

Power Factor

Many types of electrical devices operate on alternating current (ac) and require a magnetic field in order to operate. The most common example is an electric motor. Some ac electrical equipment also contains a component called a capacitor. These components also cause the ac current sine wave to become out of alignment with the voltage ac sine wave.

Alternating current flows in a circuit in a sine wave pattern, flowing in one direction when positive (+) and in the opposite direction when negative (-). For ac power in the U.S. and Canada these plus/minus cycles occur at a rate of 60 every second which is known as 60 Hz power. The voltage causes the current to flow. In the case of alternating current both the voltage and the current occur in the conductors in the form of a sine wave as shown in *Figure 226.1*. For some electrical loads the voltage and current sine waves are in alignment as shown in *Figure 226.1*, and in many circuits the voltage and current sine waves are out of alignment as shown in *Figure 226.2*.

Some ac circuits power resistive loads such as incandescent lamps and resistance type electric heating elements. An electric water heater uses a resistive heating element to heat the water. Space heaters use resistive heating elements. For resistive ac circuits the voltage and current sine waves are basically in alignment as shown in *Figure 226.1*. **Power factor (pf)** is a number that ranges from zero to one (0.0 to 1.0) that indicates how much the voltage and current sine waves are out of alignment.

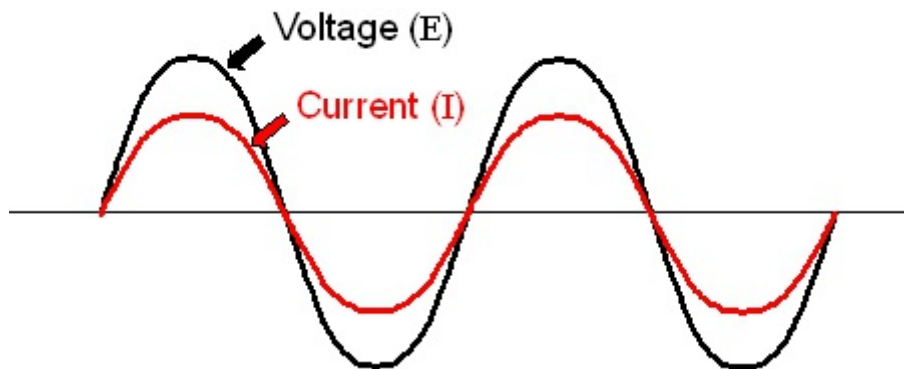


Figure 226.1 In the case of a resistive ac load the voltage sine wave and the current sine wave are in alignment. They are zero at the same time and they reach their peak value at the same time.

Power in an ac Circuit: In a direct current (dc) circuit power is simply the product of the voltage and current ($P = E \times I$). Because the voltage and current are sine waves in ac circuits the power calculation requires an additional factor added to the power equation to account for the alignment of the voltage and current sine waves. This additional factor is the **power factor (pf)**. The power equation for an ac circuit is the voltage times the current times the power factor ($P = E \times I \times pf$), Equation 226.1 .

$$P = E \times I \times pf$$

Eq. 226.1

Since the voltage and current in an ac circuit are in the form of a sine wave the level of voltage and current are constantly changing in magnitude. What is measured from an ac circuit as voltage or as current is known as the “**effective**” value of the voltage and current. The effective value is often called the “**rms**” (root mean square) value of the voltage or current. The effective or **rms** value is what is used in all calculations.

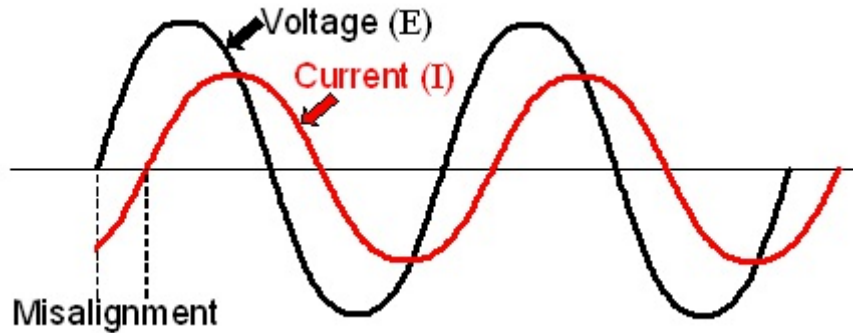


Figure 226.2 In the case of an ac circuit powering an electric motor the voltage sine wave and the current sine wave are not aligned. Power factor is a value that indicates the amount of misalignment.

Calculating Power of an ac Circuit: An electric water heater is an example of what is known as a resistive ac load. In this case the voltage sine wave and the current sine wave will be in alignment and the power factor (pf) will have a value of 1.0. As an example assume an electric water heater operates at 240 volts and has a current draw of 14.6 amperes. Determine the power rating of the water heater.

$$P = 240V \times 14.6A = 3504W$$

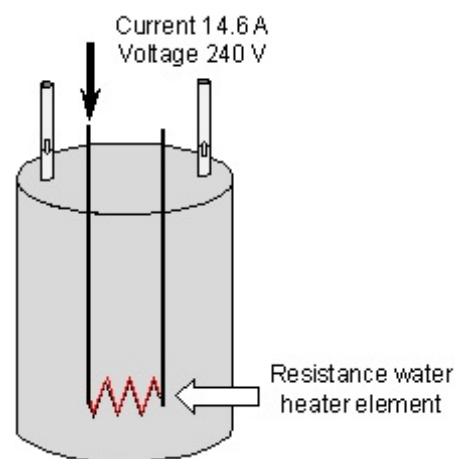


Figure 226.3 The water heater is a resistance load so the power factor is 1.0. The product of the voltage and current for this water heater is 3,504 watts.

Here is an example of an ac load where the power factor (pf) is not 1.0 and the current and voltage sine waves are out of alignment with each other (*Figure 226.4*). A common example is

an electric motor. In this case the motor is single-phase 3-horsepower and operates at 240 volts and draws 17 amperes. Assume the power factor (pf) has a value of 0.75. The task is to determine the wattage draw of this electric motor.

$$P = 240V \times 17A \times 0.75 = 3060W$$

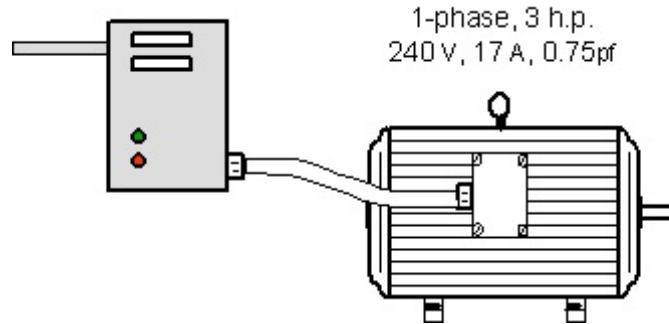


Figure 226.4 An ac electric motor powers a load where power factor (pf) has a value of **less than** 1.0. This single-phase motor draws 17 amperes at 240 volts with a power factor of 0.75.

Power factor (pf) of a load must be given when performing a power calculation. For an actual situation both power factor and power can be easily measured directly. In the case of loads such as electric motors the value of the power factor will change as the load on the motor changes. When power factor is given on a motor nameplate that value was determined under test conditions and should be fairly accurate when the motor is operating at full load.

Effective or rms Value of a Sine Wave: A sine wave such as the one shown in Figure 226.5 will have two important values. One is the peak value of the sine wave E_p . This peak value is both positive and negative in a single cycle. The value of the sine wave that is used for calculations is the *effective voltage* or sometimes called the “rms” voltage. If the sine wave for a load is not distorted the ratio of the peak voltage divided by the effective voltage is the square root of the number 2 which has a value of 1.414. If a voltmeter measures the voltage at a wall outlet to be 120 volts multiply that value by 1.414 to find the peak value. ($120\text{ V} \times 1.414 = 170\text{ V}$). The peak voltage when the effective voltage is 120 will be 170 volts. To find the effective voltage when the peak voltage is given just divide the peak voltage by 1.414.

$$E_{\text{effective}} = \frac{E_{\text{peak}}}{1.414} \quad \text{Eq. 226.2}$$

$$E_{\text{peak}} = E_{\text{effective}} \times 1.414 \quad \text{Eq. 226.3}$$

Frequently the waveform of a circuit is not a perfect sine wave. Many ammeters are only capable of reading an accurate value of the current when the ac current is a perfect sine wave. To always get an accurate reading when measuring current be sure on the face of the ammeter are the words “True rms.” Meters with this designation will give an accurate reading even when the current sine wave is distorted.

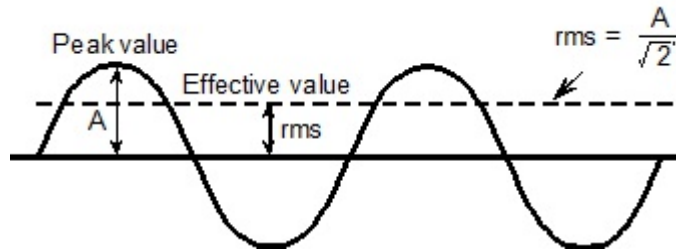


Figure 226.5 Divide the peak value by 1.414 to get the effective (rms) value of the sine wave.

Calculating 3-Phase Power: A single-phase load is supplied with only two wires but a 3-phase load is supplied with three wires. The 3-phase device is supplied three separate sine waves each off-set from the others by 120° of angle which is time of about 5.6 milli-seconds (ms). Each of these sine waves do not reach their peak at the same time and they do not become zero at the same time. Fortunately the equation to calculate 3-phase power only requires one additional factor added to the 3-phase power equation. That factor is the square root of the number 3 which has a value of 1.73. The 3-phase power equation is shown in Equation 226.4. It is the **voltage** times the **current** times the **power factor** (pf) times **1.73**.

$$P_{3-Phase} = 1.73 \times E \times I \times pf \quad \text{Eq. 226.4}$$

Even though a 3-phase load has three wires instead of two wires the current draw of an identical load will be less for 3-phase load as compared to single-phase load. This is one of several advantages to 3-phase as compared to single-phase. Here are two types of loads one is single phase and the other is 3-phase. This first set of examples deal with a resistance type load where the power factor (pf) can be assumed to be close to 1.0. The examples are 5,000 watt, 240 volt electric resistance heaters. One electric heater is single-phase and the other is 3-phase. The task is to calculate the current draw of each electric heater.

$$I_{1-Phase} = \frac{P}{E \times pf} \quad (20.8 \text{ amps}) \quad \text{Eq. 226.5}$$

$$I_{3-Phase} = \frac{P}{1.73 \times E \times pf} \quad (12 \text{ amps}) \quad \text{Eq. 226.6}$$

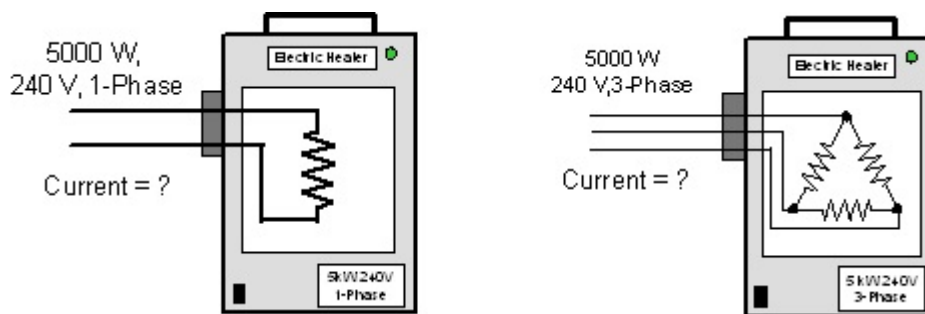


Figure 226.6 Determine the current draw of a 5 kW, 240 volt single-phase resistance heater and a 5 kW, 240 volt 3-phase resistance heater and compare the two currents. (Calculations on next page)

$$I_{1-Phase} = \frac{5000W}{240 \times 1.0} = 20.8A \quad I_{3-Phase} = \frac{5000W}{1.73 \times 240V \times 1.0} = 12.0A$$

Notice the current for the 3-phase heater is much lower which means the conductor size for the 3-phase heater will be smaller.

Figure 226.7 shows a matched single-phase motor and a 3-phase motor. Both electric motors are rated 10 horsepower and operate at 240 volts. Notice the 3-phase motor is smaller in size and draws less current than the single-phase motor. Both motors are rated 10 horsepower and both have a 0.8 power factor. (Solutions are shown below)

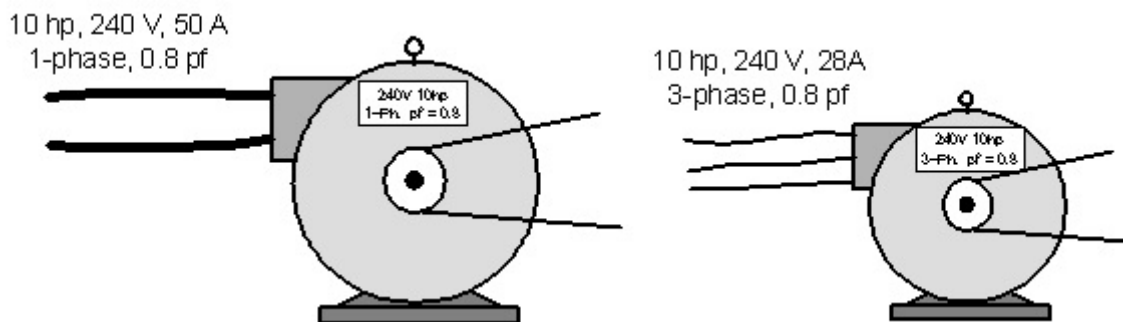


Figure 226.7 This example is of two 10 horsepower, 240 volt electric motors one that is single-phase and the other 3-phase. Each has a power factor of 0.8 but the single-phase motor draws 50 amperes and the 3-phase motor only draws 28 amperes.

The diagrams below are an easy way to remember the single-phase and 3-phase power equations. The only difference is the 1.73 for the 3-phase load. Notice on page 4 the 3-phase electric heater Equation 226.6 has the 1.73 value in the denominator.

$$P_{1-Phase} = 240V \times 50A \times 0.8 = 9600W$$

$$P_{3-Phase} = 1.73 \times 240V \times 28A \times 0.8 = 9300W$$

