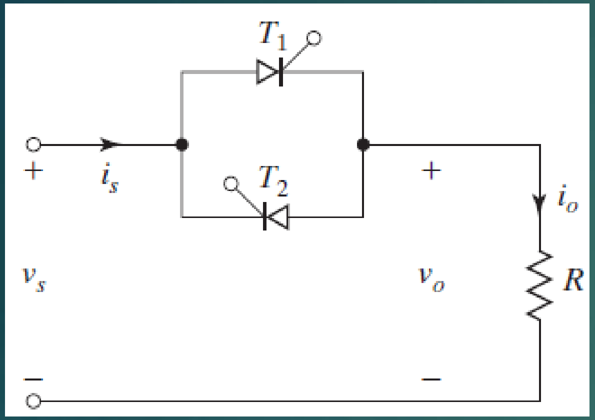
Power Electronics

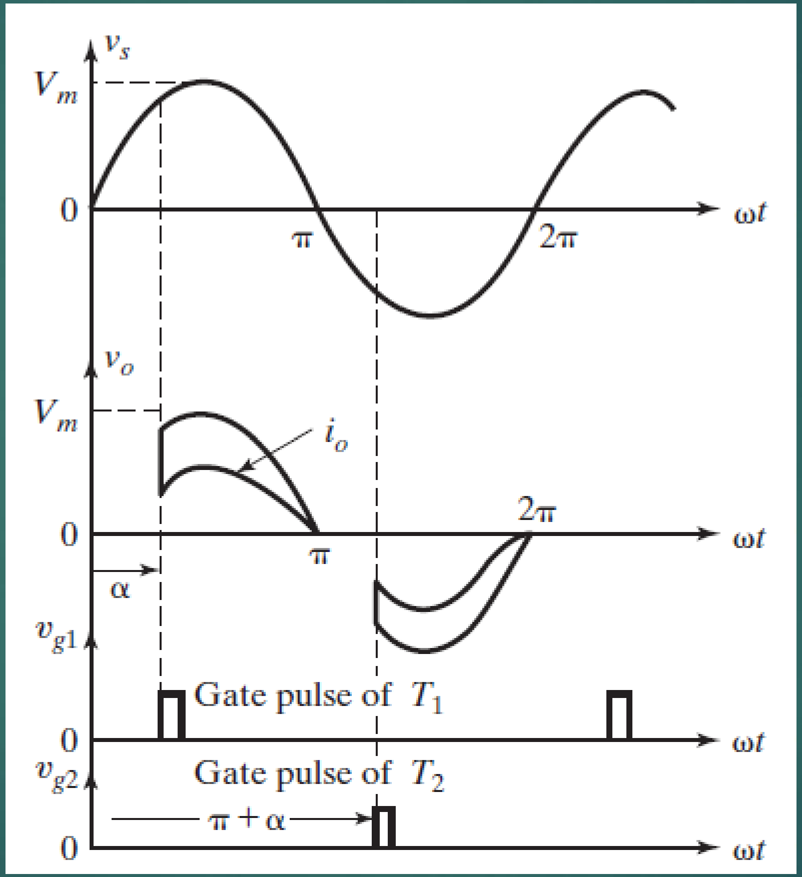
EE312


بسم الله الرحمن الرحيم

AC Voltage Controllers

11.3 SINGLE-PHASE FULL-WAVE CONTROLLERS WITH RESISTIVE LOADS





$$v_s = \sqrt{2} V_s \sin \omega t$$

$$V_o = \left\{ \frac{2}{2\pi} \int_{\alpha}^{\pi} 2V_s^2 \sin^2 \omega t \, d(\omega t) \right\}^{1/2}$$

$$= \left\{ \frac{4V_s^2}{4\pi} \int_{\alpha}^{\pi} (1 - \cos 2\omega t) \, d(\omega t) \right\}^{1/2}$$

$$= V_s \left[\frac{1}{\pi} \left(\pi - \alpha + \frac{\sin 2\alpha}{2} \right) \right]^{1/2} \quad (11.1)$$

$$RMS\ Value = \sqrt{\frac{1}{T} \int_0^T [f(x)]^2 dx}$$

$$\sin \frac{\theta}{2} = \pm \sqrt{\frac{1 - \cos \theta}{2}}$$

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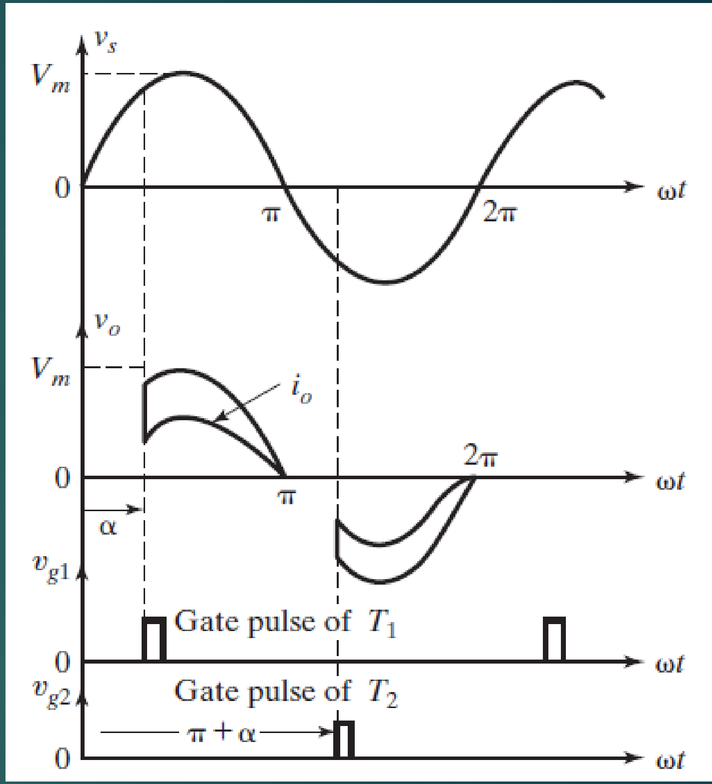
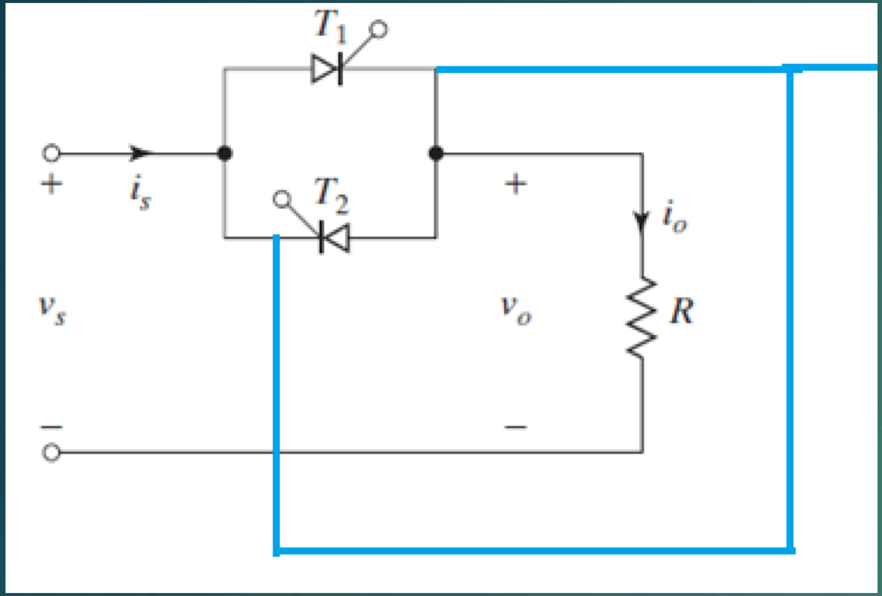
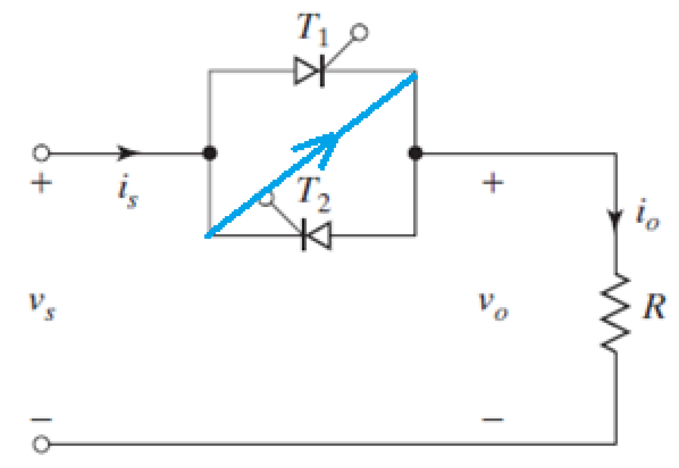
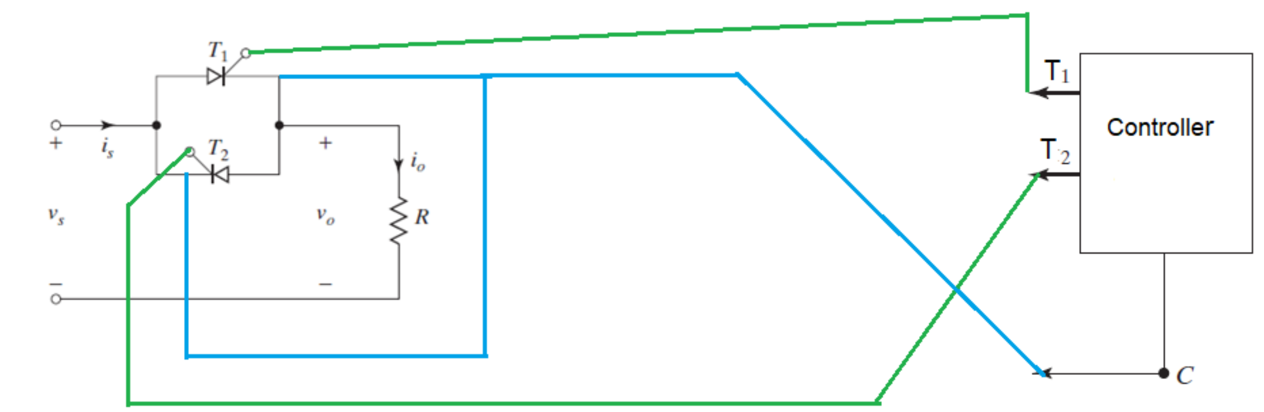
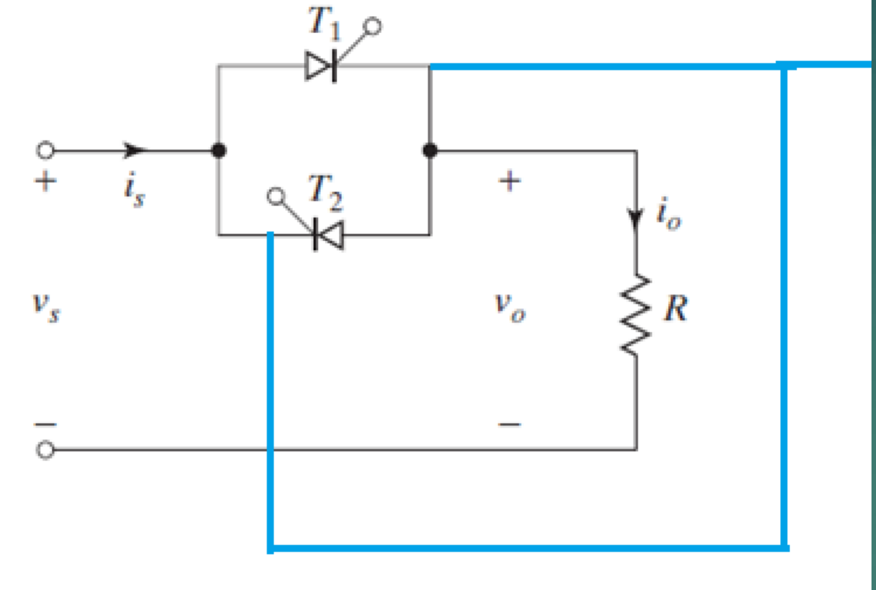



T_1
T_2
i_s
i_o
v_s
v_o
R


T_1
T_2
i_s
i_o
v_s
v_o
R


T_1
T_2
i_s
i_o
v_s
v_o
R
Controller
C



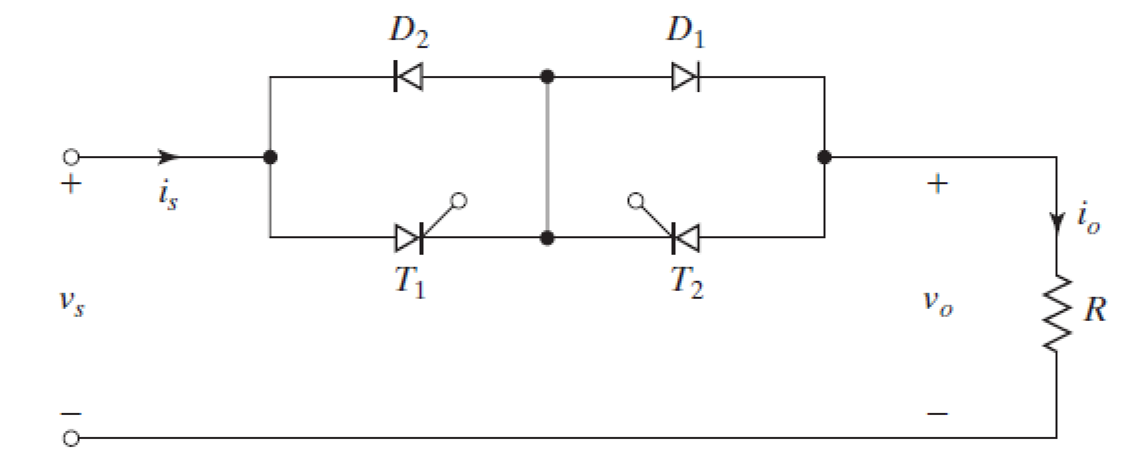
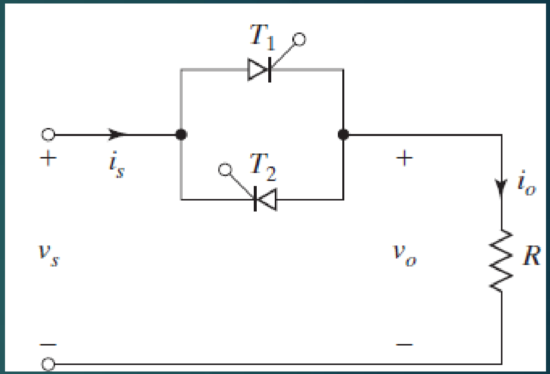


FIGURE 11.3

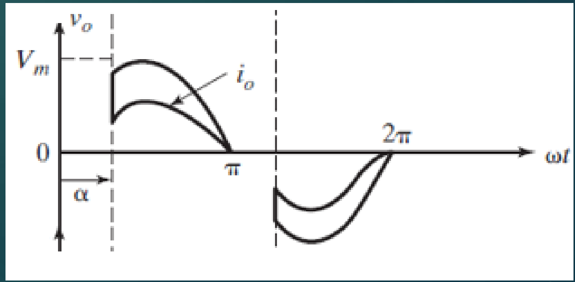
Single-phase full-wave controller with common cathode.

Example 11.1 Finding the Performance Parameters of a Single-Phase Full-Wave Controller

A single-phase full-wave ac voltage controller in Figure 11.2a has a resistive load of $R = 10\ \Omega$ and the input voltage is $V_s = 120$ V (rms), 60 Hz. The delay angles of thyristors T_1 and T_2 are equal: $\alpha_1 = \alpha_2 = \alpha = \pi/2$. Determine (a) the rms output voltage V_o, (b) the input PF, (c) the average current of thyristors I_A, and (d) the rms current of thyristors I_R.



$$V_o = V_s\left[\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2} \quad (11.1)$$



Solution

$R = 10\ \Omega$, $V_s = 120$ V, $\alpha = \pi/2$, and $V_m = \sqrt{2} \times 120 = 169.7$ V.

a. From Eq. (11.1), the rms output voltage

$$V_o = \frac{120}{\sqrt{2}} = 84.85 \text{ V}$$

b. The rms value of load current is $I_o = V_o/R = 84.85/10 = 8.485$ A and the load power is $P_o = I_o^2 R = 8.485^2 \times 10 = 719.95$ W. Because the input current is the same as the load current, the input VA rating is

$$\text{VA} = V_s I_s = V_s I_o = 120 \times 8.485 = 1018.2 \text{ W}$$

The input PF is

$$\text{PF} = \frac{P_o}{\text{VA}} = \frac{V_o}{V_s} = \left[\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2}$$

$$= \frac{1}{\sqrt{2}} = \frac{719.95}{1018.2} = 0.707 \text{ (lagging)}$$

c. The average thyristor current

$$I_A = \frac{1}{2\pi R}\int_\alpha^\pi \sqrt{2}\, V_s \sin \omega t \, d(\omega t)$$

$$= \frac{\sqrt{2} V_s}{2\pi R}(\cos \alpha + 1)$$

$$= \sqrt{2} \times \frac{120}{2\pi \times 10} = 2.7 \text{ A}$$

d. The rms value of the thyristor current

$$I_R = \left[\frac{1}{2\pi R^2}\int_\alpha^\pi 2V_s^2 \sin^2 \omega t \, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{2V_s^2}{4\pi R^2}\int_\alpha^\pi (1 - \cos 2\omega t)\, d(\omega t)\right]^{1/2}$$

$$= \frac{V_s}{\sqrt{2}R}\left[\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2}$$

$$= \frac{120}{2 \times 10} = 6\text{A}$$

11.4 SINGLE-PHASE FULL-WAVE CONTROLLERS WITH INDUCTIVE LOADS

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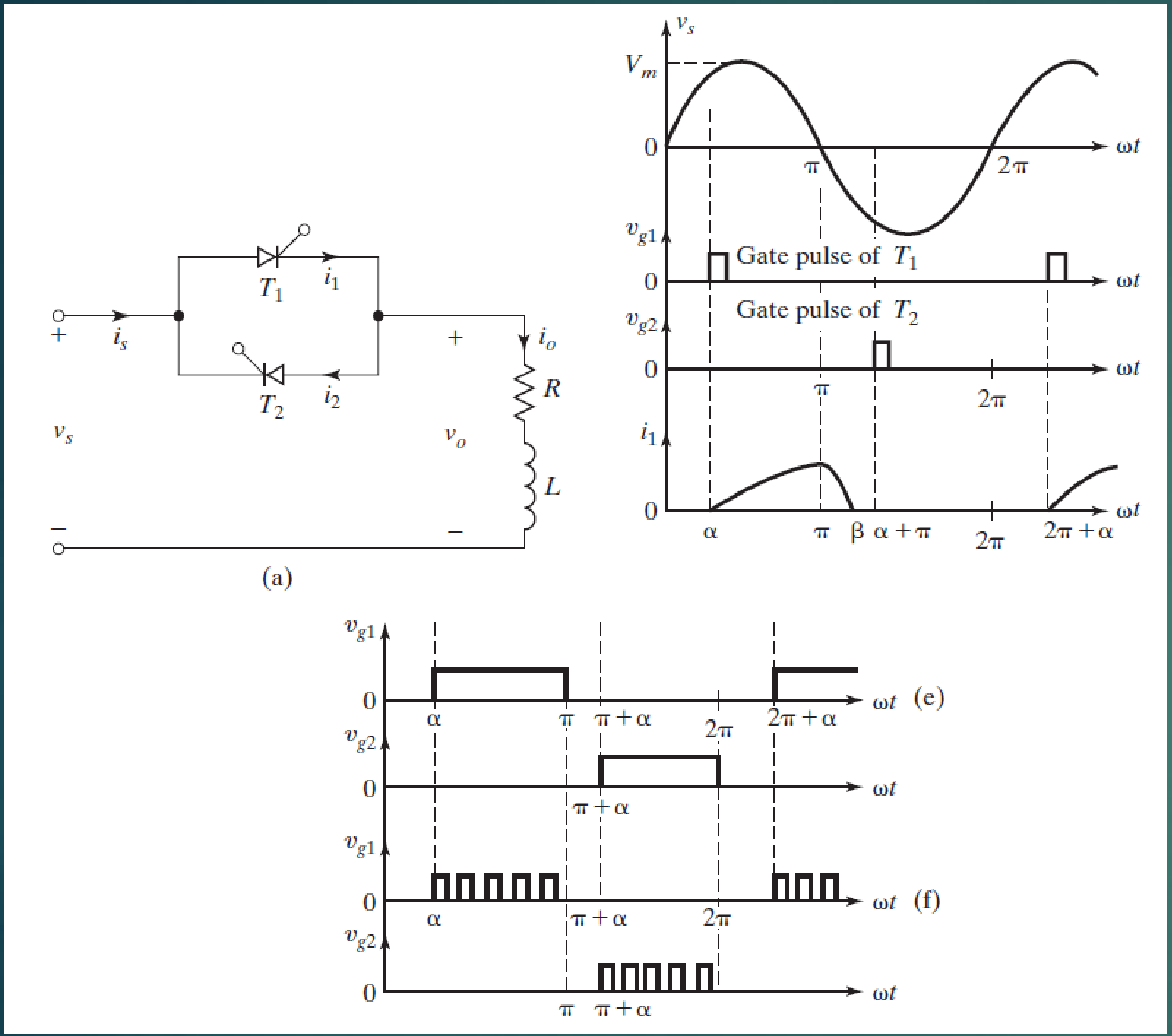

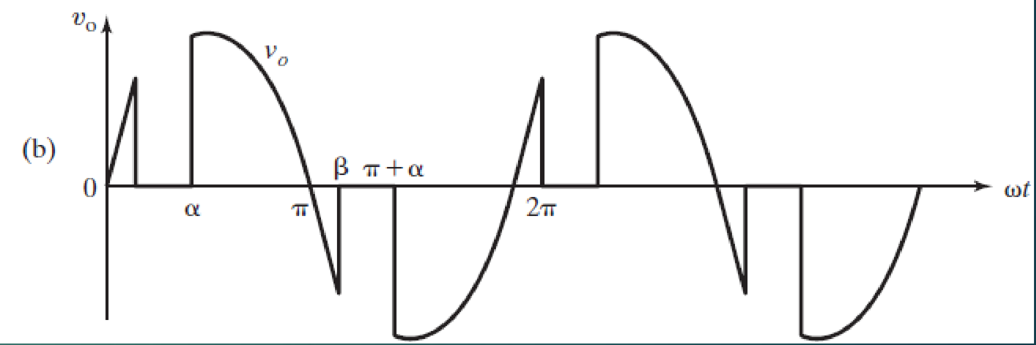

FIGURE 11.6

Typical waveforms of single-phase ac voltage controller with an RL load. (a) Input supply voltage and output current, (b) Output voltage, and (c) Voltage across thyristor T_1.

$$i_1 = \frac{\sqrt{2}V_s}{Z}[\sin(\omega t - \theta) - \sin(\alpha - \theta)e^{(R/L)(\alpha/\omega - t)}] \tag{11.8}$$

$$\sin(\beta - \theta) = \sin(\alpha - \theta)e^{(R/L)(\alpha - \beta)/\omega} \tag{11.9}$$

11.4 SINGLE-PHASE FULL-WAVE CONTROLLERS WITH INDUCTIVE LOADS

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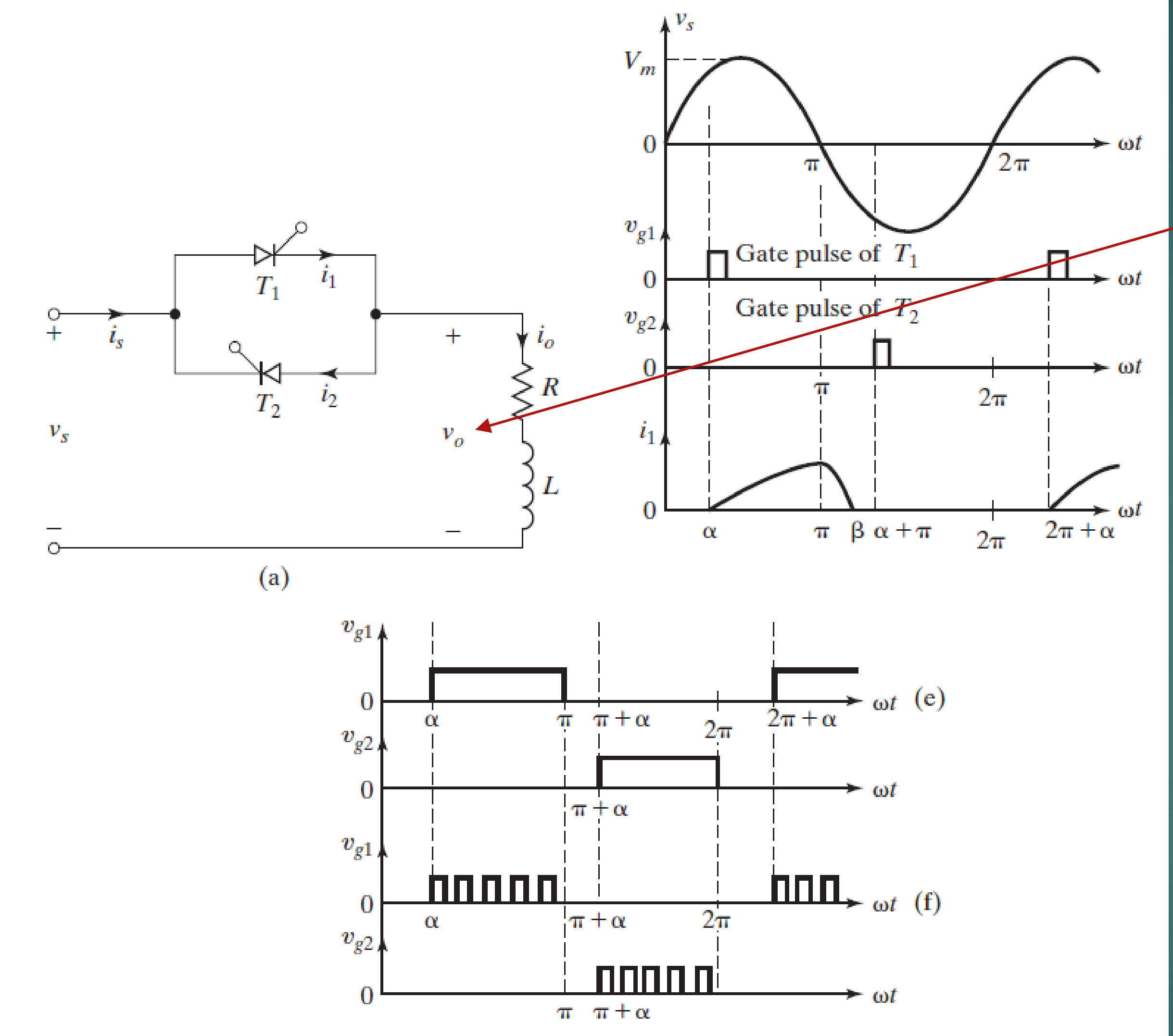

$v_o(t)$ may be evaluated via

$$v_o = L\frac{di_1}{dt} + Ri_1$$

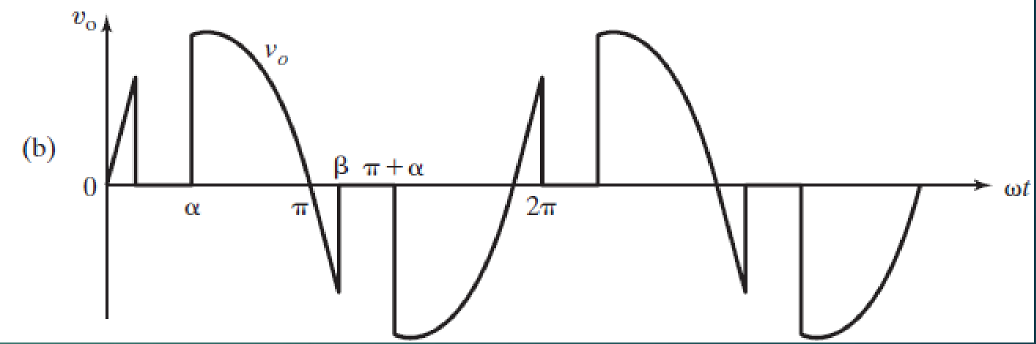

FIGURE 11.6

Typical waveforms of single-phase ac voltage controller with an RL load. (a) Input supply voltage and output current, (b) Output voltage, and (c) Voltage across thyristor T_1.

$$i_1 = \frac{\sqrt{2}V_s}{Z}\left[\sin(\omega t - \theta) - \sin(\alpha - \theta)e^{(R/L)(\alpha/\omega - t)}\right] \tag{11.8}$$

$$\sin(\beta - \theta) = \sin(\alpha - \theta)e^{(R/L)(\alpha-\beta)/\omega} \tag{11.9}$$

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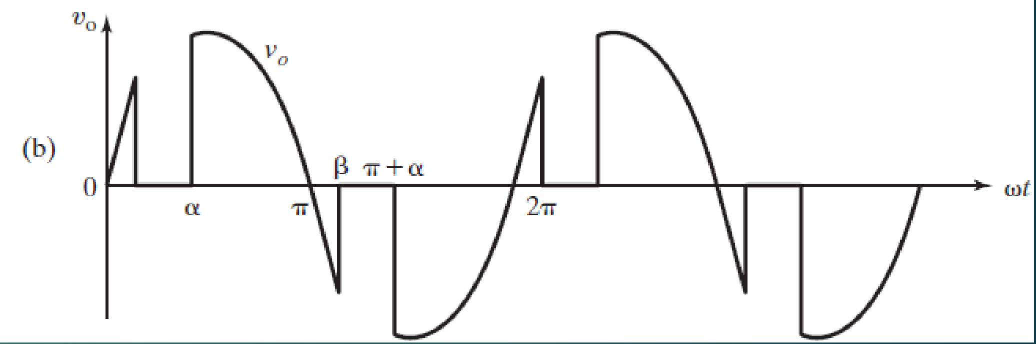
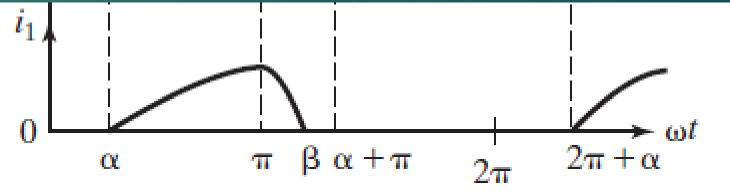
Mathematical expressions for AC/AC conv. with RL load

$$V_o = \left[\frac{2}{2\pi}\int_\alpha^\beta 2V_s^2 \sin^2 \omega t \, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{4V_s^2}{4\pi}\int_\alpha^\beta (1 - \cos 2\omega t)\, d(\omega t)\right]^{1/2}$$

$$= V_s\left[\frac{1}{\pi}\left(\beta - \alpha + \frac{\sin 2\alpha}{2} - \frac{\sin 2\beta}{2}\right)\right]^{1/2} \quad (11.11)$$





$$I_R = \left[\frac{1}{2\pi}\int_\alpha^\beta i_1^2 \, d(\omega t)\right]^{1/2}$$

$$= \frac{V_s}{Z}\left[\frac{1}{\pi}\int_\alpha^\beta \{\sin(\omega t - \theta) - \sin(\alpha - \theta)e^{(R/L)(\alpha/\omega - t)}\}^2 d(\omega t)\right]^{1/2} \quad (11.12)$$

$$I_o = (I_R^2 + I_R^2)^{1/2} = \sqrt{2}\, I_R \quad (11.13)$$

$$I_A = \frac{1}{2\pi}\int_\alpha^\beta i_1 \, d(\omega t)$$

$$= \frac{\sqrt{2}V_s}{2\pi Z}\int_\alpha^\beta \left[\sin(\omega t - \theta) - \sin(\alpha - \theta)e^{(R/L)(\alpha/\omega - t)}\right] d(\omega t) \quad (11.14)$$

$$V_o = \left\{\frac{2}{2\pi}\int_\alpha^\pi 2V_s^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

$$= \left\{\frac{4V_s^2}{4\pi}\int_\alpha^\pi (1 - \cos 2\omega t)\, d(\omega t)\right]^{1/2}$$

$$= V_s\left[\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2} \quad (11.1)$$

Example 11.2 Finding the Performance Parameters of a Single-Phase Full-Wave Controller with an *RL* Load

The single-phase full-wave controller in Figure 11.5a supplies an *RL* load. The input rms voltage is $V_s = 120$ V, 60 Hz. The load is such that $L = 6.5$ mH and $R = 2.5\ \Omega$. The delay angles of thyristors are equal: $\alpha_1 = \alpha_2 = \pi/2$. Determine (a) the conduction angle of thyristor T_1, δ; (b) the rms output voltage V_o, (c) the rms thyristor current I_R; (d) the rms output current I_o; (e) the average current of a thyristor I_A; and (f) the input PF.

Solution

$R = 2.5\ \Omega$, $L = 6.5$ mH, $f = 60$ Hz, $\omega = 2\pi \times 60 = 377$ rad/s, $V_s = 120$ V, $\alpha = 90°$, and $\theta = \tan^{-1}(\omega L/R) = 44.43°$.

a. The extinction angle can be determined from the solution of Eq. (11.9) and an iterative solution yields $\beta = 220.35°$. The conduction angle is $\delta = \beta - \alpha = 220.35 - 90 = 130.35°$.

b. From Eq. (11.11), the rms output voltage is $V_o = 68.09$ V.

c. Numerical integration of Eq. (11.12) between the limits $\omega t = \alpha$ to β gives the rms thyristor current as $I_R = 15.07$ A.

d. From Eq. (11.13), $I_o = \sqrt{2} \times 15.07 = 21.3$ A.

e. Numerical integration of Eq. (11.14) yields the average thyristor current as $I_A = 8.23$ A.

f. The output power $P_o = 21.3^2 \times 2.5 = 1134.2$ W, and the input VA rating is VA $= 120 \times 21.3 = 2556$ W; therefore,

$$\mathrm{PF} = \frac{P_o}{\mathrm{VA}} = \frac{1134.200}{2556} = 0.444 \text{ (lagging)}$$

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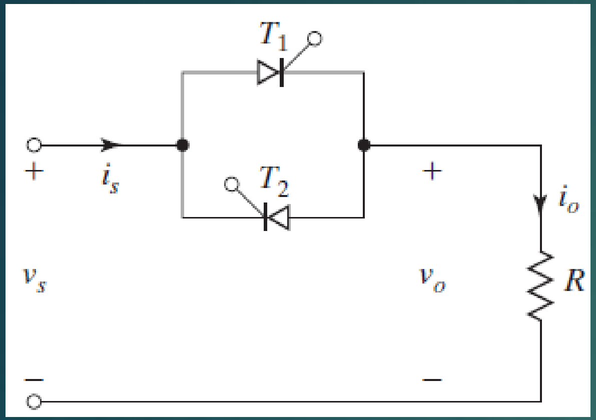
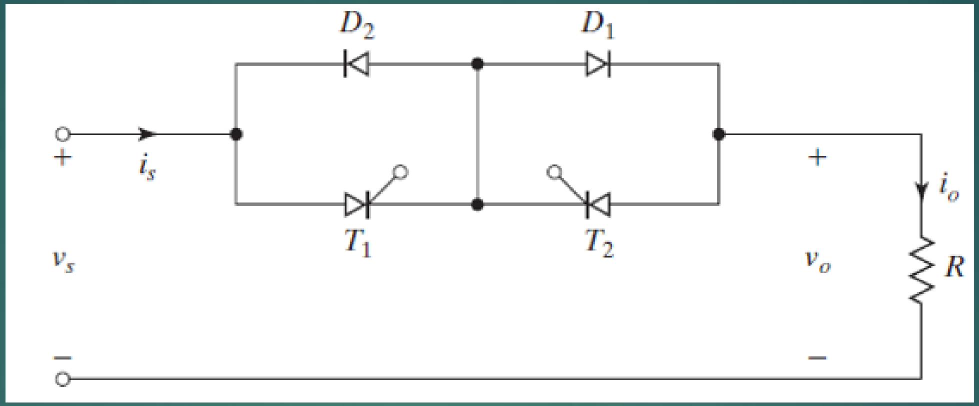
Evaluate/Assess AC/AC converters

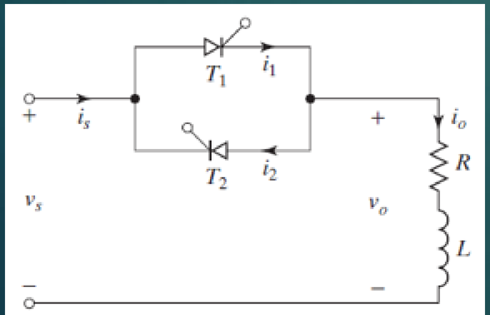




Give a comparative evaluation of the above two ac/ac converters w.r.t. output voltage magnitude and power efficiency.

Evaluate the suitability of the above converters in comparison to an AC/DC/AC power conversion.

Assess the selection of the given SCR for use in an ac/ac general purpose fan dimmer.



Type:	Phase Control
Case:	Disc
V_{RRM}/V_{DRM}:	400V
$I_{T(av)}$:	0.1 A
$I_{T(rms)}$:	0.17 A
I_{TSM}:	4 A
I^2t:	11.3×10^6 A^2s
V_{TM}:	2 V
I_{RRM}/I_{DRM}:	1 A
t_{ON}:	3 μs
t_{OFF}:	1080 μs
I_{GT}:	400 mA
V_{GT}:	2.6 V
Diameter:	150 mm
Thickness:	27 mm

11.5 THREE-PHASE FULL-WAVE CONTROLLERS

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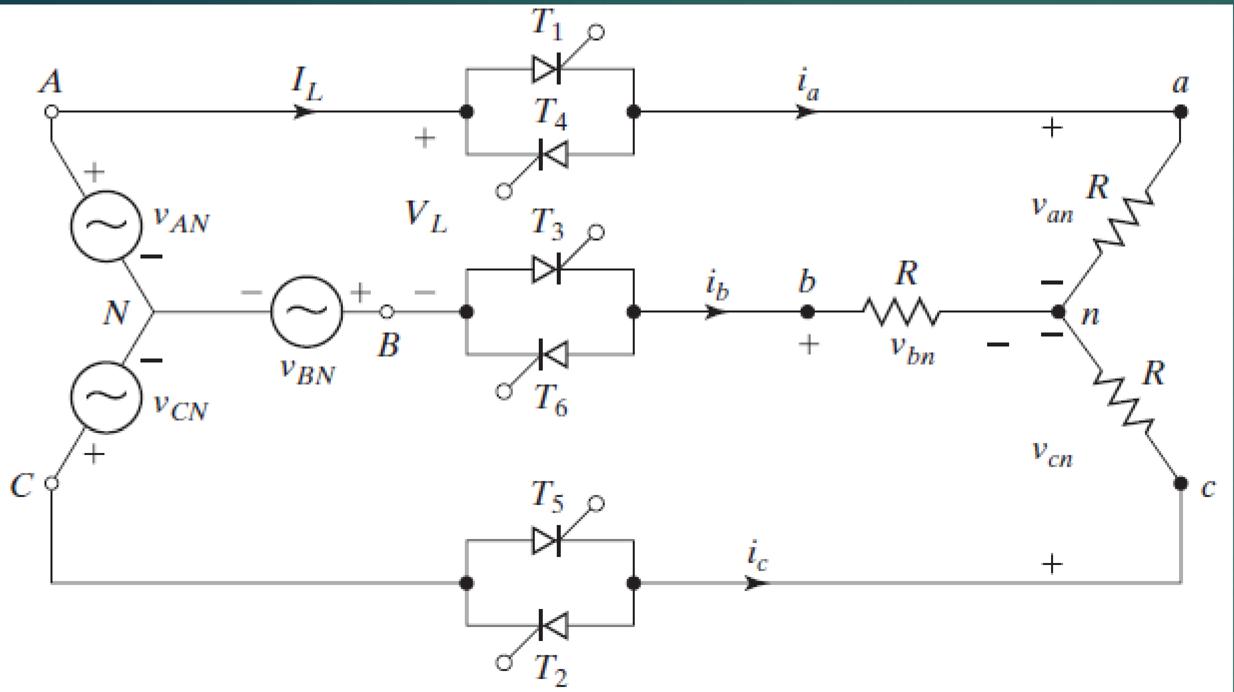
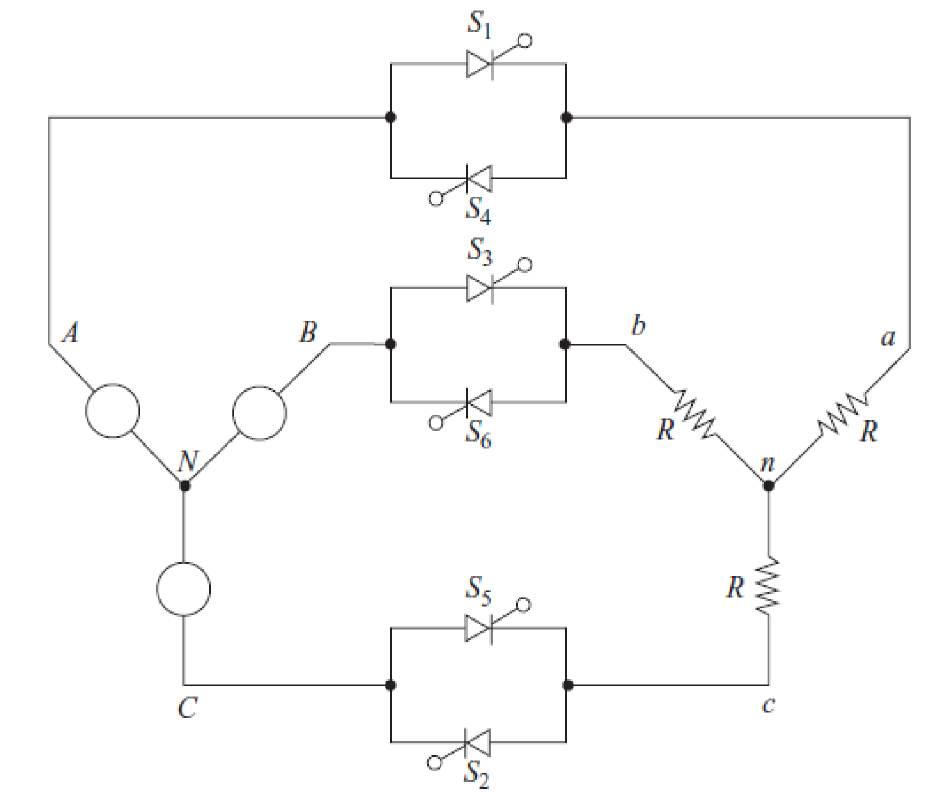
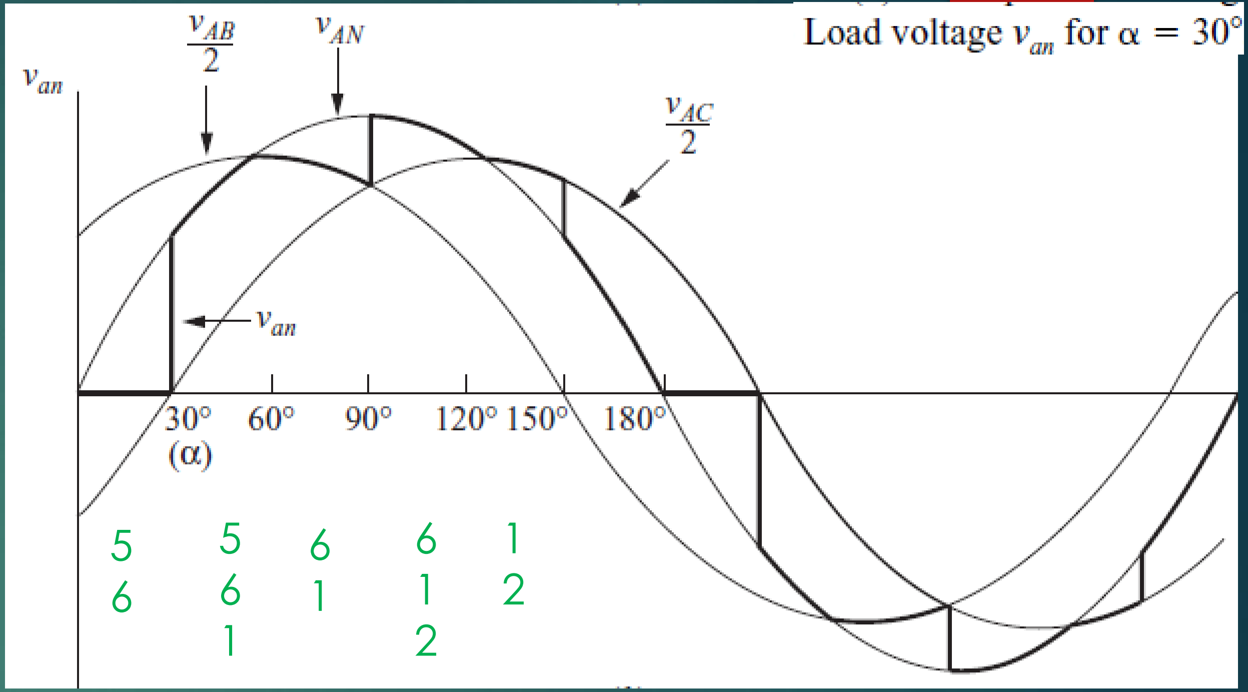


FIGURE 11.7

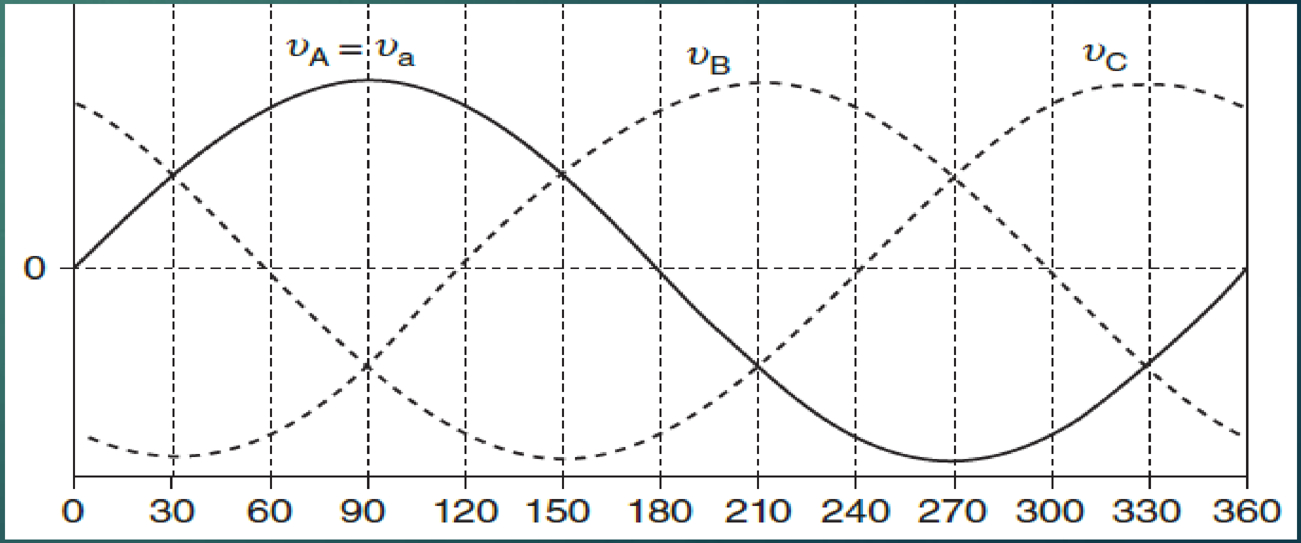
Three-phase bidirectional controller.



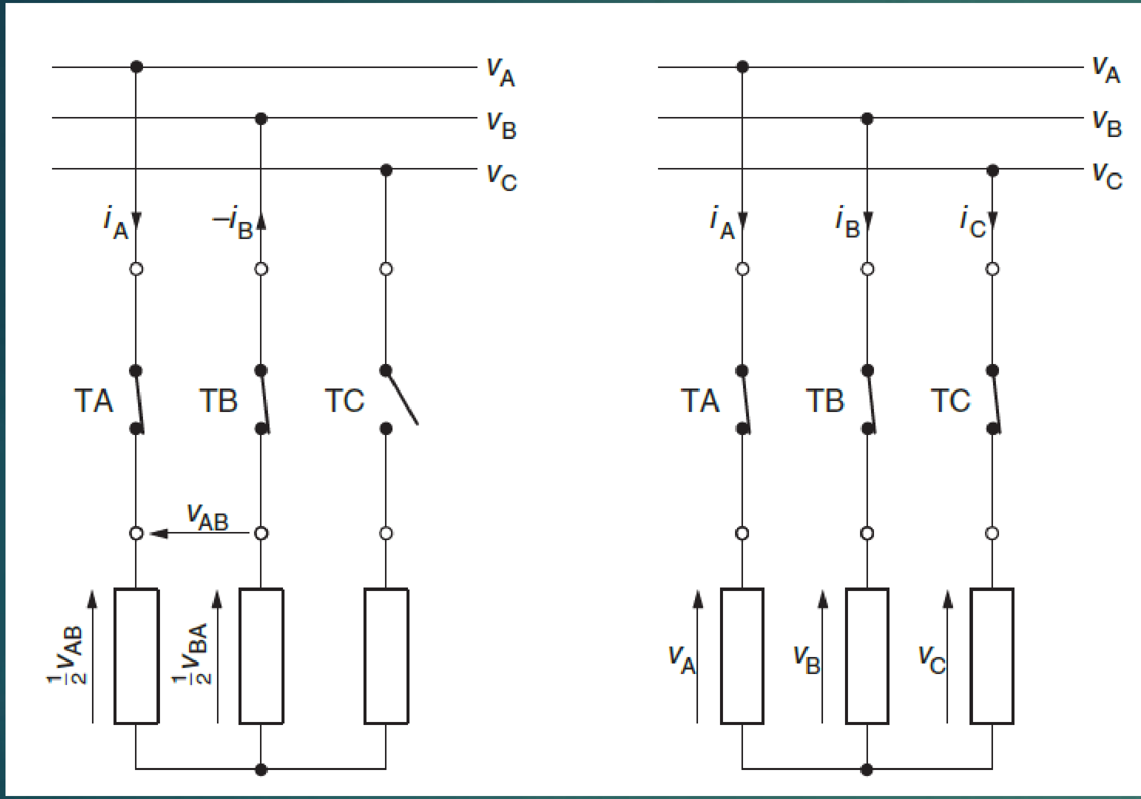
S_1
S_4
S_3
S_6
S_5
S_2
A
B
C
N
a
b
c
n
R
R
R



Load voltage v_{an} for $\alpha = 30°$
v_{an}
$\frac{v_{AB}}{2}$
v_{AN}
$\frac{v_{AC}}{2}$
v_{an}
30° (α)
60°
90°
120°
150°
180°
5 6
5 6 1
6 1
6 1 2
1 2



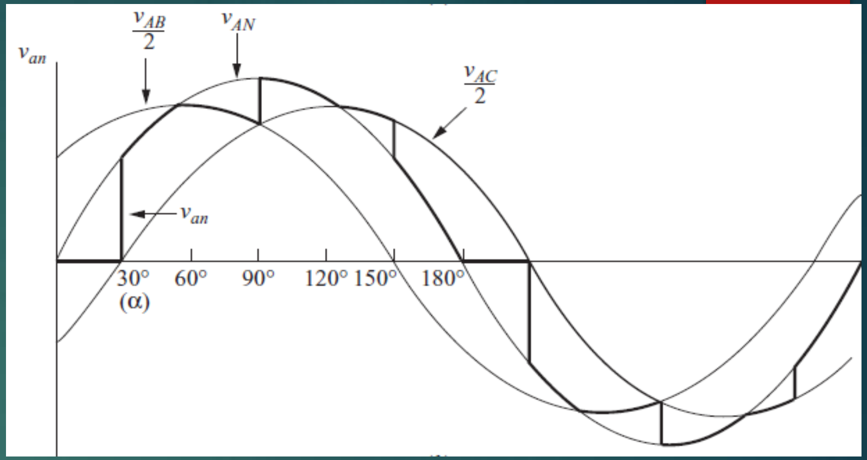
$v_A = v_a$
v_B
v_C
0
0 30 60 90 120 150 180 210 240 270 300 330 360

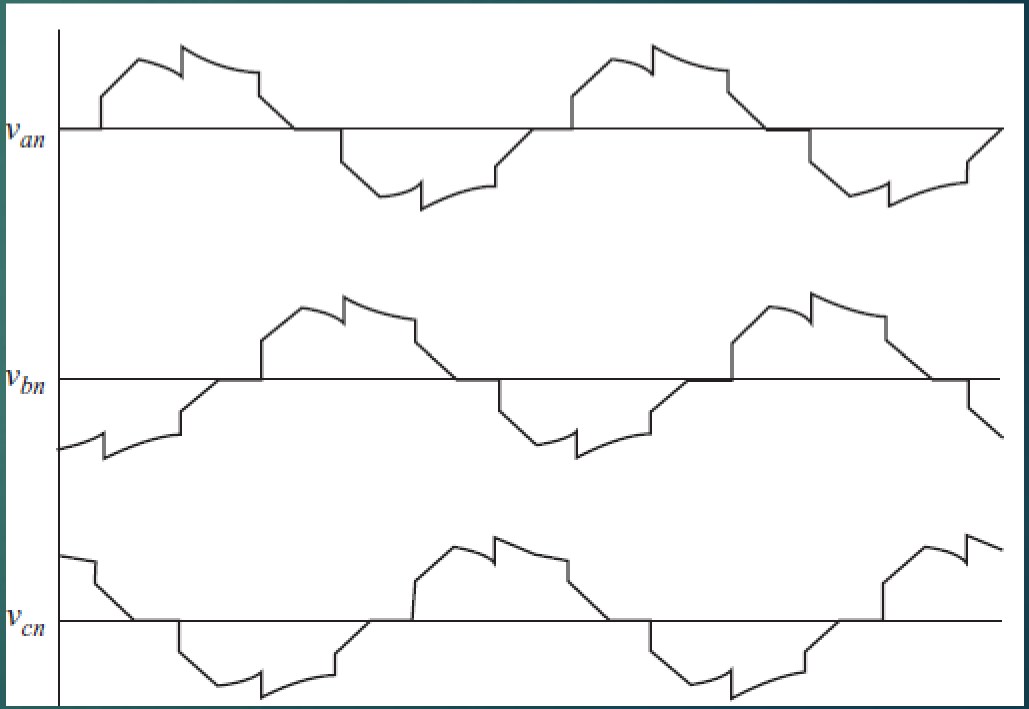


To show reduction of van to ½(vab)

$$V_o = V_i\sqrt{\frac{1}{\pi}\left[\pi - \frac{3}{2}\alpha_f + \frac{3}{4}\sin(2\alpha_f)\right]}$$

$$\text{for } 0 \le \alpha_f < 60°$$





Line-neutral voltages for 30 deg firing angle

Cyclo-converters

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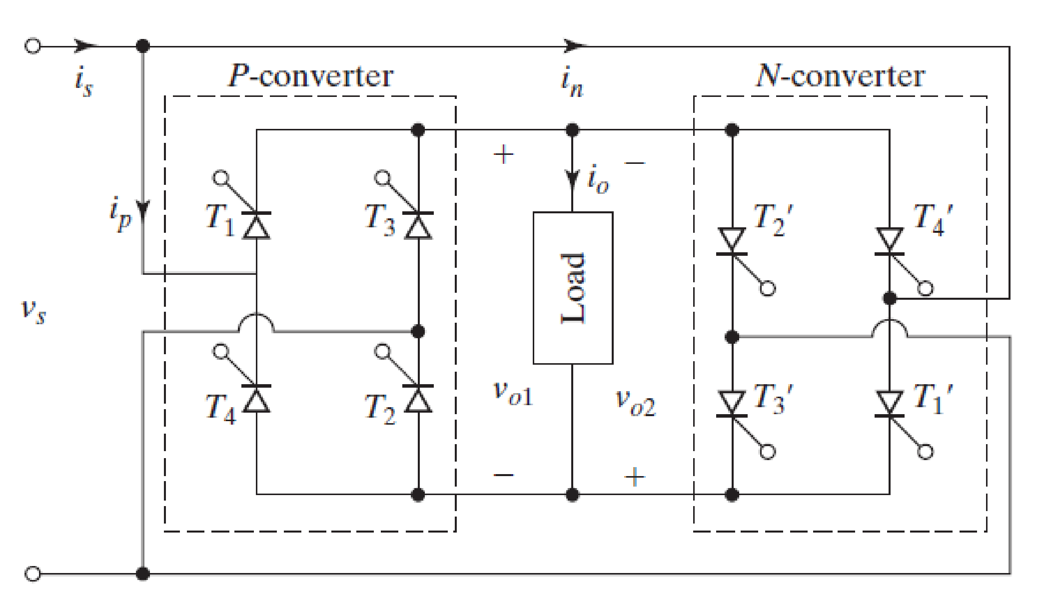
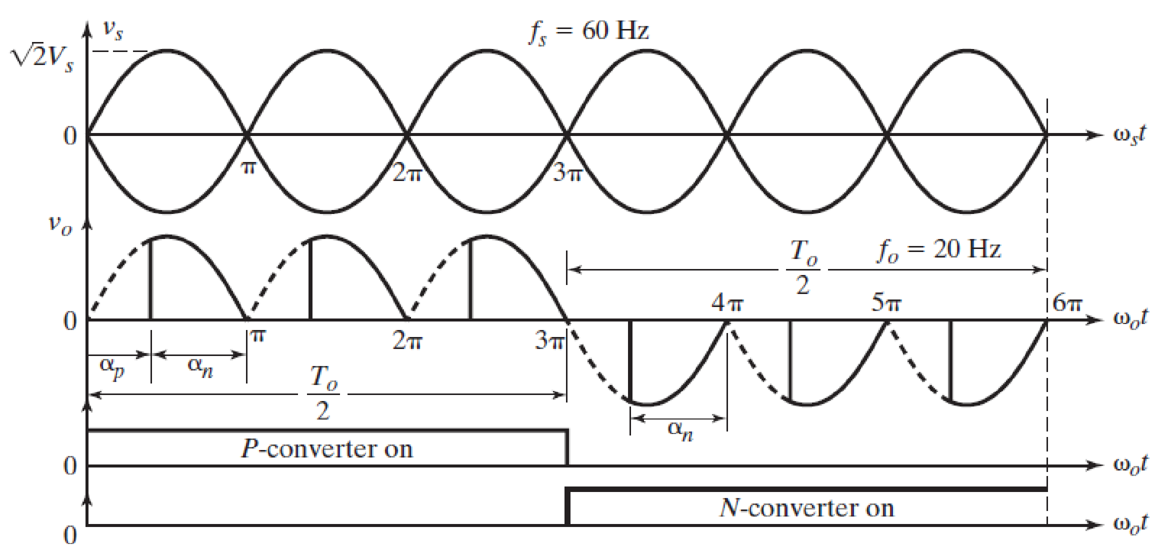




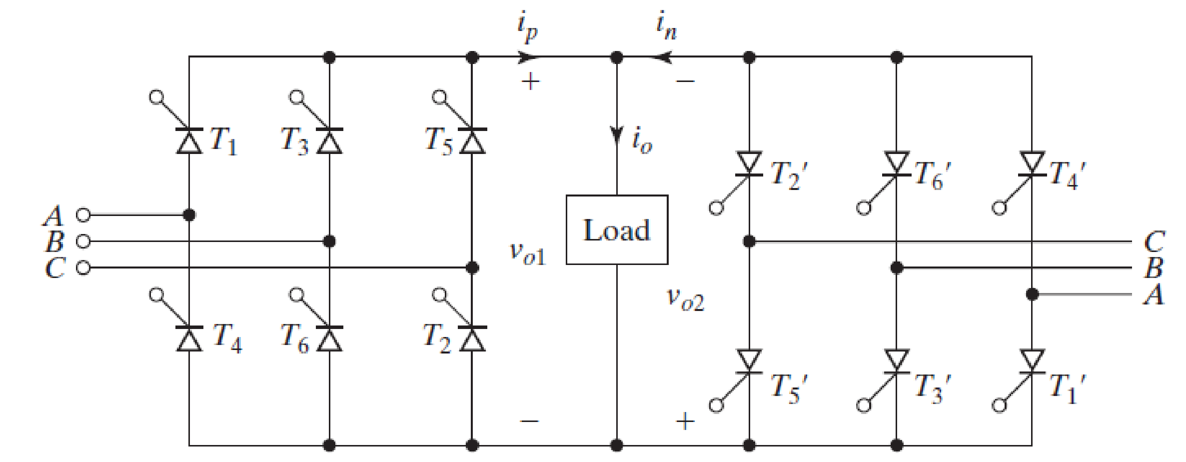
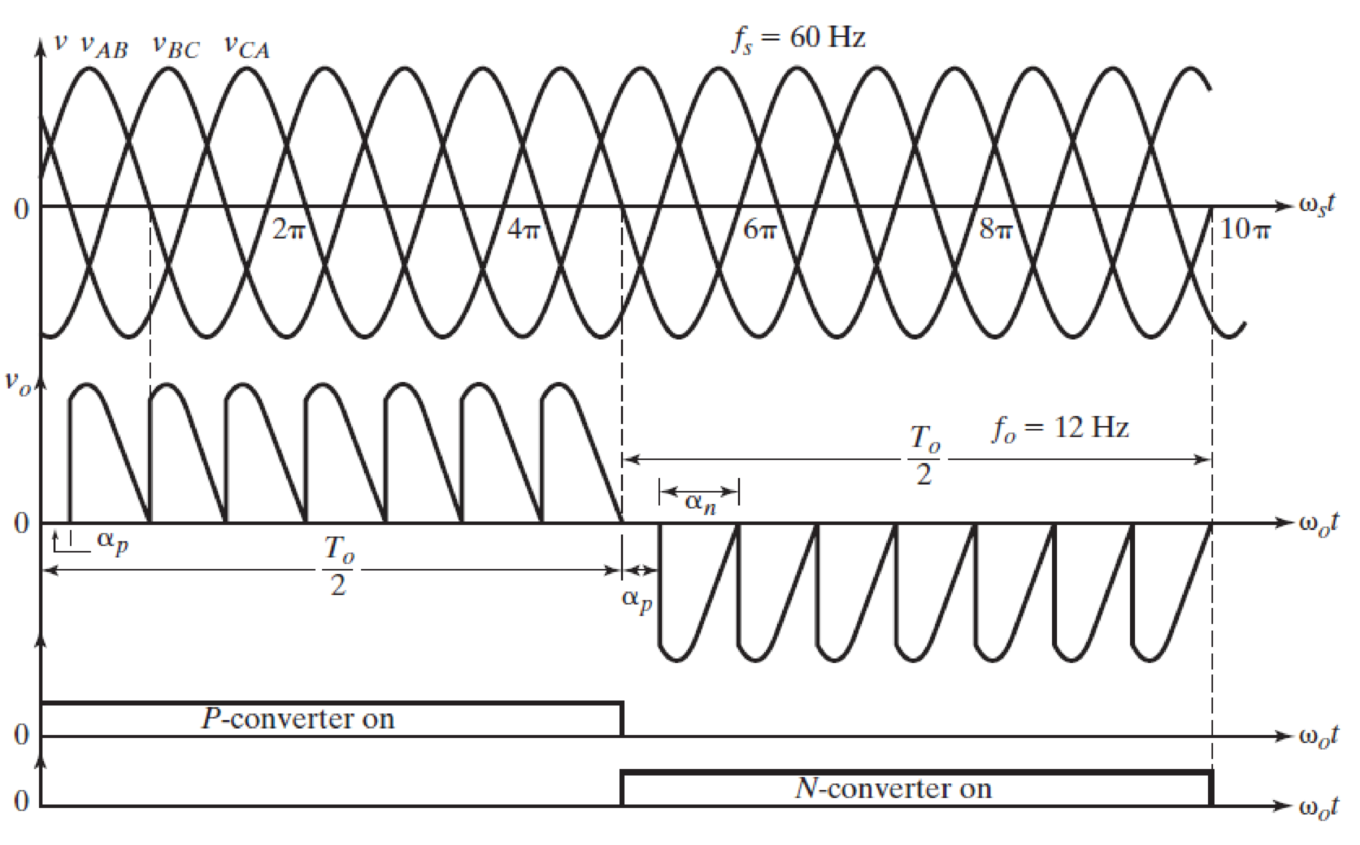


FIGURE 11.18

Three-phase/single-phase cycloconverter.



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10pi → 5 cycles

60/5 = 12 Hz

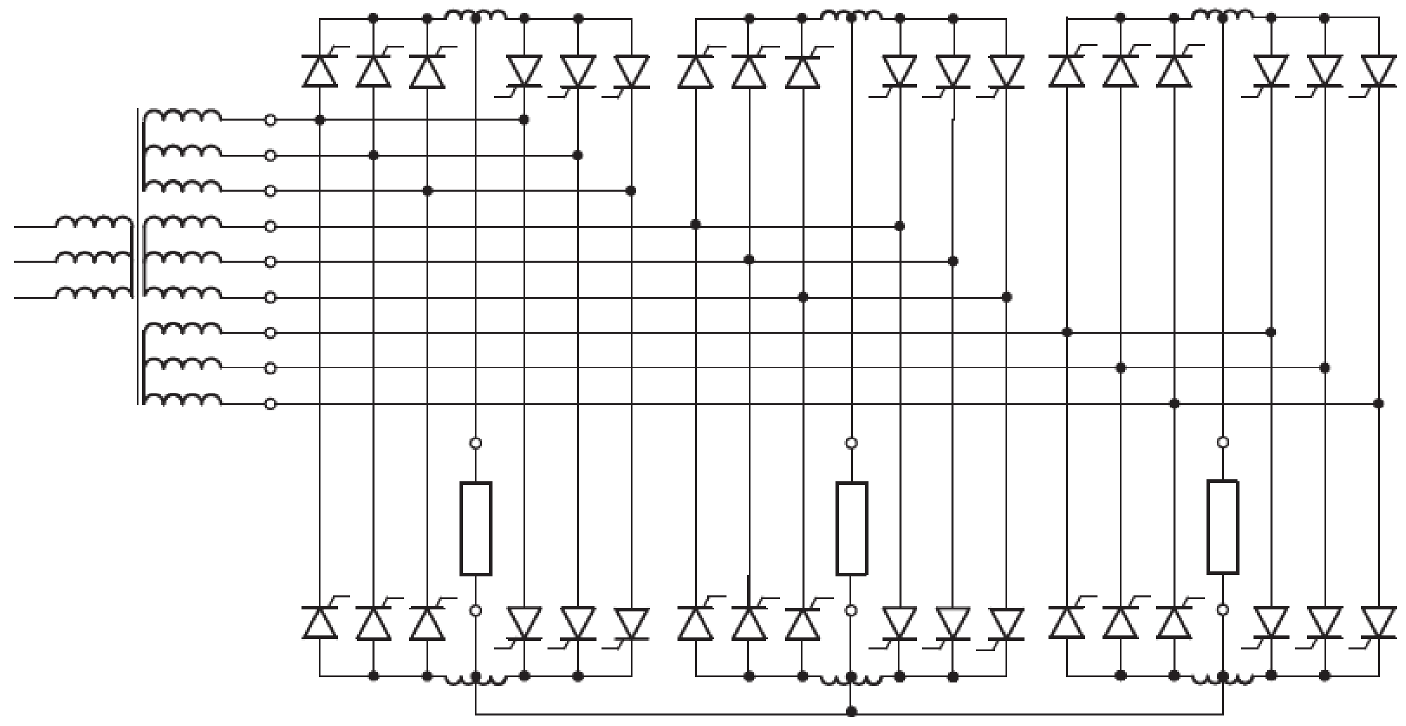
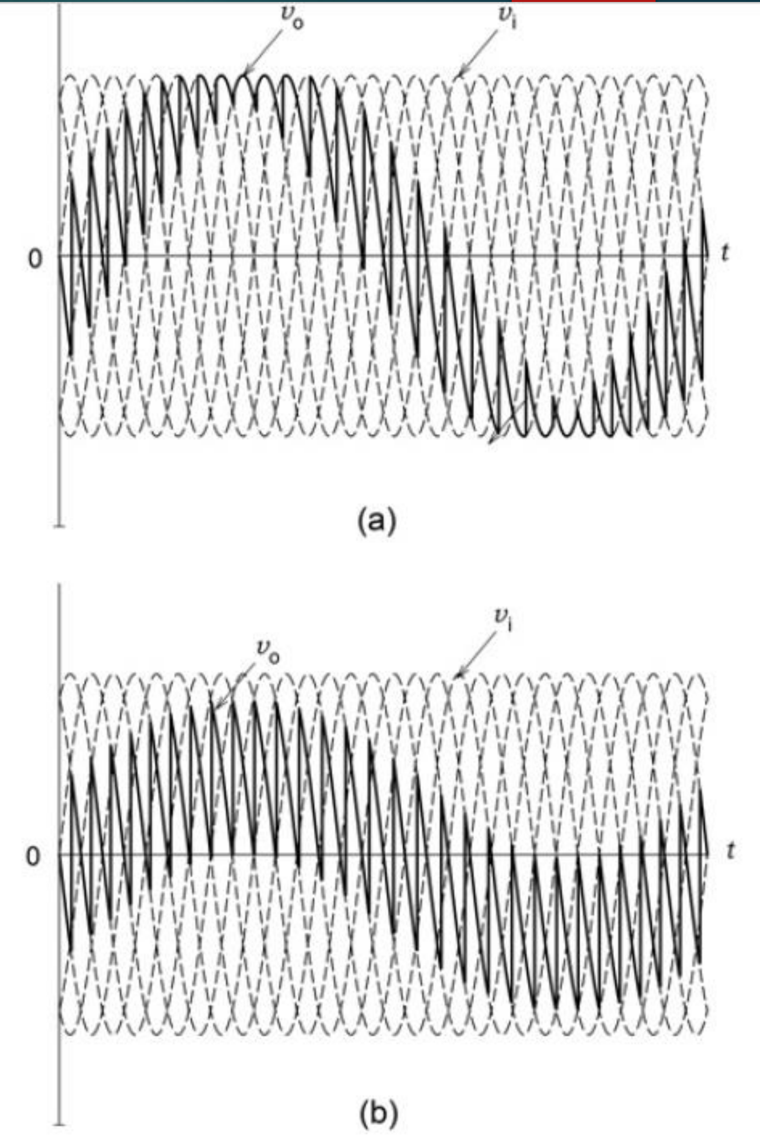


Figure 5.23 Three-phase six-pulse cycloconverter with interconnected phase loads.



5.1.3 PWM AC Voltage Controllers

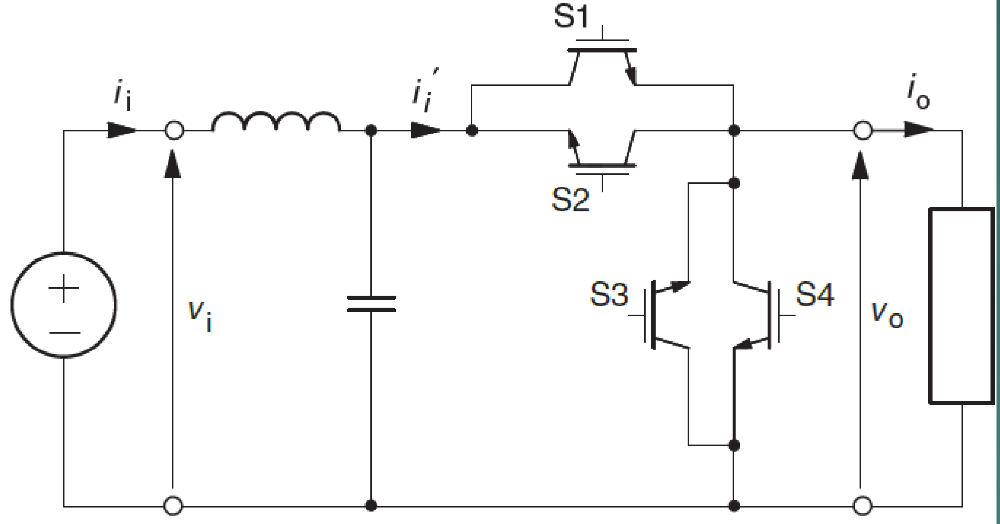
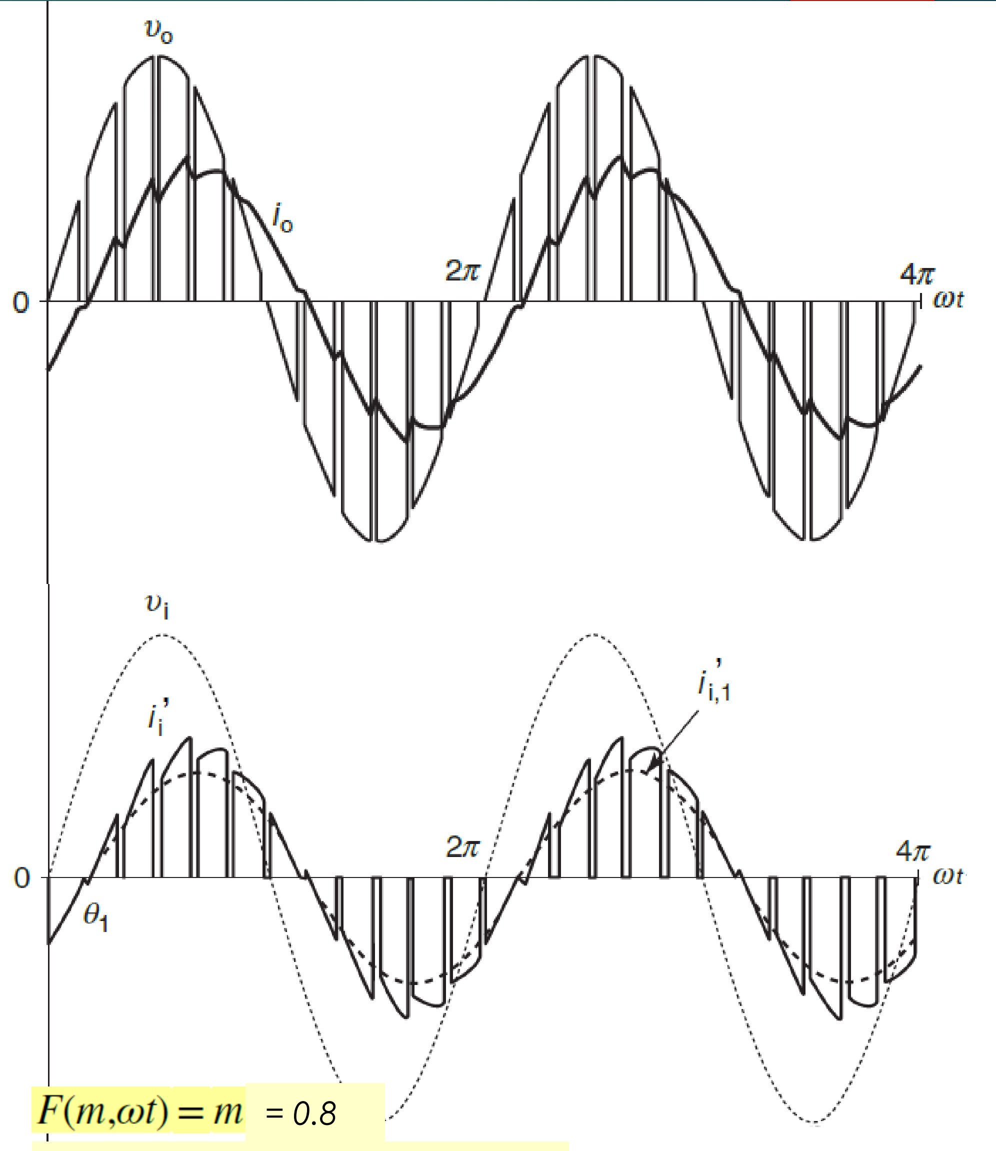


Figure 5.16 Single-phase ac chopper with input filter.

$$x_3 = \bar{x}_1$$
$$x_4 = \bar{x}_2.$$

S3, S4 are free wheeling switches



$F(m,\omega t) = m$ = 0.8

12 switching intervals per cycle

Figure 5.17 Waveforms of voltages and currents in a single-phase ac chopper: (a) output voltage and current, (b) input voltage and current (after the input filter) and the fundamental output current.

This is the value of the modulating function $F(m,\omega t)$ at $\omega t = \alpha_n$.

$$d_{1,n} = \begin{cases} F(m,\alpha_n) & \text{for } 0 < \alpha_n \le \pi \\ 0 & \text{otherwise} \end{cases}$$

$$d_{2,n} = \begin{cases} F(m,\alpha_n) & \text{for } \pi < \alpha_n \le 2\pi \\ 0 & \text{otherwise} \end{cases}$$

Duty ratios of S1 and S2 for the nth switching interval.

$$d^*_{1,n} = d^*_{2,n} = F(m,\alpha_n)$$
$$x^*_3 = x^*_4 = \bar{x}^*_1.$$

$$F(\omega t) = m$$

$$F(\omega t) = m\,|\sin(\omega t)|.$$

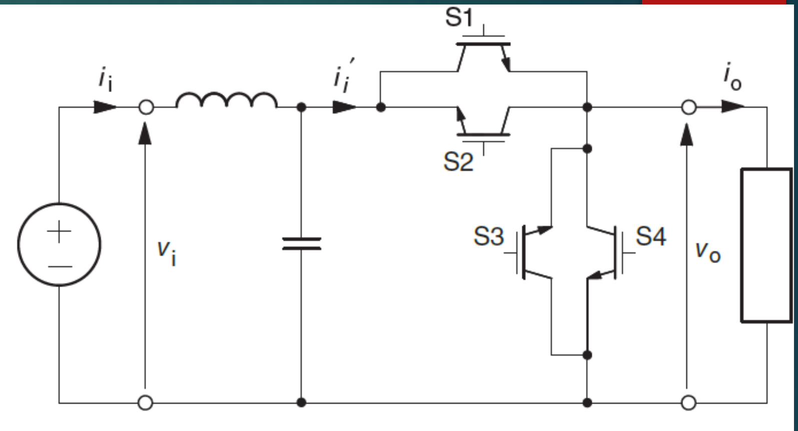


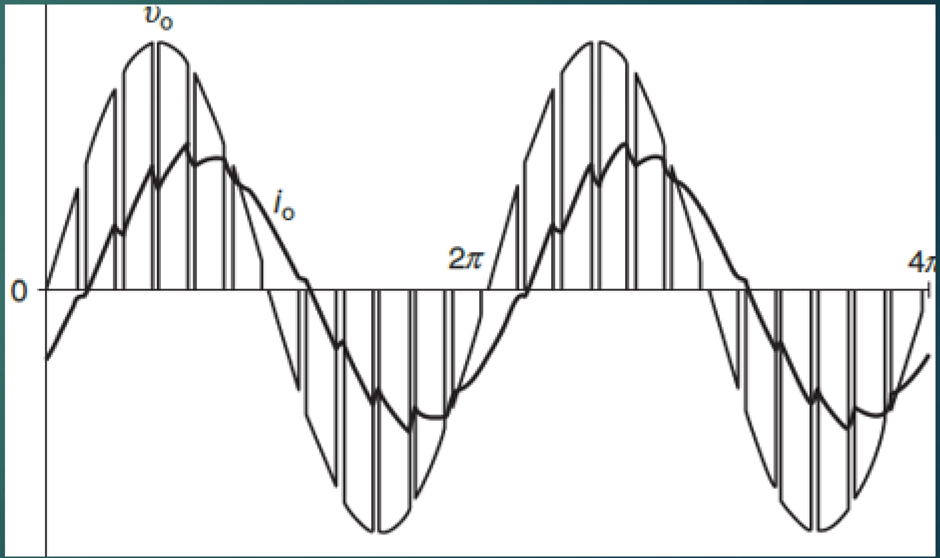
Figure 5.16 Single-phase ac chopper with input filter.

For $F(m,\omega t) = m$ **= 0.8**

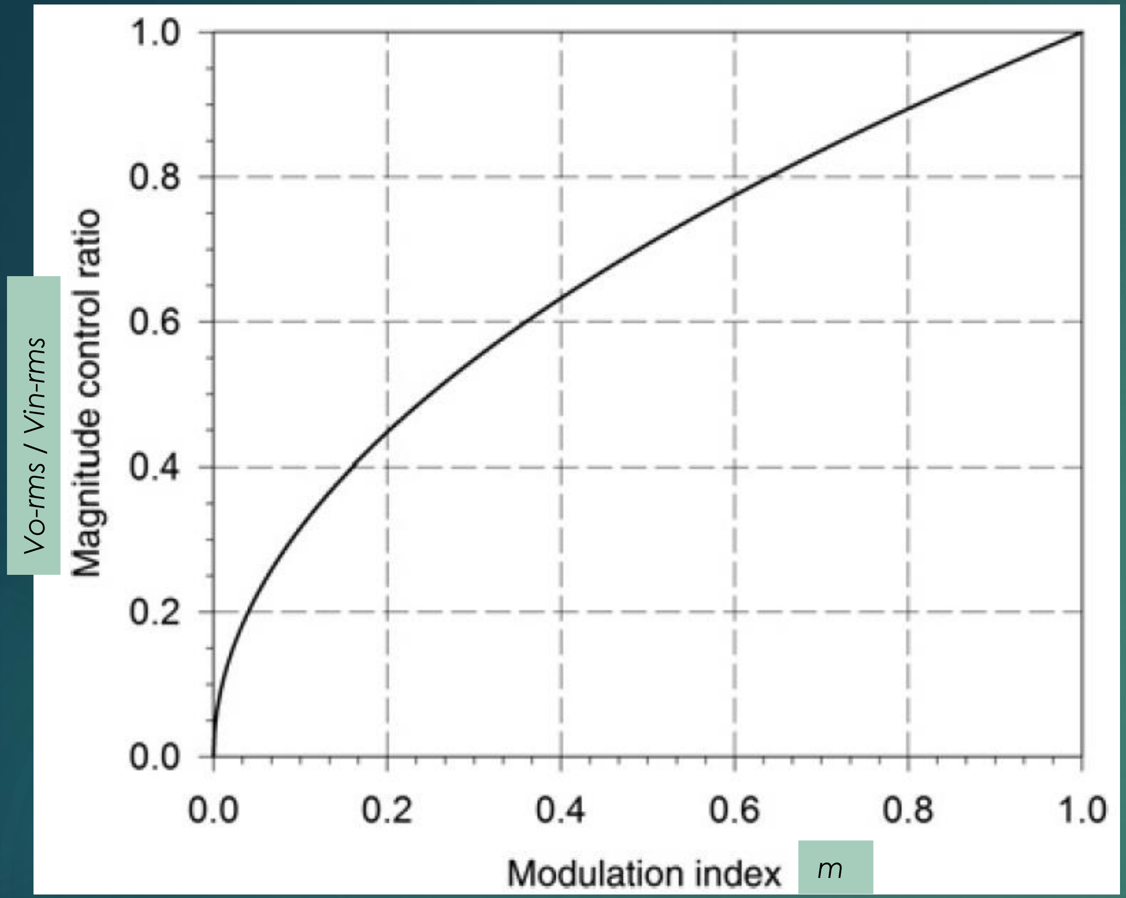
$d_{1,n}$ = 0.8

i.e. duty cycle in every switching interval is fixed equal to 0.8

$$V_o = \sqrt{m} V_i$$



$F(m,\omega t) = m$ = 0.8


1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Magnitude control ratio
Vo-rms / Vin-rms
Modulation index
m

$$V_o = \sqrt{m} V_i$$