# Power Factor – A Tale of Two Currents - Part 1

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Power Factor (PF) is an important component of an AC power circuit but, understanding its actual effect can be difficult. Why is PF mysterious to many of us? It has to do with the way it is explained. It is often defined as the ratio of the real load power to the apparent power in the circuit. Real power is the power consumed by the circuit and apparent power is the sum of the real power and reactive power. Reactive power is referred to as "imaginary", "phantom" or "borrowed" power. Real power is measured in watts while reactive power is measured in volt-amps. Isn't a watt a volt-amp? Maybe not if those amps are imaginary. Another explanation uses a vector triangle to show the relationship of real, reactive and total power. This can be useful to some but confuses others. Finally PF can be defined most simply as the cosine of the phase angle between the voltage and apparent power. I sincerely hope that this brief summary of PF has answered all of your questions.

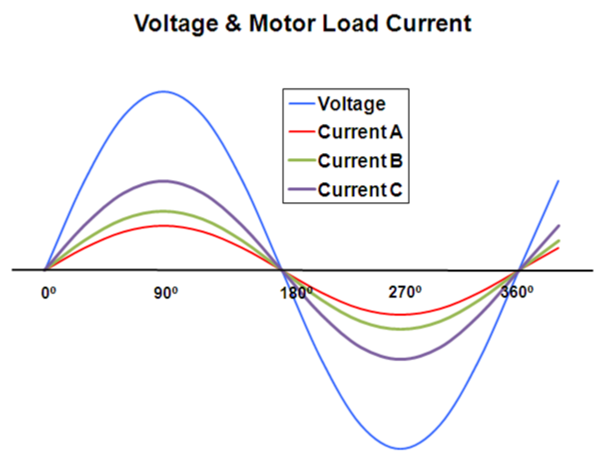
When I began presenting my AC Power and Motors seminar in the late nineties, I used some of the above to explain power factor. The result was that some of the audience gained an understanding but the majority did not. In 2007, I changed the way it was presented. Today the majority say that they understand it but, a small minority still does not. Although the results were not perfect, they are better than they used to be. I will use my current (no pun intended) approach in this article. Although there are a number of inductive devices that contribute to power factor, we will limit our discussion to AC motors. Rather than power, we will focus on the rise and fall of voltage and current during the AC cycle. The illustrations here are the ones I use in my seminars.

## What is Power Factor?

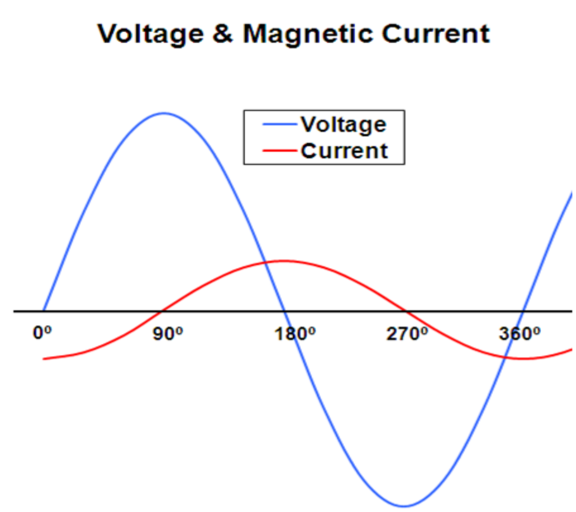
Power Factor is an indication of how effectively an AC motor uses current to perform work (torque) and ranges from 0 to 100 (or 0 to 1). Assume for a moment that a one horsepower, 230 volt, single phase motor is 100% efficient. If the motor power factor is 100 (1), which is impossible, the utility would have to supply just 3.24 amps (746 watts) for the motor to run at full load. At a more realistic power factor of 75 (0.75), it would have to supply 4.32 amps or the equivalent of

994 watts. Although that additional amperage is not consumed by the motor it still has to be provided by the utility or the motor could not operate at full load. The reason behind this conundrum is that two different types of current are required during motor operation. One is the load current which performs work and the other is the magnetizing current which initiates a magnetic field in the stator. Charles Dickens might have summed it up this way: "It was the best of currents, it was the worst of currents".

Load current is the current used by the motor to do work and increases or decreases based upon the actual load on the motor. It is never zero, even when disconnected from the load, due to the friction and windage associated with the rotor and bearings. Figure 1 shows one complete AC cycle (360 degrees). The blue curve is voltage and the other three curves are the load currents at various motor loads. The current at all loads rises and falls synchronously (in phase) with voltage and reach their peak values at 90 and 270 degrees. At any point during the cycle, power in watts is equal to the product of volts and amps as it is a true, resistive load. Even during the negative portion of the cycle the product of a negative volt and a negative amp produces a positive watt. The load power (W = V X A) is often referred to as "real power" and is measured by the utility company's kWh (kilowatt hour) meter.



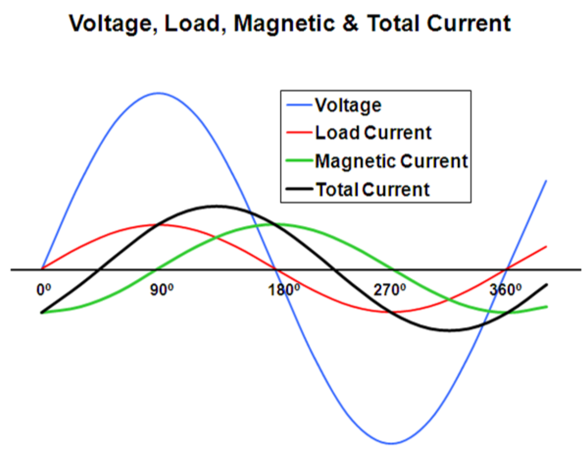

The current required to initiate a magnetic field in the stator behaves very differently. It does not flow synchronously with voltage. Figure 2 shows the voltage and magnetizing current during one full cycle. Current lags voltage by 90 degrees and peaks at 180 and 360 degrees whereas load current peaks at 90 and 270 degrees. Magnetizing current uses no energy to build the magnetic field because it is returned to the circuit when the field decays. The amount required depends upon the motor design and, unlike load current it remains relatively constant



regardless of the motor load. It is often referred to as "reactive, imaginary or borrowed power" and it is not measured by a standard kWh meter because it is out of phase with voltage. Later we will see how the combination of varying load current and constant magnetizing current will cause power factor to vary from its nameplate value.

## How Is Power Factor Calculated?

In the previous figures we saw how load and magnetizing current rise and fall during one cycle of AC. Load current is in phase with voltage while magnetizing current lags voltage by 90 degrees. Figure 3 shows the effect of both during one cycle. The red curve is load current and the green one is magnetizing current. In this example, I have chosen to show both with the same current intensity in order to keep the results simple. In the case of a fully loaded motor, the load current will be substantially higher than the magnetizing current.




You will notice that there is an additional curve in this figure. The black curve is the total current. It is the sum of the load and magnetizing current at any point in the AC cycle. The product of total RMS (root mean square) current and voltage is often called "apparent power". In this example total current peaks at 135 degrees or exactly halfway between the load and magnetizing peaks. This places it 45 degrees to the right of the voltage and load current peaks. Thus the phase angle between total current and voltage is 45 degrees and the cosine of this angle is the power factor. Therefore, power factor = cosine 45 = 0.707 (or 70.7). Power factor is simply the percentage of the total current that actually performs work. From a power perspective it is the percentage of the apparent power (kVA) that performs work. It is also the ratio of load power to apparent power (PF = kw / kVA).

If a motor nameplate shows a full load amperage (FLA) of 22 amps and a power factor of 70.7, only 15.5 amps is consumed by the motor. The remainder is used to build the magnetic field in the stator and is returned to the circuit when the field decays. Even though it is returned to the circuit, the utility still has to supply it and all of the wiring in the circuit must be sized to carry the nameplate FLA.

Earlier, I said that load current varies with the motor load while magnetizing current remains relatively constant regardless of the load. The power factor shown on the motor nameplate is the measured power factor at full load. When the motor load is reduced, the total current will peak further to the right of the load current and voltage peaks. This increases the phase angle and thus lowers power factor below the value shown on the nameplate. As motor load increases, total current will peak closer to the voltage peak and power factor increases.

Next month we will discuss the major effects of low power factor and how it can be improved by capacitive reactance.

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