Electrical Tech Note — 231

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Electrical Current

Electrical current will flow whenever a circuit is completed and a voltage is applied to the circuit at some point. *Current is the rate at which electrical charge flows in a circuit. The unit of measure of current flow is the Ampere.* The behavior of the current in the circuit is dependant upon the method used to produce the voltage or the nature of the load or other electrical or electronic devices in the circuit. Voltage is often referred to as the pressure or push, but actually *voltage is the energy applied to the charge that creates current flow*. Electrical current is generally categorized as direct current (dc) or alternating current (ac).

Direct Current (dc): A voltage source has a positive charge at one terminal and a negative charge at the other terminal. Current flows through the circuit from one terminal to the other. If one terminal is always positive and the other is always negative, the current only flows in one direction. *Current flowing only in one direction is called **direct current**.*

A common source of direct current is a chemical battery. A chemical reaction within the battery makes one terminal positively charged and the other terminal negatively charged. The voltage of the battery will remain a constant level as long as the chemical reaction can keep up with the current flow to the load. Figure 231.1 is a picture of direct current with time as the horizontal axis and current level as the vertical axis. If the positive and negative poles of the voltage source are reversed, the current flow in the circuit will reverse and the line representing current flow in Figure 231.1 will be below the zero line.

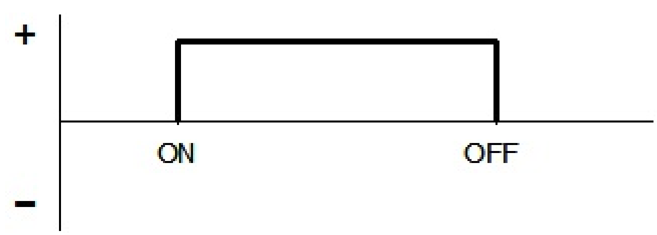

Figure 231.1 *A picture of direct current over time shows the current level either above or below the zero line and never crossing the zero line. All direct current circuits are not a steady flow as represented in this diagram.*

Typical sources of direct current are chemical batteries, fuel cells that run on hydrogen and oxygen, solar cells that produce current when light is absorbed by special silicon crystals, a magnetic generator, or made from alternating current. There are several other sources of direct current that are used primarily for instrumentation such as the thermoelectric effect and the piezoelectric effect. A mechanical generator actually produces alternating current, but it comes out of the generator as direct current by using either brushes or diodes in the generator.

Alternating Current (ac): An effective way to produce electrical power is by spinning a magnet surrounded by coils of wire set into a steel frame. The motion of the magnetic flux passing across the wires produces a current flow in the wires. Because a magnet has a North pole at one end and a South pole at the other end, the current is pushed one way in the wire by the

North pole, and in the opposite direction when the South pole passes by the wire. So once every revolution of the magnet, the current in the coil of wire is pushed first in one direction and then in the other direction. *Current that flows first in one direction then in the opposite direction at a regular interval is called* ***alternating current****.* If the magnet is spinning at a fixed speed, typically 3600 rpm, the current flows back and forth in the wire at a regular interval. This is called alternating current. As the magnet spins within the generator, the current starts at zero and builds up to a maximum (90°) then it falls off to zero (180°). As the magnet completes the revolution, the current reverses direction. If the current flow produced by a generator is shown on a graph with time as the horizontal axis and the current as the vertical axis, *the shape of the alternating current curve is called a* ***sine wave****.* Half of the current is shown above the zero line indicating current flow in one direction. The other half of the sine wave is below the zero line indicating current flow in the opposite direction. A typical sine wave is shown in Figure 231.2. Alternating current in the form of a sine wave is best produced by a magnetic generator where a magnet is spinning with a coil of wire on the outside. A 3-phase generator simply has three windings positioned 120° apart around the spinning magnet.

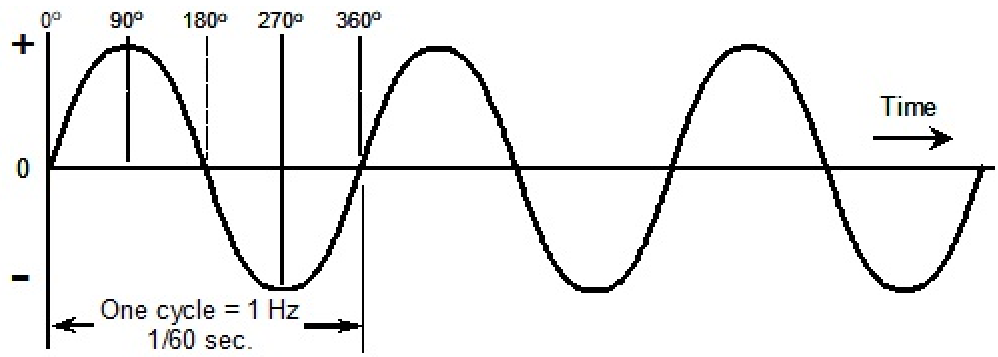

Figure 231.2 *Typical alternating current produced by a magnetic generator flows first in one direction, then in the opposite direction at a regular interval with the shape of the current pattern called a sine wave.*

Typical alternating current starts at zero (0°) as shown in Figure 231.2, builds to a maximum (90°) then decreases to zero (180°). The current reverses direction and again builds to a maximum (270°) and decreases to zero (360°). This completes one cycle. Alternating current produced by a magnetic generator spinning at 3600 rpm will complete 60 cycles each second. *One cycle per second is called a* ***Hertz*** *(Hz)*. Typical electrical power distributed in the United States is 60 Hz.

Sine Wave Magnitude: The magnitude of alternating current is constantly changing. The magnitude varies from zero to some peak value. This peak value is first positive, indicating current flow in one direction, then it is negative. In the case of direct current from a source such as a battery, the voltage is one constant value. Electrical power is intended to do work or impart energy. When direct current is passed through an electrical component such as a resistor, heat is produced. The amount of heat produced can be determined by squaring the current and multiplying by the value of resistance and the amount of time the current is flowing. This is called the effective current. When alternating current is in the shape of a sine wave, the question becomes what current should be used to determine the amount of heat produced if the alternating current is passed through a resistor? The peak value cannot be used because the current is only that high from a moment two times each cycle. Another approach is to determine the average value of current for the sine wave. The average value of a sine wave is actually zero since half the wave is positive and half is negative. An ac voltmeter rectifies the sine wave so that it is all positive. Then the average value is taken. Many samples are taken during one cycle, added together, and divided by the number of samples. As it turns out, the average value of the sine wave current is too low. More heat is produced from a sine wave passing through a resistor than can be accounted for by squaring the average current value and multiplying by the value of resistance and length of time. It was discovered that if many samples of current magnitude are taken along the sine wave, then squared, added together and the average taken, the square root of this final value can be used to predict the heat that will be produced by passing an alternating current sine wave through a resistor. The current value from a sine wave determined in this manner is called the root mean square current (rms). The rms current if squared then multiplied by the value of the resistor and length of time will equal the amount of heat produced by passing alternating current through the resistor. *The **rms** value of the current is sometimes called the effective value of the current and can be used to determine the energy of the sine wave.* The rms and peak values of a sine wave are illustrated in Figure 231.3. The rms value of current is about 11% higher than the average value of the current. It was also determined that the rms value of a sine wave can be determined by multiplying the peak value of the sine wave by 0.707. The peak value can be determined by multiplying the rms value by 1.414.

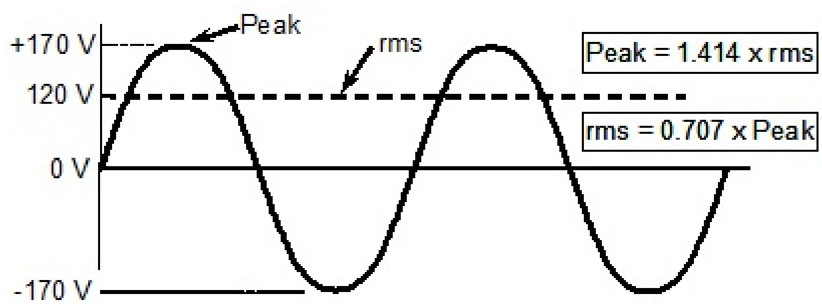

Figure 231.3 *The rms value can be determined by multiplying the peak value of a sine wave by 0.707, and the peak value can be determined by multiplying the rms value by 1.414.*

True rms Reading Instruments: The rms or effective value of any shape of current pattern, repetitive or not, can be used to determine the energy content of an electrical current by squaring the effective current and multiplying by the value of resistance and length of time the current was present. Many circuits have a repetitive shape to the alternating current, but the shape is not a sine wave. Electronic equipment supplied by a circuit have a tendency to alter the shape of the alternating current wave. Electronic equipment such as computers draw current in pulses such as shown in Figure 231.4. When measuring current in such a circuit, most often it is the effective or rms value that is desired. Many measuring instruments used for alternating current circuits are designed to sample values on a perfect sine wave. If the alternating current is not a sine wave, such as the computer current in Figure 231.4, the instrument will give a meaningless value. Many current meters measuring alternating current such as shown in Figure 231.4 will give a value only about half the true rms or effective current level. This means more current is flowing in the circuit than indicated by the instrument. *Alternating current instruments used on circuits where a sine wave may not be present, should be of the **true rms type** to make sure an accurate reading is obtained.*

Some ammeters can measure the peak current of the repetitive alternating current wave as well as the rms current. If the shape of the alternating current wave is a sine wave, the peak current divided by the rms current will be 1.414. *The peak current divided by the rms current is called the **crest factor**.* If the crest factor is not 1.414, then the alternating current wave shape is not a perfect sine wave. Checking the crest factor can be used as a test to determine if there is significant distortion of the alternating current wave. The crest factor for an alternating current such as the one shown in Figure 231.6 will be much greater than 2.

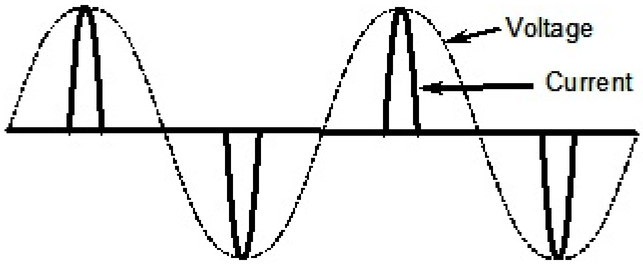

Figure 231.4 *A computer draws current in pulses. Even though the voltage supplying the current is nearly a sine wave, the current flow to the computer is not a sine wave. A true rms ammeter is required to accurately measure the current draw of a computer and most electronic equipment.*

Harmonics: Many components of an electrical circuit cause harmonic currents to flow in the circuit which combine with the 60 Hz current to distort the alternating current wave so it no longer resembles a sine wave. *A harmonic wave is any wave of higher frequency that fits within the base or fundamental frequency and has the same zero points.* A harmonic wave is a sine wave that is an exact integer multiple of the fundamental frequency. Harmonic currents are illustrated in Figure 231.5. In the case of 60 Hz alternating current, the 60 Hz wave is called the fundamental frequency or sometimes the first harmonic. The second harmonic is two times the base frequency or 2 times 60 Hz or 120 Hz. Two sine waves fit exactly within the 60 Hz sine wave. The third harmonic is 3 times 60 Hz or 180 Hz.

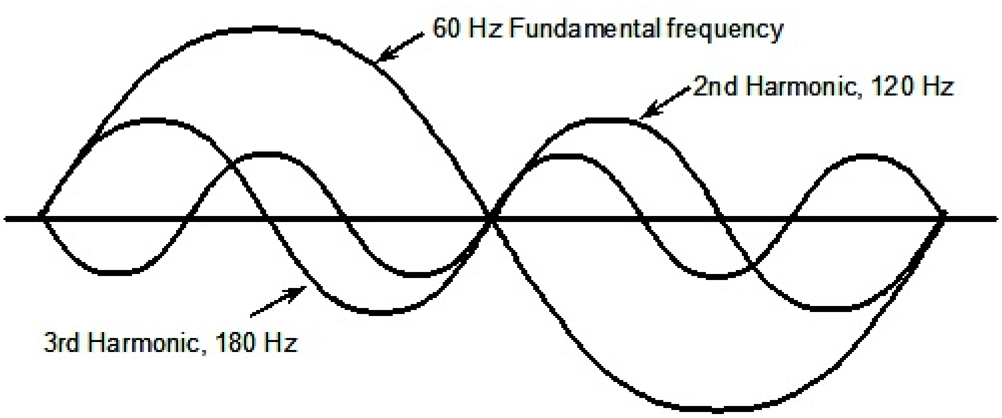

Figure 231.5 *A harmonic is a sine wave that fits exactly within the fundamental frequency and has the same zero points. This is an example of a 60 Hz fundamental frequency showing the 2nd and 3rd harmonic.*

It is not unusual for a piece of electronic equipment to create many harmonic currents which will combine with the 60 Hz to form a new alternating current wave that does not resemble a sine wave. One example of such an alternating current wave that is created using harmonic currents is shown in Figure 231.6. This alternating current wave is created using the third and fifth harmonics along with a 60 Hz sine wave, and it has a high peak current.

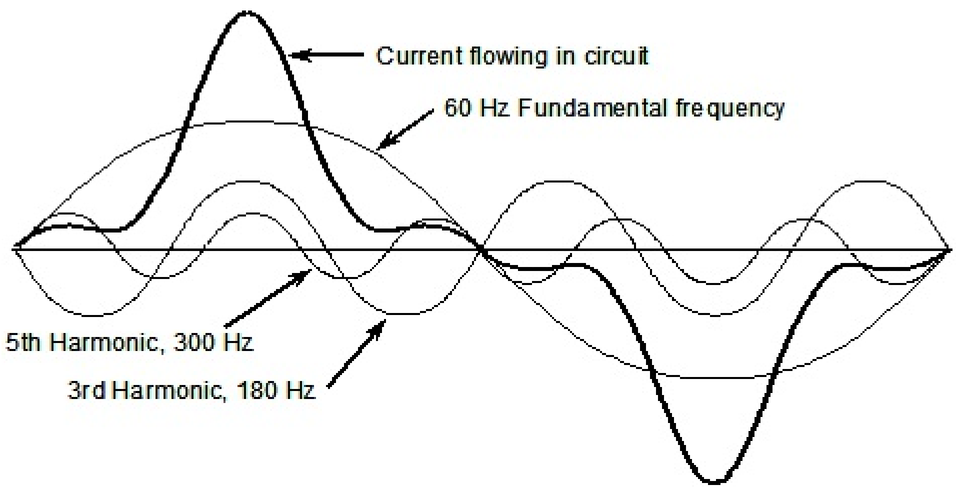

Figure 231.6 *The equipment supplied by this circuit causes 3rd and 5th harmonic currents to flow which combine with the 60 Hz current to create an alternating current wave with a high central peak.*

Transient: A transient is a short time or rapid change in the magnitude of the current from the normal alternating current sine wave. Transients generally only last for a fraction of a cycle such as shown in Figure 231.7. The conditions that cause a transient can last for more than one cycle or may repeat for several cycles. If transients are believed to cause a problem with equipment operation, filters can usually be added that will reduce or eliminate the magnitude of the transient.

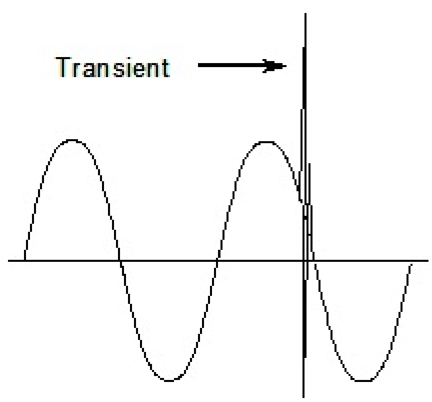

Figure 231.7 *A short time or rapid change in magnitude of the current from the normal alternating current sine wave is considered a transient.*

Rectifier: Alternating current reverses direction of flow in a circuit at regular intervals. Normal alternating power in buildings is 60 Hz and reverses direction 120 times each second so it travels in each direction 60 times each second. Many devices that receive power from an alternating current source must have direct current for operation. Electronic equipment requires direct current. *Alternating current is converted to direct current by a device called a **rectifier***. A device called a diode allows current to flow in one direction, but not in the other direction. Arranging several diodes in a specific pattern forms a diode bridge which can direct the sine wave of each of the phases of a single-phase or 3-phase supply into one direct current circuit. The output from a rectifier will be direct current, but it may not have a constant magnitude. A device called a filter can be added that smooths out any variations in magnitude so the result will be a direct current supply with a constant magnitude. Figure 231.8 shows how a single-phase 60 Hz alternating current supply is rectified and filtered to form a constant direct current output.

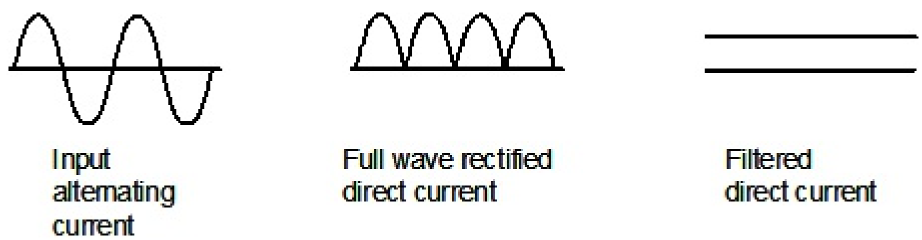

Figure 231.8 *The alternating current is rectified to form a pulsing direct current which is smoothed out to a constant magnitude by the filter.*

Inverters: Some sources of electrical power only produce direct current. An inverter can be used to produce alternating current from a direct current supply. The output of an inverter can be a sine wave or it may be a voltage that creates the approximate effect of a sine wave. Some alternating current equipment may be sensitive to the shape of the wave produce by the inverter. Figure 231.9 shows a true sine wave output from an inverter and a frequently used modified alternating current wave. Variable frequency drives for electric motors have a rectifier to convert the 60 Hz alternating current to direct current then an inverter to produce an alternating current output at the desired frequency. The output of the drive inverter is similar to the modified alternating current wave of Figure 231.9 except it is constructed for numerous voltage pulses. This method of creating alternating current for powering motors is satisfactory for most applications.

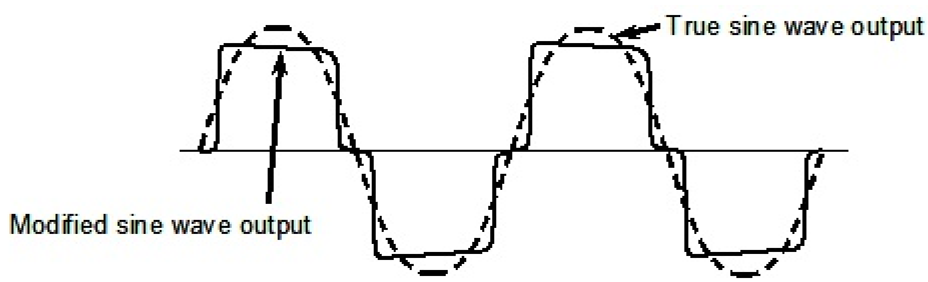

Figure 231.9 *An inverter converts a direct current supply into alternating current generally as a sine wave or sometimes as a modified alternating current wave.*

Conclusion: It is important to understand the terminology associated with alternating current and direct current. It is also important to understand the relationship between the peak value of a sine wave and the rms value. When a wire or wire termination overheats, the heat produced in proportional to the square of the rms current flow times the resistance and duration of current flow. Many ammeters in use are not of the *true rms* indicating type and do not give an accurate measurement. Even though the voltage of a circuit may be a sine wave, the current flow is often not a sine wave especially if the device supplied is electronic.