

## Volts, Amps and Ohms – Measuring Electricity

The three most basic units in electricity are voltage (**V**), current (**I**) and resistance (**r**). Voltage is measured in **volts**, current is measured in **amps** and resistance is measured in **ohms**.

A neat analogy to help understand these terms is a system of plumbing pipes. The voltage is equivalent to the water pressure, the current is equivalent to the flow rate, and the resistance is like the pipe size.

There is a basic equation in electrical engineering that states how the three terms relate. It says that the current is equal to the voltage divided by the resistance.

$$I = V/r$$

Let's see how this relation applies to the plumbing system. Let's say you have a tank of pressurized water connected to a hose that you are using to water the garden.

What happens if you increase the pressure in the tank? You probably can guess that this makes more water come out of the hose. The same is true of an electrical system: Increasing the voltage will make more current flow.

Let's say you increase the diameter of the hose and all of the fittings to the tank. You probably guessed that this also makes more water come out of the hose. This is like decreasing the resistance in an electrical system, which increases the current flow.

Electrical power is measured in **watts**. In an electrical system power (**P**) is equal to the voltage multiplied by the current.

$$P = VI$$

The water analogy still applies. Take a hose and point it at a waterwheel like the ones that were used to turn grinding stones in watermills. You can increase the power generated by the waterwheel in two ways. If you increase the pressure of the water coming out of the hose, it hits the waterwheel with a lot more force and the wheel turns faster, generating more power. If you increase the flow rate, the waterwheel turns faster because of the weight of the extra water hitting it.

In an electrical system, increasing either the current or the voltage will result in higher power. Let's say you have a system with a 6-volt light bulb hooked up to a 6-volt battery. The power output of the light bulb is 100 watts. Using the equation above, we can calculate how much current in amps would be required to get 100 watts out of this 6-volt bulb.

You know that **P** = 100 W, and **V** = 6 V. So you can rearrange the equation to solve for **I** and substitute in the numbers.

$$I = P/V = 100 \text{ W} / 6 \text{ V} = 16.66 \text{ amps}$$

What would happen if you use a 12-volt battery and a 12-volt light bulb to get 100 watts of power?

$$100 \text{ W} / 12 \text{ V} = 8.33 \text{ amps}$$

So this system produces the same power, but with half the current. There is an advantage that comes from using less current to make the same amount of power. The resistance in electrical wires consumes power, and the power consumed increases as the current going through the wires increases. You can see how this happens by doing a little rearranging of the two equations. What you need is an equation for power in terms of resistance and current. Let's rearrange the first equation:

$$I = V / R \text{ can be restated as } V = I R$$

Now you can substitute the equation for V into the other equation:

$$P = V I \text{ substituting for V we get } P = I R I, \text{ or } P = I^2 R$$

What this equation tells you is that the power consumed by the wires increases if the resistance of the wires increases (for instance, if the wires get smaller or are made of a less conductive material). But it increases dramatically if the current going through the wires increases. So using a higher voltage to reduce the current can make electrical systems more efficient. The efficiency of electric motors also improves at higher voltages.

This improvement in efficiency is what is driving the automobile industry to adopt a higher voltage standard. Carmakers are moving toward a 42-volt electrical system from the current 12-volt electrical systems. The electrical demand on cars has been steadily increasing since the first cars were made. The first cars didn't even have electrical headlights; they used oil lanterns. Today cars have thousands of electrical circuits, and future cars will demand even more power. The change to 42 volts will help cars meet the greater electrical demand placed on them without having to increase the size of wires and generators to handle the greater current.

# Voltage, Current and Resistance

In Ireland, the power outlets in the wall of your house or apartment are delivering 220 volts.

Imagine that you plug a space heater into a wall outlet. You measure the amount of current flowing from the wall outlet to the heater, and it is 5 amps. That means that it is a 1,100-watt heater.

$$\text{Volts} * \text{Amps} = \text{Watts}$$

... so 220 volts \* 5 amps = 1,100 watts.

This is the same for any electrical appliance. If you plug in a toaster and it draws 3 amps, it is a 660-watt toaster. If you plug in a light and it draws half an amp, it is a 110-watt light bulb.

Let's say that you turn on the space heater, you go outside and you look at the **power meter**. The purpose of the power meter is to measure the amount of electricity flowing into your house so that the power company can bill you for it. Let's assume that nothing else in the house is on, so the meter is measuring only the electricity used by the space heater.

Your space heater is using 1,100 watts. That is 1.1 kilowatts -- a kilowatt is 1,000 watts. If you leave the space heater on for one hour, you will use 1.1 **kilowatt-hours** of power. If your power company charges you 12 cents per kilowatt-hour, then the power company will charge you 13.2 cents for every hour that you leave your space heater on.

$$1.1 \text{ kilowatts} * 1 \text{ hour} = 1.1 \text{ kilowatt-hours}$$

$$1.1 \text{ kilowatt-hours} * 12 \text{ cents per kilowatt-hour} = 13.2 \text{ cents}$$

Similarly, if you have a 100-watt light and you leave it on for 10 hours, the light will consume 1 kilowatt-hour (100 watts \* 10 hours = 1 kilowatt-hour).

If you have a 20,000-watt heat pump and you leave it on for five hours every day, you will consume 100 kilowatt-hours per day (20 kilowatts \* 5 hours = 100 kilowatt-hours), or 12 euro per day if a kilowatt-hour costs 12c. If you do that for a month, your heat pump costs you (30 \* €12) €360 per month. That is why your electric bills can get so high when the temperature is very cold -- the heat pump runs a lot.

The three most basic units in electricity are voltage (**V**), current (**I**) and resistance (**r**). As discussed previously, voltage is measured in **volts**, and current is measured in **amps**. Resistance is measured in **ohms**.

We can extend the water analogy a bit further to understand **resistance**. The voltage is equivalent to the water pressure, the current is equivalent to the flow rate, and the resistance is like the pipe size.

There is a basic equation in electrical engineering that states how the three terms relate. It says that the current is equal to the voltage divided by the resistance.

$$I = V/r$$

Let's say you have a tank of pressurized water connected to a hose that you are using to water the garden. What happens if you increase the pressure in the tank? You probably can guess that this makes more water come out of the hose. The same is true of an electrical system: **Increasing the voltage will make more current flow.**



Let's say you increase the diameter of the hose and all of the fittings to the tank. You probably guessed that this also makes more water come out of the hose. This is like **decreasing the resistance in an electrical system, which increases the current flow.**

When you look at a normal incandescent light bulb, you can physically see this water analogy in action. The filament of a light bulb is an extremely thin wire. This thin wire resists the flow of electrons. You can calculate the resistance of the wire with the resistance equation.

Let's say you have a 100-watt light bulb plugged into a wall socket. The voltage is 220 volts, and a 100-watt bulb has 0.45 amp flowing through it. You can calculate the resistance of the filament by rearranging the equation:  $r=V/I$ . So the resistance is 489 ohms. If it is a 60-watt bulb, the resistance is 806 ohms.

### **Direct Current vs. Alternating Current**

Batteries, fuel cells and solar cells all produce something called **direct current** (DC). The positive and negative terminals of a battery are always, respectively, positive and negative. Current always flows in the same direction between those two terminals.

The power that comes from a power plant, on the other hand, is called **alternating current** (AC). The direction of the current reverses, or alternates, 50 times per second (in Europe.) or 60 times per second (in the USA and Canada for example). The power that is available at a wall socket in Ireland is **220-volt, 50-Hertz AC power.**

The big advantage that alternating current provides for the power grid is the fact that it is relatively easy to change the voltage of the power, using a device called a **transformer**. By using very high voltages for transmitting power long distances, power companies can save a lot of money. Here's how that works.

Let's say that you have a power plant that can produce 1 million watts of power. One way to transmit that power would be to send 1 million amps at 1 volt. Another way to transmit it would be to send 1 amp at 1 million volts. Sending 1 amp requires only a thin wire, and not much of the power is lost to heat during transmission. Sending 1 million amps would require a huge wire.

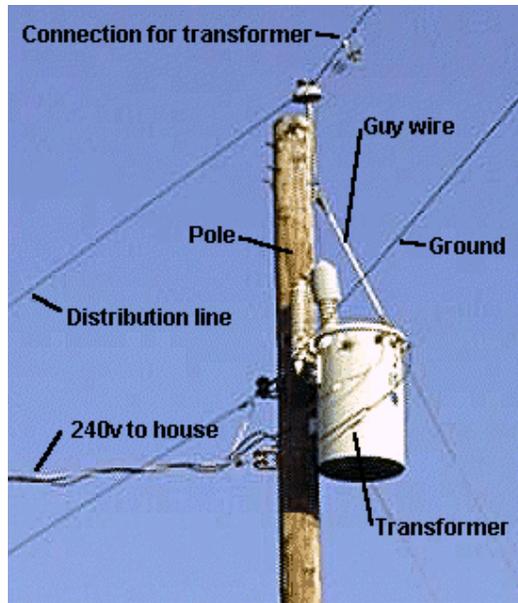
So power companies convert alternating current to very high voltages for transmission (e.g. 1 million volts), then drop it back down to lower voltages for distribution (e.g. 1,000 volts), and finally down to 220 volts inside the house for safety. It is a lot harder to kill someone with 220 volts than with 1 million volts.

### **Ground**

When the subject of electricity comes up, you will often hear about **electrical grounding**, or just **ground**. For example, an electrical generator will say, "Be sure to attach to an earth ground before using," or an appliance might warn, "Do not use without an appropriate ground."

It turns out that the power company uses the earth as one of the wires in the power system. The earth is a pretty good conductor, and it is huge, so it makes a good return path for electrons. "Ground" in the power-distribution grid is literally "the ground" that's all around you when you are walking outside. It is the dirt, rocks, groundwater, etc., of the earth.

The power-distribution system connects into the ground many times. For example, in this photo you can see that one of the wires is labeled as a **ground wire**:



In the photo below, the **bare wire** coming down the side of the pole connects the aerial ground wire directly to ground:



Every utility pole on the planet has a bare wire like this. If you ever watch the power company install a new pole, you will see that the end of that bare wire is stapled in a coil to the base of the pole. That coil

is in direct contact with the earth once the pole is installed, and is buried 6 to 10 feet (1.8 to 3 m) underground. It is a good, solid ground connection. If you examine a pole carefully, you will see that the ground wire running between poles (and often the guy wires) are attached to this direct connection to ground.

Similarly, near the power meter in your house or apartment there is a 6-foot (2-meter) long copper rod driven into the ground. The ground plugs and all the neutral plugs of every outlet in your house connect to this rod. (See "How Power Distribution Grids Work" for details.)