# Alternating Current

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What is electricity? Well the dictionary defines it as **"a fundamental property of matter caused by the presence of electrons and protons, and manifesting itself as attraction, repulsion, luminous & heating effects, and the like".** Isn't that informative?

I think this one is more meaningful -- **"an elegantly simple yet incomprehensible entity that moves at the speed of light yet remains trapped in wires destined only to bounce back and forth, weightless but still breaks the sound barrier as it plummets from the clouds, attractive yet repulsive, a taker of lives but also a restorer of life".**

Like many other properties in physics, electricity is difficult to define. It more easily lends itself to descriptions such as attraction and repulsion. Fundamentally it can be described as a force just as gravity is force or, as a form of energy. It can be static or it can be moving. Since electricity is so difficult to define, it is probably best that we just try to describe it and its effects. We will spend most of our time discussing AC power since it is the electricity we work with every day but, we will take a quick look at DC just so we can compare the two.

## AC Versus DC

"A chicken in every pot and an eagle in every pocket" or so went one slogan during the Great Depression. Had Thomas Edison won the battle over power distribution we could have added "and a power plant on every corner".

Edison was a great proponent of DC power and fought the use of AC bitterly. He invented the incandescent lamp in 1879 and began immediately to develop a power generating and distribution system to promote it. He opened his first power plant in New York City in 1882 and added several others over the next few years. His idea was to build a power grid with generating stations about four miles apart. Edison's financial partner was JP Morgan and he set about to buy up as many copper mines as possible in anticipation of the transmission wire that would soon be needed. Although Edison's efforts were a limited financial success, it was soon recognized that DC transmission systems suffered heavy power losses over any significant distance.

One of the great advantages of AC power is that its voltage can be changed easily by the transformer, a device that operates on the principle of induction and takes advantage the relationship between the volt and the ampere. That relationship states that power in watts is equal to volts times amps and, volts and amps can be any quantity. One kilowatt (KW) can be 100 volts at 10 amps or it can be 1000 volts at 1 amp. When transmitting power over long distances, the combination of higher voltage and lower amperage results in lower transmission losses. Why? Because, the energy expended (as heat) in maintaining current flow increases as the square of current intensity. In other words, if you reduce voltage by one half while leaving power constant, losses due to heat will increase by four. DC voltage, on the other hand, is difficult to change and, typically, must be generated at the same voltage at which it will be consumed. Therefore, DC current intensity is always disproportionately high and energy losses follow the rule just stated.

Edison's principal opponent at the time was George Westinghouse. He and his partner, Croatian-American engineer, Nikola Testla made long distance AC transmission practical. Testla, invented the transformer and induction motor, and also made major improvements in the AC generator. In the late 1880's LL Nunn, a mine owner from Ames Colorado, came to Westinghouse with a proposal to build a steam powered AC power plant for his mine. Westinghouse accepted and it went on line in 1891 and was the first AC power plant in the world. In 1893 Westinghouse won the right to construct a commercial AC hydroelectric plant at Niagara Falls and it was this plant that, convincingly, demonstrated the flexibility of AC power thus relegating DC to a secondary role.

Lets take a look at DC power but, before we do lets define a few terms that we will use over and over.

**Common Electrical Terms (AC & DC)**

**Volt** – A unit of potential difference. It is the difference in electromotive force (or charge) between two points. A reasonable analogy for those familiar with pumping applications is pressure. Voltage in an electrical circuit is equivalent to pressure in a pipe line.

**Ampere (Amp)** – A unit of current or the amount of the current in a circuit. When compared to water in a pipe line, current or Amps is equivalent to flow in gallons.

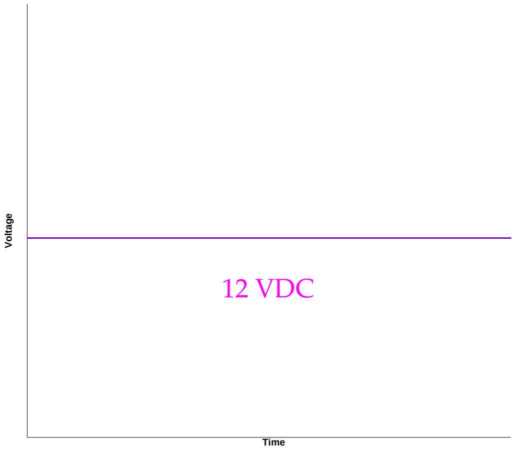
**Ohm** – A unit of resistance that impedes the flow of current in a circuit. Again, when compared to our pipe line it is analogous to friction.

**Watt** – In the English system the Watt is a unit of power and is equal to the product of volts times amps.

## DC Pros & Cons

Why was DC power so attractive to Edison and its other followers? Well, DC power is extremely simple when compared to AC. Once a DC voltage is switched on, its intensity remains constant. It also follows Ohm's law. Just about everything you need to know about a DC circuit is described by: I = E/R (or E = IR) where E is voltage, I is current, and R is the resistance. And, if simplicity is not enough, it can even be stored by a battery.

Unfortunately, its simplicity leads to a couple of major drawbacks. First, DC voltage intensity is not easily increased or decreased so it is usually consumed at the intensity at which it is generated. Also, it suffers high transmission losses when transmitted at usable voltages. Remember that power loss varies as the square of the current intensity and since "usable" DC must be generated at a relatively low voltage, current will be quite high.



I said earlier, that once a DC voltage is applied to a circuit and rises to its generated intensity, it remains constant. The DC voltage "curve" seen to the right shows voltage maintaining an unvarying 12V over time. Now lets compare AC to DC.

## AC Pros & Cons

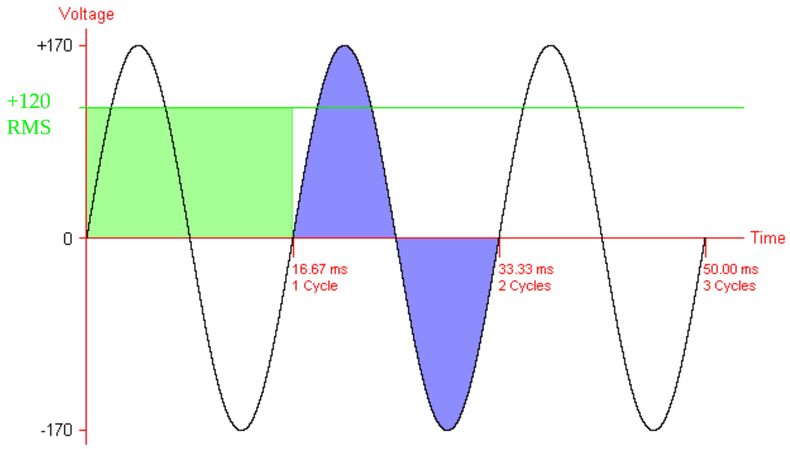
What were the advantages of AC that allowed it to become the standard? Probably the most important quality is its ability to induce a current in a nearby object. And, it is because of induction that an AC voltage can be easily changed via a transformer. It can be generated at a particular voltage, stepped up for transmission, and then stepped down for safe usage. We will discuss induction and transformers in some detail a little later.

Another advantage is that AC current can be generated as a single wave form (phase) or in multiple waves (phases). We will talk more about this advantage later. Also, its frequency (cycles per second or hertz) can be varied easily during generation or afterwards. This feature allows a simple approach to controlling an AC motor's speed (See "Variable Frequency 101"). And, finally, it is easy to convert AC to DC when DC is needed but much more expensive to convert DC to AC.

On the down side, AC power is far more complex than is DC. Fortunately for us, this is not a major factor as all of its complexities have been studied and understood by those before us. If we follow the known rules we can utilize all of its benefits and avoid any pit falls. Lets take a look at this more complex power curve.

## The AC Power Curve

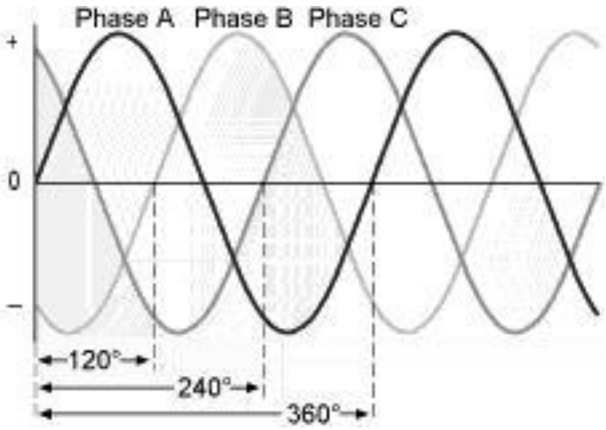
The single phase, 120V sine wave shown below, has several important characteristics. As it progresses through one full cycle (one 360 degree rotation of a generator) it peaks at 170V a quarter of the way, goes to zero at the half way point, reaches negative 170V at 270 deg and returns to zero at the end of the cycle. In the US this occurs 60 times each second so one full cycle takes about 16.67 milliseconds. A full cycle is also known as a Hertz (Hz). Three complete cycles are shown in the illustration.



Now you are probably wondering why we call this a 120V sine wave if the actual peak is at 170V. Could 120V be the average? Well, if you were to average all of the voltage values across the cycle the result would be approximately 108V, so that must not be the answer. Why then is the value, as measured by a Volt / Ohm Meter (VOM), equal to 120V? It has to do with something we call effective voltage. It turns out that the area of the green rectangle, whose upper border is at 120V, is equal to the sum of the actual areas under the upper and lower curves of a single AC cycle. This area is known as the effective voltage of the sine wave. Lets take a closer look at effective voltage.

If you were to measure the heat produced by a DC current flowing through a resistance, you would find that it is greater than that produced by an equivalent AC current. This is due to the fact that AC does not maintain a constant value throughout its cycle. If you did this in the lab, under controlled conditions, and found that a particular DC current generated a heat rise of 100 deg, its AC equivalent would produce a rise of only 70.7 deg or 70.7% of the DC value. Therefore the effective value of AC is 70.7% of that of DC. 0.707 times the peak voltage of 170 seen above equals 120V.

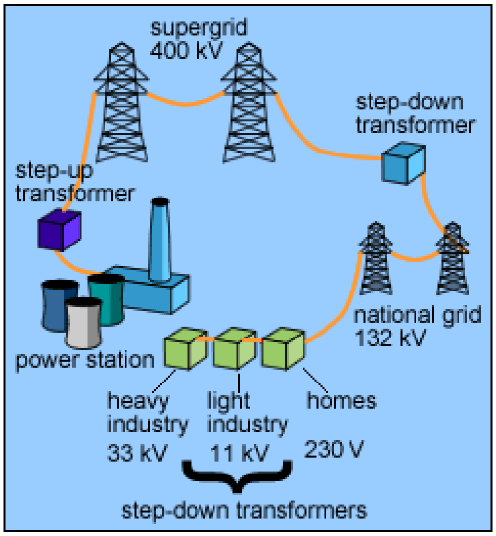
It also turns out that the effective value of an AC voltage is equal to the square root of the sum of the squares of the voltage across the first half of the curve. Thus, effective voltage is also known as the root mean square or RMS voltage. If the peak voltage were 1, the RMS calculation will also yield 0.707. It follows that the peak voltage will always be 1.414 that of the effective voltage. Remember that, unless stated otherwise, all VOM's are calibrated to display RMS voltage.



Now lets get even more complex and take a look at a three phase power curve. The curve to the right shows the output of a generator, wound in a manner, that produces three separate single phase curves, each separated (or, out of phase) by 120 electrical degrees. So why do we have three phase power? After all, it appears pretty complex and why three phases instead of two or four? Actually it is not nearly as complex as it may first appear. After all, the three phase curve is simply the combination of three, single phase curves and each is transmitted from the generator to its point of use by a separate wire. It could just as easily be produced by three separate single phase generators if their rotational speeds and timing could be controlled precisely.

But, why three phases? One big advantage that three phase power has over single phase or even two phase power is the fact that, at any given point in time, one of the three phases is nearing a peak and, never, is there more than one phase at zero. In single phase power the sine wave crosses zero volts twice during each cycle. Two phases also reduces this “zeroing” effect but not nearly as well as three phase. Higher horsepower, three phase motors and other devices such as welding equipment will therefore have a more even power output when operated on three phase power. Four phases would not improve things significantly and would add the expense of a fourth wire, so three phase was the natural settling point.

## AC Power Transmission



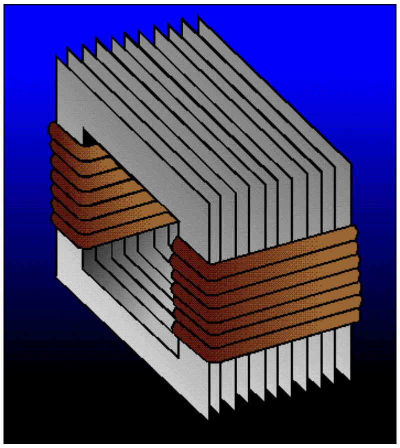
As I mentioned earlier, one of the unique qualities of AC power is that its voltage can be changed easily and in either direction – up or down. This allows us to generate power at some voltage, step it up to a higher voltage for long distance transmission (reducing losses due to heat), and then reduce it some lower voltage at its point of use. The sketch on the left shows this process. The key element in this process is the transformer and the key to its operation is a phenomenon known as induction.

## What is a Transformer

Very simply, a transformer is an electrical device that, via induction, increases or decreases AC voltage and current. We will discuss the role of induction in a few minutes. Voltage varies directly with the ratio of the transformer's primary and secondary windings while current varies inversely.

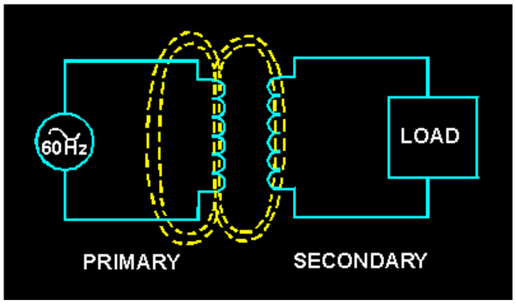
In other words, a transformer that is designed to double the original voltage will reduce the original current by one half. If, on the other hand, it reduces voltage by one half then its current output will double. The beauty of this is that power in and out, in watts, remains the same (W = V x A).

The simple transformer consists of only two parts - a metallic core made of thin insulated laminations and bundles of insulated wire wound about each end. Laminations, rather than a solid core, are incorporated to reduce eddy currents that arise during induction (similar to eddy currents in a stream). These currents produce heat thereby reducing the efficiency of the transformation. The coil that receives the incoming power is known as the primary winding and the one connected to the load is known as the secondary winding.



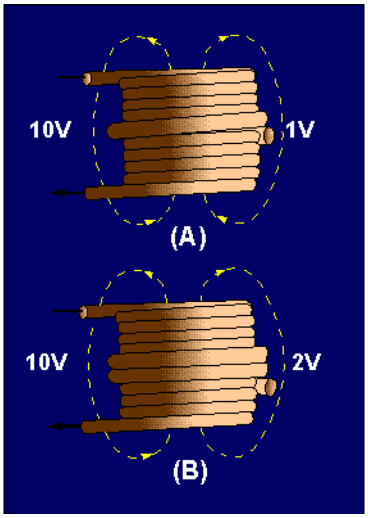
## How Transformers Work

Both transformers and AC electric motors operate via the principle of induction. You will probably remember from your high school science class that if one moves a bar magnet in or out of a coil of wire an electric current is produced. No contact is necessary, only the motion of the magnet is required. When the magnet is still no current is produced. Similarly, a charge moving through a coil of wire (AC naturally but DC also when it is switched on and off) can also create a magnetic field. And, that magnetic field can create or induce a charge in a nearby but unconnected coil of wire or other metallic object just as the magnet did. Both of these are examples of induction but it is the second one that is the stuff of transformers and motors. For a more detailed discussion of induction see "The AC Induction Motor".



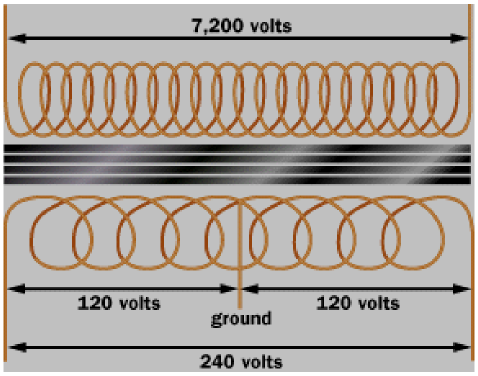
In the diagram on the left, the transformer's primary winding is connected to a 60 hertz AC voltage source. The "dotted" ovals represent the magnetic field that builds up and collapses about the primary winding during the ups and downs of each AC cycle. This expansion and contraction induces an alternating voltage in the secondary winding and, this induced voltage causes an alternating current to flow through the load. The voltage may be stepped up or down depending on the design of the primary and secondary windings.

## The Turns Ratio



The turns ratio simply defines the relationship between the primary and secondary windings of a transformer. The figure on the right shows two transformers both of which are energized with 10V at their primary. The upper one shows a secondary voltage of 1V while the lower one shows 2V. To obtain the turns ratio of each, simply divide the primary voltage by the secondary voltage. In this case we obtain 10 and 5 or 10:1 and 5:1. In the upper example, 10V applied to 10 primary turns will induce 1V in one secondary turn. This is an example of a "step down" transformer. But, had the tables been turned and a single turn primary been energized by one volt, its ten turn secondary would have produced 10V and we would have a "step up" transformer.

Now a 10:1 ratio doesn't mean that there are just 10 turns in the primary and 1 in the secondary. The actual numbers depend upon the voltage and current it must handle but the ratio always remains the same. Remember too, that a transformer that "steps up" voltage must "step down" current proportionally. Otherwise we would have a device that "creates" more energy than it uses (a no-no in physics). Likewise a transformer that "steps down" voltage will increase current so that power in watts is the same for the primary and secondary (less some losses due to heat).

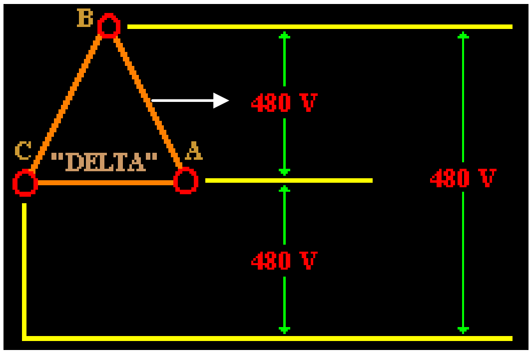


The schematic to the left shows another capability of a transformer. The "tap" in the middle of the secondary allows us the flexibility of obtaining more than one output voltage. In this case we can power two 120V loads and one 240V load simultaneously. If the tap were not there, a separate transformer would be required to lower 240V to 120V.

## Delta & Wye Connections

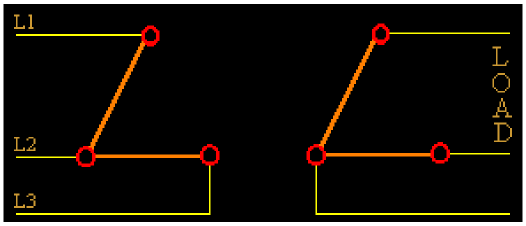
So far, all of our examples have been single phase transformers. A three phase transformer may consist of **three separate but identical** single phase transformers or it could be a **single unit** with three phase windings. Regardless of the configuration, their function is the same. The secondary windings can be configured in several ways.

The simplest three-phase system is the 3 wire **closed delta** configuration and is typically used in power transmission (up to 15,000V) and industrial installations. The diagram on the right depicts an ungrounded delta. Each conductor's voltage to ground is equal to the full phase voltage of the system or, in this case 240V. The phase to phase (leg to leg) voltage is the sum of the two phase voltages or, in this case 480V.

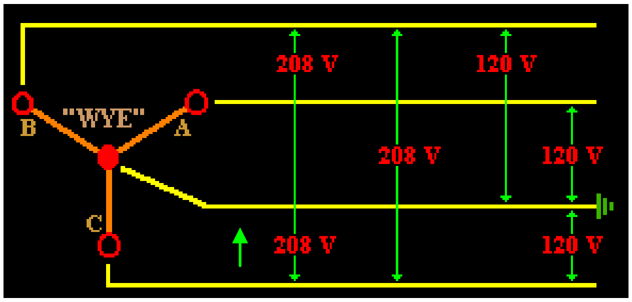


If a tap (white arrow) is added between points A and B, the configuration changes to a 4 wire system. The single-phase voltage on each side of the half-tap is one-half the voltage available in the normal phase-to-ground relationship. Point C must be avoided for single phase operation because the voltage between it and the "tap" is much higher than for points A & B (often called the crazy leg). Thus, at any given location in the system, either three-phase power at full voltage or single-phase power with half or full voltage is equally possible.

The **open delta** transformer connection can be made with only two transformers instead of three. This connection is often used when the amount of three phase power needed is relatively small and lower installation cost is a factor. It should be noted that the output power of an open delta connection is only 87% of the rated power of the two transformers and only 58% of that of a closed delta system with the same transformer rating. The voltage and current values of an open delta connection are computed in the same manner as a standard closed delta connection.



The **Wye** secondary has completely different voltage characteristics than the Delta system. In the Wye system, the phase to ground voltage is the phase voltage divided by 1.73. We will not get into phase angles here, so for a detailed discussion of this phenomenon see the "Changing Voltage Puzzler".



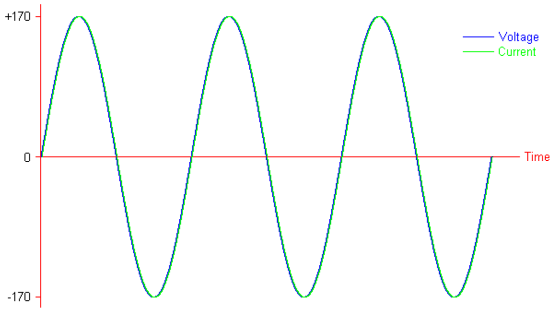
The figure to the right is an example of the Wye system, or center-grounded Wye as it is commonly called. It extends three current-carrying insulated conductors and an insulated grounded neutral to the loads. Depending on the selection of conductors, any of the following are available: a reduced voltage (120V) single phase between a phase leg and the neutral; a full-voltage (208V) single-phase circuit between any two legs; or full-voltage (208V) three-phase power. Precautions must be taken when balancing the single-phase loads in the system.

## AC Circuit Loads

There are two types of loads that occur in AC circuits - - resistive and inductive. Like it sounds a resistive load consists purely (almost) of a resistance. Examples include incandescent lighting, water heaters, clothes dryers, and the electric range -- almost anything that is designed to generate heat. Inductive loads, on the other hand, use the AC power source to "induce" a complimentary current in some nearby metallic object. Examples include electric motors, generators, and transformers. The two loads are very different and require different relationships to explain their characteristics.

## Resistive Circuits

In the case of a resistive load, AC loses much of its mystique and behaves much like DC. A purely resistive AC load (actually impossible but it can come close) follows Ohm's law (I = E/R) and has characteristics similar to that of a DC circuit. Lets take a look at voltage and current in a resistive circuit.



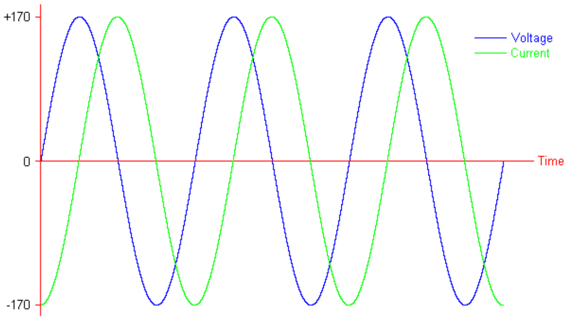
To the left is the same single phase sine wave we saw previously. There is, however, a difference. The voltage curve is shown in blue and the current curve is shown in light green. Don't worry if you cannot see both -- neither can I. Since the current curve follows the voltage curve the result is a single darker green curve. The point here is that, in a resistive circuit, voltage and current rise and fall together. They may not have the same amplitude but, at any point on the curve, current and voltage are in phase. A three phase plot would show a similar result -- three separate single phase curves with voltage and current rising and falling together. Things are quite different when an inductive load is involved.

## Inductive Circuits

In a circuit that contains an inductive load (i.e. an electric motor or transformer) the picture becomes much more complicated. A new term called impedance (Z) replaces resistance (R) in Ohm's rather simple law. Impedance combines resistance and another new term known as reactance. Reactance is a phenomenon that occurs when a current is induced in a transformer's secondary coil or the rotor of a motor. The opposing current that is generated by induction causes the inducing current to lag the voltage curve by some amount of time. (Another type of reactance causes the opposite effect. A circuit containing a capacitor will cause current to lead the voltage curve. We will get into that a little later.)

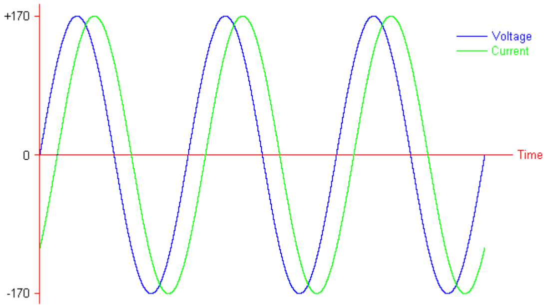
Therefore Ohm's law becomes: **$I = E / Z$**

Where Z is equal to $\sqrt{R^2 + X^2}$ and X is the combination of capacitive and inductive reactance. Lets take a look at the relationship of current and voltage in an inductive circuit.



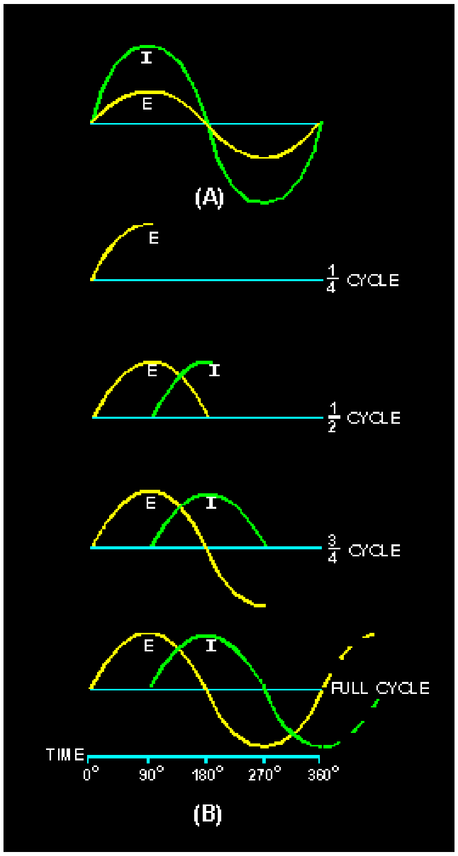
In this illustration we see a very different picture. Instead of voltage and current rising and falling together, as it did in the previous curve, the current curve lags the voltage curve. In fact, when current reaches it peak intensity voltage falls to zero. This lag in the rise of current intensity is due to inductive reactance and it can have severe consequences on the efficient usage of power. Now, this curve is a bit overstated. Under normal circumstances, induction does not cause the current curve to lag to such a great degree.

This picture depicts a more typical current lag due to induction. Here voltage drops about 20% to 25% as current peaks. It is still a substantial lag but not nearly as



great as the theoretical amount shown in the previous illustration.

## Inductive Reactance



How does induction cause current to lag voltage? In a purely resistive circuit, voltage and current rise and fall together as seen in the upper portion (A) of the illustration to the left. The current and voltage may not have the same amplitude, but they are in phase.

In the case of inductance, the induced current (i.e. in the rotor of a motor or the secondary of a transformer) opposes the current that produced it and, in effect, retards the rise of the inducing current until later in its cycle. The lower portion (B) shows the wave forms for a purely inductive AC circuit in steps of quarter-cycles.

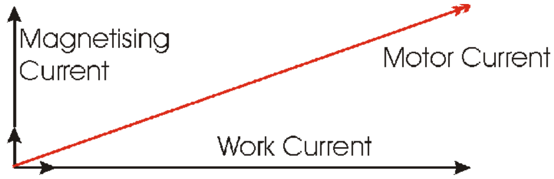
In the first quarter-cycle (0° to 90°) voltage is continually increasing. If there were no inductance in the circuit, current would also increase during this first quarter-cycle. But, this circuit does have inductance and since inductance opposes the charge that produced it, no current flows during the first quarter-cycle. In the next quarter-cycle (90° to 180°) voltage begins to decrease and current begins to flow in the circuit. It reaches a maximum value at the same instant the voltage reaches zero. A similar situation occurs during the third quarter of the curve with current falling to zero as voltage rises to its negative maximum. Finally voltage falls to zero and current peaks as the last quarter of the cycle is completed.

Well, this is really neat but of what importance is it?

## Power Factor

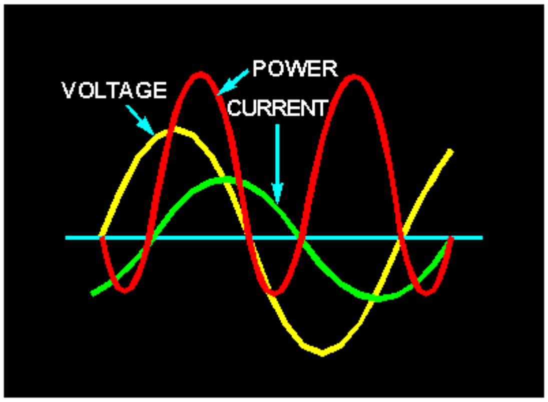
Its importance lies in something the utility company refers to as Power Factor (PF) and, it has to do with the relationship between the actual power used by an inductive device versus what it may "appear" to use. Power Factor becomes extremely important when large inductive loads or, a large number of smaller inductive loads are fed by a particular power supply. By extremely important, I mean that it can cost the user and the utility big dollars.

Now, PF is one of those areas where AC power gets a bit complex. Not only do we have voltage and current rising and falling, but also that pesky little phenomenon called induction is involved. You will remember that in a DC circuit, power (in watts) is equal to the voltage times the current, or P = E X I. If a voltage of 100 volts is applied to a circuit that draws a current of 10 amperes, the power consumed is 1000 watts. This is also true in an AC circuit when the current and voltage are in phase; that is, when the circuit is effectively resistive. But, if the AC circuit contains an inductive load, current will lag voltage by a certain amount as we saw in the previous illustration. When current is out of phase with voltage, the power indicated by the product of voltage and current is called "apparent power" which is measured in kilovolt amps (KVA). The actual or "real power" measured in kilowatts (KW) is always somewhat less. The difference between the two is the inductive component known as "reactive power". The relationship between real power and reactive power is referred to as Power Factor (PF).



This graph to the right uses a simple vector approach to illustrate the effect of inductive reactance on power factor in the operation of an AC motor. The current required to do a certain amount of work (work current or real power) is shown on the X axis. The current required to induce an opposing current in the rotor (magnetizing current or reactive power) is shown on the Y axis. The vector (motor current or apparent power) that results from these two values is shown in red. Its value is proportional to its length and, as you can see, it is somewhat greater than the work current. An increase or decrease in reactive power (magnetizing current) causes a similar change in apparent power.

Power Factor is the ratio of real power (work current) to apparent power (motor current) and is a measure of how efficiently power is used. A high PF (100% is the maximum) indicates efficient use while a low one indicates poor use.



And, you thought the preceding curves were complex! Well, I will have to admit that this one looks pretty busy but it clearly illustrates the effect of the reactive power component and how it actually "wastes" power.

The yellow voltage and green current curves are typical of an inductive load. As you can see, current is lagging voltage by about 45 degrees. The red curve represents power available and is the product of voltage and current (E x I) at all points along the X axis. Now, if voltage and current were in phase (rise and fall together) the power curve would be positive at all points (remember, -E x -I = +Power). But you will notice that portions of the red curve are on the negative side of the x axis. These portions of the curve represent power that is available but was unused by the load and therefore returned to the source. The areas under the portions of the curve that are above the x axis represent the power consumed or "real power". Those same areas plus the areas of the portions of the curve below the x axis represent "apparent power". If you were to measure the areas under the upper and lower curves and compute the ratio of real to apparent power you would find that the Power Factor is 0.82 or 82%. In other words this circuit is using only 82% of the available power to accomplish useful work!

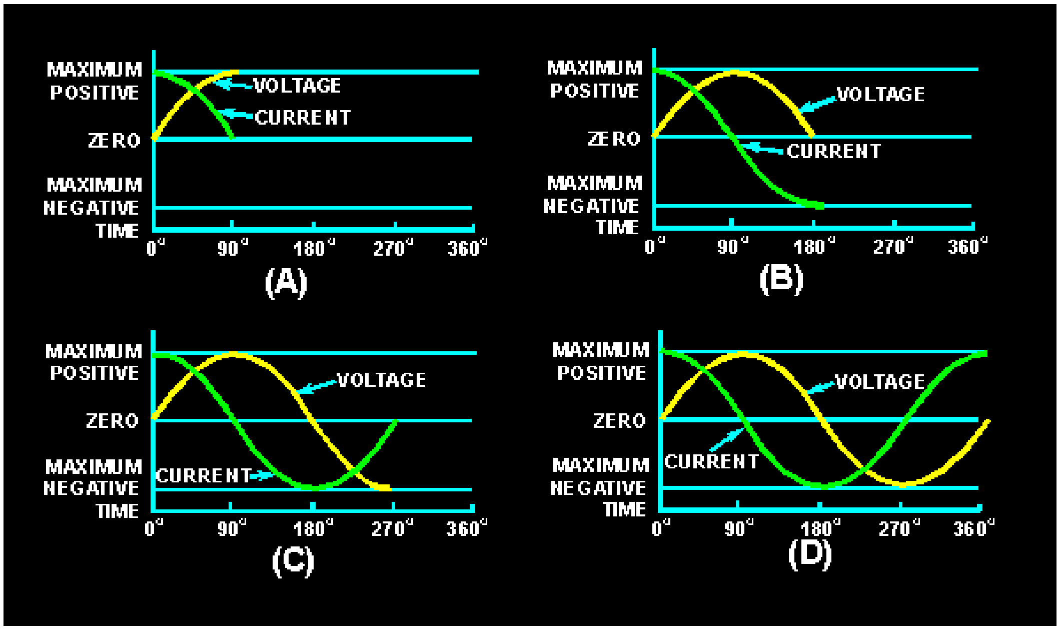
So, now we have an understanding of power factor but so what? After all the reactive power component is returned to the source so it isn't wasted – or is it?

Well it is true that it is not wasted – it is still in the circuit. And, the utility is not being cheated either because their meter records the actual power used. But it does cost them because they have to generate more power than is actually required. Regardless of PF, a motor is going to require a certain amount of power depending on how it is loaded. But if can use only 82% of that available, the utility is supplying an excess of 18%. If the reactive component is low then more of the power generated originally is consumed and an excess is not needed. Because of this excess capacity, most utilities charge a surcharge if an account does not meet its minimum power factor requirements.

Now it is reasonable to expect that a small motor is not going to have much of an influence on the overall power factor. But, in a large building with lots of small motors or, a municipal or industrial facility with many large motors the influence can be great. In addition to the inefficient use of generated power, the current carrying capability of power transmission cable diminishes significantly with a decrease in power factor. For example, an electrical system providing 100KW at 480 volts can do so with #0 cable if PF is 100%. Reduce PF to 60% and #0000 cable is required. Now, 60% is obviously an unacceptable PF but I think it reinforces the point! So, how can we reduce the effect of inductive reactance?

## Capacitive Reactance

Well, we really cannot "eliminate" reactance because it is a natural result of induction. But we can counter act it by introducing another kind of reactance that causes the opposite effect. When AC is impressed across a capacitor, power is taken from the source and stored in the capacitor as voltage rises from zero to its maximum value. Then, as voltage decreases to zero again, the capacitor discharges and returns power to the source. In doing so, an interesting event occurs and it is illustrated in the figure below.



What we see here is something very similar to the illustration on inductive reactance except (and it's a big except) current now "proceeds" voltage in the AC cycle. There is no real need for us to delve deeply into why this occurs. It has to do with electron migration from plate to plate within the capacitor. The important point is that capacitive reactance has the exact opposite effect of inductive reactance.

Therefore, when a capacitor is placed in an inductive circuit its voltage-current phase relationship can modify the phase relationship of the inductive circuit. Remember our modified Ohm's law equation for inductive circuits ($I = E/Z$ where Z equals $\sqrt{R^2 + X^2}$ and X is the combination of inductive and capacitive reactance)? Well if the correct amount of capacitance is introduced it will cancel the inductive effect and the result will look very much like a resistive circuit with voltage and current rising and falling together. Although it is difficult to mate capacitive and inductive reactance exactly, power factor correction to 93% or better is easily obtainable. If you look at most industrial motor catalogs you will see that they list PF for each motor model and often offer PF correction capacitors as an accessory item. The Franklin AIM manual includes a PF correction table for their 5 to 200 HP three phase motors.

We will end our discussion of AC power with a summary of single and three phase electrical characteristics, especially as they pertain to the operation of an electric motor.

## Single Phase Characteristics

In a single phase circuit the current is equal to the line voltage divided by the impedance. If it is a resistive circuit impedance becomes resistance.

**I = E / Z**

The power consumed in watts is always equal to volts times amps times the power factor.

**W = E x I x PF**

And, motor HP can be calculated by the equation below where 746 is the number of watts consumed by a single horsepower at 100% efficiency and $Eff_m$ is actual motor efficiency.

**Motor Amps = (HP x 746) / (E x $Eff_m$ x PF)**

## Three Phase WYE & Delta Characteristics

When three phase power is involved things get a bit more complex. The reason for this is that there can be two different transformer configurations (WYE & Delta) installed at the point of use of three phase power and their output is quite different. Not to worry though. As your will see the overall result is the same.

In a WYE connected circuit, measured amps is equal to phase amps but measured voltage is only 1.732 that of phase voltage (instead of 2.0). One would think then that the output in watts would suffer under this configuration. But in the Delta connected circuit, although measured voltage is equal to phase voltage, measured amps is only 1.732 that of phase amps. Since watts is equal to volts times amps the result is the same for both. These differences are a result of the phase angle generated by the two configurations and this topic is covered in detail in “The Changing Voltage Puzzler”.

| **WYE Connected** | **Delta Connected** |
|---|---|
| **E = 1.732 x Volts per Phase** | **E = Phase Volts** |
| **I = Phase Amps** | **I = 1.732 x Amps per Phase** |

## Three Phase Common Characteristics

Regardless of the type of transformer installed, two characteristics will always be true. Both power in watts and motor current in amps can always be calculated using the equations shown.

**W = E x I x 1.732 x PF**
**Motor Amps = (HP x 746) / (E x 1.732 x $Eff_m$ x PF)**

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