Electrical Power Engineering

By

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Lecture (5)

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Complex Power

Example 2.2

In the above circuit $V = 1200\angle 0^\circ$ V, $Z_1 = 60 + j0\ \Omega$, $Z_2 = 6 + j12\ \Omega$ and $Z_3 = 30 - j30\ \Omega$. Find the power absorbed by each load and the total complex power.

$$I_1 = \frac{1200\angle 0^\circ}{60\angle 0} = 20 + j0\ \text{A}$$

$$I_2 = \frac{1200\angle 0^\circ}{6 + j12} = 40 - j80\ \text{A}$$

$$I_3 = \frac{1200\angle 0^\circ}{30 - j30} = 20 + j20\ \text{A}$$

$$S_1 = VI_1^* = 1200\angle 0^\circ(20 - j0) = 24,000\ \text{W} + j0\ \text{var}$$

$$S_2 = VI_2^* = 1200\angle 0^\circ(40 + j80) = 48,000\ \text{W} + j96,000\ \text{var}$$

$$S_3 = VI_3^* = 1200\angle 0^\circ(20 - j20) = 24,000\ \text{W} - j24,000\ \text{var}$$

Complex Power

The total load complex power adds up to

$$S = S_1 + S_2 + S_3 = 96,000 \text{ W} + j72,000 \text{ var}$$

Alternatively, the sum of complex power delivered to the load can be obtained by first finding the total current.

$$I = I_1 + I_2 + I_3 = (20 + j0) + (40 - j80) + (20 + j20)$$
$$= 80 - j60 = 100\angle -36.87^\circ \text{ A}$$

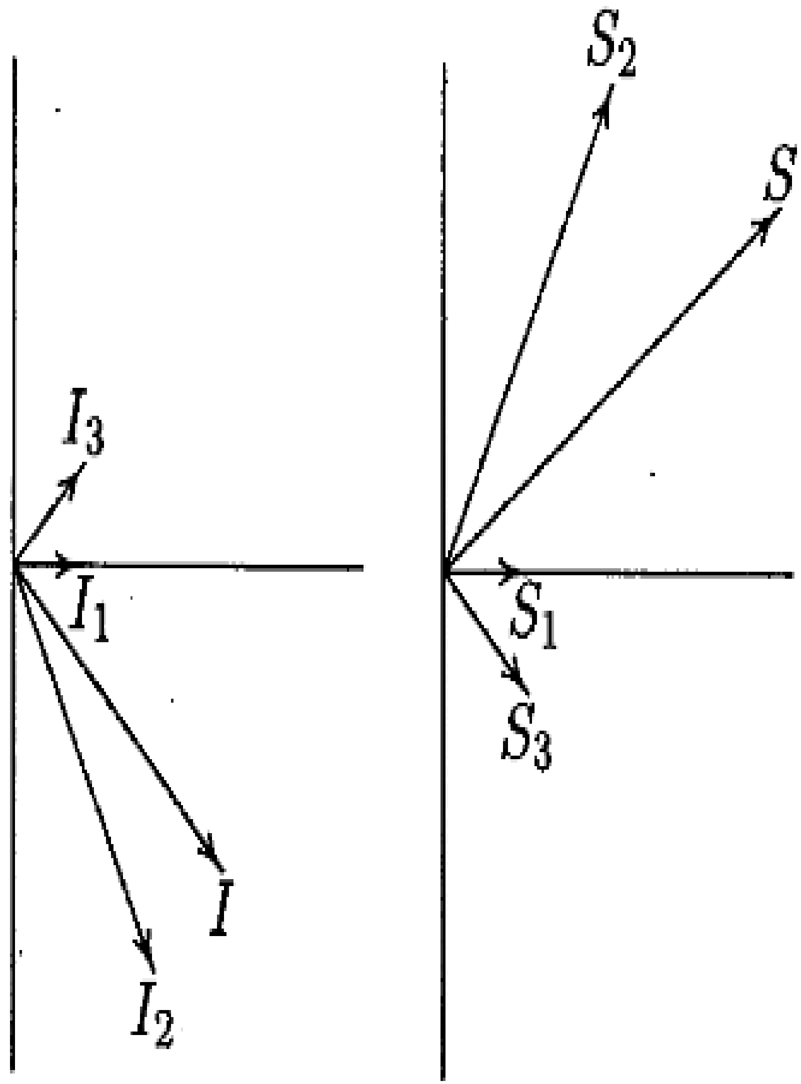
and

$$S = VI^* = (1200\angle 0^\circ)(100\angle 36.87^\circ) = 120,000\angle 36.87^\circ \text{ VA}$$
$$= 96,000 \text{ W} + j72,000 \text{ var}$$

A final insight is contained in Figure 2.6, which shows the current phasor diagram and the complex power vector representation.

Complex Power

FIGURE 2.6
Current phasor diagram and power plane diagram.



Complex Power

The complex powers may also be obtained directly from (2.14)

$$S_1 = \frac{|V|^2}{Z_1^*} = \frac{(1200)^2}{60} = 24,000 \text{ W} + j\,0$$

$$S_2 = \frac{|V|^2}{Z_2^*} = \frac{(1200)^2}{6 - j12} = 48,000 \text{ W} + j96,000 \text{ var}$$

$$S_3 = \frac{|V|^2}{Z_3^*} = \frac{(1200)^2}{30 + j30} = 24,000 \text{ W} - j24,000 \text{ var}$$

Power Factor Correction

$$P = |V||I|\cos\theta \qquad (2.7)$$

It can be seen from (2.7) that the apparent power will be larger than P if the power factor is less than 1. Thus the current I that must be supplied will be larger for $PF < 1$ than it would be for $PF = 1$, even though the average power P supplied is the same in either case. A larger current cannot be supplied without additional cost to the utility company. Thus, it is in the power company's (and its customer's) best interest that major loads on the system have power factors as close to 1 as possible. In order to maintain the power factor close to unity, power companies install banks of capacitors throughout the network as needed. They also impose an additional charge to industrial consumers who operate at low power factors. Since industrial loads are inductive and have low lagging power factors, it is beneficial to install capacitors to improve the power factor. This consideration is not important for residential and small commercial customers because their power factors are close to unity.

Power Factor Correction

Example 2.3

Two loads $Z_1 = 100 + j0\ \Omega$ and $Z_2 = 10 + j20\ \Omega$ are connected across a 200-V rms, 60-Hz source as shown in Figure 2.7.

(a) Find the total real and reactive power, the power factor at the source, and the total current.

(b) Find the capacitance of the capacitor connected across the loads to improve the overall power factor to 0.8 lagging.

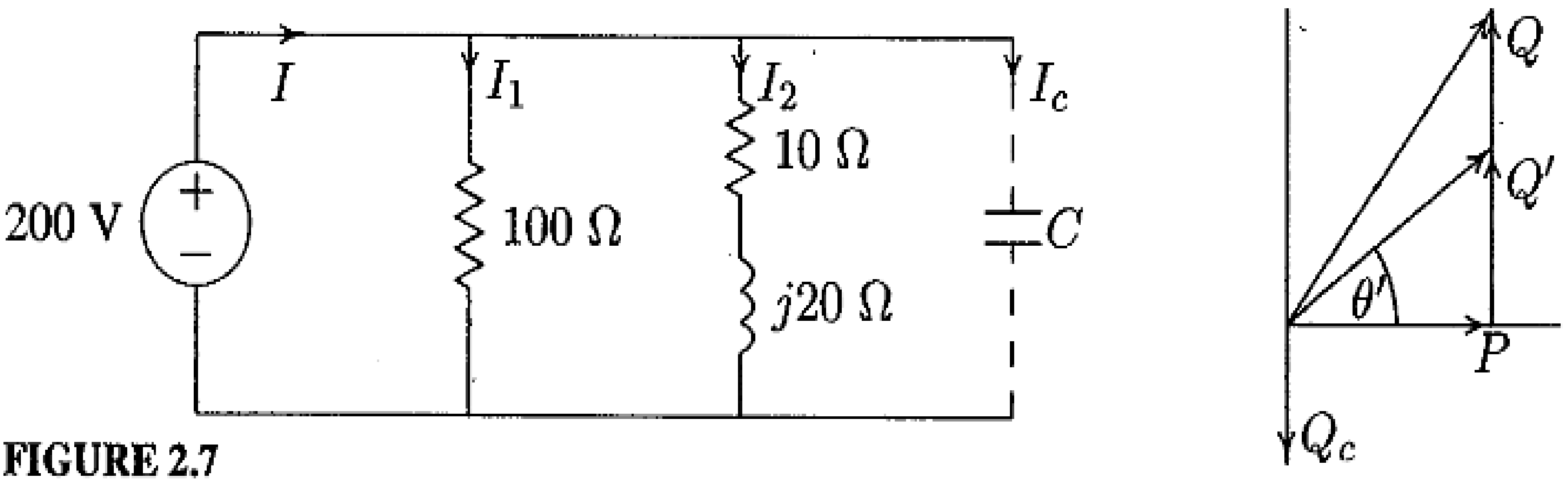


FIGURE 2.7
Circuit for Example 2.3 and the power triangle.

Power Factor Correction

(a)

$$I_1 = \frac{200\angle 0^\circ}{100} = 2\angle 0^\circ \text{ A}$$

$$I_2 = \frac{200\angle 0^\circ}{10 + j20} = 4 - j8 \text{ A}$$

$$S_1 = VI_1^* = 200\angle 0^\circ (2 - j0) = 400 \text{ W} + j0 \text{ var}$$

$$S_2 = VI_2^* = 200\angle 0^\circ (4 + j8) = 800 \text{ W} + j1600 \text{ var}$$

Total apparent power and current are

$$S = P + jQ = 1200 + j1600 = 2000\angle 53.13^\circ \text{ VA}$$

$$I = \frac{S^*}{V^*} = \frac{2000\angle -53.13^\circ}{200\angle 0^\circ} = 10\angle -53.13^\circ \text{ A}$$

Power factor at the source is

$$PF = \cos(53.13) = 0.6 \text{ lagging}$$

Power Factor Correction

(b) Total real power $P = 1200$ W at the new power factor 0.8 lagging. Therefore

$$\theta' = \cos^{-1}(0.8) = 36.87^\circ$$
$$Q' = P\tan\theta' = 1200\tan(36.87^\circ) = 900 \text{ var}$$
$$Q_c = 1600 - 900 = 700 \text{ var}$$
$$Z_c = \frac{|V|^2}{S_c^*} = \frac{(200)^2}{j700} = -j57.14\ \Omega$$
$$C = \frac{10^6}{2\pi(60)(57.14)} = 46.42\ \mu\text{F}$$

The total power and the new current are

$$S' = 1200 + j900 = 1500\angle 36.87^\circ$$
$$I' = \frac{S'^*}{V^*} = \frac{1500\angle -36.87^\circ}{200\angle 0^\circ} = 7.5\angle -36.87^\circ$$

Note the reduction in the supply current from 10 A to 7.5 A.

Power Factor Correction

Example 2.4

Three loads are connected in parallel across a 1400-V rms, 60-Hz single-phase supply as shown in Figure 2.8.

Load 1: Inductive load, 125 kVA at 0.28 power factor.

Load 2: Capacitive load, 10 kW and 40 kvar.

Load 3: Resistive load of 15 kW.

(a) Find the total kW, kvar, kVA, and the supply power factor.

(b) A capacitor of negligible resistance is connected in parallel with the above loads to improve the power factor to 0.8 lagging. Determine the kvar rating of this capacitor and the capacitance in μF.

Power Factor Correction

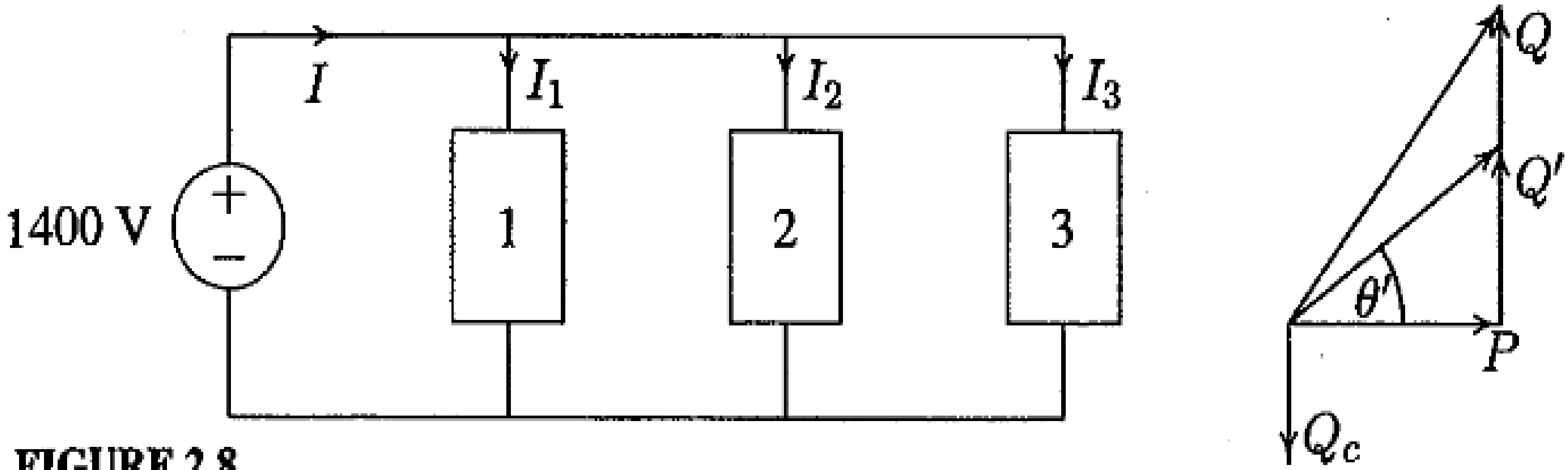


FIGURE 2.8
Circuit for Example 2.4.

Power Factor Correction

(a) An inductive load has a lagging power factor, the capacitive load has a leading power factor, and the resistive load has a unity power factor.

For Load 1: $\theta_1 = \cos^{-1}(0.28) = 73.74^\circ$ lagging

The load complex powers are

$$S_1 = 125\angle 73.74 \text{ kVA} = 35 \text{ kW} + j120 \text{ kvar}$$

$$S_2 = 10 \text{ kW} - j40 \text{ kvar}$$

$$S_3 = 15 \text{ kW} + j0 \text{ kvar}$$

The total apparent power is

$$S = P + jQ = S_1 + S_2 + S_3$$

$$= (35 + j120) + (10 - j40) + (15 + j0)$$

$$= 60 \text{ kW} + j80 \text{ kvar} = 100\angle 53.13 \text{ kVA}$$

Power Factor Correction

The total current is

$$I = \frac{S^*}{V^*} = \frac{100,000\angle -53.13^\circ}{1400\angle 0^\circ} = 71.43\angle -53.13^\circ \text{ A}$$

The supply power factor is

$$PF = \cos(53.13) = 0.6 \text{ lagging}$$

(b) Total real power $P = 60$ kW at the new power factor of 0.8 lagging results in the new reactive power Q'.

$$\theta' = \cos^{-1}(0.8) = 36.87^\circ$$

$$Q' = 60\tan(36.87^\circ) = 45 \text{ kvar}$$

Power Factor Correction

Therefore, the required capacitor kvar is

$$Q_c = 80 - 45 = 35 \ \text{kvar}$$

and

$$X_c = \frac{|V|^2}{S_c^*} = \frac{1400^2}{j35,000} = -j56 \ \Omega$$

$$C = \frac{10^6}{2\pi(60)(56)} = 47.37 \ \mu\text{F}$$

and the new current is

$$I' = \frac{S'^*}{V^*} = \frac{60,000 - j45,000}{1400\angle 0^\circ} = 53.57\angle -36.87^\circ \ \text{A}$$

Note the reduction in the supply current from 71.43 A to 53.57 A.

Activity (5)

Thank You
For Your Attention

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