Power Factor Vs. Crest Factor: Critical Application Quantities

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Introduction

Two critical quantities to specify when dealing with AC power sources are the power factor (PF) and the crest factor (CF). While both are different in their meaning, each provides insight about the capability of the equipment. Power factor refers to the general efficiency of a system. Crest factor describes the ability of an AC power source to generate current or voltage at a particular level. This paper will attempt to define each metric and explain how they relate to electrical systems.

I Have the Power!

The concept of power is derived from the fact that a change in energy will result in work being performed. The term “work” in this case does not mean showing up at the office from 9am to 5pm but rather refers to a change in energy. Picture a horse pulling a buggy behind it. If the horse is standing still, there is no change in energy because the horse is not moving. However, once the horse starts to walk, it begins to expend energy. This change in energy means that work is being done. Power is simply the energy or work expended over a certain period of time.

Power = Work/time

Power in an electrical sense is quite similar. In this case, voltage is the horse doing the work to move electrons, or current through a circuit. Current is a rate which measures the number of charges that pass through a circuit per unit time. Multiplying these two quantities together gives energy dissipated over time. This makes sense because the desired effect is to generate power in order to perform some type of work. Whether it is to drive a motor on a production line or to start your car, energy is required in order to perform these actions.

Power can be expressed by the following formula:

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

AC vs. DC Power

In a DC circuit, power analysis is simple because both voltage and current are constant (fig. 1).

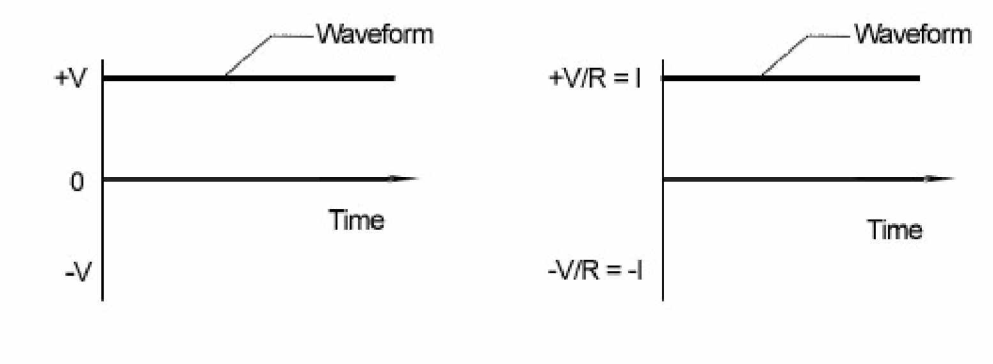

Fig. 1: DC Signal

For example, the circuit in Fig. 3 shows a DC source connected to a 12Ω resistor. The source provides 12V of DC voltage and there is 1A of current flowing through the resistance. The power in the system is P = (12V)*(1A) = 12W. However, if the system is supplying an AC voltage rather than a DC voltage, the behavior drastically changes.

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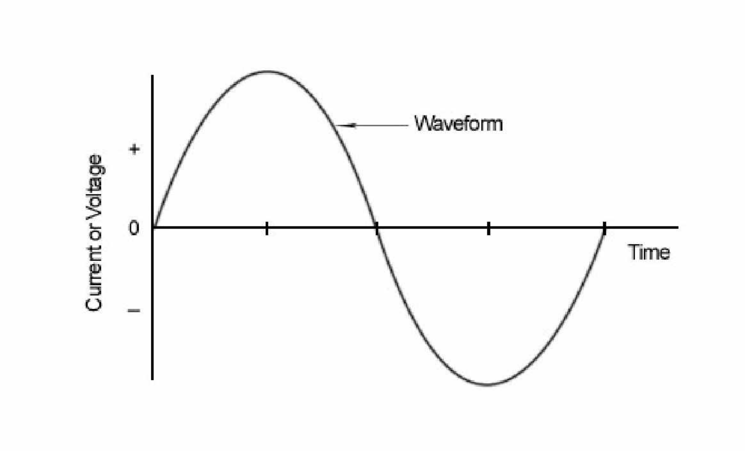

Fig. 2: AC Waveform

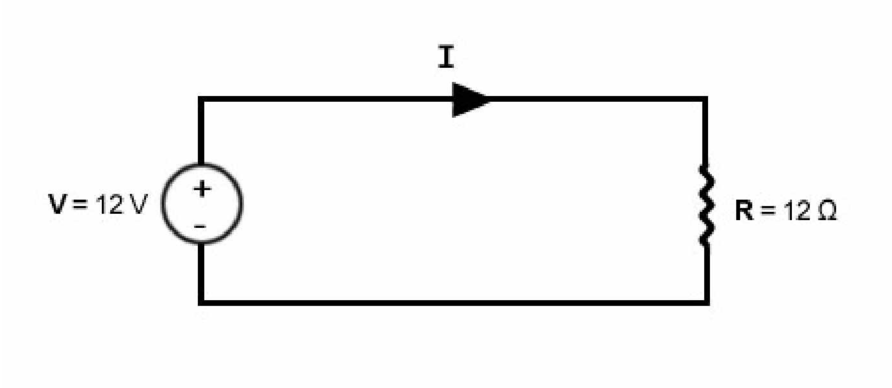

Fig. 3: Simple DC Circuit

An AC waveform is shown in Fig. 2. In an AC system, both voltage and current will be sinusoidal in nature. This means that the amplitude of the signal continually changes. Since the voltage and current are constantly changing the resulting power will also change over time. An example waveform is shown in Fig. 4. The voltage and current are said to be “in phase” with one another because the peaks match with the peaks and the zero points match with the zero points. When an electrical circuit has a purely resistive load, voltage and current will always be in phase. Power that results from a purely resistive load is known as “true power” and it is measured in watts (just like a DC circuit). However, the universe is an imperfect place with constantly changing forces.

The introduction of other circuit components such as capacitors and inductors will actually cause a shift between voltage and current. When this happens, the voltage and current will no longer line up and the analysis becomes messy.

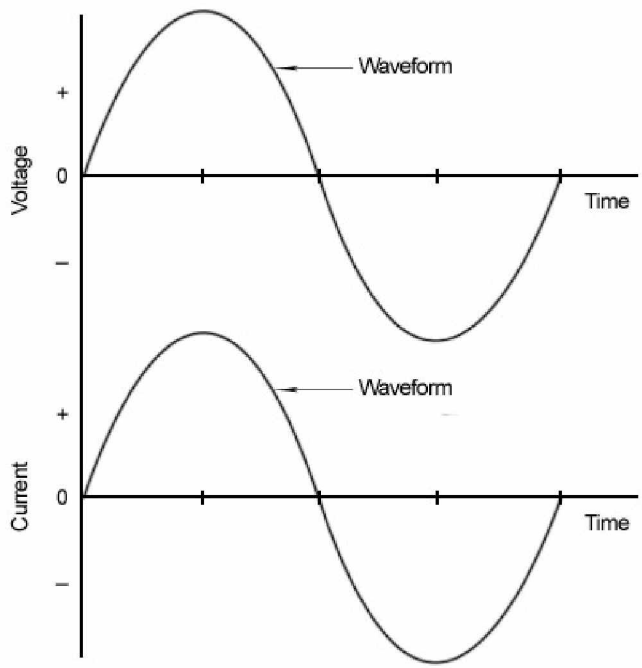

Fig. 4: In Phase Voltage and Current Signals

A shift between the voltage and current waveform caused by these circuit components is known as a phase shift. A purely capacitive or inductive load will cause a 90 degree phase shift. As shown in Fig. 5, such a system actually results in zero average power. This is because capacitors and inductors cause what is known as “reactive power”. This type of power actually counteracts the effects of the true power supplied to the system. If there is no true power, all the power in the system is reactive and no work is performed. Thus in any system, it is beneficial to maximize true power while mitigating the effects of reactive circuit components.

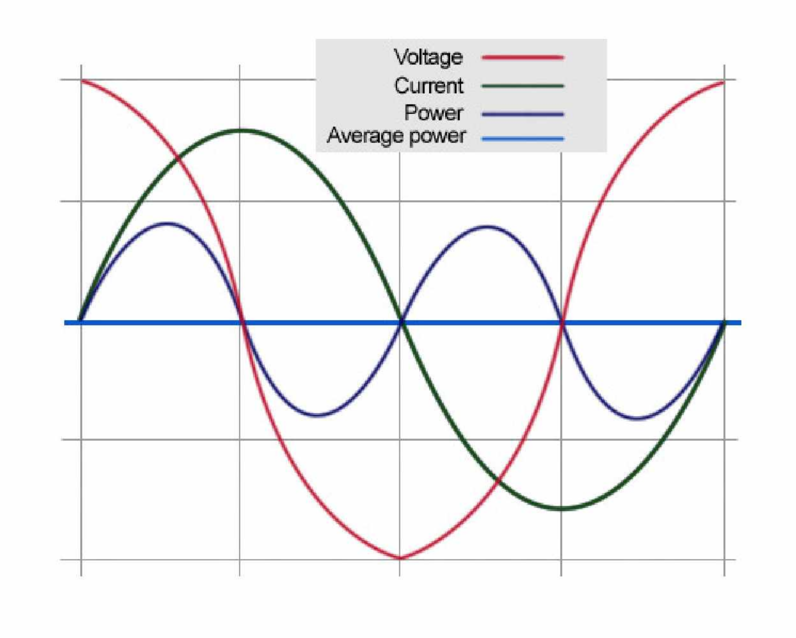

Fig. 5: Voltage, Current and Resulting Power waveforms

In reality, most systems are a combination of resistive, capacitive and inductive elements. As a result, there will be a combination of true and reactive power in nearly any application. Taking both reactive and true power into account, the combined value is known as apparent power. The relationship between these three values is shown in Fig. 6.

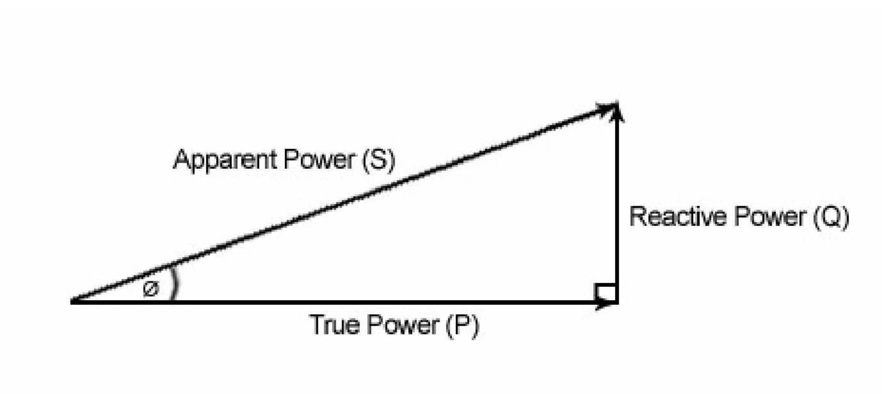

Fig. 6: The Power Triangle

P is the true power measured in Watts, Q is the reactive power measured in Volt-Amps Reactive (VAr) and S is the apparent power measured in Volt-Amps (VA). These quantities can be used to describe the efficiency of a system. Since the true power, P, performs work in the system and the reactive power Q takes away from the true power, S gives a measure of the total power out of the system.

Power Factor: A Measure of Efficiency

In the last section, apparent power was described as the power than ultimately comes out of a system considering all sources and losses. In order to determine the efficiency of a system, the power that performs work (true power) is compared against the power out of the system (reactive power). Relating the two quantities, a value for efficiency can be expressed as a value called power factor (PF):

PF = **P/S** where PF is Power Factor, (P) is true power measured in watts and (S) apparent power is in Volt-Amps

Power factor is a quantity that is used to describe the efficiency of a system. In any electrical system, there will be power input into the system and power output from the system (fig. 7).

Fig. 7: Power Input and Ouput

The ratio of the power input to the power output gives the power factor of the system. It can be expressed more simply by the following formula:

PF = Output Power/Input Power

For example, 1000W of power must be sourced in order to drive a motor that outputs 800W. This means 200W of power are lost in the system. The power factor of this system would be PF = 800W/1000W = 0.80. If the power factor is then multiplied by 100%, the end result is the efficiency of the system. So a motor with a power factor of 0.80 would have an efficiency = 0.80*100% = 80%. Since there can never be more than 100% efficiency on a system, the power factor will always be a number between 0 and 1.

The above example outlines how an electrical system is rated for efficiency. A broad spectrum of electronic equipment utilizes power factor as a specification to indicate efficiency including motors, transformers and utility systems. Knowledge of this value is important when building electronic systems or specifying electrical equipment because it tells the user how much power they need to supply in order to get the needed output power for a given application. It also gives a measure as to the cost of supplying such power. Certain utility companies in the U.S. charge a penalty on a monthly bill if the customer's overall power factor is below 0.98. The reason is because it costs the utility company extra to generate the necessary power in order to provide the customer the power necessary for their needs.

Crest Factor

Crest factor and power factor are both ratios that relate one quantity to another. They also both can be used to relate the general "effectiveness" of a signal. Crest factor is the ratio between the peak value of a waveform to its root mean square (RMS) value:

CF = Pk/RMS where CF is Crest Factor, (Pk) Peak is in volts or amps and (RMS) root mean square is in volts or amps

Why would the relationship between the peak value and the RMS value of voltage or current be important? In order to answer that question, consider what the term RMS actually means. It is often said that RMS is the effective DC value of an AC signal. Since a DC voltage is essentially constant over time, the work performed at the load for a DC voltage is also constant. However, an AC signal is constantly changing in amplitude over time. Therefore the work done at the load is also constantly changing. So the desired effect is to have the DC signal perform the same amount of work as the AC signal.

Think about this in terms of heating a thermal coil. Say that the coil is connected to a DC source and heated to a specific temperature. It will take a certain DC voltage in order to heat the coil to this desired temperature. Now the DC source is removed and an AC source is connected instead. The AC voltage that is required to heat the coil to that exact same temperature as the DC voltage is the RMS value of the AC voltage. It is the "effective" amount of voltage (i.e. energy) needed to perform the same amount of work at the load as the DC voltage. Most AC voltages specified on products are RMS values of voltage. For example, potential from a wall socket in the U.S. is 120VAC RMS. It lets the user know the effective value for that constantly changing voltage waveform. The graphical relationship between AC peak, AC RMS and DC is shown in figure 8.

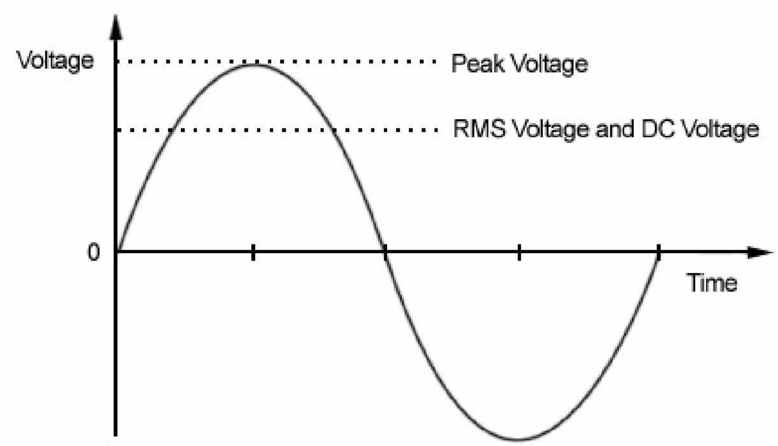

Fig. 8: AC Peak, RMS and DC

If an electrical signal is a pure sinusoidal wave, the peak value for voltage or current is 1.414 times the RMS value. So the crest factor for a pure sinusoid is 1.414. The crest factor for a DC signal would simply be 1 because the peak and RMS values are the same. An end user that requires a nearly pure sine wave for signal analysis would want a source that could supply a near perfect sine wave. They would want a source with a crest factor as close to 1.414 as possible. However, the reality is that most generated signals are not perfect in nature. Interactions between the supply and load (with all components in between) will cause distortions to signals and thus affect the relationship between the peak and RMS values.

The "optimal" value for a crest factor depends upon the application. Consider a power source as an example. An APT 6020 AC/DC power source has a specified crest factor of ≥3.The maximum allowable current for this source at 110VAC is 18.4A. The crest factor rating is telling the user that the power source can handle 3 or more times the rated current for a short period of time. So with a crest factor of ≥ 3, the 6020 can actually output more than 18.4A. Given that:

CF = 3 = Peak Current/RMS Current

and it is known that the RMS current is 18.4A, this means that:

Peak Current = 3*18.4A = 55.2A.

In this case, the crest factor is actually referring to the fact that the source can output "peaks" of current up to three times or more than the rated current. So if the user needed a source that could handle a large inrush current, this source would be a good fit for the application.

In looking at the above example, one might think that a higher crest factor is always desirable because the source has a greater capability to supply voltage or current than the rated value. However, this is not always so. As mentioned above, crest factor is the result of the interaction between source and load. So a limitation on this value could apply to the load. If a product has a rated current draw of 20A but a crest factor of 4, it could possibly draw up to 4*20A = 80A of current. If the power source did not have fail safe circuits to immediately shut off, the source could be damaged due to the high crest factor of the product. In such cases, it is important to consider the crest factor of the load as well as the source.

Conclusion

Power factor and crest factor both specify important capabilities of an electrical system. The power factor tells the user how efficient a particular product is at converting energy from one form to another. The lower the power factor, the greater the power that must be supplied to the system, and the lower the efficiency of the system. Crest factor relates the peak value of a signal to its root mean square value. This tells the end user not only the "purity" of a signal but also the capability for a system to output a particular voltage or current. Both quantities are important when determining the workings of an electrical system.