

Power Factor Correction

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Introduction

The architecture of power sources has changed dramatically over the past few years. One of the main reasons for this change is IEC 61000-3-2. This international standard requires a reduction in the amount of harmonic distortion present in power systems. This is beneficial because excessive harmonic distortion causes electrical power systems to be less efficient. The most common way to reduce harmonic distortion and increase efficiency is to increase the [power factor \(PF\)](#). This can be achieved by a method known as power factor correction (PFC). When electrical power systems run more efficiently, the cost of generating power is reduced which saves money for both utilities and customers.

What is Power?

The electrical power in a circuit is the amount of energy expended over time. Voltage or “potential” is the force necessary to move electrons through a material. Current is the rate of flow of these electrons per second through the material with that voltage applied. By taking the force (voltage) multiplied by the rate (current), the end result is energy expended over time. This quantity is power. Thus electrical power is voltage multiplied by current:

$P = V * I$ where power (P) is in watts, voltage (V) is in volts and current (I) is in amps

In a DC circuit, analysis is simple because voltage and current are maintained at a constant level. The circuit in Figure 1 shows a 9VDC source connected to a 100Ω resistor. The current flowing through the circuit is:

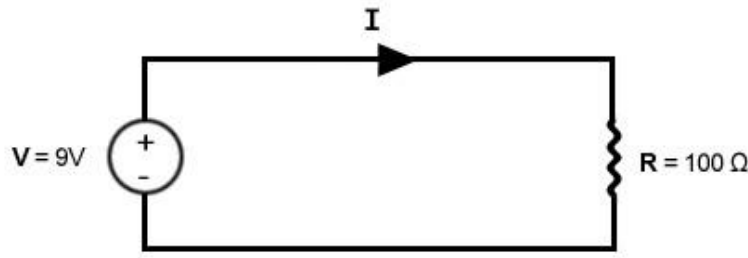


Fig. 1: Simple DC Circuit

$$I = 9V / 100\Omega = 0.09A = 90mA$$

This means that the power dissipated at the load is:

$$P = 0.09A * 9V = 0.81W$$

In an AC system, the current and voltage are constantly changing in amplitude (Figure 2). Therefore, the power will also constantly change depending on the value of the current or voltage at any given point in time.

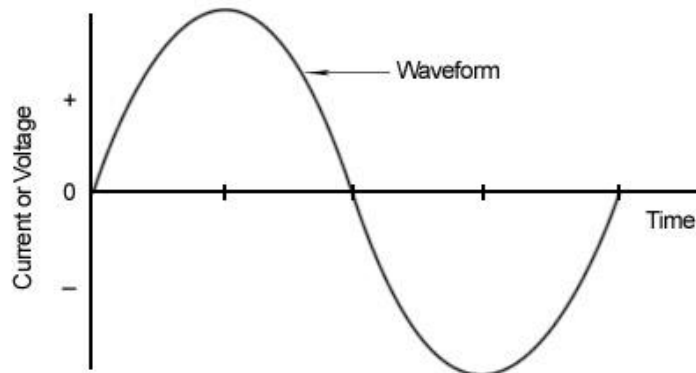


Fig. 2: AC Waveform

To make things even more complicated, the peaks and valleys of the current and voltage waveforms will not always match up. When the current and voltage waveforms line up, they are said to be “in phase.” In the case that they do not match up, the waveforms are said to be “out of phase” or “phase shifted.” A purely resistive circuit will cause no phase shift. A purely capacitive or inductive circuit will cause a 90 degree phase shift. A capacitor will cause a negative phase shift while an inductor causes a positive phase shift (Figure 3-4).

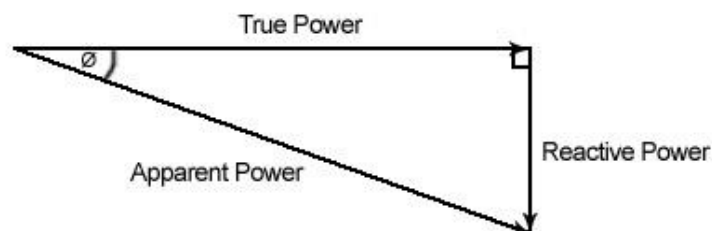


Fig. 3: Negative Phase Shift

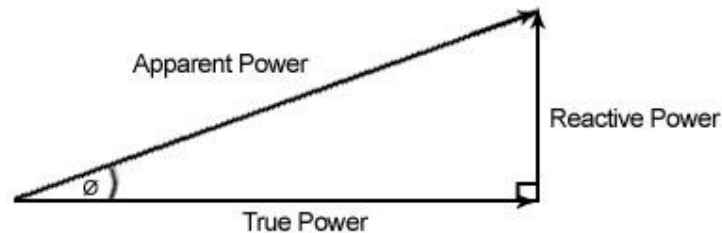


Fig. 4: Positive Phase Shift

Since a purely resistive circuit produces no phase shift between voltage and current, power is maximized. This is known as the true power and it is the power that performs work. True power is measured in watts (W). Conversely, a purely capacitive or inductive circuit will draw current that does no work. Power that performs no work is known as reactive power and it is measured in volt amps reactive (VAR). Reactive power is undesirable because, like true power, it generates current which in turn produces energy loss in the form of heat on the conductors. Unlike true power, it does not perform work at the load. This forces the source to output more power in order to compensate for these losses. As a result, it is important to know how much true power vs. reactive power exists in a system. Taking these two values into account, the overall output is known as apparent power and it is measured in volt amps (VA).

What is Power Factor?

To determine the efficiency of a circuit, the input power is compared to the output power (Figure 5). This tells us how much total power needs to be provided in order to get the necessary output at the load. This value is known as the power factor:

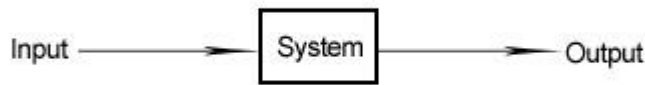


Fig. 5: Input Power Vs. Output Power

$PF = P/S$ where PF is Power Factor, (P) is true power measured in watts and (S) apparent power is in VoltAmps

Multiplying this value by 100% gives the efficiency of the system. For example, if a motor operates at 1200W but requires 1600W of power, this means there are 400W lost in the system. So the power factor is:

$$PF = 1200W/1600W = 0.75$$

Multiplying this by 100% tells the user that the motor has an efficiency rating of 75%. So 25% of the input power is lost due to the reactive components in the system. An electrical system with a low power factor is less efficient because it requires more current. A system that is 100% efficient has a unity power factor ($PF = 1.0$).

Power Factor Correction

Power factor correction is a technique used to increase the power factor of a system. Increasing the power factor of an electrical system is desirable because it reduces the reactive current and thus increases efficiency. The major hurdle in creating a higher power factor is cancelling out the reactive power of a system.

There are two main methods for power factor correction: passive power factor correction and active power factor correction. Passive PFC is the simpler route of the two. It is generally done by introducing an inductance to a system to counteract the reactive current due to capacitance. Recall that inductors introduce positive reactive power while capacitors introduce negative reactive power (Figure 3-4). So if there is a large capacitive value associated with a system, there will be a large amount of negative reactive power. Introducing an inductance to the system will counteract this effect by bringing the negative reactive power back towards zero.

Think of this like a tug of war battle. On one side of the rope is Mr. Bodybuilder (capacitance). On the other side is your Mr. Average Joe (resistance). Obviously, there is no contest and the Mr. Bodybuilder will easily pull Mr. Average Joe to the middle. This is akin to the reactive component overcoming the resistive elements and phase shifting the current in a system (lowering the power factor). Now picture that six Mr. Average Joes team up against the Mr. Bodybuilder. Now Mr. Average Joe's side starts to pull Mr. Bodybuilder until there is almost an even match between the two sides. This is a very similar concept to how introducing a large inductor "pulls" the reactive current component back towards the middle (Figure 6).

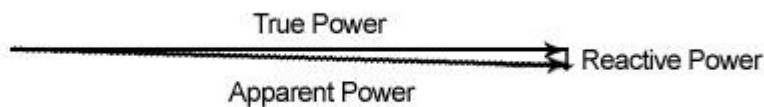


Fig. 6: Corrected Apparent Power

As a result, the power factor increases and the system becomes more efficient because reactive losses have been minimized.

Active PFC involves using complex circuitry to counteract the effects of the reactive components. Such a discussion is beyond the scope of this paper but the concept is similar to the tug of war reference. Most power sources and systems manufactured presently utilize active power factor correction. The reason is because once a source or system reaches a certain size (over about 200-250VA), the inductor necessary for passive PFC becomes too large for a feasible design.

Conclusion

PFC is rapidly becoming a mandatory feature in AC power sources because IEC 6100-3-2 requires the use of PFC circuits. Active and passive PFC circuits are designed to bring the PF of a system closer to unity ($PF = 1.0$). While no system is 100% efficient, most PFC technology makes the power factor of a system greater than 0.95. Highly efficient electrical systems have the advantage of supplying less current to drive a load. This is beneficial to customers that have low power factor problems because utilities sometimes charge penalties for low power factor. While cost savings from PFC on small AC sources isn't nearly as noticeable as money saved from PFC on large systems, in the long run PFC will provide reduced costs for high energy consumers.