Electrical Tech Note — 311

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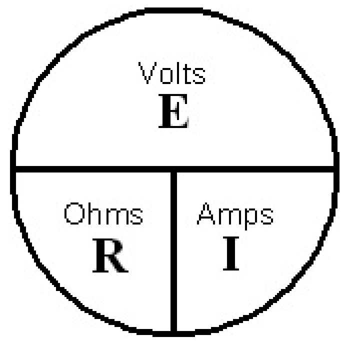
Terminology and Formulas

Ohm's Law: This is the linear relationship between voltage (E), current (I), and resistance (R). For a given conducting material, an increase in voltage will cause an increase in current flow.

Voltage (E) = Current (I) x Resistance (R)

$$\text{Current (I)} = \frac{\text{Voltage (E)}}{\text{Resistance (R)}}$$

$$\text{Resistance (R)} = \frac{\text{Voltage (E)}}{\text{Current (I)}}$$

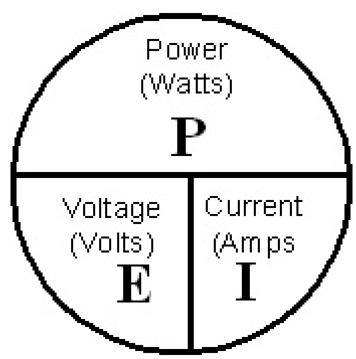


Power Formula: The power formula is the relationship between voltage, current and watts. This is a very useful formula, especially in the electrical trade. Power refers to how rapidly energy is used or converted into another form of energy. Electrical energy is expressed in either the watt or joules per second. The equations and illustration below is a special case of the power formula which only applies to direct current loads and certain alternating current loads such as incandescent light bulbs and electric heaters (resistive loads). This formula, as shown below, does not work for loads such as motors and fluorescent lights (inductive loads).

Power = Voltage (E) × Current (I)

$$\text{Current (I)} = \frac{\text{Power (P)}}{\text{Voltage (E)}}$$

$$\text{Voltage (E)} = \frac{\text{Power (P)}}{\text{Current (I)}}$$



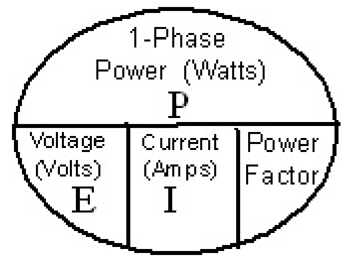
Power is the product of voltage and current, although in the case of an alternating current circuit, the voltage and current sine waves may be shifted in phase from each other by some angle theta (θ). The power factor in the formula accounts for the voltage and current being out of phase. The formula is different for single-phase and three-phase circuits. In the case of a direct current circuit, or an alternating current circuit where the load is an incandescent lamp or a resistance heater, the power factor is 1. In all other alternating current circuits, the power factor will be a number less than 1.

1-phase Power:

Power = Voltage (E) × Current (I) × Power factor (pf)

$$\text{Current (I)} = \frac{\text{Power (P)}}{\text{Voltage (E)} \times \text{Power factor (pf)}}$$

$$\text{Power factor (pf)} = \frac{\text{Power (P)}}{\text{Voltage (E)} \times \text{Current (I)}}$$



3-phase Power:

Power (P) = 1.73 × Voltage (E) × Current (I) × Power factor (pf)

$$\text{Current (I)} = \frac{\text{Power (P)}}{1.73 \times \text{Voltage (E)} \times \text{Power factor (pf)}}$$

$$\text{Power factor (pf)} = \frac{\text{Power (P)}}{1.73 \times \text{Voltage (E)} \times \text{Current (I)}}$$

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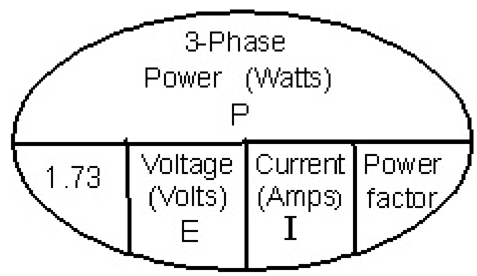

Resistive, Inductive, Capacitive Circuits: The current and voltage for a typical alternating current circuit can each be represented by a sine wave. When the circuit is powering a load such an incandescent lamps or a resistance heater (resistive loads), the current and the voltage sine waves are lined up perfectly with both sine waves reaching a maximum at the same time and being zero at the same time *(Figure 1a)*. Circuits powering loads, such as electric motors, have a significant amount of inductive reactance which causes the current and voltage sine waves to be out-of-alignment with each other. For an inductive circuit, the current sine wave will lag behind the voltage sine wave *(Figure 1b)*. The more the voltage and current sine waves are out-of-alignment the smaller the power factor in the power formula. This means the circuit wires and components must carry more current to deliver the same load. Capacitors can be added to a circuit to counteract the effect of the inductance in a circuit. Capacitive reactance in a circuit can be large enough to cause the current to actually lead the voltage *(Figure 1c)*.

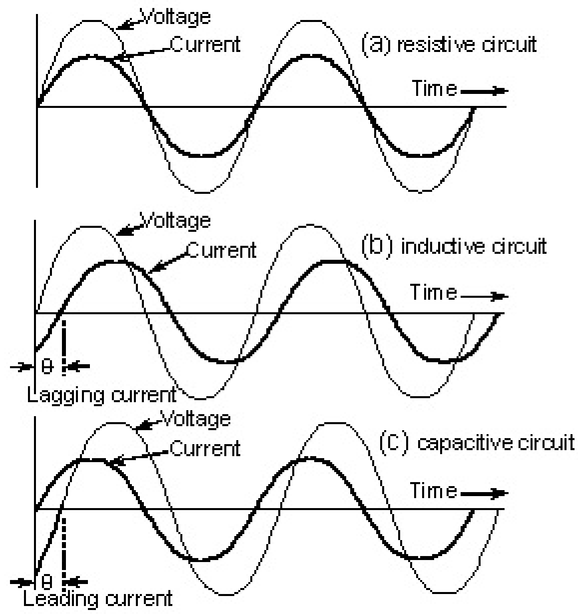

Figure 311.1 *The current and voltage in a circuit can both be represented by sine waves. For a resistive load such as an incandescent lamps (**a**) the voltage and current waves are lined up. With an inductive load such as for most motors (**b**), the current wave lags behind the voltage wave. When the circuit is capacitive (**c**), the current wave leads the voltage wave.*

Work: Work is the amount of energy expended to do a job or move a load. Force must be applied to lift or move an object. The greater distance the object is moved, the more work that is required. Work is the product of force (F) and distance (L) *(Figure 311.2)*. If the force is in pounds (lb) and the distance is in feet (ft), the units of work will be pound-feet (lb-ft).

Work = Force × Distance

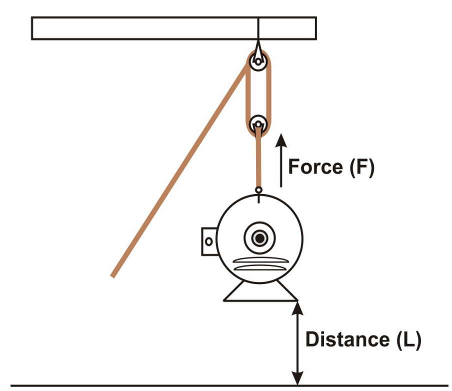

Figure 2 Work is the product of a force required to move a load and the distance the load was moved.

Figure 311.2 Work is the produce of force required to move a load and the diatance the load moves.

Torque: Torque is twisting force. It is force acting perpendicular to the end of a lever. A lever will have a turning point and will act as the radius of a circle with the force applied at the end of the radius (Figure 311.3). To get torque, multiply the force, by the length of the lever arm or radius. The symbol for torque is the Greek letter tau (τ). A common unit of torque in the English measurement system is pound-feet. In the metric system, the common unit is Newton-meters. Compare the formula for torque and work and note the difference , In one case, the force is acting over a distance and in the other the force is acting at the end of a radius. An engine or motor will produce torque at an output shaft. A device or machine that requires power will usually have a shaft to which a certain amount of torque must be applied. For example if a 5- pound force is placed at the end of a 2-foot torque arm the resultant torque would be 10 lb.-ft. (5 lb. x 2 ft.).

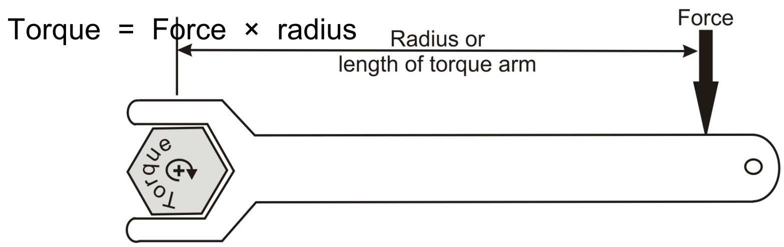

Figure 311.3 *Torque is a twisting force equal to the product of the force and the length of the torque arm or radius.*

Levers: Understanding the principles of levers is necessary to understanding couplings between the shaft of a motor and the shaft of a machine. A motor with a low power rating can operate the same machine as a motor with a higher power rating, it just cannot do the job as fast. Doubling the diameter of a pulley or gear on a machine drive shaft will result in the shaft turning at half the speed, but only half as much force will be required to turn the pulley or gear. The torque required to turn the shaft remains equal, that the as radius is doubled, only half the force is needed to maintain a constant torque. This rule abides by the principle of a lever. A person weighing 200 lbs. can lift a one ton weight by standing on a lever 10 ft from the fulcrum where the weight is only 1 ft from the fulcrum. The distance the person must be from the fulcrum in ths case is at least 10 times the distance from the fulcrum to the weight. The distance the person will move will be 10 times the distance the weight will move. The following formulas describe the action of a lever *(Figure 311.4)*.

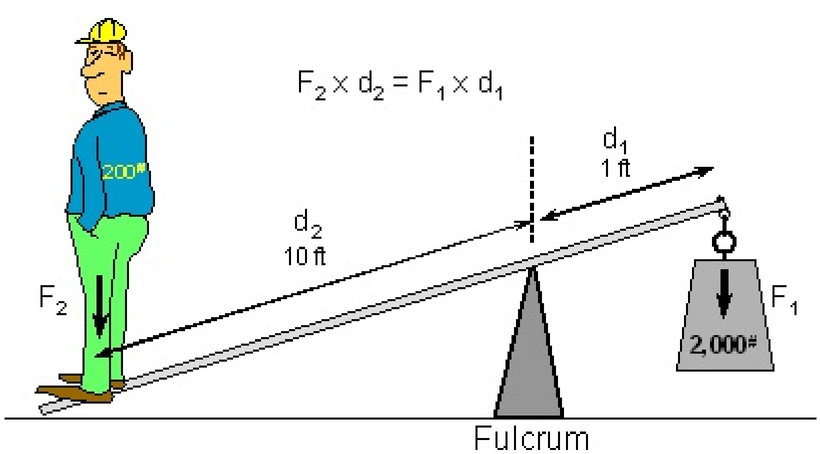

Figure 311.4 *A heavy weight can be lifted by applying a small force using a lever.*

Motor Mechanical Drives: When building or modifying machinery it is necessary to calculate the size of gears or pulleys required to run a piece of equipment at a certain speed. Speed adjustments can be made with gear drives or pulleys. A pulley can be used to change the output speed of a motor, provided the manufacturer limits are not exceeded. To determine the pulley size needed, the speed of the motor (motor rpm), the speed of the machine being driven (load rpm) and the diameters of the pulleys on both the motor and the machine being driven must be considered.

$$\text{Motor}_{\text{Pulley Diameter}} \times \text{Motor}_{\text{RPM}} = \text{Load}_{\text{Pulley Diameter}} \times \text{Load}_{\text{RPM}}$$

Example of Calculating Pulley Diameter

Examine *Figure 311.5.* What is the required load pulley diameter if a motor is running at 1,725 rpm has a 6 inch pulley and the load is to operate at 900 rpm?

$$\text{Load}_{\text{Pulley Diameter}} = \frac{\text{Motor}_{\text{Pulley Diameter}} \times \text{Motor}_{\text{RPM}}}{\text{Load}_{\text{RPM}}} = \frac{1{,}725 \text{ rpm} \times 6\text{-inch}}{900 \text{ rpm}} = 11.5 \text{ inch}$$

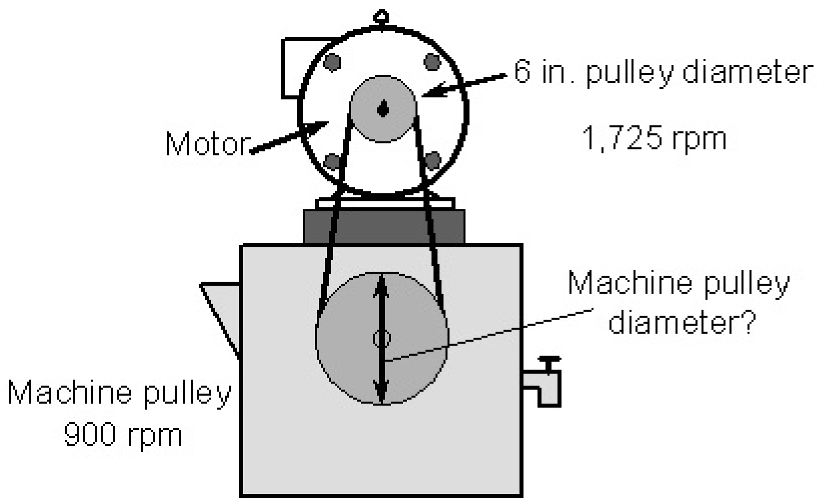

Figure 311.5 *A pulleys can be used to change the output speed of a motor.*

Electrical Energy Units: Electrical energy is sold in units of kilowatt-hours. An electrical meter, as shown in Figure 6, registers energy use in kilowatt-hours (kWh). The basic unit of electrical power is the watt, but this is a relatively small unit so electrical power is sold in units of 1000 watts or kilowatts (kW). Electrical energy is power over time, so the common electrical energy unit is a kilowatt used for one hour or the kilowatt-hour (kWh). If this was converted to heat, one kWh is equal to 3,413 Btu.

Estimating Cost to Operate Equipment: The cost of operating electrical loads and equipment involves estimating the kilowatt-hour usage and multiplying by the average cost for electrical energy. The following example is for a farmer who is considering using infrared heat lamps for raising baby pigs.

Example using average energy cost: A farmer is planning to use infrared heat lamps rated at 250 watts and 120 volts each, in a hog farrowing barn. If twelve of the heat lamps will be used, what will be the approximate cost of operating the heat lamps for one day?

First it is necessary to determine the number of kilowatt-hours (kWh) of electrical energy used by the twelve 250-watt, heat lamps in one day which is 24 hours. Multiply 12 lamps, times 250 watts, times 24 hours, to get 72,000 watt-hours. Kilowatt-hours are needed not watt-hours, so divide 72,000 by 1,000 to convert to kWh. The heat lamps will use 72 kWh in one 24 hour period.

$$12 \text{ lamps} \times 250 \text{ W} \times 24 \text{ hrs.} = 72{,}000 \text{ Wh}$$

$$\frac{72{,}000 \text{ Wh}}{1{,}000} = 72 \text{ kWh}$$

Before the average cost of operating the heat lamps can be determined, it will be necessary to determine the average cost per kWh. To do this, divide the monthly charge for electrical energy on the electric bill by the number of kWh used during that month. Assume the electric bill for the month was $171.60 and the electrical energy used during the month was 1,560 kWh. Determine the average cost for electrical energy by dividing $171.60 by 1,560 kWh to get $0.11 per kWh. Next, multiply the 72 kWh by the average cost per kWh. It will cost approximately $7.92 per day to operate 12 heat lamps.

$$\$171.60 \div 1{,}560 \text{ kWh} = \$\,0.11 \text{ per kWh}$$

$$72 \text{ kWh} \times \$0.11/\text{kWh} = \$7.92$$

Horsepower: The horsepower (hp) is the most commonly used unit of measure of mechanical power. Horsepower is the rate of doing work such as moving a weight a certain distance, in a unit of time. Turning a shaft requiring a certain torque at a high rpm will require more power than turning the same shaft at a low rpm. Horsepower can be determined from a turning shaft, if the torque of the shaft can be determined along with the revolutions of the shaft in a unit of time. If torque is in pound-feet, and shaft rotation is in revolutions per minute (rpm), then the following formula will give the horsepower required. (Pi, (π), is 3.14)

$$\text{Horsepower} = \frac{2 \times \pi \times \text{torque} \times \text{rpm}}{33{,}000}$$

Watt — Horsepower Conversion: There are times when a conversion may be necessary for converting from watts to horsepower. One horsepower is equal to 746 watts.

$$1 \text{ horsepower} = 746 \text{ watts}$$

Efficiency: Most electrical and mechanical systems will have a loss in efficiency. Efficiency is output divided by the input. Efficiency is a unitless number that is expressed in a percentage (%). In the case of an electric motor, the output is the horsepower available at the motor shaft. The input to the motor is the power being drawn from the circuit which requires a simple calculation of power using the power formula or a measurement of power using a wattmeter. In the case of an electric motor if output is in horsepower and input is in watts one or the must be converted using the conversion factor before making a calculation.

$$\text{Efficiency (\%)} = \frac{\text{Output}}{\text{Input}} \times 100$$

Example of calculating motor efficiency: If a given 5 horsepower motor is drawing, 4,663 watts the motor is operating with an efficiency of 80%.

$$80\% = \frac{\text{5-hp x 746 W/hp}}{\text{4,663 watts}} \times 100$$

Heat: Electricity is converted into heat for many applications. The watt can be a measure of the amount of heat produced by electricity. The heat produced by an electric heater is equal to the power in watts multiplied by time in hours. Heat can also be represented by a variation of this equation where the current (I) is squared and multiplied by the resistance of the heating element.

Heat = Watts x time in hours

Heat = I^2 x R x time in hours

Heat is more often measured in British Thermal Units (**Btu**) in the English system of measurements. In the metric system, the joule (J) is the unit measure of heat.

1 kWh = 3,413 Btu = 3.6 megajoule (MJ)