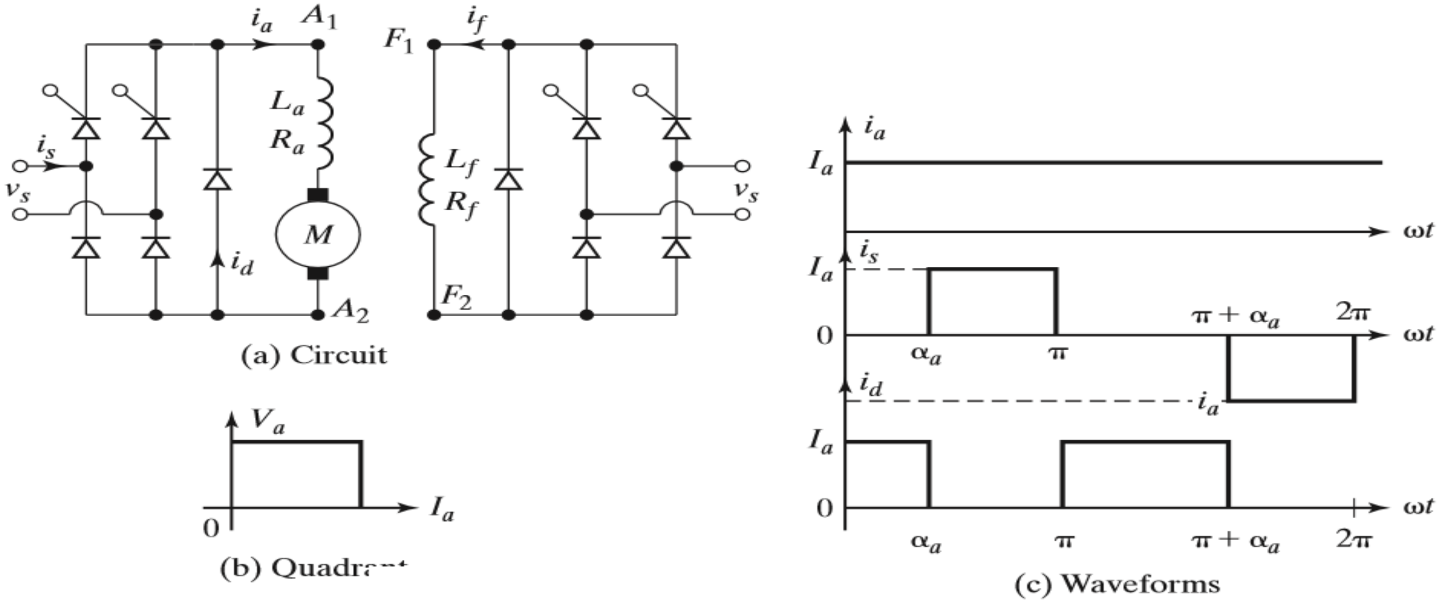
كلية الهندسة	الكلية
الكهرباء	القسم
Electrical Drives	المادة باللغة الانجليزية
المسوقات	المادة باللغة العربية
الرابعة	المرحلة الدراسية
م.م. زياد طارق محمد	اسم التدريسي
Single phase semiconverter Drives	عنوان المحاضرة باللغة الانجليزية
محركات أشباه الموصلات أحادية الطور	عنوان المحاضرة باللغة العربية
4	رقم المحاضرة
1) Mohummed Rashid" Power electronics circuits, Devices application" 4th edition, 2014 and 2) Gopal K. Dubey " power semiconductor controlled Drives" 1st edition, 1989	المصادر والمراجع

AC –DC single phase drive

1 -single-phase semiconverter Drives

A single-phase semiconverter feeds the armature circuit, as shown in Figure below .It is a one-quadrant drive, and is limited to applications up to 15 kW. The converter in thefield circuit can be a semiconverter.

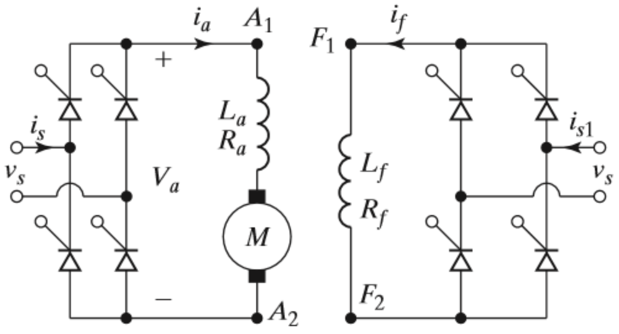


Single-phase semiconverter drive.

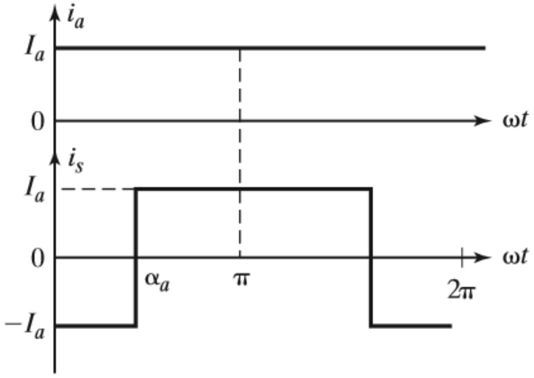
$$V_a = \frac{V_m}{\pi} (1 + \cos \alpha_a) \qquad \text{for } 0 \leq \alpha_a \leq \pi$$

2- single-phase full-Converter Drives

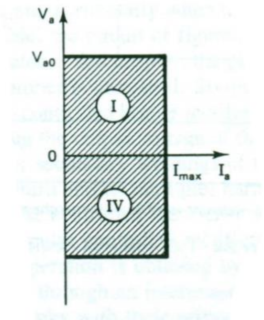
The armature voltage is varied by a single-phase full-wave converter, as shown in Figure below It is a two-quadrant drive, and is limited to applications up to 15kW. The armature converter gives +Va or -Va, and allows operation in the first and fourth quadrants.



(a) Circuit



(c) Waveforms



(c) Quadrants of operation

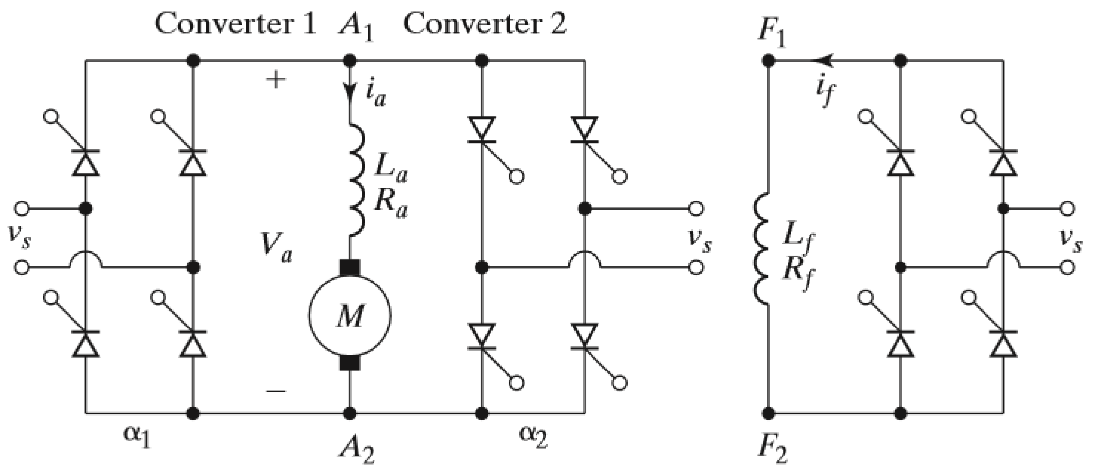
$$V_a = \frac{2V_m}{\pi} \cos \alpha_a \qquad \text{for } 0 \le \alpha_a \le \pi$$

$$V_f = \frac{2V_m}{\pi} \cos \alpha_f \qquad \text{for } 0 \le \alpha_f \le \pi$$

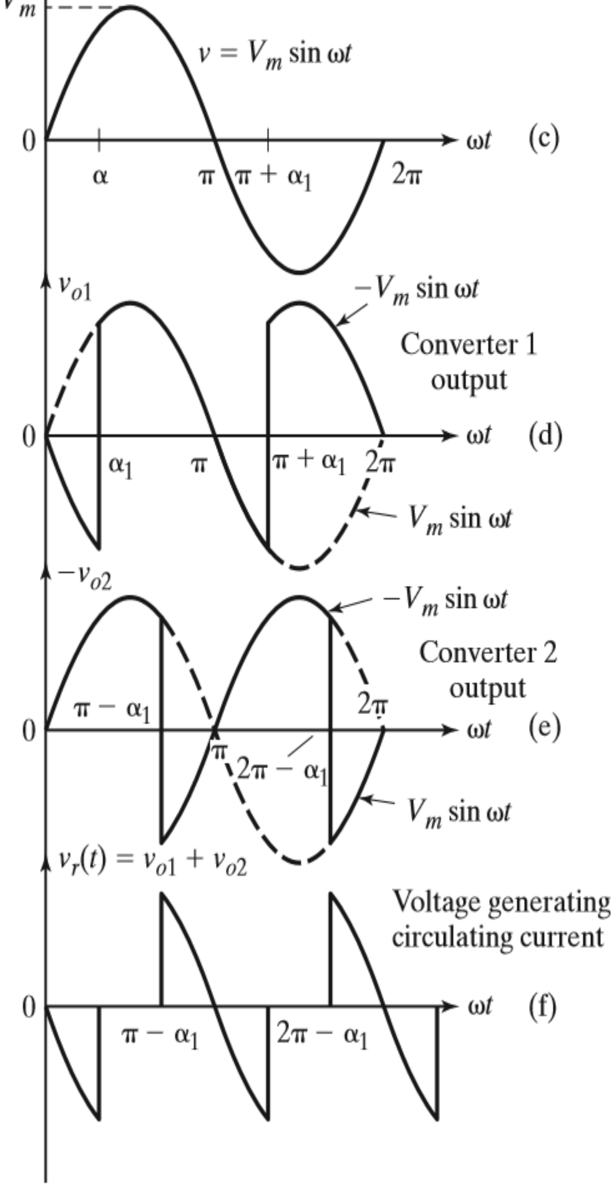
Single-phase full-converter drive.

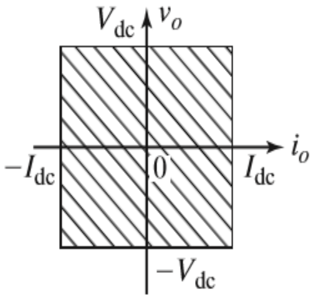
3-single-phase Dual-Converter Drives

Two single-phase full-wave converters are connected, as shown in Figure below. Either converter1 operates to supply a positive armature voltage, Va, or converter 2 operates to supply a negative armature voltage, -Va. Converter1 provides operation in the first and fourth quadrants, and converter2, in the second and third quadrants. It is a four-quadrant drive and permits four modes of operation: forward powering, forward braking (regeneration), reverse powering, and reverse braking (regeneration). It is limited to applications up to 15 kW. The field converter could be a full-wave, a semi-, or a dual converter.



Single-phase dual-converter drive.





(b)

$$V_{dc1} = \frac{2V_m}{\pi} \cos \alpha_1$$

and

$$V_{dc2} = \frac{2V_m}{\pi} \cos \alpha_2$$

Because one converter is rectifying and the other one is inverting,

$$V_{dc1} = -V_{dc2} \quad \text{or} \quad \cos \alpha_2 = -\cos \alpha_1 = \cos(\pi - \alpha_1)$$

Therefore,

$$\alpha_2 = \pi - \alpha_1$$

Note. Read example 10.3 to know about circulating current

AC –DC three phase drive

The armature circuit is connected to the output of a three-phase controlled rectifier or a forced-commutated three-phase ac–dc converter. Three-phase drives are used for high-power applications up to megawatt power levels. The ripple frequency of the armature voltage is higher than that of single-phase drives and it requires less inductance in the armature circuit to reduce the armature ripple current. The armature current is mostly continuous, and therefore the motor performance is better compared with that of single-phase drives. Similar to the single-phase drives, three-phase drives may also be subdivided into:

1. Three-phase half-wave-converter drives .
2. Three-phase semiconverter drives .
3. Three-phase full-converter drives.
4. Three-phase dual-converter drives

1. Three-phase half-wave-converter drives

A three-phase half-wave converter-fed dc motor drive operates in one quadrant and could be used in applications up to a 40-kW power level. The field converter could be a single-phase or three-phase semiconverter. This drive is not normally used in industrial applications because the ac supply contains dc components.

$$V_a = \frac{3\sqrt{3}V_m}{2\pi}\cos\alpha_a \qquad \text{for } 0 \le \alpha_a \le \pi$$

$$V_f = \frac{3\sqrt{3}V_m}{2\pi}(1 + \cos\alpha_f)$$

2- Three-phase semiconverter Drives

A three-phase semiconverter-fed drive is a one-quadrant drive without field reversal, and is limited to applications up to 115 kW. The field converter should also be a single-phase or a three-phase semiconverter.

With a three-phase semiconverter in the armature circuit.

$$V_a = \frac{3\sqrt{3}V_m}{2\pi}(1 + \cos \alpha_a) \qquad \text{for } 0 \leq \alpha_a \leq \pi$$

With a three-phase semiconverter in the field circuit,

$$V_f = \frac{3\sqrt{3}V_m}{2\pi}(1 + \cos \alpha_f) \qquad \text{for } 0 \leq \alpha_f \leq \pi$$

3-Three-phase full-Converter Drives

A three-phase full-wave-converter drive is a two-quadrant drive without any field reversal, and is limited to applications up to 1500 kW. During regeneration for reversing direction of power flow, the back emf of the motor is reversed by reversing the field excitation. The converterin the field circuit should be a single- or three-phase full converter. With a three-phase full-wave converter in the armature circuit.

$$V_a = \frac{3\sqrt{3}V_m}{\pi}\cos \alpha_a \qquad \text{for } 0 \leq \alpha_a \leq \pi$$

$$V_f = \frac{3\sqrt{3}V_m}{\pi}\cos \alpha_f \qquad \text{for } 0 \leq \alpha_f \leq \pi$$

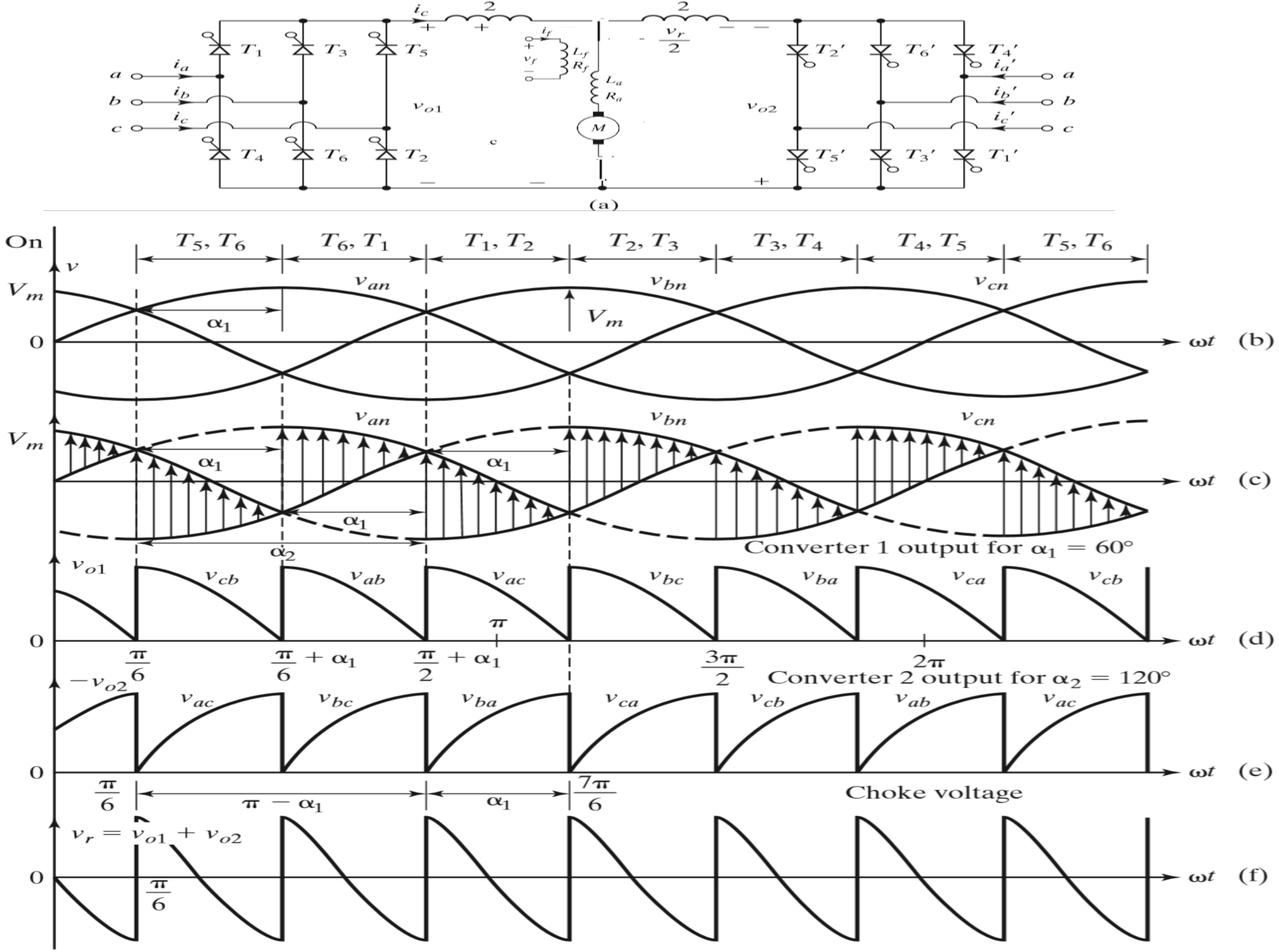
4-Three-phase Dual-Converter Drives

Two three-phase full-wave converters are connected in antiparallel. Either converter 1operates to supply a positive armature voltage, Va, or converter 2 operates to supply a negative armature voltage,-Va. It is a four-quadrant drive and is limited to applications up to1500 kW. Similar to single-phase drives,the field converter can be a full-wave converter or a semiconverter. If converter 1 operates with a delay angle of α_{a1},

$$V_a = \frac{3\sqrt{3}V_m}{\pi} \cos \alpha_{a1} \qquad \text{for } 0 \leq \alpha_{a1} \leq \pi$$

$$V_a = \frac{3\sqrt{3}V_m}{\pi} \cos \alpha_{a2} \qquad \text{for } 0 \leq \alpha_{a2} \leq \pi$$

$$V_f = \frac{3\sqrt{3}V_m}{\pi} \cos \alpha_f \qquad \text{for } 0 \leq \alpha_f \leq \pi$$



Three-phase dual converter. (a) Circuit, (b) Triggering sequences, (c) Input supply voltages, (d) Output voltage for converter 1, (e) Output voltage for converter 2, and (f) Circulating inductor voltage.

Example 15.2 Finding the Performance Parameters of a Single-Phase Semiconverter Drive

The speed of a separately excited motor is controlled by a single-phase semiconverter in Figure 15.12a. The field current, which is also controlled by a semiconverter, is set to the maximum possible value. The ac supply voltage to the armature and field converters is one phase, 208 V, 60 Hz. The armature resistance is $R_a = 0.25\ \Omega$, the field resistance is $R_f = 147\ \Omega$, and the motor voltage constant is $K_v = 0.7032$ V/A rad/s. The load torque is $T_L = 45$ N·m at 1000 rpm. The viscous friction and no-load losses are negligible. The inductances of the armature and field circuits are sufficient enough to make the armature and field currents continuous and ripple free. Determine (a) the field current I_f; (b) the delay angle of the converter in the armature circuit α_a; and (c) the input power factor (PF) of the armature circuit converter.

Solution

$V_s = 208$ V, $V_m = \sqrt{2} \times 208 = 294.16$ V, $R_a = 0.25\ \Omega$, $R_f = 147\ \Omega$, $T_d = T_L = 45$ N·m, $K_v =$ 0.7032 V/A rad/s, and $\omega = 1000\ \pi/30 = 104.72$ rad/s.

a. From Eq. (15.16), the maximum field voltage (and current) is obtained for a delay angle of $\alpha_f = 0$ and

$$V_f = \frac{2V_m}{\pi} = \frac{2 \times 294.16}{\pi} = 187.27 \text{ V}$$

The field current is

$$I_f = \frac{V_f}{R_f} = \frac{187.27}{147} = 1.274 \text{ A}$$

$$I_a = \frac{T_d}{K_v I_f} = \frac{45}{0.7032 \times 1.274} = 50.23 \text{ A}$$

From Eq. (15.2),

$$E_g = K_v \omega I_f = 0.7032 \times 104.72 \times 1.274 = 93.82 \text{ V}$$

From Eq. (15.3), the armature voltage is

$$V_a = 93.82 + I_a R_a = 93.82 + 50.23 \times 0.25 = 93.82 + 12.56 = 106.38 \text{ V}$$

From Eq. (15.15), $V_a = 106.38 = (294.16/\pi) \times (1 + \cos \alpha_a)$ and this gives the delay angle as $\alpha_a = 82.2°$.

c. If the armature current is constant and ripple free, the output power is $P_o = V_a I_a = 106.38 \times 50.23 = 5343.5$ W. If the losses in the armature converter are neglected, the power from the supply is $P_a = P_o = 5343.5$ W. The rms input current of the armature converter, as shown in Figure 15.12, is

$$I_{sa} = \left(\frac{2}{2\pi} \int_{\alpha_a}^{\pi} I_a^2 \, d\theta \right)^{1/2} = I_a \left(\frac{\pi - \alpha_a}{\pi} \right)^{1/2}$$

$$= 50.23 \left(\frac{180 - 82.2}{180} \right)^{1/2} = 37.03 \text{ A}$$

and the input volt–ampere (VA) rating is $VI = V_s I_{sa} = 208 \times 37.03 = 7702.24$. Assuming negligible harmonics, the input PF is approximately

$$\text{PF} = \frac{P_o}{VI} = \frac{5343.5}{7702.24} = 0.694 \text{ (lagging)}$$

From Eq. (10.61),

$$\text{PF} = \frac{\sqrt{2}(1 + \cos 82.2°)}{[\pi(\pi - 82.2°)]^{1/2}} = 0.694 \text{ (lagging)}$$

Example 15.3 Finding the Performance Parameters of a Single-Phase Full Converter Drive

The speed of a separately excited dc motor is controlled by a single-phase full-wave converter in Figure 15.13a. The field circuit is also controlled by a full converter and the field current is set to the maximum possible value. The ac supply voltage to the armature and field converters is one phase, 440 V, 60 Hz. The armature resistance is $R_a = 0.25\ \Omega$, the field circuit resistance is $R_f = 175\ \Omega$, and the motor voltage constant is $K_v = 1.4$ V/A rad/s. The armature current corresponding to the load demand is $I_a = 45$ A. The viscous friction and no-load losses are negligible. The inductances of the armature and field circuits are sufficient to make the armature and field currents continuous and ripple free. If the delay angle of the armature converter is $\alpha_a = 60°$ and the armature current is $I_a = 45$ A, determine (a) the torque developed by the motor T_d, (b) the speed ω, and (c) the input PF of the drive.

Solution

$V_s = 440$ V, $V_m = \sqrt{2} \times 440 = 622.25$ V, $R_a = 0.25\ \Omega$, $R_f = 175\ \Omega$, $\alpha_a = 60°$, and $K_v = 1.4$ V/A rad/s.

a. From Eq. (15.18), the maximum field voltage (and current) would be obtained for a delay angle of $\alpha_f = 0$ and

$$V_f = \frac{2V_m}{\pi} = \frac{2 \times 622.25}{\pi} = 396.14\ \text{V}$$

The field current is

$$I_f = \frac{V_f}{R_f} = \frac{396.14}{175} = 2.26\ \text{A}$$

From Eq. (15.4), the developed torque is

$$T_d = T_L = K_v I_f I_a = 1.4 \times 2.26 \times 45 = 142.4\ \text{N}\cdot\text{m}$$

$$V_a = \frac{2V_m}{\pi}\cos 60° = \frac{2 \times 622.25}{\pi}\cos 60° = 198.07 \text{ V}$$

$$E_g = V_a - I_a R_a = 198.07 - 45 \times 0.25 = 186.82 \text{ V}$$

$$\omega = \frac{E_g}{K_v I_f} = \frac{186.82}{1.4 \times 2.26} = 59.05 \text{ rad/s or } 564 \text{ rpm}$$

c. Assuming lossless converters, the total input power from the supply is

$$P_i = V_a I_a + V_f I_f = 198.07 \times 45 + 396.14 \times 2.26 = 9808.4 \text{ W}$$

The input current of the armature converter for a highly inductive load is shown in Figure 15.13b and its rms value is $I_{sa} = I_a = 45$ A. The rms value of the input current of field converter is $I_{sf} = I_f = 2.26$ A. The effective rms supply current can be found from

$$I_s = (I_{sa}^2 + I_{sf}^2)^{1/2}$$

$$= (45^2 + 2.26^2)^{1/2} = 45.06 \text{ A}$$

and the input VA rating, $VI = V_s I_s = 440 \times 45.06 = 19{,}826.4$. Neglecting the ripples, the input power factor is approximately

$$PF = \frac{P_i}{VI} = \frac{9808.4}{19{,}826.4} = 0.495 \text{ (lagging)}$$

or

$$PF = \left(\frac{2\sqrt{2}}{\pi}\right)\cos \alpha_a = \left(\frac{2\sqrt{2}}{\pi}\right)\cos 60° = 0.45 \text{ (lagging)}$$

Example 15.4 Finding the Delay Angle and Feedback Power in Regenerative Braking

If the polarity of the motor back emf in Example 15.3 is reversed by reversing the polarity of the field current, determine (a) the delay angle of the armature circuit converter, α_a, to maintain the armature current constant at the same value of $I_a = 45$ A; and (b) the power fed back to the supply due to regenerative braking of the motor.

Solution

a. From part (b) of Example 15.3, the back emf at the time of polarity reversal is $E_g = 186.82$ V and after polarity reversal $E_g = -186.82$ V. From Eq. (15.3),

$$V_a = E_g + I_a R_a = -186.82 + 45 \times 0.25 = -175.57 \text{ V}$$

From Eq. (15.17),

$$V_a = \frac{2V_m}{\pi} \cos \alpha_a = \frac{2 \times 622.25}{\pi} \cos \alpha_a = -175.57 \text{ V}$$

and this yields the delay angle of the armature converter as $\alpha_a = 116.31°$.

b. The power fed back to the supply is $P_a = V_a I_a = 175.57 \times 45 = 7900.7$ W.

Dc–dc converter (or simply chopper) drives are widely used in traction applications all over the world. A dc–dc converter is connected between a fixed-voltage dc source and a dc motor to vary the armature voltage. In addition to armature voltage control, a dc–dc converter can provide regenerative braking of the motors and can return energy back to the supply. This energy-saving feature is particularly attractive to transportation systems with frequent stops such as mass rapid transit (MRT). Dc–dc converter drives are also used in battery electric vehicles (BEVs). A dc motor can be operated in one of the four quadrants by controlling the armature or field voltages (or currents). It is often required to reverse the armature or field terminals to operate the motor in the desired quadrant.

If the supply is nonreceptive during the regenerative braking, the line voltage would increase and regenerative braking may not be possible. In this case, an alternative form of braking is necessary, such as rheostatic braking.

Choppers are used for the control of de motors because of a number of advantages such as high efficiency, flexibility in control, light weight, small size, quick response, and regeneration down to very low speeds. Chopper controlled dc drives have applications in servos and traction. In traction, they have been used in underground transit, in battery operated vehicles such as forklift trucks, trolleys, and so on.

For a dc motor control in open-loop and closed-loop configurations, the chopper offers a number of advantages over controlled rectifiers. Because of the higher frequency of the output voltage ripple, the ripple in the motor armature current is less and the region of discontinuous conduction in the speed-torque plane is smaller

The possible control modes of a dc–dc converter drive are:

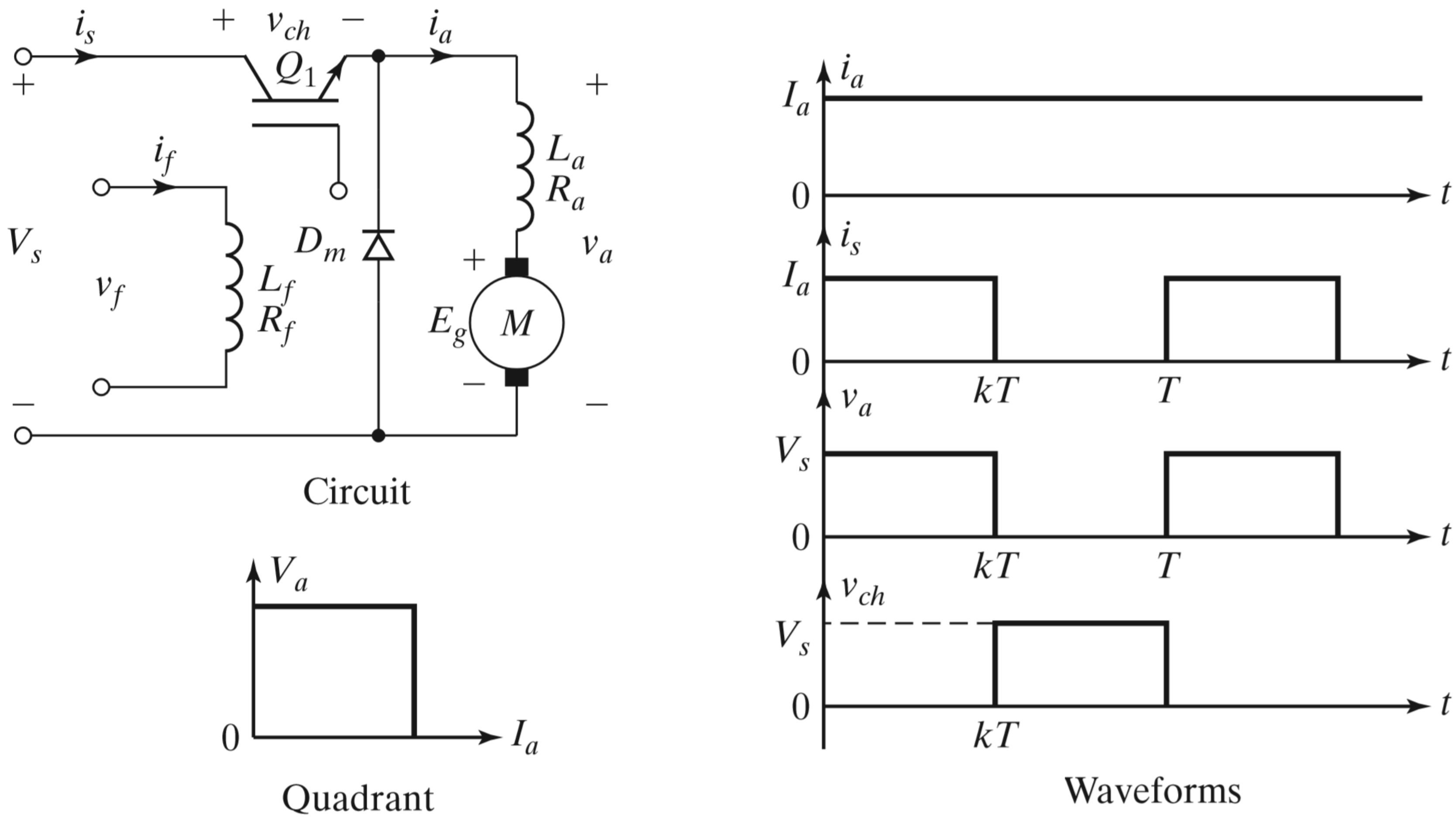
1. Power (or acceleration) control
2. Regenerative brake control
3. Rheostatic brake control
4. Combined regenerative and rheostatic brake control

1-principle of power Control

The dc–dc converter is used to control the armature voltage of a dc motor. The circuit arrangement of a converter-fed dc separately excited motor is shown in Fig.1. The dc–dc converter switch could be a transistors or an IGBT.This isa one-quadrantdrive, assuming a highly inductive load. The average armaturevoltage is $V_a = kVs$

Where k is the duty cycle of the dc–dc converter. The power supplied to the motor is $Po = V_a I_a = kVs I_a$

Where I_a is the average armature current of the motor and it is ripple free. Assuming a lossless dc–dc converter, the input power is $P_i = P_0 = kV_s I_s$. The average value of the input current is $I_s = kI_a$



Converter-fed dc drive in power control.

The equivalent input resistance of the dc–dc converter drive seen by the source is

$$R_{eq} = \frac{V_s}{I_s} = \frac{V_s}{I_a}\frac{1}{k}$$

By varying the duty cycle k, the power flow to the motor (and speed) can be controlled. For a finite armature circuit inductance. be approximated to $\Delta I_{max} = \frac{V_s}{4L_m f}$

Where R_m and L_m are the total armature circuit resistance and inductance, respectively. For a separately excited motor, $R_m = R_a$ + any series resistance, and $L_m = L_a$ + any series inductance. For a series motor, $R_m = R_a + R_f$ + any series resistance, and $L_m = L_a + L_f$ + any series inductance.

Example .1 .A 250-V separately excited motor de has an armature resistance of 2.5 ohm. When driving a load at 600 rpm with constant torque, the armature takes 20 A. This motor is controlled by a chopper circuit with a frequency of 400 Hz and an input voltage of 250 V.

1. What should be the value of the duty ratio if one desires to reduce the speed from 600 to 400 rpm, with the load torque maintained constant?

Solution: With an input voltage of 250 V and at a constant torque, the motor will run at 600 rpm when k= l.

1. At 600 rpm $E_g = V_a - I_a R_a = 250 - 20 \times 2.5 = 200$ V

At 400 rpm, the back emf $E_{g2} = 200 \times (400/600) = 133$ V

The average chopper output voltage KVa = Eg + I.Ra = 133+ 20 x 2.5 = 183 V. Now K= 183/250 = 0.73.

Example 2 Finding the Performance Parameters of a Dc–dc Converter Drive

A dc separately excited motor is powered by a dc–dc converter from a 600-V dc source. The armature resistance is $R_a = 0.05\ \Omega$. The back emf constant of the motor is $K_v = 1.527$ V/A rad/s. The average armature current is $I_a = 250$ A. The field current is $I_f = 2.5$ A. The armature current is continuous and has negligible ripple. If the duty cycle of the dc–dc converter is 60%, determine (a) the input power from the source, (b) the equivalent input resistance of the dc–dc converter drive, (c) the motor speed, and (d) the developed torque.

Solution

$V_s = 600$ V, $I_a = 250$ A, and $k = 0.6$. The total armature circuit resistance is $R_m = R_a = 0.05\ \Omega$.

a. $$P_i = kV_sI_a = 0.6 \times 600 \times 250 = 90 \text{ kW}$$

b. $$R_{eq} = 600/(250 \times 0.6) = 4\ \Omega.$$

c. $V_a = 0.6 \times 600 = 360$ V. The back emf is

$$E_g = V_a - R_mI_m = 360 - 0.05 \times 250 = 347.5 \text{ V}$$

the motor speed is

$$\omega = \frac{347.5}{1.527 \times 2.5} = 91.03 \text{ rad/s} \quad \text{or} \quad 91.03 \times \frac{30}{\pi} = 869.3 \text{ rpm}$$

d. $$T_d = 1.527 \times 250 \times 2.5 = 954.38 \text{ N} \cdot \text{m}$$