Chapter 12

SYNTHESIS OF DC AND LOW-FREQUENCY SINUSOIDAL AC VOLTAGES FOR MOTOR DRIVES AND UPS

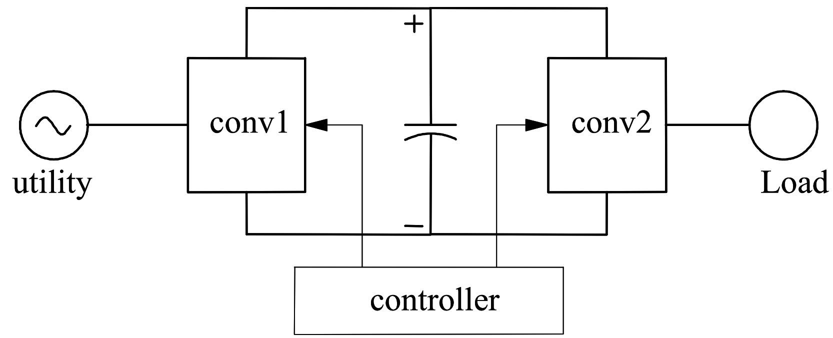
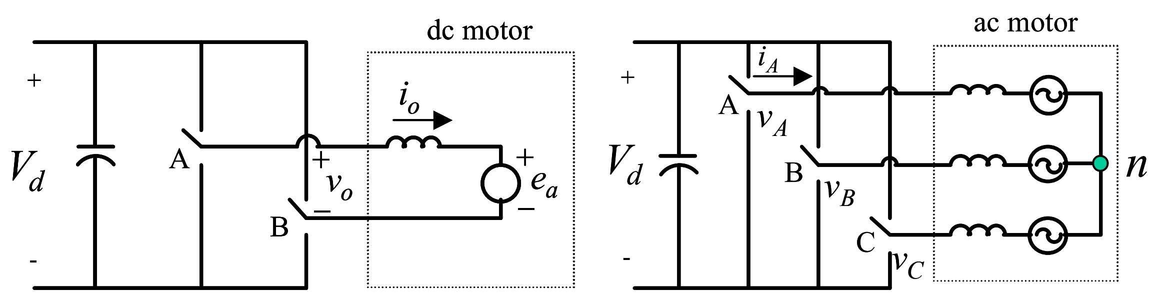


Figure 12-1 Voltage-link system.



(*a*) (*b*)

Figure 12-2 Converters for dc and ac motor drives.

SWITCHING POWER-POLE AS THE BUILDING BLOCK

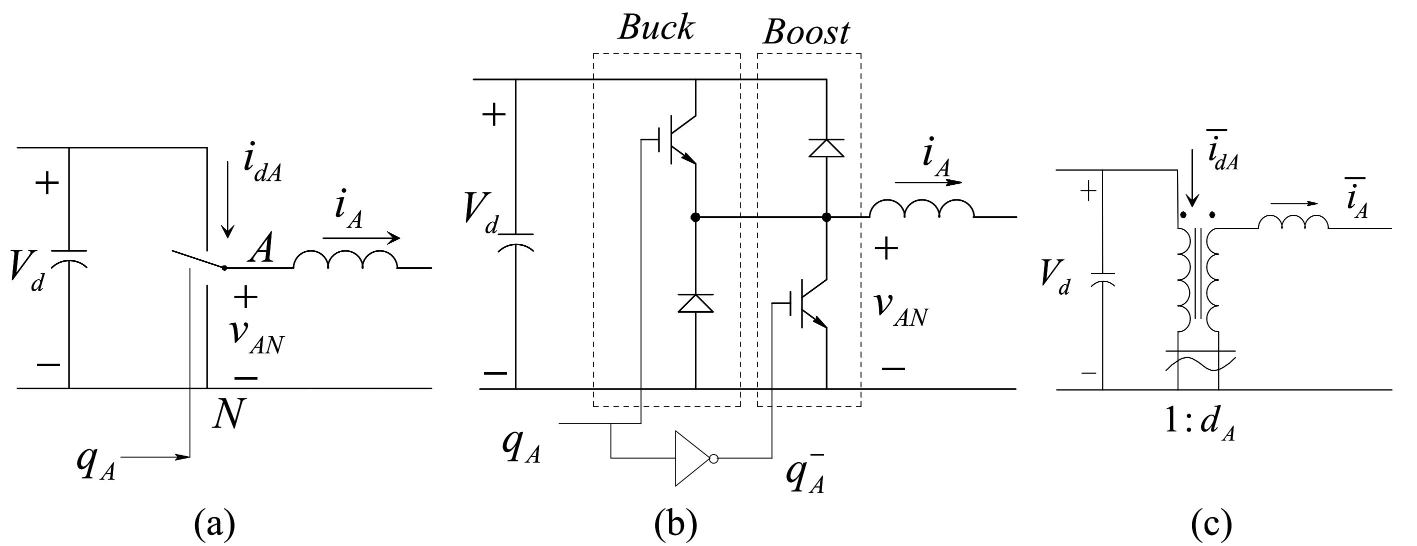


Figure 12-3 Bi-directional switching power-pole.

Pulse-Width-Modulation (PWM) of the Bi-Directional Switching Power-Pole

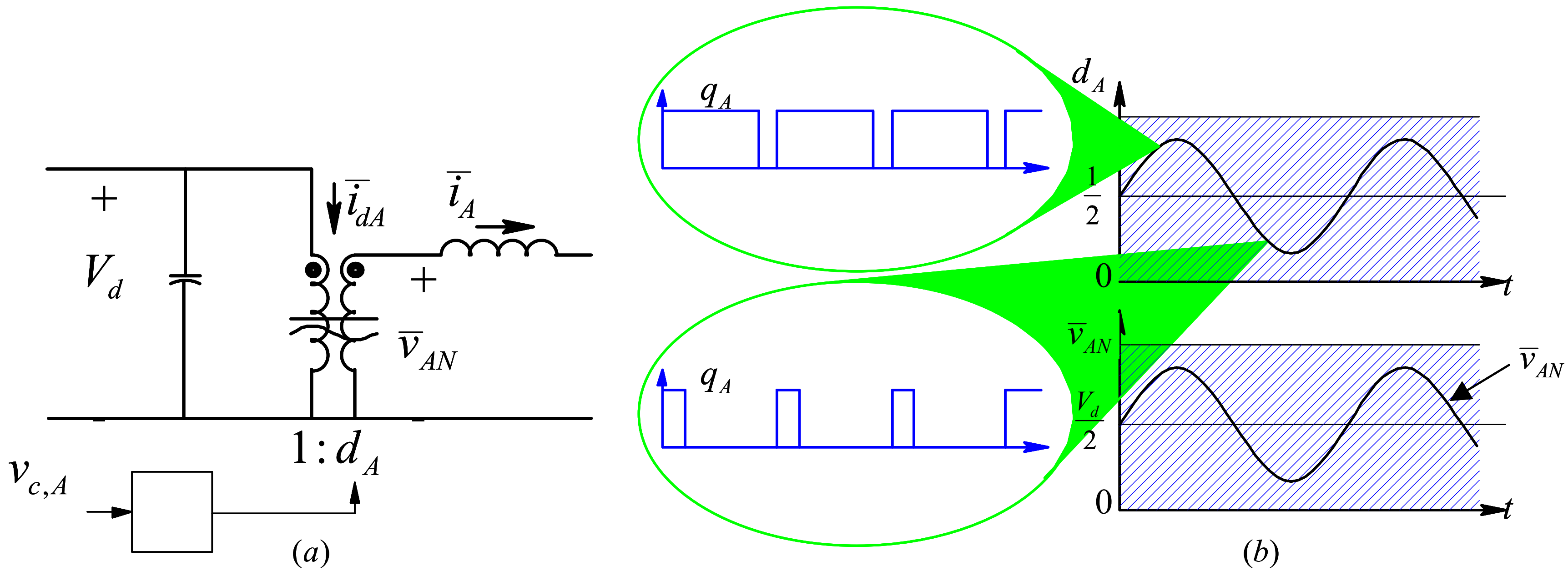


Figure 12-4 Varying the duty-ratio around 0.5 varies $\bar{v}_{AN}$ around $V_d/2$.

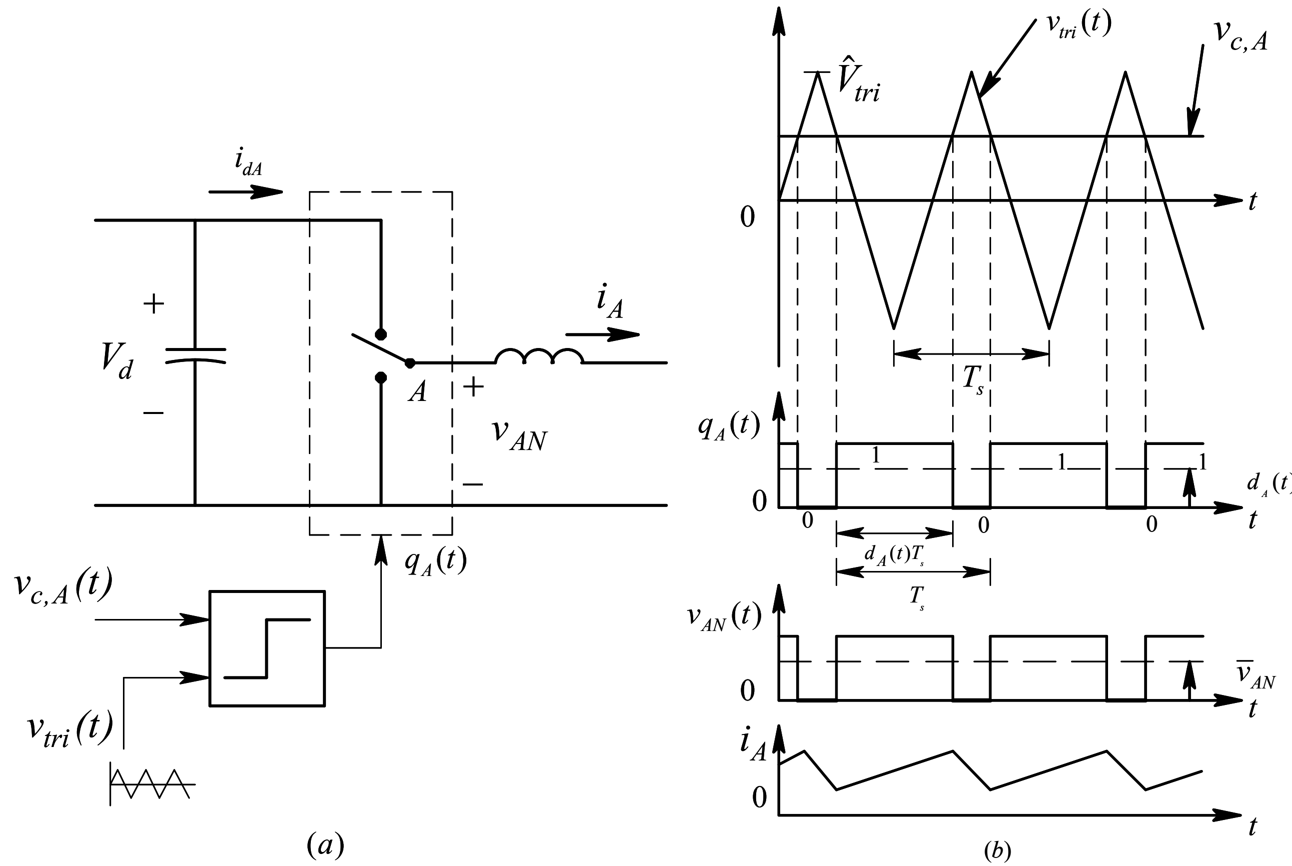


Figure 12-5 Switching power-pole and its voltage and current waveforms.

$$d_A(t) = 0.5 + 0.5\frac{v_{c,A}(t)}{\hat{V}_{tri}}$$

$$\overline{v}_{AN}(t) = d_A(t)V_d = \underbrace{0.5V_d}_{dc\,offset} + \underbrace{0.5\frac{V_d}{\hat{V}_{tri}}}_{k_{pole}} v_{c,A}(t)$$

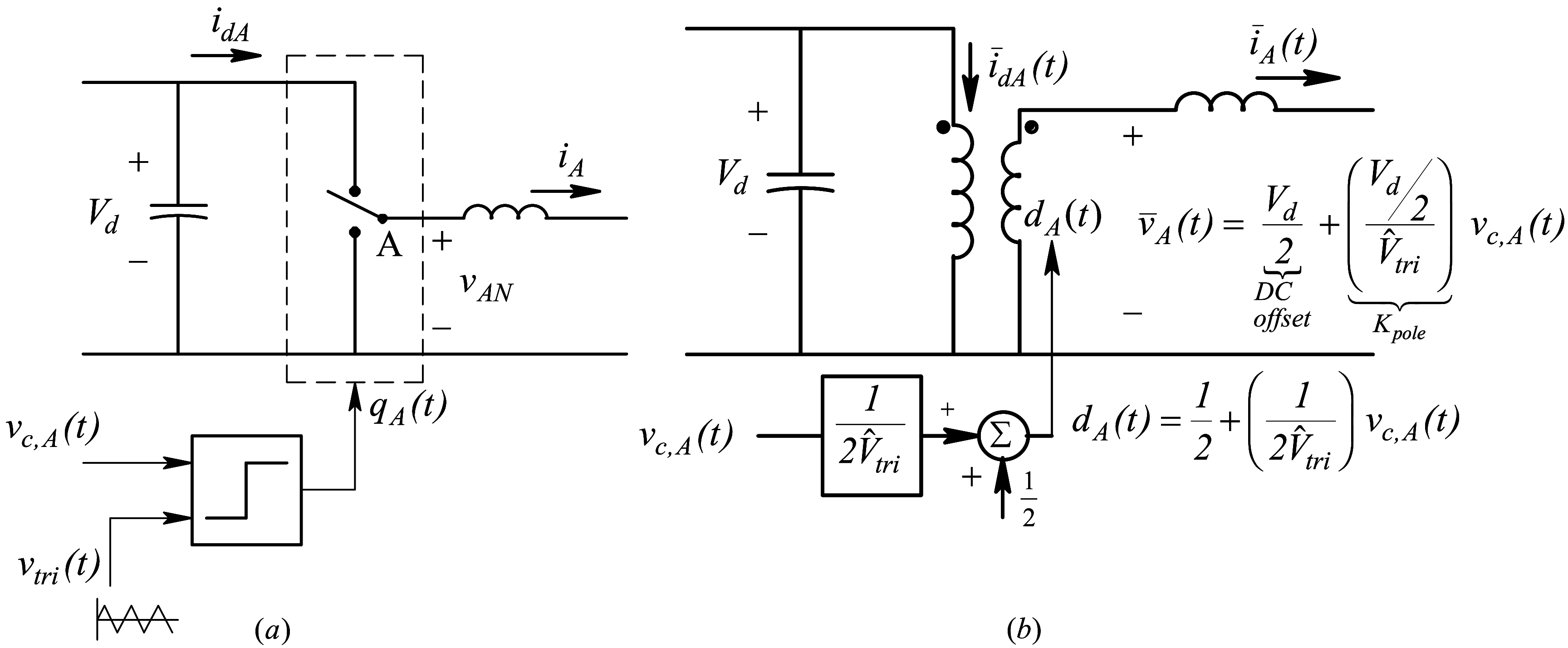


Figure 12-6 Average representation of the pulse-width-modulated power-pole.

Harmonics in the PWM Waveforms v_A and i_{dA}

$$f_h = k_1 f_s \pm \underbrace{k_2 f_1}_{\text{sidebands}}$$

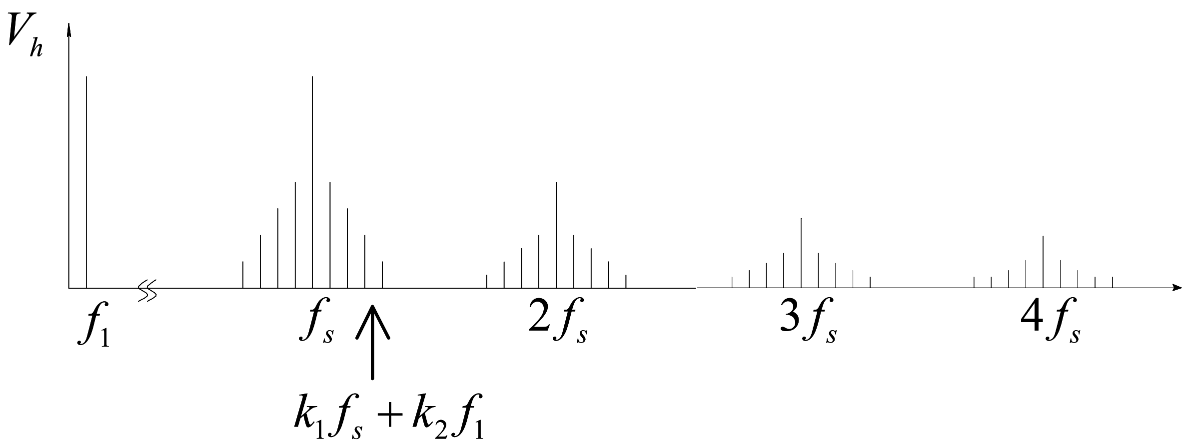


Figure 12-7 Harmonics in the switching power-pole.

DC-MOTOR DRIVES

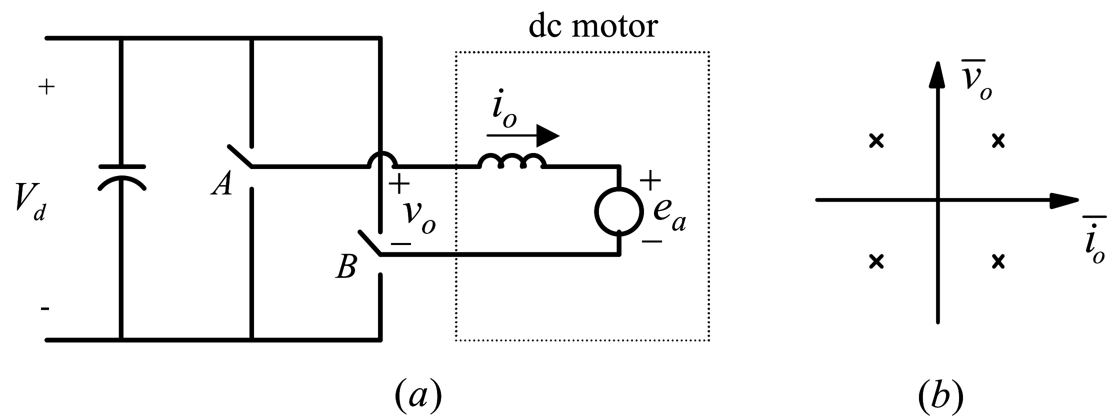


Figure 12-8 DC-motor four-quadrant operation.

$$\overline{v}_{AN}(t) = d_A(t)V_d = 0.5V_d + 0.5\frac{V_d}{\hat{V}_{tri}}v_c(t)$$

$$\overline{v}_{BN}(t) = d_B(t)V_d = 0.5V_d - 0.5\frac{V_d}{\hat{V}_{tri}}v_c(t)$$

$$\overline{v}_o(t) = \overline{v}_{AN}(t) - \overline{v}_{BN}(t) = \underbrace{\frac{V_d}{\hat{V}_{tri}}}_{k_{pwm}}v_c(t)$$

$$\overline{i}_d(t) = \overline{i}_{dA} + \overline{i}_{dB} = d_A(t)\overline{i}_A(t) + d_B(t)\overline{i}_B(t)$$

$$i_A(t) = -i_B(t) = i_o(t)$$

$$\overline{i}_d(t) = \frac{v_c(t)}{\hat{V}_{tri}}\overline{i}_o(t)$$

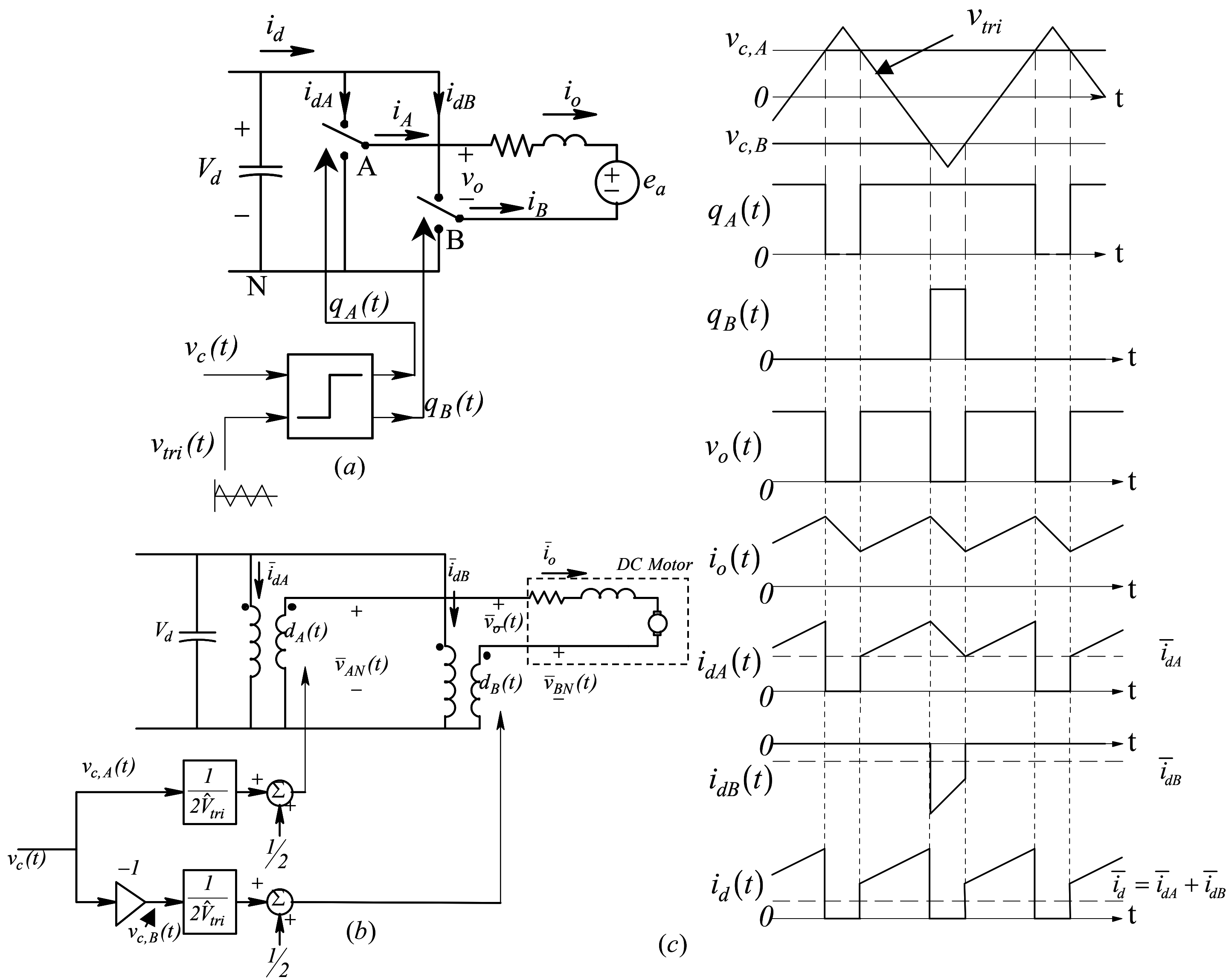


Figure 12-9 Converter for dc-motor drives.

AC-MOTOR DRIVES

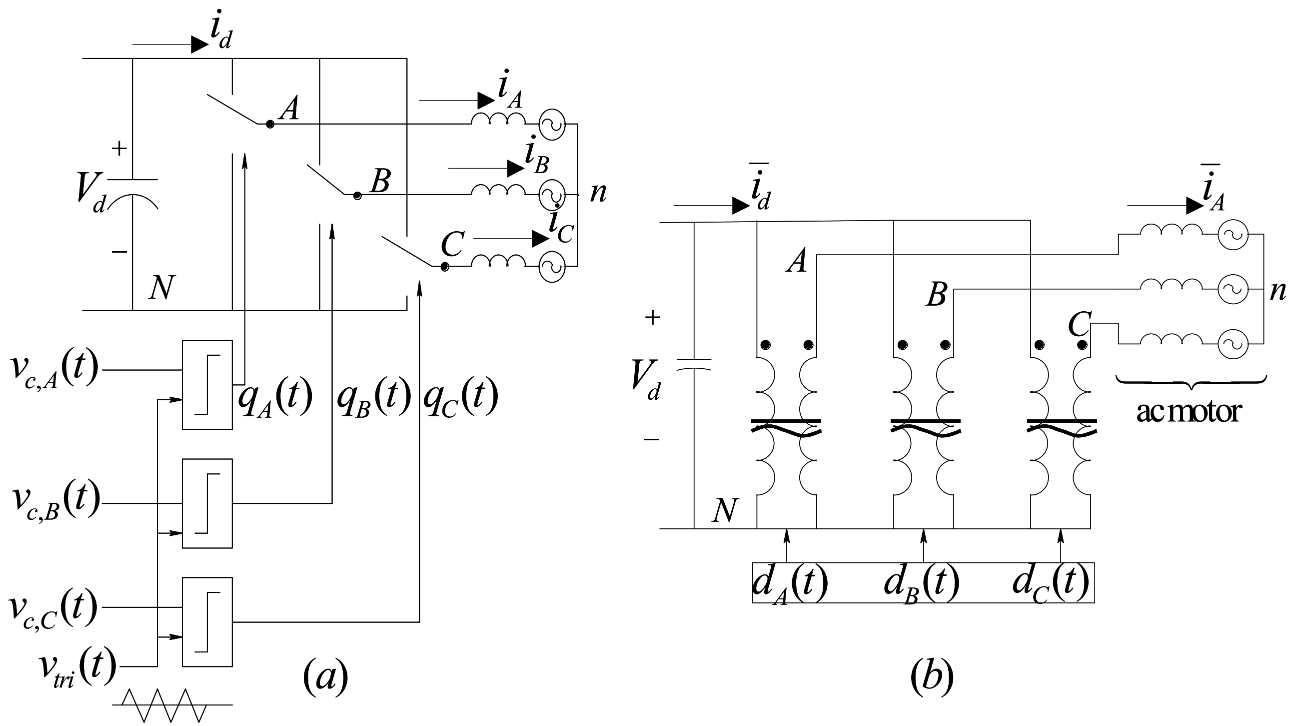


Figure 12-10 Converter for three-phase motor drive and UPS.

$$d_A(t) = 0.5 + \frac{\hat{V}_c}{\hat{V}_{tri}} \sin \omega_1 t$$

$$v_{c,A}(t) = \hat{V}_c \sin \omega_1 t$$

$$v_{c,B}(t) = \hat{V}_c \sin(\omega_1 t - 120^o)$$

$$v_{c,C}(t) = \hat{V}_c \sin(\omega_1 t - 240^o)$$

$$d_B(t) = 0.5 + \frac{\hat{V}_c}{\hat{V}_{tri}} \sin(\omega_1 t - 120^o)$$

$$d_C(t) = 0.5 + \frac{\hat{V}_c}{\hat{V}_{tri}} \sin(\omega_1 t - 240^o)$$

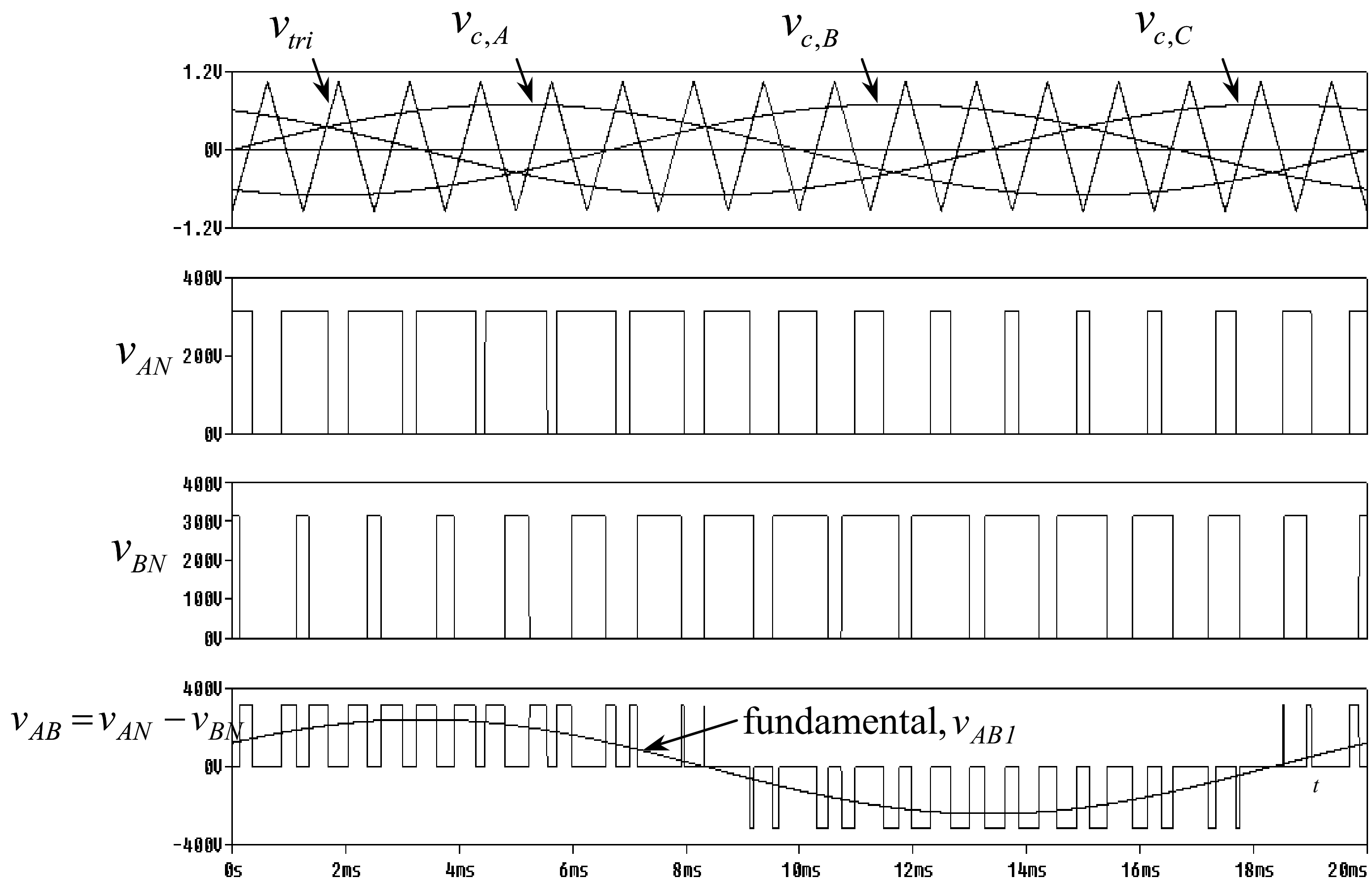
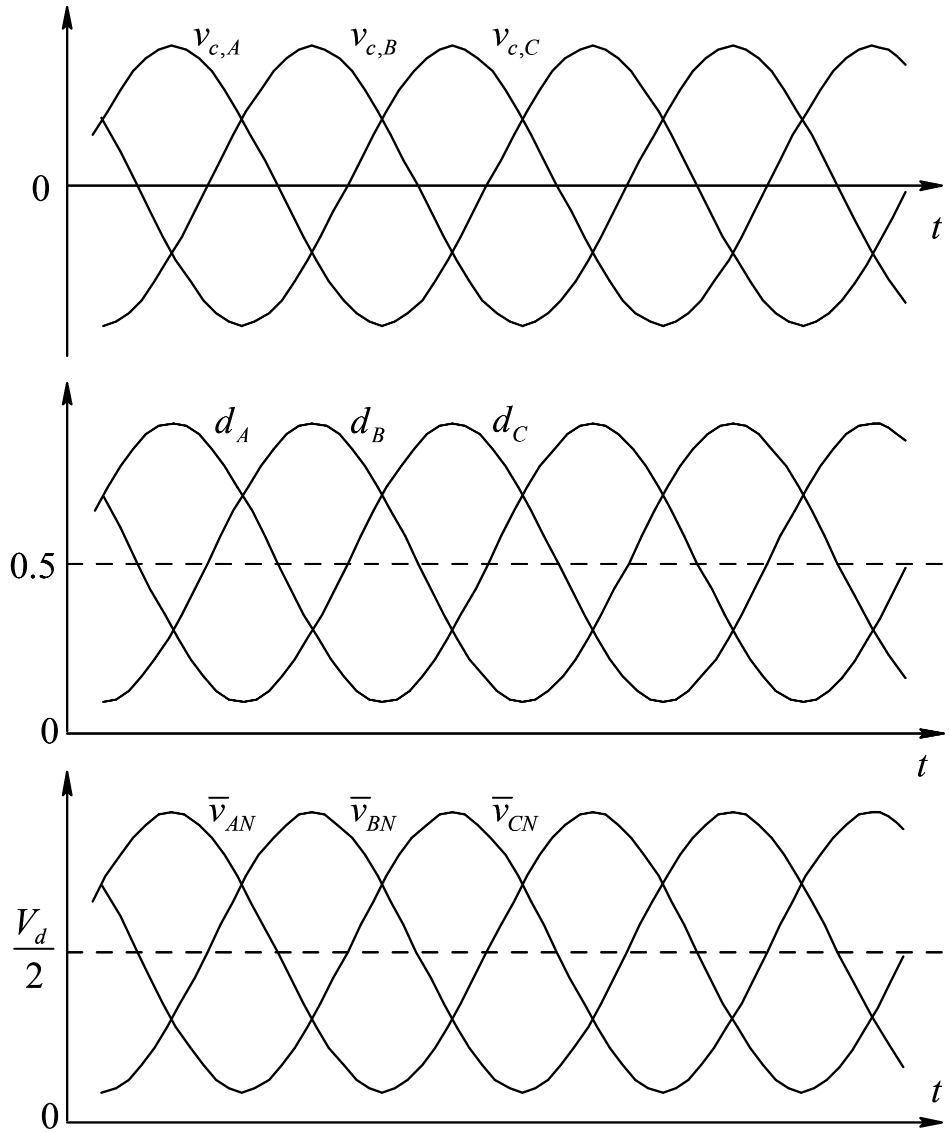


Figure 12-11 Switching waveforms in three-phase converter.

$$\bar{v}_{AN}(t) = 0.5V_d + \underbrace{0.5\frac{V_d}{\hat{V}_{tri}}}_{k_{pole}} \underbrace{\hat{V}_c \sin\omega_1 t}_{v_{c,A}}$$

$$\bar{v}_{BN}(t) = 0.5V_d + \underbrace{0.5\frac{V_d}{\hat{V}_{tri}}}_{k_{pole}} \underbrace{\hat{V}_c \sin(\omega_1 t - 120^o)}_{v_{c,B}}$$



$$\bar{v}_{An}(t) = \left(0.5\frac{V_d}{\hat{V}_{tri}}\right)\hat{V}_c \sin\omega_1 t$$

$$\bar{v}_{Bn}(t) = \left(0.5\frac{V_d}{\hat{V}_{tri}}\right)\hat{V}_c \sin(\omega_1 t - 120^o)$$

$$\bar{v}_{Cn}(t) = \left(0.5\frac{V_d}{\hat{V}_{tri}}\right)\hat{V}_c \sin(\omega_1 t - 240^o)$$

$$\hat{V} = \left(\frac{\hat{V}_c}{\hat{V}_{tri}}\right)\frac{V_d}{2}$$

Figure 12-12 Duty-ratios and the average output voltages of the power-pole.

$$\overline{i}_A(t) = \hat{I}\sin(\omega_1 t - \phi_1)$$
$$\overline{i}_B(t) = \hat{I}\sin(\omega_1 t - \phi_1 - 120^o)$$
$$\overline{i}_C(t) = \hat{I}\sin(\omega_1 t - \phi_1 - 240^o)$$

$$\overline{i}_{dA}(t) = d_A(t)\,\overline{i}_A(t) = 0.5\,\overline{i}_A(t) + 0.5\frac{v_{c,A}(t)}{\hat{V}_{tri}}\,\overline{i}_A(t)$$
$$\overline{i}_{dB}(t) = d_B(t)\,\overline{i}_B(t) = 0.5\,\overline{i}_B(t) + 0.5\frac{v_{c,B}(t)}{\hat{V}_{tri}}\,\overline{i}_B(t)$$
$$\overline{i}_{dC}(t) = d_C(t)\,\overline{i}_C(t) = 0.5\,\overline{i}_C(t) + 0.5\frac{v_{c,C}(t)}{\hat{V}_{tri}}\,\overline{i}_C(t)$$

$$\overline{i}_d(t) = \overline{i}_{dA}(t) + \overline{i}_{dB}(t) + \overline{i}_{dC}(t)$$

$$\overline{i}_A(t) + \overline{i}_B(t) + \overline{i}_C(t) = 0$$

$$\overline{i}_d(t) = \frac{0.5}{\hat{V}_{tri}}\left[v_{c,A}(t)\overline{i}_A(t) + v_{c,B}(t)\overline{i}_B(t) + v_{c,C}(t)\overline{i}_C(t)\right]$$

$$\overline{i}_d(t) = 0.5\frac{\hat{V}_c}{\hat{V}_{tri}}\hat{I}\begin{bmatrix}\sin(\omega_1 t)\sin(\omega_1 t - \phi_1) + \sin(\omega_1 t - 120^o)\sin(\omega_1 t - \phi_1 - 120^o) \\ +\sin(\omega_1 t - 240^o)\sin(\omega_1 t - \phi_1 - 240^o)\end{bmatrix}$$

$$\overline{i}_d(t) = I_d = \frac{3}{4}\frac{\hat{V}_c}{\hat{V}_{tri}}\hat{I}\cos\phi_1$$

$$V_d\,\overline{i}_d(t) = \frac{3}{2}\hat{V}\,\hat{I}\cos\phi_1$$

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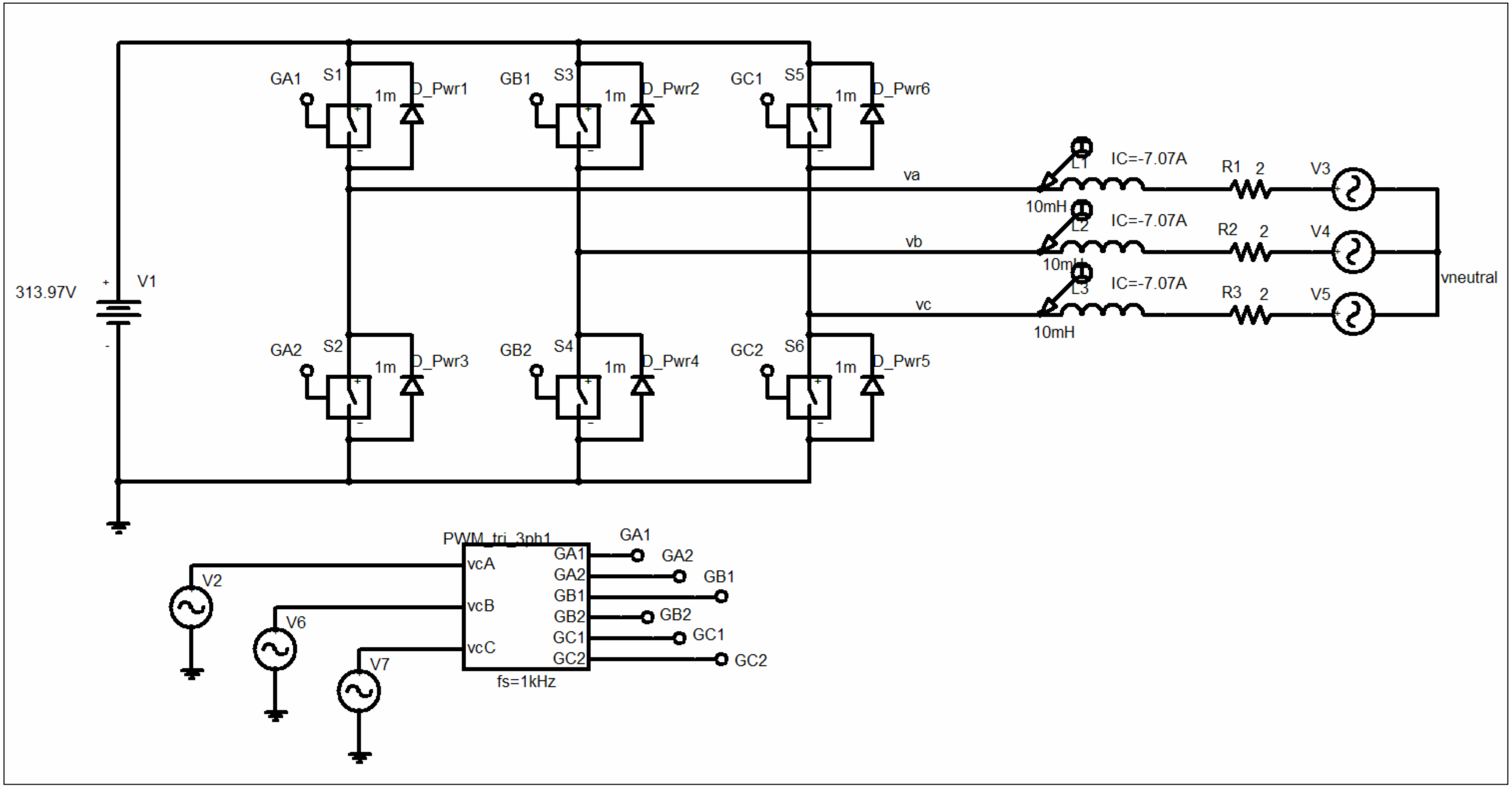

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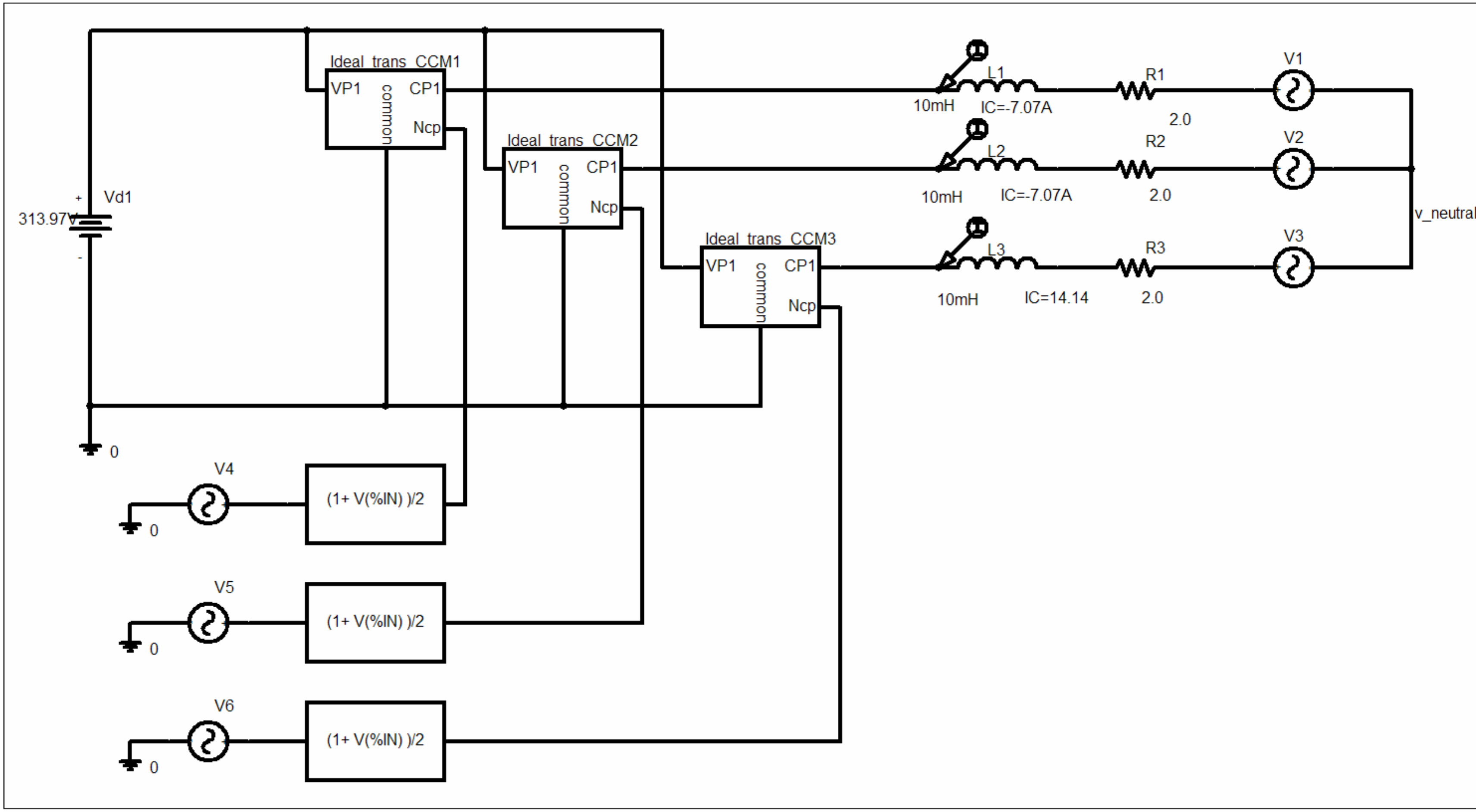
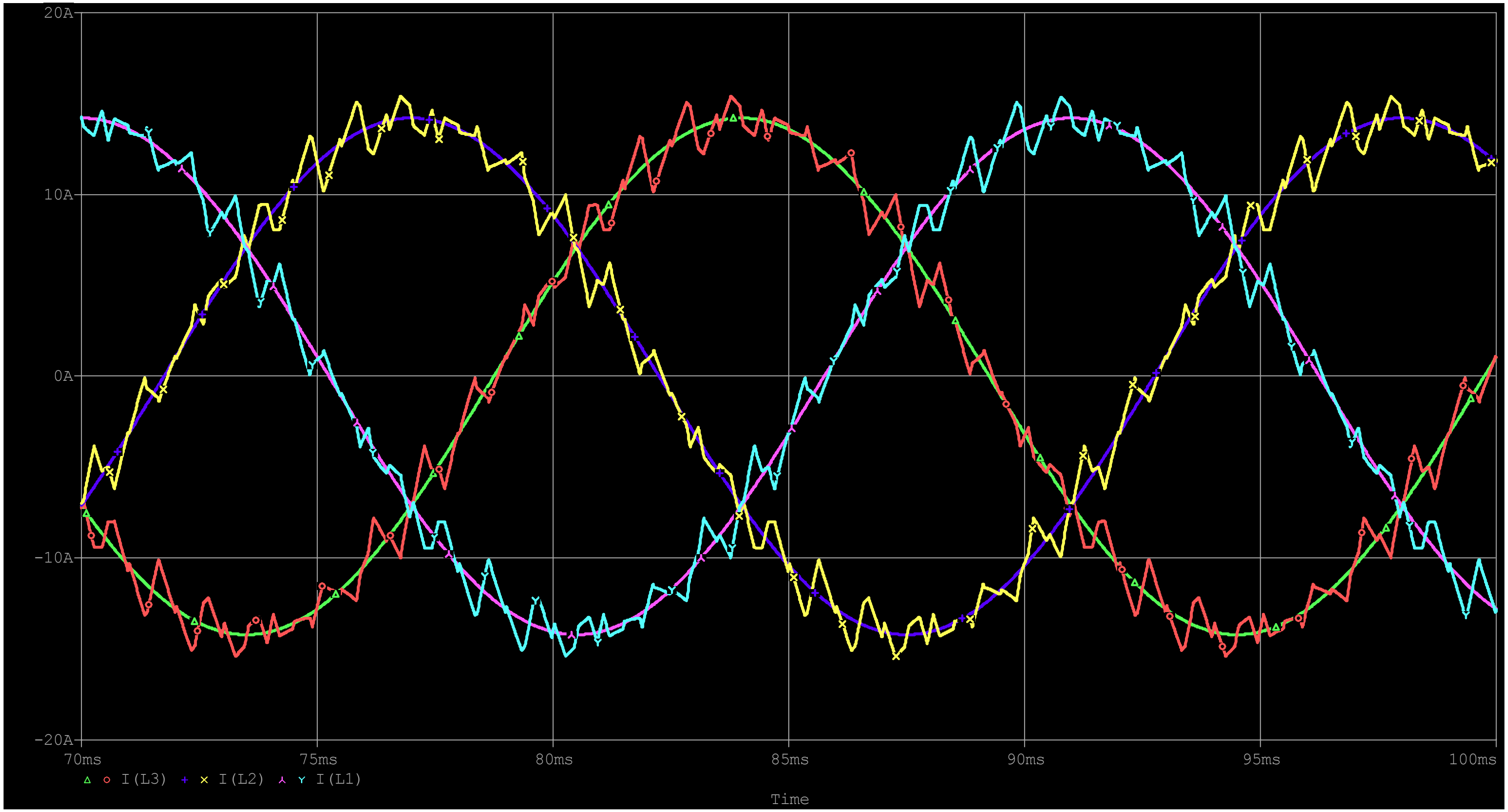
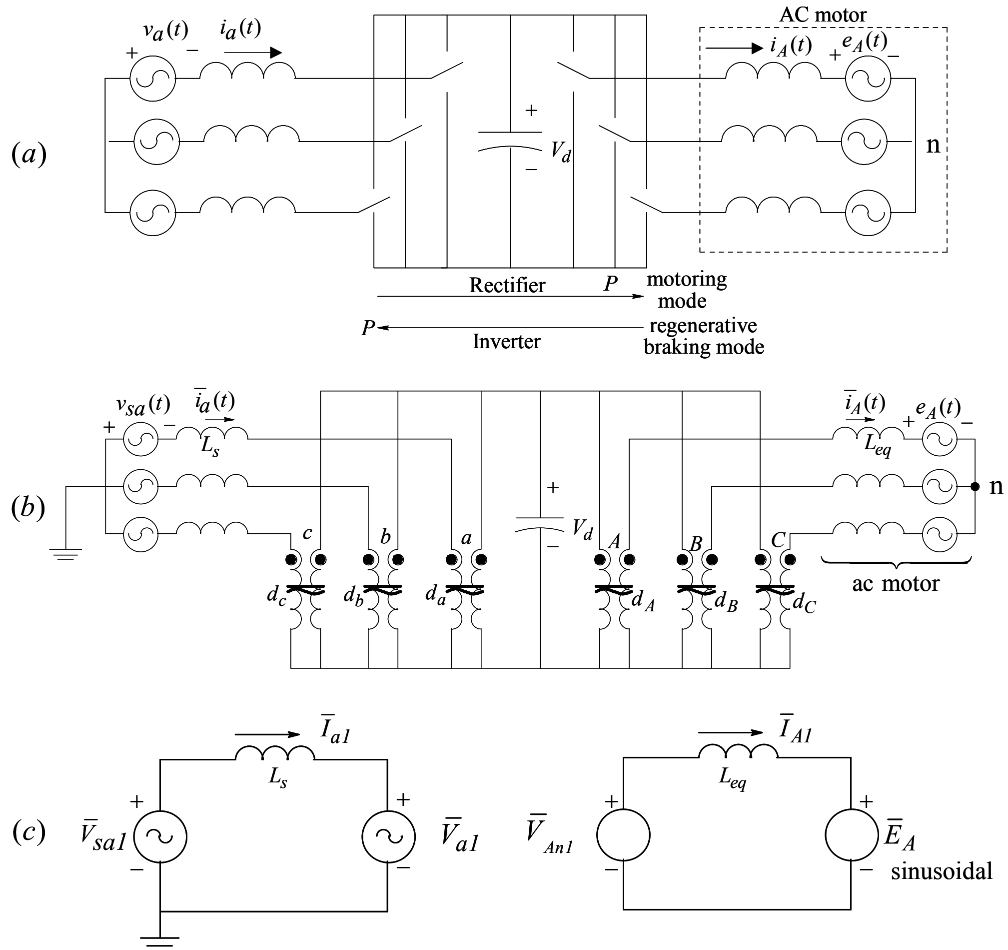


Simulation Results



VOLTAGE-LINK STRUCTURE WITH BI-DIRECTIONAL POWER FLOW



$$\overline{I}_{a1} = \frac{\overline{V}_{sa} - \overline{V}_{a1}}{j\omega_s L_s}$$

$$\overline{I}_{A1} = \frac{\overline{V}_{An1} - \overline{E}_A}{j\omega_1 L_{eq}}$$

Figure 12-13 Voltage-link structure for bi-directional power flow.

UNINTERRUPTIBLE POWER SUPPLIES (UPS)

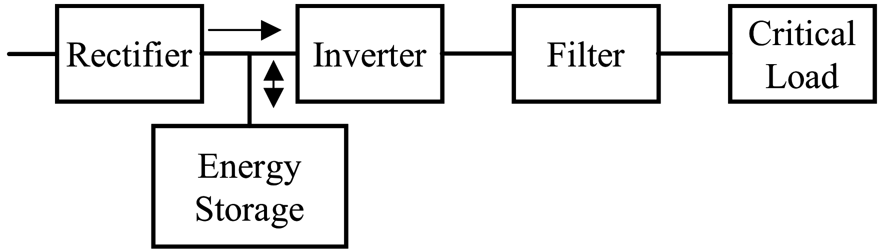


Figure 12-14 Bock diagram of UPS.

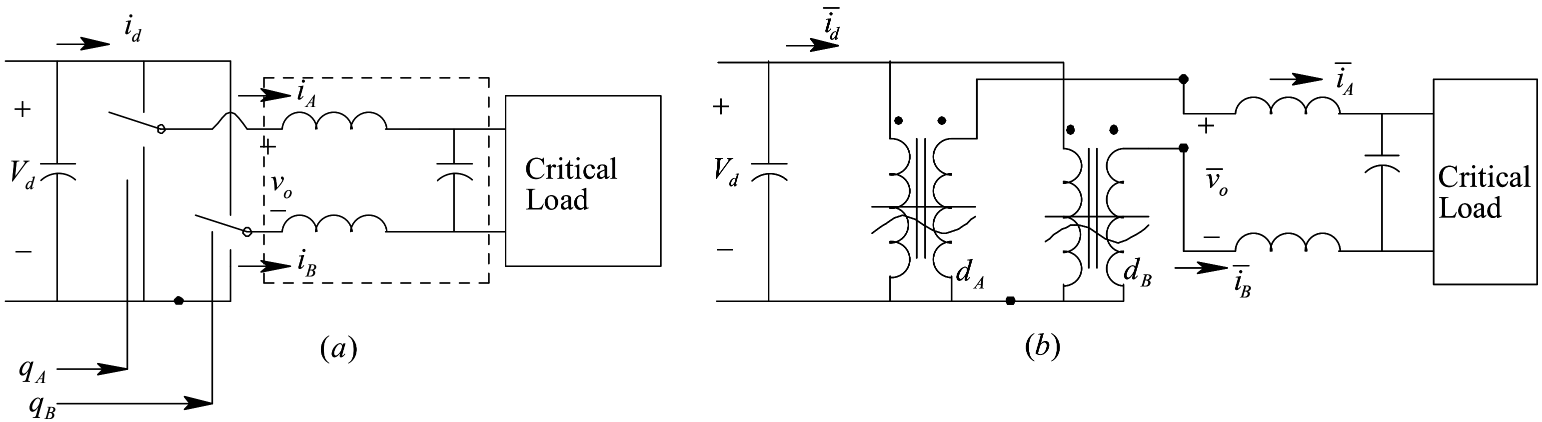


Figure 12-15 Single-phase UPS.

$$v_c(t) = \hat{V}_c \sin \omega_1 t \qquad v_{c,B}(t) = \hat{V}_c \sin\left(\omega_1 t - 180^0\right) = -\hat{V}_c \sin \omega_1 t$$

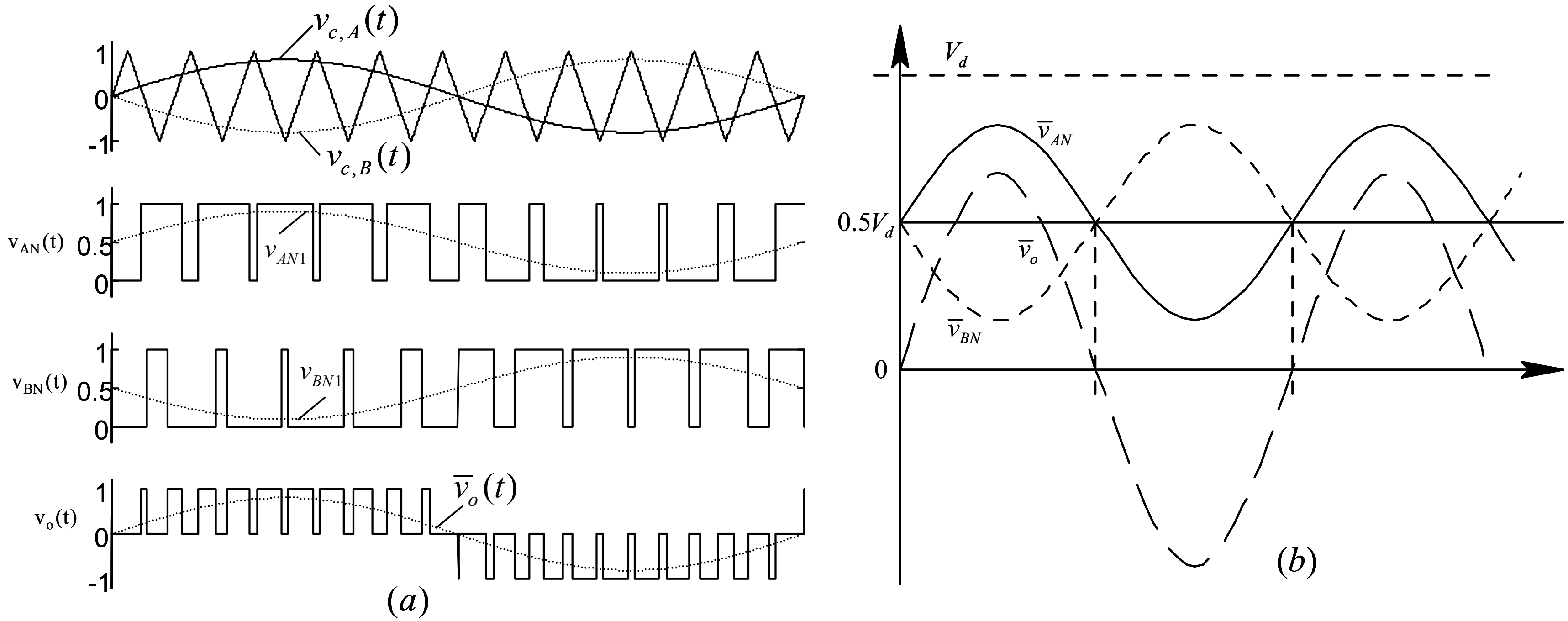


Figure 12-16 UPS waveforms.

$$d_A(t) = 0.5 + 0.5\frac{\hat{V}_c}{\hat{V}_{tri}}\sin\omega_1 t$$

$$d_B(t) = 0.5 - 0.5\frac{\hat{V}_c}{\hat{V}_{tri}}\sin\omega_1 t$$

$$\overline{v}_{AN}(t) = 0.5V_d + 0.5\frac{\hat{V}_c}{\hat{V}_{tri}}V_d\sin\omega_1 t$$

$$\overline{v}_{BN}(t) = 0.5V_d - 0.5\frac{\hat{V}_c}{\hat{V}_{tri}}V_d\sin\omega_1 t$$

$$\hat{V}_o = \frac{\hat{V}_c}{\hat{V}_{tri}}V_d$$

$$\overline{v}_o(t) = \overline{v}_{AN}(t) - \overline{v}_{BN}(t) = \frac{\hat{V}_c}{\hat{V}_{tri}}V_d\sin\omega_1 t$$

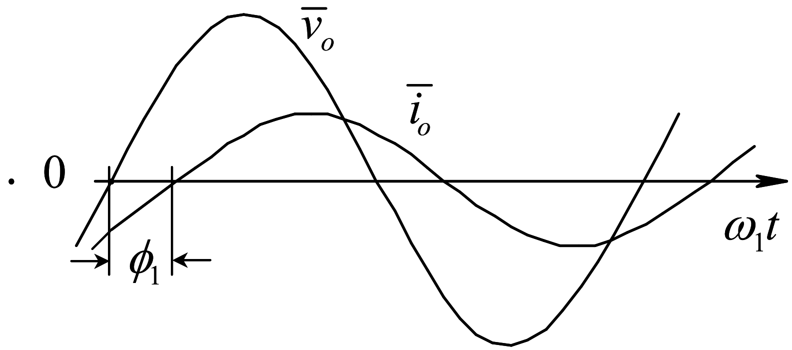


Figure 12-17 Output voltage and current.

$$\overline{i_o}(t) = \hat{I}_o \sin\left(\omega_1 t - \phi_1\right)$$

$$\overline{i_d} = \frac{\overline{v_o}\,\overline{i_o}}{V_d} = \frac{\hat{V}_c}{\hat{V}_{tri}} \hat{I}_o \sin\omega_1 t \times \sin\left(\omega_1 t - \phi_1\right)$$

$$= \underbrace{0.5\frac{\hat{V}_c}{\hat{V}_{tri}} \hat{I}_o}_{I_d} - \underbrace{0.5\frac{\hat{V}_c}{\hat{V}_{tri}} \hat{I}_o \sin\left(2\omega_1 t - \phi_1\right)}_{i_{d2}(t)}$$