Chapter 6

Thyristor Converters

- Controlled conversion of ac into dc

Thyristor Converters

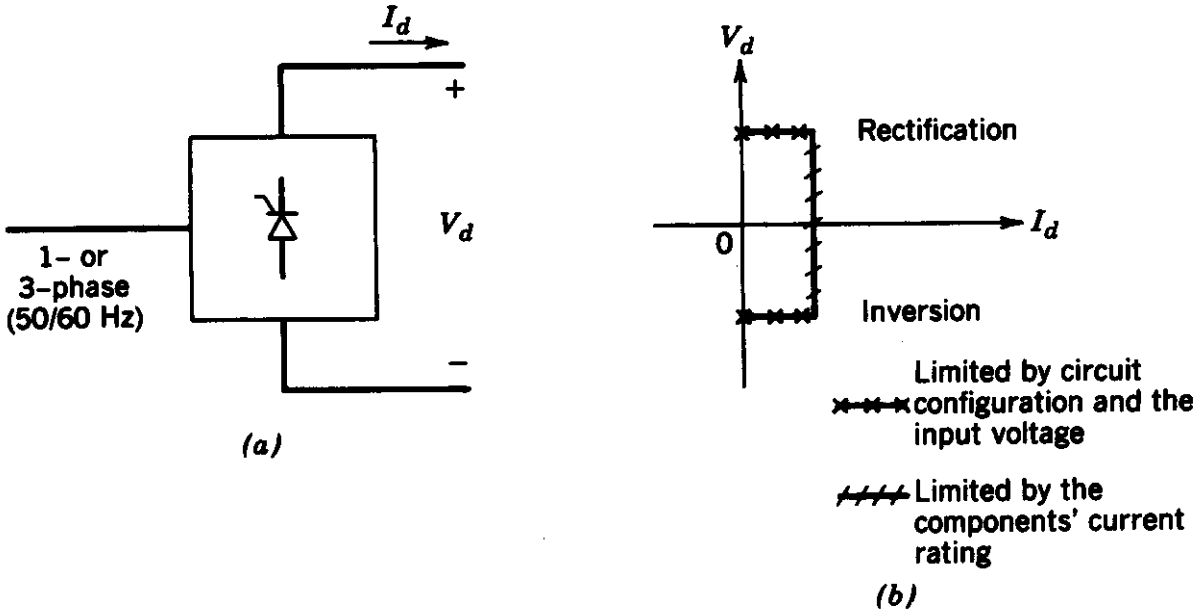

Figure 6-1 Line-frequency controlled converter.

- Two-quadrant conversion

Primitive circuits with thyristors

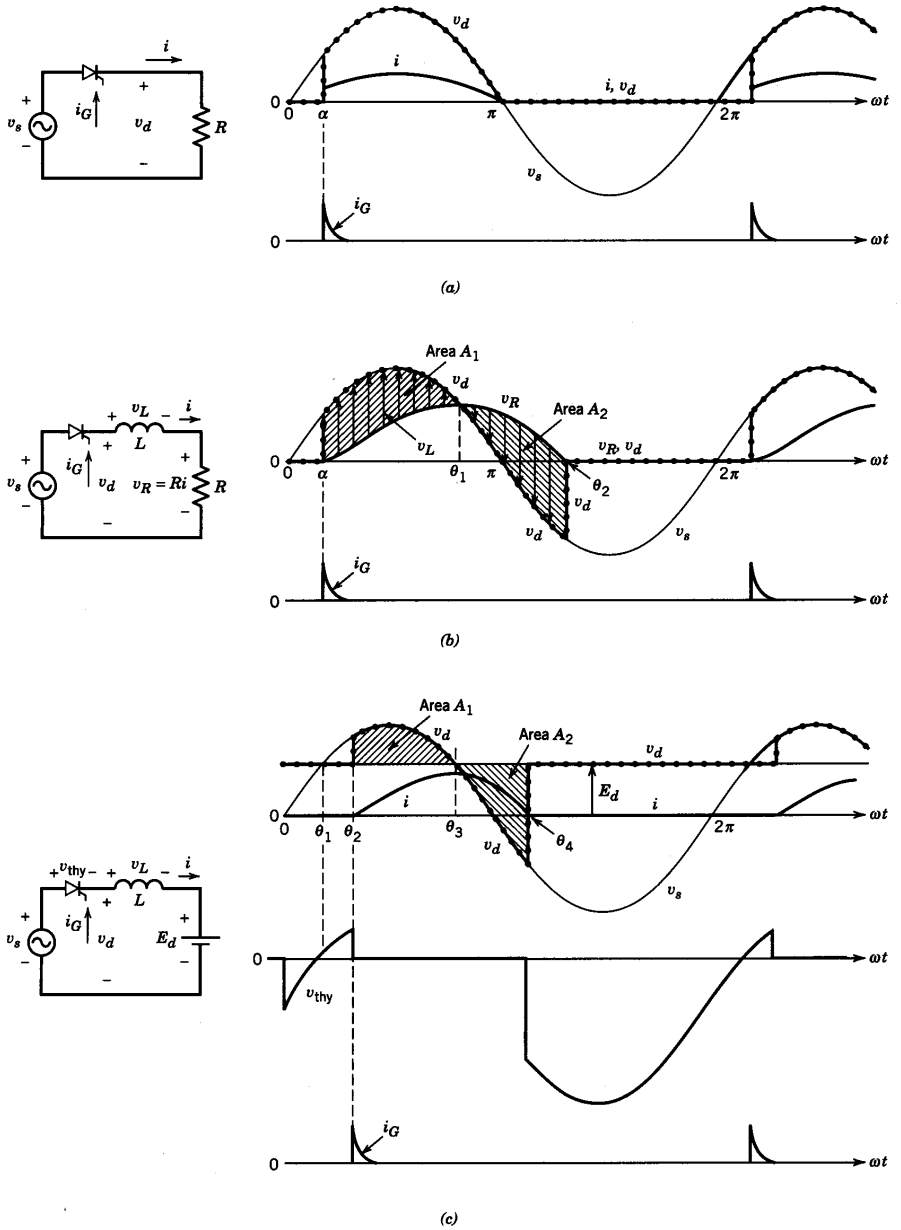

Figure 6-2 Basic thyristor converters.

Thyristor Triggering

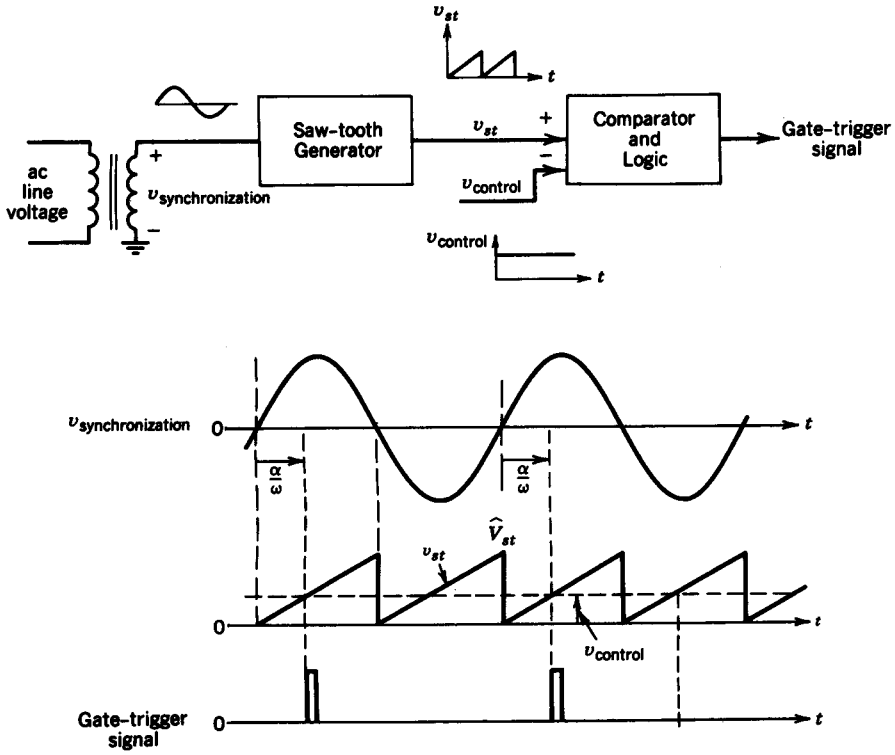

Figure 6-3 Gate trigger control circuit.

- ICs available

Full-Bridge Thyristor Converters

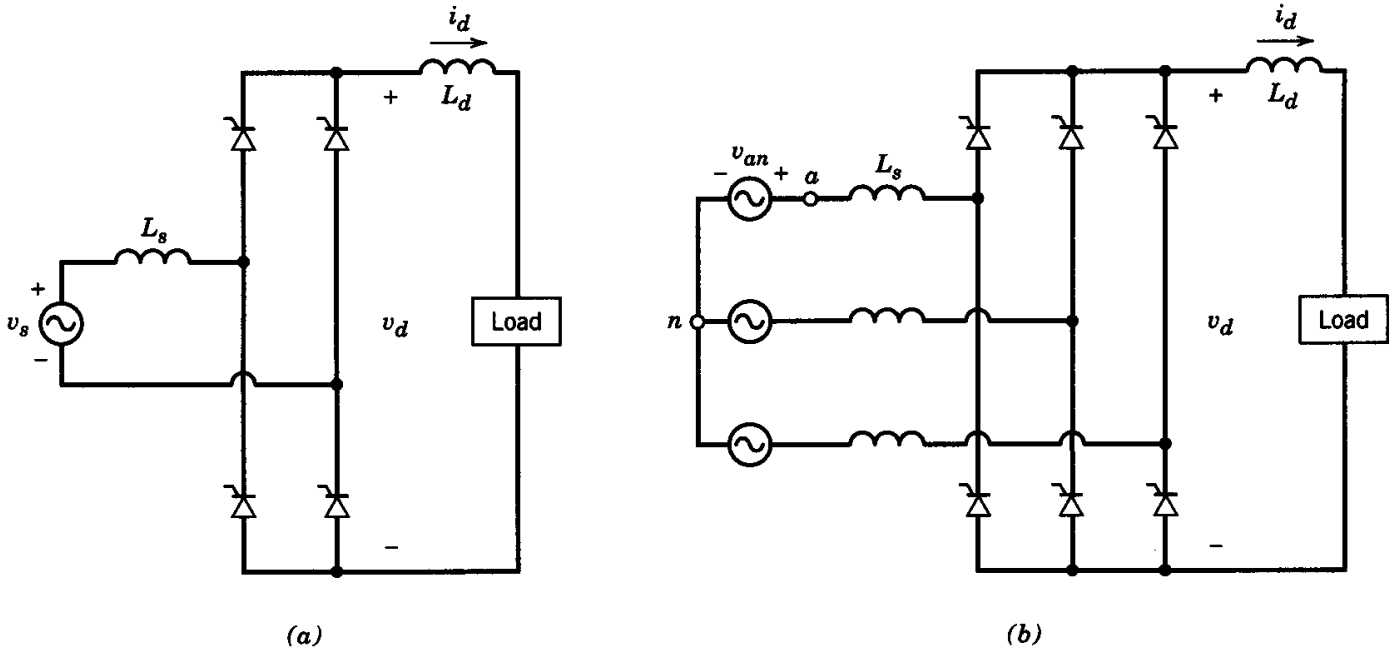

Figure 6-4 Practical thyristor converters.

- Single-phase and three-phase

Single-Phase Thyristor Converters

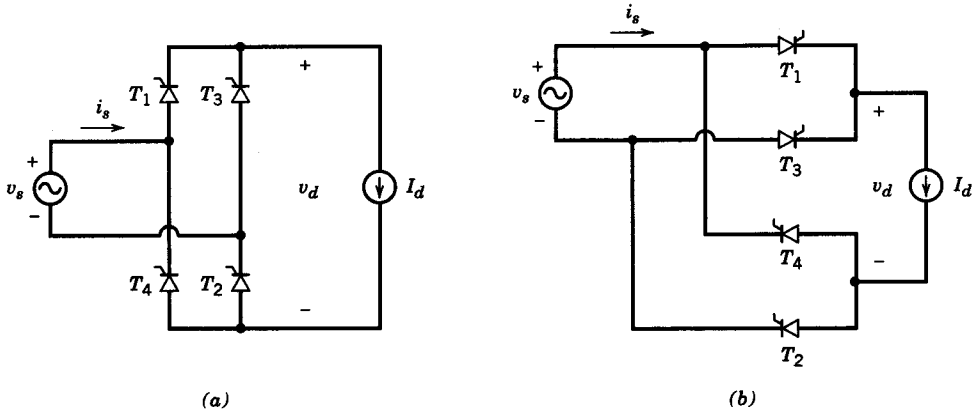

Figure 6-5 Single-phase thyristor converter with $L_s = 0$ and a constant dc current.

- Two groups with two thyristor each

1-Phase Thyristor Converter Waveforms

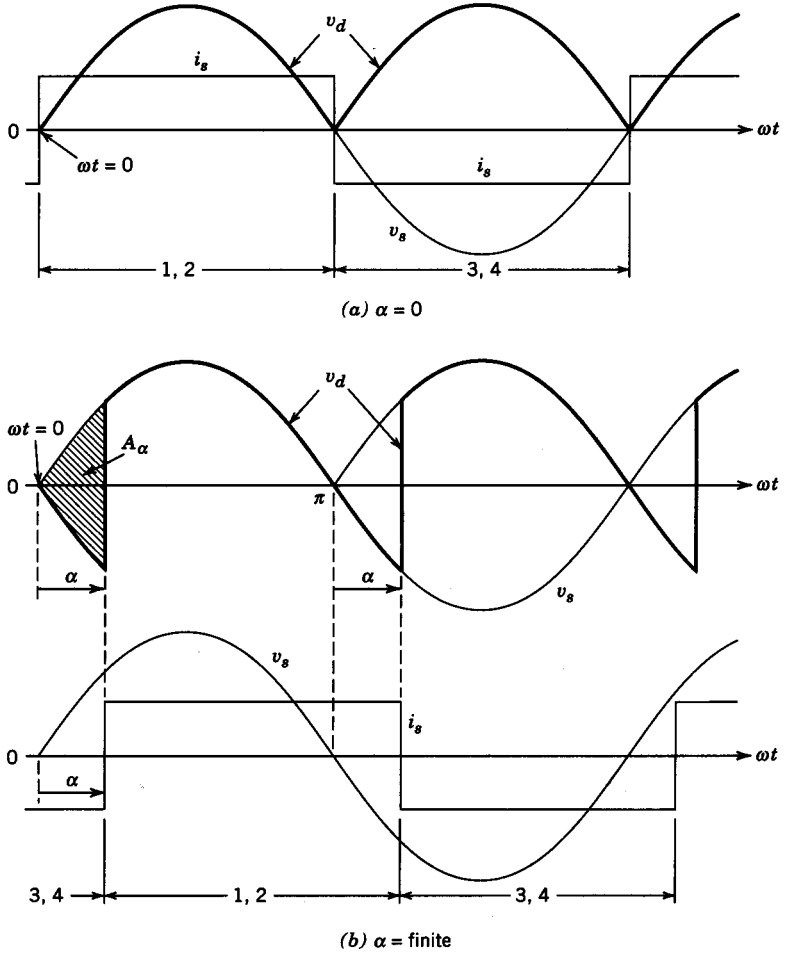

Figure 6-6 Waveforms in the converter of Fig. 6-5.

- Assuming zero ac-side inductance

Average DC Output Voltage

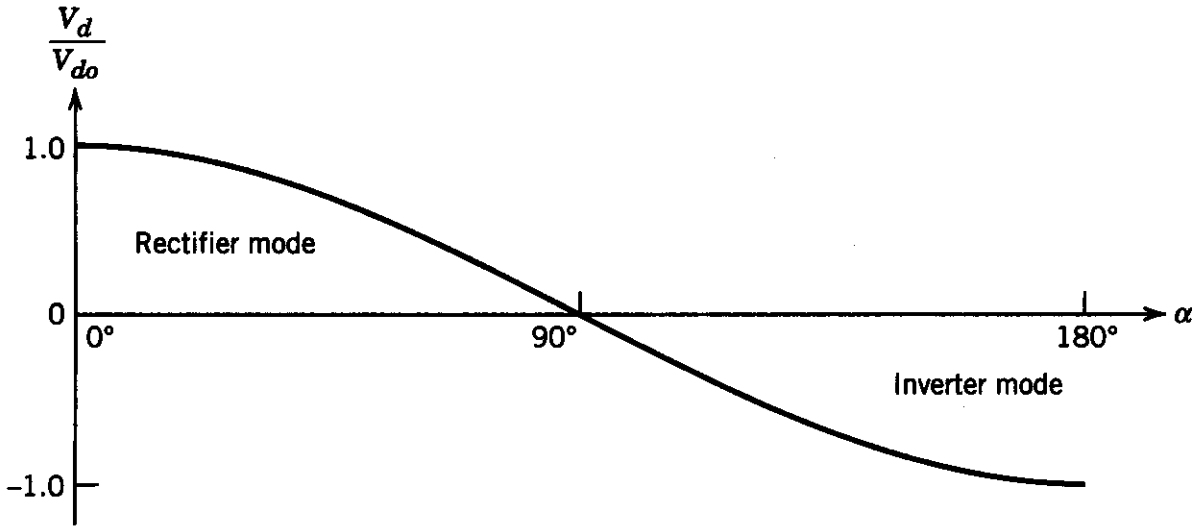

Figure 6-7 Normalized V_d as a function of α.

- Assuming zero ac-side inductance

Input Line-Current Waveforms

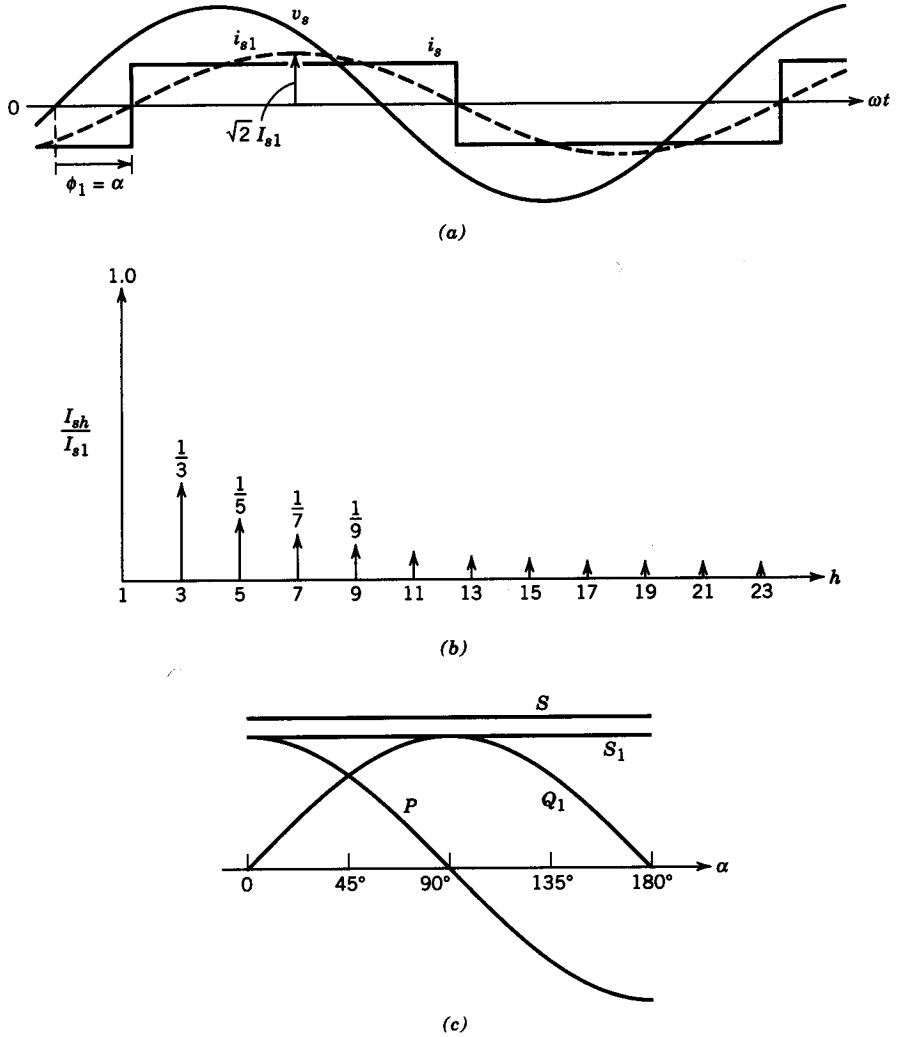

Figure 6-8 The ac-side quantities in the converter of Fig. 6-5.

- Harmonics, power and reactive power

1-Phase Thyristor Converter

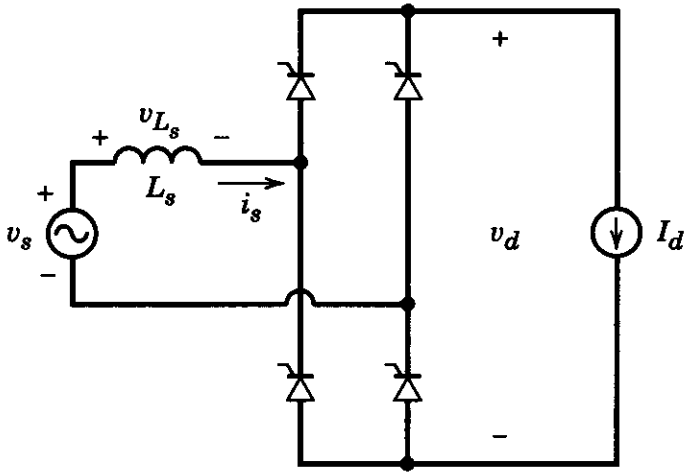

Figure 6-9 Single-phase thyristor converter with a finite L_s and a constant dc current.

- Finite ac-side inductance; constant dc output current

Thyristor Converter Waveforms

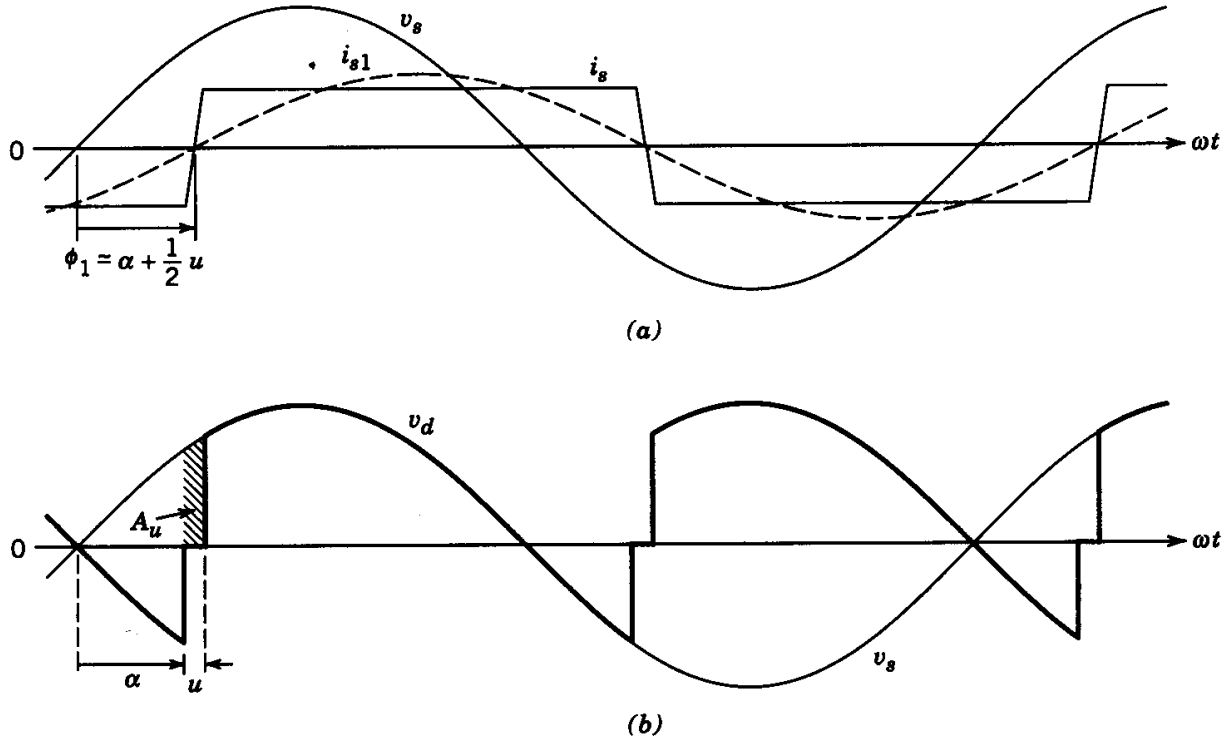

Figure 6-10 Waveforms in the converter of Fig. 6-9.

- Finite ac-side inductance

Thyristor Converter: Discontinuous Mode

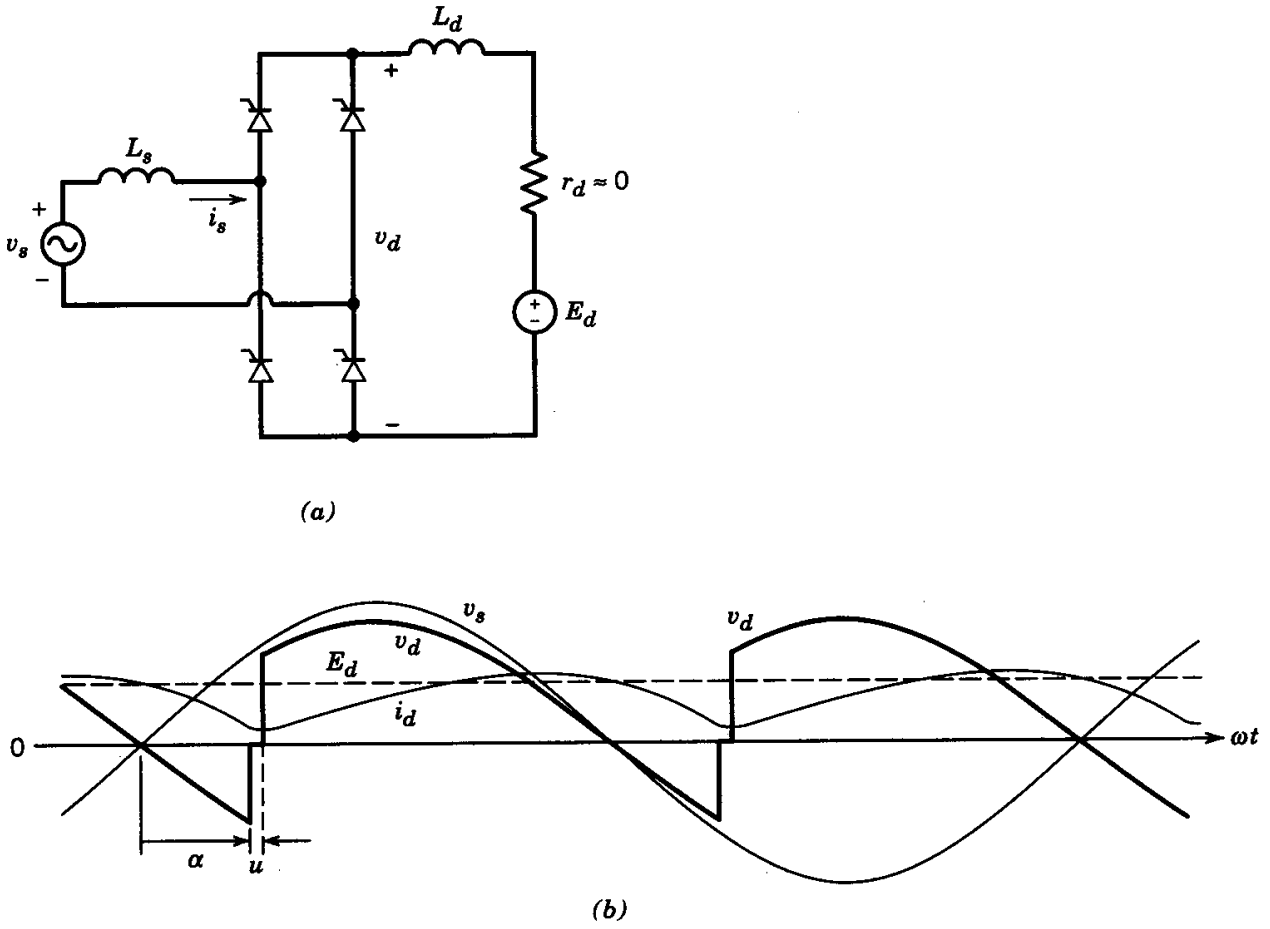

Figure 6-11 (*a*) A practical thyristor converter. (*b*) Waveforms.

- This mode can occur in a dc-drive at light loads

Thyristor Converter Waveforms

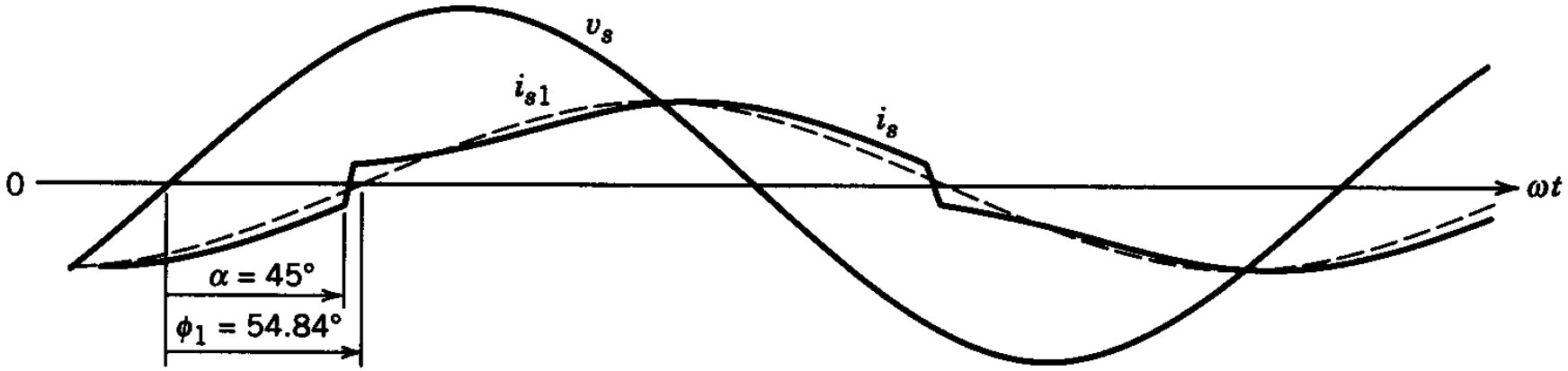

Figure 6-12 Waveforms in Example 6-2 for the circuit of Fig. 6-11*a*.

- PSpice-based simulation

Thyristor Converter Waveforms: Discontinuous Conduction Mode

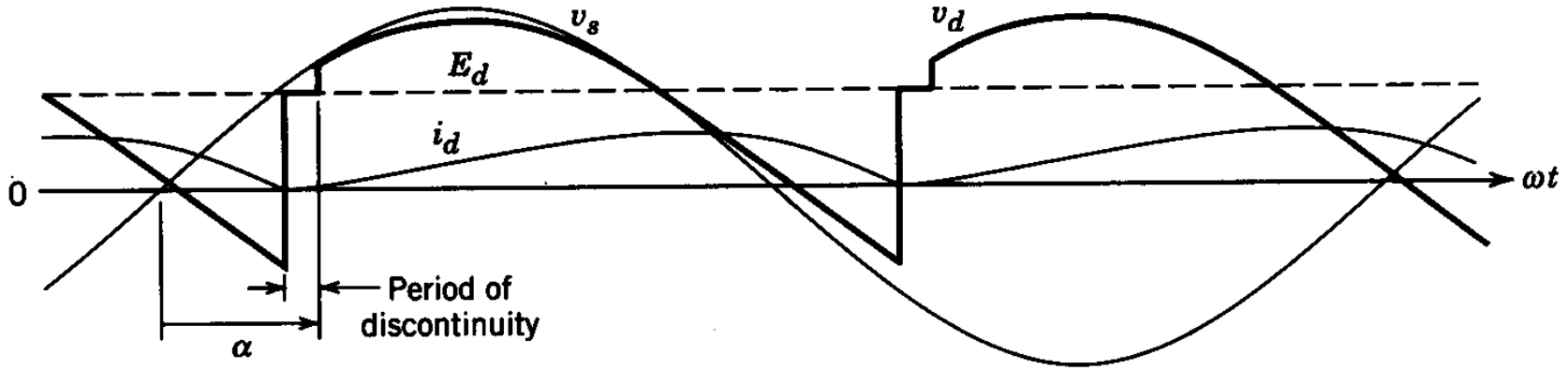

Figure 6-13 Waveforms in a discontinuous-current-conduction mode.

- PSpice-based simulation

DC Voltage versus Load Current

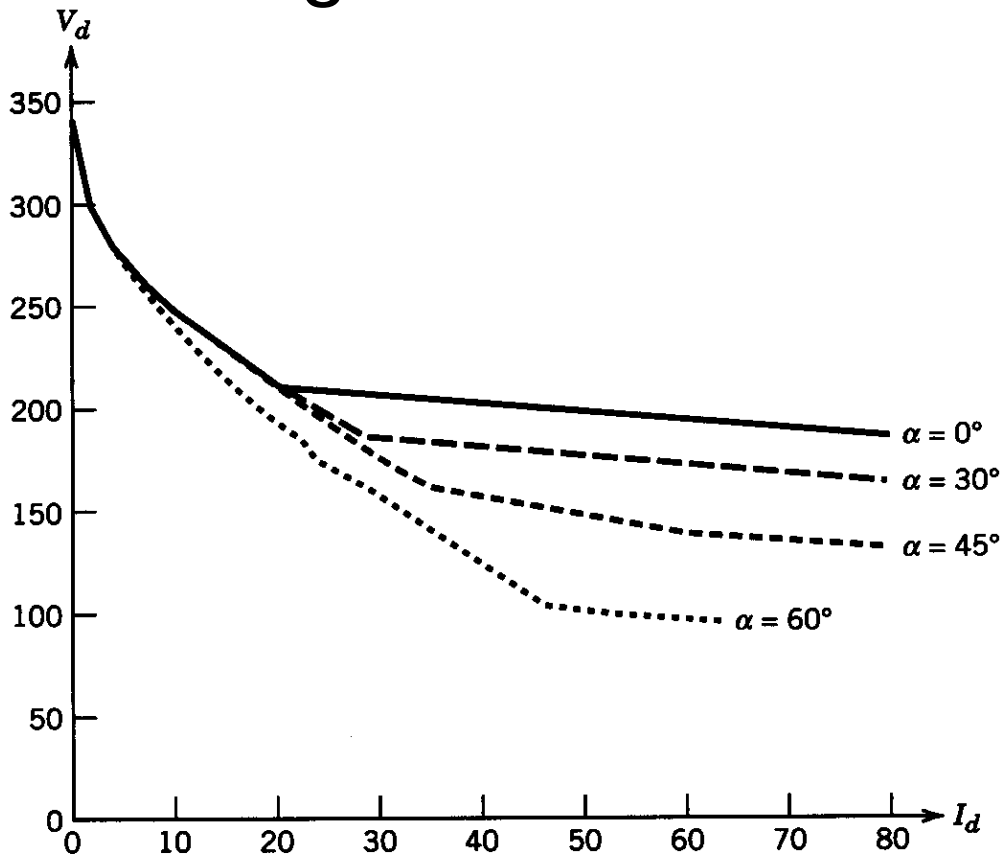

Figure 6-14 V_d versus I_d in the single-phase thyristor converter of Fig. 6-11*a*.

- Various values of delay angle

Thyristor Converters: Inverter Mode

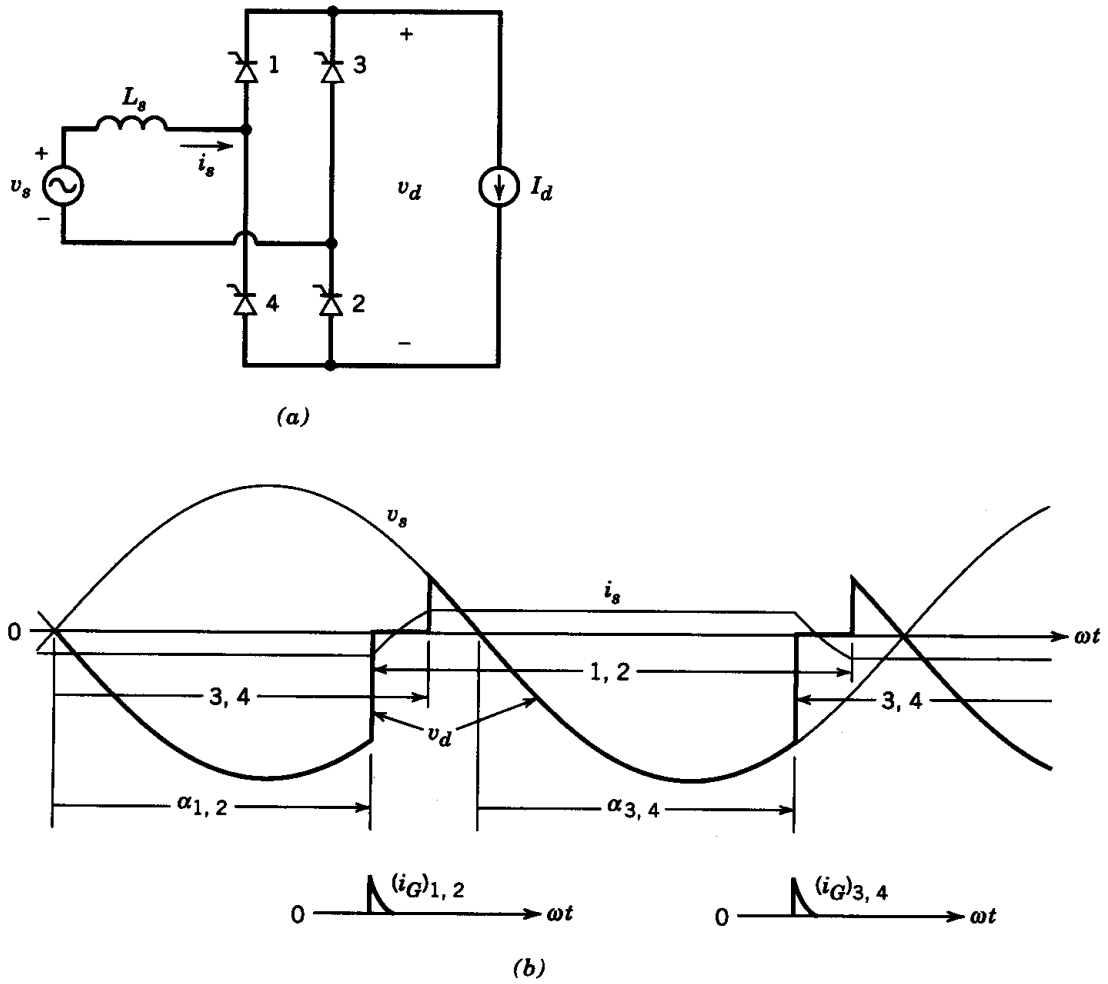

Figure 6-15 (*a*) Inverter, assuming a constant dc current. (*b*) Waveforms.

- Assuming the ac-side inductance to be zero

Thyristor Converters: Inverter Mode

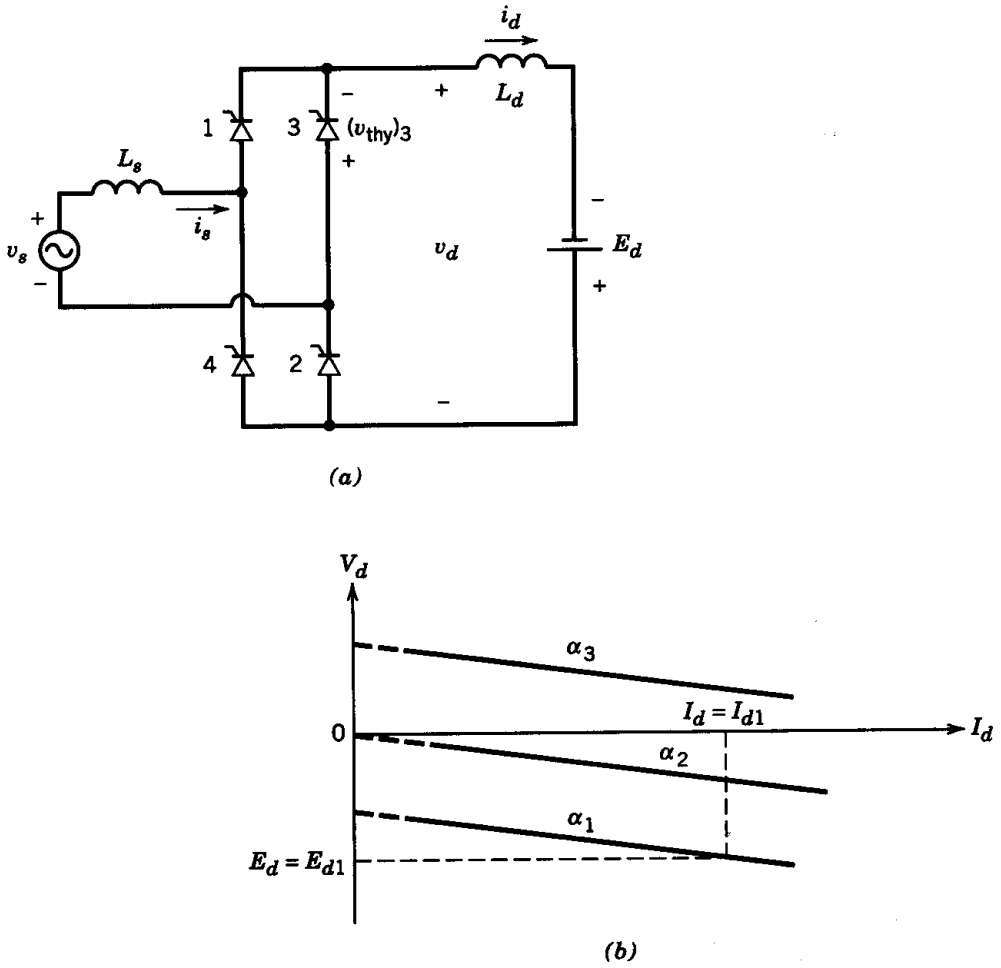

Figure 6-16 (*a*) Thyristor inverter with a dc voltage source. (*b*) $\mathbf{V_d}$ versus I_d.

- Family of curves at various values of delay angle

Thyristor Converters: Inverter Mode

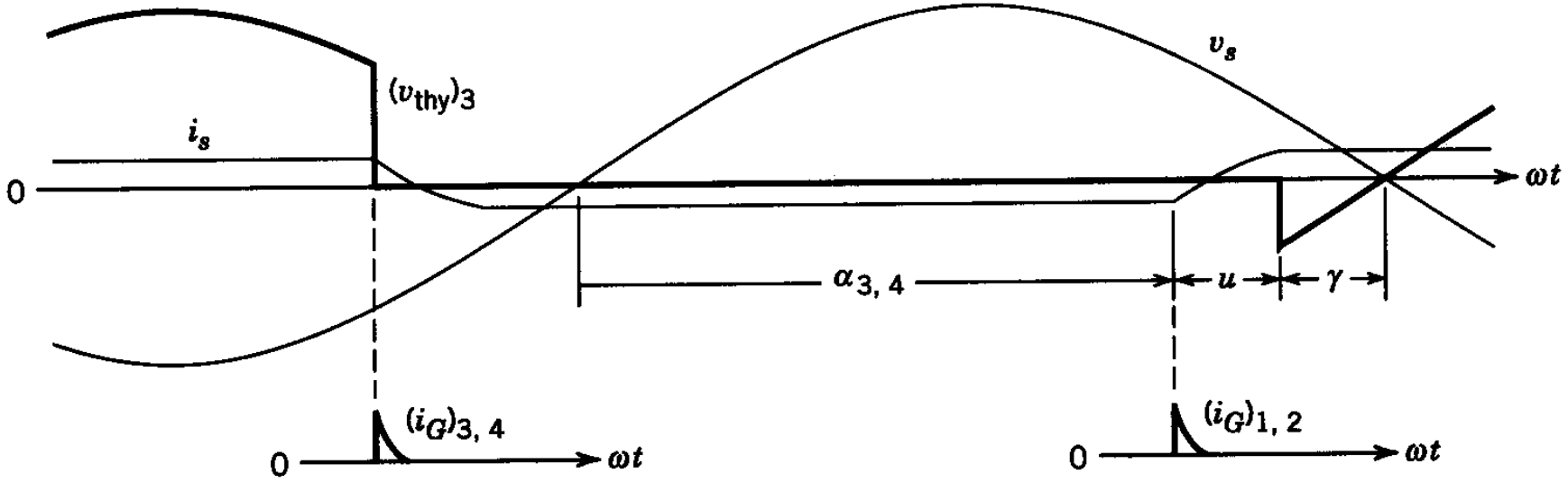

Figure 6-17 Voltage across a thyristor in the inverter mode.

- Importance of extinction angle in inverter mode

Thyristor Converters: Inverter Mode

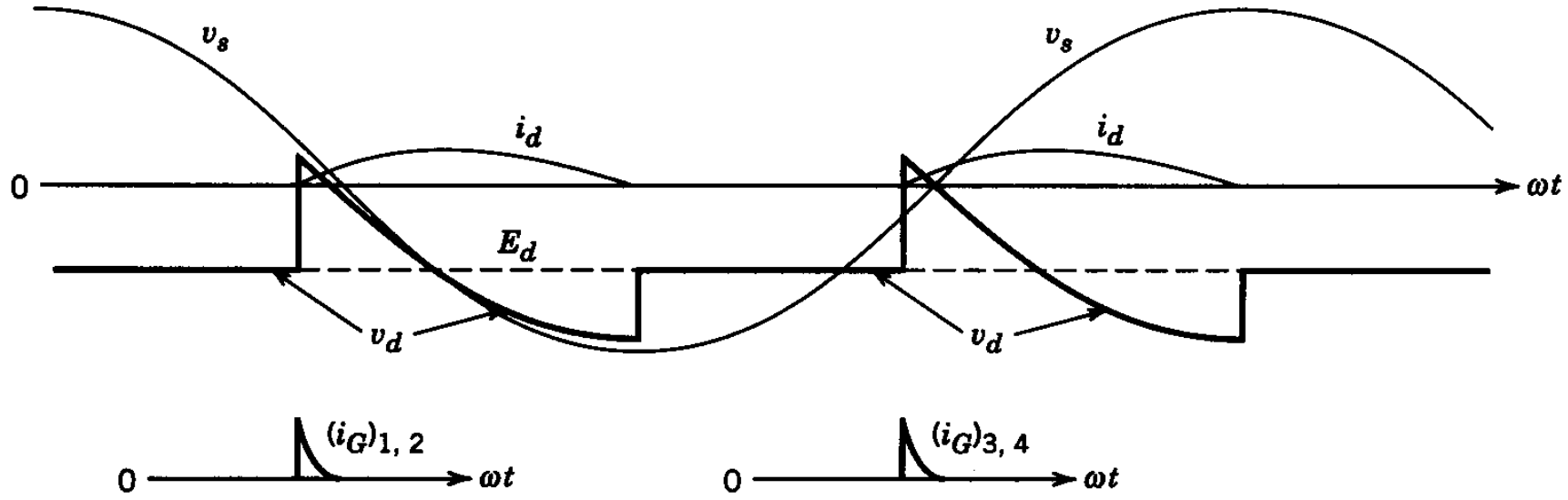

Figure 6-18 Waveforms at inverter start-up.

- Waveforms at start-up

3-Phase Thyristor Converters

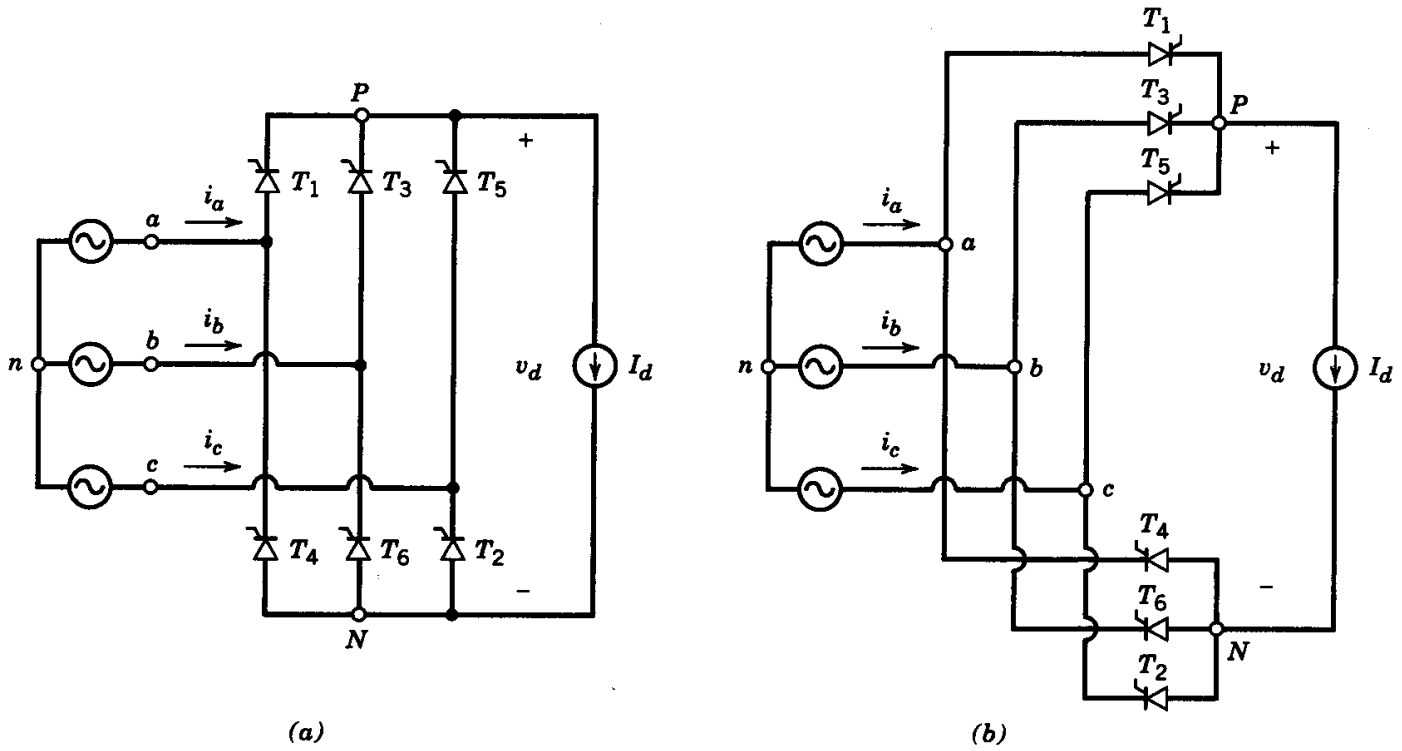

Figure 6-19 Three-phase thyristor converter with $L_s = 0$ and a constant dc current.

- Two groups of three thyristors each

3-Phase Thyristor Converter Waveforms

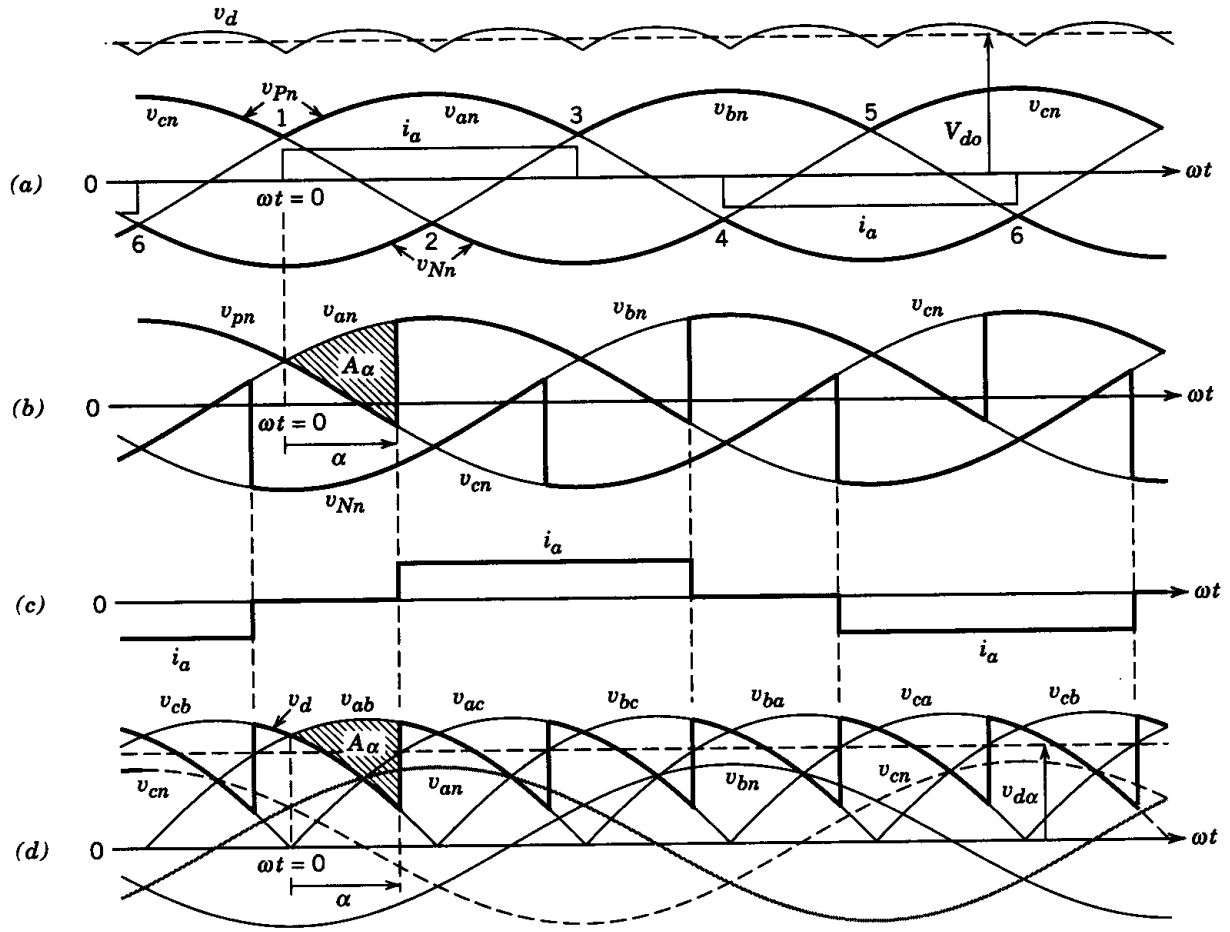

Figure 6-20 Waveforms in the converter of Fig. 6-19.

- Zero ac-side inductance; purely dc current

DC-side voltage waveforms assuming zero ac-side inductance

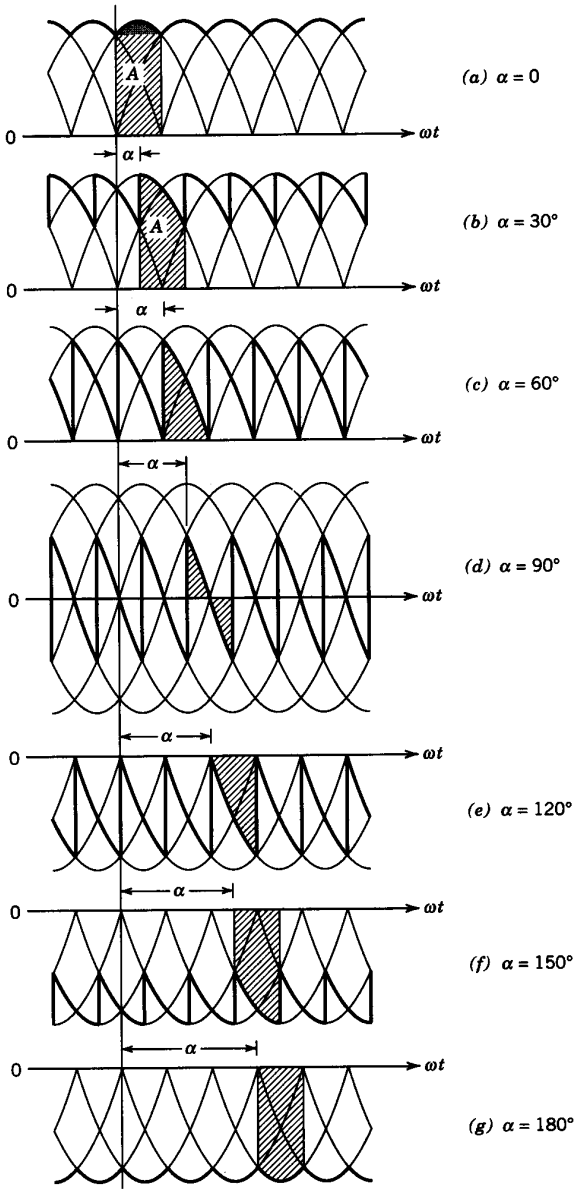

Figure 6-21 The dc-side voltage waveforms as a function of α where $V_{d\alpha} = A/(\pi/3)$. (From ref. 2 with permission.)

Input Line-Current Waveform

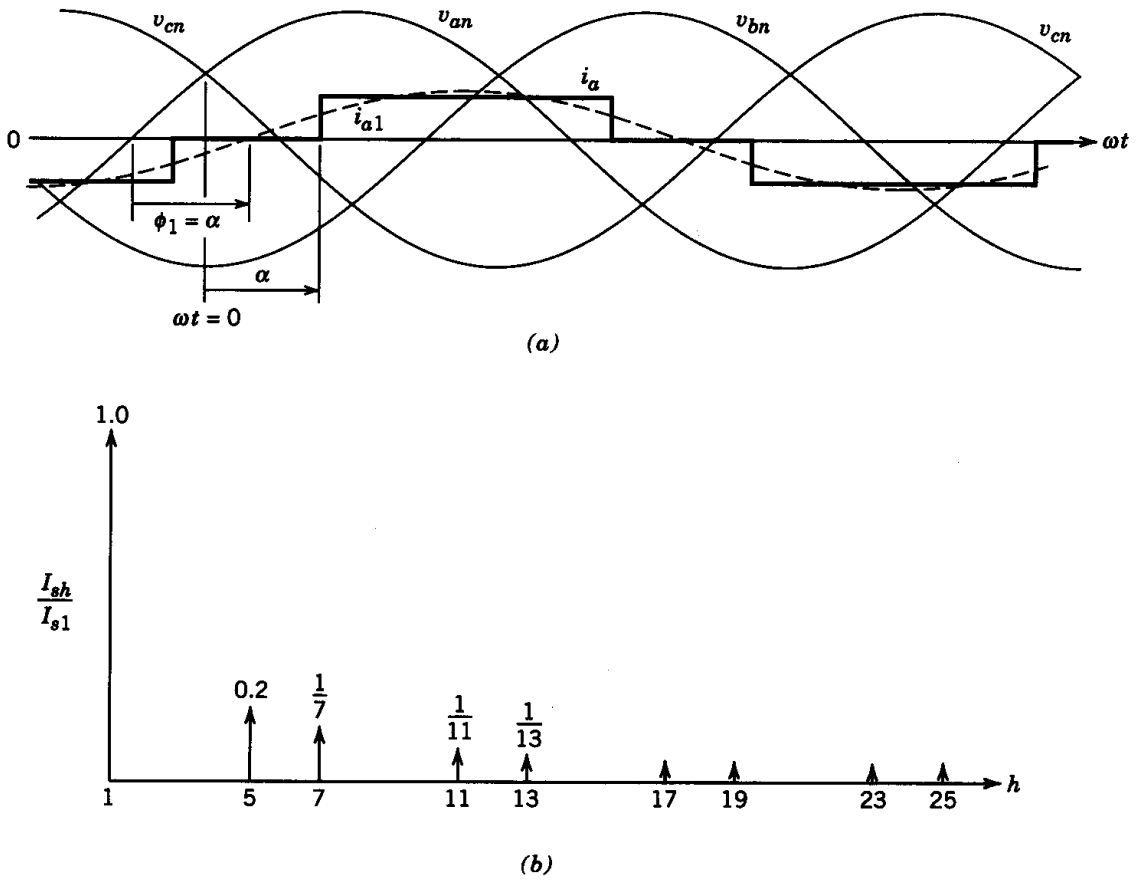

Figure 6-22 Line current in a three-phase thyristor converter of Fig. 6-19.

- Zero ac-side inductance

Input line-current waveforms assuming zero ac-side inductance

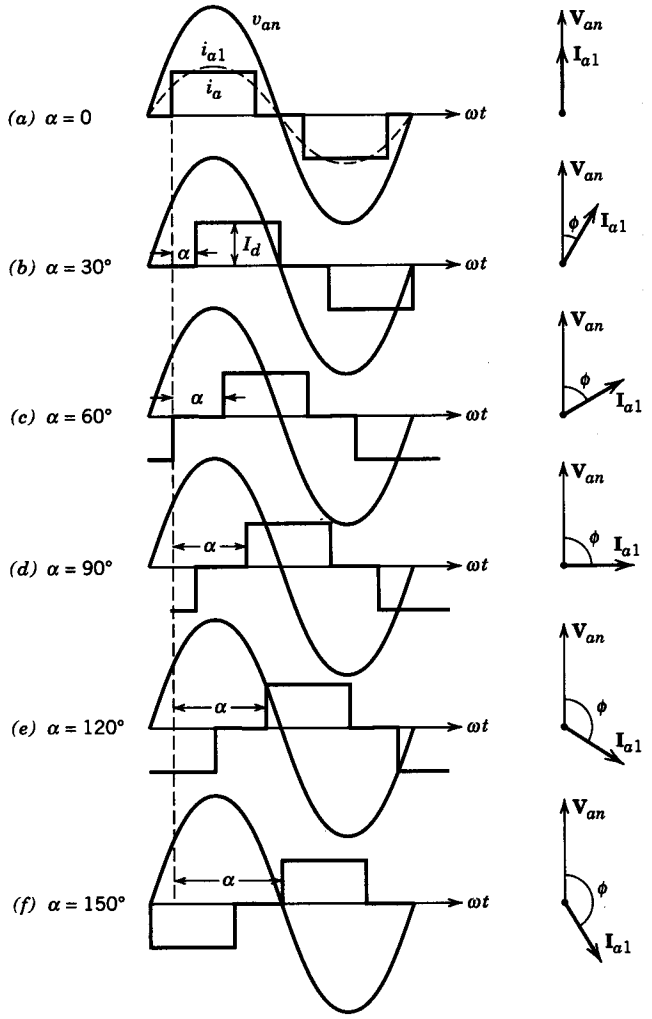

Figure 6-23 Line current as a function of α. (With permission from ref. 2.)

Three-Phase Thyristor Converter

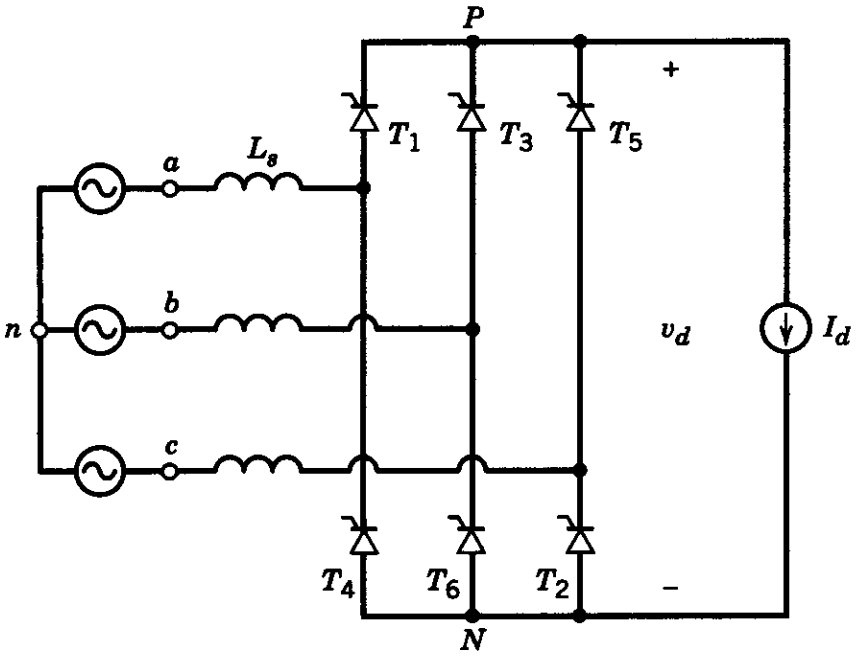

Figure 6-24 Three-phase converter with L_s and a constant dc current.

- AC-side inductance is included

Current Commutation Waveforms

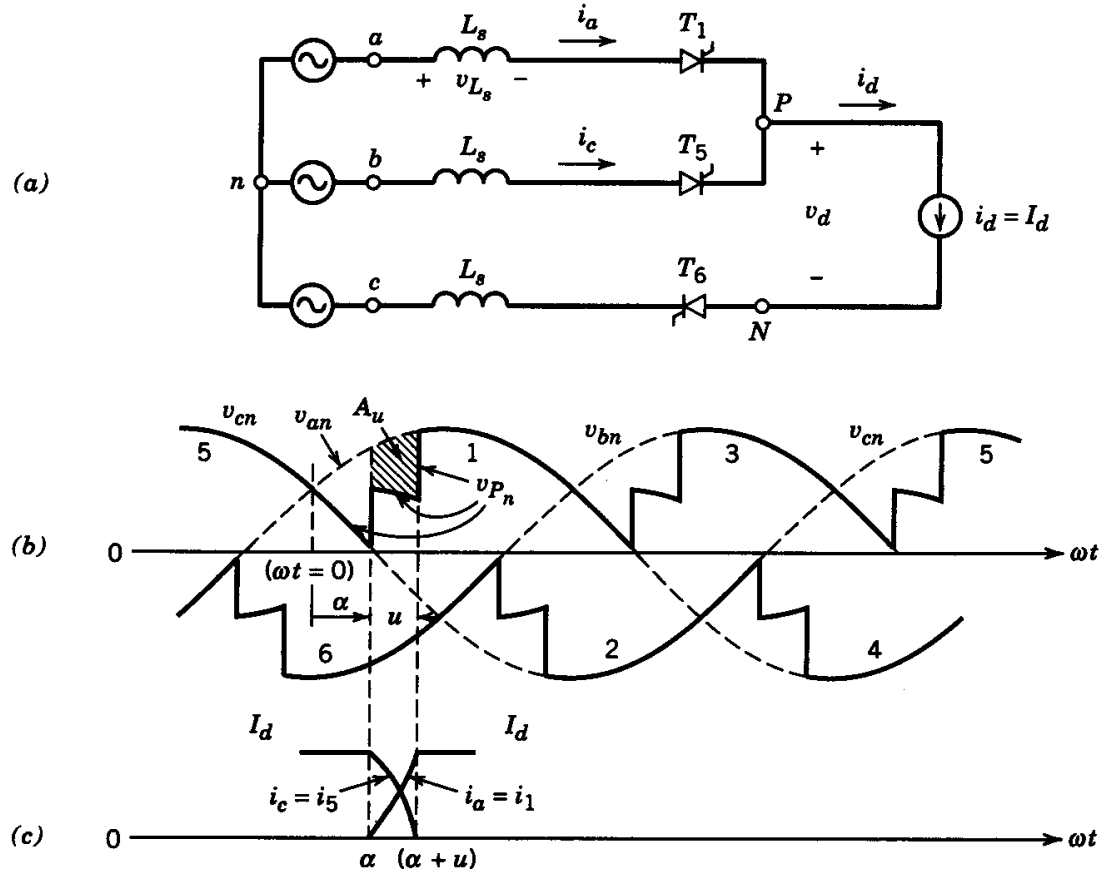

Figure 6-25 Commutation in the presence of L_s.

- Constant dc-side current

Input Line-Current Waveform

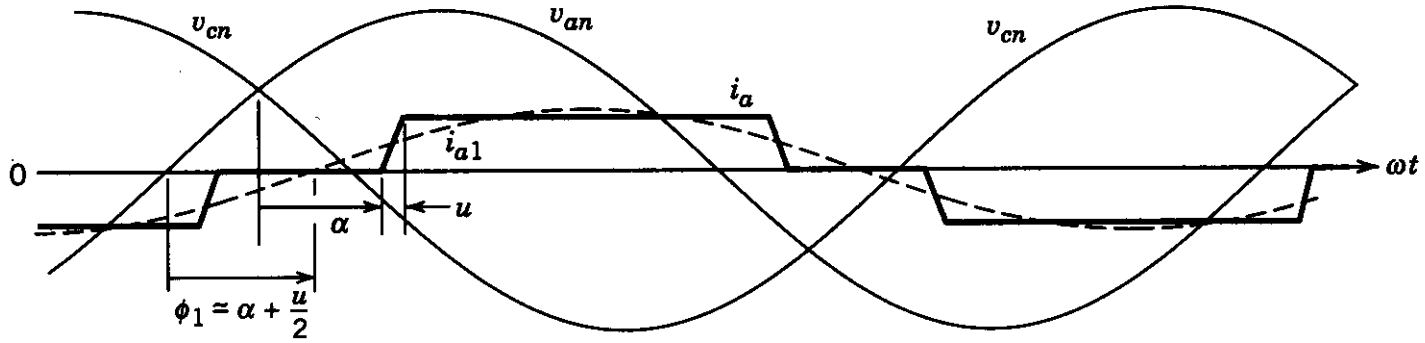

Figure 6-26 Line current in the presence of L_s.

- Finite ac-side inductance

Input Line-Current Harmonics

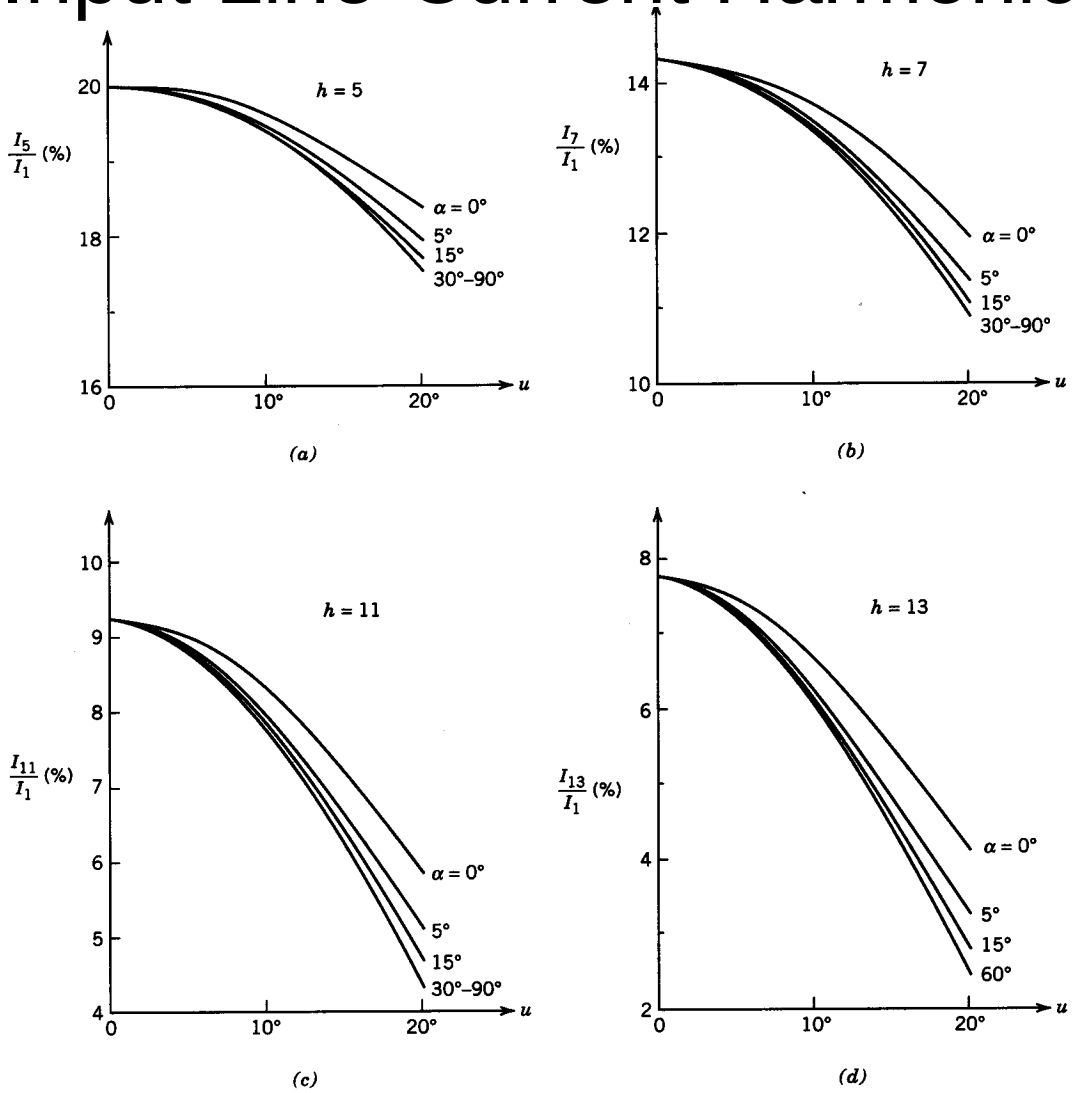

Figure 6-27 Normalized harmonic currents in the presence of L_s. (With permission from ref. 2).

- Finite ac-side inductance

Input Line-Current Harmonics

Table 6-1 Typical and Idealized 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 and idealized

Three-Phase Thyristor Converter

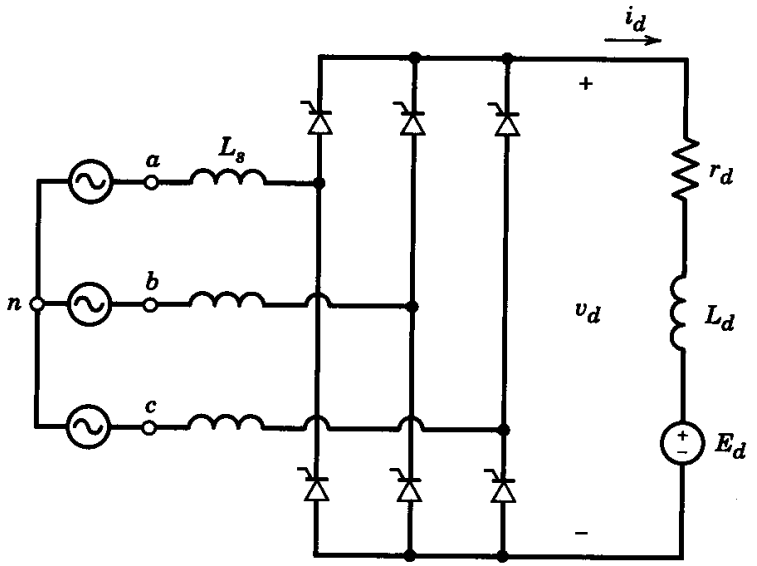

Figure 6-28 A practical thyristor converter.

- Realistic load

Thyristor Converter Waveforms

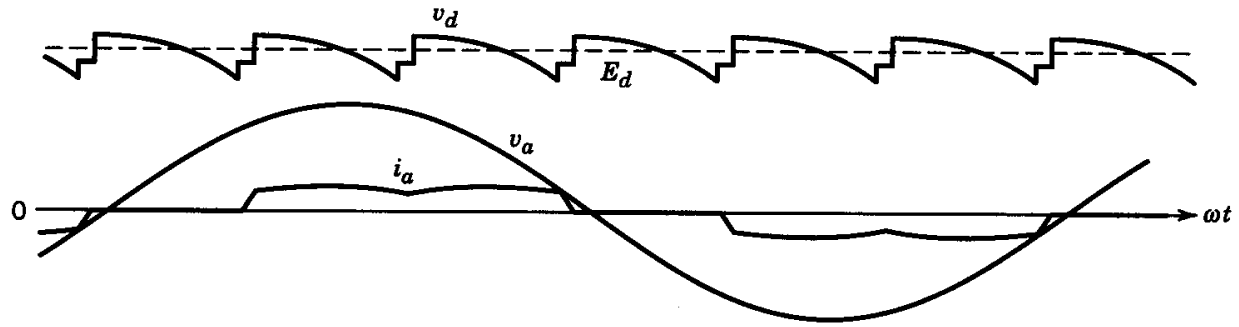

Figure 6-29 Waveforms in the converter of Fig. 6-28. ■

- Realistic load; continuous-conduction mode

Thyristor Converter Waveforms

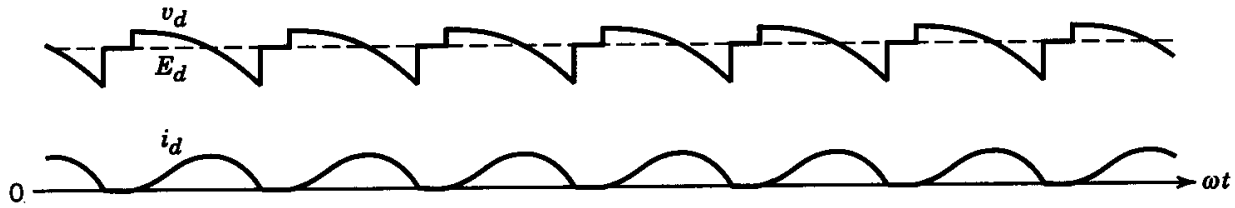

Figure 6-30 Waveforms in a discontinuous-current-conduction mode.

- Realistic load; discontinuous-conduction mode

Thyristor Inverter

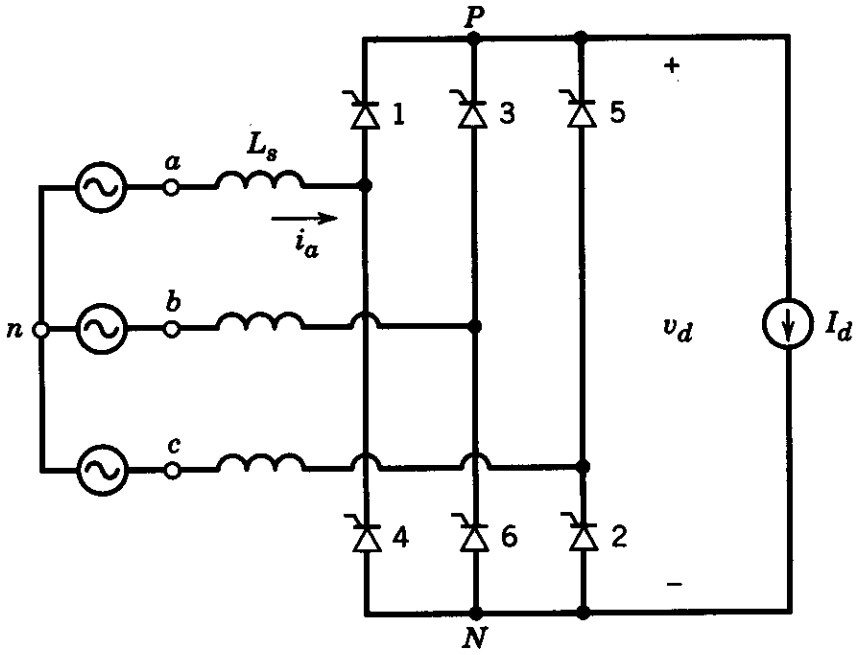

Figure 6-31 Inverter with a constant dc current.

- Constant dc current

Thyristor Inverter Waveforms

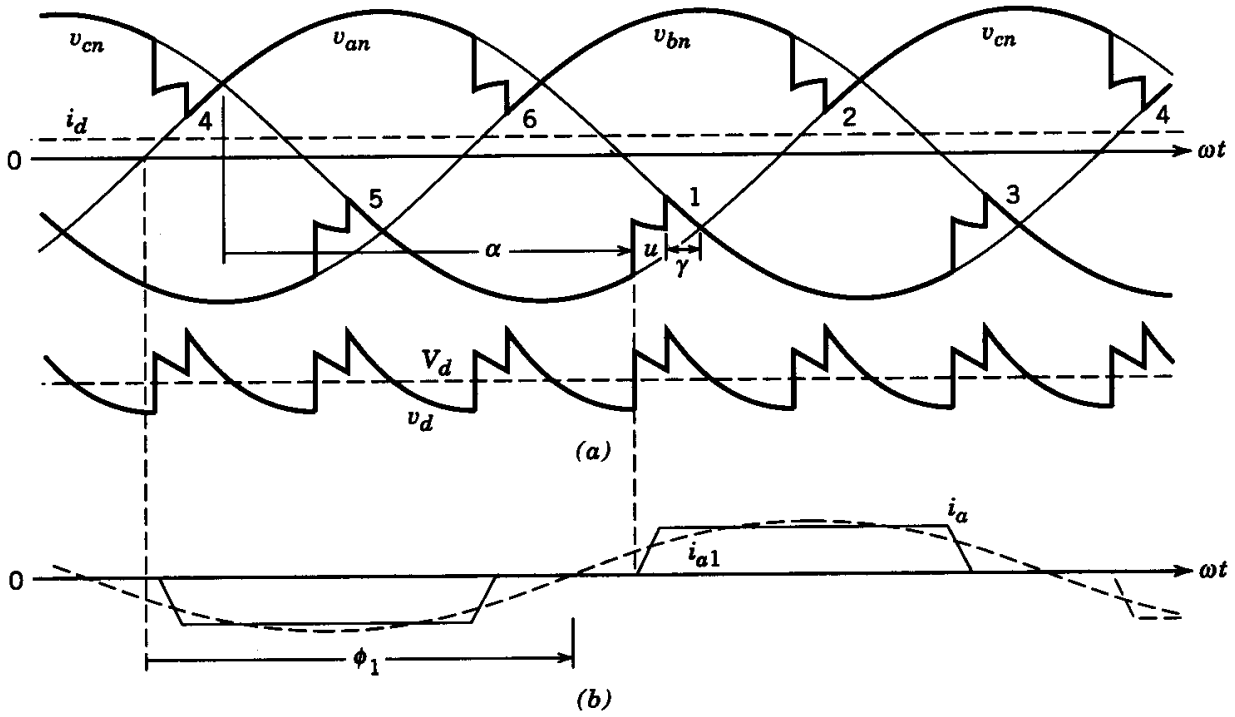

Figure 6-32 Waveforms in the inverter of Fig. 6-31.

- Finite ac-side inductance

Thyristor Inverter

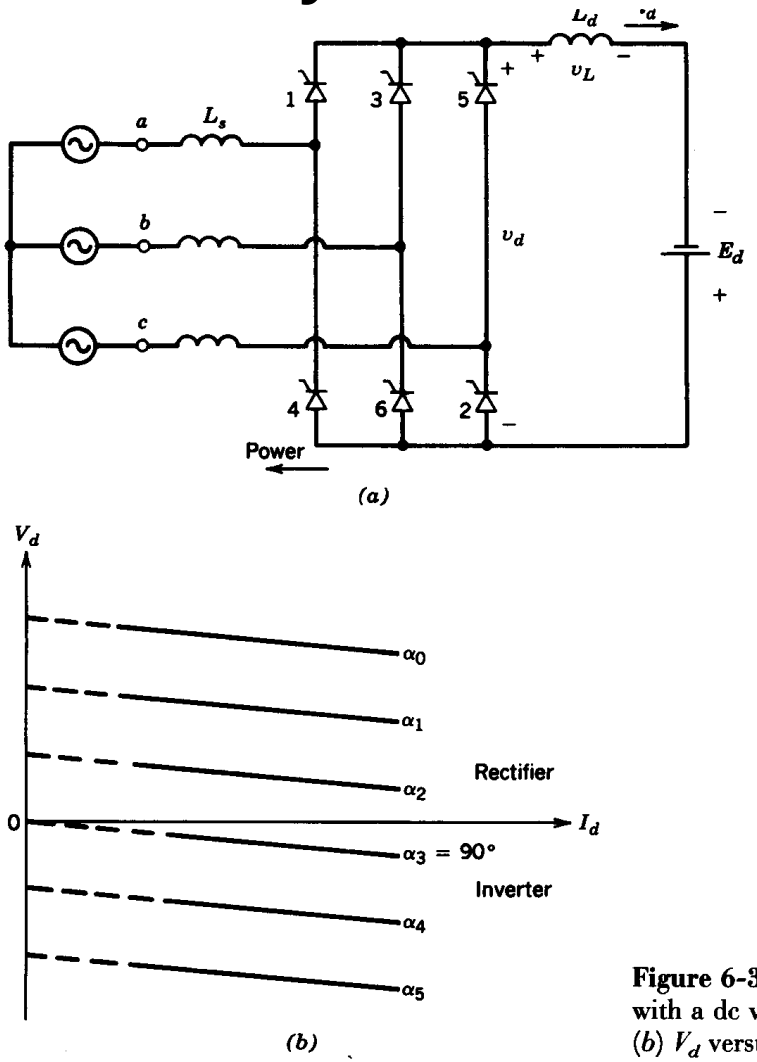

Figure 6-33 (*a*) Thyristor inverter with a dc voltage source. (*b*) V_d versus I_d.

- Family of curves at various values of delay angle

Thyristor Inverter Operation

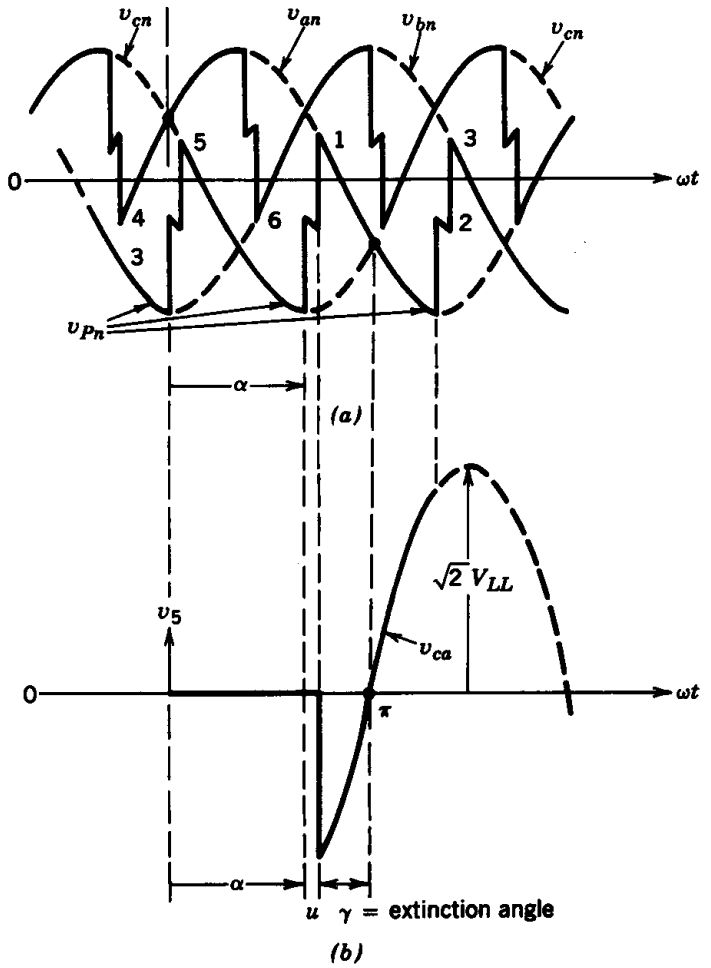

Figure 6-34 Voltage across a thyristor in the inverter mode.

- Importance of extinction angle

Thyristor Converters: Voltage Notching

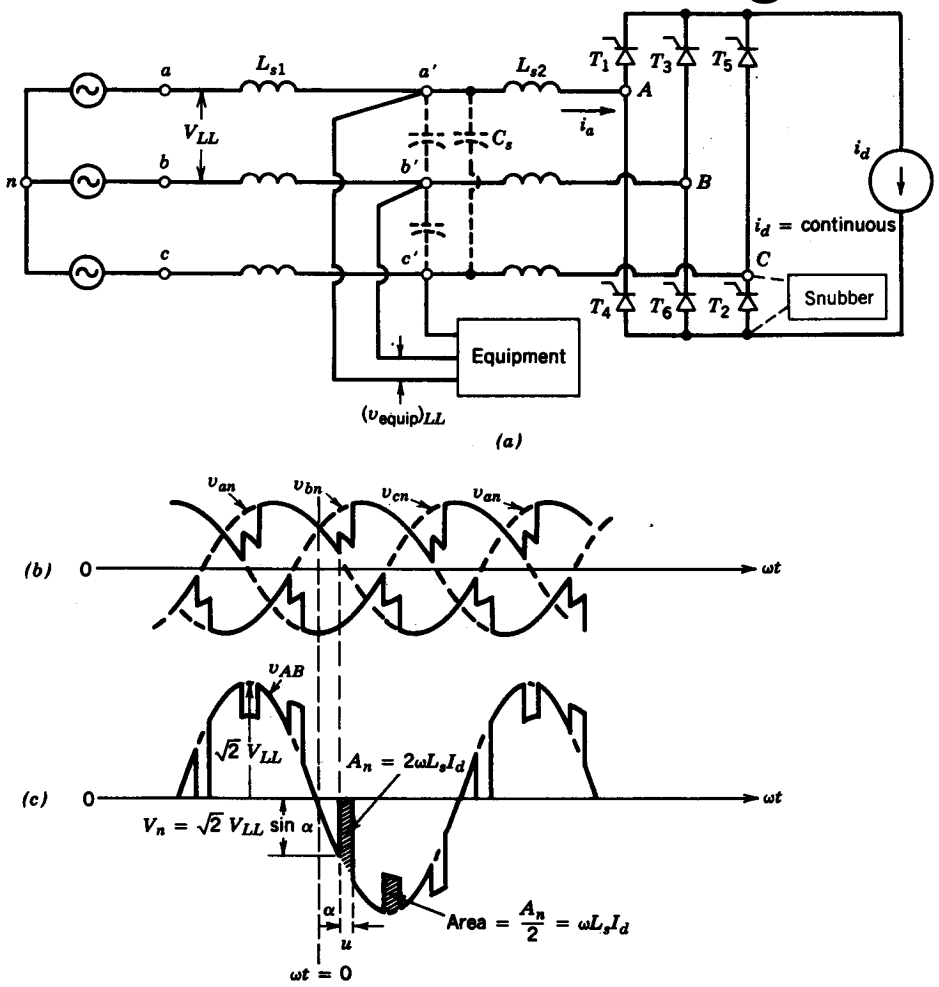

Figure 6-35 Line notching in other equipment voltage: (*a*) circuit, (*b*) phase voltages, (*c*) line-to-line voltage v_{AB}.

- Importance of external ac-side inductance

Limits on Notching and Distortion

Table 6-2 Line Notching and Distortion Limits for 460-V Systems

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

- Guidelines

Thyristor Converter Representation

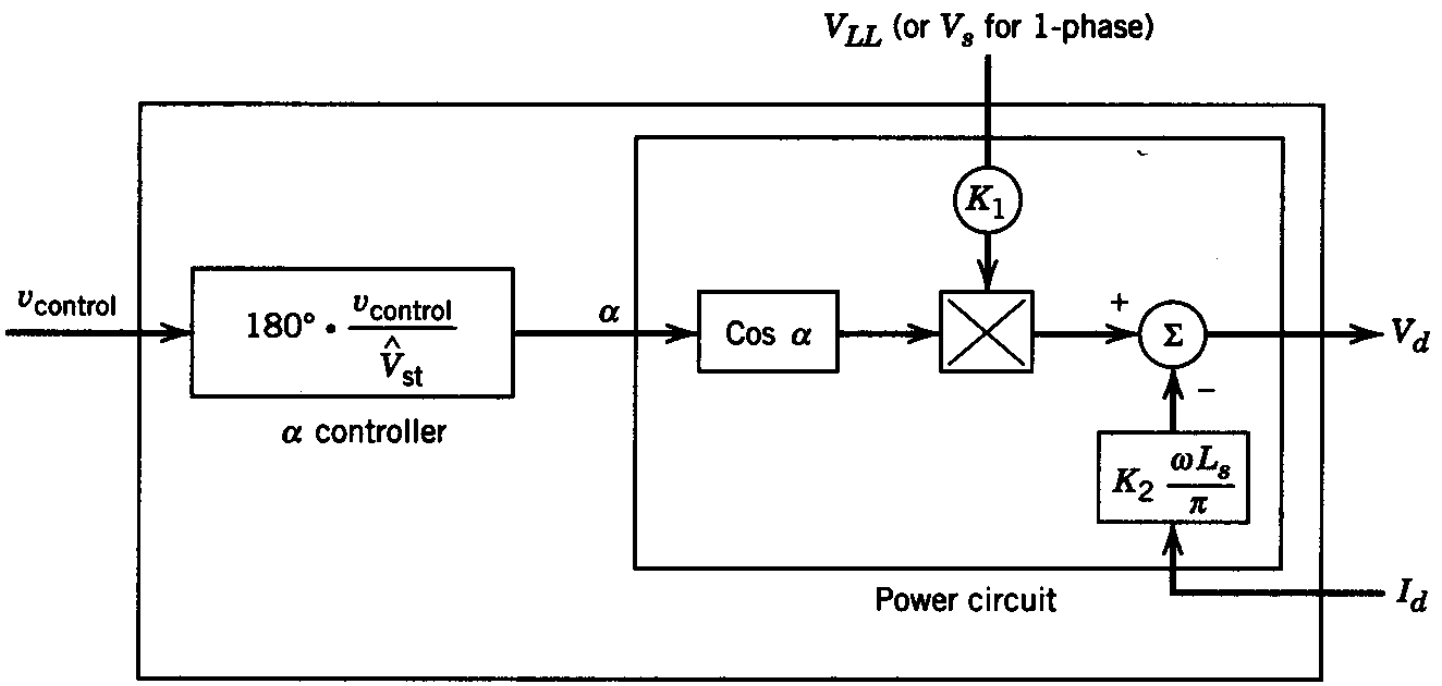

Figure 6-36 Summary of thyristor converter output voltage with a dc current I_d.

- Functional block diagram