Direct and Alternating Current

A Preface to Inverter Technology

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March, 2000

In order to understand how inverters work, we must be familiar with electrical terms and the differences between direct current and alternating current. This discussion is not meant to be an intense review for electrical engineers, but rather an explanation to help RV owners gain a better understanding of electricity to preface a discussion of inverter technology. Electricity is not easily described or understood. Engineering types may feel this discussion is imprecise, while novices may find it confusing. We are seeking a balance between the two. If you find yourself lost, continue through the article. Then read it again. We find this technique helpful for complicated subjects. With subsequent reading, we often find the concepts begin to clear and ultimately the light goes on. Ed remembers that he had to live over 50 years and drive through El Paso at least a dozen times before he realized that "El Paso" means "the pass."

DIRECT CURRENT

Many people find it easier to understand water supply systems than electricity, so let's compare direct current electricity to a water system. Voltage is electrical potential stored in a battery. It is similar to the water reservoir, untapped power waiting to do work. When a switch is turned on, current starts to flow just as when a faucet is turned on, water begins to flow. Water flow is measured in gallons per minute. The stream of electrical current is measured in amperes-sometimes called amperage or just plain amps. An ampere is 6,250,000,000,000,000,000 electrons passing a given point in one second. When water flows through a hose, it meets resistance. Resistance increases as the length of the hose is increased and/or the hose diameter is decreased. This same resistance effect occurs with electricity flowing through a wire and is measured in Ohms. Most inverter manufacturers will recommend short runs of heavy gauge wire (large diameter) between the inverter and the battery bank (short hose with a large diameter to reduce resistance). If the hose breaks, there is a flood, no work is accomplished, and the reservoir runs dry. This is similar to an electrical short circuit. The battery is quickly discharged and no work is accomplished. However, if the hose is connected to a sprinkler, the water is regulated and performs the work of watering the lawn. Likewise, when electrical current is restricted by a load, like a light bulb or other device, it performs work. Electrical work is measured in watts.

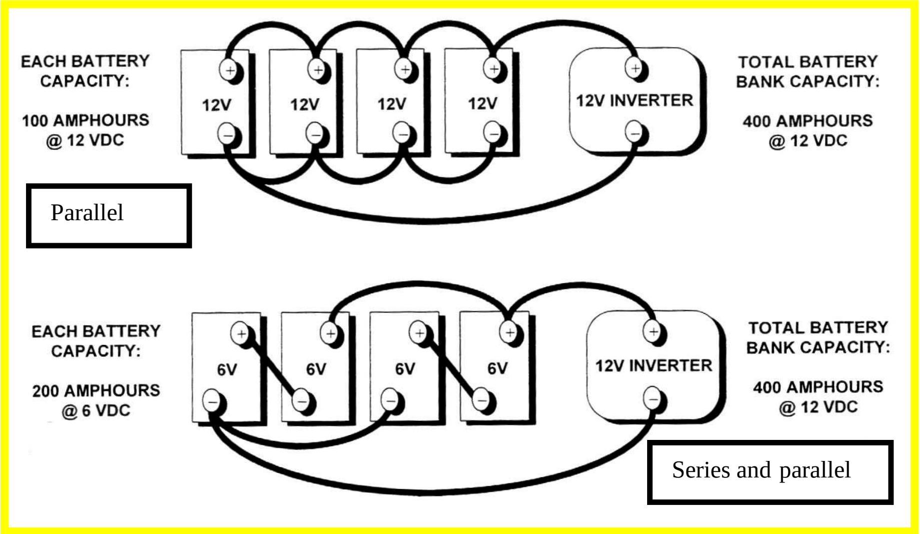
Ohm's Law applied to Direct Current

Volts = Amps multiplied by Resistance
Amps = Volts divided by Resistance
Resistance = Volts divided by Amps

Understanding the definition of watts will be important when we discuss inverters because there is a difference in power measurements between direct and alternating current. For direct current (DC), watts equal volts multiplied by amps, and Ohm's Law describes the relationship of volts, amps, and resistance. In equations, "V" or "E" represents voltage, current is "I" or "A," and resistance is "R." If you know any two of these, you can determine the value of the third.

Several terms need to be included in any electrical discussion. *Conductors* are materials that allow electrons to travel freely. These include iron, copper, silver, gold, and other metals. *Insulators* are materials that prevent the flow of electrons. These include glass, plastic, paper, wood, and rubber. A *capacitor* is an electrical device for storing charge (electrons). A simple capacitor is comprised of two conductors separated by an insulator. DC voltage can be stored in a capacitor but it will not pass through the capacitor. AC voltage, on the other hand, appears to pass through a capacitor. The higher the frequency, the easier this seems to occur. Strictly speaking, AC voltage or current does not actually pass through a capacitor. What really happens is that charge builds up on one plate of the capacitor until the current flow reverses. As the charge lowers on one plate, it builds on the opposite plate, which gives the appearance of current flow. We know that a capacitor consists of two conductors separated by an insulator. Current does not flow through an insulator, but current does move as charge builds up on the plates.

In *Inverter History & Technology*, there will be references to series and



Drawing Courtesy of Trace Engineering

parallel circuits. The diagram below shows batteries wired both in series and parallel. Other components such as resistors, capacitors, diodes, and transistors can be wired similarly. Some transistors and diodes are more easily adaptable to parallel configurations than others. A circuit wired in series means that current flows through one component before it flows through another. Components in a parallel circuit are connected so that current does not have to flow through one to go to another. The mathematical calculation of the values for components wired in series or parallel will not be discussed in this article.

Electric currents produce magnetic fields, and magnetic fields can be used to produce electric currents. A wire that conducts a current generates a magnetic field, which circles around the wire and differs depending upon whether the wire is straight, looped, or coiled. Some of the energy in the field around a coil can be transferred (induced) to a second nearby coil. Induction is the production of an electric current by *changing* a magnetic field through a conducting loop of wire. Magnetic flux is the flow of a magnetic field. The magnetic field through a loop can be changed by altering the magnitude of the field or by altering the area of the loop. An example of this phenomenon in a DC application is the automotive ignition coil. To make our calculations easier, we will arbitrarily state that our primary coil has 100 turns, our secondary coil has 100,000 turns (1:1000 ratio), and, though impossible, it has 100% efficiency. The positive terminal of the primary coil is attached to the 12 V source (battery ignition lead) and the negative terminal of the primary coil is attached to the ignition point(s) or transistor switch. Opening the points disrupts the 12 V flow. Each time the points close, the 12 V circuit is briefly grounded, causing 5 amps to flow through the primary coil. When the points open, a change in the magnetic field occurs which produces magnetic flux. This magnetic flux induces a voltage in the secondary coil. Because of the 1:1,000 ratio of turns, the 12 V at the primary coil becomes 12,000 volts at the secondary coil. Since energy cannot be created or destroyed, the power remains the same. Having 12,000 volts means that there are 0.005 amps available at the secondary coil. A high voltage wire passes from the secondary coil to the distributor and then through the distributor to a spark plug. The high voltage is transmitted down the spark plug wire to the center terminal of the spark plug and from there, a spark jumps to the ground electrode. In this example, the induction has occurred because of the change of magnetic flux with the intermittent grounding of the primary coil.

Power =VA
12V x 5 amps = 60 watts
12,000V x .005 amps = 60 watts

ALTERNATING CURRENT

Rotating a coil in a magnetic field produces alternating current (AC). The graph shows voltage according to where the coil is in its rotation. The waveform produced is a sine wave - much different from the straight line that represents DC power. When describing DC, we could liken it to water flowing from a reservoir because DC flows one way. Electrons flow from negative to positive potential (i.e., battery terminals). AC current does not exhibit one-way flow. AC electrons move at the speed of light but they go in one direction for a while and then in the opposite direction for a while. When describing alternating current, we like Dave Smead's (*Living on 12 Volts with Ample Power*) analogy of comparing it to "a train that is used to haul ore from a mine tunnel. The train goes into the tunnel and out of it. Overall, the train doesn't really go anywhere, but in the process of going nowhere, it does much work."

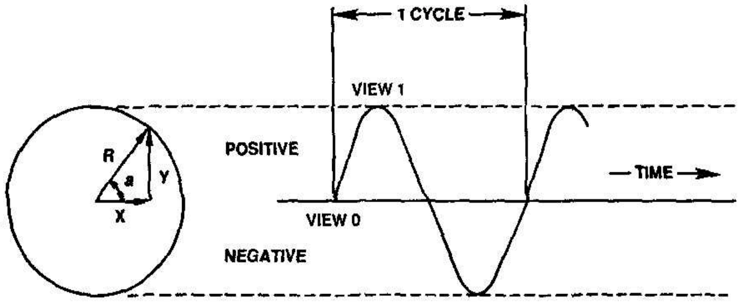
In AC, voltage is changing at 60 cycles per second. With two voltage spikes per cycle, there are 120 magnetic flux changes per second. With each change of magnetic flux, current can be induced in a nearby coil. This induction is the operating principle of the transformer. Just as in the DC induction example, AC voltage can be stepped up to a higher voltage, which drops the amperage. This makes AC ideal for transport to distant locations. The low amperage explains why the high voltage wires that bring electricity from a power company can have a relatively small diameter. Once the high voltage arrives at the distant location, a step down transformer reverses the process to lower the voltage and increase the available amperage.

Power measurement in AC is not the simple volts multiplied by amps as in DC. Looking at an oscilloscope trace of the AC voltage waveform, we see that there is a peak value of 170 volts. This yields an *effective value* of 120 Volts AC. The technologically correct term for the effective value is RMS, which represents root mean squared. This term will be seen in manuals and other literature. The RMS calculation is a way of comparing AC to DC measurements as seen on a gauge by smoothing out the sine wave to the value of a straight line. Another way to think of RMS, which also reflects power requirements, is that it measures the area within the outline of the sine wave. This area is the effective value. Because it is not a rectangle or other straight edged figure, the mathematical formula for calculating the area of the curved sine wave is more difficult. Fortunately, it is not important that anyone besides electrical engineers can do the calculation-we just need to remember that for a sine wave, RMS equals 0.707 times the peak voltage.

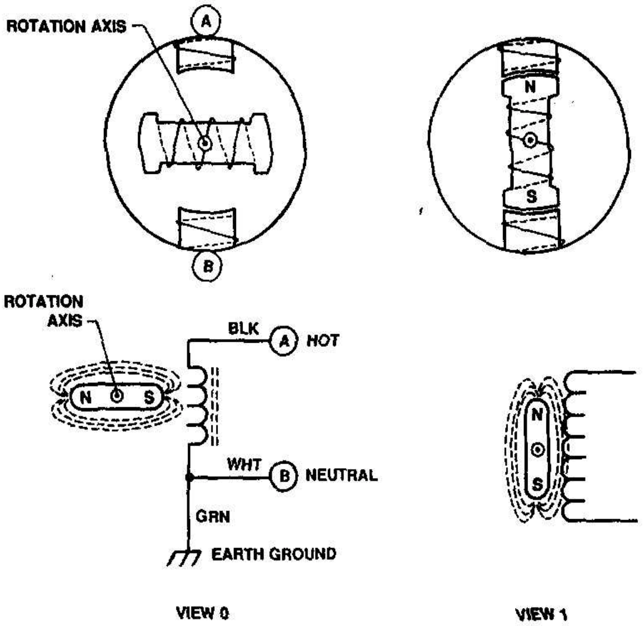
If you measure AC voltage in a home with a voltmeter, you will see a value of 120 Volts. If you view the same voltage on an oscilloscope, you will see a sine wave with a peak voltage of 170 volts. An inexpensive voltmeter rectifies the AC voltage to DC and then performs calculations to read 120 Volts AC. A true RMS meter, which is considerably more expensive, calculates the effective voltage. For most applications, the inexpensive voltmeter will provide adequate information about under and over voltage conditions. However, only true RMS meters can measure the output of a modified sine wave inverter. This will be discussed in more detail in the inverter technology section.

When you power an electric water heater, a voltmeter reads 120 volts and an ammeter reads 10 amps. A graphic representation can show the AC voltage sine wave plus another sine wave, which represents the amperage. When both waves reach their peak value at the same time, they are exactly *in phase*. The RMS value for both voltage and amperage is 0.707 times the peak value. When the voltage and amperage are *in phase*, they are said to have a "Power Factor of 1."

When you power a clothes washer, a voltmeter also reads 120 volts and an ammeter reads around 21 amps. A graphic representation (as below) would again show the AC voltage and amperage as sine waves. When they reach their peak value at different times, they are said to be *out of phase*. The Power Factor is less than 1. The more out of phase the two sine waves, the lower the Power Factor and the more amps are required to do the same amount of work.

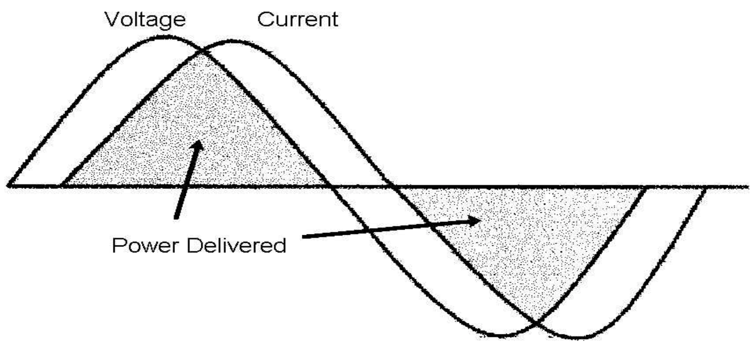


Sine Wave Generation



AC Generator Views

`From Living on 12 Volts with Ample Power, reprinted with permission from Rides Publishing Enterprises, LLC.'



This phase shift between voltage and current reduces the overlap between the two curves and effectively delivers less power to the loads. The more "out of phase" the two sine waves, the lower the Power Factor and the more amps are required to do the same amount of work.

Drawing courtesy of Trace Engineering

As we have already seen, the waveform for DC power is a straight line, so it is *always in phase and has a power factor of 1 at all times.* If AC were always in phase, power calculations would be the same simple calculations of DC, that is "power = volts X amps." Since AC power is often not in phase, the power calculations become more difficult to visualize. Power factoring is used to compare the power requirements when the amperage and voltage are *out of phase* to what they would be if they were *in phase*. This means if a device were rated with a power factor of 0.7, it would require approximately one-third more power than if it were rated at 1.

By adding capacitors to an inductive load, you can improve the power factor. Capacitors are also used to reduce the surge required to start motors. Loads with capacitors are said to have capacitive reactance. Because the voltage takes time to build an electric charge on the plates of a capacitor, the voltage lags behind the current by 90 degrees. Those having a coil, such as a motor, are said to have inductive reactance. Because the current takes time to build a magnetic field around the coil, the current lags behind the voltage by 90 degrees. Most loads are not purely resistive, inductive, or capacitive, but rather some combination of these. The clothes washer is an example of an appliance with a motor having a coil and a capacitor. The important thing to remember is that when you are measuring AC power, the amperage will be determined by the voltage and the impedance. Impedance is the opposition to flow and is represented by "Z" in equations. For AC circuits, Ohm's Law will read V=IZ, where "Z" is a combined value of the resistive, capacitive, and inductive impedance.

It is not necessary to remember all the details in the previous paragraphs. What you should carry from this discussion is that AC power determinations are far from the simple "volts X amps" measurement that RV sales people tend to offer. No matter how good the instruments are, they only give us a "snapshot in time." The better the instrument, the more accurate the information, but even with the most accurate instruments, we cannot see the variations in an AC circuit waveform.

AC and DC ripple:

When we discuss inverters later in this series, we will talk about voltage and amperage pulsations. When there is a large amperage draw on a DC circuit, there is an associated voltage drop. An example most of us have seen occurs when starting an automobile engine with the headlights on. The headlights will dim as the starter motor attempts to start the engine. This occurs because the starter motor demands a large amperage draw and causes a voltage drop in the battery. If the engine does not start and the starter motor is turned off, the battery voltage recovers and the headlights will brighten.

To produce 120 volt, 60 cycle AC from a 12-volt battery source, an inverter makes a high amperage draw **120 times per second**. Imagine the dynamics as you compare this to engaging the automobile starter 120 times per second. During inverter operation, a DC ammeter may read a 100 amp discharge, but that reflects an effective or <u>average</u> discharge. The amperage draw on the battery is switching from a value greater than 100 amps to zero and then back to a value greater than 100 amps again. The DC ammeter gauge is dampened to show an effective value and not the pulsations. These pulsations are the basis for current ripple in the DC system. Voltage ripple exists as a result of current ripple. Inverters can impose AC ripple (120 times per second) on the DC electrical system unless special circuits are used to isolate the AC system from the DC system.

The importance of the Power Factor rating and the significance of a DC bus will be important when we discuss new charger technology. It will also help explain why there is noise in the DC system and poor radio reception with older technology.

For more detailed discussions of AC and DC systems, we recommend the following:
Getting Started in Electronics, Forrest Mimms, III (Radio Shack)
Living on 12 Volts with Ample Power, Smead & Ishihara