# Chapter 3: Electrical circuits and powers

## 3.1 Single-phase circuits and electrical powers

Consider an electrical energy transmission system where the generator provides a fixed voltage (sinusoidal alternating current). The energy is transported to the receiver (consumer shown in Figure 3.1) bya **line**distribution, single phase. The system (source and receiver) is said**single phase.**

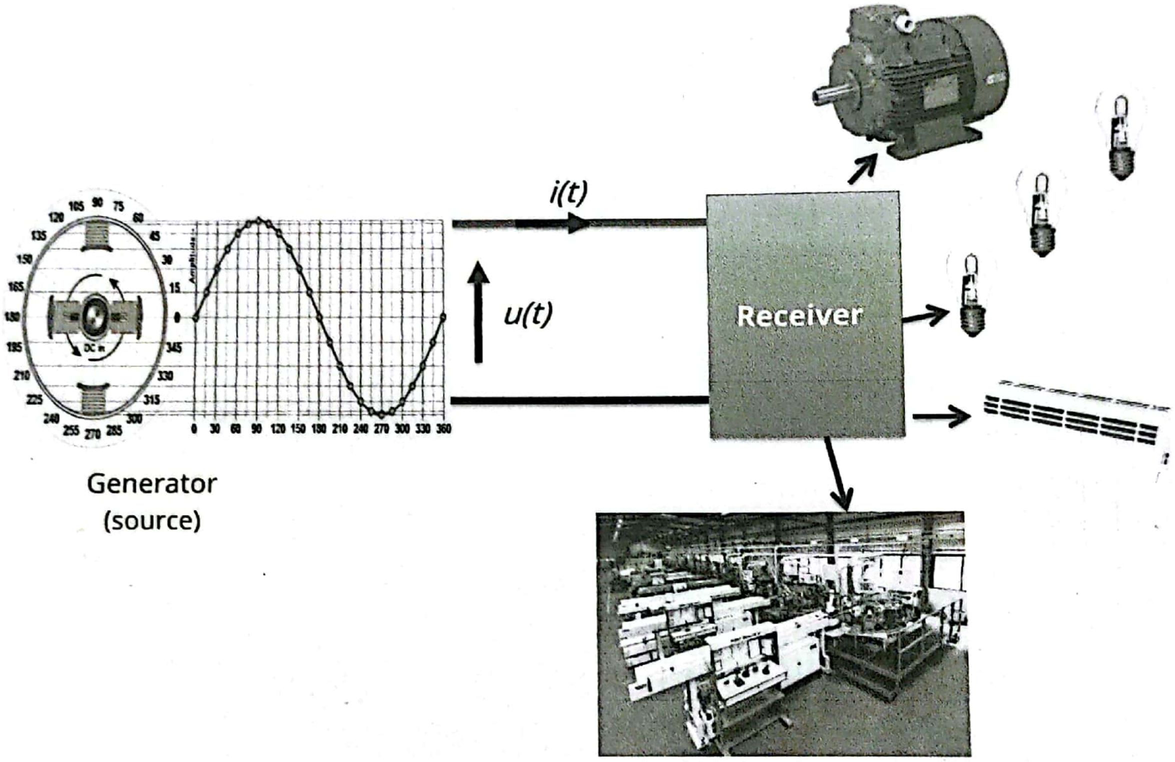


**Figure 3.1**Single-phase installation.

Single-phase circuits consist of a single phase and the neutral. A single-phase current can be produced from a three-phase network by connecting one of the three phases and the neutral.

The receiver represents the electrical installations and blocks of buildings. Generally, they can be classified into three types:

- **Inductive receiver (motor). Resistive**
- **receiver (oven, radiator).**
- **Capacitive receiver (capacitor).**

### 3.2 Single-phase electrical powers

The equations of the electric powers established in the previous chapter, corresponding to the average power, to the active, reactive and apparent power, can be represented geometrically by means of a triangle called " "*triangle of powers*". The electrical installation is characterized by a power triangle.

Consider the case of an inductive receiver (motor): the current *I* is behind the voltage *V*, which is taken as the origin of the phases.

We replace the vectors *V* And *I* by the components *cos* And *sin*.

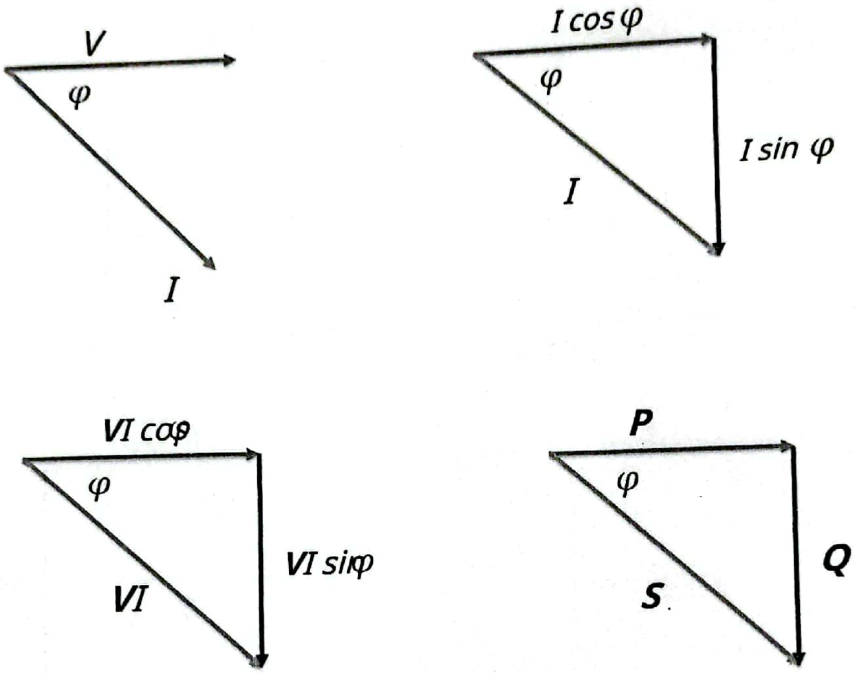


**Figure 3.2** Power triangle for an inductive load.

**In summary we have:**

Average (active) power : $P = VI\cos\varphi$

Reactive power : $Q = VI\sin\varphi$

Apparent power : $S = VI$

Power factor $PF = \cos\varphi = \frac{P}{S}$

A capacitive receiver can be used in the same way.

**Noticed**

In the case of a receiver of a resistive nature $\varphi = 0$ $(\varphi = 0)$

$$\begin{cases} P = VI \\ Q = 0 \\ S = P = VI. \end{cases} \quad (3.1)$$

Apparent power is equal to active power, Figure 3.3 shows the power diagram for a resistive load.

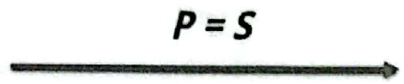


**Figure 3.3**Power diagram for a resistive load.

#### 3.2.1 Example of a study of an installation

A single-phase electrical installation, supplied with a voltage of 230V; 50 Hz, includes:

- 02 radiators with power P = 5 kW.
- 03 motors absorb 3 kW (for each motor), with a power factor :
  $PF_1 = 0{,}74$ , $PF_2 = 0{,}72$ , $PF_3 = 0{,}71$ .
- A welding station with electrical power P3 = 4 kW and power factor :
  $PF = 0{,}83$
- An electric dryer that absorbs 5 kW

We are interested in the sizing of the power balance, for this, we will:

**1-**Calculate the total active power P when all receivers are in functioning.

**2-**Calculate the total reactive power Q when all receivers are in functioning.

**3-** Then calculate the total apparent power S and deduce the power factor Fp of the installation as well as the line current I.

**4-**A capacitor is added in parallel with the installation. What should be the capacitor capacity to raise the power factor to 0.94? **Solution**

Solution

We start with a graphic representation of the installation, then we determine the powers of each element of the installation. Figure 3.4 represents a synoptic diagram of the installation.

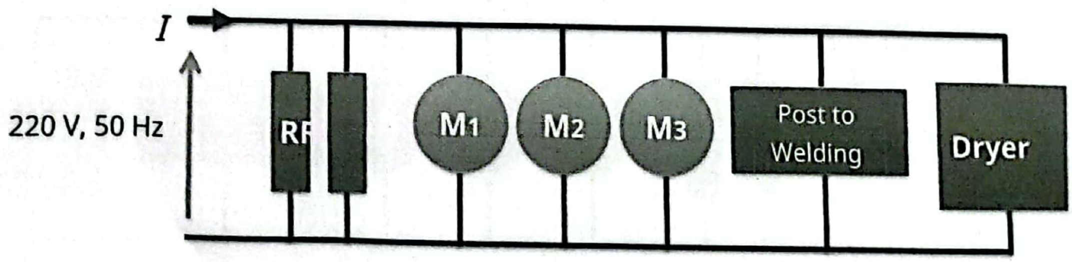


**Figure 3.4**Synopsis of the installation.

**1- Calculation of the total active power P**

To calculate this power, we calculate the active power of each element and then apply Boucherot's theorem. For radiators, the absorbed power is**totally** dissipated in the form of heat. Therefore the reactive power is zero. Mathematically, at the terminals of a resistive load the phase shift is zeroΔ = 0 ,SO :

| Two radiators | A welding station | An electric dryer | Three engines |
|---|---|---|---|
| $P_{2R}$=2*5= 10 KW | $P_{PS}$= 4 KW | $P_F$= 5 kW. | $P_{3M}$= $P_{M1}$+ $P_{M2}$+ $P_{M3}$ =3* P<br>$P_{3M}$= 9KW |

$$P_T = P_{2R} + P_{PS} + P_F + P_{3M} = 28KW$$

**2-Calculate the total reactive power Q**

Reactive power, according to the power triangle:

$$\boxed{Q = P * \tan\varphi}$$

**A- Two Radiators**

$Q = P * \tan\varphi = 0$

$Q_{2R} = 0$

**B- Three Engines**

| Engine 1 | Engine 2 | Engine 3 |
|---|---|---|
| $Q_1 = P_1 * \tan\varphi_1$ | $Q_2 = P_2 * \tan\varphi_2$ | $Q_3 = P_3 * \tan\varphi_3$ |
| $\varphi_1 = \cos^{-1}(0{,}74)$ | $\varphi_2 = \cos^{-1}(0{,}72)$ | $\varphi_3 = \cos^{-1}(0{,}71)$ |
| $\varphi_1 = 42{,}26°$ | $\varphi_2 = 43{,}94°$ | $\varphi_3 = 44{,}76°$ |
| $Q_1 = 3\,tg(42{,}26°)$ | $Q_2 = 3\,tg(43{,}94°)$ | $Q_3 = 3\,tg\,\varphi_3$ |
| $\boxed{Q_1 = 2.73 \text{ kVAR}}$ | $\boxed{Q_2 = 2.89 \text{ KVAR}}$ | $\boxed{Q_3 = 2.97 \text{ KVAR}}$ |

SO :

$Q_{3M} = Q_{M1} + Q_{M2} + Q_{M3} = 2.73 + 2.89 + 2.97$

$Q_{3M}$= 8.60 KVAR

**C- A welding station**

$Q = P * \tan \varphi$

$\varphi = \cos^{-1}(0{,}83)$

$\varphi = 33{,}90°$

$Q_W = 4 \, Tg \, 33{,}9$

$Q_W = 2{,}68$ KVAR

**D- An electric dryer**

The electric dryer has the same behavior as the radiators, so we will have:

$Q_d = 0$ VAR

SO :

$Q_T = Q_{2R} + Q_{3M} + Q_{PS} + Q_{s.e.} = 0 + 8.60 + 2.68 + 0 = 11.28$ **KVAR**

$\boxed{Q_T = 11{,}28 \text{ KVAR}}$

**3- Then calculate the total apparent power S and deduce the factor of power Fp of the installation as well as the line current I.**

The figure below represents the power triangle, we can deduce that:

$S_T = \sqrt{P_T^2 + Q_T^2} = 30{,}18$ KVA.

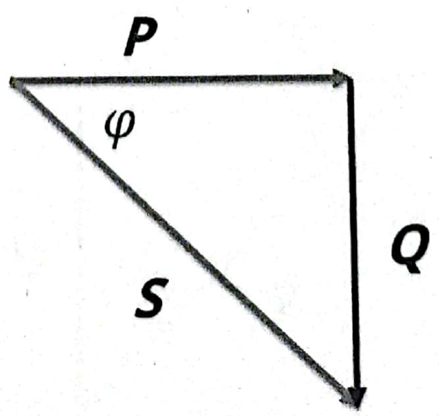


**Figure 3.5**Power triangle.

**B- Power factor**

$$\cos\varphi = \frac{P}{S} = \frac{28}{3964} = 0{,}91$$

**C-**Current intensity: We have the equation:

$$S = VI$$

$$I = \frac{S}{V} = \frac{30{,}64\times10^{3}}{220} = 139{,}27\ A$$

$$\boxed{I = 139{,}27A}$$

### 3.3 Power factor improvement

In industrial applications, it is often desirable that the apparent power S be as close as possible to P, that is to say that the angle tends towards zero (0°), and the power factor towards 1.

In the usual case of motors (inductive load), it is very often possible to improve the power factor by connecting capacitors in parallel with the receiver [3].

At the capacitor terminals, the phase shift is negative

The active power of the capacitor is: (3.2)

$$P_c = VI\cos\left(-\frac{\pi}{2}\right) = VI\times0 \quad (3.3)$$

$$\boxed{P_c = 0W}$$

It should be noted then that the active power does not change. Reactive power: (3.4)

$$Q_c = VI\sin\left(-\frac{\pi}{2}\right) \quad (3.5)$$

$$\boxed{Q_c = -V^2\omega C} \quad (Q_c<0)$$

Since the reactive power of the capacitor is negative, then = ,SO : (3.6)

$$Q'_T = Q_T + Q_c\ ,\quad Q'_T < Q_c$$

If we want to improve the power factor of the previous installation to 0.94, (3.7)

$$P'_T = P_T$$

Reactive power: (3.8)

$$Q'_T = P'_T\ \mathrm{tg}\ \varphi'$$

$$\cos\varphi' = 0{,}94$$

$$\varphi' = 19{,}94^{0}$$

$\tan \varphi = 0.36$

$Q'_T = P'_T \tan \varphi' = 28 * 0.36 KVAR$ $Q'_T =$

$\boxed{10.16 KVAR = Q'_T}$

$\Delta Q = Q'_T - Q_T = 10.16 - 11.28$

$\Delta\varphi = Q_C = -1637.35 VAR$

$-1637.35 = -V^2 \omega C$

$$C = \frac{\Delta Q}{V^2 2\pi F} = \frac{1637.35}{(220)^2 * 2\pi * 50} = \frac{1637.35}{16610600} = 107.68\ \mu F$$

$\boxed{C = 107.68\ \mu F}$

We then connect a capacitor in parallel to the installation:

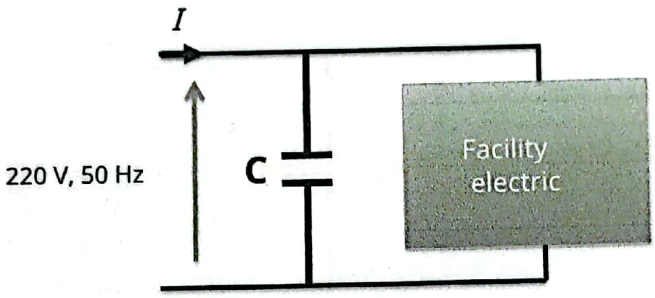


**Figure 3.6**Improvement of thecos .

It is very interesting to note that the active or useful power P does not change, since the voltage across the load or receiver remains the same power. While the reactive power supplied by the capacitor is negative so the total reactive decreases and the power factor increases. The current and the apparent power decrease and consequently the efficiency of the distribution system increases.

### 3.4 Three-phase system → Next chapter.

In industry, single-phase power or single-phase network is generally insufficient. The use of three-phase networks makes it possible to triple the power.

This network consists of 03 sinusoidal alternating currents of the same frequency and the same amplitude (see figure 3.7), but out of phase with each other by 120° [6].