Electricity in the Woodshop (Revised)

A comprehensive discussion of electrical issues for woodworkers.

By Rick Christopherson

Preface

Since this article first appeared at The Oak Factory in 1997, I have reformatted it, and added some further information. This article is written for the typical woodworker who runs into the occasional electrical question. While I have carefully verified the information presented here, I cannot be responsible for changes in Electrical Codes, nor the omission of information.
*The last section of this article has a listing of definitions. I have tried to place any uncommon terms into this section, and reference them as they come up. None of the links used in this document will send you to another file (**except** the new discussion on phase converters), so you won't miss anything if you don't click on one; you'll get to the same point eventually.*

Day in and day out we all deal with electricity, but it seems to be some illusive concept that few woodworkers really understand. Electricity drives our tools, and drives our everyday life. Electricity has the versatility to replace many older forms of energy. Without it we would still be using lanterns for light, fires for heat, and oxen for work.

1. Terminology

The best way to understand electricity and its terminology, is to develop some analogies between electricity and topics which are easy to understand. Even though electricity and water don't mix, the concepts are actually fairly similar. By comparing electrical terminology to water flowing in a pipe, we should be able to gain a deeper understanding of electricity. This analogy between water and electricity is commonly used in textbooks and classrooms.

1.1 Pressure and Voltage

The pressure in a pipe is analogous to electrical voltage across a wire. If the pressure on both ends of a pipe is the same, then no water will flow. This is what makes a siphon work, where the weight of the water is applying the pressure. If you took two water tanks of the same size, where one was full and the other was empty, and connected them together with a hose at their bottoms, water would flow from the full tank into the empty tank. The water would stop flowing when the depth of the water in each tank was the same. The full tank has a higher pressure at the bottom (where the hose is connected) than the empty tank. When the depth of the water is equal in each tank, then the pressure at the bottom of both tanks is equal.

If both ends of a wire are connected to the same voltage, say the positive terminal of a battery, then no current will flow either. In either case, it is the difference in pressure or voltage which causes the water or electricity to flow.

1.2 Current

Regardless whether we are referring to water flow or electrical current, current is the movement of water or electricity. When discussing the flow of water, we are referring to how many gallons per minute are passing though a hose. For electricity, we are looking at how many electrons per second are passing a point . Literally, 1 Ampere is equal to 6.24×10^{18} electrons per second. (The way this number is written is called scientific notation, and is used for very large numbers. This number, if written out would be 6,240,000,000,000,000,000.) Since it is too difficult to work with numbers this large on a daily basis, we use the much simpler term of Amperes, or Amps for short.

The flow of water through a pipe, or electrical current through a wire, is directly related to the pressure or voltage difference across the pipe or wire. Going back to the example of our two tanks. If you were to fill one tank with a couple of inches of water, the flow of water wouldn't be very fast filling the empty tank. If you then filled the first tank with several feet of water, the speed at which the water flowed out of the hose into the second tank would be much higher. The same is true with electricity. The greater the difference in voltage from one end of the wire to the other, the higher the current.

1.3 Pipe Diameter and Resistance

The more resistance in a circuit, the lower the current will be. Similarly, the smaller the diameter of a water pipe, the less water can flow through the pipe. Going back to the tanks example, it should be obvious that if we connect the two tanks with a small hose, the time it takes to fill the second tank will be longer. Also, the longer the hose, the slower the transfer.

Resistance is related to not only the size of a wire, but also the length of a wire. Consider the windings of a motor. They are made up of a very long, and very thin piece of copper wire. The reason this wire doesn't just melt, is because it is long enough and thin enough to act as a resistor, which slows down the flow of electricity

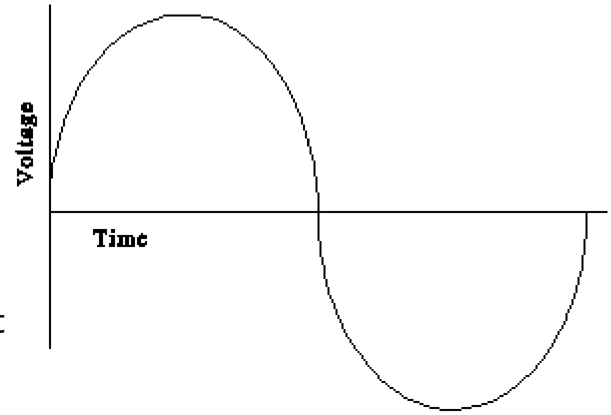
1.4 Ohms' Law

In electrical systems, there is a relationship between current, voltage, and resistance. This is known as *ohms law*, and can be written in many different forms, but always boils down to **V=IR**, where V is voltage, I is current, and R is resistance. This equation holds true whether we are dealing with AC, DC, Capacitive, Inductive, Three Phase, or any other type of circuit. However, it should be noted that sometimes the values for current and/or voltage are no longer simple values. The V and I of Ohms' Law can be replaced by complex mathematical expressions, but they still represent the current and voltage. In fact, it isn't that the equations change, it is the values of current and voltage which become *complex*. For example, we may replace the simple term "I" with the complex term "I*cos(*p*)", where *p* represents a shift in the phase angle, or timing, of the current. As I mentioned, Ohms law can be written in different forms, but are still the same equation. The three common forms of Ohms law are:

V=I *R
I=V/R
R=V/I

1.5 AC versus DC

A battery is direct current (DC). The polarity of a battery is always the same; positive on one side and negative on the other. In an AC system, the polarity is constantly changing every 1/60th of a second (60 times per second, or 60 Hz). If you had a very small (and very fast) person sitting on that 9 volt battery inside your TV's remote control, and he was switching the positive and negative wires back and forth 60 times every second, {well, your TV would be going haywire, and this would give a whole new definition to channel surfing}, but you would have a 9 volt AC power source. In the AC system in our homes, this switching between positive and negative is a little smoother, and if you could look at it, it would look like a sine wave. The electrons traveling through a wire aren't actually moving up and down like the picture, this is just a mathematical representation of their movement. The electrons are actually moving forward, then backward in the wire, where their speed is represented by the height of the sine wave.



1.6 Ground, Neutral, and Hot

These are terms we use to describe the parts of an electrical wiring system. These are just relative terms, and are the names we have given to the wires used in a standard electrical system. They are kind of like nicknames.

1.6.1 Ground

If you had a Really Big voltmeter, and placed one probe way out in space and one probe on the Earth, you would show a voltage between the Earth and Space. I don't know what this voltage would be, it could be one volt or it could be a million volts. In simple terms, we use the Earth as a reference point (we say the Earth is at zero volts, even though we know it is not). The Ground wire in your home or shop is literally connected to an eight foot copper rod driven into the Earth. Therefore, we say the Ground wire is at zero volts. (Believe it or not, the Earth is a conductor of electricity. Not as good as copper, but it does conduct.)

Let's look at another analogy for this. If we have a helium balloon: if we don't hold it down, it will float away. We don't know where it will go, or how high it will float, but we know it will float away nonetheless. If we tie a string to the balloon, it won't float away. By tying off this balloon, we in a sense, *anchor* it to a known height. (As dumb as that sounds, please bear with me, as this terminology is going to come up throughout this document: *anchor and free-floating*.) The ground wire in our homes is just like this piece of string. With it, we *anchor* the whole electrical system to a known height or value. Without it, it will drift off to some unknown voltage, and we have no control of what that voltage would be.

If the tools in our shop were not grounded (electrically free-floating), they would have a voltage difference with respect to Earth, just as the free-floating Earth has a voltage difference with respect to outer space. The chassis of a tool is connected to the Ground wire, which kind of acts like an anchor to keep the chassis' voltage at zero. In short, the Ground wire is a safety device which anchors our tools to zero volts, but is not supposed to carry any current unless something with the appliance is malfunctioning. *(An appliance is a generic term for any device, such as a lamp, saw, oven, motor, and so on. It is not limited to the typical home appliance.)* If something does go wrong with the appliance, then the ground wire will, and should, carry current. But the main purpose of the ground wire is to always ensure that the chassis of the appliance remains at zero volts.

1.6.2 Neutral and Hot

The only difference between the Neutral wire and Hot wire(s) of a modern electrical system is that the Neutral wire is forced to be at zero volts (anchored) by connecting it to Ground back at the circuit breaker panel. If we did not anchor Neutral to Ground, then both the Neutral wire and the Hot wire would be at some intermediate voltage (both would be free-floating). This is done as a safety issue. It is much easier to work on a system when we only have one wire with a non-zero voltage. Unlike the Ground wire however, the Neutral wire is designed to carry current during normal operation.

Since the Neutral wire is at zero volts however, there is no voltage difference between it and Ground, and that means there is little chance for a user to get electrocuted by touching the Neutral. This is why it is normal electrical procedure to have the Neutral wire pass directly to an appliance without going through a switch or circuit breaker. Switches and circuit breakers are placed on the Hot leg of a system.

1.6.3 Circuit Protection (Circuit Breaker)

The purpose of the circuit breaker is to protect the wires between the breaker and the load, although it also serves as a service disconnect. A circuit breaker is not intended to protect the appliance, only the wire between the breaker and the outlet. In your home, you will have 15 or 20 amp breakers, but the motor that you plug into the outlet may self destruct if the current exceeds 10 amps (hypothetically). The motor is responsible to protect itself if the current goes over 10 amps, not the circuit breaker. National Electric Code mandates that ALL Hot wires going to a load must, not only have a circuit breaker, but ALL circuit breakers feeding that device must trip together. Therefore, a 240 volt tool must use a two-pole breaker, and a three phase tool must use a three-pole breaker.

1.6.4 Circuit Path and Safety

You should of course already know to always turn the power off before you do any electrical work, but you should take this concept a little further. You should remove all possibility for someone else to turn the power back on. If a tool has a plug, then unplug it and place the cord within your line of sight, so that you can see if someone goes to plug it back in. If the tool only has a circuit breaker, and it is out of your line of sight, find a way to lockout the breaker in the off position. Most breakers have a small hole through the trip handle, and this can be used with a small lock, or similar object to prevent the breaker from being turned on. At the same time, you should label the lockout with a tag which indicates the circuit is being serviced. This is called a *lockout/tagout* and is a concept which is controlled by OSHA. Removal of a lockout/tagout by any individual other than the person who placed it there, is punishable by some pretty stiff fines, and maybe even imprisonment (literally, even if that original person is no longer alive, you still cannot remove the lock without a lot of red tape. That's how strict this is!)

There may be times when there is no way of turning the power off. In most cases, when I work on an electrical system, it would hardly matter if someone turned the power back on while I was working, because I always treat the system as though it were active, or live. This is just an additional safety concept which I use. To explain this, I need to explain how a person can or cannot be electrocuted. People are electrocuted by current passing through their body, not by voltage. Don't key on that statement yet! Voltage can kill you, but it is the difference in voltage which causes the problem, and the difference in voltage is what causes current to flow through a person's body. A bird does not get electrocuted when it lands on a power line, because its entire body is elevated to that voltage (free-floating). If the wingtip of the bird touched a different voltage source, like Ground or another wire, it would be zapped like a bug in one of those yard bug-zappers, and so would you!

In order for current to flow, there must be a path from a higher voltage to a lower voltage. If there is no path, current cannot flow. This path can include a wire, a metal water pipe, the chassis of an electrical panel, or water-logged shoes on earth-ground. There are many cases depicted by Hollywood of electrocution which are not realistic, but I need to be careful about debunking them. What I will say, is that water by itself, does not constitute a Ground. Water provides a path to Ground just as a wire would. Going back to the bird, if a birdbath were placed on the high voltage wire, the bird still would not be electrocuted because the water in the birdbath would also be "free-floating" in terms of voltage. Bathtub electrocutions are not caused just because of the water, but because the water completes a circuit path from the person, through the water, to the metal water pipe, which eventually enters the earth as it comes from the street.

I apply these principle when ever I perform wiring. Any time I am in contact with a wire which has even a remote chance of being Live, I make sure no other part of my body is touching either a Ground source, or another voltage source. Whenever possible, I will even perform specific tasks with only one hand to ensure that the other hand does not inadvertently touch somewhere it shouldn't.

1.6.5 Back Fed Voltage/Current

What makes the above mentioned approach all the more important is the unlikely occurrence of a back fed voltage. This situation has killed and maimed many professional electrical workers. This doesn't apply to a situation where you can unplug the entire system, like a tool with a plug. It applies to working on a system, or part of a system which is not completely isolated from all other parts, like a wall outlet. You may have disconnected the Hot wire from the source, and maybe even the Neutral too, but there could be a circuit path somewhere downstream from your location that you don't consider, or are unaware of.

Some time ago, a licensed electrician was working on a circuit. He was going to replace a circuit breaker on a 120 volt circuit. Once the breaker was removed from the panel, it is typically considered dead, and there is little chance for electrocution. Well, the electrician didn't realize that further down the circuit someone had improperly connected a 240 volt motor without using a two-pole breaker. He was kneeling on the ground when he touched the "inactive" wire. Current flowed backward from another circuit, through the motor's windings, through his arm, and out his knees. When his leg muscles involuntarily contracted, the jolt threw him several feet backwards onto his back. While this injured his back, it actually saved his life, because he let go of the wire.

He didn't think it could happen to him either.

1.7 Capacitors and Inductors (Motors)

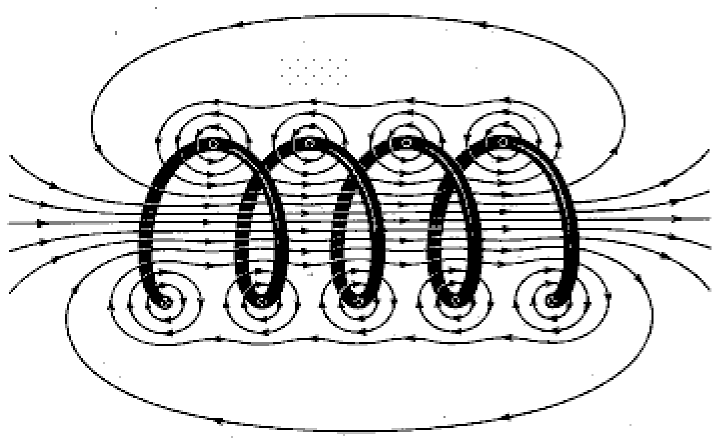
Capacitors and inductors are two types of devices which store energy, like a battery does. But each of these stores different types of energy and in different ways. It is this ability to store energy which makes capacitors and inductors somewhat complicated when evaluating electrical systems.

1.7.1 Capacitors

In very simple terms, a capacitor is made from two parallel plates of metal which are separated by an insulating material. Since the plates of a capacitor are separated by this insulating material, no current actually flows through the capacitor, although it does sometimes appear to. Each plate of the capacitor will hold an electrical charge kind of like a battery, where one plate will have a negative charge and the other plate will have a positive charge (you can picture this as static electricity, like when you rub a balloon over your hair. Your head will have a positive charge, and the balloon will have a negative charge {or vise versa}). Since no current can flow across the insulating material, energy is stored in the capacitor in the form of electric charge between the two plates. When you put voltage to a capacitor and then remove the wires, the capacitor will hold that voltage until it is discharged. (This is why capacitors can pose a grave safety hazard: They can seriously shock a person long after a tool is unplugged.)

> *I was recently working with several large capacitors for a motor's starting circuit. While rearranging how these capacitors were connected together, I had the tool unplugged. Every time I moved a wire from one capacitor to another, there would be a rather large spark as one capacitor charged up the other. Since the tool was completely unplugged, this was rather disconcerting to see such large sparks.*

1.7.2 Inductors



An inductive device is any coil of wire, which includes motors, transformers, and generators. Every time electricity flows through a wire, it creates a small magnetic field around the wire. (This is the same type of magnetism that holds a refrigerator magnet to the refrigerator, except that it is only present when current is flowing.) This magnetic field forms circular lines of flux around the wire. When we coil up a wire, we not only concentrate the wire itself into a small area, but we also concentrate the wire's magnetism into a small area too. In the drawing to the right, you can see how the circular rings around each section of the wire get clumped together in the center of the coil, and no longer form circles, but instead line up together along the length of the coil. By concentrating the magnetism, we make it stronger. An inductor stores energy in the magnetic field around the coils. How? Well it takes energy to develop the magnetic field around the coils, and the magnetic field gives off energy as it collapses (it collapses when the current is stopped or reversed.)

In an AC circuit, remember that the voltage is changing from positive, through zero, to negative 60 times every second. When we connect an inductor, like a motor or transformer, to an AC circuit, the magnetic field around the wires are also constantly changing as a result. They are continually expanding and contracting as the current is reversing.

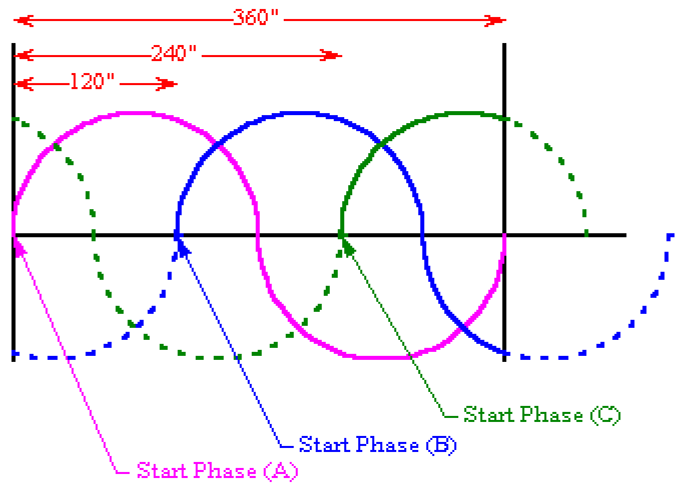
1.7.3 Effects of Capacitive and Inductive Devices

To summarize the above information, capacitors will store voltage, while inductors will store current. When we put a voltage to a motor, the effect of storing this current will delay the flow of current by a fairly small amount of time. This is referred to as a phase shift in the current. I will return to this topic after we discuss some graphical tools, as this then becomes easier to visualize, and has a significant bearing on a motor or generator's ability to provide power.

2.0 Using Graphics to Understand Electricity

We frequently use pictures and graphs to help us understand electricity a little better, just like we used the analogy above comparing electricity to water. I am discussing these graphical methods now, because I will need to use them to help cover some topics below.

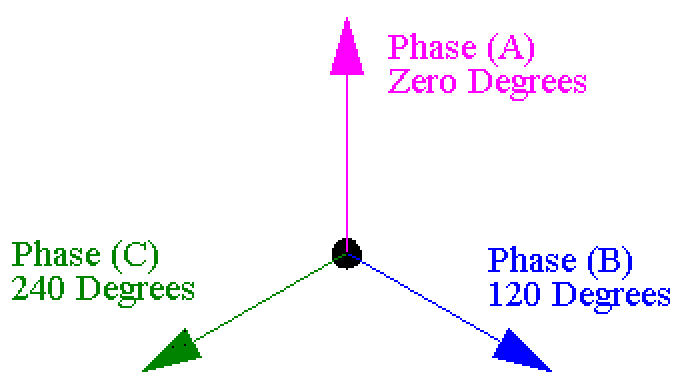
2.1 Sine Waves (oscilloscopes)



Frequently, when we think of an AC voltage, we mentally picture a sine wave, like what is displayed on an oscilloscope. The picture to the right is similar to what would be displayed on an oscilloscope when connected to a 3 phase system. This really isn't what electricity looks like, but it is one of the more common pictures we use. When electrons are flowing through a wire, they don't move up and down like what is shown in the drawing, but this drawing does *mathematically* represent their motion. (The reason why I chose to draw a 3 phase sine wave instead of a single phase sine wave is that I hope the transition from this picture to the next one is a little easier to understand, and I am going to use some of the information shown in this picture to explain the next one.)

If you can remember your geometry classes, a sine wave repeats itself every 360° (a full circle). In the picture above, I have drawn the first sine wave (purple) starting at zero and ending (repeating) at 360. The blue line starts at 120 (1/3 of a circle), and the green line starts at 240 (2/3 of a circle). Notice that the starting points of these three lines break a circle up into 3 parts, hence, a 3 phase system. But none of this really looks like a circle, does it? So let's draw it in a circle.

2.2 Phasor Diagram



A phasor diagram is a graphical representation of an electrical system. From a visual standpoint, there is not much correlation between a phasor diagram and an electrical circuit, but from a mathematical standpoint, they are the same. The phasor diagram is an important tool which will help explain some of the issues below covering electric motors. In the phasor diagram to the right, the purple arrow is pointing straight up and I am calling this zero degrees. The blue arrow is pointing 120° from zero, and the green arrow is pointing 240° from zero. Notice how these angles correlate to the starting points from the drawing above. The angle of each of these arrows represents the *phase or phase shift* of each of the three phases. We can also use the length of the arrows to represent other information like the voltage or current. For example, if the length of the arrow was 120, then this could mean that our voltage was 120 volts.

By the way, a 3 phase system commonly has a neutral too. Since the neutral is typically considered to be at zero volts, it is represented by the black dot in the center of the phasor diagram, and by the black horizontal line in the oscilloscope diagram.

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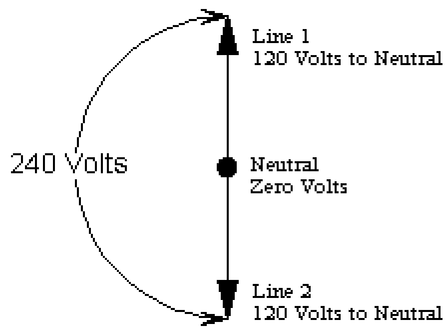
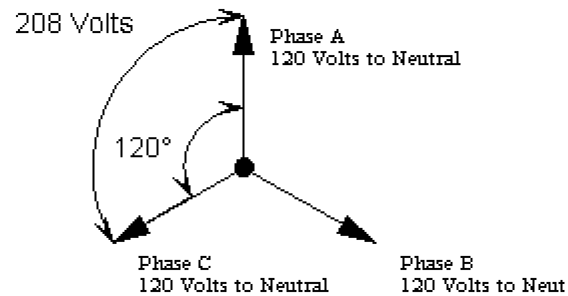
3. Types of Electricity in the Shop



Single Phase,
Two Pole System



Three Phase System

There are three common terms used to describe the electricity used in the shop. Single phase 120 volt, Single phase 240 volt, and three phase 208 volt. Don't be confused if you hear the terms 110 volts instead of 120 volts, or 220 volts instead of 240 volts. These are out of date terms which people still refer to, but all *public* utilities in the US deliver 120 volts and 240 volts for consistency and *load sharing*. Most tools and motors use these other terms (110/220) just to indicate that they will still perform if the voltage drops to that level.

3.1 Single Phase 120/240

Single phase 120 volt and 240 volt lines, are just different parts of the same system. This is actually a 240 volt system, but we split it in half to get two, 120 volt systems. This is the reason why it is called a single phase system: It is just one phase of power at 240 volts. To get the 120 volts, we use what is called a *center-tap*. Standard outlets in the shop use the Neutral wire (the center tap) and one Hot wire, where the voltage between the Neutral and Hot is 120 volts. The 240 outlets in the shop use both Hot wires, where one wire is 120 volts above the Neutral and the other is 120 volts below the Neutral (as before, we anchor the Neutral to Ground, and let the two Hot lines "float" above and below). It is said that each of the Hot legs (called poles) of a single phase system are 180° out of phase. It can be confusing that this system is called single phase, but it might be helpful to refer to this as a *two pole* system. (Using the term *two pole* is correct, but calling it a *two phase* system is incorrect.)

3.2 Three Phase System

Where the single phase system has two poles 180° out of phase, the three phase system has three poles which are 120° out of phase (note 3*120° = 360°,= full circle). Just as before, the voltage between the Hot and Neutral is 120 volts, but because of the phase angle, the voltage between any two Hot wires is 208 volts, which is 240*(0.866) = 208 volts. (Where 0.866 is the cosine of 120° This is straight forward trigonometry applied to the drawing above.)

The majority of three phase motors don't use the Neutral wire. This is called a *Delta Connected* system. (If you drew lines between each of the arrow heads above, you would have a triangle, or delta.) When the Neutral is used, it is called a *wye connected* system. The majority of power sources are "wye connect". A delta connected load (motor) can always be connected to a wye source by just ignoring the Neutral wire, but the reverse is virtually never true. (It can be done, but it requires a center tap, three phase, transformer to artificially create the Neutral.)

3.2.1 Current in the Neutral Wire

This is a question I get asked by even very experienced people. "If the current through the Neutral wire is the sum of the currents through each of the Hot wires, then shouldn't the maximum current in the Neutral be three times that of any one leg (at maximum power)?" That is, if 20 amps is flowing through each of the three Hot wires, then shouldn't the Neutral have 60 amps flowing through it? The answer is NO. (The following explanation is based on the three phase system, but it also holds true for the single phase, two pole system.) The current flowing through the Neutral wire is the sum of the currents flowing though each of the phases; yes, but what complicates this, is that each of the phase currents has both a *magnitude* and *direction*. Any time we have an expression which has both magnitude and direction, it can be expressed as a *vector* (the arrows I have drawn in the above diagram are vectors). We can't just add the magnitude of vectors without considering the direction as well.

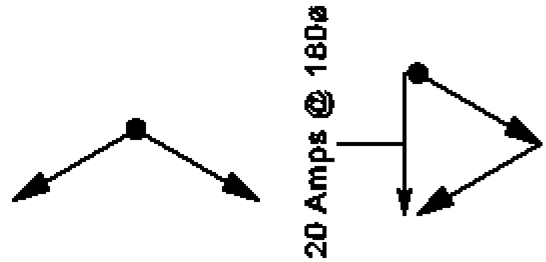
3.2.1.1 Vector Mathematics

In order to explain the current in the Neutral wire, we need to understand some principles of vector mathematics. Vectors can be used to describe anything which has a magnitude and direction. One example deals with travel, where the length of travel is the magnitude, and the direction is just that, direction. If we walk 10 feet East then turn around and walk 10 feet West, it is said that our net travel is zero (we are at the same point we started at.) If we walk 10 feet East and 10 feet North, then we could have accomplished the same travel by walking 14 feet Northeast (@45°). In determining the 14 feet Northeast, we could either draw a picture, or use trigonometry. The drawing method is called *tip-to-tail* because we redraw the vectors such that the second one starts where the first one stops. That's all there is to adding two or more vectors. This is the easiest method to describe, so I will stick with that.

To prepare for the examples discussed in the section below: if we walk 20 feet at 120°(120° from north), and then turn and walk 20 feet at 240° from north, we could accomplish the same travel by walking 20 feet due south. (By the way, the reason for the 20 feet due South, and not 24 feet or some other number, is because 120° and 240° make up what is called a *perfect triangle*. If it wasn't for these *nice* angles, it would have resulted in some other length, not 20 feet.) The first diagram below shows this example.

3.2.1.2 One Phase at Max Current, Two at Zero

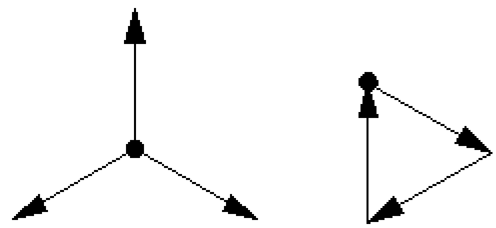
To understand how the current through the Neutral is determined, we will examine three *worst-case* situations. First, when one phase is at twenty amps, and the other two phases are at zero, the current in the Neutral will of course be 20 amps. Let's say the (A) phase has 20 amps and the (B) & (C) phases are zero.



Sum of Two Phases
Net = 20 amps

3.2.1.3 Two Phases at Max Current, One at Zero

When the current in two phases is 20 amps and the third is zero (the one pointing straight up is zero), the current in the Neutral will be 20 amps at 180° (see the drawing to the right). The sum of 20 amps at 120° plus 20 amps at 240° is 20 amps at 180° (pointing down)



Sum of Three Phases
Net = Zero

3.2.1.4 All Three Phases at Max Current

When all three phases carry the maximum current, they all cancel out, and the net current through the Neutral is zero amps. The second drawing to the right shows that placing all three arrows tip to tail, we go in a full circle (or triangle), and end up where we started, back at zero.

In short, the current through the Neutral can never exceed the maximum current in any one of the Hot legs. (There is one exception which I discovered while formulating the proof of this statement, but it is both rare, and complex.)

4.0 Apparent Power, Real Power, and Power Factor

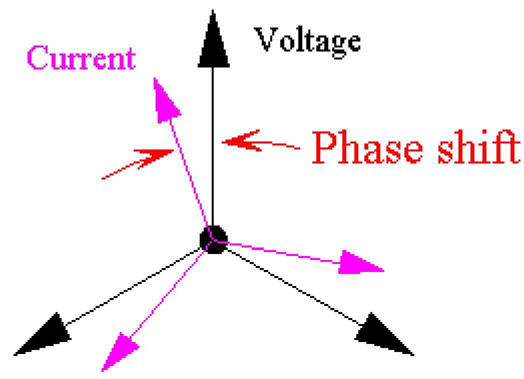
Power is the ability of a system to perform work. Water performs work when it turns the turbine blades of a hydroelectric plant. Electricity performs work when it heats up a heating element or turns a motor. It takes power to store energy, like in capacitive or inductive devices, while these devices then release some energy, or power, at a later time. (These devices can both expend power and deliver power.)

4.1 Power (in General)

For DC systems, power is the product of Current times Voltage, and will take on the form **P=I*V**. For AC systems with only resistive loads, the same holds true. But in capacitive or inductive circuits on an AC system, the device will momentarily store some power (or delay it), and so the issue becomes slightly more complicated. We need to compensate for this delay in power transmission, and this is where the term *Powerfactor* come in.

4.2 Powerfactor

When we us any capacitive or inductive device on an AC circuit, the current or voltage flowing through the circuit will be slightly delayed, or *out of phase*. The diagram to the right shows a pictorial representation (called a Phasor Diagram) of a three phase system with the current lagging behind the voltage. The angle between the black arrow (voltage) and the purple arrow (current) is called the *phase angle*. A motor is an inductive element, and the current lags behind the voltage (remember, the inductor had the ability to store current). In a capacitor the voltage lags behind the current (the capacitor stores voltage). You may sometimes hear the phrase: *the current leads voltage in a capacitor*, but this is just a matter of convention where the voltage is assumed to always be the same and the current either leads or lags. Now that I have explained why one lags behind the other, I am going to rephrase this but use the *standard convention*: Current LAGS voltage in an Inductor and Current LEADS voltage in a Capacitor.



Phasor Diagram
of 3 Phase System

For a purely capacitive or inductive circuit with zero resistance, the angle of lead/lag is 90°..; Adding resistance to the circuit will decrease the leading/lagging angle. The term "*Powerfactor*", is the cosine of the phase angle. For a purely inductive circuit, the lag angle is 90°., and the powerfactor is zero {cosine(90)=0}. A common powerfactor for electric motors is 0.8, which gives us a lagging angle of 36° (This is because there is some resistance inside the motor windings).

4.3 Apparent Power (KVA)

Apparent power is defined as the power which is "apparently" absorbed by a system. That is, the product of current times voltage tells us a device *appears* to be using a certain amount of power. However, this does not take into account the fact that the device can store (or delay) current or voltage, and this results in the calculations being slightly skewed. Apparent power is useful when we have a device like a diesel-electric generator, where the wires inside have a limited capacity to pass current, and we may not know in advance what will be connected to the generator. In other words, it doesn't matter what the delay (or phase angle) is, the generator can only allow a limited amount of current to pass through its wires. Because of this, many generators are rated in volt-amperes (VA), or thousand-volt-amperes (KVA). A 25 KVA generator can deliver no more than 70 amps per phase @ 208 volts before it burns out the windings. This can therefore power 25 kilowatts of heaters, but only 20 kilowatts for motors (assuming 80% powerfactor), because both of these loads will use 70 amps. Since the manufacturer does not know what the generator will ultimately be used for, they rate it in KVA because this indicates the maximum current regardless of the load's powerfactor.

4.4 Real Power (Watts)

The real amount of power a device is using, or results in actual work performed, is called the *Real Power*. Real power takes into account the fact that current or voltage is stored, or delayed. The real power tells us how much actual work can be performed, or how much horsepower our motor is delivering. For a resistive and/or DC circuit, the apparent power and the real power are the same, but for a capacitive or inductive circuit, the real power is heavily dependent on the amount that the current or voltage is delayed. Real power is presented in *Watts*. There is mathematically no difference between watts and volt-amperes, except that we use one term for apparent power, and one term for real power, but they are both units of power. We use the powerfactor to go from apparent power to real power. The real power of a system is equal to the apparent power times the powerfactor. In every day use, this boils down to **P=I*V*pf**.

4.5 Efficiency

Regardless of the type of system, *Efficiency is the difference between power in and power out*. If you are peddling a bike, your legs are *Power in*, and the tire against the road is *Power out*. The difference between these two is the *efficiency* of power transmission. For a bike, this loss of power, or efficiency, would be primarily the friction of the chain (even the friction of your trousers against your legs), wind resistance in the spokes, and even small frictional losses between the tire and the road, but it is not due to the steepness of the hill or wind resistance against you and the bike's frame, as this is a portion of the *work* the bike is performing (the load). In a motor, the loss of power is due to the resistance of the windings, friction in the bearings, air resistance inside the motor, and what is known as Hysteresis losses in the iron core of the motor. (Hysteresis is too complex for this discussion, and is not really all that important to us. I only mention it to be thorough.)

5.0 Phase Converters

I have decided to move this whole section into its own document because of the complexity. If you click on Phase Converters you will be sent to a NEW document which covers this topic.

6.0 Motors

Without motors, there would be no modern woodworking; they play an integral part in nearly all aspects of the woodshop. To understand motors we need to understand the basic relationships between electricity and magnetism.

6.1 Magnetic Principles

6.1.1 Magnetic Poles

All magnets, regardless of type or origin, will have a north and south pole. This is very similar to a battery always having a positive and negative terminal. If you have two magnets, the poles with opposite polarity will attract one another, while poles with the same polarity repel one another. These attraction and repulsion forces can be quite strong, and this is what will make a motor turn.

6.1.2 Induction

If you have a magnet, and you are physically moving a wire near this magnet, it will create a current in the moving wire. The faster you move the wire, the larger the current. Furthermore, the bigger the magnet, the larger the current. If you change the direction the wire moves, the current will also change direction. This is the basic premise for a simple generator, where we use a diesel engine to move wires past a magnetic field.

6.1.3 Electromagnet

Any flowing electric current creates a magnetic field. When this current is flowing through a wire, the magnetic field forms circular rings around the wire. We can concentrate the magnetic field by coiling the wire into tight loops, thereby making an *electromagnet*. We can concentrate the magnetic field even more, by wrapping the wire around an iron bar. This electromagnet also has both north and south poles like any other magnet, but the polarity of the poles changes as the electricity changes. If we send 60hz line power through an electromagnet, the polarity of the magnetic poles will alternate sixty times per second.

6.2 Parts of the Motor

A motor is made up of electric and/or permanent magnets which are constantly attracting and/or repelling one another. This creates movement of the spinning rotor. The only thing that differs from one type of motor to another is how these magnets are created and controlled.

6.2.1 Stator

This is the stationary magnetic component in motors, and constitutes the chassis in some cases. On most motors, the stator's magnetic field is created from electromagnets. One notable exception is small DC motors found in such items as toy trains etc, where these use small permanent (bar-type) magnets. Permanent magnets are not normally used in larger motors because they can loose their magnetism if the magnetic field in the windings is too strong. This would saturate the permanent magnet, and re-magnetize the stator in reverse polarity.

6.2.2 Rotor

The rotor is the component which makes up the spinning shaft of the motor. It is almost always electromagnetic in nature (coils).

6.2.3 Windings

These are the coils of wire which make up the electromagnet. They are usually wrapped around a laminated stack of iron sheets. The reason for the laminations is too complex to get into, but for those already familiar with the basic concepts, it is to reduce hysteresis losses in the iron core.

6.2.4 Commutator

This is found in universal and DC motors which will be discussed below. This device, along with the brushes serve to switch the polarity of the windings as the motor makes a revolution. (A forward and reversing switch, in short)

6.2.5 Brushes

These are typically carbon/graphite bars which carry the current from the incoming wires to the commutator, and then to the rotor windings. The brushes are soft such that they will form to the commutator contacts as it spins.

6.3 Simple Motor

Let's consider a very simple motor. The stator (the round casing of the motor itself) is a simple magnet, with the North pole pointing up, and the south pole pointing down. The rotor (the main shaft) is also a magnet. Right now, the north pole is also pointing up and the south pole is pointing down. Since opposite's attract and like's repel, the rotor is going to turn 180° until the rotor's south pole is closer to the stator's north pole.

Once this has happened, the rotor will not turn any further, unless we can somehow change the polarity of the rotor's magnetic field. We can, and we do this by using an electromagnet. By changing the polarity of the current flowing through the windings of the rotor, we change the polarity of the magnetic field as well. So now, our simple rotor will turned 180° again.

To prevent the rotor from turning backwards, we use momentum to keep it spinning. This means we need to reverse the polarity of the rotor's windings very quickly. That's the purpose of the *commutator*. The commutator is just a reversing switch to change the polarity of the rotor's windings as it spins. For our simple motor, the commutator would be two semicircular sleeves connected to our single winding motor. As the rotor makes a half turn, the commutator sleeves are in contact with the opposite brush, and this changes the polarity of the rotor windings.

6.3.1 Universal Motor

The universal motor is one of the most common motors found in the woodshop. It is used in drills, routers, and even most common 12" planers. The concept of the universal motor was originally based on a DC design, but was modified to allow for AC operation. The difference between our simple motor and a universal motor are minor. To make a simple DC motor capable of running on AC current, we need to replace the permanent magnets of the stator with electromagnets. Because the non-varying permanent magnets can now change polarity, and do so at the same time the rotor's electromagnets change, the motor doesn't know the difference, since both the rotor and stator magnets are changing at the same time. The commutator is still changing the polarity of the rotor magnets, but the change in polarity is with respect to the stator magnets. For the most part, any motor in the shop with brushes is going to be a universal type motor.

6.3.2 Induction Motor

This is one of the most common motors found in industrial tools. It is also found in many common household appliances like fans, blowers, washers, and so on. This motor is sometimes called a "*squirrel cage*" motor because of the concept behind the basic rotor. Instead of having multi-turn windings of copper wire, the rotor is made of single bars of copper, and to an extent, it resembles the exercise wheel for a hamster (well maybe they had squirrels for pets back then?) All of the same principles apply in terms of magnets inducing current in a conductor, and current carrying conductors being magnetized. What is different, is that there is no wire leading to the rotor, and no need for brushes. All of the current flowing through the rotor is induced by the magnetic field of the stator. This means no brushes, no sparks, just a couple of coils of wire plugged into the wall.

6.4 Horsepower Ratings of Motors

When you buy a tool, the manufacture's horsepower rating may be a little deceptive. In short, not all 5 horsepower motors are the same. The worst case I have documented is between two 5 horsepower compressors which I own. The primary compressor is an industrial unit and is a *true* 5 hp motor. The portable unit is retail quality, and is still rated at 5 hp, even though it's actual power output is closer to 2 hp. Manufacturers rate their motors differently in order to make them sound better than they really are: beware of the term "developed horsepower".

6.4.1 Buying Motors, How to Compare

If the manufacturer's information is deliberately deceiving, then how do we as consumers know what is for real? The answer, is to do some of our own calculations to determine a more realistic horsepower rating. These calculations are not designed to provide absolute accurate numbers! They are designed to provide numbers which can be compared from one motor to the other. The reason for the inaccuracy is because some of the information we need for these calculations is not always provided on motor nameplates. If a term is not provided on both motor name plates, then we cannot use that term on either motor's calculation, as this would skew the results. For example, my industrial motor provided all of the variables I would need to calculate, within reason, the actual shaft horsepower. However, the retail motor provided nothing more than rated current and voltage. Because of this, I would have to completely ignore the additional information from the industrial motor if I wanted to have a reasonable comparison between the two. No, I'll never really know what the actual shaft horsepower is on the retail motor, but I'll know enough to determine that the two motors are not equal.

6.4.2 Calculations

Due to the principles of *Conservation of Energy* (energy can neither be created nor destroyed, only converted from one form to another.), we can say that the power into the motor, as electricity, is equal to the power out of the motor, as horsepower, minus any losses or inefficiencies in this conversion process. A motor is nothing more than a converter of energy. It converts electrical energy into mechanical energy plus a little heat as a byproduct. (Note that losses or inefficiencies do not violate the physical law of "conservation", these losses result in heat or other forms of energy.)

The overall equation for converting electrical power to mechanical horsepower is: $HP=W/745$. Where HP is horsepower, W is watts, and 745 is a conversion factor. We know from our previous discussion that power, in volt-amperes, is given by the following equation: P=I*V. For an inductive device like a motor, we also need to take into account the phase angle between current and voltage by adding the powerfactor term (pf). Our equation for power becomes P=I*V*pf. Our final equation then becomes: **HP=I*V*pf/745**.

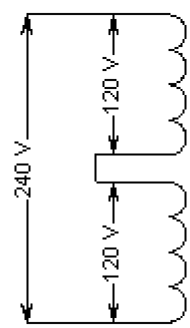
6.4.2.1 Some Notations

I have deliberately left out any discussion of the efficiency factor, since most motor name plates will not show this number. Just for discussion, the efficiency factor represents the difference (or loss) from PowerIn to PowerOut, and you can read further at efficiency.

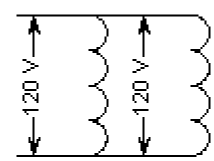
Many motors do not provide a power factor. If one of your motors does not provide a power factor, then you cannot use this term for calculating any of the motors, and you can only compare their apparent power. If you are comparing a universal motor with an induction motor, and you cannot use the powerfactor term, your results will be skewed, as the universal motor frequently has a much smaller power factor than the induction motor.

6.5 Rewiring a Motor, 120 versus 240

I have read many Internet discussions regarding rewiring a 120 volt motor for 240 volt operation. Many people believed that this change will provide greater power at the shaft. The truth is, the motor will output the same amount of power regardless of how it is wired.



240 V Config.



120 V Config.

6.5.1 Voltage in the Windings

When you have a motor which is able to be rewired for either 120 or 240 volts, you have a motor with *split windings*. The windings are either connected in parallel for 120 volt operation, or in series for 240 volt operation (see the diagram to the right). The net result, is that the individual windings never see more than 120 volts. If the voltage across the windings does not change, then neither does the power output. In short, the motor does not care how it is wired. Each winding still sees 120 volts from the source regardless of the configuration. The only thing that changes is the current in the wires within your house, but the power consumed remains the same.

6.5.2 Voltage Drop in the Lines

Some people have argued that using the motor at 240 volts versus 120 volts will result in lower voltage drop across the power lines. The truth is, if your shop is wired according to electrical code, there will be virtually no appreciable voltage drop across your house wiring. If the wire feeding your motor is below rated size, then yes, of course, you can get an appreciable voltage drop across the wire, but then you also run the grave risk of burning your shop down too!

6.5.3 When Should You Rewire?

The only reason to ever consider rewiring a motor, is if the power lines running to the motor are too small for the current rating at the lower voltage. As you double the voltage, you half the current. However, if it is not a dedicated circuit, you could not change the voltage anyway, as this would put 240 volts into the other 120 volt outlets. In short, before you spend the time and risk of rewiring a motor, evaluate why you want to do it: it doesn't help the motor. It doesn't change the power drawn from your service panel. It makes virtually no difference in voltage drop. It will only make a difference if you already have an existing, dedicated 120 volt circuit, and it was wired for a smaller motor. If you have not realized it yet, I am highly opposed to rewiring a motor. To date, I have only encountered a couple of cases where it would be better to rewire a motor.

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7. Wiring a Shop

Regardless whether our workshop is in the garage or basement, we usually need to update the existing wiring to meet the higher demands of our tools. This can be a daunting task, but if completed correctly, it can flow together quite easily.

7.1 Disclaimer

Although the National Electrical Code is used in most areas, some cities, like Chicago, have their own electrical code. Because of this, I will not refer to specific code issues as if they are absolute. The reader is responsible for determining what the code requirements are for their specific area. The information present here is intended to be a guideline only, and I cannot take any responsibility for accuracy, implementation, or omission.

7.2 Planning

Preinstallation planning is the most important part of the wiring project. I used a CADD system to layout the shop design just so I could see tool placement, the paths and lengths of the infeed and outfeed, and walking and working paths. Not only should you plan for the layout of the tools in the shop, but you should also plan for future expansion, and plan for future changes to your currently planned layout. I started planning the layout and electrical needs of my shop months before the shop was built. Even so, I am contemplating making a significant layout change less than three years after the shop became operational. (Update: *I did in fact make these changes last year. As a matter of fact, I ended up changing the location of 6 tools during this single rearrangement. Because of the excessive layout (overkill) I did when I built the shop, I only had to relocate one low-power 240 volt circuit.)* Furthermore, I have added several large tools to the shop. One point however, if you are not going to sheet rock the work area, then it is not as critical to worry about future changes, since you will still have access to the wiring system.

7.3 Layout

Different types of shops will have different layout needs. My shop is primarily for cabinetry, and large project construction. It is separated into three basic areas: the machine area, fabrication, and finishing. The machine area has the highest concentration of power. The majority of this power is 240 volt circuits, but there is also a significant number of 120 volt convenience outlets. The fabrication area has almost no 240 volt circuits, but is heavily loaded with 120 volt circuits. And the finishing area has only the outlets needed for spray equipment. (Actually, the wires are in the wall, and boxes are installed for more outlets, but I did not bother installing the receptacles due to a lack of need. This is planning for change, as the area may have a different use in the future.)

For a cabinet shop, the table saw is typically the central tool. Because of this, the saw was located in the center of the longest wall of the shop where I have unlimited infeed, and a fourteen foot outfeed (an exit door prevents the saw from being moved back further, as 14' is not always enough). The other tools for the shop were planned around the table saw location. The next tool I placed was the jointer. It is placed just behind the table saw so I can run a board through the jointer, then the saw, and then back to the jointer for gluing raised panels. For me, these two tools are the most *interdependent*. The next tool was the planer. I use this almost exclusively for *width planing* in creating frame stock, etc. Because of this, the lumber goes through the table saw, and then the planer, so the planer was also placed behind the table saw. Additionally, because the frame stock going though the planer is typically longer than the lumber going through the jointer, the planer took priority and has unlimited infeed and outfeed, while the jointer has about eight feet in&out. The wide belt sander falls into the same category with unlimited infeed and outfeed. I have the cut off saws on the forward side of the table saw. This allows my table saw outfeed table to be used as a work surface during component cutting. The shaper was placed opposite the table saw simply because this area has twelve feet infeed and outfeed. (Update: *This whole layout has changed, as I mentioned above. Even though the purpose of this was to get 30 feet of space for my cutoff saws, I still followed the same rationale to relocate the displaced tools. The shop is not nearly as efficient as it was before, but the needs have been met. The only tool which is in the wrong place is the jointer. It is now on the far side of the table saw. This may sound trivial, but the effects are very noticeable.)*

For the layout of your shop, you should go through the same type of rationale taking into account the type of shop you run, the type of tools you have/will have, and the shape and size of the shop. Part of the reason the layout of my shop was fairly difficult, is because the shop is not square, it has several odd angled walls. These types of issues need to be thought out during the planning phases of your shop.

7.4 Outlets

For 120 volt outlets, I placed mine with a maximum 6 foot spacing. This may be overkill, but I wouldn't even consider anything less. Furthermore, if there is a workbench area, I would drop to 2 or 4 foot spacing. Also, I placed all of my outlets at 4 foot height so I don't have to stoop down to use them. If there is an area where you may have dense power needs, like a battery charging area, you may want to consider using a quad outlet instead of the normal duplex outlet. As for outlet placement, since it only costs about $2 per duplex outlet and junction box, overkill is preferred. You may even consider adding some junction boxes in the ceiling. Even if you don't use them right away, you can add a pendant (hanging) outlet in the future. (Make sure to use the appropriate strain relief and cord for a pendant.) For the duplex cover plates, you might want to consider the additional cost and use metal plates, since they can be subjected to some severe abuse in the work area, although I didn't.

For 240 volt outlets, place them based on your layout so they are nearest the machine they operate. In some cases, it may be better to suspend cords from the ceiling for tools not located against the wall. Some of my tools are semi-portable, like a multi-tool workstation cart and the 15" planer (on wheels). For these, I installed a flexible cord and cord cap, like a permanent extension cord coming from the wall, to allow the tool to travel further from the wall than its own cord permits.

Most of my larger tools did not come with a cord cap (plug) installed. Because of this, I had to install one on each tool. I used twist-lock cord caps and receptacles throughout the shop. This prevents tools from coming unplugged at inopportune times. If a cutting tool loses power in the middle of a cut, it can cause a violent kick-back.

7.5 Conductors and Breakers

The outlets throughout your home are probably on 15 amp circuits. This meets NEC (National Electric Code), and so that's how an electrician will wire a home. But that doesn't mean it is the best design. Ever trip a circuit breaker in the bathroom, because the hair dryer is going at the same time as your wife's curling iron? It can be even worse in the shop with power tools.

Circuit breakers are a protection device to protect the system when it is operating beyond design parameters. If your breakers are tripping frequently, then the system was not designed properly. All of the outlets in my shop are 20 amp capacity and use 12 gauge supply wire. In three years of operation at this shop, I have never tripped a breaker. For larger tools, the size of the breaker will depend on the tool. The owner's manual, or motor name plate will tell you what the current load of the motor should be.

After determining the size of the breaker you need for the circuit, you need to select the wire size from the chart to the right. This chart provides NEC current limits for various wire sizes. Note that the chart makes no mention of voltage. It is current which heats up and melts wire, not the voltage. Make sure to use wire sizes appropriate for the current load.

Current Rating	Wire Size
15 Amps	14 Ga.
20 Amps	12 Ga.
30 Amps	10 Ga.
40 Amps	8 Ga.
55 Amps	6 Ga.
70 Amps	4 Ga.
85 Amps	3 Ga.
95 Amps	2 Ga.

7.6 Circuits

There is no hard and fast rule for the number of outlets to put onto a circuit. This will vary depending on how many outlets will be used at the same time. In a kitchen for example, several countertop appliances can be operated simultaneously. And so the number of outlets per circuit is kept low, such that the sum of all device currents is below the breaker rating (typically 80% is strived for). Some parts of the shop can be like this too, like the battery charging area or the work bench. However, since most power tools require user operation, there should be fewer cases where several tools operate at the same time. This will be dependent on the types of tools used in your shop, and whether you work alone. I used about six outlets per 20 amp circuit. I could have used more outlets per circuit, but I am prone to overkill, as you may have noticed.

When I laid out the 240 volt circuits, I did double up some of them, where two tools are on the same circuit. I did this on tools with similar power needs and proximity, but I evaluated which tools would be operating at the same time. The dust collector is on its own circuit, since it will run with virtually all tools. The same is true for the table saw, being the primary tool. But since the radial arm saw and the shaper are virtually never operated at the same time, and they both require 30 amp circuits, I have them on the same circuit. This rationale can help with both cost and time, but it could come back to haunt you if you rearrange the shop layout. (*After rearranging the shop, the radial arm saw and the jointer are now on the same circuit. These two tools DO run at the same time. Fortunately, their combined power draw is still below the current rating of the circuit.*)

7.7 Service Size

The size of the load center (a.k.a. service panel, circuit box, circuit panel, and sometimes service disconnect) you install is dependent on the number of circuits you will need for the shop. Count the number of circuits you need, add a couple more for expansion, and use this for getting a service panel. (Don't forget, 240 volt circuits count as two circuits.) My shop uses somewhere between 20 and 25 circuits. With this, you could probably get by with a 60 amp service panel with half-height breakers. This is the kind commonly found in mobile office trailers, and provides 60 amps per leg or 120 amps total. I think that even my shop, with a significant number of industrial motors, and the possibility for several tools running at one time, should operate on this size service panel. My overkill mentality would probably step in, however, and put in a 100 amp service.

7.7.1 New Service from the Utility Company

If you are adding a whole new service from the power companies pole or underground vault, you need to check with them to determine how much of this they will complete, and how much you need to complete. For my power company, I had to bury the wire from the transformer vault, through the service meter, and into the main load center in the basement. The utility company then came out, made the connection at the transformer, and installed *their* meter into *my* meter panel. This can be a complex task, so you would probably be better off hiring an electrician to do this for you, or at least to help and/or consult with you. There are a couple of things to keep in mind in running the incoming service:

- I have been told that the service meter DOES have a polarity to it, with respect to incoming versus outgoing terminal points. The electrician I hired as a consultant told me that if the wires (or the meter itself) were installed upside down, then the meter would run backwards. (Maybe this is only true in some areas, like a farm or industrial facility, so it wouldn't hurt to ask. Ask the utility company, not the hardware store clerk.)
- If the wire is direct burial, make sure to install *frost loops* when approaching a rigid structure like the house. This allows for seasonal ground movement,

etc., and is nothing more than making a loop of the wire before entering the above ground conduit. Also, check with the local inspector as to when conduit is required. Some areas require conduit under driveways, while others require it everywhere.

- Use anti-oxidant grease on the lugs.
- The NEC publishes bending radiuses for various wires. Do not put sharp bends in the wire. Use large flowing loops.
- Make sure that all of your connections are completed between the transformer and your main breaker (sometimes referred to as the service disconnect) before you call the utility company to come out and connect at the transformer. Once they make that connection, you will not have a way to turn off the incoming power, unless your meter has a service disconnect built in. (A service disconnect is any device designed to break the circuit coming into your main panel. Removing the meter from its socket is a common way for the utility company to disconnect the service, for work at your load center.)
- There are a lot of rules about this work, and I don't know them all. Please consult with your utility company, or an electrician.

7.7.2 Sub-Service Connection

Most likely, you would be adding a sub panel to your existing load center. This isn't quite as complicated as a new service. However, if you are running power from one building to another, then some of the complications listed above can come back into play. One of the forum respondents asked which was better, buried or overhead power. That's for you to decide, not me. Buried cable is more back-work, but I think overhead is probably more complex, in terms of electrical code. In either case, the issues are too complex to get into, so I will just concentrate on placing an internal panel in the same building.

The reason for putting in a new sub-service in the same building as the main service could be because the main load center is in the garage, and your shop is in the basement; or your existing load center does not have enough positions available for new circuits. (My 200 amp load center, which has 40 circuits, is full, and has no room for expansion. So if I add even one more circuit, which I already have started to do, then I must install a whole new sub-panel.)

- Select the size sub-panel you will need. The sub-panel does not require a main breaker since you will be installing the breaker back in your old load center.
- Secure your new sub-panel to the wall. Make sure it has plenty of clearance on the sides and front for fire code regulations.
- The new load center may have a maximum, or suggested current rating. Use this to determine the size of the feeder cable (wire from the old load center to the new load center), as well as the circuit breaker you will be adding to the old load center to power the new load center.
- Starting at the new load center, connect your feeder cable, and string it back to the old load center.
- Remove one of the *knock-outs* from the new load center, and install a cable

clamp which is large enough to accommodate the feeder cable.

- Strip back enough of the cable's jacket, or *sheath*, such that all of the wire inside of the new load center is free and unbounded by the outer sheath, but still has the insulation on each wire. (Each separate wire has insulation around the copper. The bundle of wire is enclosed in the plastic outer sheath. Remove the sheath, <u>not the insulation</u>.)
- Connect the Neutral wire to the Neutral bus bar, typically running vertically alongside the area of the breakers.
- Connect the Ground wire to the chassis of the load center. More often than not, there is typically a Ground bus bar, which looks similar to the Neutral bus, but may be smaller. However, some load centers combine the Neutral and Ground Busses into one bus.)
- I wire a lot of office trailers through my Tech Services Company. Some of these 60 amp load centers have *main power lugs* at the top of the panel, which is where the incoming power lines are connected to. Try to find a load center that has these lugs for the main connection, as it will be much easier. If you can't find a load center with main lugs, then you have to buy a separate two-pole circuit breaker and use that as the incoming power connection lugs.
- Whether or not you have a main breaker at the new load center, you will have to add a breaker to the old load center. This is the only method for connecting your wires to the power. <u>Do not connect the new wires directly to your main, incoming wires of the old panel</u>. Connect the new wires to the old panel as described above. It is far easier to connect the Hot wires to the circuit breaker before you place the circuit breaker into the panel.

7.8 Bonding

Bonding is the term used to describe connecting the ground and neutral wires together. Your main load center will be bonded, in that there is a screw, or similar connection between the ground and neutral buss bars or wires. The purpose of tying the neutral and ground wires together is to anchor the neutral at zero volts. Most of the time, your sub-panel should not be bonded, and you should remove this screw or other connection device from the sub-panel, but there are exceptions to this. The rule of thumb is: If your two panels share a common ground path, then the second panel should not be bonded. To explain this, I am going to cover a couple of examples which have been presented to me recently: (The information presented below has been confirmed with the Minnesota State Board of Electricity as of September, 1998)

7.8.1 Shared Ground System

A shared ground system is one where their is a ground wire or path which is common to all panels. In a shared ground system, only the main load center can be bonded (neutral tied to ground). At no other point in the system can their be a connection between ground and neutral. Any, and all, sub-panels must be wired with separate wires for neutral and ground which originate back at the main load center. By default, all electrical systems within the same building are of the shared ground type.

Because of this, if you add a sub-panel in your basement or attached garage, then you must carry a ground wire from the main panel to the sub-panel, and you must remove the bonding screw from the sub-panel.

7.8.1 Split Ground System

In a split-ground system, you have two totally separate grounding systems. The electrical systems cannot be contained in the same building, and there must be no path to ground which they have in common (**this must also include water pipes**). When there is a completely separate grounding system between two electrical systems, then each system must be bonded.

One simple example of a split system is where incoming power from the utility enters a distribution panel (a splitter panel), and passes to two separate buildings. In each of these buildings, there is a separate load center, and a separate ground rod. There is no ground wire which connects the two buildings. In this case, there is no sub-panel, as each panel is considered a main load center.

Another example which is probably more common is adding power to a detached garage. At the time of the installation of the secondary wiring system, only a neutral and two hot wires were run, but no ground wire to reduce installation costs. Even though the garage's load center is a sub-panel of the main load center, the grounding system is separate, and permissible, because the buildings are separate. (Keep in mind, that you <u>can</u> run a ground wire from the house's load center to the garage if you wish, but you are not required to. If you run the ground wire, then you do not bond the sub-panel. If you don't run the ground wire, then you bond the panel)

7.9 Miscellaneous Notes

- When stringing wire into a junction box, remove 8-10 inches of sheathing, such that at least 6 inches of unsheathed wire is sticking out from the front edge of the box, and no unsheathed wire is back inside the wall.
- The wire must be clamped as it enters the junction box. If the box is the type with a built-in clamp, or a screw in clamp, that is sufficient. If the box is plastic, you must use a wire staple within at least 6 inches of the box.
- When drilling holes through studs and/or wire-stapling the romex to the side of a stud, make sure there is at least 1 1/4 inches from the wire to the front edge of the stud to prevent a nail from piercing the wire during sheet rock installation. (This is a significant code issue, not just convenience.)
- When placing wire staples, I think the maximum spacing is 3-4 feet...use more. Also, do not pinch the sheathing or puncture the wires. Going back to the 1-1/4" clearance, you are permitted to place one wire on top of the other and staple both down with the same staple. Make sure the staples are the right size for the wire so they don't pinch the sheath.
- When stripping the insulation off from the wires, only strip 1/2" for connection into an outlet/switch/breaker, and 3/4" for wire nutting.
- Use the appropriate size wire nut for the number of wires in it and the size of the wires. The box of wire nuts should list what they can be used for. I

recommend not using wire nuts which do not have steel threads inside. (Not all wire nuts are the same, and I will only use one specific kind (GB brand), they have large ribs, but not the wings, but its only my personal preference.) I don't pre-twist my wires before I put on the wire nut, but many electricians do. Again, this is just preference, because if you turn the wire nut hard enough when it goes on, the wires will twist themselves. After the wire nut is on and very tight, pull on each wire to see if it is loose. If it is, either redo the whole thing, or tighten the nut further if possible. (There is a tool which fits into screw guns which will drive certain types of wire nuts--the type I described above--this can be a handy tool to have for even small jobs, to apply sufficient torque to the nut. {I could not locate one retail, so I used an 8-point socket.})

- Most receptacles today have both screw-type lugs, and push-in clamps (the small holes on the back). My electrical inspector informed me that he would not allow me to use the push-in connections on outlets if I were using #12 wire. He also said that I could not use the receptacle to complete the connection from incoming and outgoing wires. I was required to wire nut the incoming and outgoing wires plus include a *pigtail* which connected to the receptacle. I did not bother confirming this with NEC, because the inspector has the authority to dictate.
- On that note, you may want to call your inspector and ask if there are any specific issues he may require both covered by NEC and not covered. This can save you a fair amount of rework after a failed inspection.

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8. Glossary

Analogous - adjective/ having resemblance; similar; corresponding in certain ways

Appliance - this is a generic term used to describe a tool, light, or any other device which uses electricity. It isn't just something you find in the kitchen. By this definition, a light bulb is an appliance, and so is a motor, etc.

Load - A device or appliance which is using power. (See Source)

Source - This is the incoming electricity which is supplying power. (See Load)

Electric Charge - This is the buildup of electrons, or even the absence of electrons in a particular area. When you rub a balloon against your hair, electrons will be passed from one surface to the other. The surface which has more electrons than the other will have a negative electrical charge.

Phase Angle - This represents the amount of delay a current or voltage signal has with respect to a reference signal. The section on inductors and capacitors explains this the best, but it also applies to the difference between phases of a three phase system.

Two-Pole/Three-Pole Breakers - These are circuit breakers which are *slaved* to one another. That is to say, if the current through any one of the two or three wires exceeds rated current, then both, or all three, breakers will trip together. Slaved means that all others will do the same as the first.

Vector - A graphical representation of a commodity, electricity in this case, which has both a magnitude and direction. Here, the voltage and/or current is the magnitude, given in volts and/or amps; and the phase angle is the direction given in degrees.

Perfect Triangle - This is a triangle where all three inside angles are 60° (the outside angles are therefore 120°). Because of this, all three legs of the triangle are the same length. In short, all of the angles are equal, and all of the legs are equal.

Tip-to-Tail - A graphical method for adding vectors together where the second vector is placed with its starting point on the end-tip of the first vector (same for third and forth, etc.) and the result is a new vector drawn from the starting point of the first vector to the end-point of the last vector. As the vectors are moved, they maintain their direction and magnitude.

Load Sharing - This is a situation when two or more power supply units share the same load. When one utility company cannot handle the load for it's district, or if there is some sort of generator failure, then electricity is purchased from another district to fill the gap. Power generation stations are networked together, such that if one station falters, the other stations will pick up the slack, and the customer never knew there was a problem.

Center Tap - A term used most frequently with transformers, where an additional wire, or connection is made in the middle of a transformer coil which results in the voltage being cut in half at that point.

Microfarads - A unit of measure when dealing with capacitance, just as a mile is a unit of measure for distances.

Volt-Amperes - This is a unit of measure for power. It is very similar to the Watt, just like the Foot is similar to the Meter.

Pigtail - This is a term to describe a short electrical wire used to make a connection to another wire. It can also be viewed as a method for tapping into another connection with a short wire. Inside of an electrical outlet's junction box, you may have one wire coming into the box, one wire going out of the box, and a pigtail connecting these two wires to the outlet.

Service - This is a slang term for the incoming power into a building or main panel, and usually refers to the power lines provided by the utility company.

Service Disconnect - A service disconnect is any means or device which breaks , interrupts, or disconnects the path of electricity from the service/source to the load. Service disconnects can be circuit breakers, switches, or even the plug on a tool. It is required to have a service disconnect within sight of any motorized device, so that device can be worked on without the danger of it starting unexpectedly.

Load Center, Service Panel, Circuit Box, Many More - these are some of the terms used to describe the main circuit breaker panel.

Single Phase versus Two Phase Systems - As I mentioned in Section 2.1, Single Phase Systems, it is not correct to refer to 240 volt systems as two phase. One reader who Emailed me said he had a motor which was listed as "two phase". It took quite some time, but I stumbled across a definition of two phase power. Two phase power does exist, or at least did, and it is when the two 120 volt (Hot) wires are 90° out of phase instead of the customary 180°. Because of this phase angle, the voltage from either of the Hot wires to Neutral will be 120 volts. As far as I know, this system does not exist anymore, but I added this information just in case someone else ran into this type of motor rating. (I don't know if you can operate a two phase motor on single phase power.)