ELECTRICITY (E)

Electricity – how it works, how we measure and pay for it.

INTRODUCTION:

HOW ELECTRICITY WORKS:

E completely surrounds us. Modern life would be rather primitive without it.

A few examples are:

Outlets where you can plug in all sorts of electric appliances.

Battery powered or DC devices/radios, I pods, computers.

Thunderstorms releasing lightening.

The static electric charge on the human body dissipates in a spark on the surface of a pet or door knob with a different charge.

So, what is this mysterious stuff that we call E? Where does it come from? Where does it go and why is it able to do so many different things?

BASICS:

E starts with electrons. Every atom contains one or more electrons. Each electron has a negative charge. All materials are made of atoms, in some the electrons are tightly bound to the atoms, such as wood, glass, plastic, ceramic, air and cotton. These are all examples of material in which the electrons stick with their atoms very tightly. Because the electrons will not move, these materials cannot conduct E very well, if at all. These materials are electrical insulators in contrast to other materials which have electrons that can detach from their atoms and move around. These are called “free electrons”. Metals, i.e. gold, silver, copper, aluminum, iron, etc. all have freely movable electrons. The loose electrons make it easy for electricity, or the electrons, to move or flow through these materials so they are known as electrical conductors. They conduct electricity. The moving electrons transmit electrical energy from one point to another.

E needs a conductor or path in order to move. There also has to be a reason or force to make the electron want to move from one point to another. One way to get electrons to flow is to use a generator or push them by passing an electromagnetic field over the material, which will motivate the electrons to move.

GENERATORS:

A generator uses a magnet and its fields to get electrons moving. There is an inseparable link between electricity and magnetism. If an electron moves, it creates a magnetic field. If a magnetic field moves near an electron, it makes the electron move. This interaction is how a generator creates E. If you allow electrons to move through a wire, they will create a magnetic field around the wire. Similarly, if you move the magnet near the wire, the magnetic field will cause electrons in the wire to move. The generator is a simple device that moves the magnet near a wire to create a steady flow of electrons in the wire. One simple way to think about a generator is to imagine it acting like a pump, pushing water along. Instead of pushing water, however, a generator uses a magnet to push electrons along. This is a slight over-simplification, but it is nonetheless a very useful analogy. There are two things that a water pump can do with water.

A water pump moves a certain **number** of water molecules,

A water pump applies certain of **pressure** to the water molecules in the same way a magnet does in a generator.

1. Can push a certain number of electrons along (amperage or current, I).
2. Apply a certain amount of “pressure” to the electrons (voltage, V).
3. The size and resistance of the pipe will be discussed later (resistance, r).

In an electric circuit, the number of electrons that can be moved is called amperage or the current and it is measured in amps. The pressure pushing the electrons along is called voltage and is measured in volts. So, you might hear someone say, if you spin this generator at 1,000 rpms, it can produce 1 amp at 6 volts. One amp is the number of electrons moving (1 amp physically means that 6.24 x 10 to the 18^{th} electrons move thru a wire every second) and the voltage is the amount of pressure behind those electrons. Now, let us take closer look at an electronic circuit.

Electrical Circuits

Whether you are using a battery, a fuel cell to produce electricity, there are three things that are always the same.

1. A source of electricity will have two terminals, a positive terminal and a negative terminal. The source of electricity (whether it is a generator or battery, etc) will want to push electrons out of its negative terminal at a certain voltage. For example, a AA battery typically wants to push electrons out at 1.5 volts.

2. The electrons will need to flow from the negative terminal to the positive terminal through a copper wire or some other conducting material.

3. When there is a path that goes from the negative to the positive terminal, you have a circuit and electrons can flow through the wire. You can place a load of any type, light bulb, motor, TV, etc. in the middle of the circuit. The source of electricity will power the load and the load will do its thing (create lights, spin as a shaft, generate moving pictures, etc.)

Electrical circuits can get quite complex, but at the simplest level, we always have a source of electricity (a battery, etc), a load (a light bulb, motor, etc.) and two wires to carry electricity between the battery and the load. Electrons move from the source through the load and back to the source or home.

Moving electrons have energy. As the electrons move from one point to another, they can do work. In an incandescent light bulb for example, the energy of the electrons is used to create heat and the heat, in turn, creates light. In an electrical motor, the energy in the electron creates a magnetic field, and this field can interact with other magnets through magnetic attraction and repulsion to create motion. Each electric appliance harnesses the energy of electrons in some way to create the useful side effect (motion).

Now that you know what electricity is and how it works on a basic level, let’s learn more about some of the concepts associated with it, such as voltage, current and resistance.

VOLTAGE, CURRENT AND RESISTANCE:

If you live in the United States the power outlets in the wall of your house or apartment are delivering 120 volts. Imagine that you plug a space heater into the wall outlet. You measure the amount of current flowing from the wall outlet to the heater and the amp-meter shows it is 10 amps. That means that it is a 1200 watt heater, volts x amps equal’s watts. So, 120 volts x 10 amps equal 1200 watts. This is the same for any electric appliance. If you plug in a toaster and it draws 5 amps, it is a 600 watt toaster because 5 x 120 equals 600. If you plug in a light and it draws half of an amp or 0.5 into a 120 volt socket, it is a 60 watt light bulb, i.e. 0.5 x 120 volts equals 60 watts.

Let’s say that you turn on your heater, you go outside and you look at the power meter. The purpose of the power meter is to measure the amounts of electricity flowing into your house so that the power company can keep accurate records of the amount of electricity for which they bill you. Let’s assume that nothing else in the house is on so that meter is measuring only the electricity used by the space heater. Your space heater is using 1200 watts. That is 1.2 kilowatts. That is simply the difference between watts and kilowatts. One kilowatt is the same as 1000 watts. If you leave the space heater on for one hour, you will use 1.2 kilowatt hours of electric power. If your power company charges you 10 cents per kilowatt hour, then the power company will charge you 12 cents for every hour that you leave your space heater on. 1.2 kilowatts or 1200 watts x one hour equals 1.2 kilowatt hours. 1.2 kilowatt hours x 10 cents per kilowatt hour equals 12 cents. Similarly, if you have an 100 watt light bulb and you leave it on for 10 hours, the light will consume 1 kilowatt hour. 100 watts times 10 hours equals 1 kilowatt hour. If you have a 20,000 watt heat pump and you leave it on for 5 hours every day, you will consume 100 kilowatt hours per day (20 kilowatts x 5 hours equals 100 kilowatt hours or $10.00 of power per day in cost, if a kilowatt hour costs 10 cents.) If you do that for one month, your heat pump cost will be 30 days x $10.00 or $300.00 per month. That is why your electric bill can get so much higher when the temperature is very low or very high.

The three most basic units of electricity are: voltage (V), current (I) and resistance (r). As discussed previously, voltage is a measure of volts and current is a measure in amps. Resistance is measured in ohms. You can extend the water analogy a bit further to understand resistance, which is measured in ohms. Voltage is equivalent to the water pressure, the current is equivalent to the flow rate, and resistance is like the pipe size and resistance to flow. There is a basic equation in electrical engineering that states how the three terms relate. It says that 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. 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, or electrons flow. Let's say you increase the diameter of the hose and all 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 allows an increase in the current flow.

This is also where different materials demonstrate high and low resistance, i.e. wood, aluminum, copper, steel, etc. Each one has it own ability to resist or enhance electron flow.

When you look at a normal incandescent light bulb, you can physically see the water analogy in action. The filament of the light bulb is an extremely thin wire. This thin wire resists the flow of electrons. You can calculate the resistance in the wire with an resistance equation. Let's say you have 120 watt light bulb plugged into a wall socket of 120 volts. The voltage is 120V and the 120 watt bulb has 1 amp flowing through it (one Amp x 120 v equal 120 watt bulb). You can calculate the resistance of the filament by rearranging the equation. r=V/I ?=120/1. So the resistance is 120 ohms. If it is a 60 watt light bulb, the resistance is 240 ohms. (?=120/0.5)

Beyond these core electronic concepts, there is a practical distinction that happens in the area of current. Some currents are direct and some current is alternating and this is a very important distinction.

DIRECT VERSUS ALTERNATING CURRENT:

Batteries, fuel cells, solar cells all produce something called direct current (DC). The positive and negative terminals of the battery are always marked "positive" and "negative". Current always flows in the same direction between those two terminals. Power that comes from the power plant, on the other hand, is called alternating power (AC). The direction of the current reverses, or alternates back and forth, 60 times per second like a line of pool balls being pushed back and forth and back and forth. The energy which shakes the balls (electrons) at the generator is transmitted down the wire and transferred to the appliances in the home or business.

In the United States, this alternating power moves at 60 times per second, or 50 times per second in Europe. That is why there are different types of plugs. The power that is available at the wall socket in the United States is 120 volts, 60 cycle AC power, single phase. The AC power system is relatively low voltage and safe the humans. The big advantage that AC power provides is its relative easy of transmition over long distances using transformers. Power companies can save a lot of energy (money) in heavy wire and extra work. Here is how it 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 that transmission. Sending 1 million amps would require a huge wire and still there would be major loss of energy. The power companies convert alternating power to very high voltage alternating power for transmission, i.e. 1 million volts, then they drop it back down to lower voltages at the distribution points and finally drop it down to 120 volts inside the house for safety. It is a lot harder to kill someone with 120 volts than with 1 million volts. Most electric deaths are prevented all together by using ground fault interrupter circuitry to prevent these accidents.

ELECTRIC GROUND:

When the subject of electricity comes up, you will often hear about electric grounding, or just ground. For example, electric generators will say, "Be sure to attach to an earth ground before using", or an appliance might warn "do not use without an appropriate ground or grounded plug". It turns out that the power company uses the earth as one of the wires in the power system. The earth is an excellent conductor and it is used so it makes good return paths for electrons. Ground in the power distribution grid is literally the ground that is all around you when you are walking outside in the dirt, rocks, etc. The power distribution connects into the ground many times.

The wires labeled as grounding wire are bare wire coming down the side of the pole and connecting the aerial wire directly to the 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 the 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 buried 6-10' under ground giving a good, solid ground connection. If you examine the pole carefully, you will see the ground wire running between poles and often the guide wires are attached to this direct wire connected to the ground. Similarly, near the power meter at your house or apartment, there is a 6' or 2 meter long copper rod driven into the ground. The ground plugs and all the natural plugs in every outlet in your house connect to this rod. That is how power is grounded. Electricity can be used in so many different ways.

HOW POWER GRIDS WORK:

Electric power is a little bit like the air we breathe. You do not really think about it until it is missing. Power is just there, meeting our every need constantly. It is only during power failure when you walk into a dark room and instinctively hit the useless light switch that you realize how important power is in our daily life. We use it for heating, cooling, refrigeration, lights, computation, and entertainment. Without it life can get cumbersome.

Power can be generated from multiple sources, i.e. nuclear, coal, wind, waterfalls, wave action, elevators and can be used just as food is consumed in a correct balance of starvation and gluttony. Power travels from the power plant to your house through an amazing system called power distribution grid. Power grid distribution lines can be above or under ground. The grid is quite public. If you live in a suburban or rural, chances are it is right out in the open for all to see. It is so public, in fact, that you probably do not even notice it any more. Your brain likely ignores all the power lines because it has seen them so often. The next time you look at a power line grid, you will be able to really see and understand what is going on.

POWER PLANT:

Electric power starts at the power plant. In almost all cases, the power plant consists of a spinning electric generator. Something has to spin that generator, i.e. a windmill, a nuclear powered steam turbine, waterfall, coal, oil, gasoline, natural gas or combination thereof. But, in most cases, the thing spinning the generator is a steam turbine. The steam might be created by burning coal, oil, natural gas or nuclear fuel, or the steam may come from underground sources.

POWER PLANT – ALTERNATING CURRENT:

Single-phase power is what we have in our homes. We generally talk about household electric service as a single-phase 120 volt, AC service. If you use an oscilloscope and look at the power found in a normal wall plug in your home, what you will find is that the power in the wall looks like a sign wave and that wave oscillates between 170 volts positive and negative. The peaks are, indeed, at 170 volts. It is the effect RMS volts that is 120 volts. In other words, the effective electron pushing power. The rate of oscillation for the sign wave is 60 cycles per second in the United States and 50 cycles in Europe. Oscillating power like this is generally referred to as AC, or alternating current. The alternative to AC power is DC power, or direct current, which is batteries, which produce the DC power, such as in your car or boat of flashlight or computer. A steady stream of electrons flows in one direction only from the negative to the positive terminal in a battery scenario. AC and DC power can be converted through devices to supply the power type needed by the appliance being used.

AC power has at least three advantages over DC power in a power distribution grid.

One: large electrical generators happen to generate AC naturally, so conversion to DC would involve an extra step.

Two: you can use transformers to transfer power over great distances.

Three: It is easy to convert AC to DC, but expensive to convert DC to AC, so if you were going to pick one or the other, AC would be the better choice and it has worked that way for 100 years.

The power plant, therefore, produces AC power in three phases.

POWER PLANT – THREE PHASES:

Power plant produces three phase power for all to use but a household only needs one of these phases. Power plant produces three different phases of AC power simultaneously and the three phases are offset 120 degrees from each other. There are four wires coming out of every power plant. The three phases, plus a neutral or ground common to all three. If you were to look at the three phases on a graph, they would look like this relative to the ground. Again, a sign wave, but crowded together. There is nothing magical about three phase power. It is simply single-phase synchronized and offset by 120 degrees, or three single-phase wires together. Why three phase, why not one or two or four?

In one-phase or two-phase power, there are 120 moments per second when a sign wave is crossing the zero point of voltage. In three-phase power, at any given moment, one of the three phases is nearly at peak. High power of three-phase motors used in industry and things like three-phase welding equipment, therefore, have more power output or requirements. Four phase would not significantly improve things, but would add a fourth wire. So three-phase is a natural settle point for industry, both to produce and consume high levels of power.

What about the ground, as mentioned above. The power company essentially uses the earth as one of the wires in the power system. The earth is a pretty good conductor and it is used, so it makes a good return path for the electrons. Car manufacturers do something similar. They use the metal body of the car as one of the wires in the car's electrical system to attach negative poles of the battery to the car's body. The ground at the power distribution grid is literally the ground. It is all around you when you are walking outside in the dirt, rocks, etc. In Europe you will see many cars dragging a flat piece of metal, which is an additional grounding wire that attaches the car to the ground, which is a different system, but the same idea.

TRANSMISSION SUBSTATION:

The three-phase power leaves the generation station or power plant and enters the transmission substation at the power plant. The substation uses large transformers to convert the generated electricity voltage which is at thousands volts level up to extremely high voltage for long distance transmission. All power towers such as this one shown have three wires with three phases. Many towers like the others shown above have extra wires running along the tops of these. These are ground wires and are there primarily to attempt to attract lightening and diffuse it into the ground.

DISTRIBUTION GRID:

For the power to be useful in a home or business, it comes off the transmission grid and is stepped down to the distribution grid. This may happen in several phases. The place where the conversion from transmission to distribution occurs is in the power substation. A power substation typically does two or three things.

It has transformers that step transmission voltage in the tens of hundreds of thousands of voltage down to distribution voltage, typically less than ten thousand volts. It has a bus that can split the distribution power off in multiple directions. It often has circuit breakers as switches so that the substation can be disconnected from the transmission grid or separate distribution lines can be disconnected from the substation when necessary.

DISTRIBUTION BUS:

The power goes from the transformer to the distribution bus. In this case, the bus distributes power to two separate sets of distribution lines or two different voltages. The smaller transformer attaches to the bus for stepping the power down to standard line voltage, usually 7,200 volts for one set of lines, while power leaves in the other direction at a higher voltage off the main transformer. The power leaves the substation in two sets of three wires, each heading down the road in different directions (see picture). The next time you are driving down the road, you can look at the power lines in a completely different light. In a typical scene, pictured at the right, the three wires on the top of a pole are the three wires of the three-phase power. The fourth wire on the poles is a ground wire and in some cases there will be an additional wire, typical phone or cable wire, riding on the same pole. As mentioned above, the particular substation produces two different voltages. The wires at the higher voltage need to be stepped down again, which will often happen at another substation or small transformer somewhere down the line. For example, you will often see a large green box, perhaps 6’ near the entrance to a substation. It is performing a step down function for the subdivision.

REGULATOR BANK:

You will also find regulator banks located along the lines, either underground or in the air. They regulate the voltage in the line preventing over and under voltage conditions. Up towards the top are three switches that allow these regulator banks to be disconnected for maintenance, if necessary. At this point, we have typical line voltages that are 7,200 volts running through the neighborhood with three wires with the fourth ground wire lower on the pole.

TAPS:

A house needs only one of the three phases of power. So, typically you will see three wires running down the main road and taps for one or two of the phases running off on side streets. Pictured below is a three-phase to two-phase tap with two phases running off to the right. Here is a two-phase to one-phase tap with a single wire running out to the right.

AT THE HOUSE:

Finally, we are down to the wire that brings power to your house. Past the typical house runs a set of poles with one-phase of power, 7,200 volts and a ground wire. At each house there is a transformer drum attached to the pole like this (see picture). In many suburban neighborhoods, the distribution lines are underground and there are green transformer boxes at every house or two. Here is some detail on what is going on at the pole (see picture). The transformer's job is to reduce the 7,200 volts down to 240 volts that makes up normal household electric service.

Let's look at this pole one more time at the bottom to see what is going on. (See picture)   There are two things you notice in the picture. There is a bare wire running down the pole; this is the grounding wire. Every utility pole on the planet has one. If you ever watch the power company install a pole, you will see that the end of the pole's wire is stapled to the coil at the base of the pole and, therefore, in direct contact with the earth running 6-10" underground. It is a good, solid ground connection. If you examine the pole carefully, you will see that the ground wire running between the two poles, often the guide wires, are attached to the direct connection to the ground.

There are two wires running out of the transformer and three wires running to the house. The two from the transformer are insulated and the third wire is bare. The bare wire is the ground wire. The two insulated wires each carry 120 volts, but they are 180 degrees out of phase. So, the difference between them is 240 volts. This arrangement allows the household to use both 120 and 240 volt appliances. The transformer is wired in this sort of configuration (see picture). The 240 volt enters your house through a typical watt hour meter like the one shown. The meter lets the power company charge you for putting all this equipment in and maintaining it. The meter is an electric motor (electromechanical) and the amount of load and frequency of turns is measured by the dials that calculate the electric bill. The newer meters are not motors but circuits designed to measure power and transmit the data back to the power provider.

SAFETY DEVICES AND FUSES:

Fuses and circuit breakers are safety devices. Let's say that you do not have fuses or circuit breakers in your home and something went wrong. What could possibly go wrong? Here are some examples:

> A fan motor burns out a bearing, seizing, overheating and melting, cause a direct connection between power and ground. A wire comes loose in a lamp and directly connects power to the ground. A mouse chews through an insulation in a wire and directly connects power to ground. Someone accidentally vacuums up a lamp wire with a vacuum cleaner, cutting it in the process and directly connecting it to the ground. A person is hanging a picture in the living room and the nail used for hanging happens to puncture the power line in the wall directly connecting the power to ground.

When the 120 volt power line connects directly to ground, its goal is life is to pump as much electricity as possible through the connection, and either the device or the wire in the wall will burst into flames in such a situation. The wire in the wall will get hot like an element in an electric oven gets hot, which is to say, very hot. A fuse is a simple device designed to overheat and burn out rapidly. In such a situation, a fuse's thin piece of foil or wire quickly evaporates and kills the power to the wire immediately protecting it from overheating. Fuses must be replaced, they cannot be reset.

A circuit breaker uses the heat from the overload to trip the switch. Therefore, the circuit breakers are resettable. The power enters the home from the typical circuit breaker panel like this one above. (See picture)

SAFETY DEVICES, CIRCUIT BREAKER:

Inside the circuit breaker panel (right) you can see two primary wires from the transformer entering the main circuit breaker at the top. The main breaker lets you cut power to the entire panel when necessary. Within this overall setup, all the wires of the different outlets and lights in the house, each has a separate circuit breaker. If the circuit breaker is on, then power flows through the wire in the wall and makes it way eventually to the final destination – the outlets or lights or appliances.

HOW WE MEASURE AND PAY FOR ELECTRIC POWER:

Electric Meters are either electro-mechanical, (essentially a small motor) with the wheel or digital, (a precision shunt) without the wheel. Either type may be fitted with a remote reader for the meter reader to access from the street outside your home, and now some utilities (Con Ed) are using this remote read capacity to send information inside the house for the customer.

Meter watchers: a optical device designed to fit on the meter glass and watch the wheel turn. This unit will send data inside the house. The only catch is weather the utility will allow the consumer to install anything on the meter glass since it belongs to the utility.

Amp probe clamp-on or solid circular core the reverse of a generator, when an electron passes in the wire the amp-probe is clamped around a current is induced and then measured in the amp-probes core, hall effect sensor or secondary voltage calibration are method of measurement. Alternatively a simple open core can be placed around a current caring wire and a pressure or voltage signal will be generated which is directly proportionate to current flow.

Superposition metal cores are open architect cores which can assume special shapes and read the electromagnetic field generated by current flowing in one, two or three wire sets without disrupting the wires cover or continuity, calibration is performed with precision loads which are placed in the circuit and read remotely.

Controllers, people, electromechanical, timers, photo sensitive.

Generally we are billed at a money rate per kilowatt hour used. Additional cost is administrative and moral considerations.

How do we understand how much energy our appliances are supposed to use and how much they actually use day o day.

If you were to make a chart of the appliances in your home and rank them in order of their use of power it might look like this

Device, typical consumption, cost per hour, duty cycle, appliance label amps, date install, life span

Heat pump 15,000 watts 1.50

Air conditioner 15,000 watts 1.50

Water Heater 4,000 watts .0.40

Cloth Dryer 4,000 watts 0.40

Water pump 3,000 watts 0.30

Space Heater 1,500 watts 0.15

Hair Dryer 1,200 watts 0.12

Electric range burner 1,000 watts 0.10

Refrigerator 1,000watts 0.10

Computer and monitor 400 watts 0.04

Light bulb 60 watt 0.06

Wall transformer 2.5 watts 0.01

This table assumes that a kilowatt-hour is $0.10 which duty cycles is an average rate. Projected payback period,

Audit your electric bill and know who to read it.

What impact hot water heating? The shape the hvac system is in. Identify high use months and establish criteria for appliances.

How do we do an energy audit?

Powerkuff Monitor System and teaching kit was designed for this purpose.