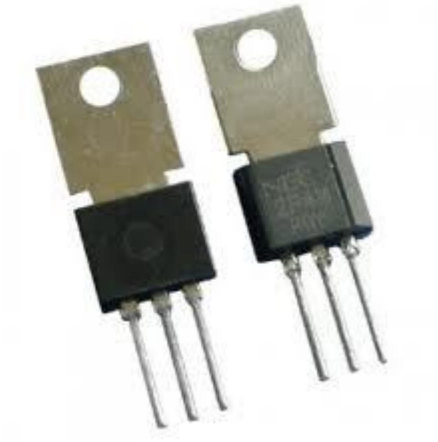
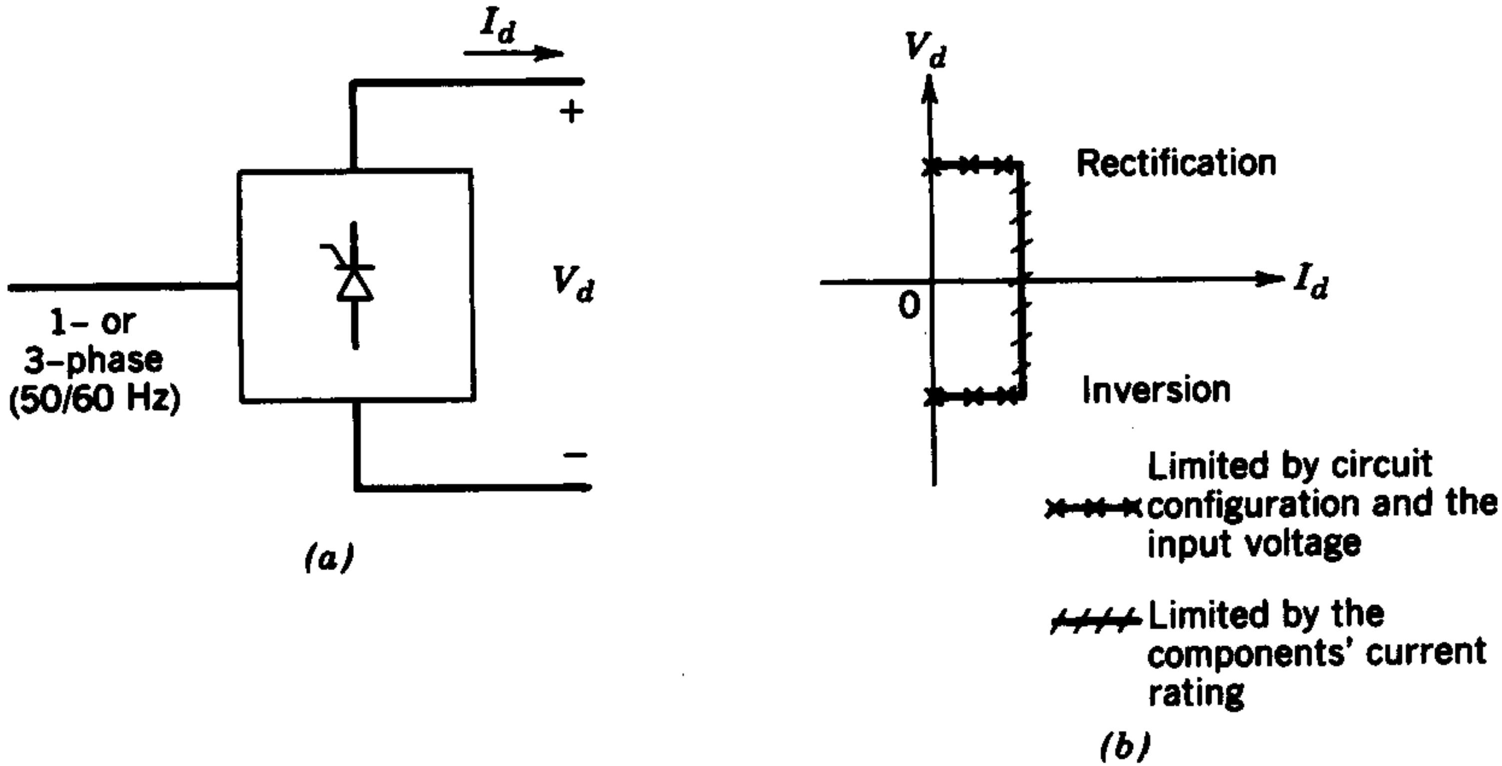


Thyristor Converters

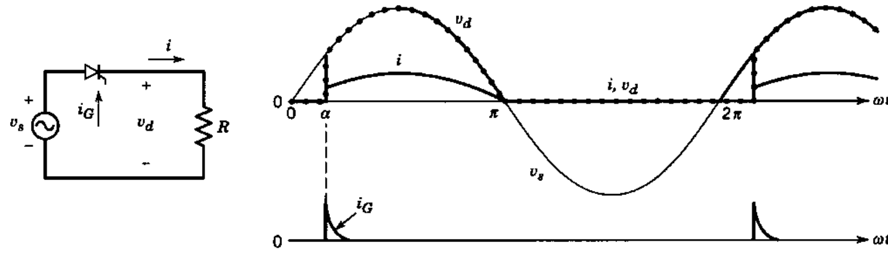
EE 442-642

Thyristor Converters

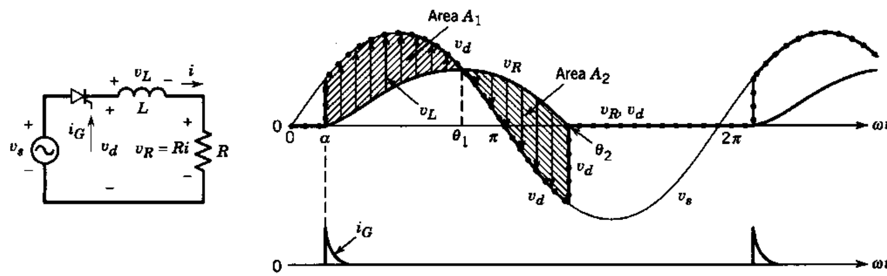


- Two-quadrant conversion

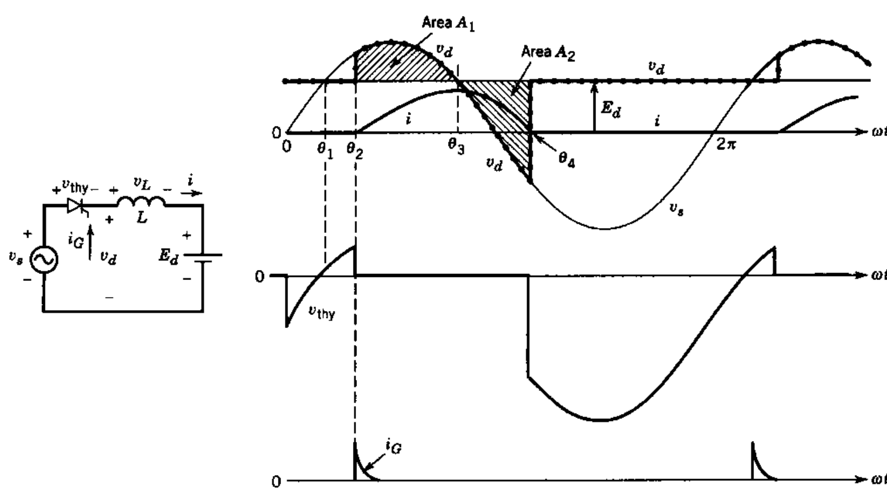
Simple half-wave circuits with thyristors



(a)

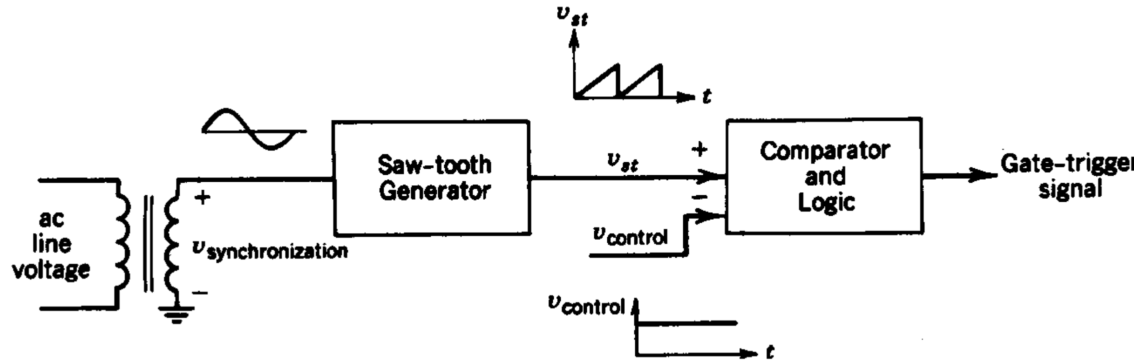


(b)

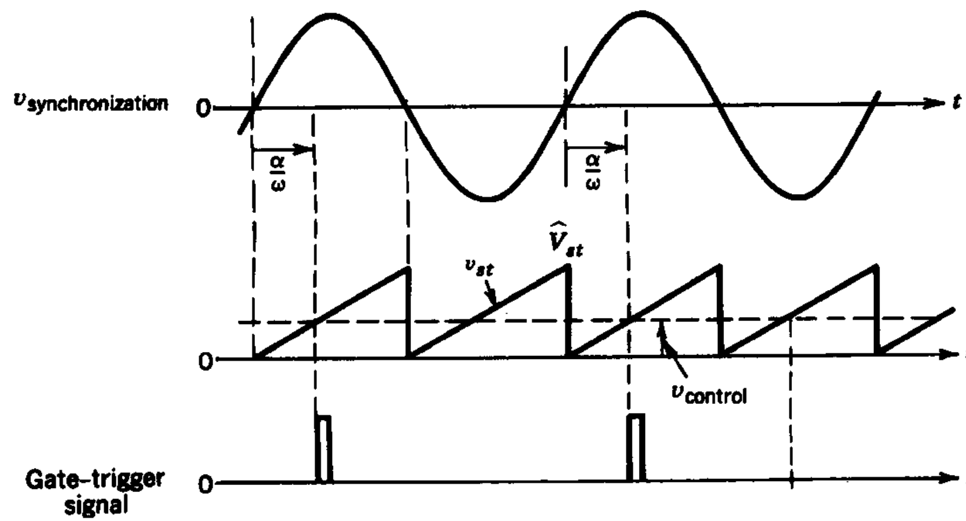


(c)

Thyristor Triggering

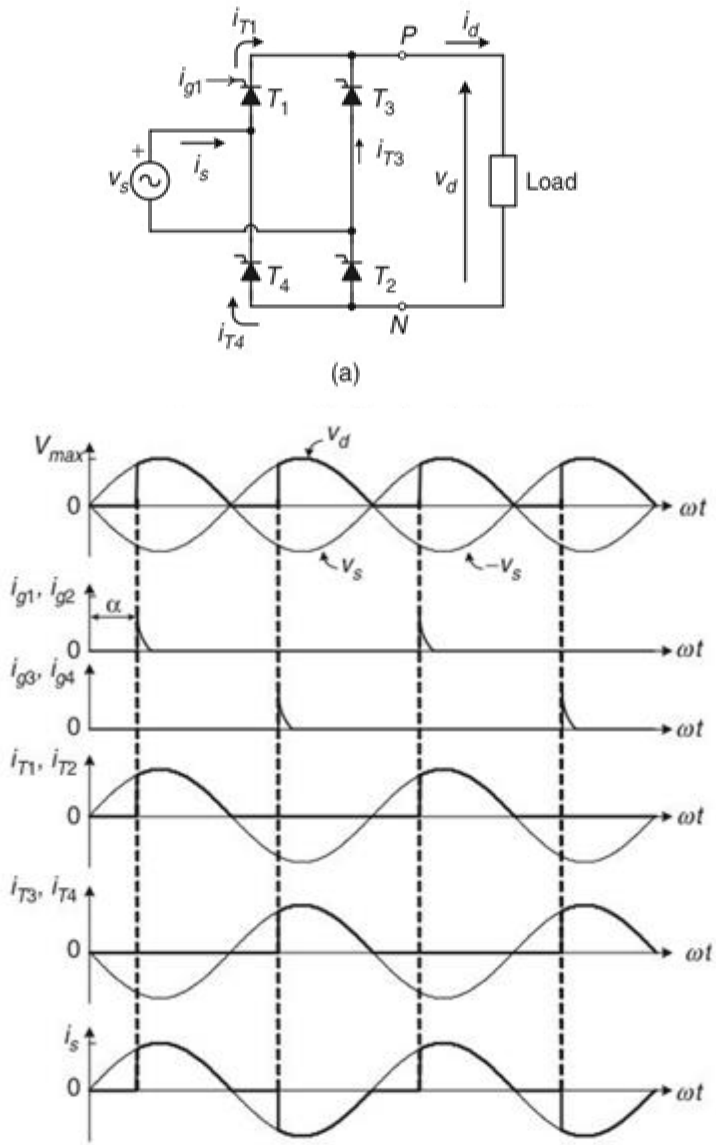


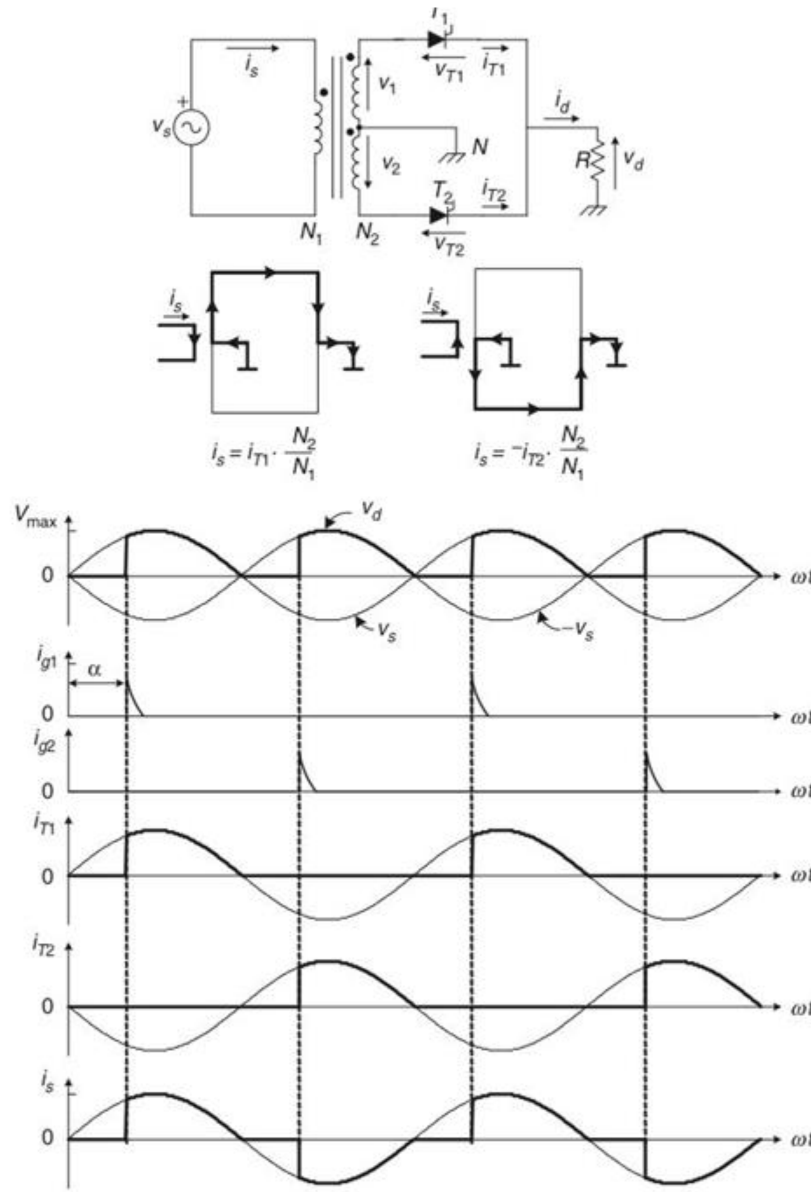
$$\alpha^o = 180^o \frac{v_{control}}{\hat{V}_{st}}$$



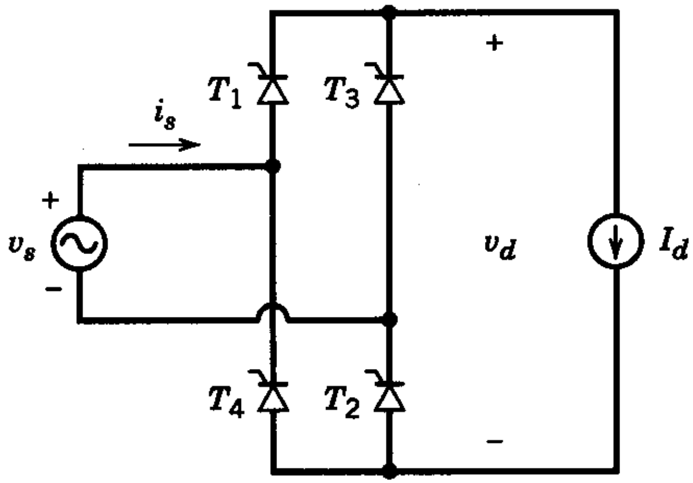
- ICs available

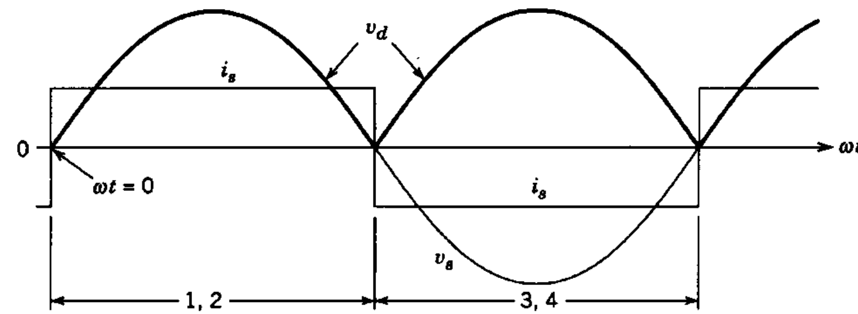
Case of Pure Resistive Load



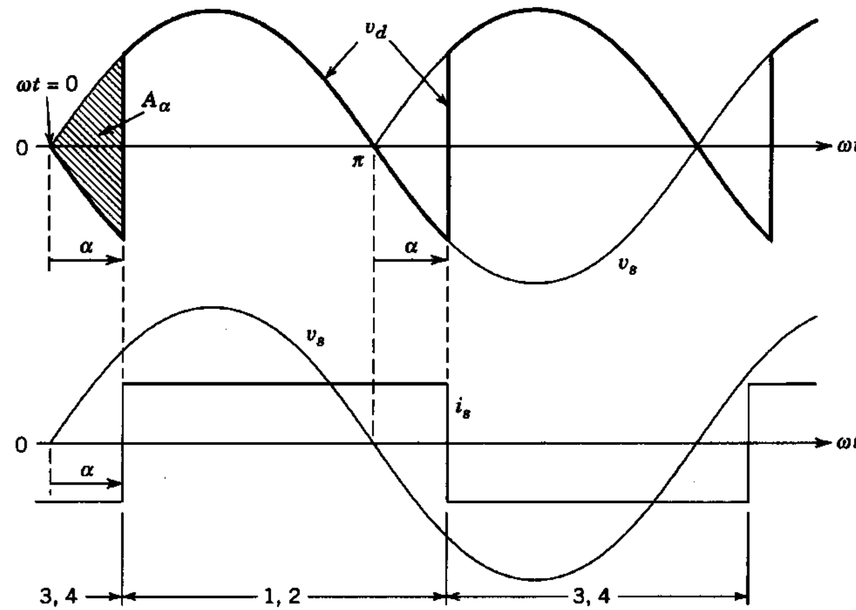


Full-Bridge Thyristor Converters – Constant DC Current



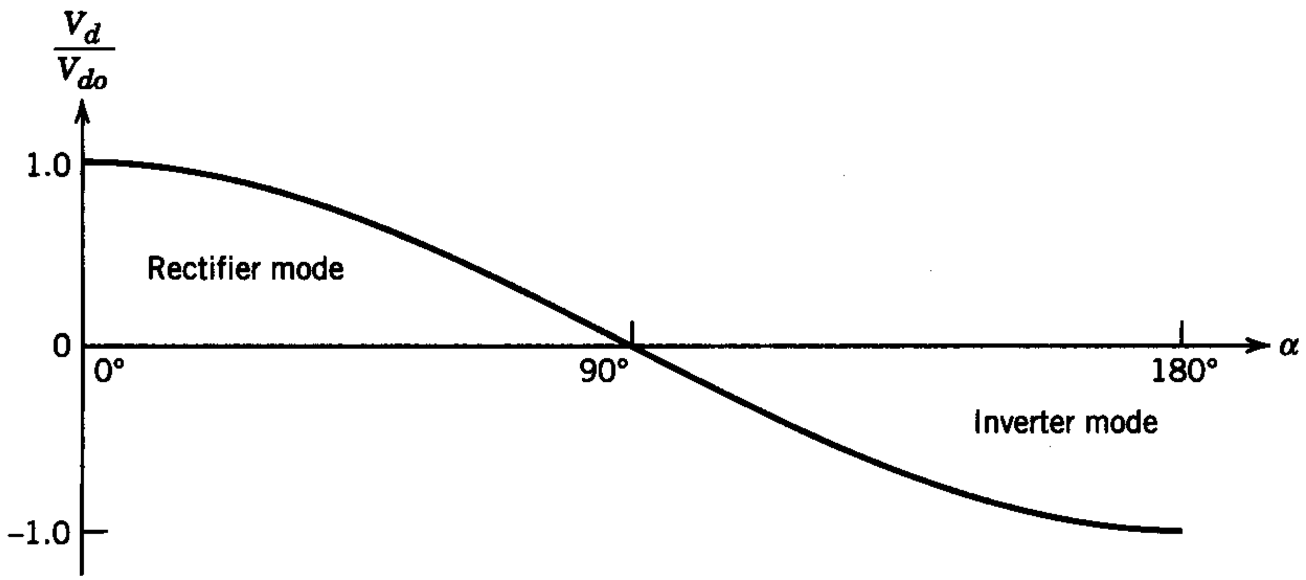


(a) $\alpha = 0$



(b) α = finite

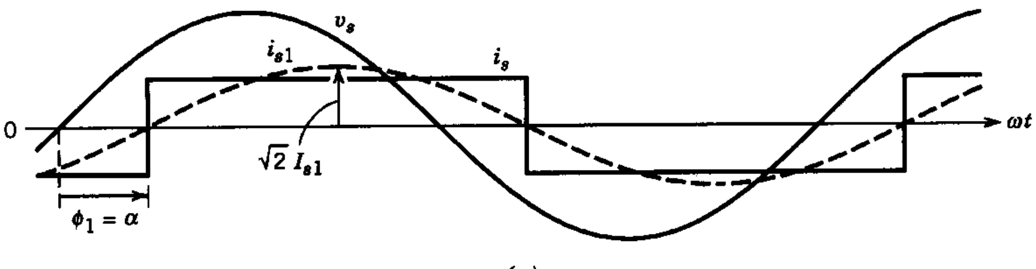
DC-Side Voltage



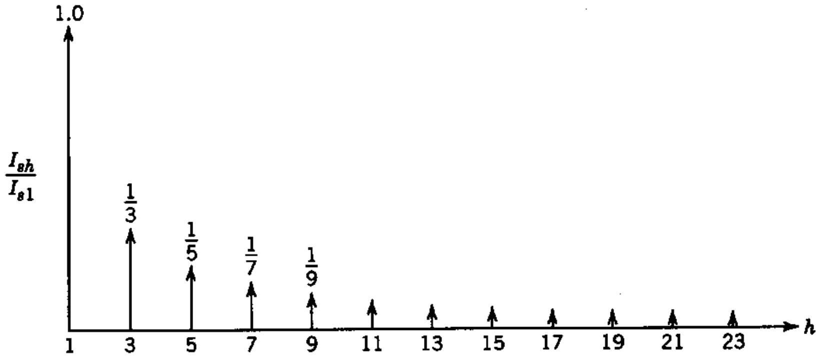
Average DC voltage: $V_{d\alpha} = V_{do} \cos\alpha$

where $V_{do} = 0.9V_s$

AC-Side Current



(a)



RSM value of source current $I_s = I_d$

RMS value of fundamental current $I_{s1} = (2\sqrt{2}/\pi) I_d \approx 0.9 I_d$

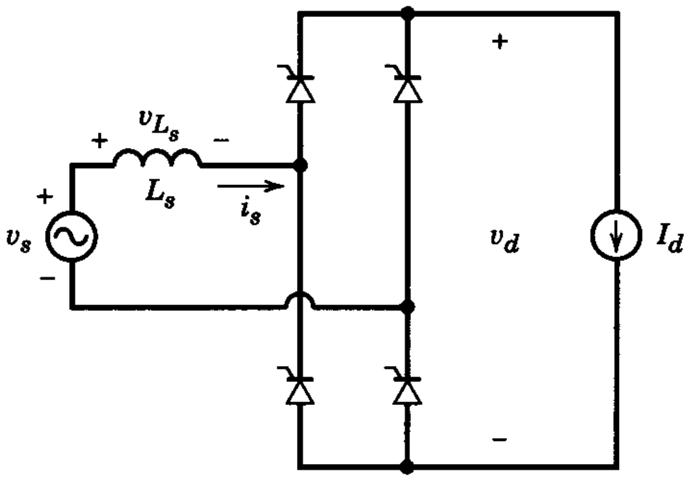
RMS value of harmonic current $I_{sh} = I_{s1}/h, \quad h = 3,5,7,...$

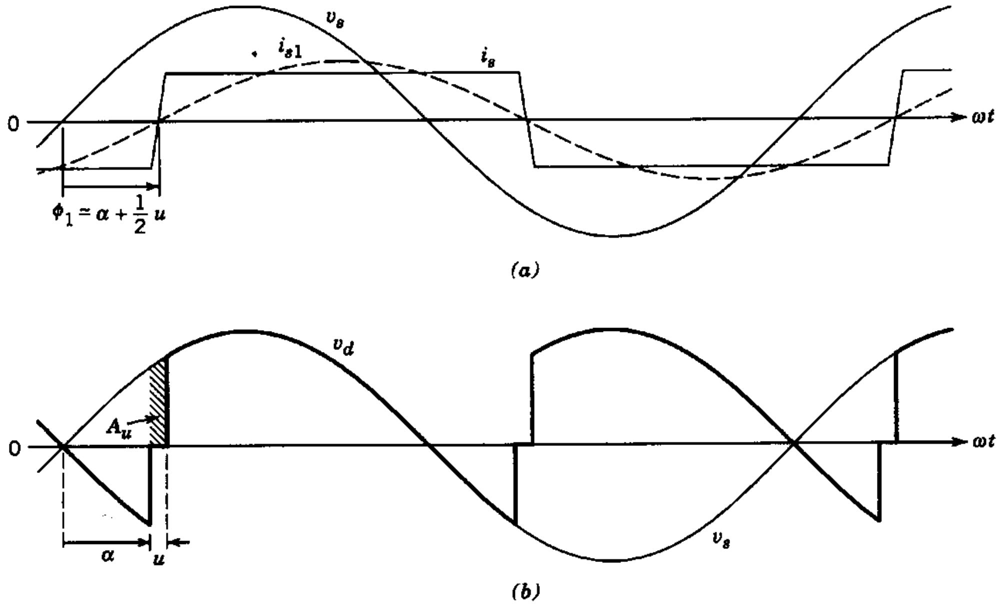
Current THD $THD = 100\sqrt{(\pi^2/8) - 1} = 48.43\%$

Displacement Power Factor $DPF = \cos\alpha$

Power Factor $PF = 0.9\cos\alpha$

Effect of Source Inductance





Commutation angle:

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

Average of DC-side voltage:

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

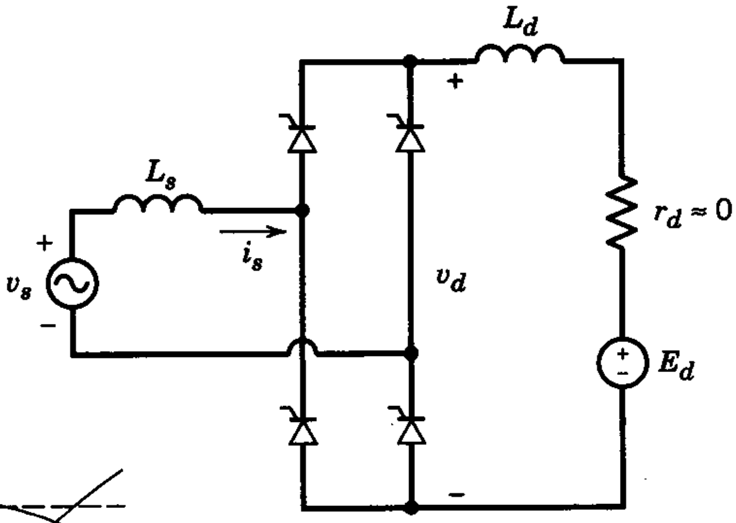
Displacement Power Factor

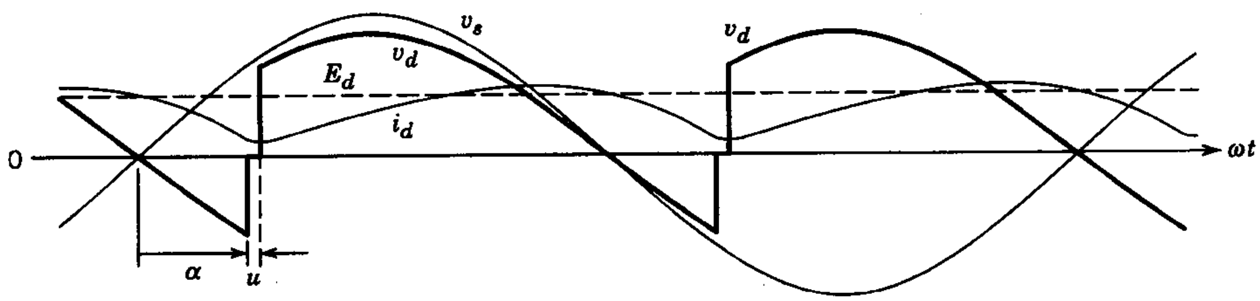
$$DPF \approx \cos(\alpha + 0.5\mu)$$

RMS fundamental current

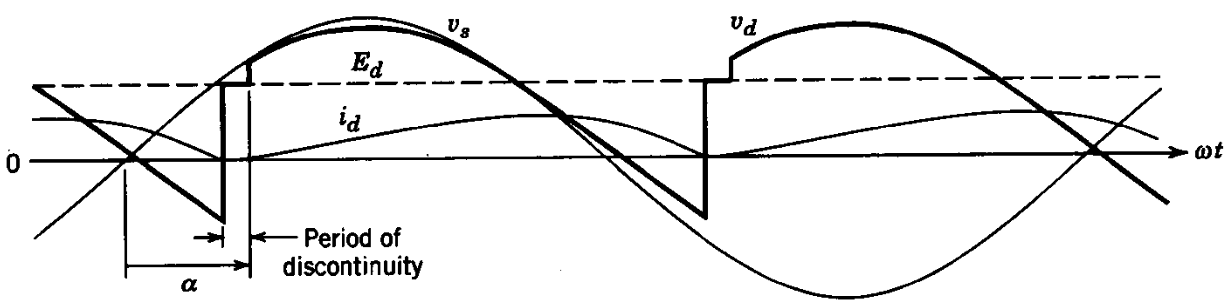
$$I_{s1} = \frac{V_d I_d}{V_s DPF} \approx \frac{0.9 V_s I_d \cos\alpha - (2/\pi)\omega L_s I_d^2}{V_s \cos(\alpha + 0.5\mu)}$$

Thyristor Converter with DC Source





Continuous current conduction mode



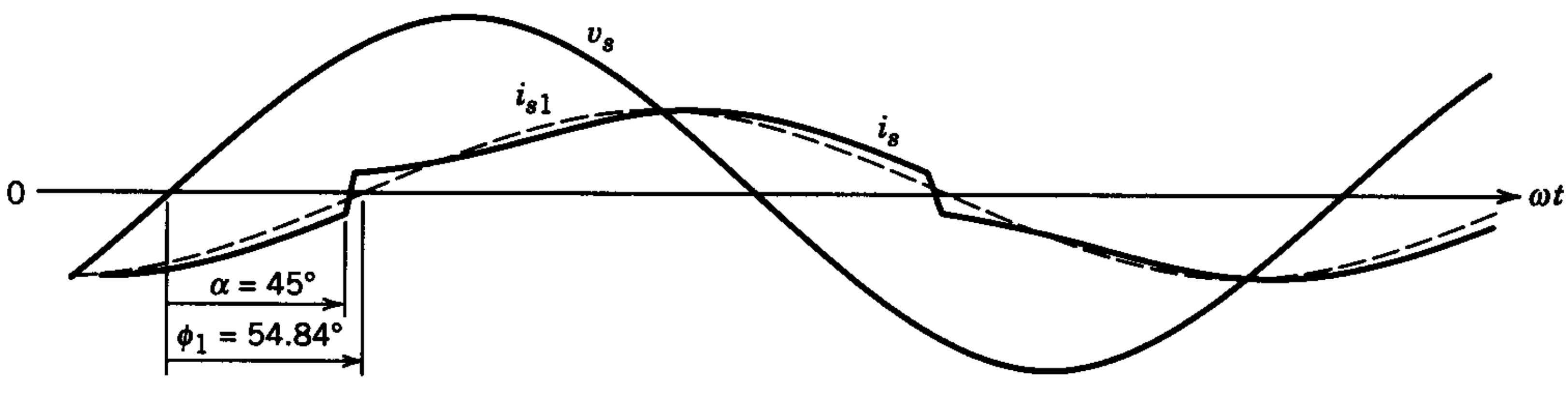
Discontinuous current conduction mode

AC-Side Current Waveform

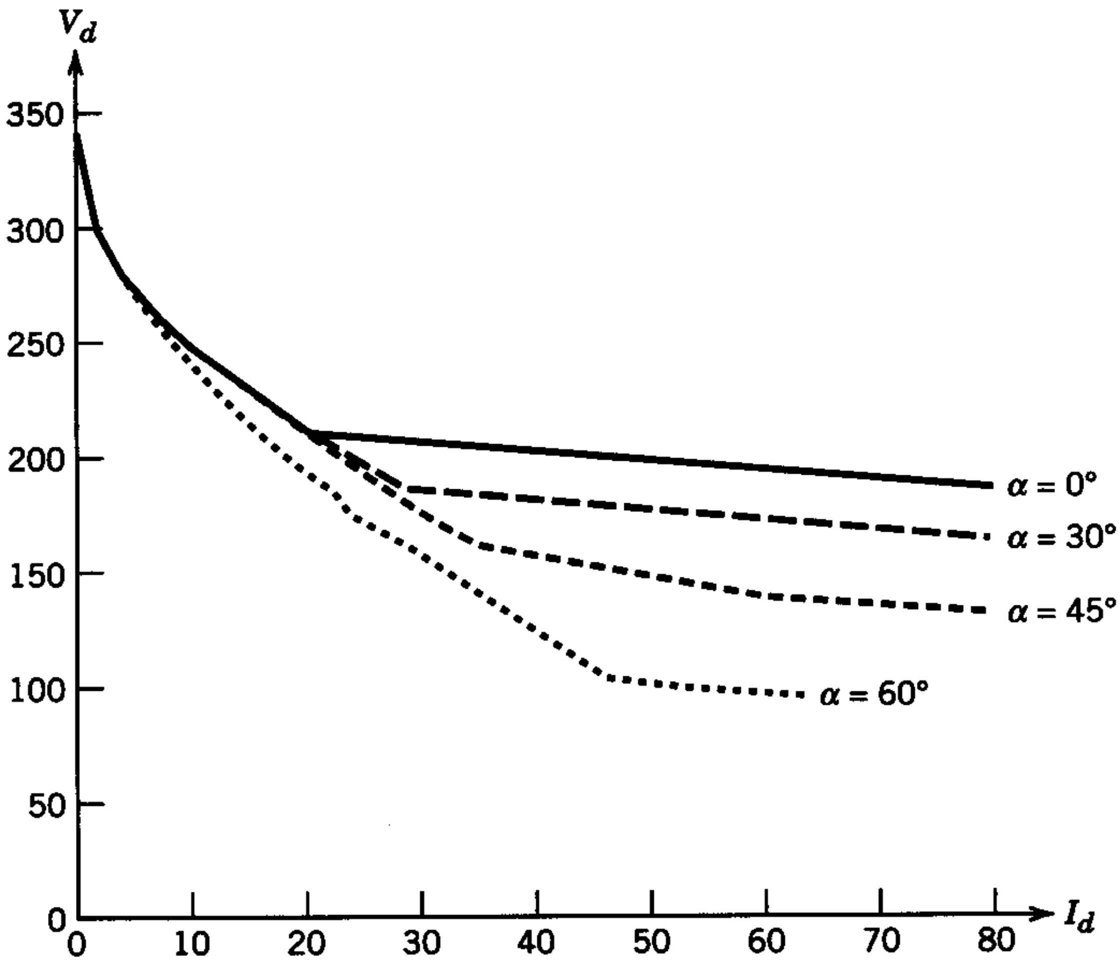
(continuous conduction mode)

PSpice-based simulation example: Vs = 240 V, f = 60 Hz, Ls = 1.4 mH, α = 45 deg., Ld = 9 mH, Ed = 145 V.

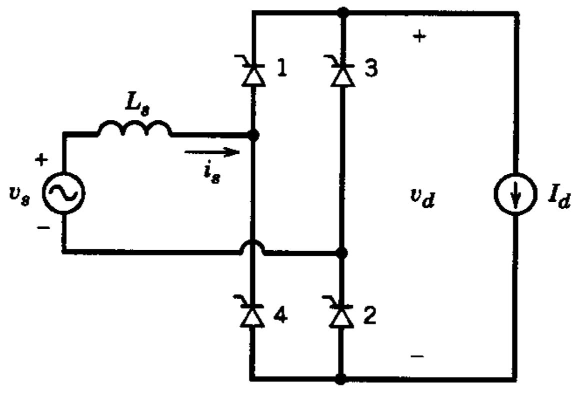
Solution: Is = 60.1 A, Is1 = 59.7 A, DPF = 0.576, PF = 0.572, THD = 12.3%



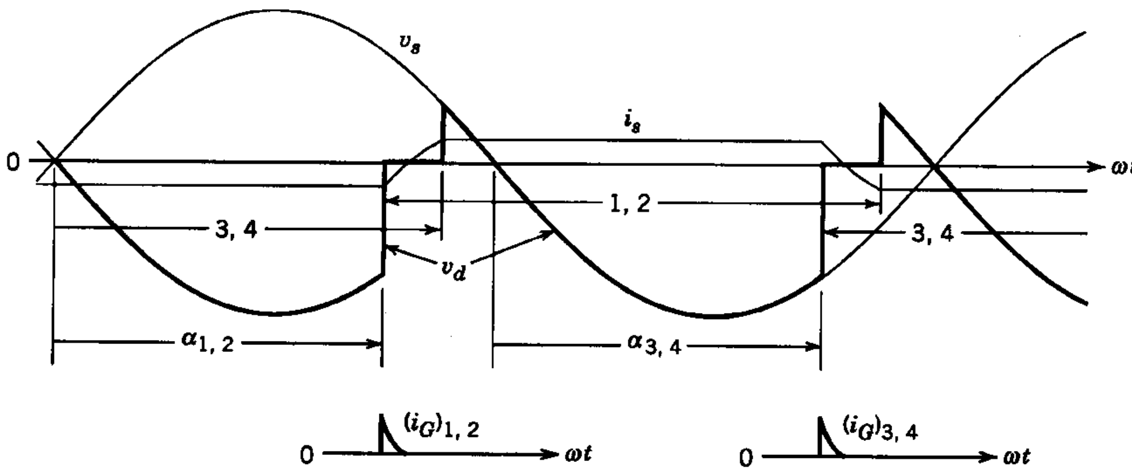
DC Voltage versus Load Current



Inverter Mode (α > 90°)

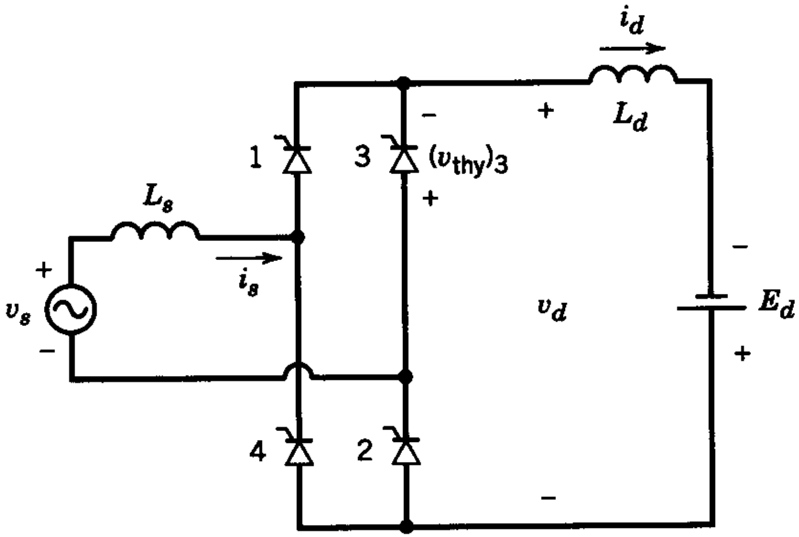


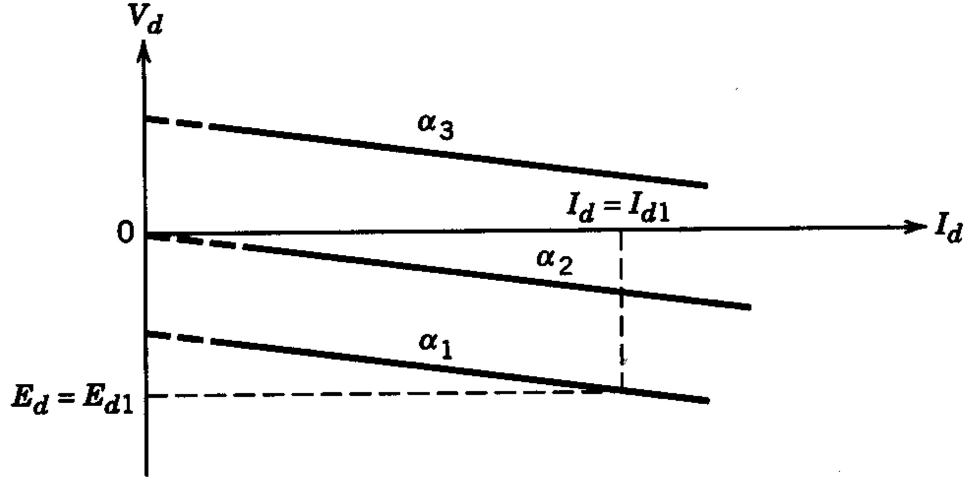
(a)



(b)

Inverter Mode with DC Voltage Source

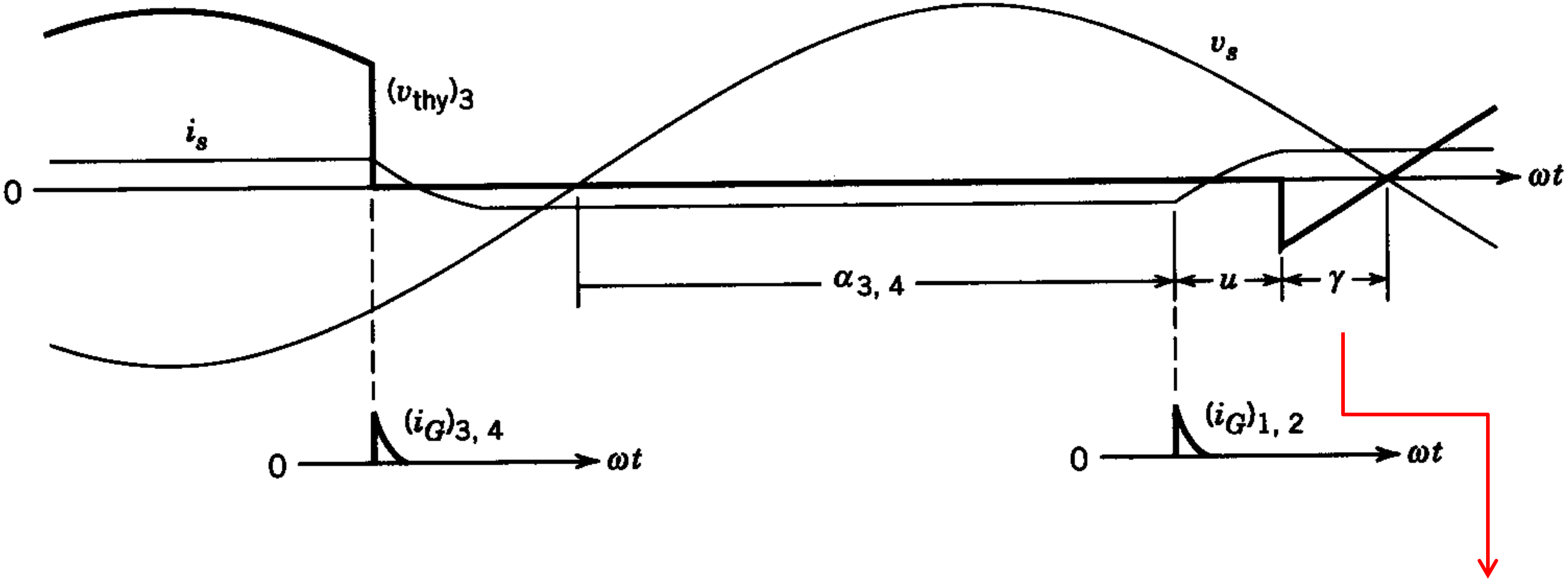




- For a large value of L_d, i_d can be assumed constant (= I_d), then

$$E_d = V_d = 0.9V_s \cos\alpha - \frac{2}{\pi}\omega L_S I_d$$

Inverter Mode: Extinction Angle

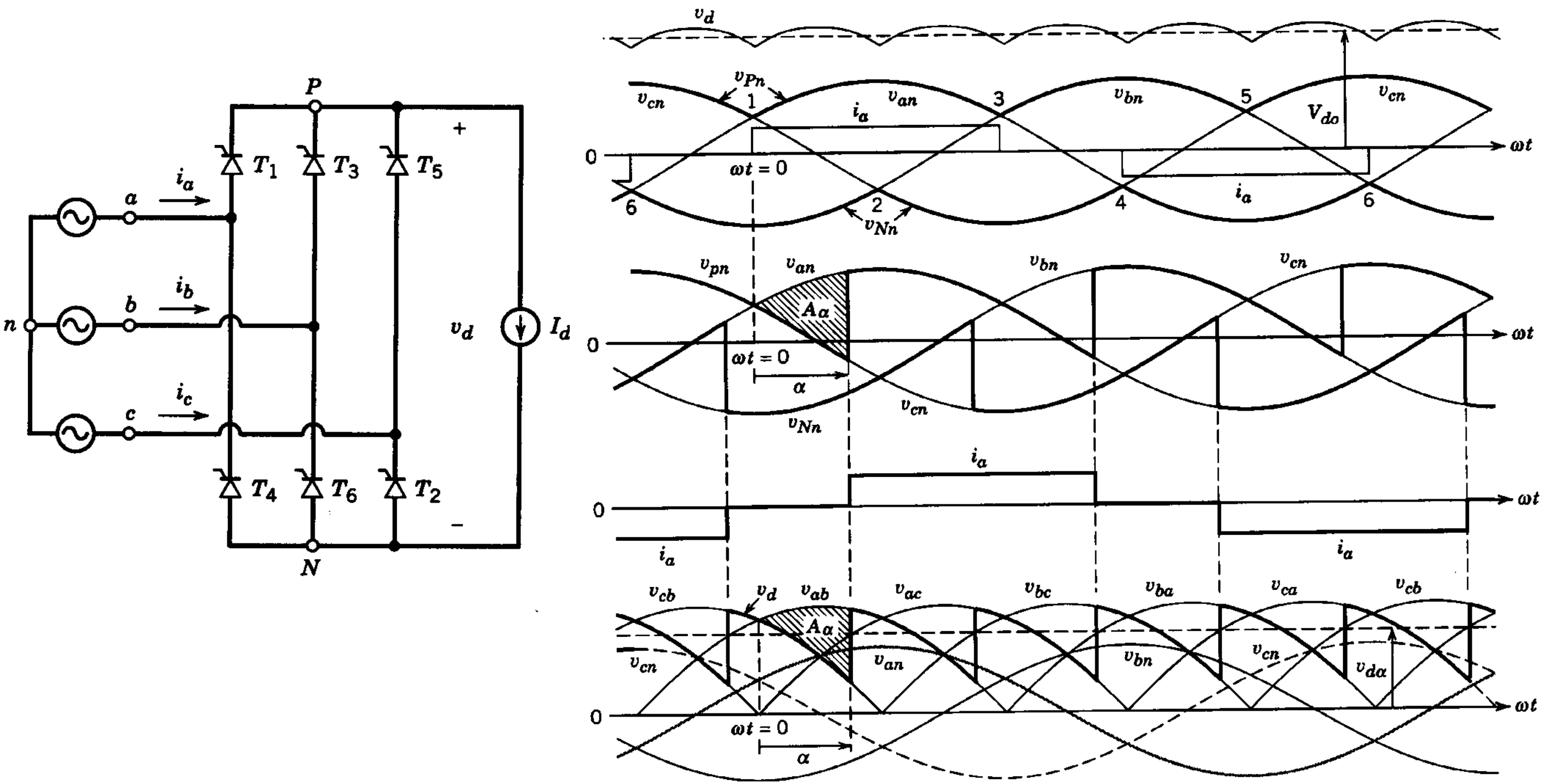


$$\gamma = 180^o - (\alpha + \mu)$$

Importance of extinction angle in inverter mode: The extinction time interval should be greater than the thyristor turn-off time:

$$t_\gamma = \frac{\gamma}{\omega} > t_q$$

3-Phase Thyristor Converters: Simplified Case

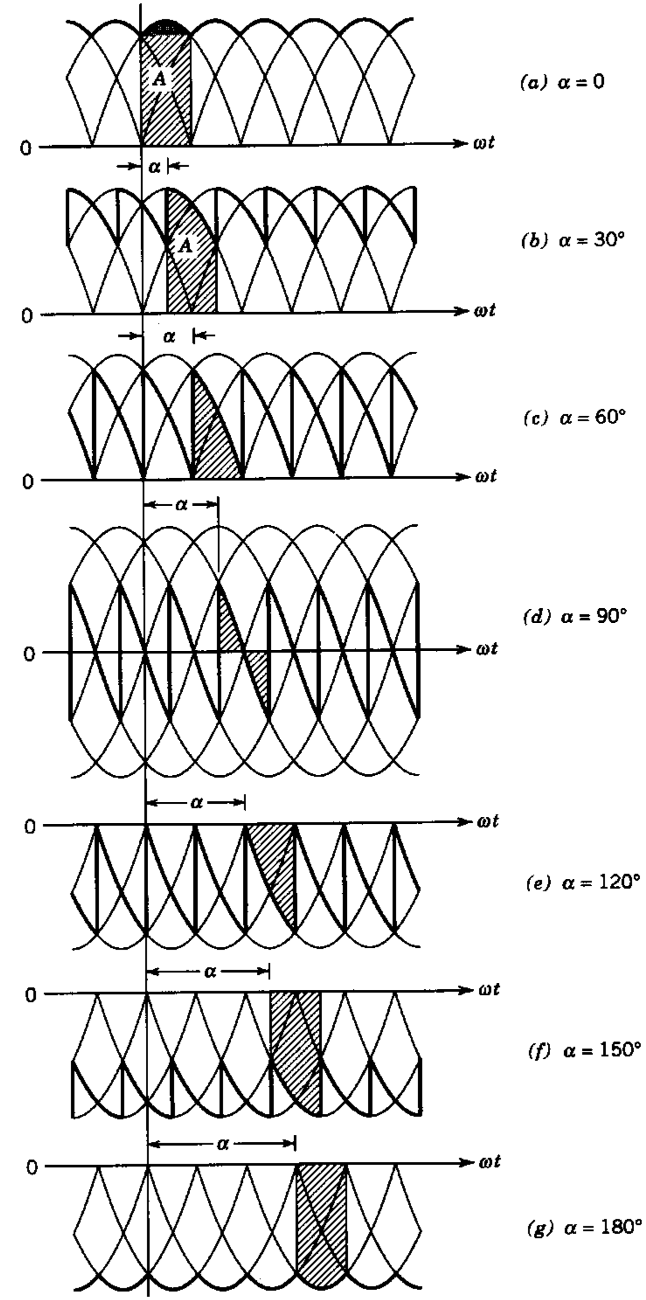


DC-side voltage waveforms assuming zero ac-side inductance

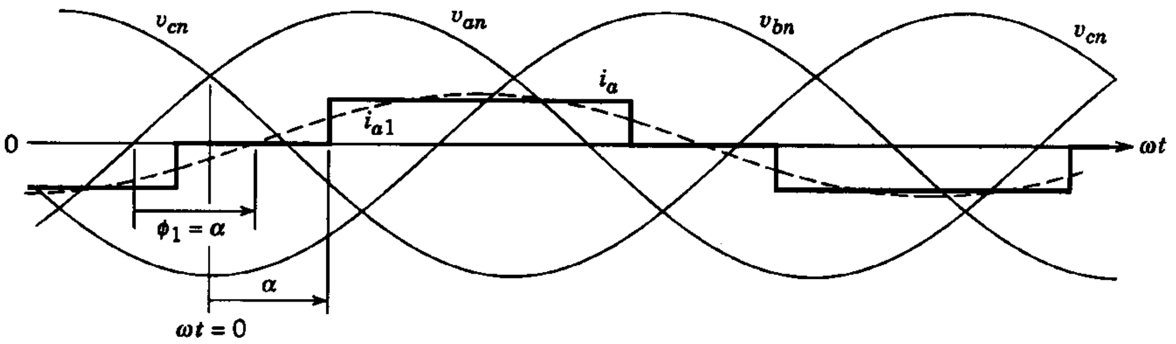
$$V_d = V_{do} \cos\alpha$$

$$= \frac{3}{\pi}\sqrt{2}V_{LL} \cos\alpha$$

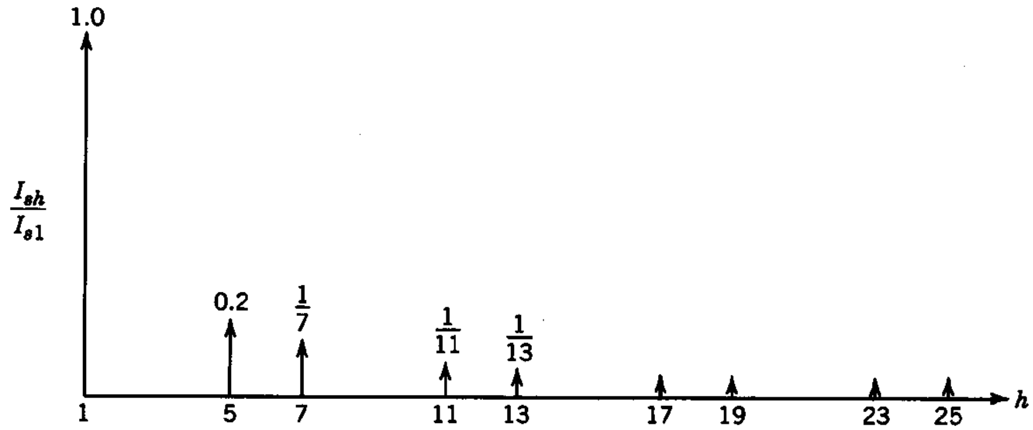
$$= 1.35 V_{LL} \cos\alpha$$



Input Line-Current Waveform

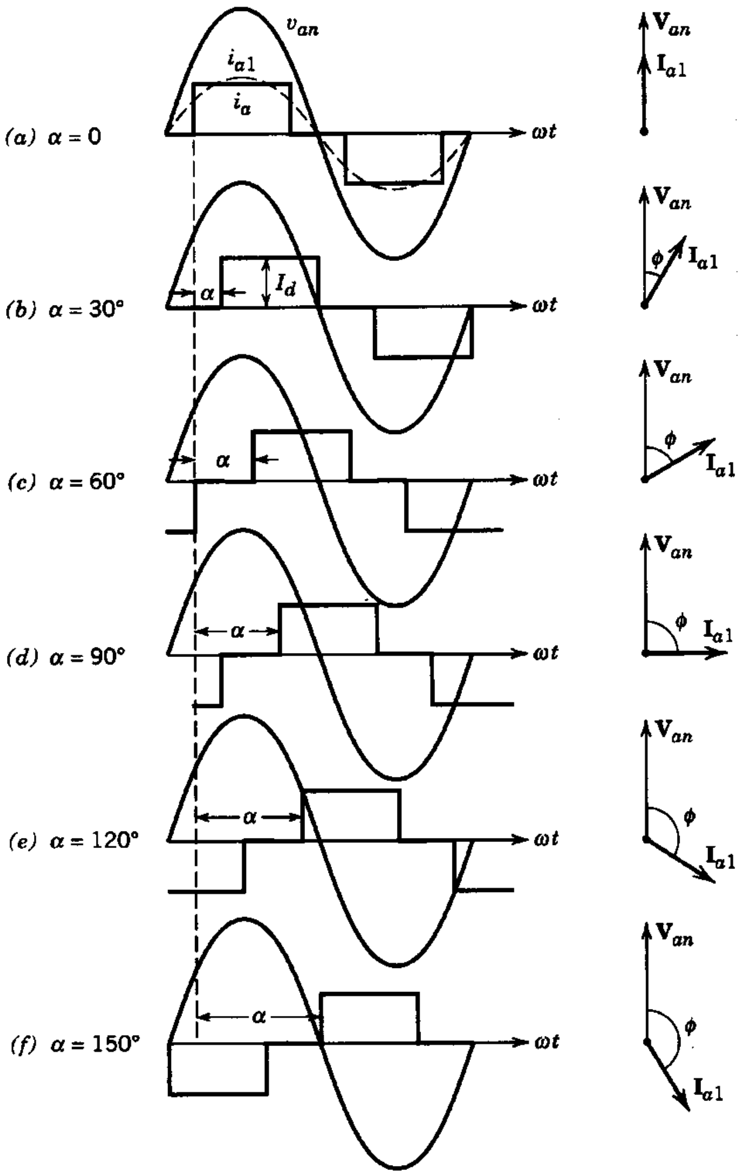


(a)



(b)

Input line-current waveforms assuming zero ac-side inductance



$$I_s = \sqrt{2/3} I_d = 0.816 I_d$$

$$I_{s1} = (\sqrt{6}/\pi) I_d \approx 0.78 I_d$$

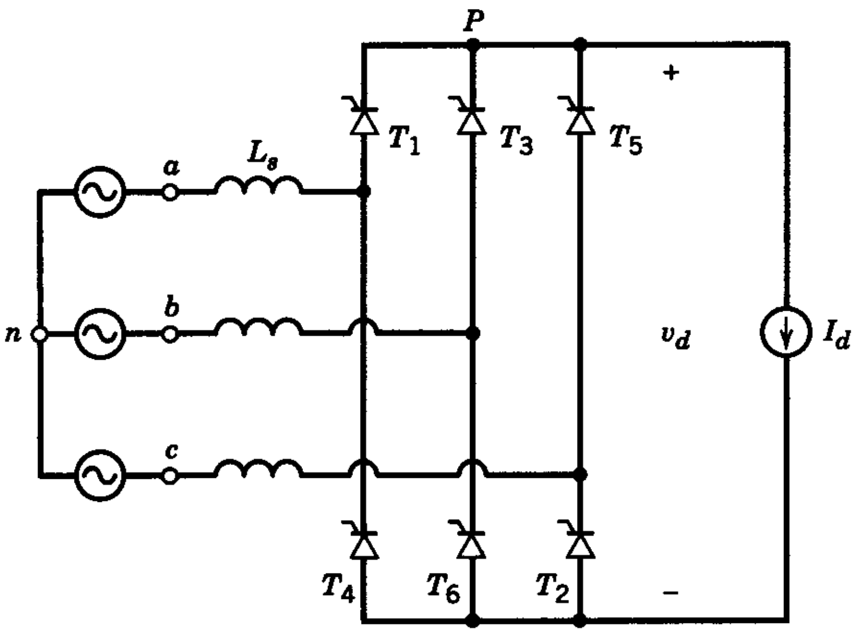
$$I_{sh} = I_{s1}/h, \quad h = 3,5,7,...$$

$$THD = 100[\sqrt{(\pi^2/9) - 1}] = 31\%$$

$$DPF = \cos\alpha$$

$$PF = \frac{3}{\pi}\cos\alpha = 0.955\cos\alpha$$

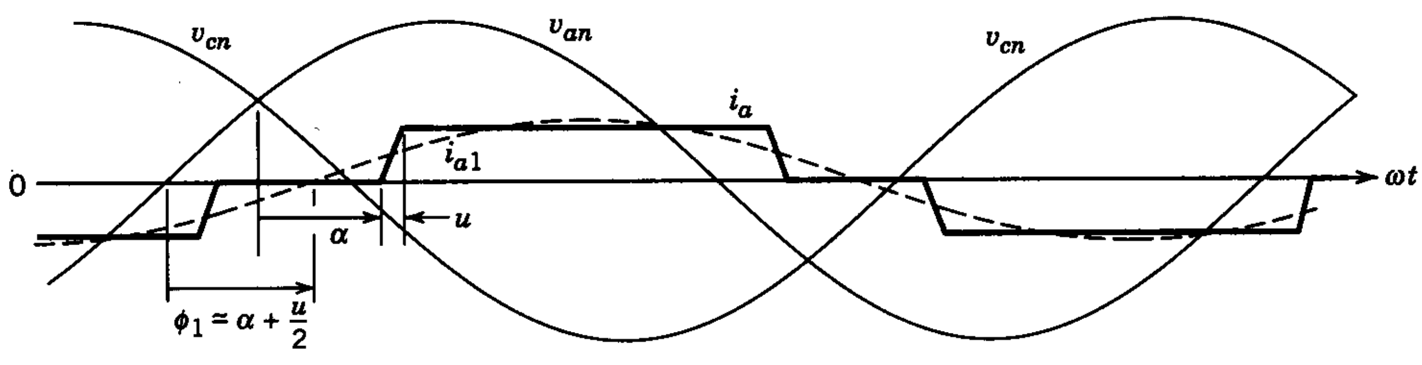
3-Phase Thyristor Converter with AC-side Inductance



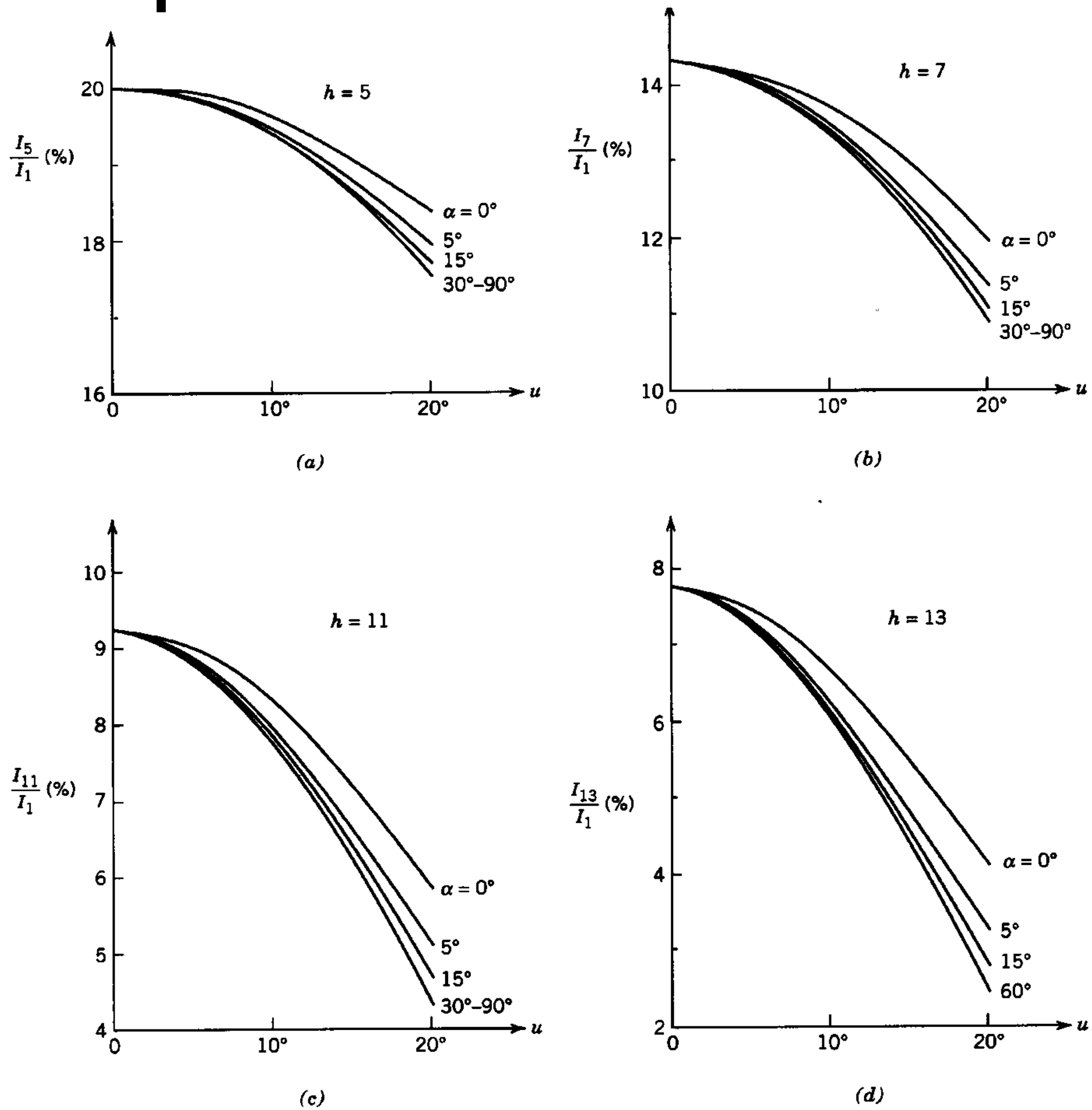
$$\cos(\alpha+\mu)=\cos\alpha-\frac{2\omega L_s I_d}{\sqrt{2}V_{LL}}$$

$$V_d=1.35V_{LL}\cos\alpha-\frac{3\omega L_s I_d}{\pi}$$

$$DPF\approx\cos(\alpha+0.5\mu)$$



Input Line-Current Harmonics



Input Line-Current Harmonics

	h	5	7	11	13	17	19	23	25
Typical	I_h/I_1	0.17	0.10	0.04	0.03	0.02	0.01	0.01	0.01
Idealized	I_h/I_1	0.20	0.14	0.09	0.07	0.06	0.05	0.04	0.04

Typical Passive Filter Block (for each phase)

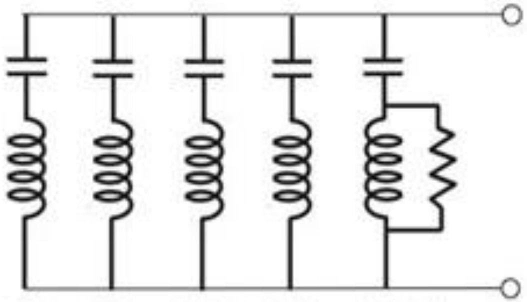
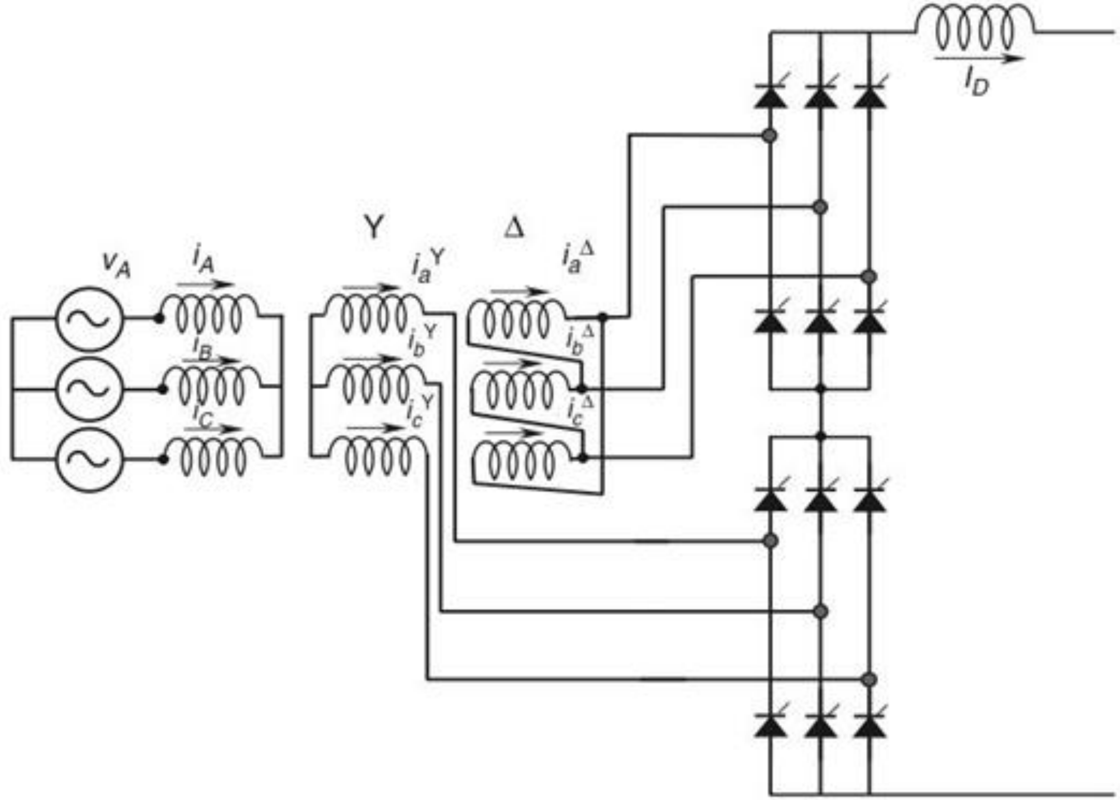


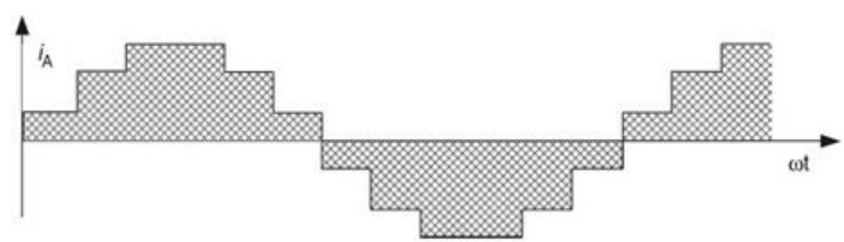
TABLE 12.1 Harmonic current limits in percent of fundamental

Short circuit current (pu)	$h < 11$	$11 < h < 17$	$17 < h < 23$	$23 < h < 35$	$35 < h$	*THD*
<20	4.0	2.0	1.5	0.6	0.3	5.0
20–50	7.0	3.5	2.5	1.0	0.5	8.0
50–100	10.0	4.5	4.0	1.5	0.7	12.0
100–1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

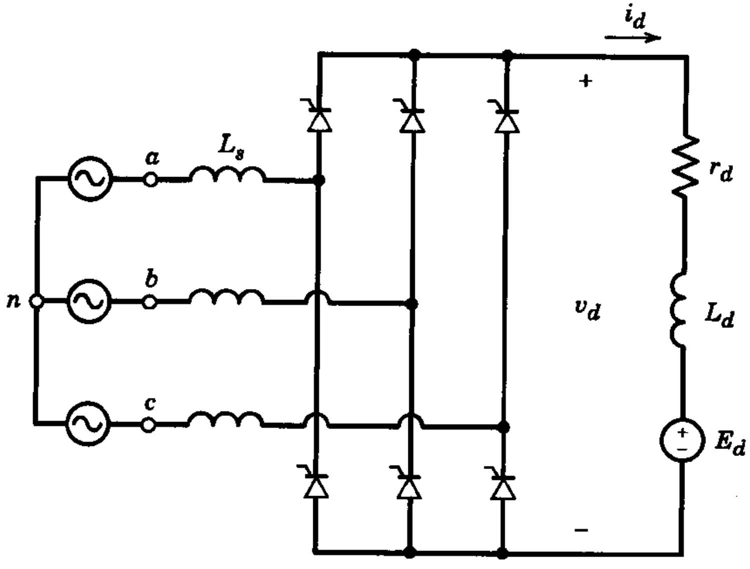
12-Pluse Phase Controlled Rectifier



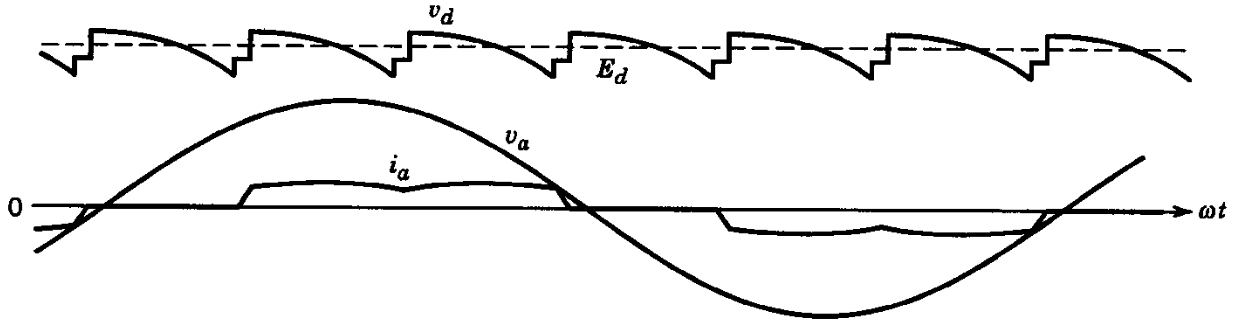
Harmonic Order: 1, 11, 13, 23, 25, …



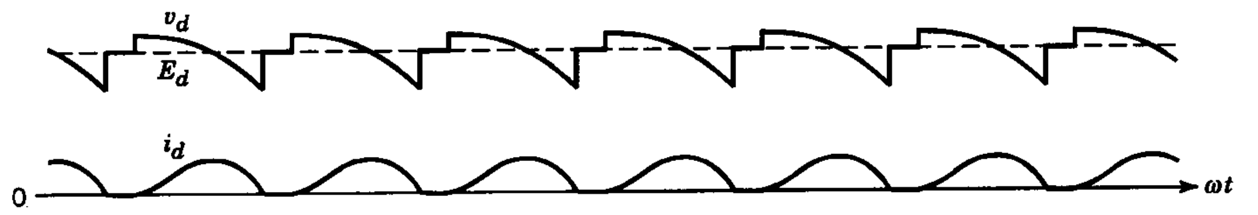
3-Phase Thyristor Converter with Realistic Load



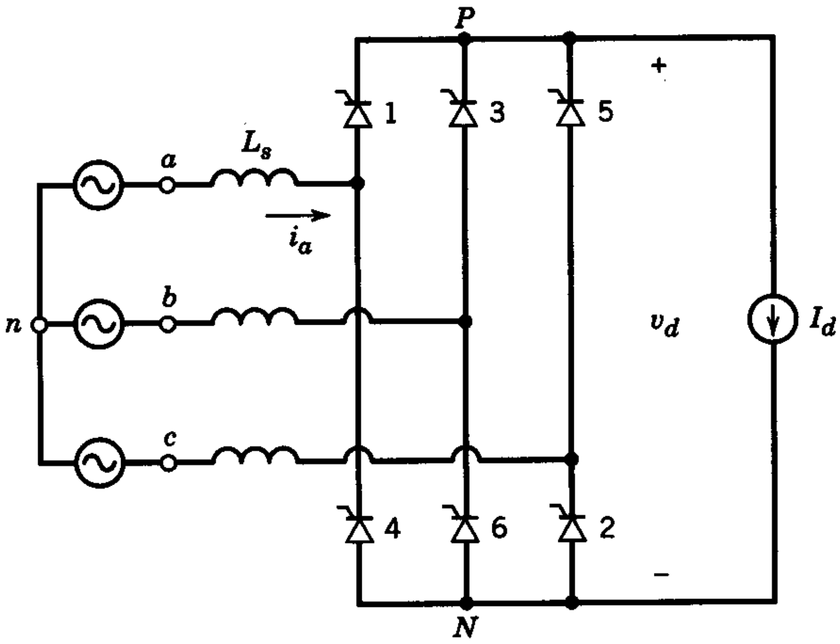
Continuous conduction Mode

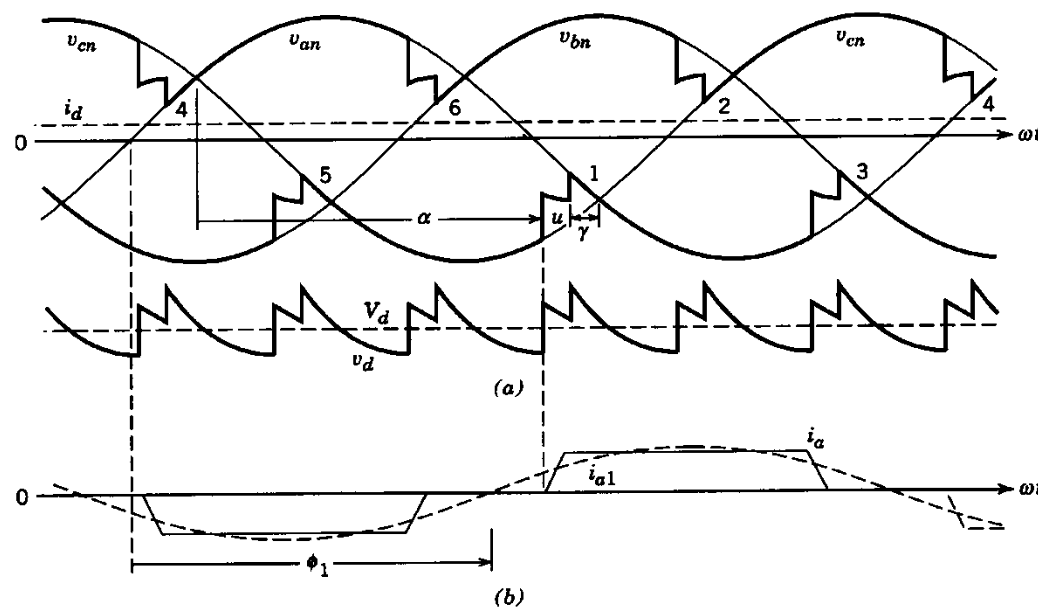


Discontinuous conduction mode

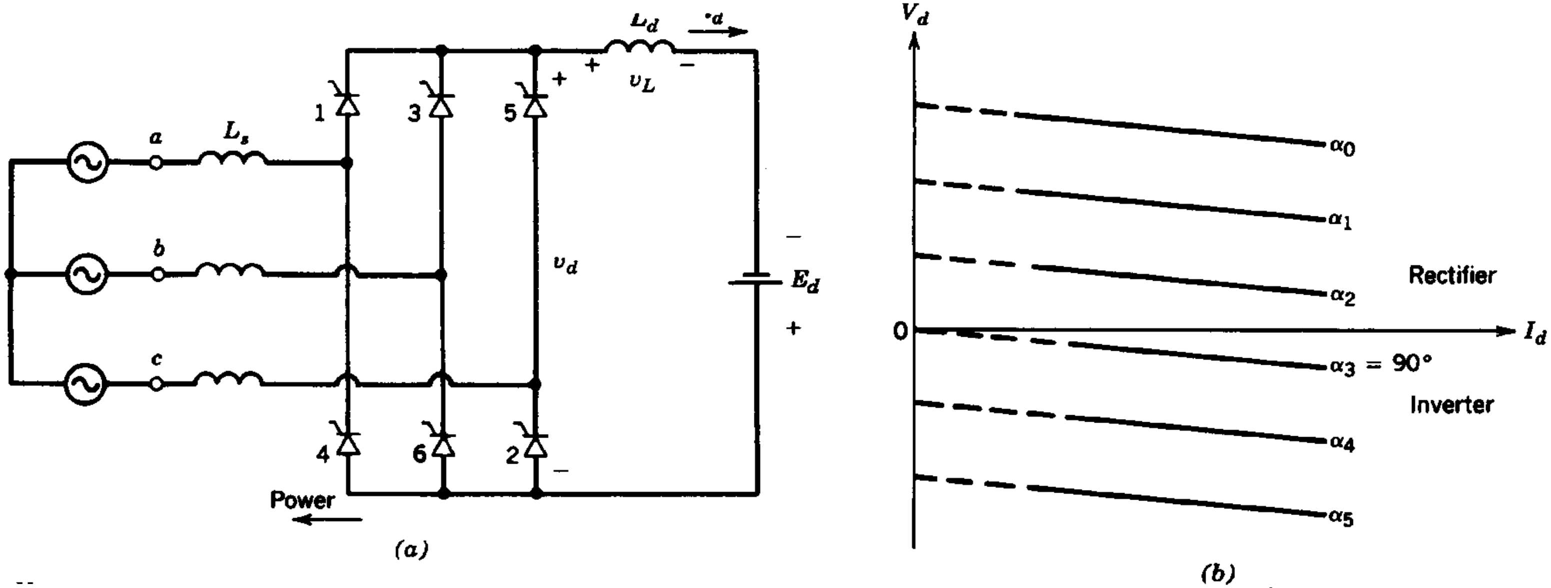


3-Phase Thyristor Inverter – Constant Current

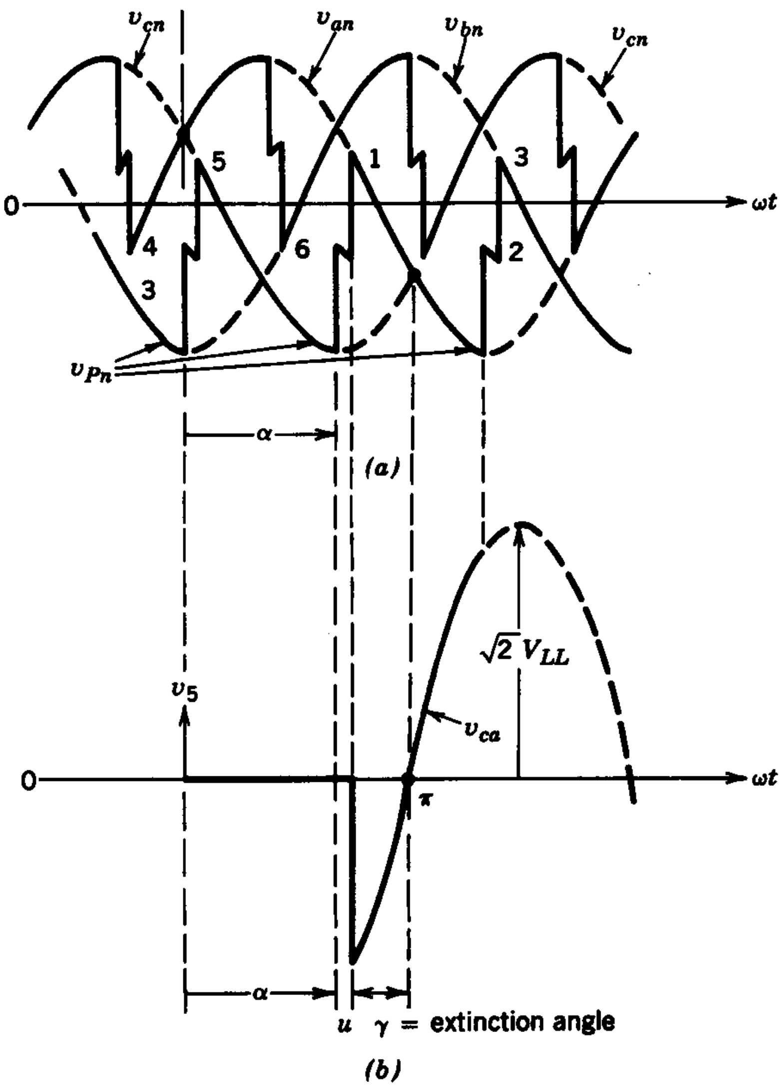




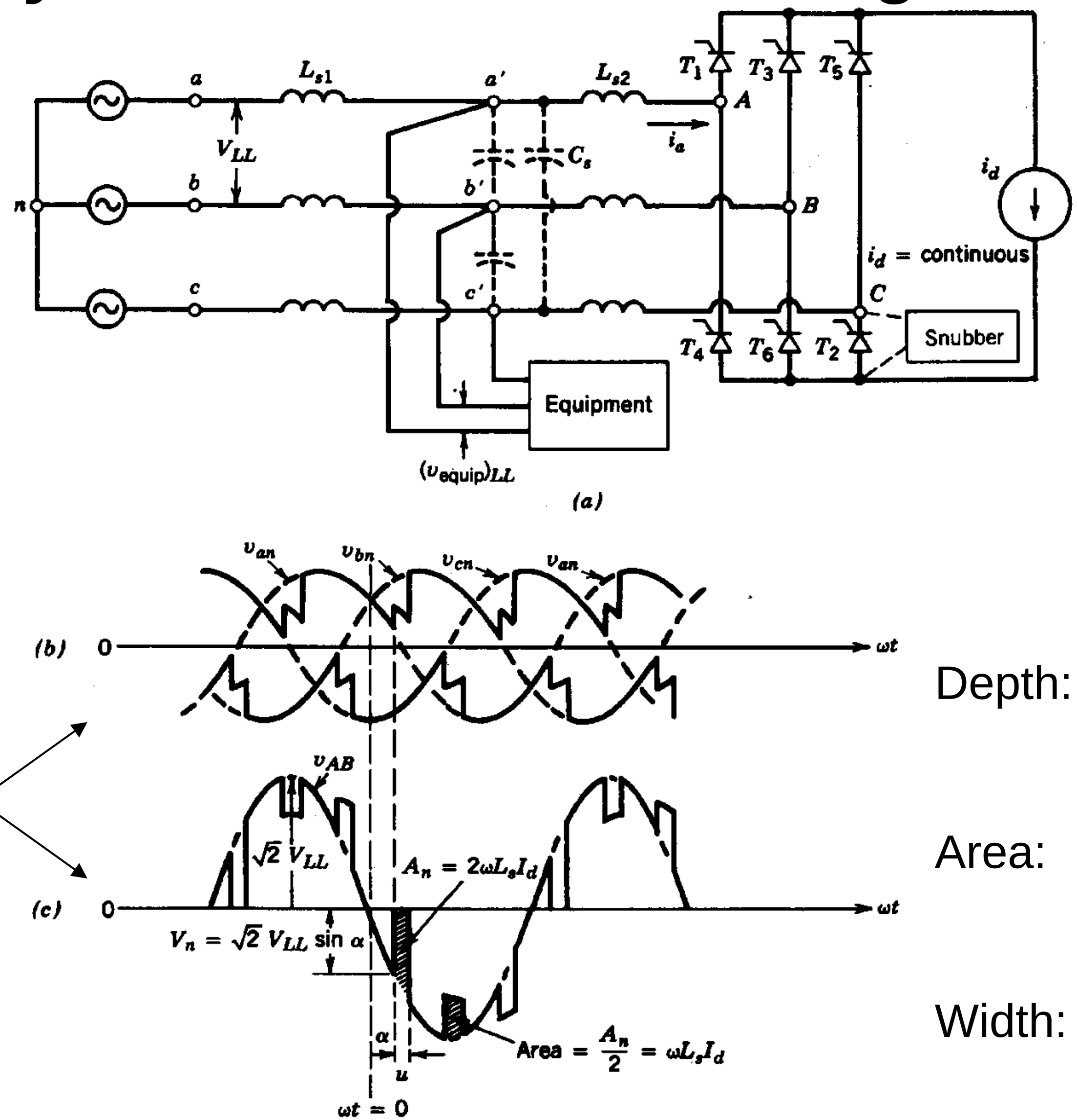
Thyristor Inverter – Constant Voltage & Current



Thyristor Inverter Operation: Extinction Angle



Thyristor Converters: Voltage Notching



$$L_{s1} = L_s$$
$$L_{s2} = 0$$

Depth: $V_n = \sqrt{2} V_{LL} \sin\alpha$

Area: $A_n = 2\omega L_s I_d$

Width: $\mu \approx \dfrac{2\omega L_s I_d}{\sqrt{2} V_{LL} \sin\alpha}$

Limits on Notching and Distortion

In practice, the notch depth at PCC depends on L_{s1} relative to L_{s2}. Let depth factor be defined by

$$\rho = \frac{L_{s1}}{L_{s1} + L_{s2}}$$

Given L_{s1} , a higher value of L_{s2} results in a smaller notch.

Class	*Line Notch Depth* ρ*(%)*	*Line Notch Area* *(V·μs)*	*Voltage Total Harmonic Distortion* *(%)*
Special applications	10	16,400	3
General system	20	22,800	5
Dedicated system	50	36,500	10