Chroma Systems Solutions, Inc.

AC Power Definitions

615xx, 616xx, 617xxx, 646x, 64xx, 65xx Series Programmable AC source

Keywords: Peak, RMS, Phase, Inrush Current, Power Factor, Crest Factor, Apparent Power, True Power, Volt-Ampere

Title: # AC Power Definitions

Product Family: **615xx, 616xx, 617xxx, 646x, 64xx, 65xx Series Programmable AC source**

Scope

There are a wide variety of terms used in conjunction with AC power and circuits. Today's generation of AC programmable sources feature a wide variety of parameters that can be displayed and recorded. This application note discusses the various terms associated with AC power and AC programmable sources.

Peak

The peak value of a signal is the magnitude of the largest positive value or negative value.

RMS - root-mean-square

The effective or rms value of a sinusoidal signal is important in calculating real and reactive power. For a sinusoidal signal the *RMS = (0.707) * Vpeak*. The RMS value F_{rms} of most periodic functions *f(t)* can be determined by the formula below.

$$F_{\mathrm{rms}} = \sqrt{\frac{1}{T}\int_{t_0}^{t_0+T} f^2(t)\,dt},$$

Note: For a DC signal peak, average and RMS values are all the same.

Phase

Phase is the angular relationship between current and voltage in an AC circuit.

For a purely resistive circuit, voltage and current are in phase

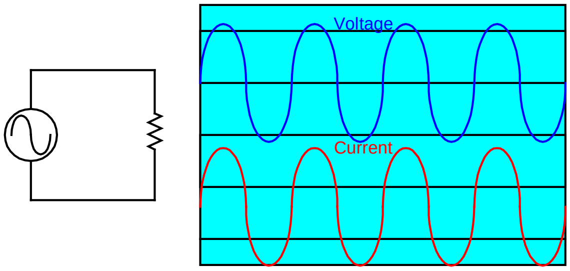

Figure 1. Phase Relationship for Resistor

For a purely capacitive circuit, current leads voltage by 90 degrees (ICE).

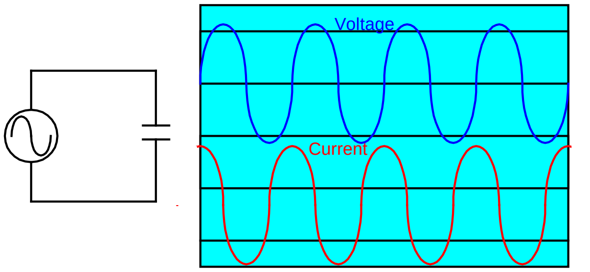

Figure 2. Phase Relationship for Capacitor

For a purely inductive circuit, voltage leads current by 90 degrees (ELI).

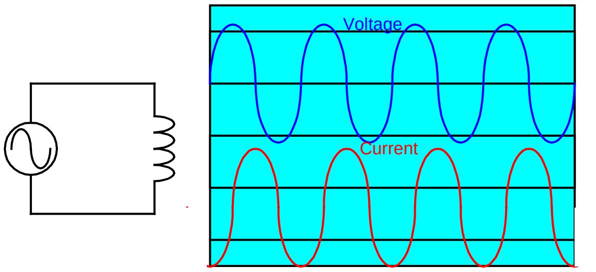

Figure 3. Phase Relationship for Inductor

Average

Average value is often referred to as the DC component of the signal. A sinusoidal signal has an average value of zero. The average value of a signal can be determined using the following formula.

$$V_{avg} = \frac{1}{T}\int_{0}^{\infty} v(t)dt$$

Average Voltage Equation

Inrush Current

When a power is first applied to a device the initial current draw can be several times more than the steady state current. This initial current draw is referred to as inrush current.

Devices such as switching power supplies, motor and compressors have very high inrush current that can be up to 20 times the steady state current. The inrush current can last from several milliseconds to hundreds of milliseconds.

Measuring this inrush current is important during the design of devices for compliance with various standards and design considerations such as wire size and fuses.

Thermistors are devices whose resistance changes with temperature. Negative Temperature Coefficient (NTC) thermistors are a popular device for reducing inrush current. In the case of NTC thermistors the resistance is high to start and decreases with temperature. This allows the device to limit inrush current on initial start up when the NTC thermistor is cold, then decrease resistance once steady state operation has been achieved. NTC thermistors are popular due to their low cost, and are available in a wide variety of currents rating from less than 1 A to over 36A. It is important to correctly size the thermistor for current to avoid overheating and damage.

Figure 4. NTC Thermistor

Most AC power sources have the capability of measuring inrush current as well as steady state RMS current.

Power Factor

The power factor of a signal is defined as the ratio of true power to apparent power. So the ratio of Watts to VA. For a purely resistive circuit the power factor is 1 and for a purely capacitive or inductive circuit the power factor is zero. It is desirable to have loads and power supplies with a power factor as close to 1 as possible. The reason being is reactance does not dissipate power so there is no ability to do work. That is not to say that reactance cannot be useful in the design of circuits and electronic products. For example, it would be highly desirable to have transmission lines that have a power factor of 0 so there is no loss.

The power factor can also be determined by the Cosine of the phase angle between resistance and reactance in a circuit or true power and reactive power.

Crest Factor

The crest factor of a signal is defined as the ratio of the peak value to the rms value of the signal. A true sinusoidal signal has a crest factor of 1.414.

Apparent Power

Apparent Power is a measure of alternating current (AC) power that is computed by multiplying the root-mean-square (rms) current by the root-mean-square voltage. In a direct current (DC) circuit, or in an AC circuit whose impedance is a pure resistance, the voltage and current are in phase, and the following formula holds:

$$P = E\text{rms}I\text{rms}$$

where P is the power in watts, Erms is the root-mean-square (rms) voltage in volts, and Irms is the rms current in amperes. But in an AC circuit whose impedance consists of reactance as well as resistance, the voltage and current are not in phase. This complicates the determination of power.

In an AC circuit, the product of the rms voltage and the rms current is called *apparent power*. When the impedance is a pure resistance, the apparent power is the same as the true power. But when reactance exists, the apparent power is greater than the true power. The vector difference between the apparent and true power is called reactive power.

If *P*a represents the apparent power in a complex AC circuit, *P*t represents the true power, and *P*r represents the reactive power, then the following equation holds:

$$P_a^2 = P_t^2 + P_r^2$$

True Power

True Power is the power manifested in tangible form such as electromagnetic radiation, acoustic waves, or mechanical phenomena. In a direct current (DC) circuit, or in an alternating current (AC) circuit whose impedance is a pure resistance, the voltage and current are in phase, and the following formula holds:

$$P = E_{rms} I_{rms}$$

where *P* is the power in watts, *E*rms is the root-mean-square voltage in volts, and *I*rms is the rms current in amperes. But in an AC circuit whose impedance consists of reactance as well as resistance, the voltage and current are not in phase. This complicates the determination of power.

In the absence of reactance, this voltage-current product represents *true power*. But when there is reactance in an AC circuit, the product *E*rms*I*rms is larger than the true power, and is known as apparent power.

The vector difference between the apparent and true power is called reactive power, and represents energy alternately stored and released by an inductor and/or capacitor.

Volt-ampere

Volt-ampere (VA) is a measurement of true power in a direct current (DC) electrical circuit. The VA specification is also used in alternating current (AC) circuits, but it is less precise in this application because it represents apparent power, which often differs from true power.

In a DC circuit, 1 VA is the equivalent of one watt (1 W). The power, *P* (in watts) in a DC circuit is equal to the product of the voltage *V* (in volts) and the current *I* (in amperes):

$$P = VI$$

In an AC circuit, power and VA mean the same thing only when there is no reactance. Reactance is introduced when a circuit contains an inductor or capacitor. Because most AC circuits contain reactance, the VA figure is greater than the actual dissipated or delivered power in watts. This can cause confusion in specifications for power supplies. For example, a supply might be rated at 600 VA. This does not mean it can deliver 600 watts unless the equipment is reactance-free. In real life, the true wattage rating of a power supply is 1/2 to 2/3 of the VA rating.

When purchasing a power source such as an uninterruptible power supply (UPS) for use with electronic equipment (including computers, monitors, and other peripherals), be sure the VA specifications for the equipment are used when determining the minimum ratings for the power supply. The VA figure is nominally 1.67 times (167 percent of) the power consumption in watts. Alternatively, you can multiply the VA rating of the power supply by 0.6 (60 percent) to get a good idea of its power-delivering capability in watts.

Volt-Amp-Reactive (VAR)

Magnetic loads like motors can draw more VA power than actual real power. The extra component is called a Volt-Amp-Reactice (VAR). A VAR is basically magnetic power which causes a phase shift between voltage and current curves. This phase shift between voltage and current reduces the overlap between the two curves and effectively delivers less power to the loads. See Figure 5 below:

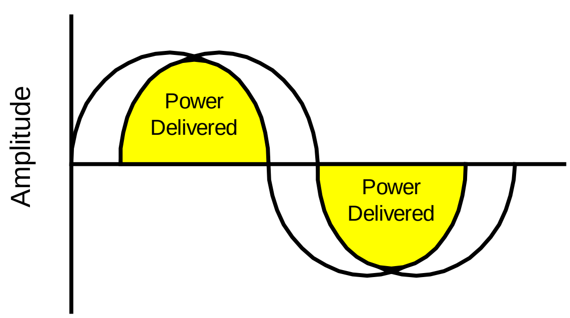

Figure 5: Delivered Power Voltage to Current Phase Shift

Difference Between VA & Watts

The purpose of this Tech Note is to clear up a common misunderstanding about the measurement of power in alternating current (AC) circuits. Most people with electrical experience have heard that power equals amps x volts. This is always true for direct current (DC) circuits, but the situation is more complicated with AC circuits. If an AC load is purely a resistive load, such as incandescent light bulbs and heaters without fans, then the power is indeed the product of volts and amps. However, in the world of alternating currents, there are three types of "power":

(A) Apparent power

The product of rms (root mean square) volts and rms amps. (VA, volt-amps)

(B) Real power

The time average of the instantaneous product of voltage and current (Watts).

(C) Reactive power

The time average of the instantaneous product of the voltage and current, with current phase shifted 90 degrees.

Volt-amps reactive (VAR) Apparent power (VA) is the easiest to measure. It is what you get when you measure the rms volts with one meter and the rms amps with another meter, and multiply the two.

P = V x A = VA

Equation 1 - Apparent Power

The measurements must be made with "True RMS" meters. Unfortunately, this does not represent the real power consumed by a "reactive" load such as a motor. A person may measure that a well pump consumes 120 V and 6 A. It would seem that this means it uses a total of:

P = 120 V x 6 A = 720 Watts

Equation 2 - Incorrect Calculation of Real Power

However, this is only a calculation of apparent power, which is really measured in VA and is not equal to the real power consumed. The well pump has a power factor (PF) associated with it. PF is the ratio of real power to apparent power.

PF = Real Power / Apparent Power

Equation 3 - Power Factor

When the pump operates, it has some magnetic characteristics resulting in drawing a larger "apparent" power (VA) than "real" power (Watts). Measurement of the real power (definition B above) requires the use of special instruments. There is an older style of meter called an electrodynamic wattmeter which can measure real power; a modern equivalent would be the Fluke model 41 power meter. The Fluke meter can only achieve an accuracy of a few percent because of its use of a clamp-on current probe. Accuracy of less than 1 percent will require avoiding the clamp-on probe for measuring the current. The Fluke 41 also measures the "power factor" (PF), which is the real power divided by the apparent power. If the well pump’s PF is 0.8 this could be used to calculate the real power by:

P = 120 V x 6 A x 0.8 = 576 Watts

Equation 4 - Correct Calculation of Real Power

Therefore, it is correct to calculate AC Watts by:

P = V x A x PF = Watts

Equation 5 - Real Power

The PF is used to compute real power. Real power is always expressed in Watts, while apparent power is expressed in VA. The reason real power is important is that the power consumed by an inverter from a battery is proportional to the real power delivered to the load, not the apparent power. Two separate meters (measuring amps and volts) cannot measure the real power unless the load is purely resistive (for example, incandescent light bulbs or heaters without fan motors).

Graphical Representation of Real Power, Reactive Power, Apparent Power and Power Factor

Real power, VA and VAR's are related as vectors, shown in the diagram below. The apparent power is the square root of the sum of the squares of the reactive power and the real power.

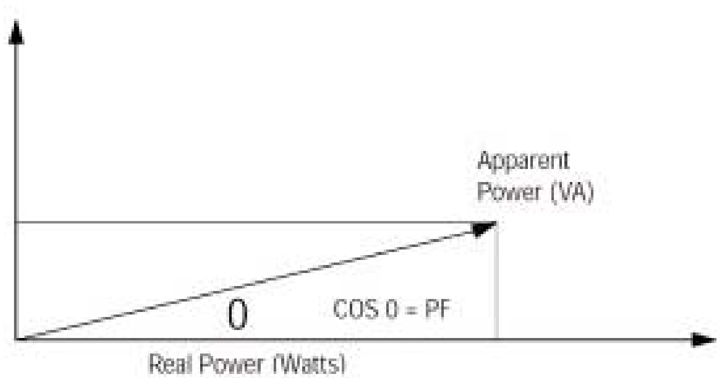

Figure 6: Relationship Between the Three Types of Power

The vector graph in Figure 6 illustrates the components of a power draw. The VAR component represents the reactive power component while the watt component represents real power. The combination of the two represents VA, the apparent power. The angle between the real power axis (horizontal) and the apparent power vector is theta. The cosine of angle theta is equal to the power factor, as identified in equation 3. Often, electrical equipment manufacturers will identify the power factor by cos (theta), rather than PF. Thus, when an inverter is operating loads with power factors less than 1, the inverter capacity is effectively reduced. If a 5000 VA inverter has a 5000 VA, 0.8 PF load connected, the real power output of the inverter is only 4000 watts. In this scenario, the capacity of the inverter is fully utilized, and the batteries will be drained as though we had a load of 4000 watts, the real power, and not 5000 watts, the VA on the battery bank. The efficiency in the previous example will be approximately that found on the inverter efficiency curve at the 5000 VA level. This is lower than the 4000 VA efficiency, even though the inverter is only providing 4000 real watts. This lower efficiency is the penalty associated with low power factor loads.

Load Regulation

Change in output voltage due to a varying load. Expressed as a percent of the normal output voltage, a power supply with tight load regulation delivers optimum voltages regardless of system configuration.

This is tested by measuring the difference in output voltage when applying a light load and a heavy load. Typical load regulation for most modern AC sources is 0.2%

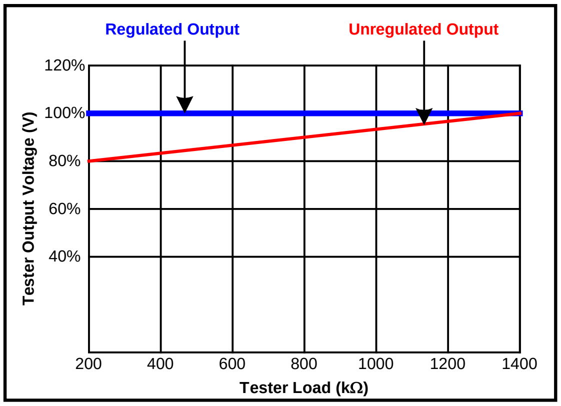

Figure 7: Load Regulation

Line Regulation

Line regulation is the change in output voltage due to varying input voltage. Expressed as a percent of the normal output voltage, a power supply with tight line regulation delivers optimum voltages throughout the operating range. This is tested by measuring the difference in output voltages while varying the input voltage from minimum to maximum, i.e., from 85 to 135 volts.

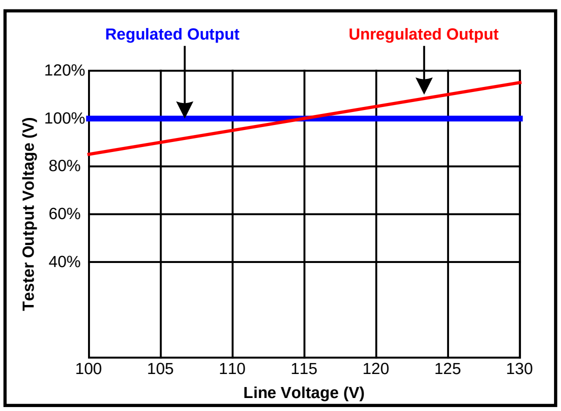

Figure 8: Line Regulation

Ripple

AC voltage superimposed onto the DC output, expressed as a percent of the normal output voltage or as peak to peak volts. A power supply with clean DC output is essential for computers with high-speed CPUs and memory.

Overpower protection

Circuit that shuts down the power supply if the output power exceeds a specified limit.

Overcurrent protection

Circuit that shuts down the power supply from excessive current, including short circuits.

Overvoltage protection

Circuit that shuts down the power supply if the output voltage exceeds a specified limit.

Remote Voltage Sensing

Sense leads can be used to eliminate voltage drop due to leads from the AC source to the DUT. Remote sense leads are used to monitor the voltage at the load instead at the output terminal of the AC source. This ensures an accurate voltage, as programmed, at the load by automatically compensating for the output voltage drop over the connecting cables.

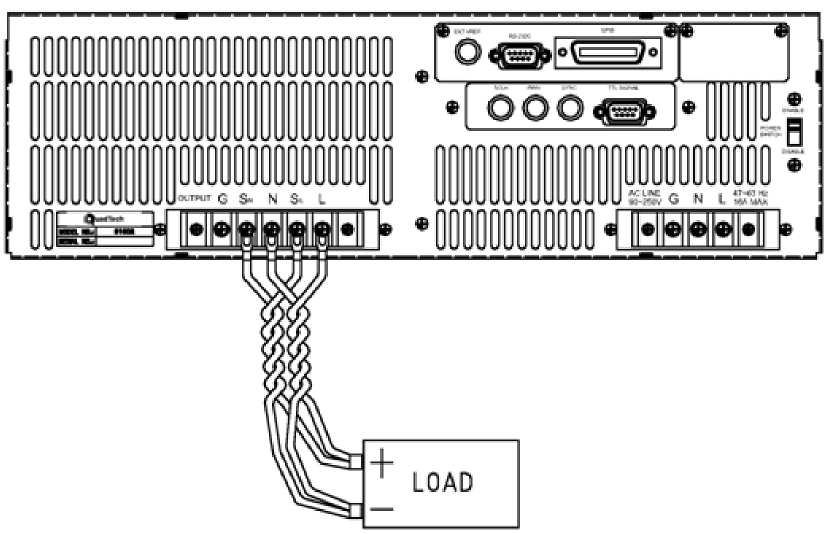

Figure 9: Chroma 61500 Series AC Source with Sense Leads connected to Load

Single Phase Power

Single phase power as stated earlier is the most commonly used power for residential applications in North America. Single phase power uses one conductor, line plus neutral. The load is placed between line and neutral conductors. The voltage is 120VAC L-N at 60Hz for North America. The color code for the U.S. is black for hot conductor and white for neutral. Residential wiring will also contain a ground which is a bare wire with no plastic insulation. Most household appliances such as refrigerators, blenders, toasters, radios, lamp etc operate at 120VAC single phase.

Split Phase Power

Split Phase power is actually what is delivered to most US households. There are three wires that connect into the utility meter on the residence. There are two hot wires each supplying 120VAC L-N which are black, and one neutral wire which is black and normally wrapped with white tape. The voltage measured between the two hot wires is 240VAC L-L.

Three Phase Power

There are three common types of power used in North America. Single phase and split-phase are most common to household power. Most power distribution uses polyphase system, typically 3-phase. 3 phase is primarily used because it is more economical and efficient than single phase distribution. 3 Phase power is also used in industrial applications where there is high power consumption.