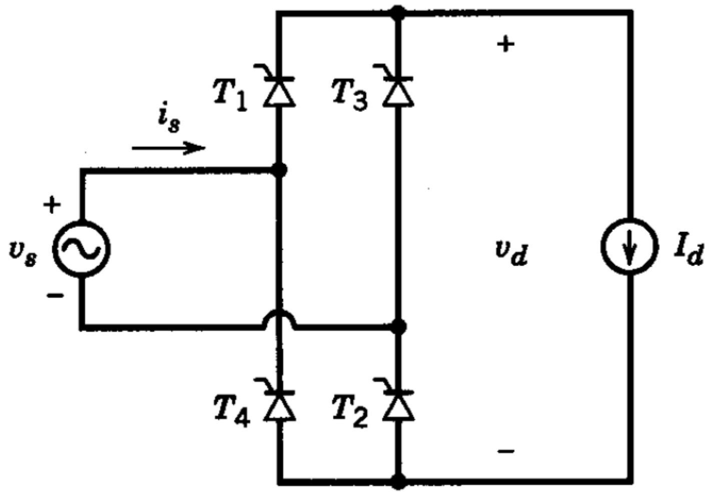
Single Phase Thyristor Rectifier

Single Phase Thyristor Rectifier



Single Phase Thyristor Rectifier

Ideal Case



Can you plot the output voltages?

It is identical to diode rectifier with $\alpha = 0$

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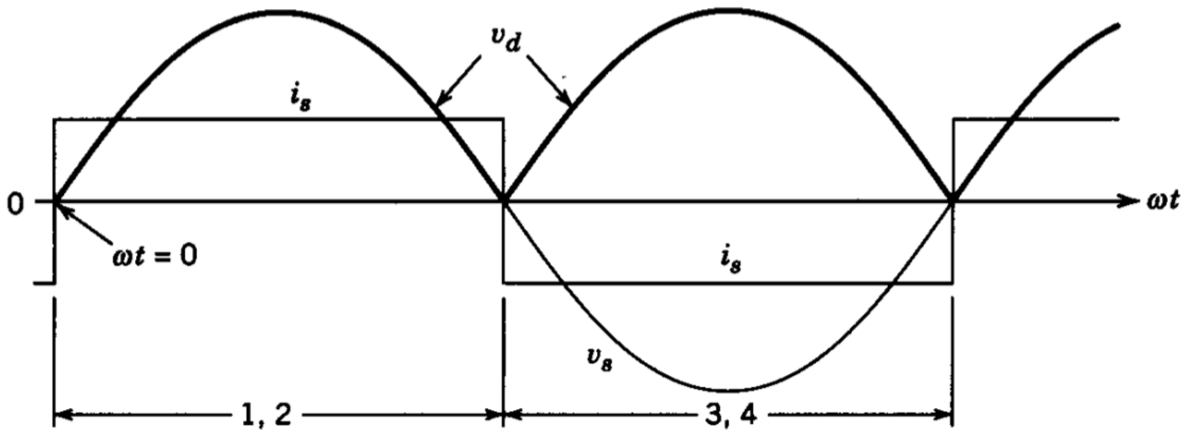

(a) $\alpha = 0$

What about with a large firing angle?

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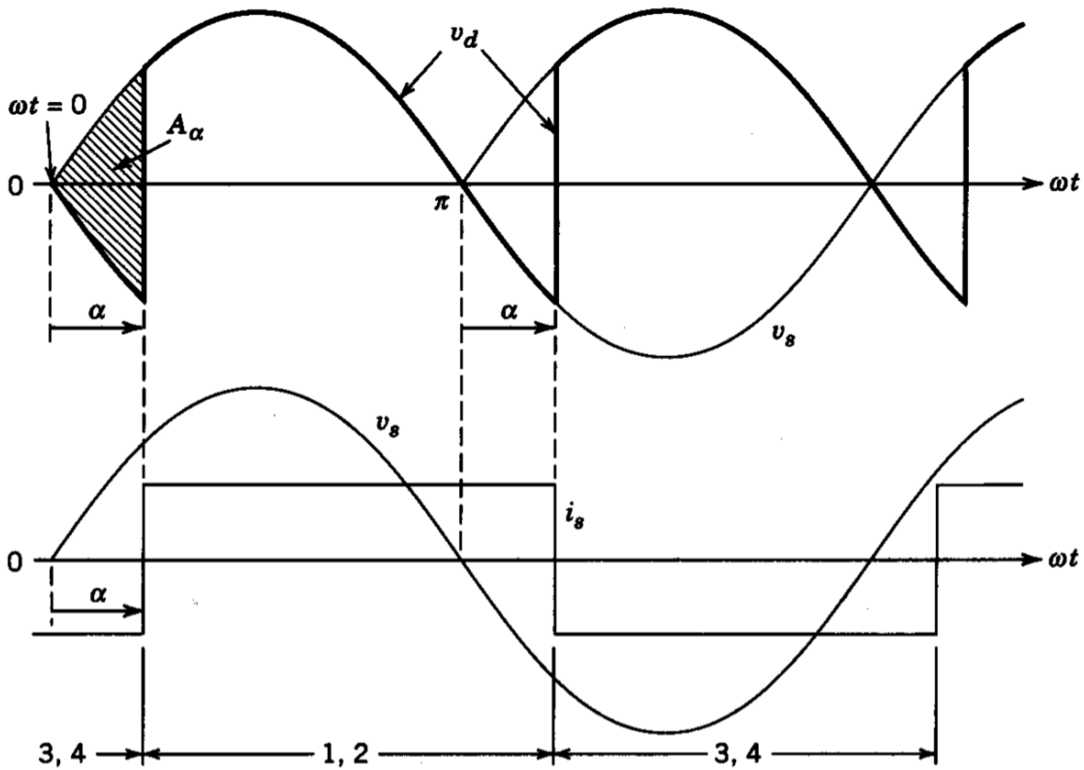

How can you calculate the average voltage?

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$$Vd_\alpha = \frac{2\sqrt{2}Vs}{\pi}cos(\alpha)$$

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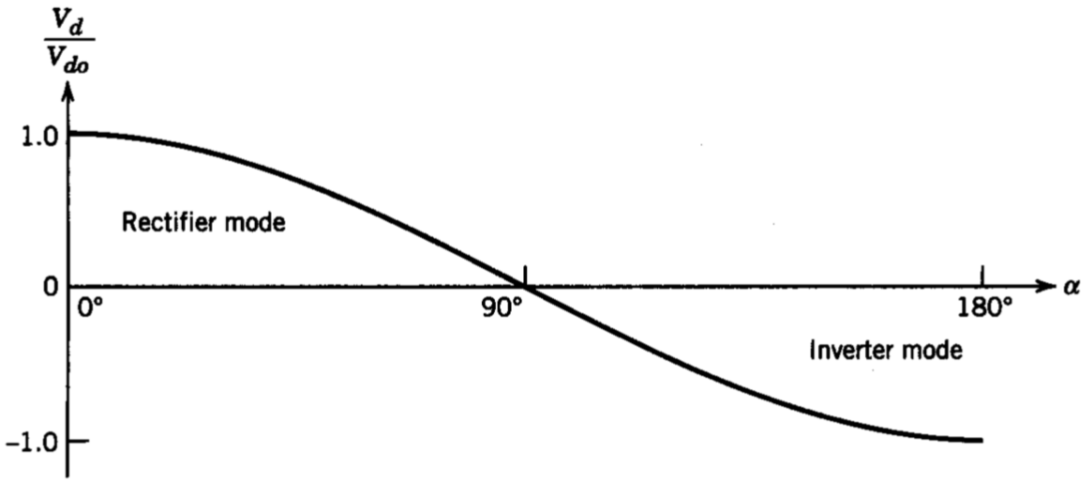
- $\alpha < \pi/2 \rightarrow Vd > 0$

How can you calculate the average voltage?

$$Vd_\alpha = \frac{2\sqrt{2}Vs}{\pi} cos(\alpha)$$

- $\alpha = 0 \rightarrow$ Diode rectifier
- $\alpha < \pi/2 \rightarrow Vd > 0$
- $\alpha > \pi/2 \rightarrow Vd < 0$

Operating Modes



Power Flow

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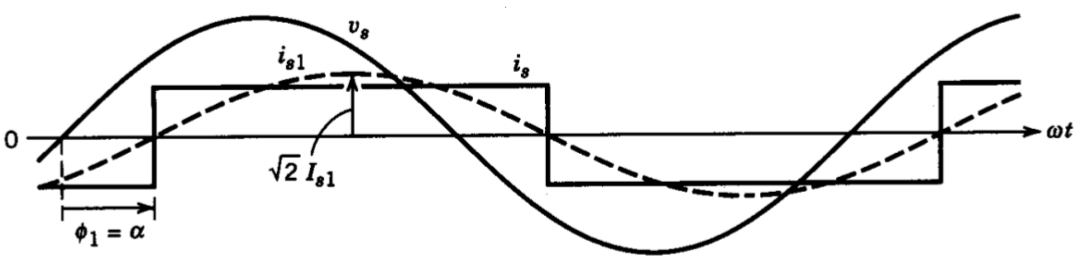
$$P = \frac{1}{T}\int p(t)dt$$

Power Flow

$$P = \frac{1}{T} \int p(t)dt$$

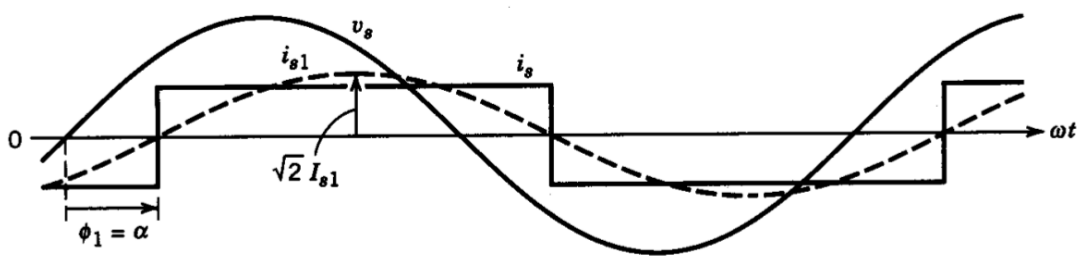
$$P = I_d \frac{1}{T} \int v_d(t)dt = 0.9 V_s I_d cos(\alpha)$$

Line Current



Shifted by α, but still a square wave

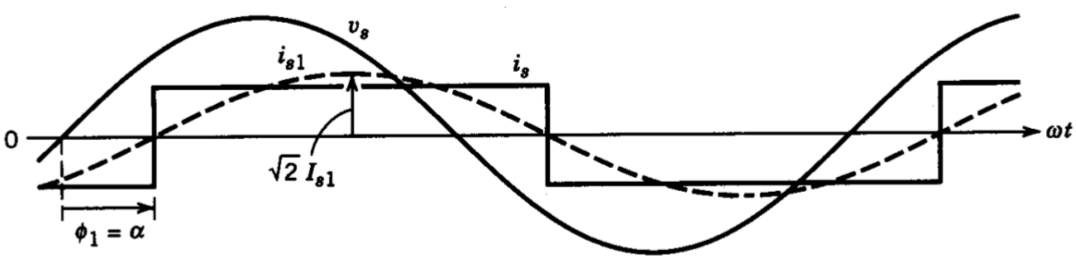
Line Current



Shifted by α, but still a square wave

Harmonics, THD, I1?

Line Current



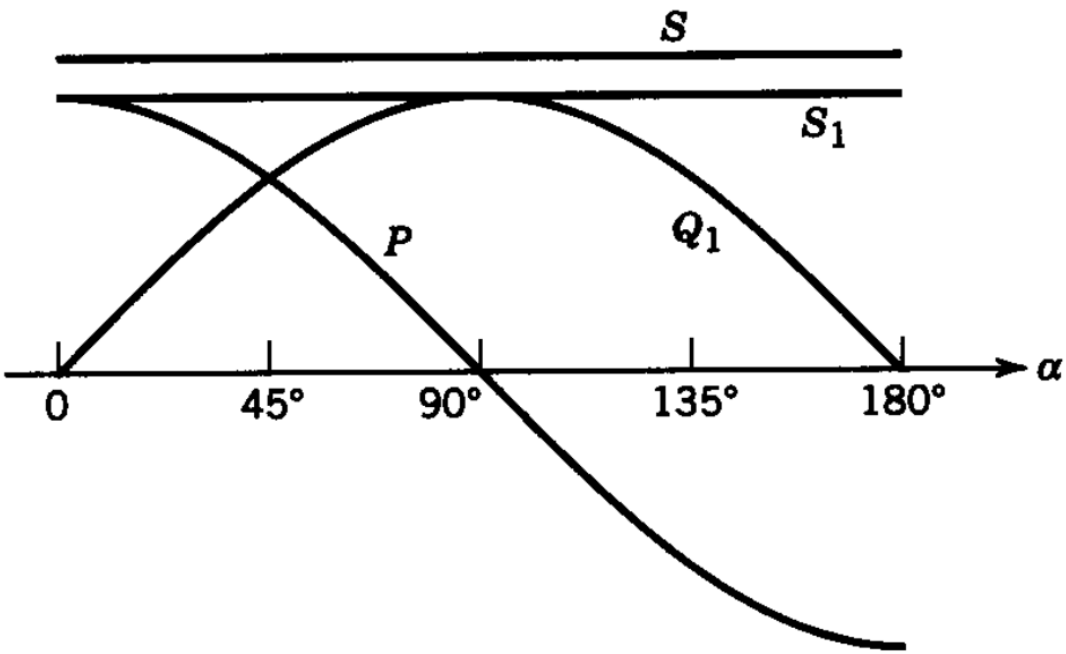
Shifted by α, but still a square wave

Harmonics, THD, I1?

What about PF, DPF?

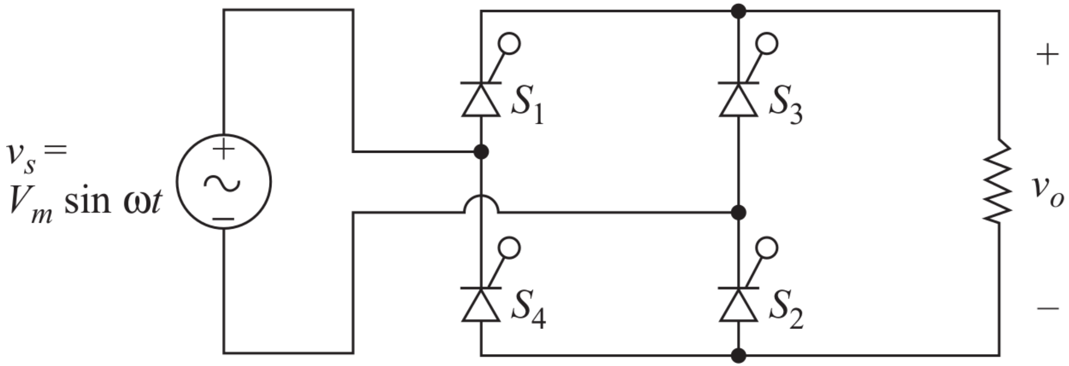
Real Power, Apparent Power

Real Power, Apparent Power



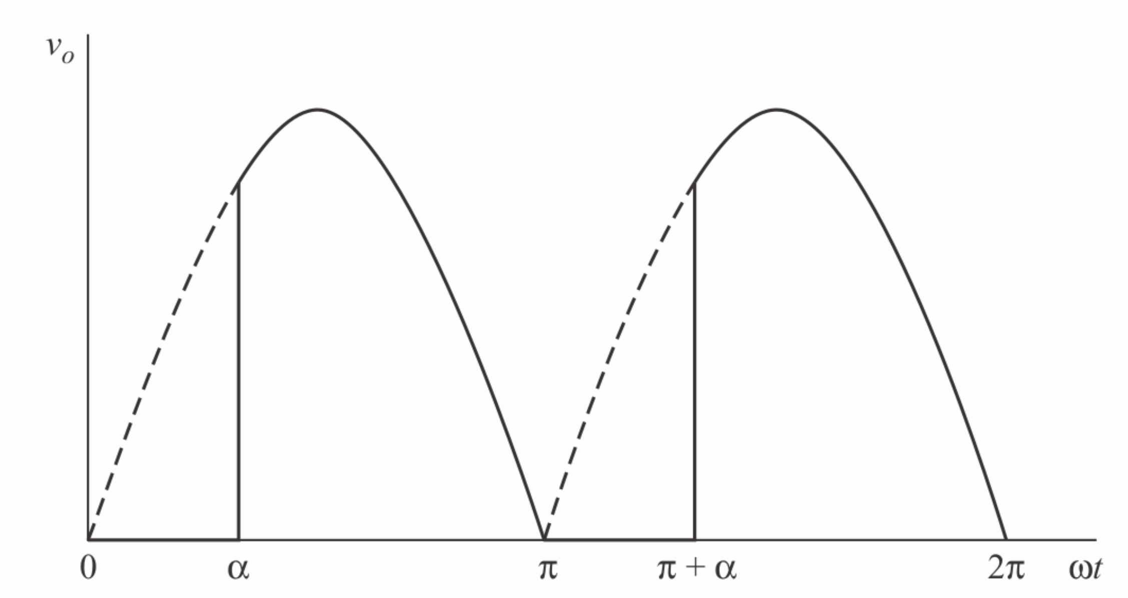
[MultiSim]

Single Phase Rectifier with Resistive Load

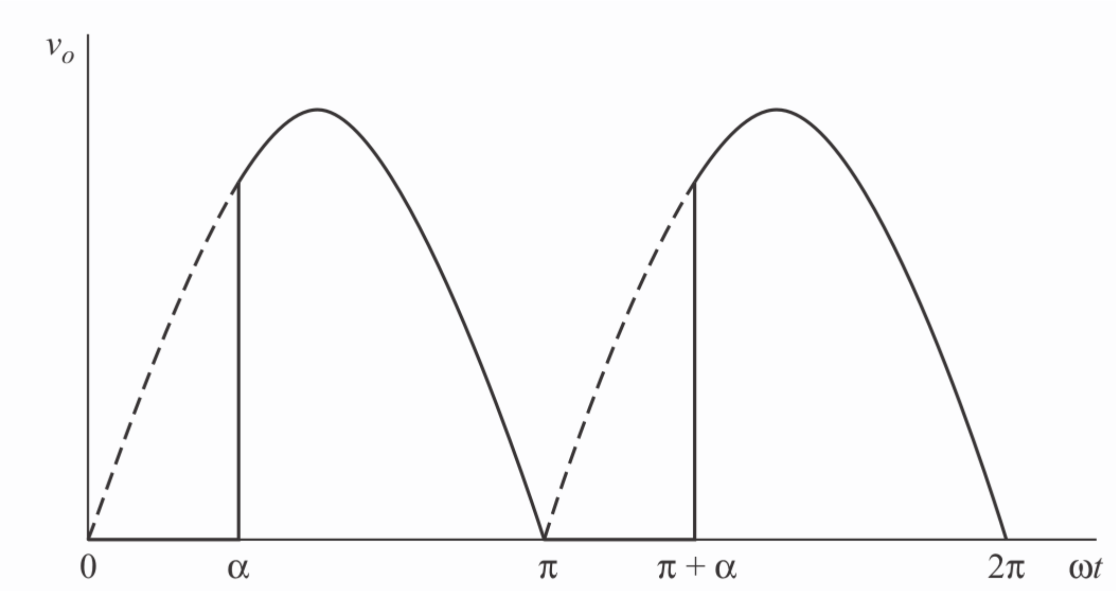


Voltage Waveform?

Single Phase Rectifier with Resistive Load

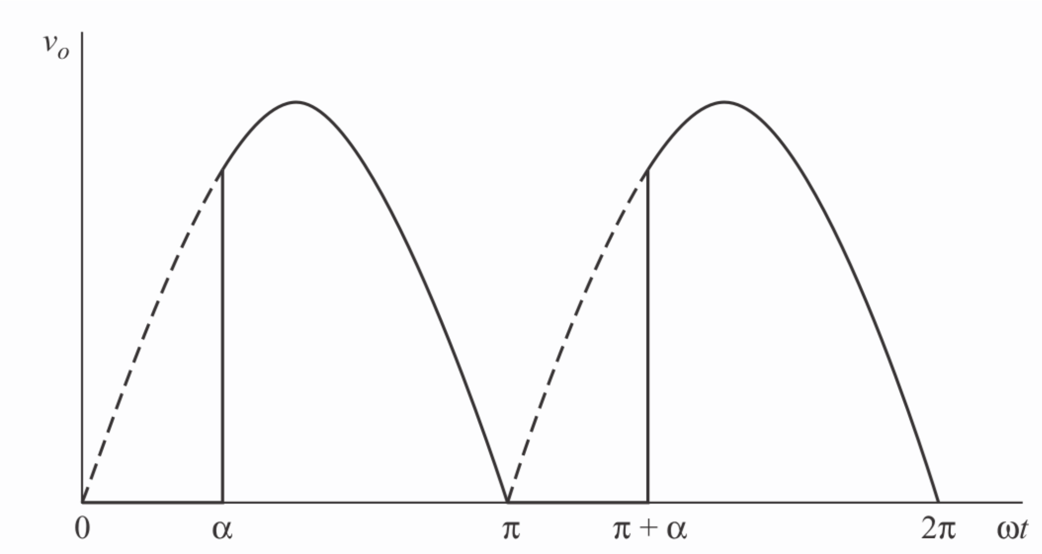


Single Phase Rectifier with Resistive Load



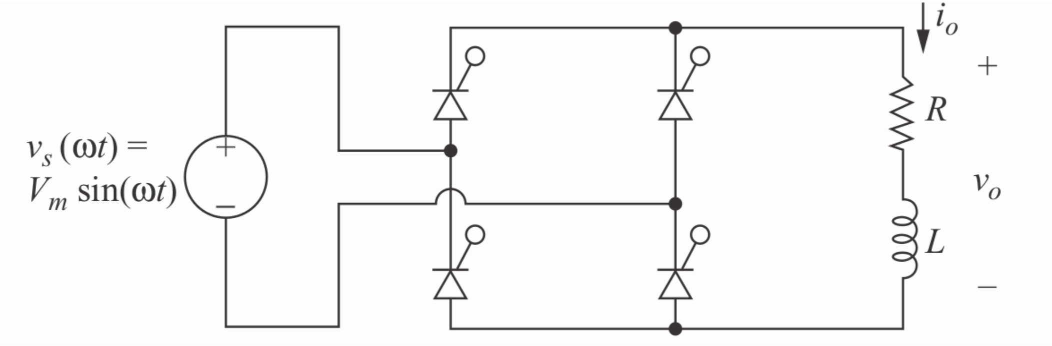
Average Voltage?

Single Phase Rectifier with Resistive Load

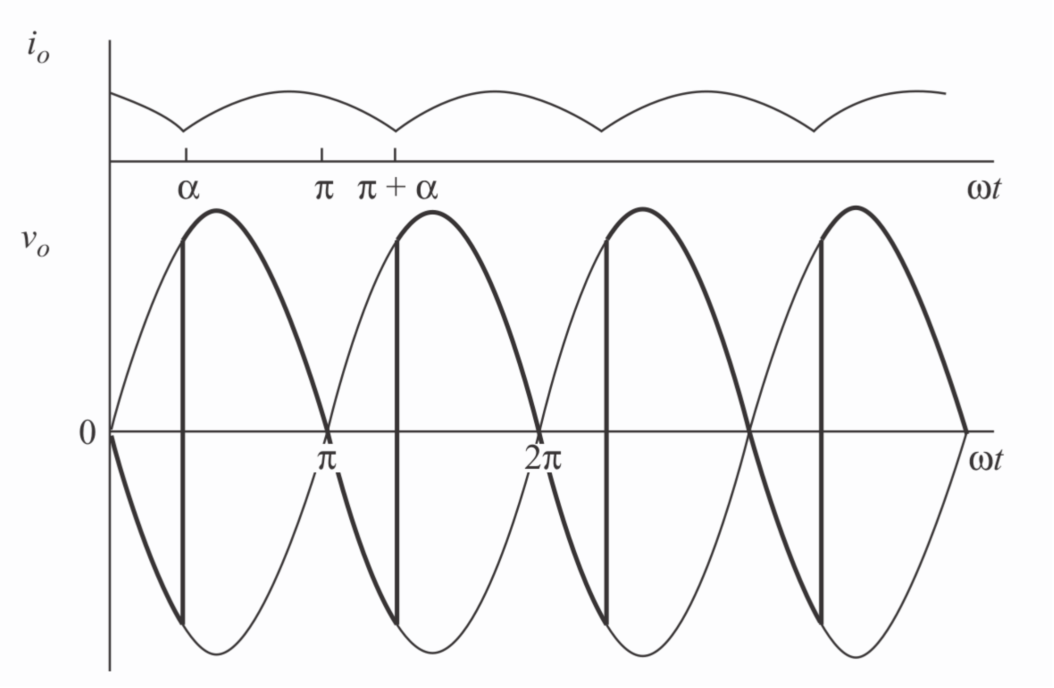


$$Vd_{\alpha} = \frac{\sqrt{2}Vs}{\pi}(1 + cos(\alpha))$$

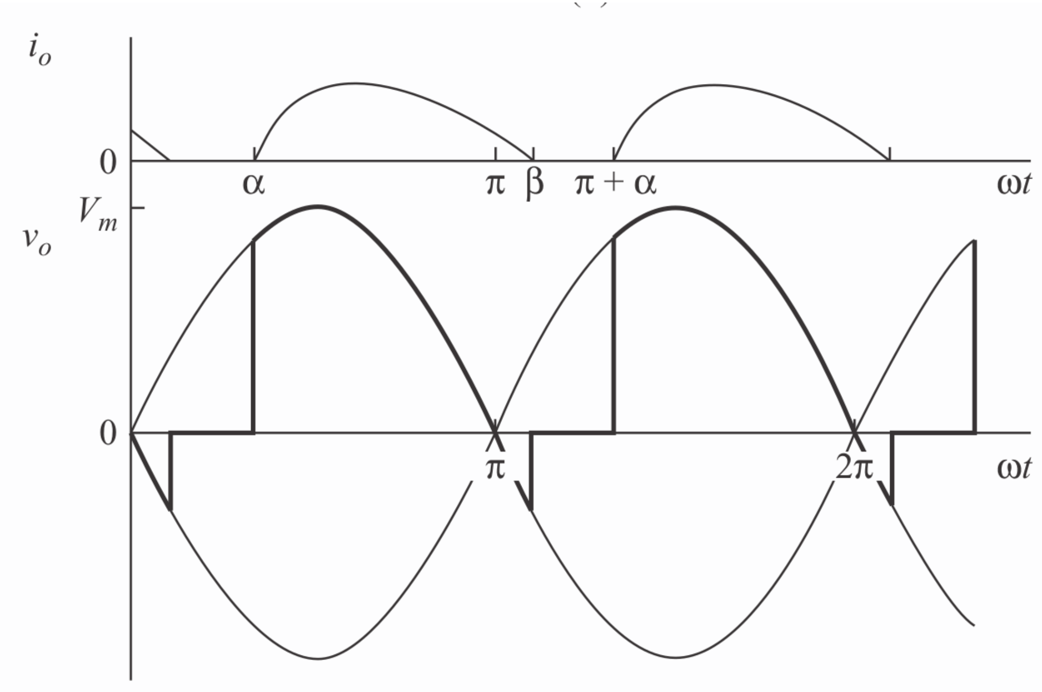
Single Phase Rectifier with R-L Load (Continuous Current)



Single Phase Rectifier with R-L Load (Continuous Current)



Single Phase Rectifier with R-L Load (Discontinuous Current)



Single Phase Rectifier with Freewheeling Diode

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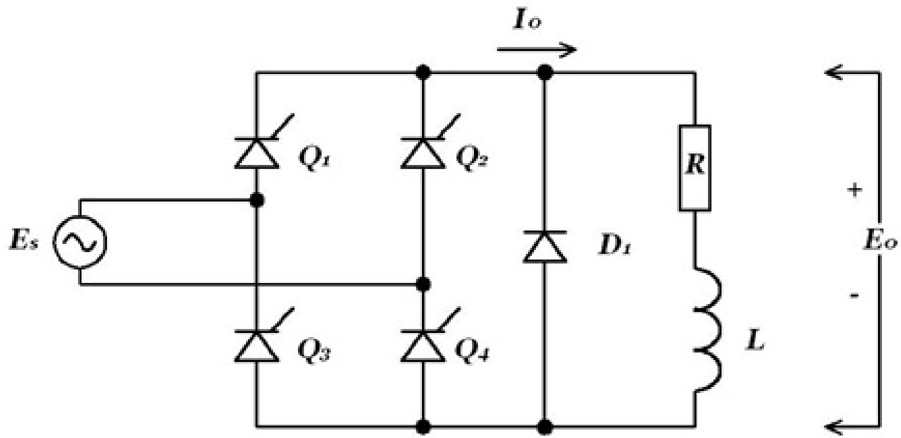
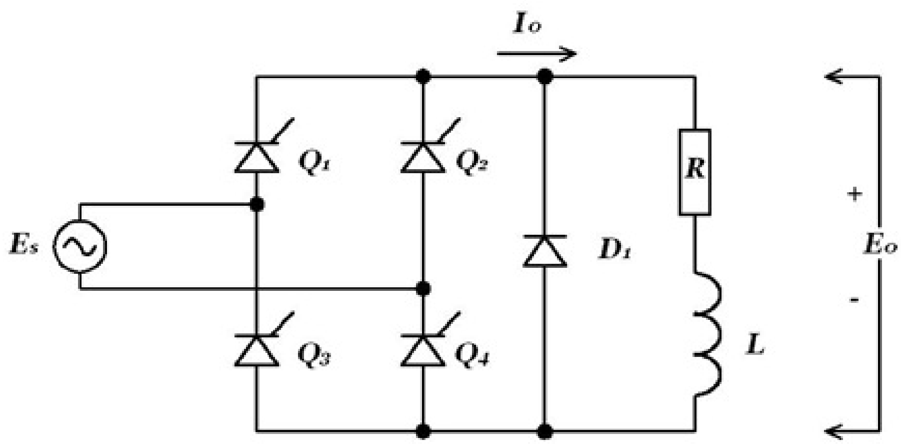


Can you plot the voltage, current waveform?

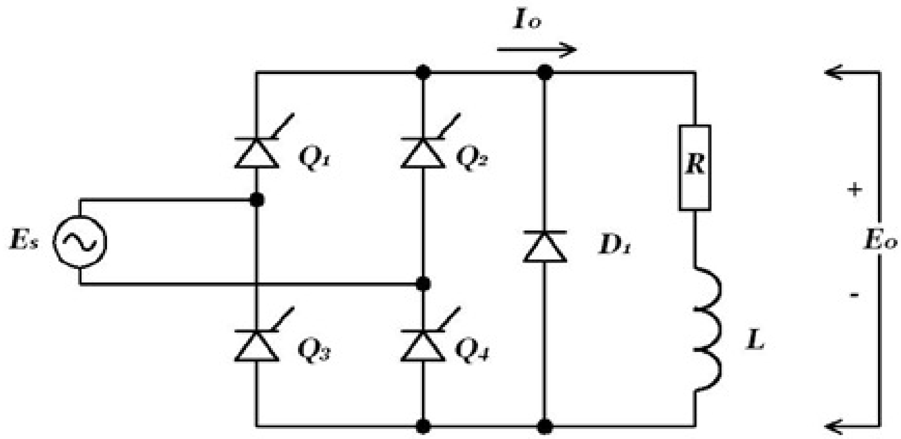
Single Phase Rectifier with Freewheeling Diode



Can you plot the voltage, current waveform?

What are the advantages, disadvantages?

How can you make this circuit cheaper?



Full Bridge Half Controlled Rectifier

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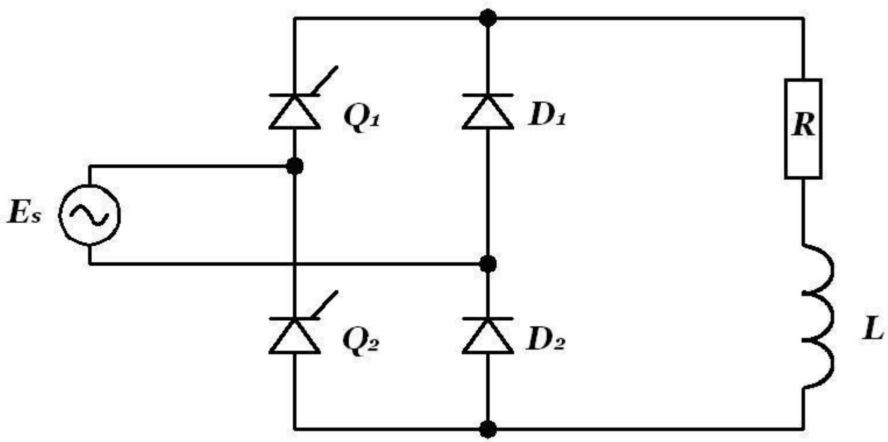
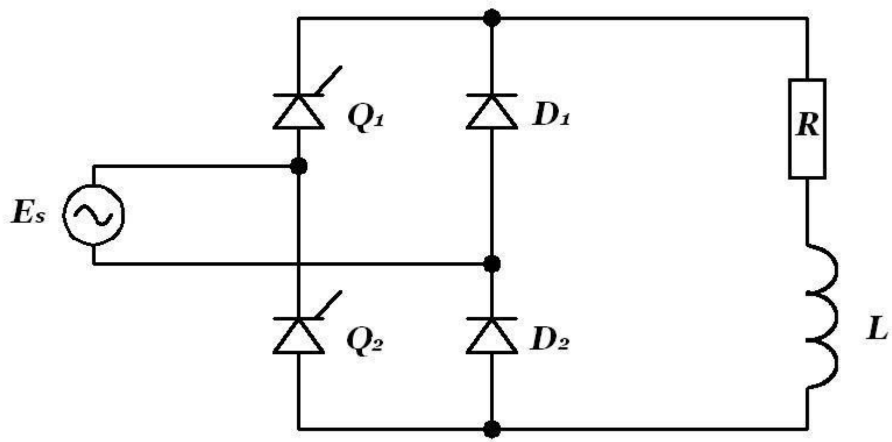


D1, D2 works as freewheeling diodes

Full Bridge Half Controlled Rectifier

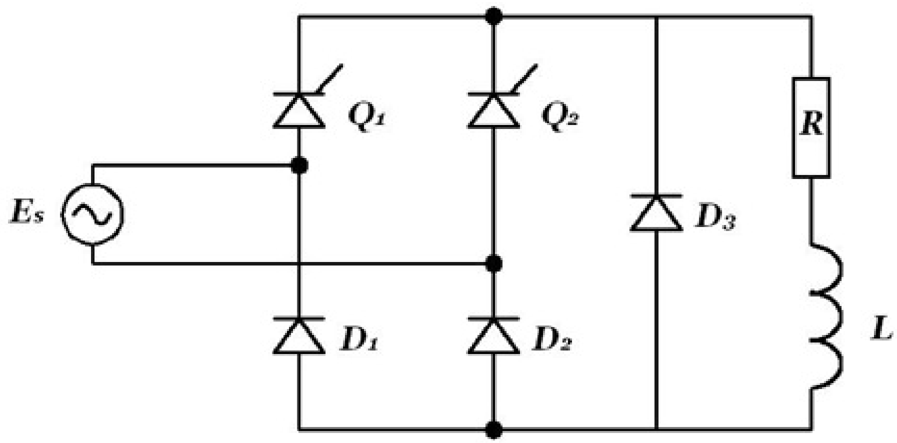


D1, D2 works as freewheeling diodes

Vd cannot be negative

Full Bridge Half Controlled Rectifier

Alternative (Same Output)



D3 can be removed (depending on load, and thyristor gate signals)

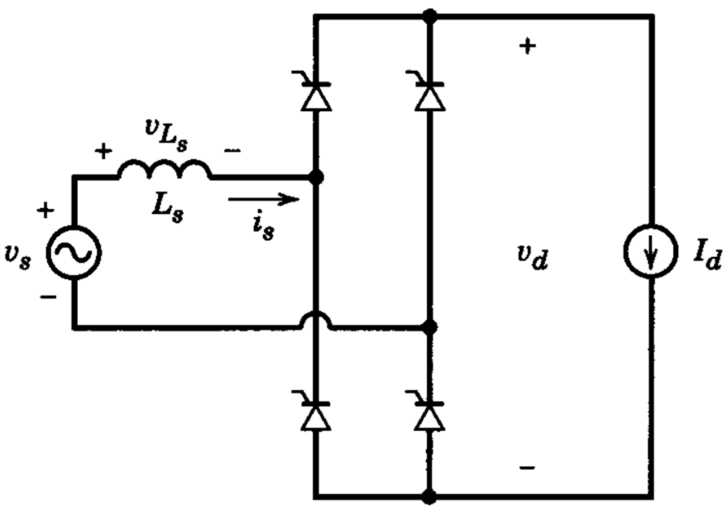
Commutation

Commutation

With source side inductance (Ls)

Commutation

With source side inductance (Ls)



Commutation

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Can you plot the voltage and current outputs?

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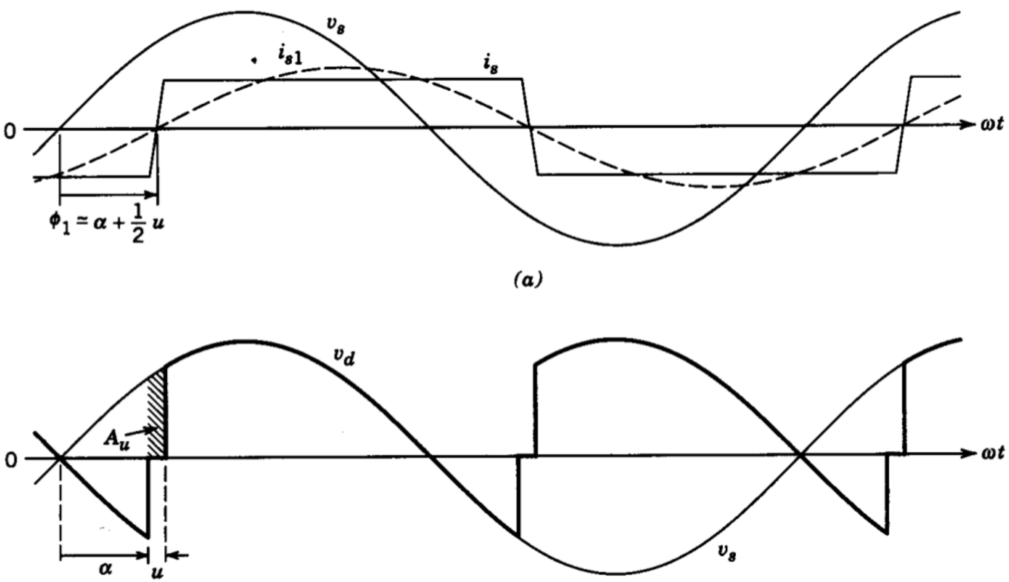

Commutation

Effect on the output voltage

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Effect on the output voltage

$$A_u = \sqrt{2}V_s(cos(\alpha) - cos(\alpha + u)) = 2\omega L_s I_d$$

Commutation

Effect on the output voltage

$$A_u = \sqrt{2}V_s(cos(\alpha) - cos(\alpha + u)) = 2\omega L_s I_d$$

$$cos(\alpha + u) = cos(\alpha) - \frac{2\omega L_s I_d}{\sqrt{2}V_s}$$

Commutation

Voltage drop due to commutation

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$$\Delta V_{du} = \frac{A_u}{\pi} = \frac{2\omega L_s I_d}{\pi}$$

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Voltage drop due to commutation

$$\Delta V_{du} = \frac{A_u}{\pi} = \frac{2\omega L_s I_d}{\pi}$$

$$V_d = 0.9 V_s cos(\alpha) - \frac{2\omega L_s I_d}{\pi}$$

Example

Mohan Ex. 6.1

Practical Thyristor Converter

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Consider a case as a DC motor drive

Practical Thyristor Converter

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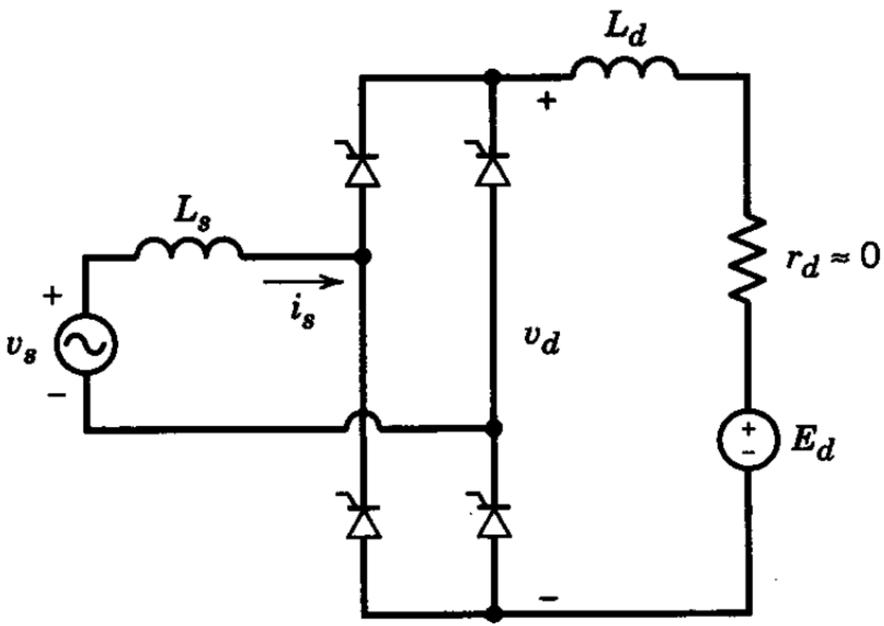

Practical Thyristor Converter

Continuous Conduction (id is always > 0)

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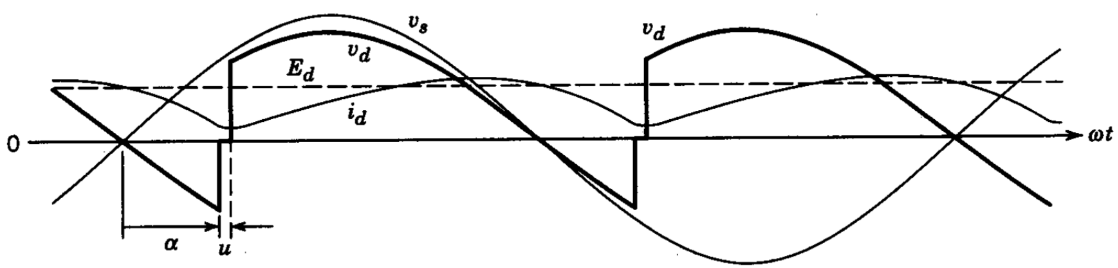
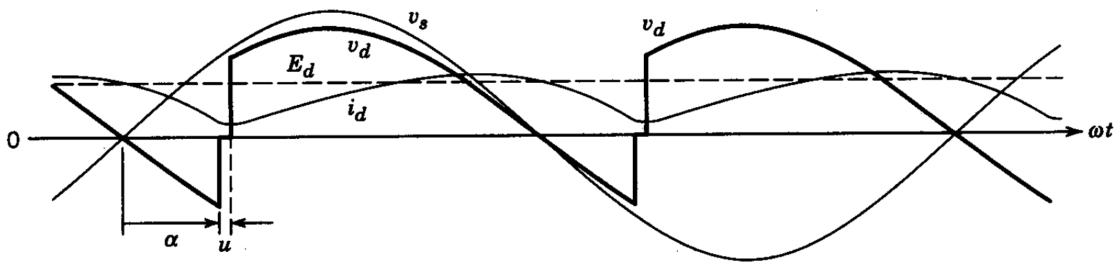


Practical Thyristor Converter

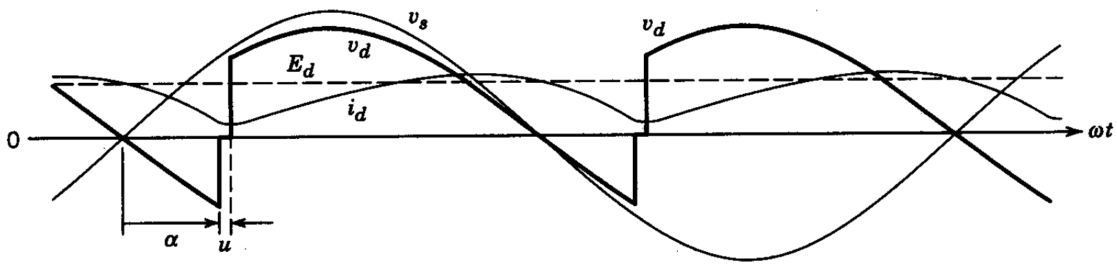
Continuous Conduction (id is always > 0)



Average voltage with commutation?

Practical Thyristor Converter

Continuous Conduction (id is always > 0)

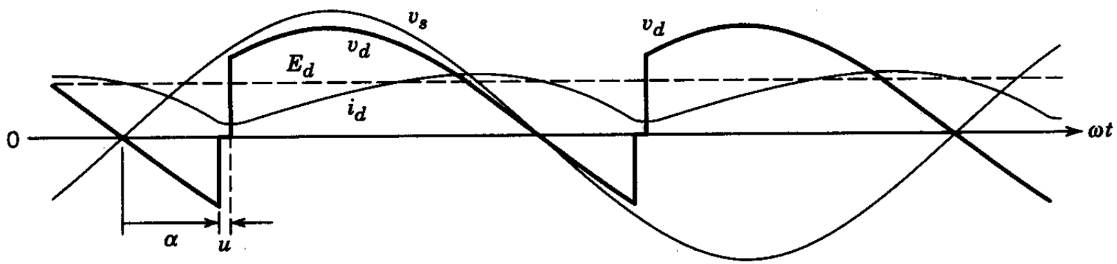


Average voltage with commutation?

$$V_d \approx 0.9V_s cos(\alpha) - \frac{2\omega L_s I_{d,min}}{\pi}$$

Practical Thyristor Converter

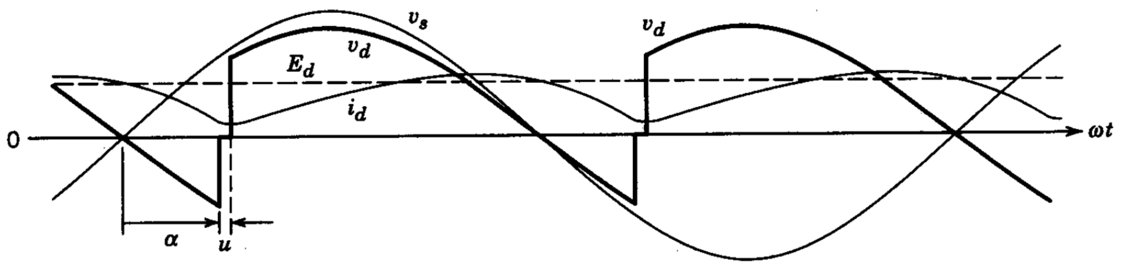
Continuous Conduction (id is always > 0)



Average Current?

Practical Thyristor Converter

Continuous Conduction (id is always > 0)



Average Current?

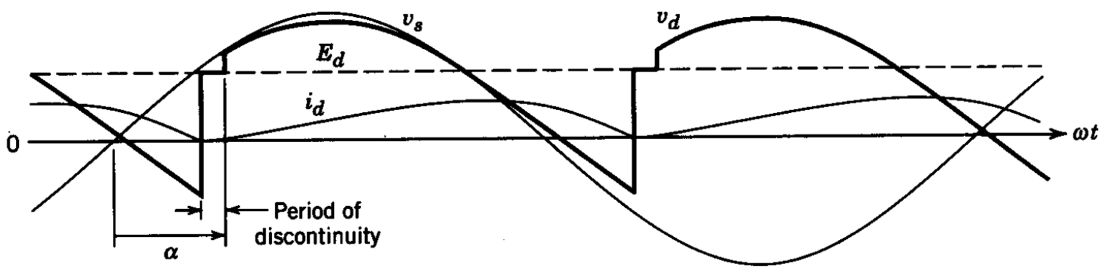
$$I_d = \frac{V_d - E_d}{r_d}$$

Practical Thyristor Converter

What happens if Id is small?

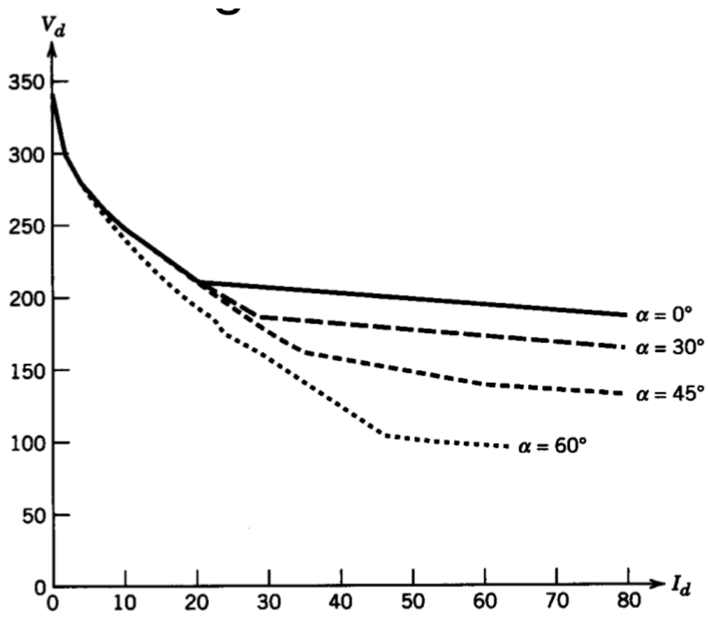
Practical Thyristor Converter

Discontinuous Conduction



Practical Thyristor Converter

Discontinuous Conduction



Inverter Mode

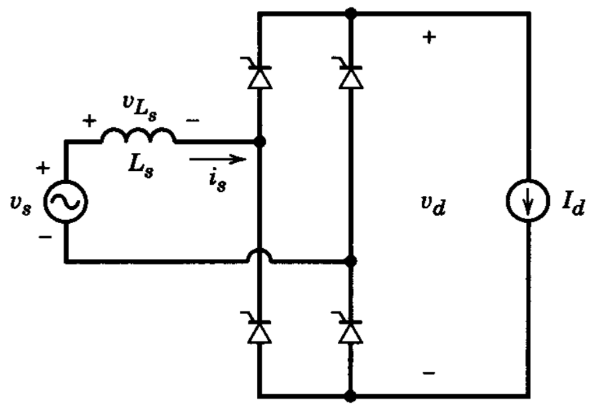
Inverter Mode

90 < Firing Angle < 180

Inverter Mode

90 < Firing Angle < 180

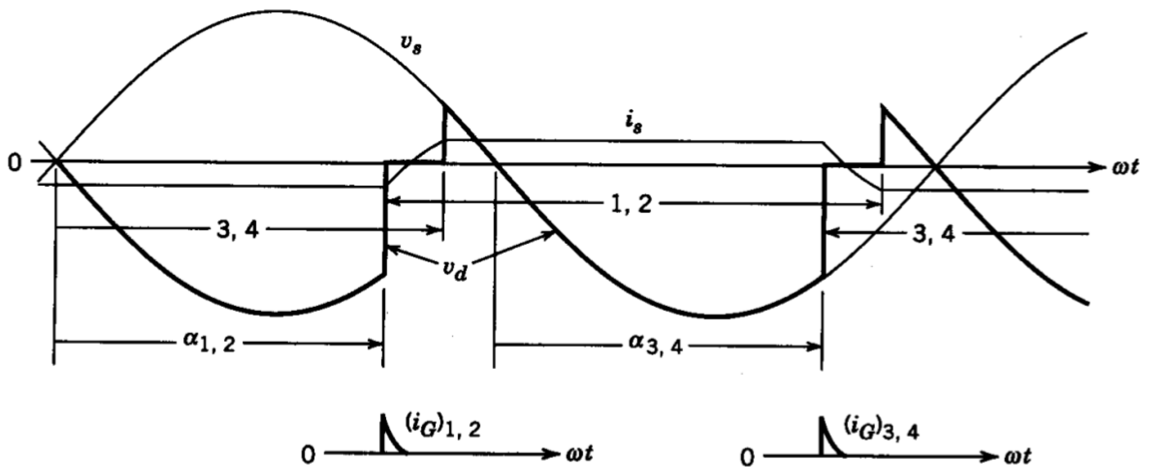
Average power<0 (Power flows from DC to AC)



Only with active power source on DC side

Inverter Mode

90 < Firing Angle < 180

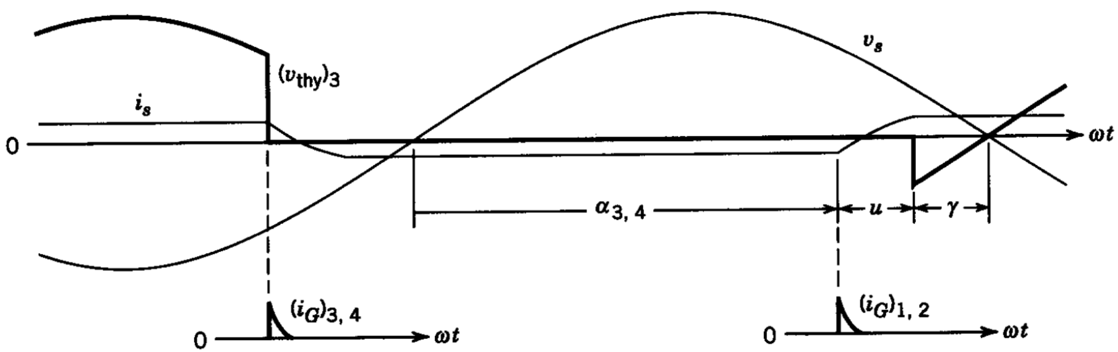


Inverter Mode

Thyristor Voltage

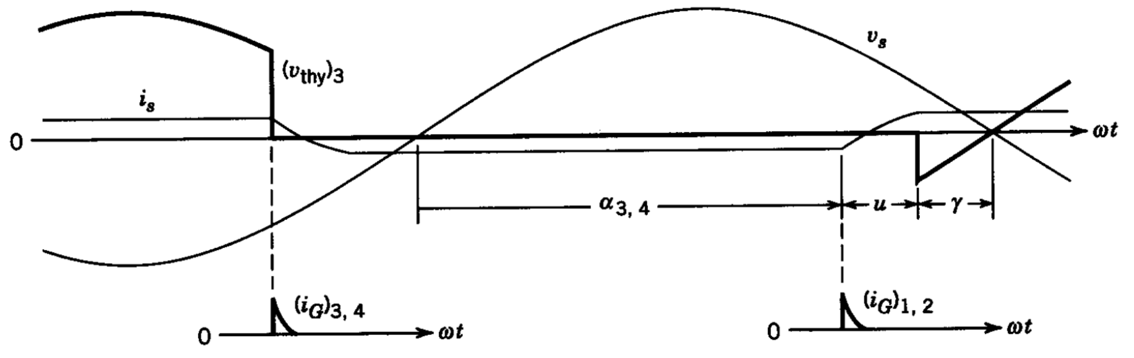
Inverter Mode

Thyristor Voltage



Inverter Mode

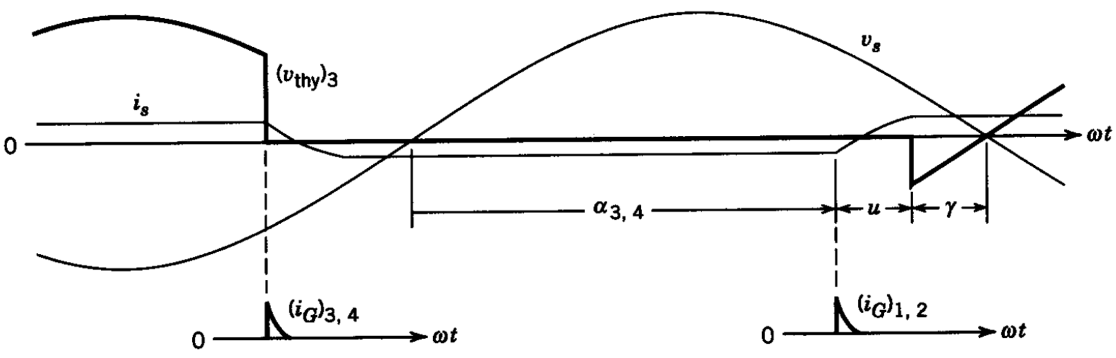
Thyristor Voltage



Extinction Angle ($\gamma = 180 - (\alpha + u)$)

Inverter Mode

Thyristor Voltage



Extinction Angle ($\gamma = 180 - (\alpha + u)$)

Extinction time should be larger than thyristor turn-off time (t_q)!

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