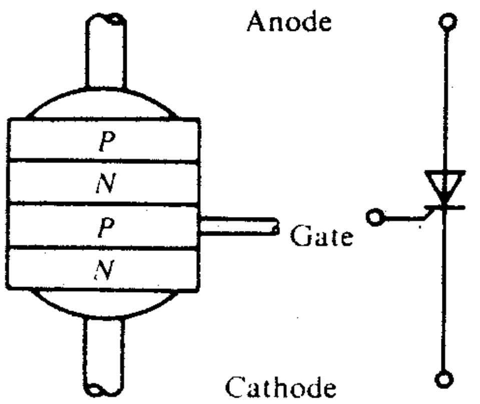
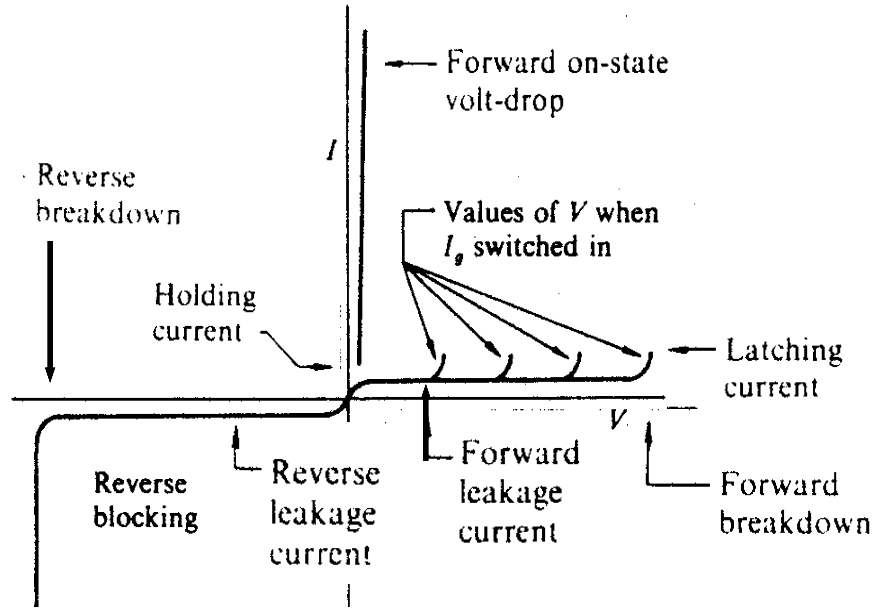
Chapter 3

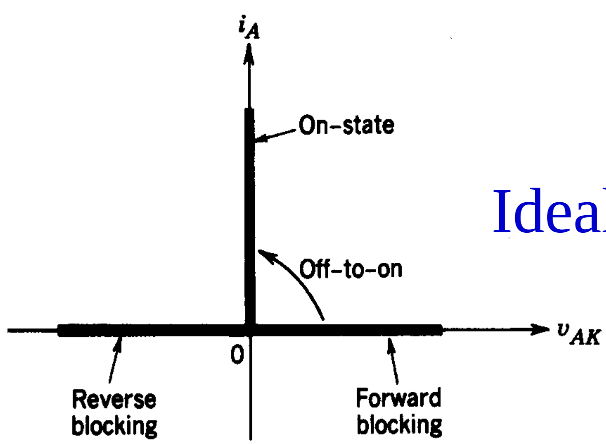
Thyristor
AC-DC Converters

Thyristor Characteristics



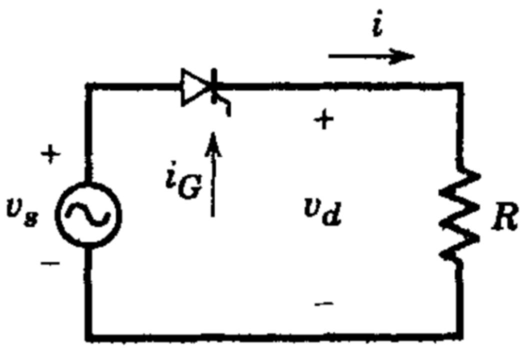
Structure and Symbol

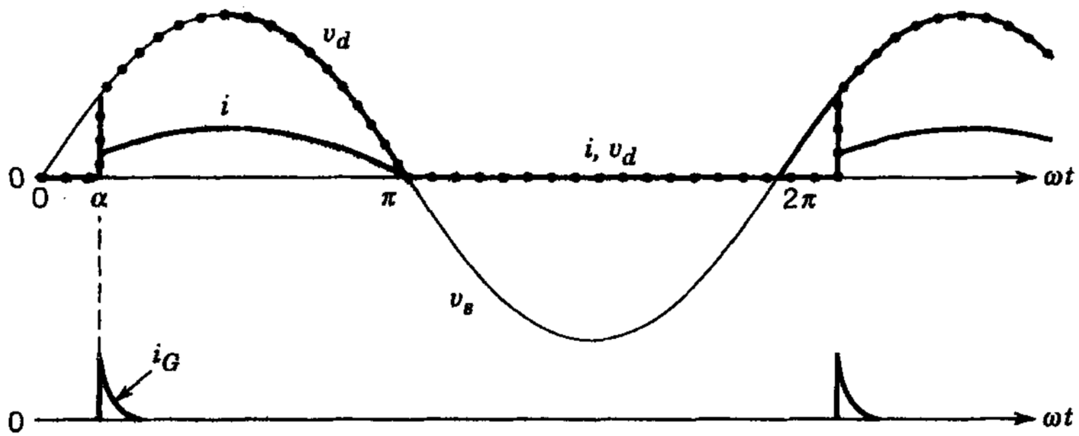




Ideal Characteristics

A Simple Circuit





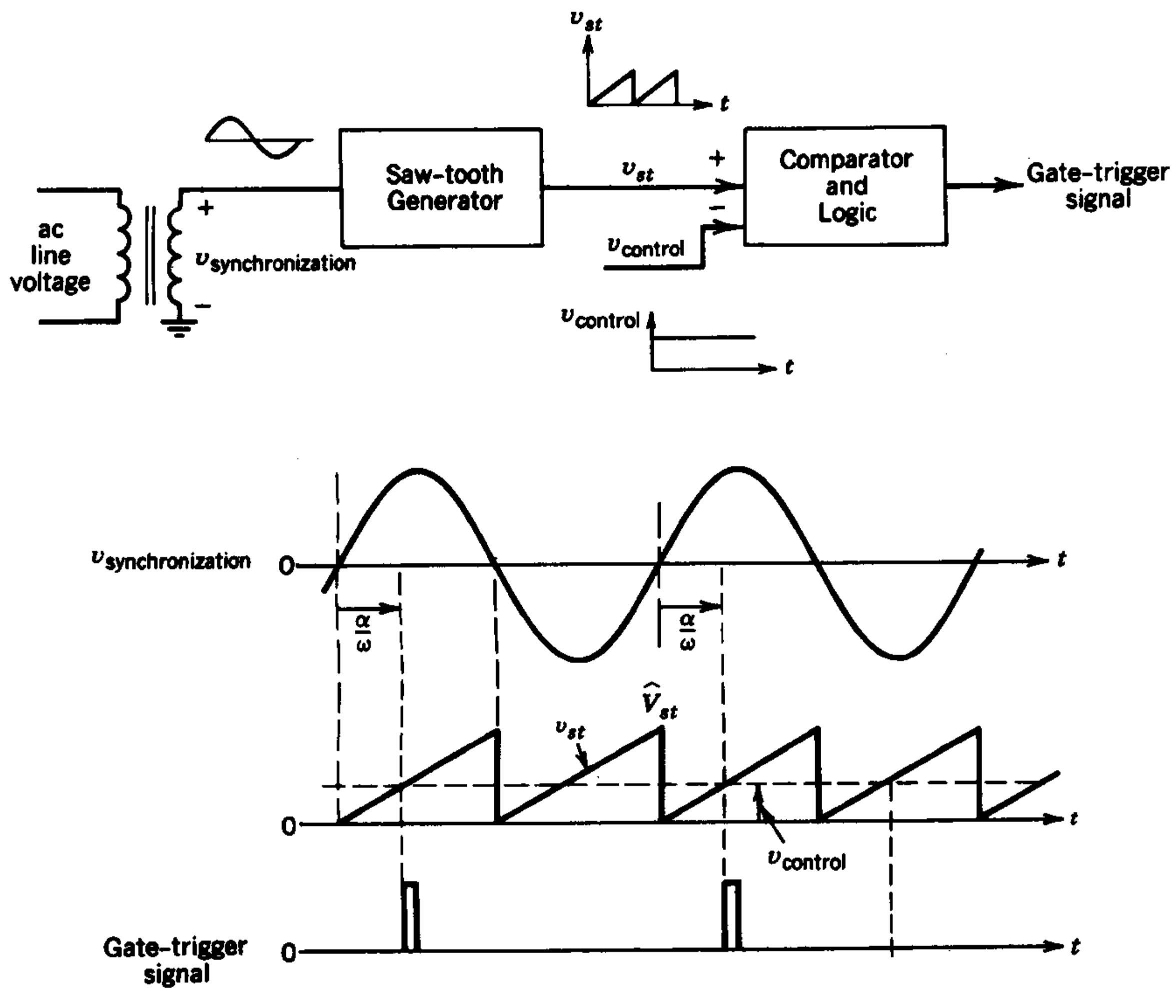
Controlled by firing delay angle

α — **relative to supply voltage zero**

$$V_d = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_{s(max)} \sin\theta \, d\theta$$

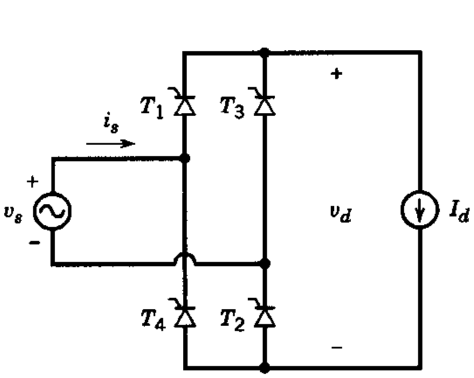
$$= \frac{1}{2\pi} V_{s(max)}(1 + \cos\alpha)$$

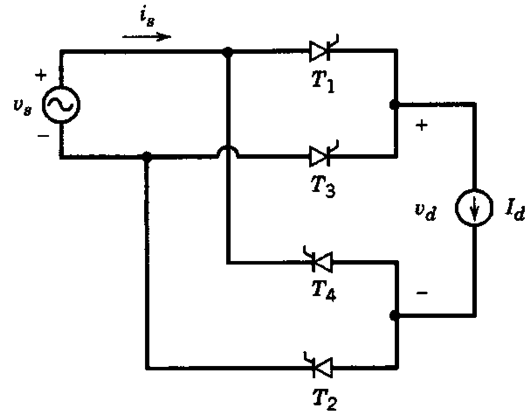
Thyristor Triggering

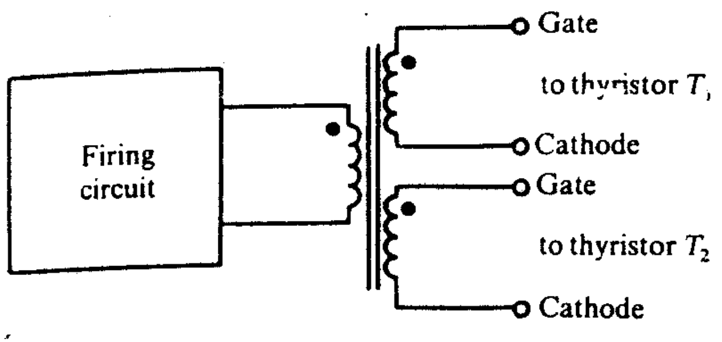


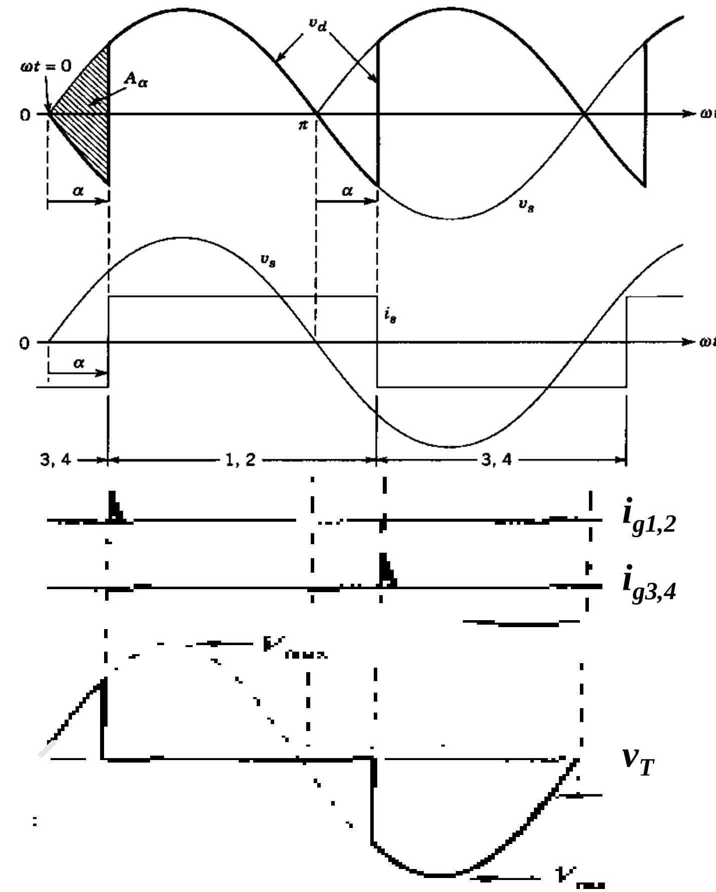
- ICs available

Single-phase Bridge









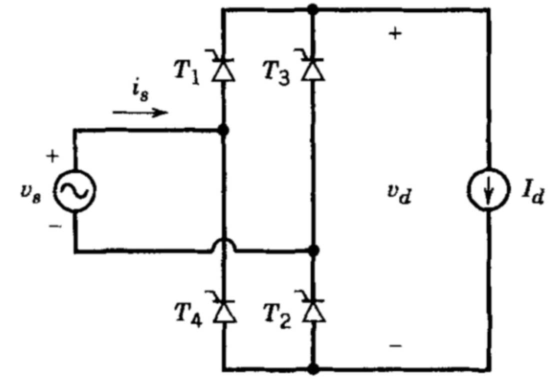
Q1: What is time sequence of trigger signals?

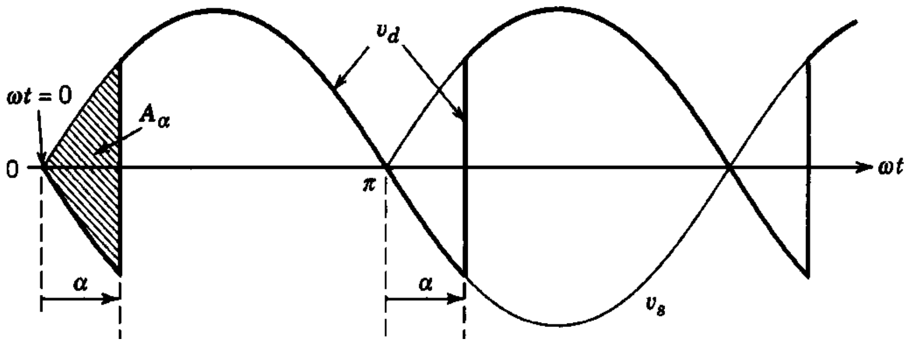
Q2: How many switching times in one line frequency?

Q3: When does commutation happens?

Single-phase Bridge

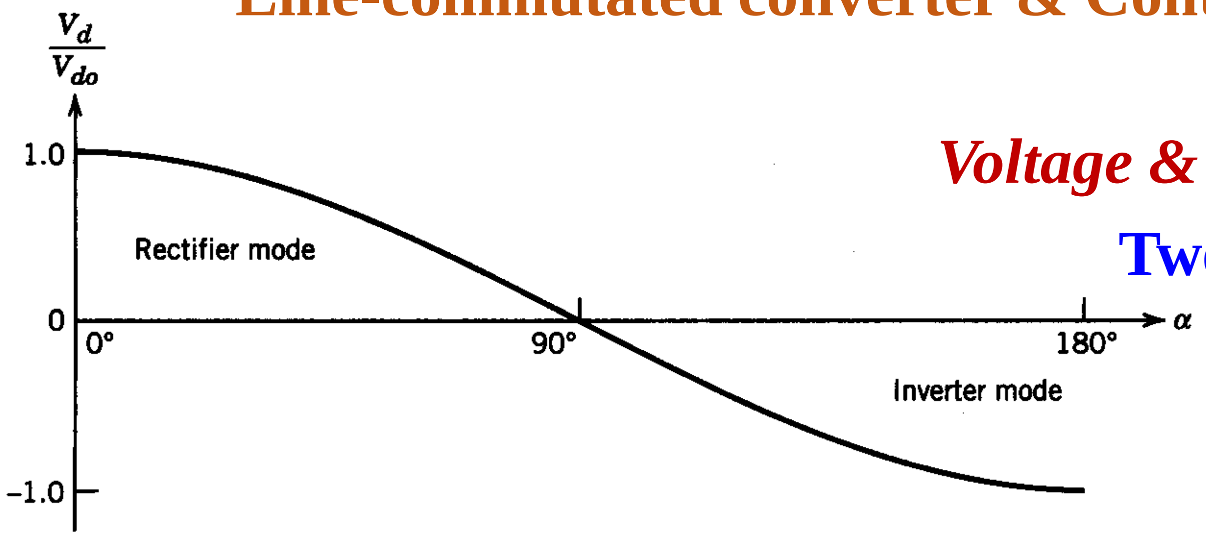
Average DC Output Voltage





$$V_d = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_{s(max)}\, \sin\theta\, d\theta$$
$$= \frac{2}{\pi} V_{s(max)} \cos\alpha$$

Line-commutated converter & Controlled DC voltage

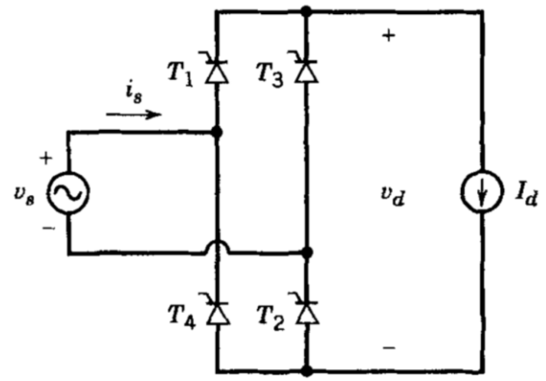


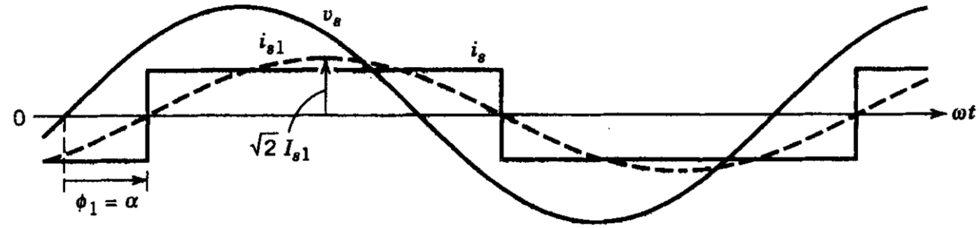
Voltage & current direction?

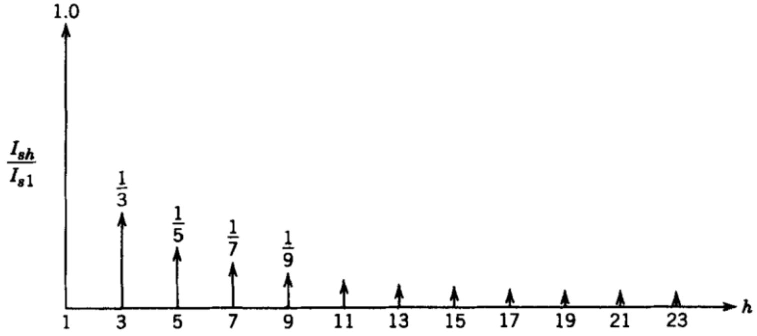
Two-quadrant

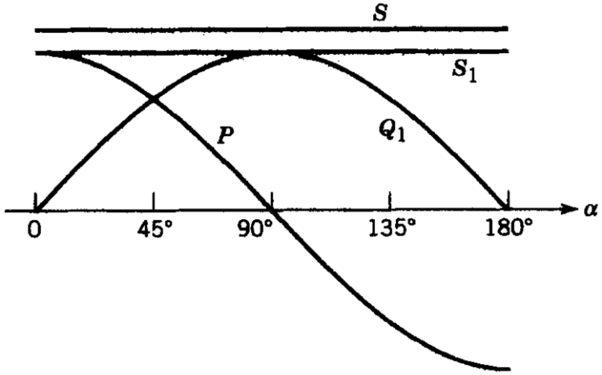
Single-phase Bridge

Input Line-Current and its Harmonics
Power and reactive power









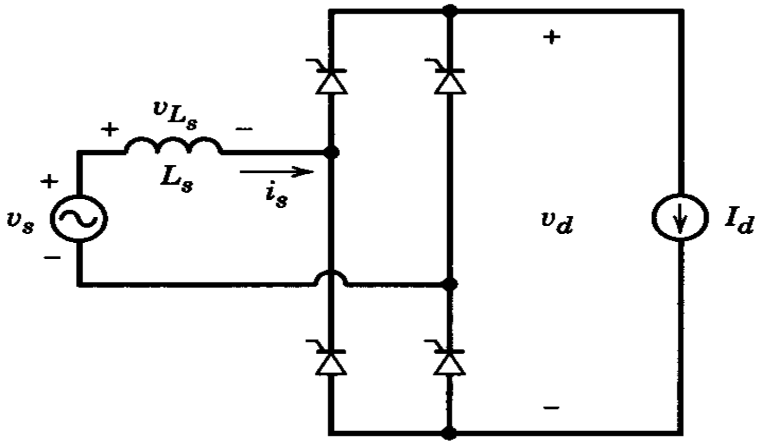
$$I_{s1} = 0.9 I_{\mathrm{d}}$$

$$\mathrm{PF} = 0.9 \cos \alpha$$

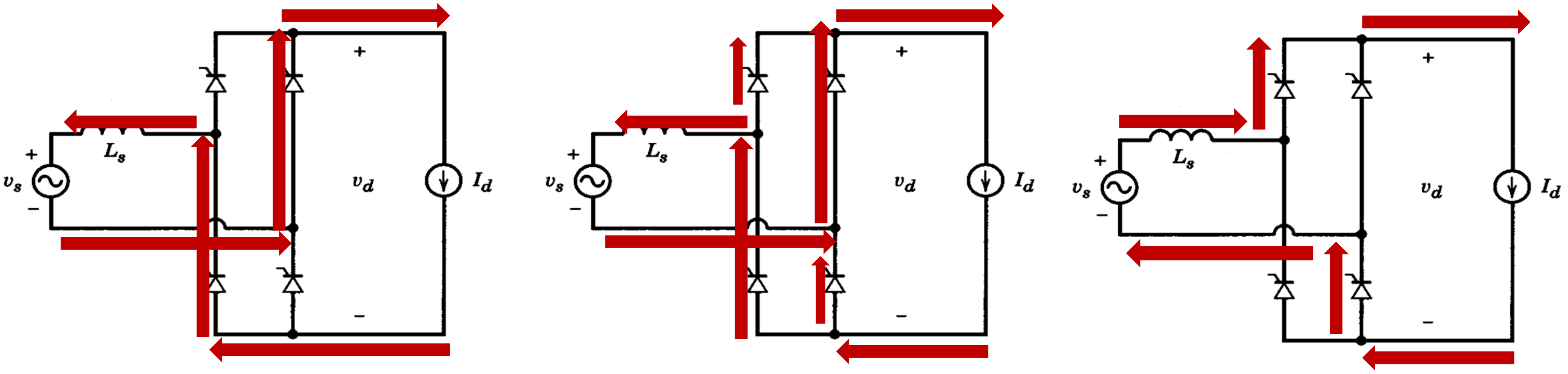
Operation region?

Two-quadrant

Single-phase Bridge



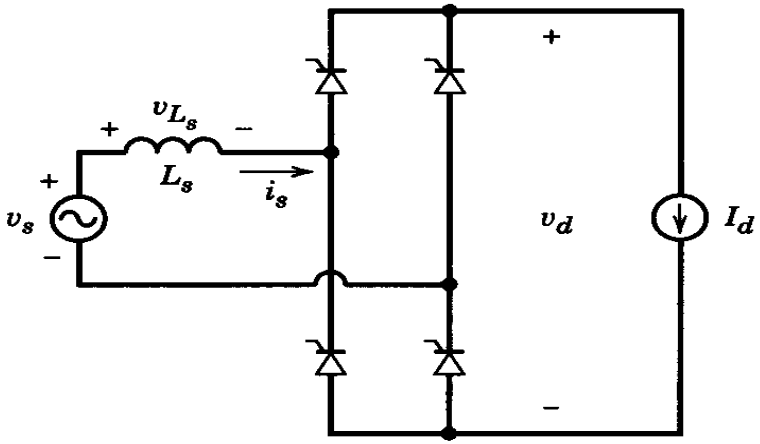
Considering ac-side inductance



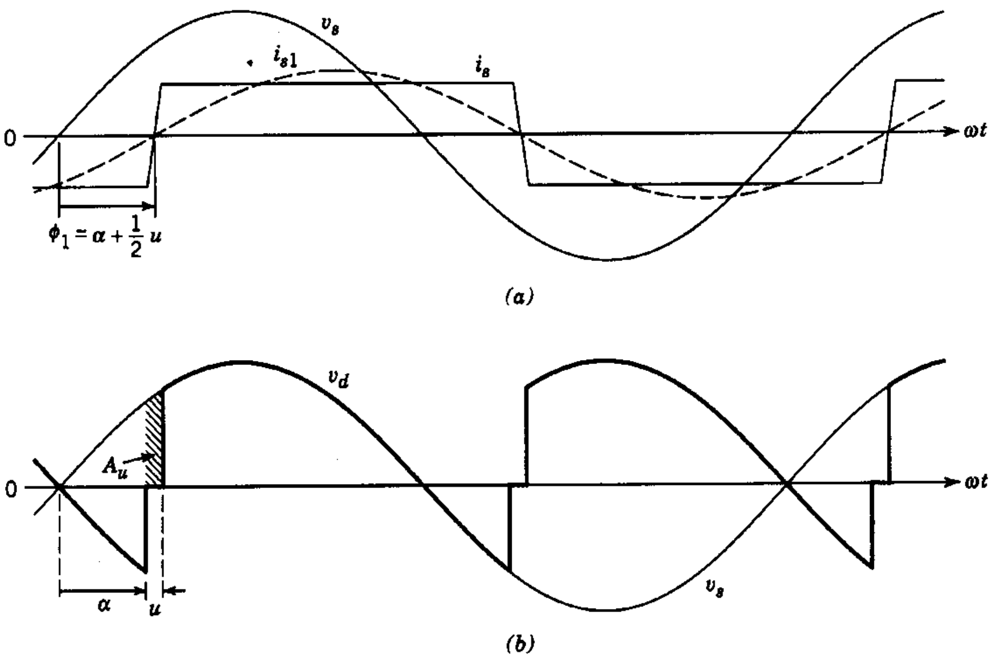
i_{T1} and i_{T2} increase from 0 to I_d

i_{T3} and i_{T4} decrease from I_d to 0

Single-phase Bridge



Considering ac-side inductance



$$v_s = V_{s(max)}\sin(\omega t + \alpha) = L_s\frac{di_s}{dt}$$

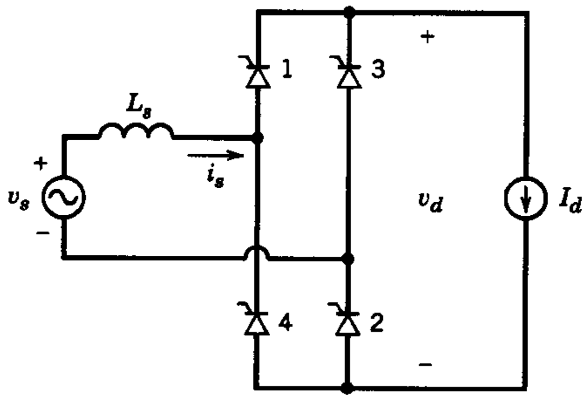
$[\omega t = 0, \quad i_s = -I_d]$

$[\omega t =$ ***u (overlap angle)***, $\; i_s = I_d]$

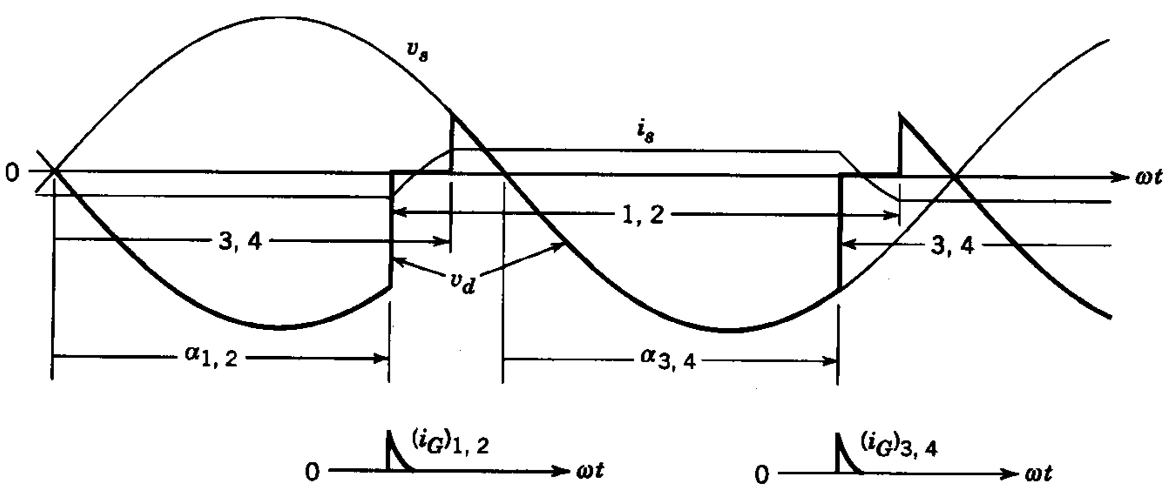
……

Single-phase Bridge

Inverting Mode (α > 90°)



(a)



(b)

extinction angle δ

$\delta = 180 - \alpha - u$

$\delta_{min} > 5°$

Rectifying mode:

$\alpha < 90$

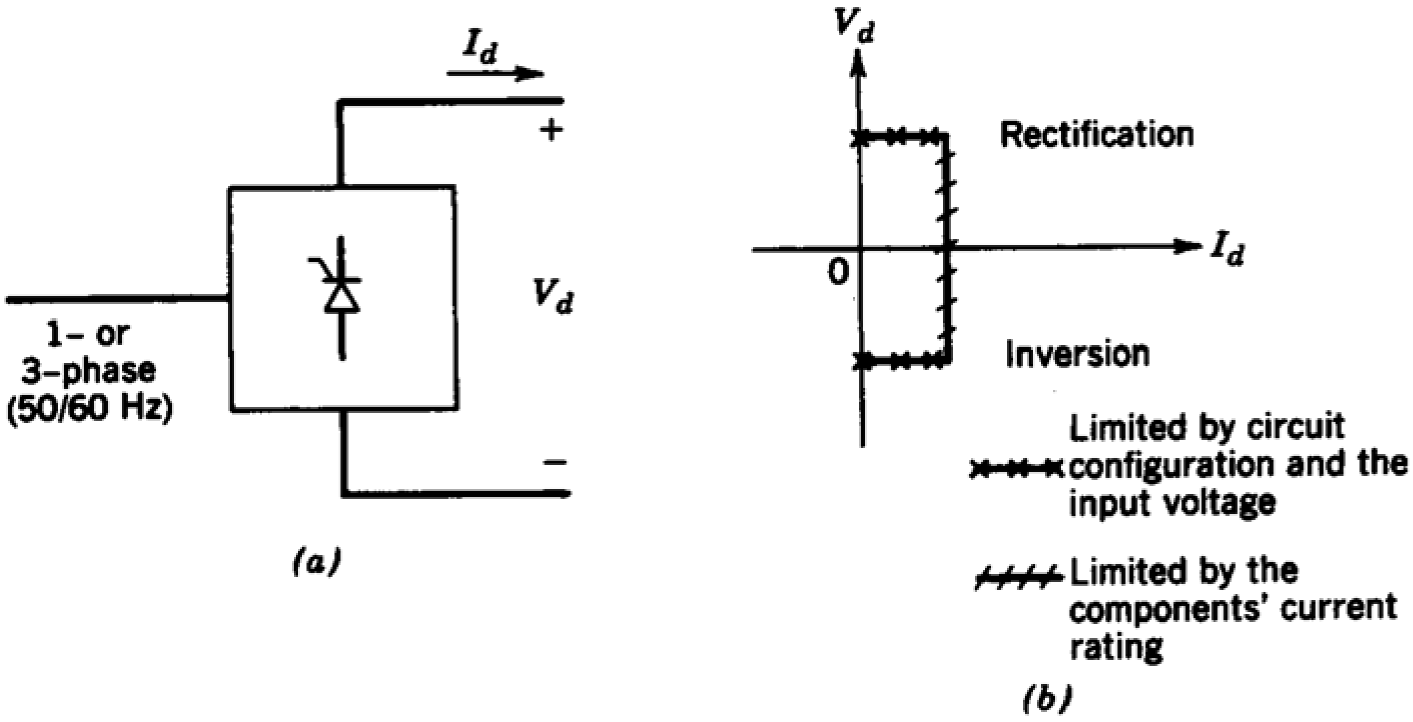
Inverting mode:

α: $90 \sim 180 - \delta_{min}$

thyristor converter:

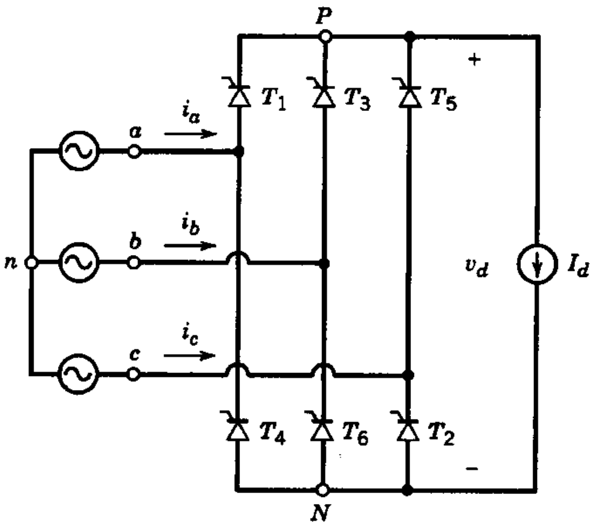
a line-frequency AC voltage $\rightarrow$ a controlled DC voltage

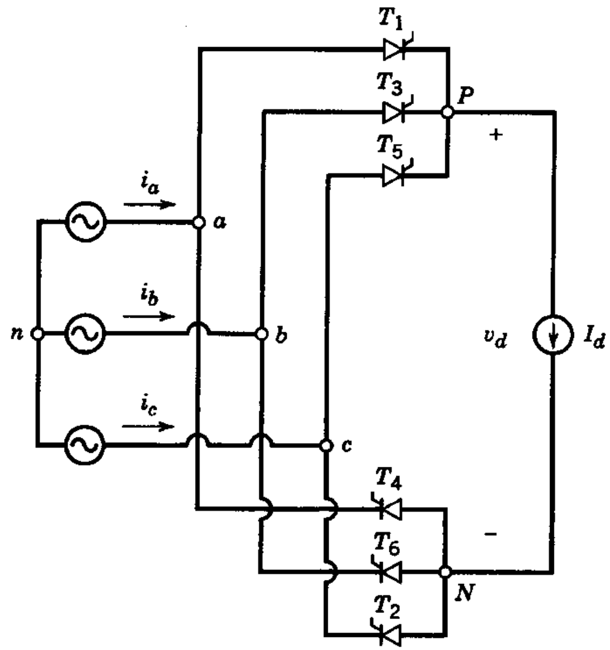
AC/DC Conversion: rectifying mode & inverting mode

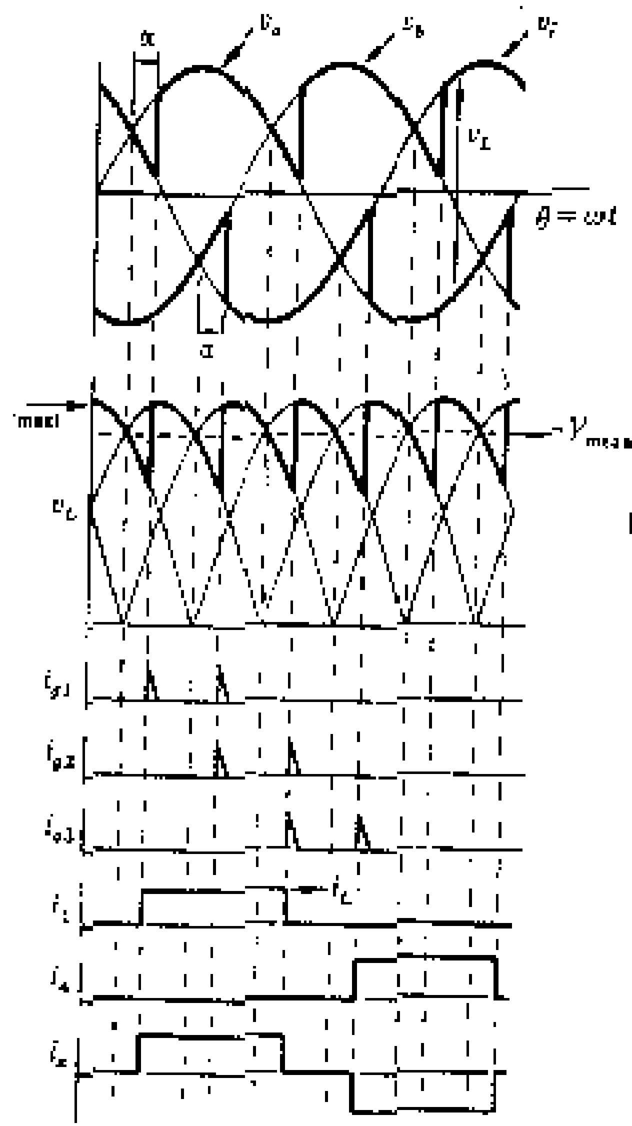


Thyristor Converter - two-quadrant converter

Three-phase Bridge







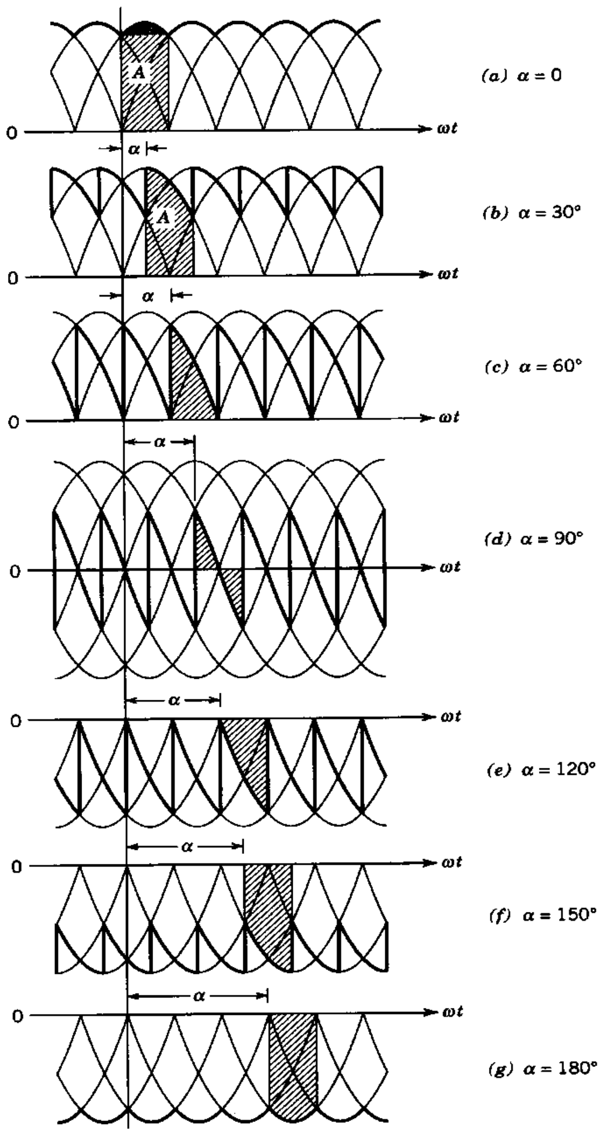
$$V_d = \frac{3}{\pi} V_{s(max)} \cdot \cos\alpha$$

Starting problem:

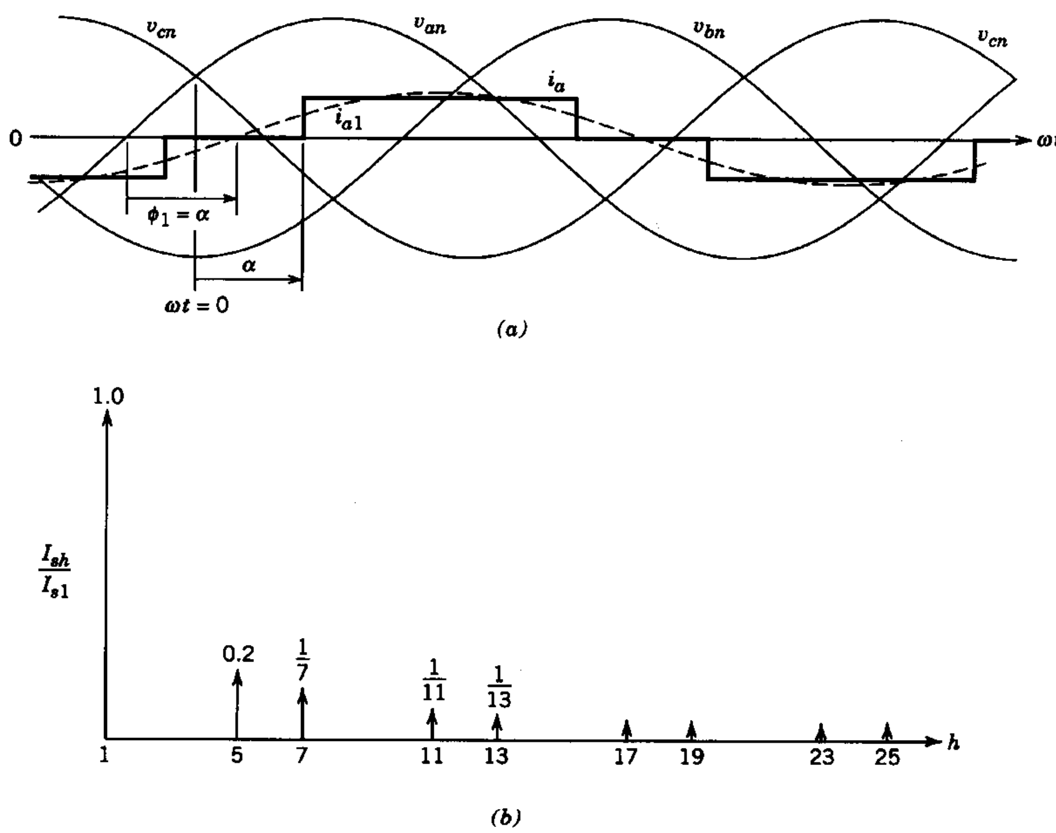
In order to start the circuit functioning, two thyristors must be fired at the same time in order to commence current flow.

Three-phase Bridge

DC-side voltage waveforms



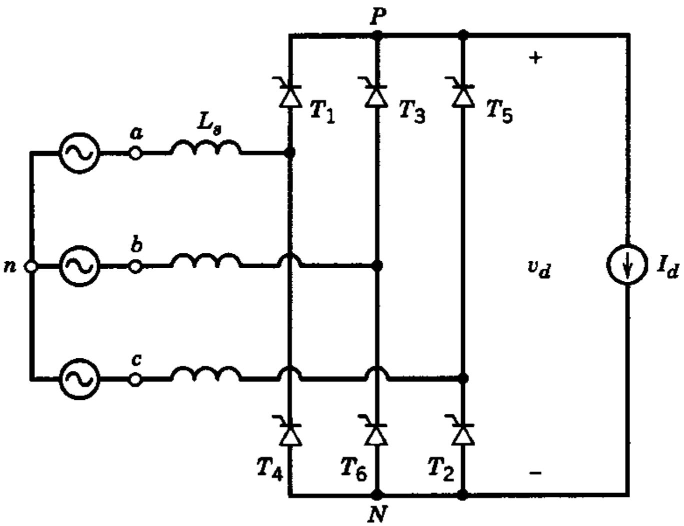
Input Line-Current and its Harmonics



$I_{s1} = 0.78 I_{\mathrm{d}}$ $\qquad$ $\mathrm{PF} = 0.955 \cos \alpha$

Three-phase Bridge

AC-side inductance included



$$v_a - v_c = V_{\text{line(max)}} \sin(\omega t + \alpha)$$

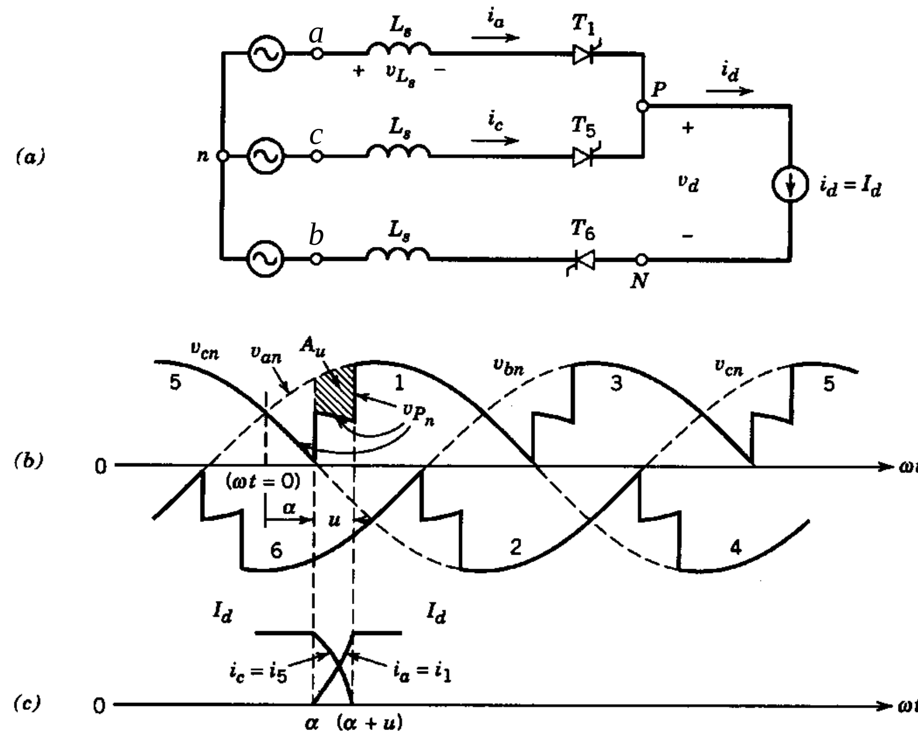
$$= 2L_s \frac{di_a}{dt}$$

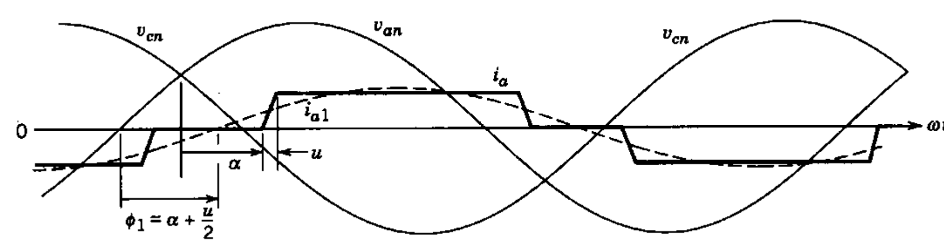
$$[\omega t = 0, \quad i_a = 0\,]$$

$$[\,\omega t = u\,, \; i_a = I_d\,]$$

……

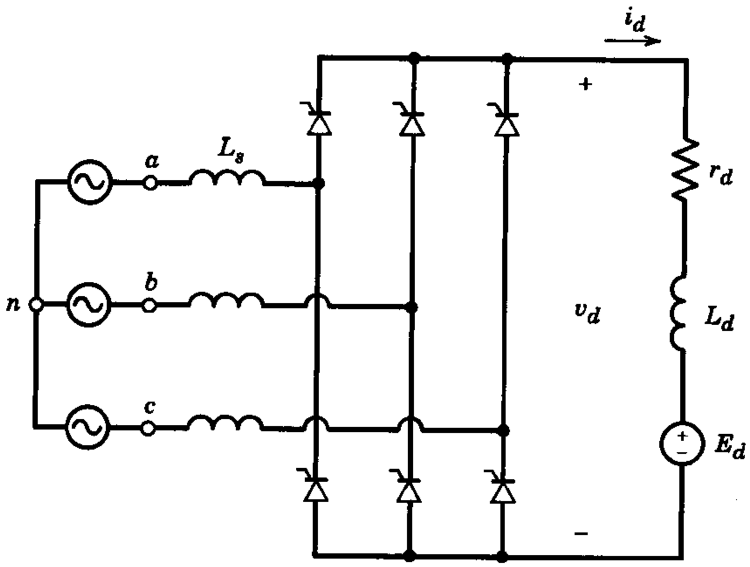
Current Commutation Waveforms



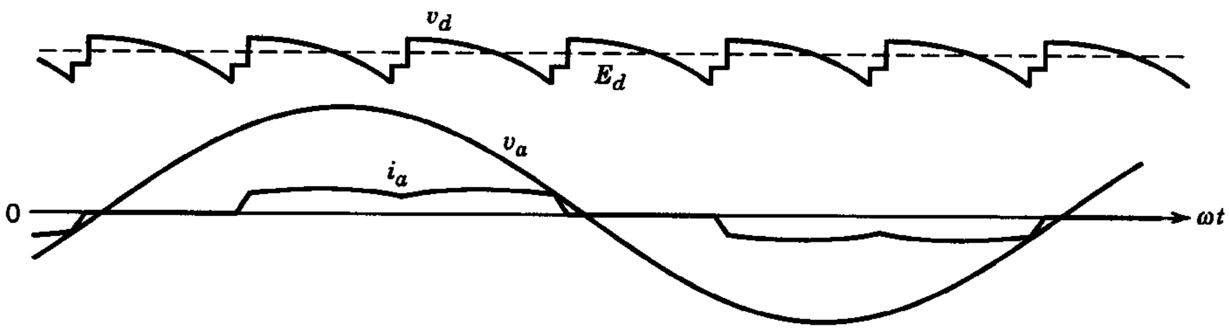


Three-phase Bridge

A practical thyristor converter



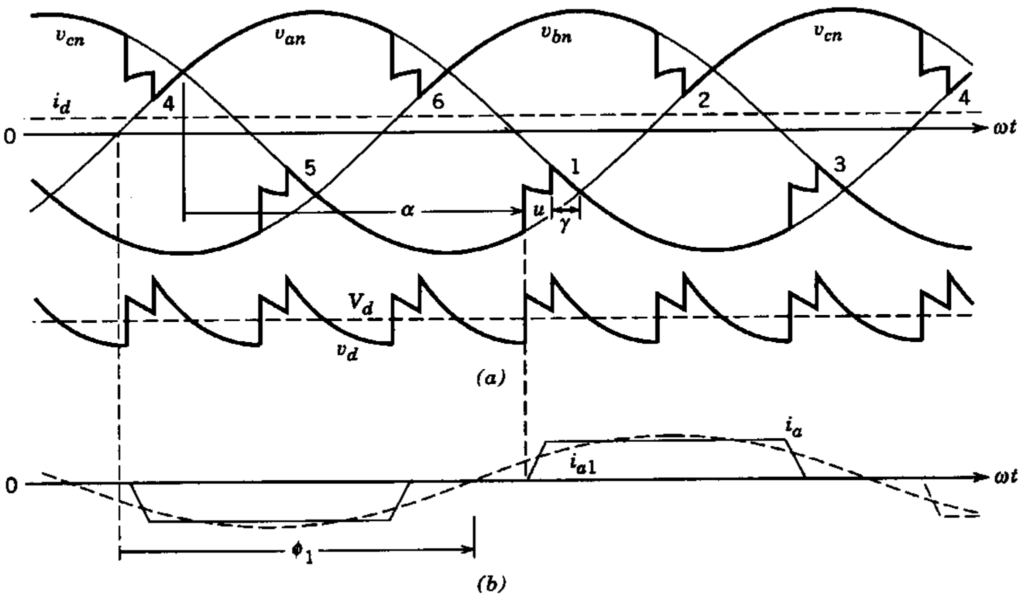
Realistic load

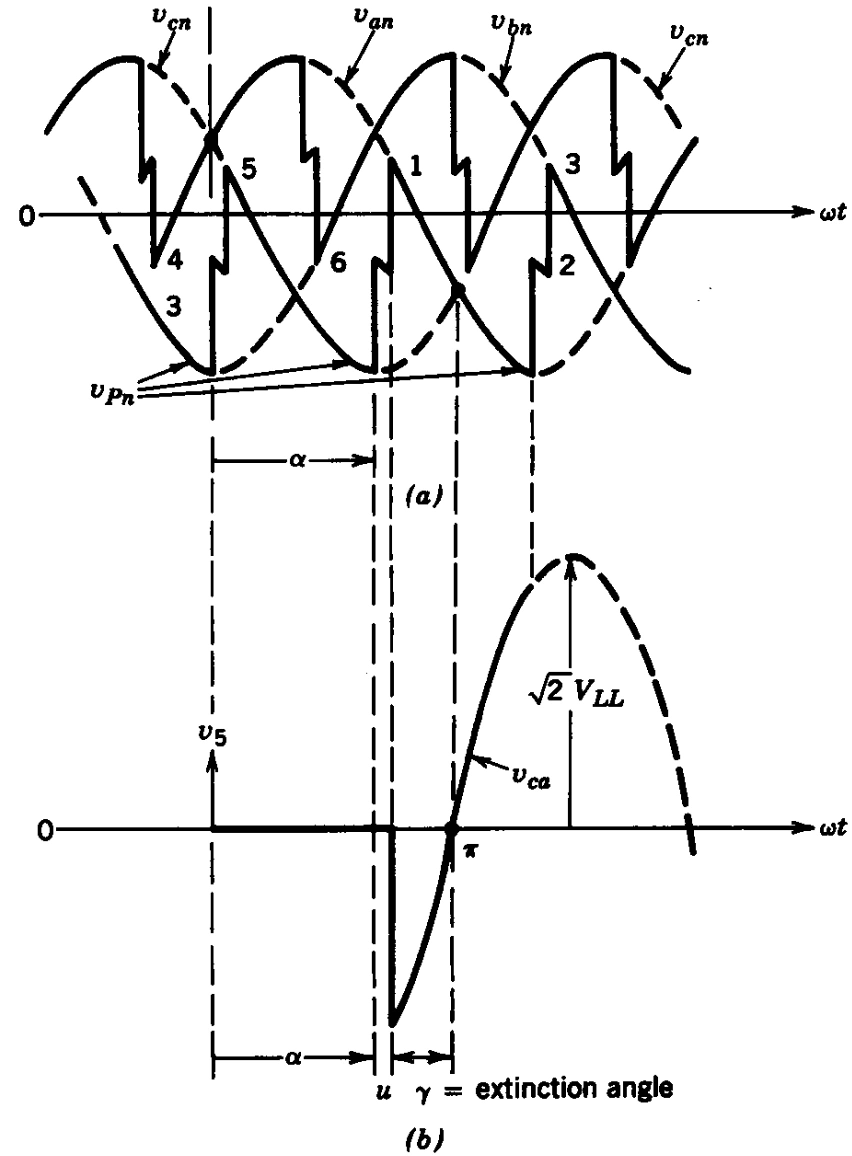


Continuous-conduction mode

Three-phase Bridge

Inverting Mode ($\alpha > 90°$)





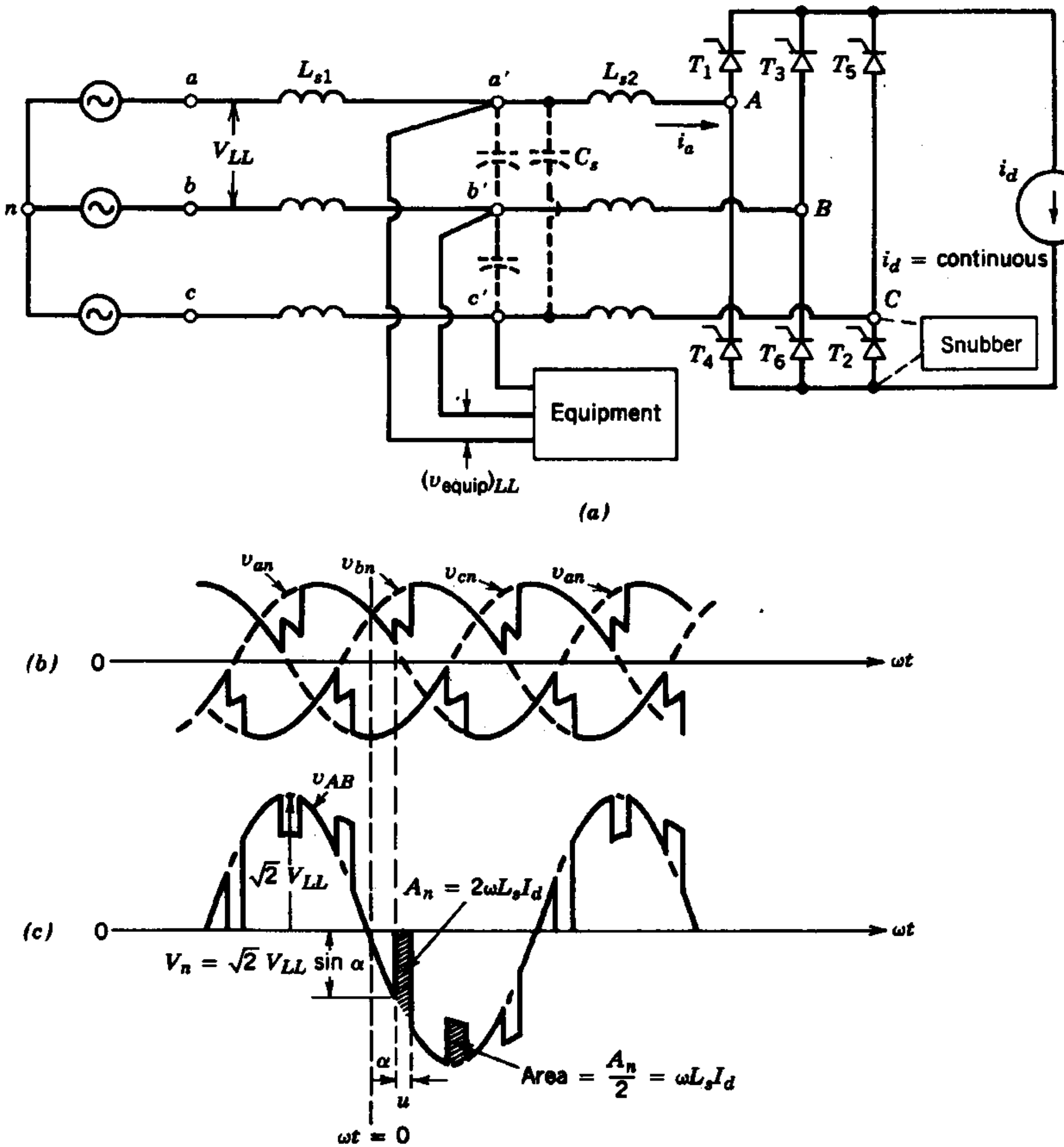
extinction angle δ

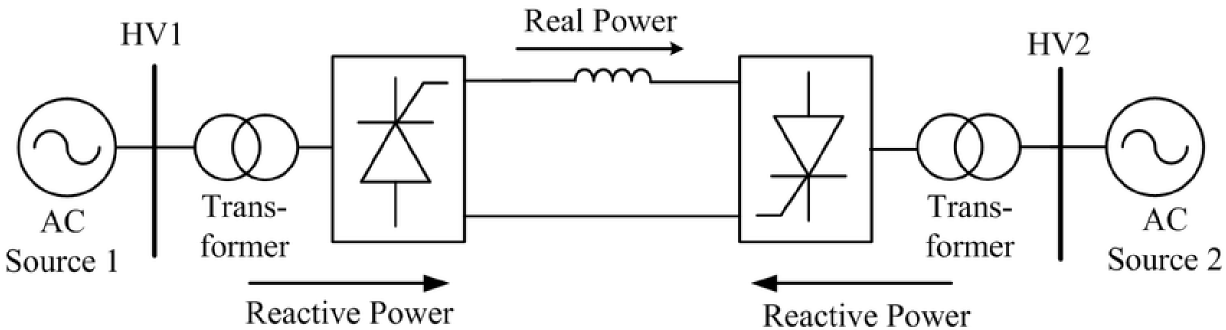
$$\delta = 180 - \alpha - u$$

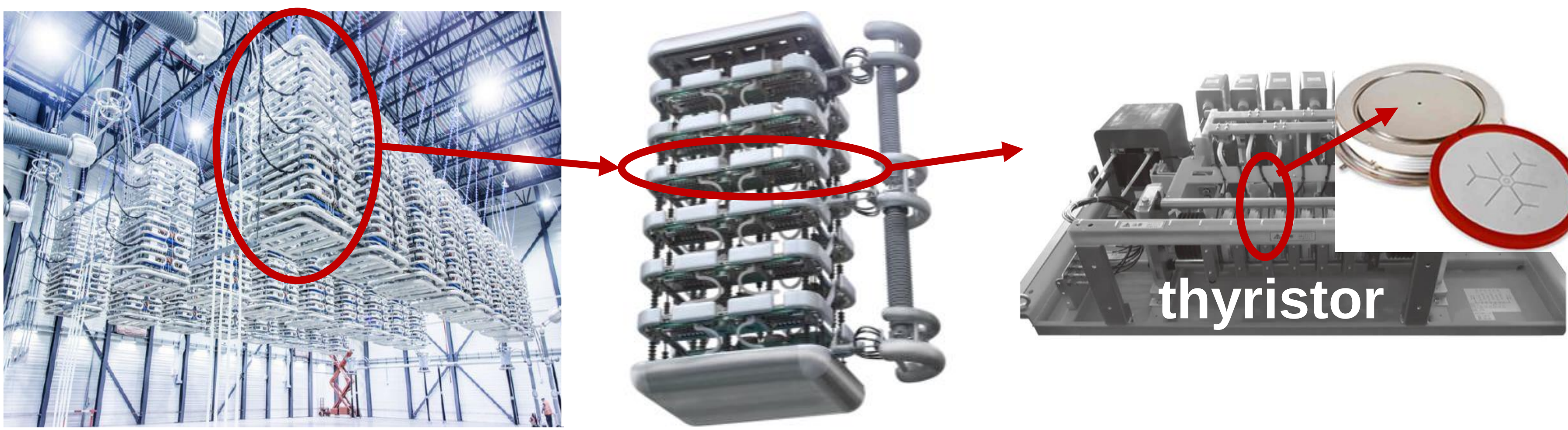
$$\delta_{min} > 5°$$

Three-phase Bridge

Voltage Notching







HVDC station

Summary:

- Thyristor AC-DC: controlled DC, two-quadrant
- Analysis according to key waveforms

Key waveforms

DC output: v_d, i_d

AC input: v_s, i_s

Devices: v_T, i_T

Firing delay angle

⇨

Calculations according to waveforms

DC output: V_d, I_d

AC input: I_{s1}, ξ, PF

Rectifying & inverting mode

ac-side inductance, extinction angle, voltage notching

Required both for single-phase and three-phase diode rectifiers

The End