Electrical Tech Note — 204

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Electrical Calculations

Direct Current: Common direct current circuits have two wires. One wire is positive (+) and the other wire is negative (-). Positive wires generally have a “red” marking and negative wires have a “black” marking. A direct current source such as a battery, solar photovoltaic cell, or a device called a fuel cell each have an output of two wires, one positive (+) and one negative (-). There are two common equations used to make direct current calculations. One equation is **Ohm,s law** that relates voltage, current, and resistance (see *Figure 204.1*). The other is the **power equation** which relates power, voltage, and current (see *Figure 204.2*). Power is measured in watts, voltage is measured in volts, and current is measured in amperes. Resistance is measured in ohms. In an equation the symbol for **volts** is the letter “**E**”, **current** in amperes is the letter “**I”**, **resistance** in ohms is the letter “**R**”, and **power** in watts is the letter “**P**.” An easy way to remember and use these two equations is shown in *Figure 204.1*.

Ohm’s law: **E = I x R** **Eq. 204.1**

Power equation: **P = E x I** **Eq. 204.2**

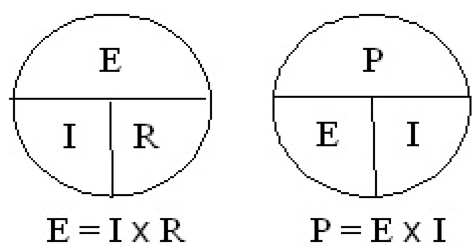

Figure 204.1 *These circles make it easy to figure out what equation is needed to determine whether to divide one by the other or to multiply one by the other. Cover up the quantity desires and the circle shows the equation. Example: To find current divide the voltage by the resistance. If power is known divide the power by the voltage to get the current.*

Sample dc equations: First consider Ohm’s law, *Equation 204.1.* If a dc circuit has 12 volts between the wires and the resistance of the wire is 2 ohms, the current flowing in the wire can be determined by dividing 12 volts by 2 ohms.

$$I = \frac{E}{R} = \frac{12V}{2\Omega} = 6amps$$

Here is how the power equation works. A solar module has an output of 30 volts and 8 amperes. Determine the solar modules output power. Multiply the 30 volts by 8 amps.

$$P = E \times I = 30V \times 8A = 240W$$

Alternating Current: An alternating current circuit does not have a wire that is positive or a wire that is negative. One wire has a voltage with respect to the earth or ground. The *National Electrical Code (NEC)* refers to this wire as the "ungrounded" wire. This wire can be black, red, blue, yellow, or any color other than green, white or gray. The other wire is intentionally grounded to the earth and it is called the "grounded" wire or the "neutral." Alternating current systems can be single-phase with two hot wires with 240 volts between the two wires. From each of the ungrounded (hot) wires to the neutral will be 120 volts. The neutral wire is required by the electrical Code to have white or gray insulation. For many calculations the power *Equation 204.2* works for some alternating current problems. Ohm's law works for both "dc" and "ac" calculations.

Sample "ac" example: Here is an alternating current calculation that can be solved using *Equation 204.2.* An electric heater has a rating of 1,500 watts powered at 120 volts. Determine the amount of current the heater will draw.

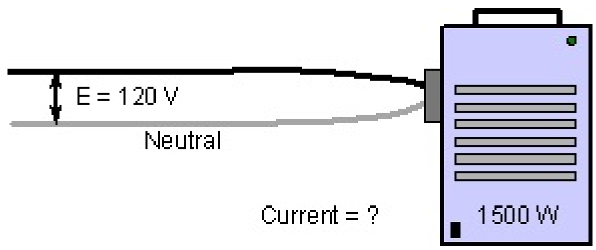

Figure 204.2 *Determine the current draw of this 1,500 watt 120 volt electric heater. Refer to the power equation in Figure 204.1.*

$$I = \frac{P}{E} = \frac{1500W}{120V} = 12.5Amps$$

The "dc" power equation does not work for many types of "ac" circuits because voltage and current in an "ac" circuit are each separate sine waves as illustrated in *Figure 204.3.* One sine wave is the voltage and a separate sine wave is the current. When the sine waves are aligned with each other like the left diagram in *Figure 204.3 the* power *Equation 204.2* works for an "ac" circuit like the previous calculation of an electric heater. For an "ac" load such as an electric motor the voltage and current sine waves are out of alignment as shown in the right diagram of *Figure 204.3.* In this case an additional number must be added to the power equation which is called the "***power factor.***"

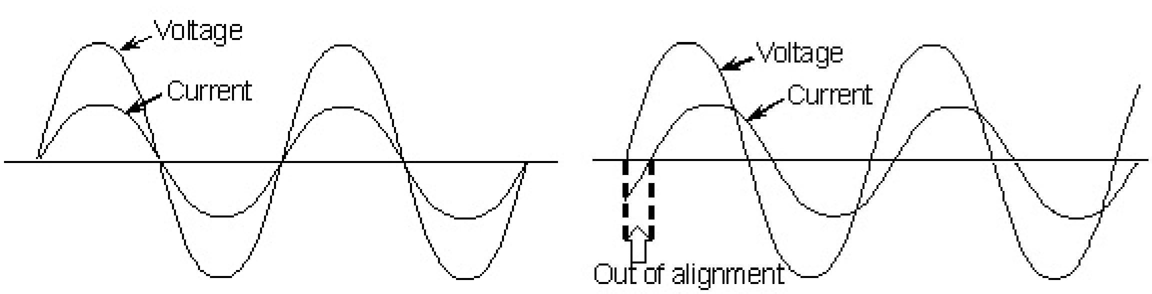

Figure 204.3 *For most "ac" circuits the voltage and current sine waves are out of alignment.*

Power Factor: When the current and voltage sine waves are not in alignmant the power of the circuit is a value smaller than the product of the voltage and current. Power factor (pf) has a value that ranges from 1.0 to 0.0. When the voltage and current sine waves are perfectly aligned the power factor is 1.0 (pf = 1). A typical device that has a ***power factor smaller than 1.0*** is an electrical motor. A single-phase electric motor powering a large load may have a power factor as low as (pf = 0.8). This power factor (pf) must be included as a part of the power equation (***Equation 204.3***). Consider a single-phase electric motor operating at 240 volts, drawing 40 amperes with a power factor of 0.8. (See *Figure 204.4*)

ac 1-phase power equation: $P = E \times I \times pf$ **Eq. 204.3**

Example: **P = 240 V x 40 A x 0.8 = 7,680 W**

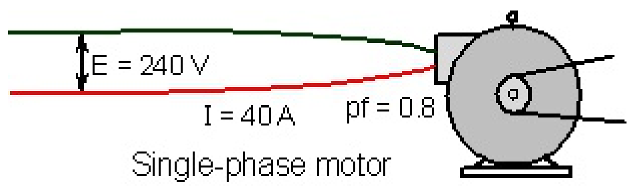

Figure 204.4 *This single-phase motor is powered at 240 volts and draws 40 amperes with a power factor of 0.8.*

Ac electrical devices may be single-phase or 3-phase. A single-phase electrical device is typically supplied with two current carrying wires. (There are some exceptions). A 3-phase device is typically served with three wires. The 3-phase power equation has an additional number in the equation which is 1.73. The 3-phase power equation is ***Equation 204.4.*** There is also an example of 3-phase motor powering a heavy load. The 3-phase motor is powered at 240 volts, draws 23 amperes, and has a power factor of 0.8. (See *Figure 204.5)*

3-phase ac power equation: $P = 1.73 \times E \times I \times pf$ **Eq. 204.4**

Example: **P = 1.73 x 240 V x 23 A x 0.8 = 7,640 W**

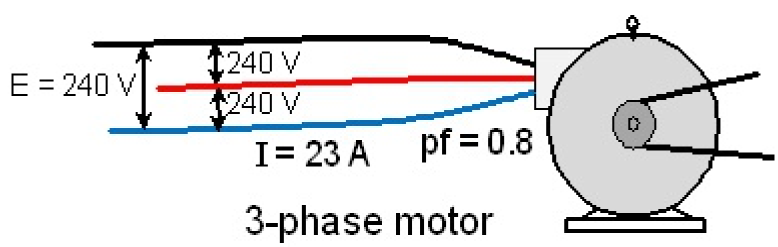

Figure 204.5 *This 3-phase motor is powered at 240 volts, and draws 23 amperes with a power factor 0.8.*

What causes power factor to be smaller than 1.0: Electric motors have internal windings that create strong magnetic fields that are required to make the rotor shaft turn. These strong magnetic fields are what causes the power factor to have a value smaller than 1.0. Some ac devices such as resistance type electric heaters do not create strong magnetic fields in the same ways as an electric motors so the power factor for these heating devices is considered to have a value of 1.0. An example of an ac resistance heating load is shown in *Figure 204.6.* This is a single-phase ac resistance heater powered at 240 volts and has a rating of 5,000 watts. In order to determine the size of wire and circuit breaker for the circuit the electrician must calculate the current draw of the heater.

$$I = \frac{W}{E \times pf} = \frac{5000W}{240V \times 1.0} = 20.8A$$

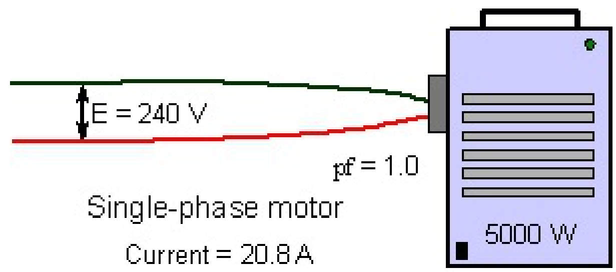

Figure 204.6 *Look at the single-phase power equation in Figure 204.7 and notice the wattage is above the volts and pf. This means the wattage is to be divided by the volts and power factor as shown in the calculation above.*

Power equations for alternating current circuits: To use these power diagrams put your finger over the variable you need to find. If your finger is over one of the variables in the bottom row divide the power by each of the remaining variables in the bottom row. If you want to calculate power simply multiply all of the variables in the bottom row.

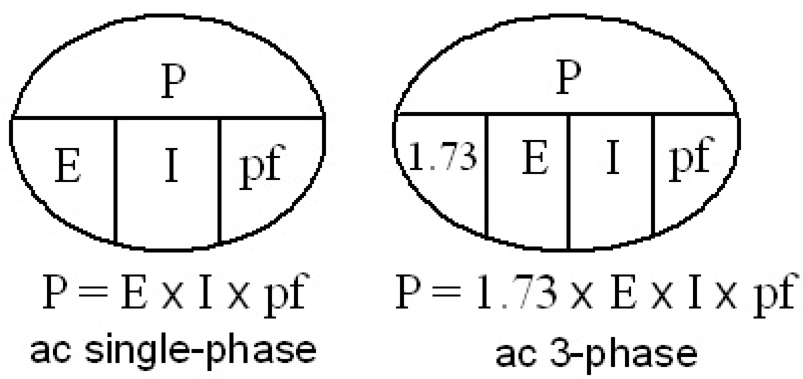

Figure 204.7 *The left diagram is single-phase and the right diagram is 3-phase. For a dc calculation just ignore the power factor and use the left diagram.*