Understanding Power Factor and Crest Factor

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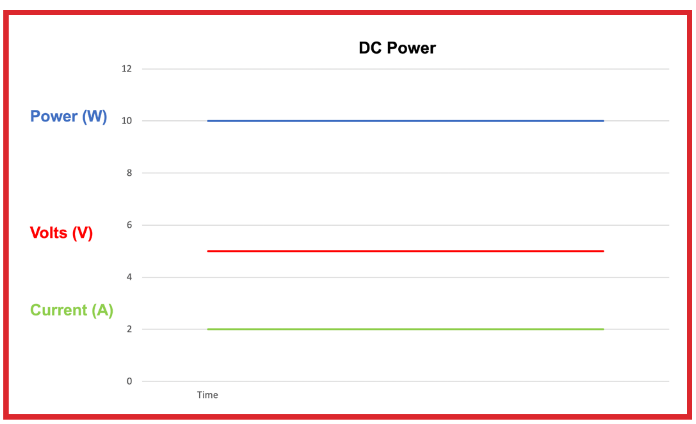
As microprocessor technology advances, we see extended functionality enter the marketplace at lower and lower costs. An example of this is electronic metering, or *Metrology* functionality being incorporated into point of use power protection devices. Metrology functionality not only includes Voltage/Current measurement, instantaneous Power Consumption and Energy Usage measurements, but can also include Oscilloscope functionality.

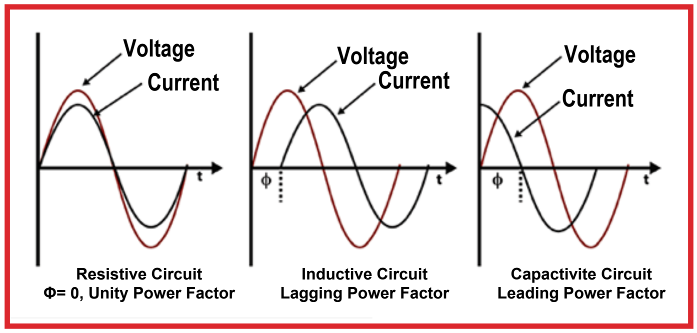
Two items that are often included in a metrology IC's measurement suite are *Power Factor* and *Crest Factor*. The purpose of this paper is to define these measurements, explain how they can shed light on the power condition of the branch circuit, and what these measurements tell us about the connected electronic loads.

Power Factor

Power Factor can be defined and interpreted in many ways; however, they are all interconnected. But before we get to the definition of *Power Factor*, let's first define *Power*. Power most simply, is the rate at which electrical energy is converted to another form (heat, mechanical energy, or energy stored in electric and magnetic fields), and is defined as Voltage across an electronic load (V) multiplied by the Current through the electronic load (I). This mathematical expression V * I describes the Power consumed by the electronic load and is very easy to visualize in a DC or Direct Current circuit. In a DC circuit, the voltage is a constant number and the current is a constant number. So, it is easy to see that the power consumed is also a constant number.



However, in an AC or Alternating Current circuit, calculating the power consumption is much more complicated. While DC voltage is constant, AC Voltages are constantly varying in a sinusoidal pattern. As you can see from the graph below, some electronic loads pull current at different points along the voltage waveform. Purely resistive electronic loads pull current in a sinusoidal pattern that "line up" or are in step with the voltage waveform. However, more complex electrical loads that are either capacitive or inductive in nature will pull current in a way in which the peak of the current draw either leads or lags the peak of the voltage waveform.



The classic definition of Power Factor is:

$$PF = \frac{\text{[Real or Actual Power Consumption]}}{\text{[Apparent Power Consumption]}}$$

Real/Actual power consumption is what an electronic load actually consumes while doing its job and is measured in Watts, while Apparent/Total power is a measurement of what the electrical source has to supply in order for the load to do its job and is measured in Volt-Amps or VA. The Power Factor is a number between 0 and 1, and at a value of 1, Real Power = Apparent Power. Therefore, Power Factor can be looked at as a measure of how efficiently an electronic device uses the electrical power that is delivered to it. (Note that Power Factor is not a measure of the efficiency of an electronic device, which is defined as the ratio of Energy Out/Energy In.)

In some cases, the current waveform is not sinusoidal at all. In fact, when an electronic load does not draw current in a sinusoidal pattern, it causes issues for the power company. The blue waveform below shows the current draw of a typical switch-mode power supply. Notice that the current draw has a high peak value. If we multiply peak current by the corresponding voltage at that point in time (which is also at a peak), the instantaneous power draw is very large. Multiply these by the billions of switch-mode power supplies powering all sorts of electronic devices these days, and you can see that at each peak point of voltage waveform, the power company must deliver a high amount of current, hence a high amount of power. The power company's capacity is determined by that peak amount, meaning as more electronic devices exhibiting this type of current draw are added to the grid, the more power plants need to be built.

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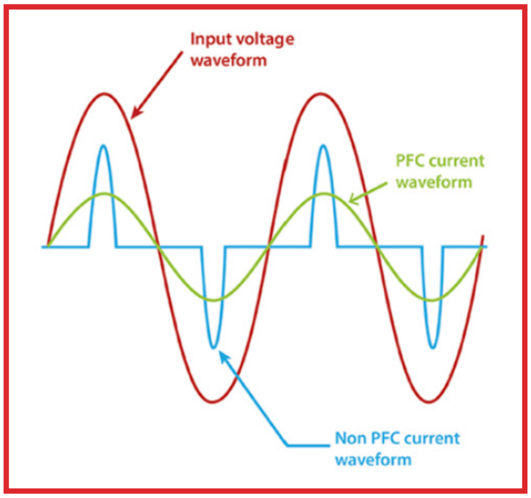
To help with easing this burden, Power Factor Correction (PFC) circuitry is utilized. The green waveform below is the current draw of the same switch-mode power supply, but with PFC circuitry added. Notice that the peak of the PFC current waveform is about half of the Non-PFC current waveform. What is not so obvious is that the average current draw (and thus the average power consumption) of the PFC and Non-PFC power supplies is the same. The load is consuming the same amount of power in either case, but the peak power is lowered using PFC.

PFC circuitry not only helps the power company by lowering instantaneous demand, but it also helps the consumer. If sophisticated smart power meters are utilized, power rates are based on peak power consumption rather than average power consumption, so lowering the peak consumption will reduce rates.



However, another usage of Power Factor comes into play when comparing capabilities of Uninterruptable Power Supplies or UPS's. The PF rating of a UPS gives an indication of how much Real Power a UPS can deliver.

Most companies will rate their UPS's based on its Apparent Power capabilities rather than its Real Power delivery because the Apparent Power rating is always a higher number. However, the Real Power that the UPS can deliver is defined as [Apparent Power] x [Power Factor]. For example, UPS A with a 2150VA rating on the surface may seem like it can deliver more power than UPS B with a 2000VA rating. However, UPS A has a Power Factor of 0.75 while UPS B has a Power Factor of 0.9.

UPS A: 2150VA x 0.75 PF = 1720 Watts of Real Power Delivery
UPS B: 2000VA x 0.9 PF = 1800 Watts of Real Power Delivery

Measuring the Power Factor of a connected load can also give some insights into the health of the equipment. If the average PF is known or is measured over time and there is an abrupt change, it could be an indication of an issue with the connected load's power supply and possible premature failure.

Crest Factor

The Crest Factor (CF) is another mathematical relationship that is used by electrical engineers to analyze waveforms. In some cases, CF is used to characterize the quality of a waveform, and in other cases CF is used to show if a waveform contains a great deal of peaks.

Crest Factor is defined as:

$$\text{CF}= \frac{\text{[Peak Value of Waveform]}}{\text{[RMS Average Value of Waveform]}}$$

CF can be measured for any type of waveform such as a square wave, triangle wave, or even DC electrical signals. For DC, the CF by default is 1 because the Peak Value = Average Value. But in AC power systems, voltage is produced as a sine wave, so the calculation is a bit more complicated.

A quantity called Root Mean Square, or RMS, is used to describe a type of average value of a time-varying signal. For pure sine waves, the RMS value is [Peak Value] / [$\sqrt{2}$]. If the Peak Value is 1, then the RMS Average is 0.707. However, if you rearrange the formula one can solve for a theoretical CF that is not dependent on the Peak Value:

$$\text{CF}= \frac{\text{[Peak Value]}}{\text{[Peak Value]}/[\sqrt{2}\,]}$$

$$\text{CF}=\sqrt{2}$$

$$\text{CF}=1.414$$

This means that if the sine wave is a perfect sinusoid, then the CF, regardless of its peak value, should be 1.414, and cannot go above 1.414.

While the above explanation assumes that the waveform is sinusoidal, it should be noted that CF can be calculated even on non-sinusoidal waveforms given the right test equipment. Meters with the capability of measuring both the Peak Value well as the Ture RMS Average Value of a waveform are commonly available. Also, note that if the waveform is non-sinusoidal, CF can go well above 1.414. This is an indication that the peaks of the waveform are much higher than the RMS Average Value of the waveform. This will come into play later when we discuss the difference between Voltage CF and Current CF.

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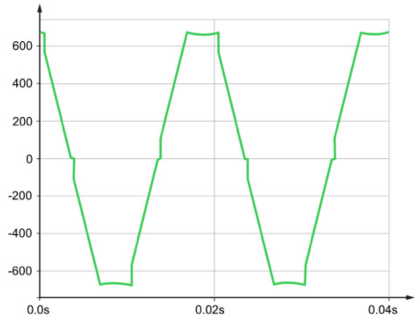
Voltage Crest Factor



Voltage waveforms associated with Power distribution start out sinusoidal but are often not perfect by the time they get to the point of use. A common issue in AC electrical systems is called "Flat-Topping". Flat-Topping occurs when the resistance of the wire in the branch circuit (wire that connects the breaker panel to the outlet) is too high due to a combination of the length and gauge (thickness) of the wire. When high peak currents are drawn, such as in the Non-PFC switch mode power supply shown earlier, instead of reducing the entire sinusoidal voltage waveform proportionally, only the top gets "clipped" off. In this case, the Peak Value is lowered, resulting in the Voltage CF being less than 1.4.

Monitoring Voltage CF is a great way detect possible issues with building wiring. For instance, if an unloaded electrical branch circuit shows a Voltage CF of near 1.4 and it changes to some number less than 1.1 when an electronic load is plugged in, this may be an indication that the branch circuit wiring is either near or over its maximum power transfer capability. This is a common problem when wire length is too long for the wire gauge used. In this case, the remedy would be to run a new wire using a larger wire gauge.

Crest factor measurements detect potential wiring and loading concerns that a simple voltage measurement will not identify. For example, a basic voltage measurement may yield 115V, which is within -5% of a nominal 120V, and seemingly implies a normal, healthy circuit. But let's say that the CF measurement is 1.38-1.39 – this implies an overloaded or underserved circuit whose equipment may be experiencing a more severe voltage reduction during the time they pull power, which is at the peaks!

Current Crest Factor

While the voltage waveform in power distribution is generated as a sine wave, the current draw by an electronic load may or may not be sinusoidal. Purely Resistive loads will pull current in a sinusoidal pattern, but everything else, such as switch-mode power supplies in the above example, will pull current in non-sinusoidal patterns. This means that Current CFs will often be well above the 1.414 value we see for Voltage CFs.

Current CF measurements can be used in a variety of ways. For instance, electronic loads with Current CF's above 3 indicate that the load is probably not Power Factor Corrected and pulls current in peaks.

Most circuit breakers in use today are thermally-triggered mechanical switches. The thermal trigger looks for sustained amounts of current above its trip point in order to actuate. In some cases, electronic loads that pull current in peaks will heat up the thermal trigger and inadvertently trip circuit breakers. Therefore, devices with a high Current CF may account for unintended circuit breaker trips.
Current CF is also used to characterize the performance of a UPS. Since CF is defined as the ratio of Peak Value to RMS Average Value, UPSs with high Current CF have the ability to supply the required current to loads that may not be Power Factor Corrected and pull current in peaks. If a UPS does not have a high Current CF and an electronic load is connected that pulls current in peaks, the UPS may inadvertently limit the current supplied, and distort the voltage waveform presenting unwanted harmonic distortion to the electronic load.

SUMMARY:

- The Power Factor of an electronic load is a number between 0 and 1 and is an indication of how efficiently it makes use of the AC electrical supply but is not a measure of how efficient it is in terms of energy usage.
- Monitoring and detecting drastic changes to the Power Factor of an electronic load could indicate that the load has been damaged in some way or is close to failure.
- The Power Factor rating of a UPS indicates how much true power the UPS can deliver.
- The Voltage Crest Factor in an AC power system is an indication of the quality of the voltage waveform being presented to the electrical load.
- The Voltage Crest Factor in an AC power system is an indication of the loading of the circuit.
- The Current Crest Factor in an AC power system is an indication of how an electronic load pulls current.
- Loads with high Current CF can inadvertently trip circuit breakers.
- UPSs should be chosen with high Current CF capability in order to supply current to all loads without distorting the voltage waveform.