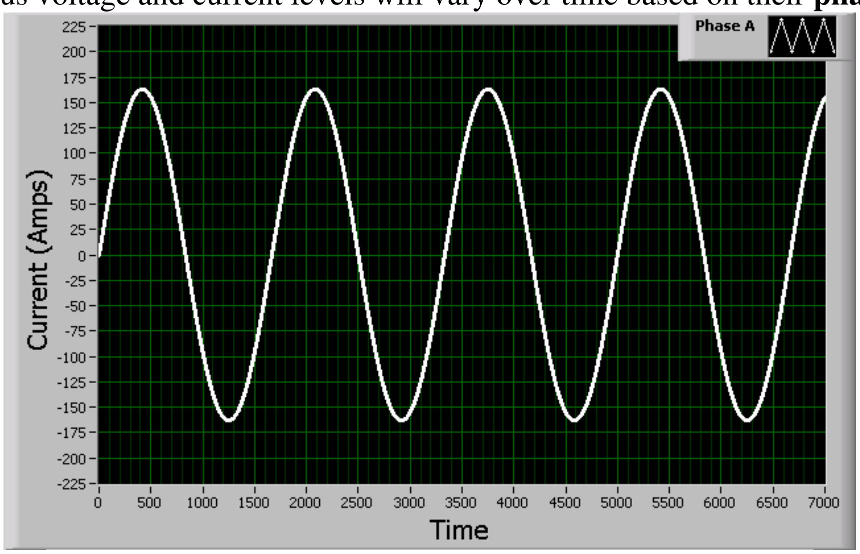
Power Quality Monitoring and Power Metering Tutorial

Power generation and transmission today are accomplished using three phase alternating-current. To understand electrical power quality monitoring and electrical power metering you must first have a basic understanding of three-phase power.

Electricity Basics

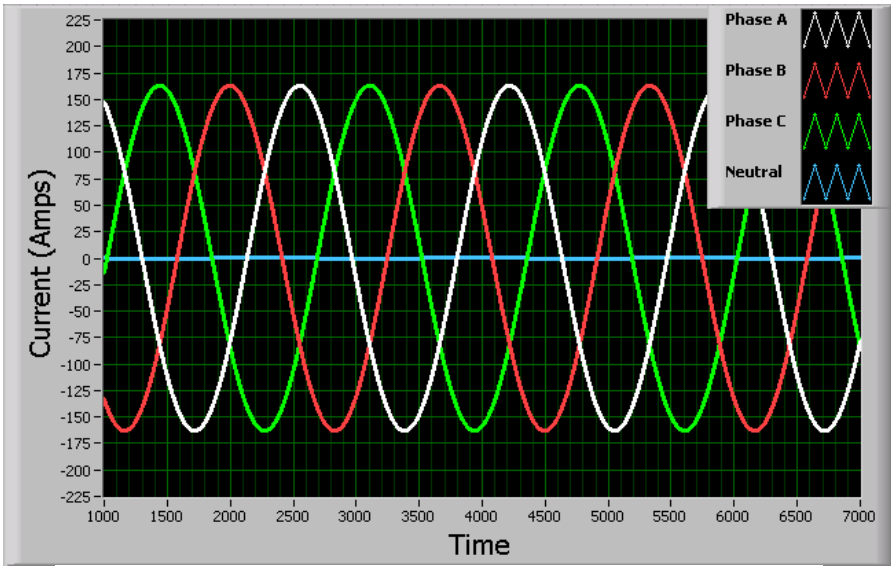
As a mechanical engineer, my favorite explanation of power is the analogy of a water system. In a water system you have a pipe that can carry water. The larger the pipe the more water it can carry. To move the water through the pipe you need to pressurize the water and when the water has the ability to move from a high pressure area to a low pressure area (like when you open a valve) you get flow. In our electrical analogy we replace the pipe with a wire. Instead of carrying water the wire carries electrons. The larger the wire the more electrons it can carry. You pressurize the electrons by applying **voltage**. When the circuit is complete the electrons will flow from the high voltage to the lower voltage and you get flow, know as **current**.

In a DC circuit the voltage and current will be constant (with a constant load). However in an AC circuit the voltage and the current will vary in a sinusoidal manner. The instantaneous voltage and current levels will vary over time based on their **phase**.



In a single sine wave the voltage and current levels vary according to the phase.

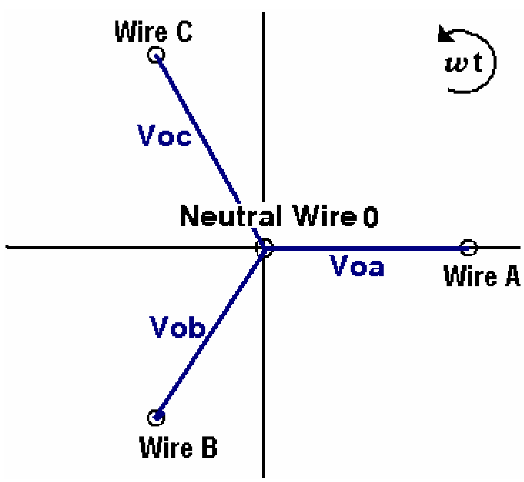
Phase in an AC circuit, indicates the value of the voltage or current measured in degrees with 360° equal to one complete cycle. The value of the sine of the phase angle is proportional to the voltage level. **Three-phase power** refers to three voltages that are offset from each other by 120° or one third of a cycle. These voltages (and currents) are usually carried on 3 wires.



In a three phase power the sine waves are offset 120º.

Three phase power is the standard throughout the world because it uses fewer and smaller conductors than multiple single phase systems to provide the same power. Three phase power also has the ability to drive motors with constant torque instead of the pulsating torque of single phase motors. Because each of the phases carries equal voltage (and current through a balanced load) at 120° offset, the total power provided from all three phases is constant.

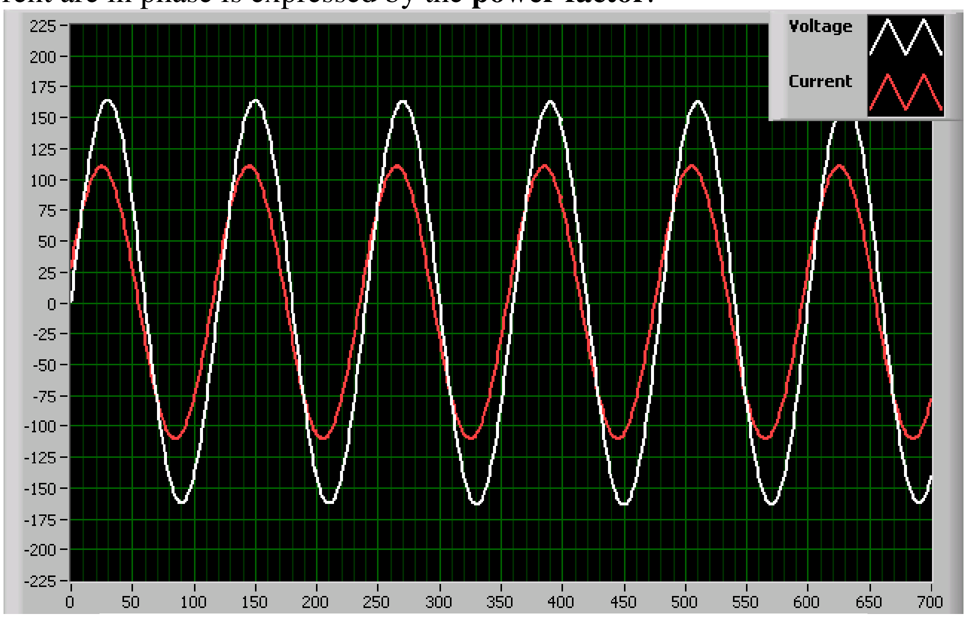
When we use electrical power we must connect a load. With AC power, the ideal configuration is when each of the three phases is connected to an equal load, also called a **balanced load**. Because the three phases are synchronized at 120° offset, you can connect all three of these wires together through equal loads to a fourth wire called neutral. This is the called a **wye connection** because of the way it appears on a phasor diagram.



A phasor diagram showing a wye connection.

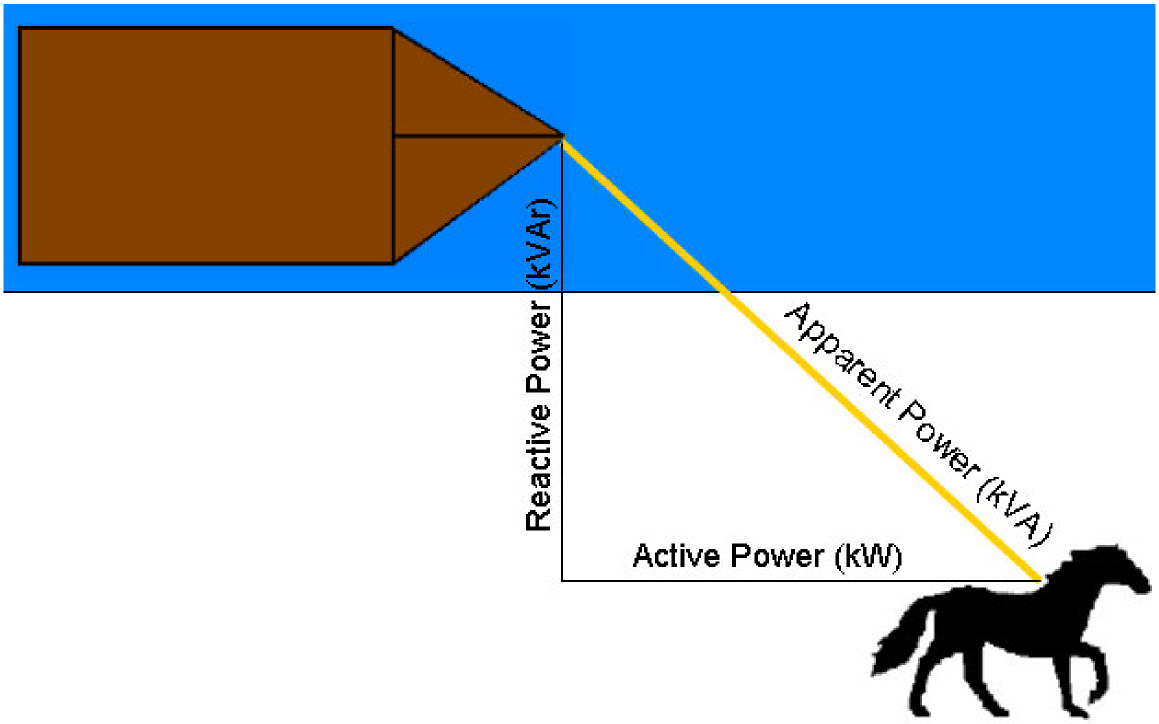
The three phases can also be connected direction together in a delta connection. While a wye connection can tolerate imbalanced loads by sending current through the neutral wire a delta connection does not have a neutral wire so the loads must be balanced.

Electrical power is measured in watts or **kilowatts** (kw) and occurs when a voltage is accompanied by a current flow. A watt is equal to 1 volt of potential and 1 amp of current. When power is applied over a period of time work is done. This work is measured in the amount of power applied multiplied by the period of time and is usually expressed in **kilowatt hours** (kwh). When we look at an AC power system we can see that when the voltage and current are exactly in phase the maximum amount of work can be accomplished and the more out of phase the voltage and current are the less useful work can be accomplished. When the signals are 15 degrees of out phase you can accomplish 97% useful work, at 60 degreed you can accomplish 50% useful work, and at 90% out of phase you can accomplish 0% useful work. The degree to which the voltage and current are in phase is expressed by the **power factor**.



Single phase power with a 15º phase lag.

One way to understand power factor is think about a horse pulling a barge along a canal. The horse must pull the barge from the shore; therefore it is pulling the barge at an angle to the direction of travel. Because the horse is pulling at an angle, not all of the horse's effort is used to move the barge along the canal. The effort of the horse is the total power or **apparent power (kVA)**, the power used to move the barge is the working power or **real power(kW)**, and the power that is trying to pull the barge to the side of the canal is nonworking power or **reactive power(kVAr)**. The ratio of the real power to the apparent power it also known as the **power factor**. If the horse is led closer to the edge of the canal the angle of the rope will decrease and more of the apparent power will be used as real power, increasing the power factor.



One way to understand power factors is to consider a horse pulling a barge. Only the cosine of the pulling angle multiplied by the total pull of the horse is used to move the barge.

In the case of electricity the power factor is based on the phase difference between the current and the voltage sine waves. If the phase is zero then all the apparent power can be used as real power and the power factor is 1. This is also called "unity power factor". As the phase difference increases the power factor will decrease and more current needs to be supplied to give the same amount of real power.

Power Quality Events

Many facilities today have sensitive computerized equipment or telecommunications equipment that use ground as the reference for all their internal operations and connect throughout the plant. This makes them susceptible to ground differences and to power quality problems. While many people believe that most power quality problems come from the power supplier, the majority of power quality problems are introduced inside the plant.

Leading / Lagging Power

Because the electrical utility must supply additional current to compensate for lower power factors they must increase their infrastructure to generate and handle higher currents. They pass this additional cost to customers as a charge based on power factor. In a plant, the power factor, or difference in the phase of the voltage and current waves, is caused by inductive and capacitive loads. An inductive load, like a motor, will cause the current to lag behind the voltage. A capacitor will have the opposite effect and will cause the current to lead the voltage. Since the average industrial sites use 80% of their power to drive motors, most industrial sites tend to have a “lagging power factor”. To help compensate for this many sites will install capacitor banks to help correct the power factor and save on utility company charges.

RMS Voltage variations

RMS, or the root mean squared, is the standard way to measure the level of a sinusoidal wave. The RMS value of a sine wave is equal to the equivalent value had the wave been a DC signal. In power the voltage (and current) levels are measured in RMS. There are three types of RMS voltage variations; a **sag**, a **swell**, and an **interruption**.

A sag is when the RMS voltage level drops to below 90% of the typical RMS level, but is greater than 10% of the nominal voltage. A swell is when the voltage increases to greater than 110% of the typical RMS voltage. An interruption is when the RMS voltage falls to below 10% of the nominal voltage.

Sags are the most common power quality disturbance and are usually caused by problems within the facility as opposed to supply problems from the electric utility. Sags caused within the facility are often caused by load variations or improper wiring. One common cause of a sag is starting an electrical motor. When a motor is started it has a very high inrush current (sometimes 6-10 times the normal operation current).

Interuptions in a facility are typically caused by fault protection from a circuit breaker or from a fuse. They can sometimes also be traced to a loose wiring connection.

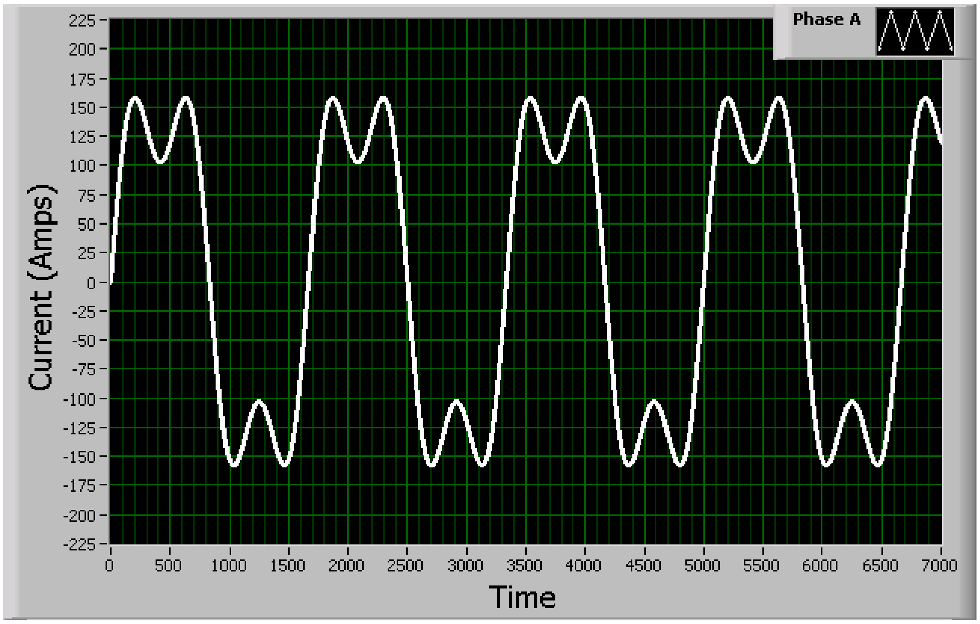
Swells are typically caused by a rapid decrease in load such as when an electric heater shuts off.

Sags and swells that last longer than 3 minutes are called sustained undervoltage or overvoltage conditions. A sustained undervoltage condition (also called a brown out) is caused by improper transformer tap settings or supply problems from the electric utility. Sags and interruptions can cause problems in a facility by shutting down sensitive elctronics, computers, or process equipment.

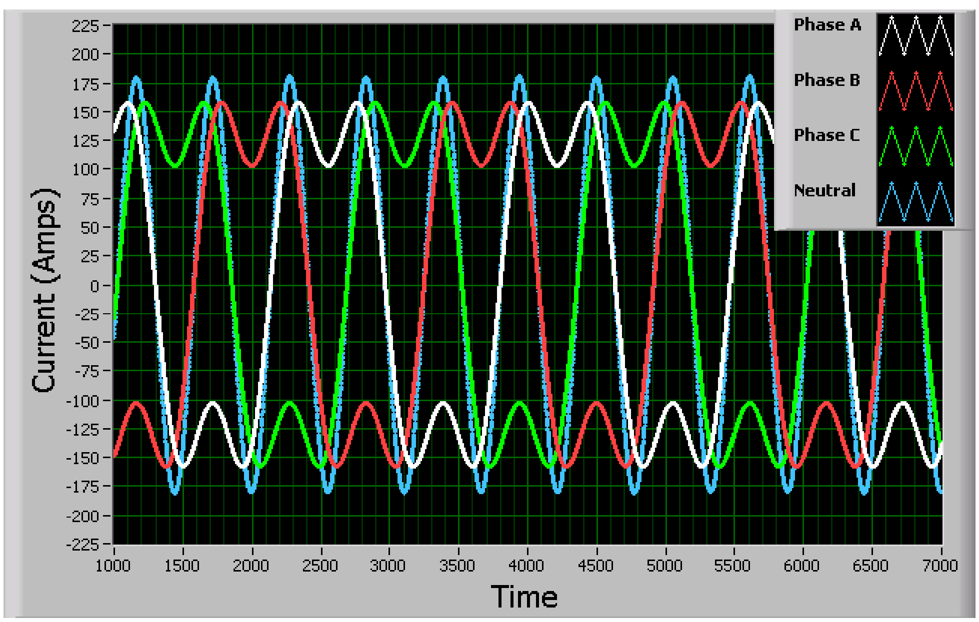
Waveform Harmonics

While we think of power as a clean 60 Hz sine wave, in practice the actual wave form may contain other harmonics. Harmonics occur at an integer multiple of the base frequency (60 Hz, 120 Hz, 180 Hz. . .) Waveform harmonic power quality problems are usually caused by equipment with a nonlinear current draw. Modern electrical equipment such as computerized equipment and telecommunication equipment often use switching power supplies to “step up” or “step down” the voltage. This introduces a nonsinusoidal load which pulls current in short pulses during every cycle. Other nonlinear devices such as digital/electronic components and arching devices like fluorescent lamps can cause abnormal waveforms and serious decreases in power quality.

Pulling power in a nonlinear manner introduces harmonics in the electrical system and can overheat plant distribution transformers. These harmonics can cause current transmission over the neutral power conductor in a wye power system. In an ideal balanced 3 phase power system without higher order harmonics there is no current transmitted along the neutral conductor. When nonlinear devices induce harmonics, the current from each of the three phases no longer cancels and current is forces through the neutral conductor. Electrical systems are especially susceptible to triplen harmonics (3rd, 6th, 9th, etc) because in a three phase system the triplen harmonics are additive.



Single phase 120A sine wave with a third order harmonic of 35 Amps.



Three phase 120A sine waves with a third order harmonics of 35 A. Current spikes on the neutral line of 180 A peak.

This high current can overload circuits, breakers, and transformers. In some instances plants have been forced to install power conditioning equipment or a second neutral conductor.

Summary

A basic power quality system will monitor the voltages and currents from each phase. It may also monitor the voltages and currents on the neutral line if imbalanced loads or harmonics are suspected. A basic power metering system will monitor the RMS voltages and currents from each of the three phases and will monitor the power factor.

Power quality monitoring and power metering will allow plants to perform predictive maintenance, energy management, cost management, and quality control.