Electrical Systems & Troubleshooting for Landscape Irrigation Systems

" I THINK YOU MISUNDERSTOOD OUR AD FOR A LINEMAN "

Electricity

What is electricity? It is a lot easier to describe what electricity does than what it is.....it operates our lights and runs our air conditioners and electric motors.

Electricity - a form of "<u>energy</u>" similar to chemical and mechanical energy.

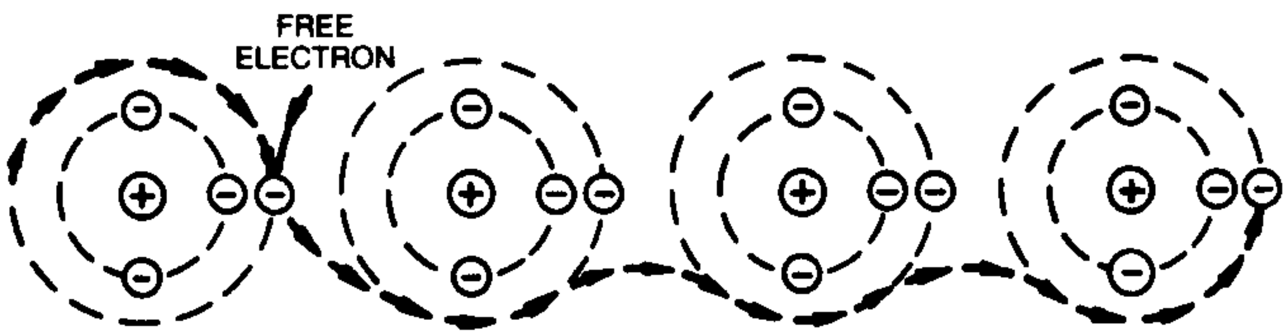
* Electricity is the most widely used form of energy ranging from miniature batteries and power use devices in your wristwatch to melting steel in large arc furnaces.

* That still doesn't tell us what it is.

Electricity - the flow (movement) of electrons through a material.

* You may remember from science class that atoms are made of protons, neutrons, and electrons.

* When electrons move from one atom to another, electricity flow has occurred.



* This flow of electrons is what causes lights to operate or motors to turn.

We can't see electricity, but we can see its effects, such as light or heat.

* Electricity must be converted to other forms of energy such as heat, light, or mechanical power to be useful.

* In fact, Edison himself never thought electric power could be sold, since power itself had no "value." He thought people would have to be sold light or heat – a thought that is coming back into vogue at this time with "end-use pricing".

Types of Electricity

There are two basic types of electricity; direct current (DC) and alternating current (AC).

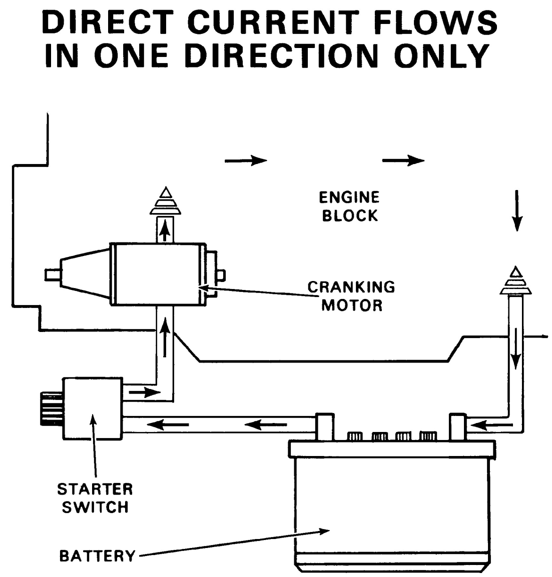
Direct Current (DC)

Direct current is a type of electricity in which the electrons flow only in one direction.

DC electricity is utilized in many applications including most battery operated devices and internally for most electronic and computing devices

DC power can be produced by several common methods including:

batteries, solar panels, fuel cells, and special DC generators like wind turbines.



Alternating Current (AC)

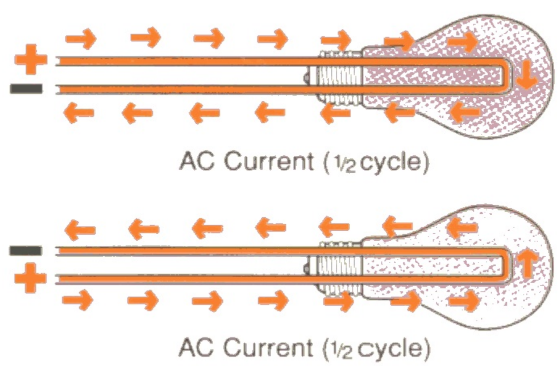
Alternating current is electricity in which the movement of electrons is first in one direction and then reversed and moving in the opposite direction.

AC electricity is utilized in most lighting, heating, and motor applications supplied by power from the electrical grid.

AC power is produced using an AC generator.

AC has a distinct advantage over DC for commercial electric power systems.

AC voltage and current can be varied at will using transformers which makes economical transfer of large amounts of electricity over long distances possible.



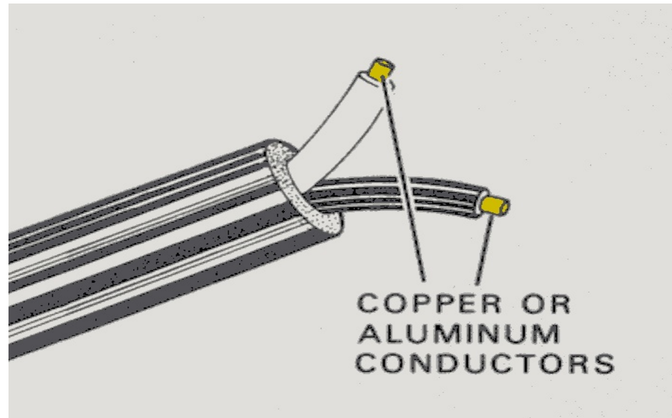
(b) AC Current –
full cycle occurs 60 times per second (60 HZ)

Conductors

Materials that are made up of atoms which readily allow their electrons to be transferred from atom to atom are called conductive materials or "conductors" for short.

Soft metals like platinum, gold and silver allow their electrons to flow very readily from atom to atom and since these materials allow electrons to move very easily, they make the best conductors of electricity.

Copper and aluminum are good conductors of electricity that most electric wires or "conductors" are commonly made from.



Copper Wire

Copper wire is used as an electrical conductor primarily on the customer side of the electric meter.

> Wires installed in the walls of most residences are most likely made of copper.

Aluminum Wires

Aluminum wires are used as electrical conductors on the electric utility transmission and distribution systems.

> The overhead wires running on the utility poles are made of aluminum and do not have insulation around them.

Copper vs Aluminum

Copper wires generally cost more than aluminum wires but have some advantages like less maintenance requirements in homes and businesses.

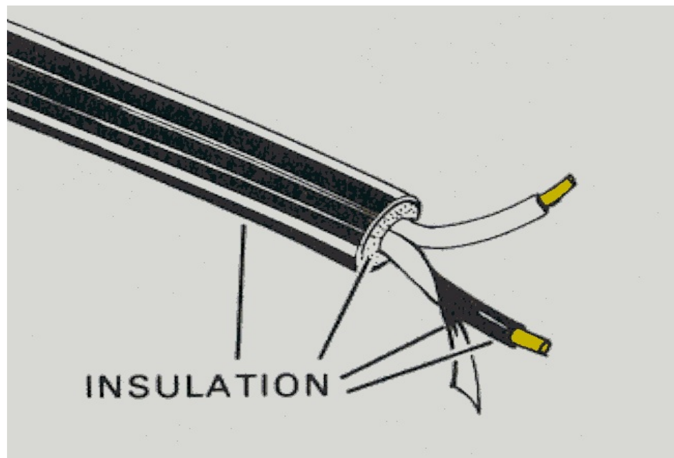
> Copper is a better conductor than aluminum so a smaller copper wire can be installed in many instances compared to an aluminum wire.
>
> Copper wires are required by most national codes to be used as the conductor material for wiring most residential type locations.
>
> Aluminum wires may also be allowed in some areas but you should always check with the local electrical inspector or building code authority first.
>
> Aluminum's two advantages over copper as a conductor for utility lines include its light weight and lower cost.

Insulators

Materials that are made up of atoms with the electrons tightly bound to the nucleus which do not flow easily are called insulating materials or "insulators" for short.

Glass, rubber, porcelain, and most plastics are examples of good insulating materials.

These materials do not readily conduct electricity since their electrons do not move easily from atom to atom.



"Insulators" are used to prevent the flow of electricity.

Insulating materials are put on the outside of extension cords and appliance cords to prevent us from being shocked when we plug and un-plug them.

Question: How about wood...Is it an insulator or conductor?

Answer: It depends on the moisture content of the wood.

In its dry processed form like the top of a wooden desk, wood is a good insulator. In its live growing state with sap it like a tree branch, wood can be a good conductor of electricity.

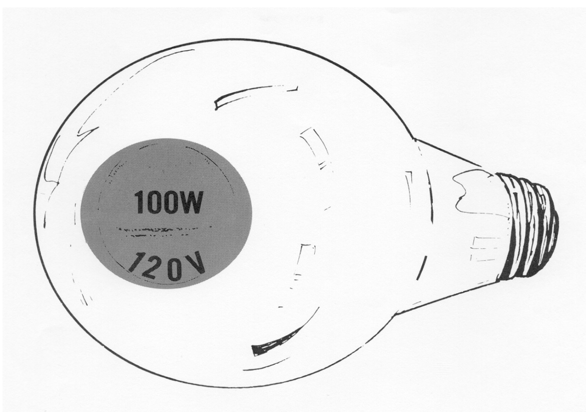
It is important to remember that many materials can be either an insulator or conductor depending on their moisture content or condition.

4. Voltage (Volts) - E or V -

Voltage or volts for short, is the electrical force that pushes the electrons from atom to atom through a material.

"Volts" are a measure of the "electrical pressure" and denote the force with which electricity is flowing through a wire at a given instant of time. (Some engineers use the word "potential" as an interchangeable word for "voltage".)

Just as water needs some pressure to force it along in a pipe, so electricity needs some force to make it flow. In the water pipe, the pressure is in pounds per square inch. In an electrical circuit pressure is measured in volts. Given the same size of water hose, if the water pressure increases, the volume of water increases. In an electrical circuit, the higher the voltage, the more amps it can push through the conductor in a certain time period. If there is no voltage difference between two items, then no electrical flow between the two items occurs, since there is no pressure difference to force the electrons to move between the two items.



The voltage is supplied by the electrical source, typically either a generator or battery. This makes it similar to the water pump in a water piping system which supplies the water pressure to push the water through the pipe.

The scientific symbol for voltage is an "E", dating to early days of electricity when it was called the "Electromotive force". Scientists and engineers use the "E" symbol for voltage, while electricians and wiring books use "V" as the voltage symbol. This can create some confusion, since either might be used.

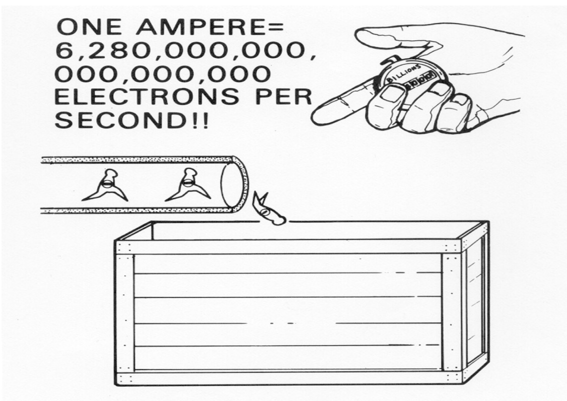
When you think about a 120 volt outlet, know you know that the outlets circuit has 120 volts of electrical pressure to push electrons through the appliance.

5. Amperes (Amps) - I or A -

Amperes or “amps” are a measure of the rate of “current” flow of the electricity through the material

This flow of electrical current develops when electrons are forced from one atom to another.

Using a water pipe as an analogy, the amps would be similar to the rate of flow of water through the pipe measured in gallons per minute.



Think of electrical current or amps as how many electrons pass a given point in a given amount of time.

Measuring current in electrons/second would be cumbersome due to the large numbers, so think of an amp as a huge number of electrons per second.

The flow of current through a conductor results in both heat and a magnetic field being produced.

Heat

Every time an electron moves from atom to atom through a conductor, a small amount of heat is produced.

The higher the number of electrons moving (amps) the more heat produced from the conductor.

That is why the amount of amps flowing on a circuit is important.....the more amps flowing, the more heat that is produced.

This can be important since given sizes of wire can handle only so much heat before they melt.

When a wire carries more amps than it can handle without overheating, we say it is “overloaded”.

Wires must be protected from too many amps so they do not melt.

The scientific symbol for amperage is an "I", dating to the early days of electricity. Scientists and engineers use the "I" symbol for amperage, while electricians and wiring books use "A" as the amperage symbol. This can create some confusion, since either might be used.

Impedance

The term “impedance” is used to describe the affect of various different properties that impede or slow the current flow in a wire and it is measured in units called “ohms”.

The impedance of an electrical system is made up of both its resistance and reactance.

Resistance is caused by the electrical properties of the wiring material itself.

There are two types of Reactance.....Inductive and Capacitive.

Inductive reactance is caused by the constant change of the magnetic field in AC equipment containing coils of wires like electric motors.

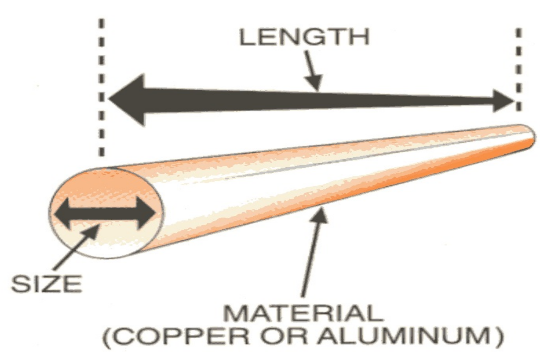
Capacitive reactance is caused by capacitors...devices that store energy.

Resistance

Electrical resistance is defined as the resistance to flow of electricity through a material and is measured is measured in units called ohms. Think of resistance as a measurement of how loosely or tightly a material holds on to its electrons. Some metallic materials like gold, sliver, copper, and aluminum have low resistance to the flow of electricity and make good conductors. They allow electricity to flow through them fairly easily. Other materials like porcelain, rubber, plastic and glass have a very high resistance to the flow of electricity and do not allow electricity to flow through them and make good insulators.

The resistance value in ohms for most materials can be looked up in physics and other science books. Copper would have a lower electrical resistance measured in ohms than aluminum since copper is a slightly better conductor than aluminum. The lower the resistance of a material measured in ohms, the better the conductor the material is.

When using a water piping system as an analogy to an electrical system, the analogy to the resistance in the water piping system is the friction in the water pipe which resists the flow of water. Several things can resist the flow of water in the pipe. Things such as rust or corrosion inside the pipe, objects stuck inside the pipe, even the size of the pipe. The same is true of electricity. A number of things resist its flow. Smaller wires have more resistance than larger diameter wires. Longer wires have more resistance than shorter wires.



The scientific symbol for electrical resistance, measured in ohms, is the Greek Omega (Ω). Many times electricians and practical wiring books use an "R" representing resistance. This can create some confusion since either may be used.

Electrical Power

Electrical power is a measure of the rate of work an electric current can accomplish.

Think of this as how fast electrical energy is being converted into some other form of energy like light or rotating mechanical energy.

In general, the higher the power consumption of a device, the greater its ability to do work, or deliver energy.

In the electrical world, there are three types of Power; Real, Apparent, and Reactive.

The difference between the real power and the apparent power is called the power factor.

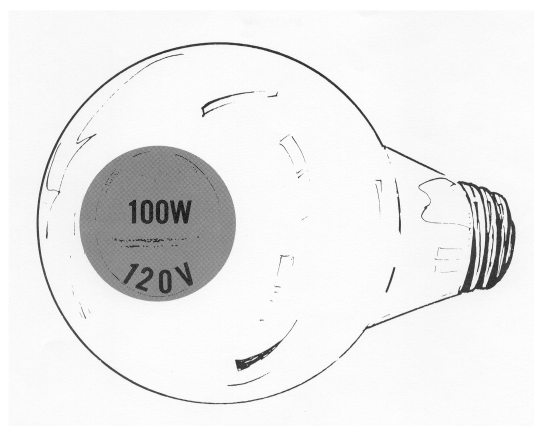
<u>Real Power (Watts, Kilowatts, Megawatts, etc)</u>

Real power in a circuit is the portion of apparent power that actually does the work (converts electrical energy into some form of useful energy either as heat or work).

Real power is measured in watts or kilowatts and is what most people are referring to when discussing power.

(Watts)

Real power measured in units of watts or wattage is a measure of the useful a device or appliance consumes.



The 100 watts on a light bulb is not how much light it produces, but how much electrical power it uses to operate.

Appliance manufacturers indicate how much electrical power an appliance uses in units of watts, which are commonly found on the appliance nameplate.

Electric utilities measure the power usage of customers in kilowatts. 1 kilowatt is equal to 1000 watts. Utilities measure the power produced by a generator or power plant in units of megawatts. 1 megawatt = 1 million watts.

Motor manufacturers still rate motors using the english system of units and indicate the power produced by an electric motor in units of horsepower. The English Unit System for measuring power is 1 Horsepower = 746 watts.

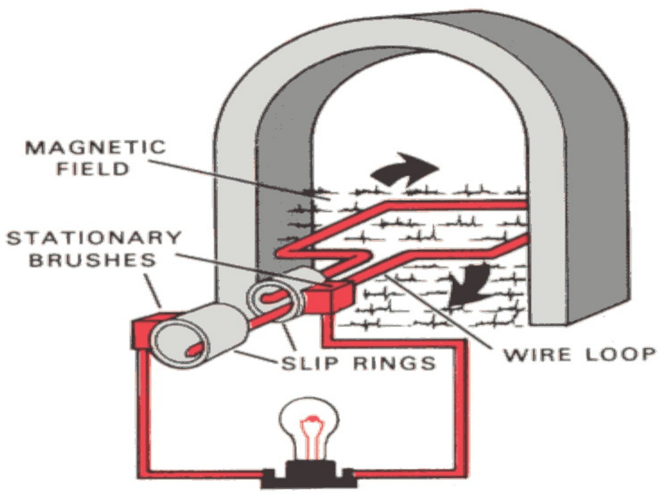
Power is generally shown using a "P" as the symbol. The scientific symbol for the watt is the "W". The kilowatt is shown as "kW" with a little k and capital W. The megawatt is shown as "mW" with a little m and capital W. There are several types of power you should understand including real power, apparent power and reactive power.

Electrical Generation Principles

There are several types of "power plants" used to make electricity including hydroelectric plants, steam turbines, gas turbines, combined cycle, nuclear plants, and newer types such as geothermal, solar, wind turbines and fuel cells. While the fuel or source of energy for these "power plants" varies, the general principle of how the electricity is actually produced at each of these plants with the exception of solar panels is essentially the same. For most of these plants, the principle of magnetic induction is the driving force behind "how" the electricity is actually made.

Magnetic Induction:

The process of producing electricity by moving a magnetic field in close proximity to an electrical conductor that meets the requirements for an electrical circuit.



The most common method of producing electrical energy in large quantities to serve the home, farm, business, and factory is by means of magnetic induction in a generator. Both AC and DC currents can be generated by moving wires through a magnetic field. The wire loop in the generator is mechanically driven by a machine like an engine or some other source of rotary motion. The source of power for the machine might be common fuels, falling water, or atomic energy.

A typical AC generator has a large electromagnet spinning inside a large stationary coil of wire. As the magnetic field produced by the ends of the magnet moves across the turns of the stationary coil, an voltage potential is produced in the wire which causes electrical current to flow. More electricity can be generated in the wire by increasing the magnetic field strenght, the number of coils in the wire or both.

There are two types of alternating current generators in use today: Single Phase and Three Phase.

Single Phase power is most commonly found in homes, small businesses, and locations where minimal electrical power is required. Single phase power requires fewer wires to be run on the electrical system.

Three Phase power is most commonly found in larger businesses and industrial settings where large amounts of power are required although it can be used in homes and smaller businesses. Three phase power requires more wires to be run on the electrical system.

Electrical Formulas and Relationships

1. Ohm's Law:

Volts = Amps X Ohms; OR $E = I \times R$

2. Watt's Law -

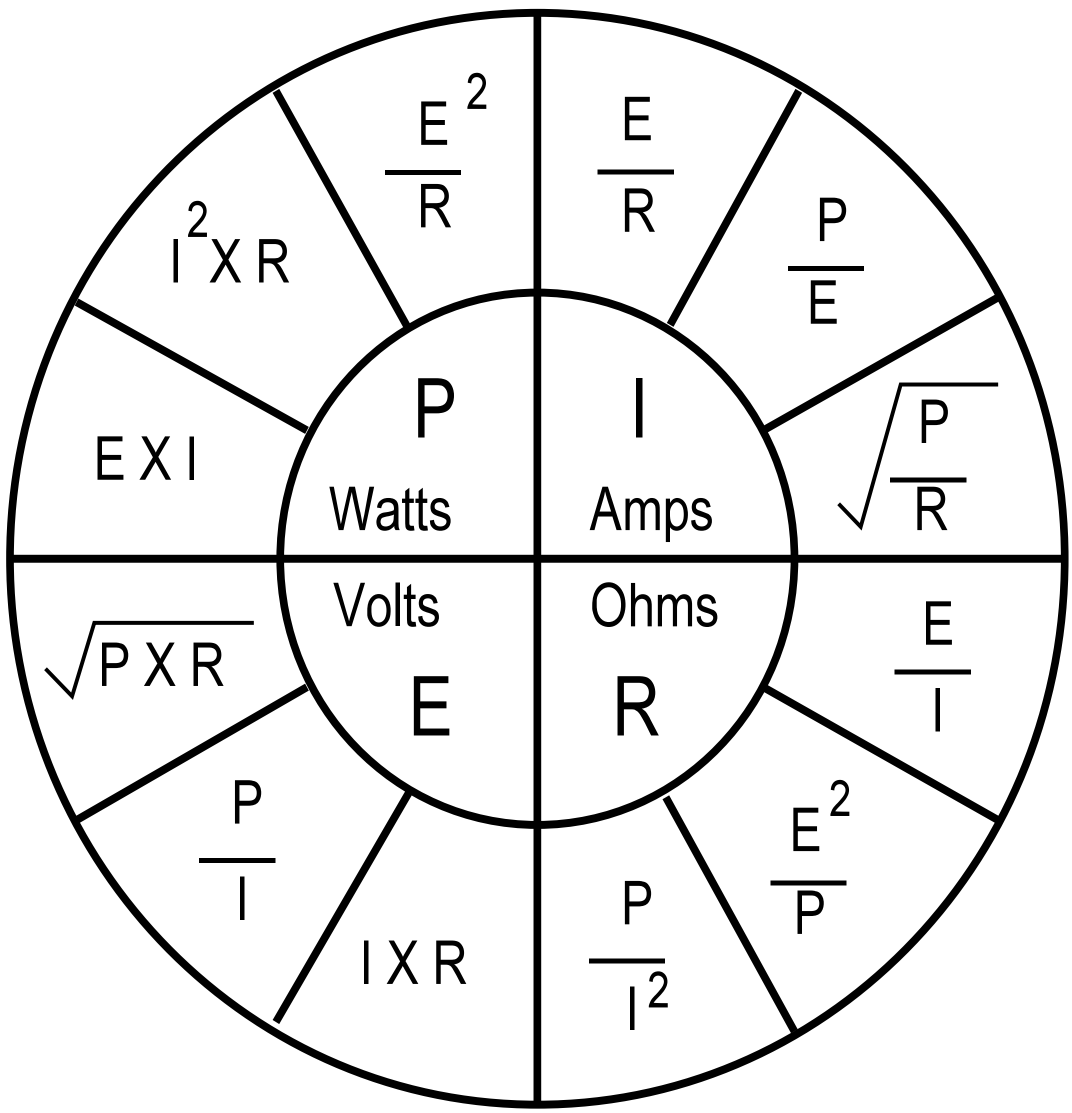
a. Single Phase:

Watts = Volts X Amps X Power Factor; OR $W = E \times I \times p.f.$

b. Three Phase:

Watts = Volts X Amps X Power Factor X Square Root of 3; OR $W = E \times I \times p.f. \times 1.732$

OHM'S LAW & WATT'S LAW RELATIONSHIPS



P = POWER (Watts)

R = RESISTANCE (Ohms)

E = VOLTAGE (Volts)

I = CURRENT (Amps)

ELECTRICAL CIRCUITS

A path through which electric current flows is called a circuit. Circuits permit electrons to flow from an electrical source to an electrical load. A circuit must have a complete path from the electrical source to the electrical load and back. There are five components that can be involved in an electrical circuit, three are required and the other two are options.

ELECTRICAL CIRCUIT REQUIREMENTS:

1. **Source** -- Something to produce the electricity.

2. **Load** -- Something to use the electricity.

3. **Path** -- For an electrical circuit to function, there must be an uninterrupted path from the source to the load and back to the source.

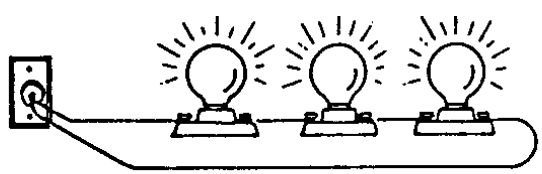
ELECTRICAL CIRCUIT OPTIONS:

4. **Control Device** -- Something to make the electricity flow where we want it to go when we want it to go there.

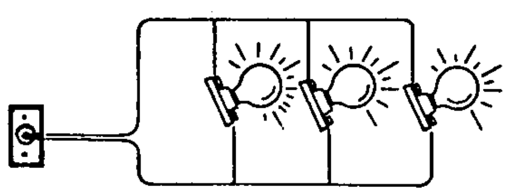
5. **Protective Device** -- Something to protect either the loads or path from to much heat (amps).

ELECTRICAL CIRCUIT TYPES:

SERIES CIRCUIT: A circuit in which there is only one path from the source through all of the loads and back to the source.



PARALLEL CIRCUIT: A circuit in which there is a separate independent path through each load in the circuit and back to the source.

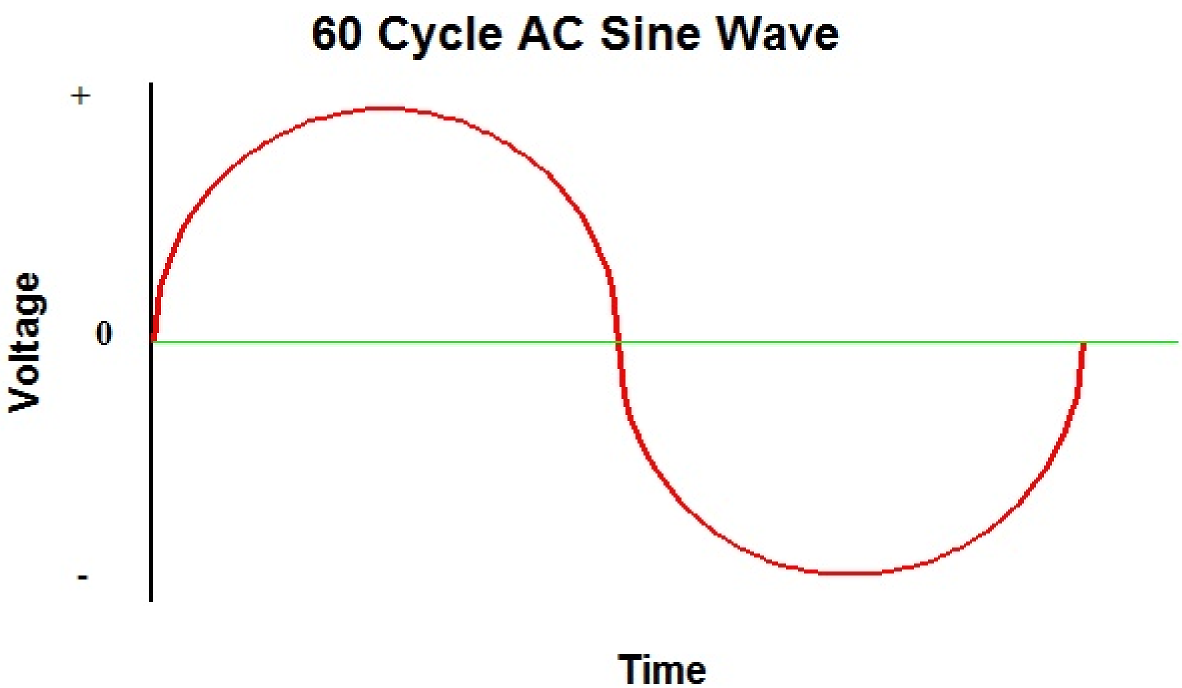


SHORT CIRCUIT: A special circuit in which the electricity has found an alternative path to return to the source without first going through the load. (This usually represents a dangerous situation.)

OPEN CIRCUIT: A circuit where the path has been removed or "opened" at some point so that the circuit will not operate.

Generating Single Phase Alternating Current

Alternating Current (AC) flows in a circuit first in one direction and then in the opposite direction. If you graphed the voltage supplied by a single phase generator on a very fast meter it would look like this shape below which is called a "sine wave".



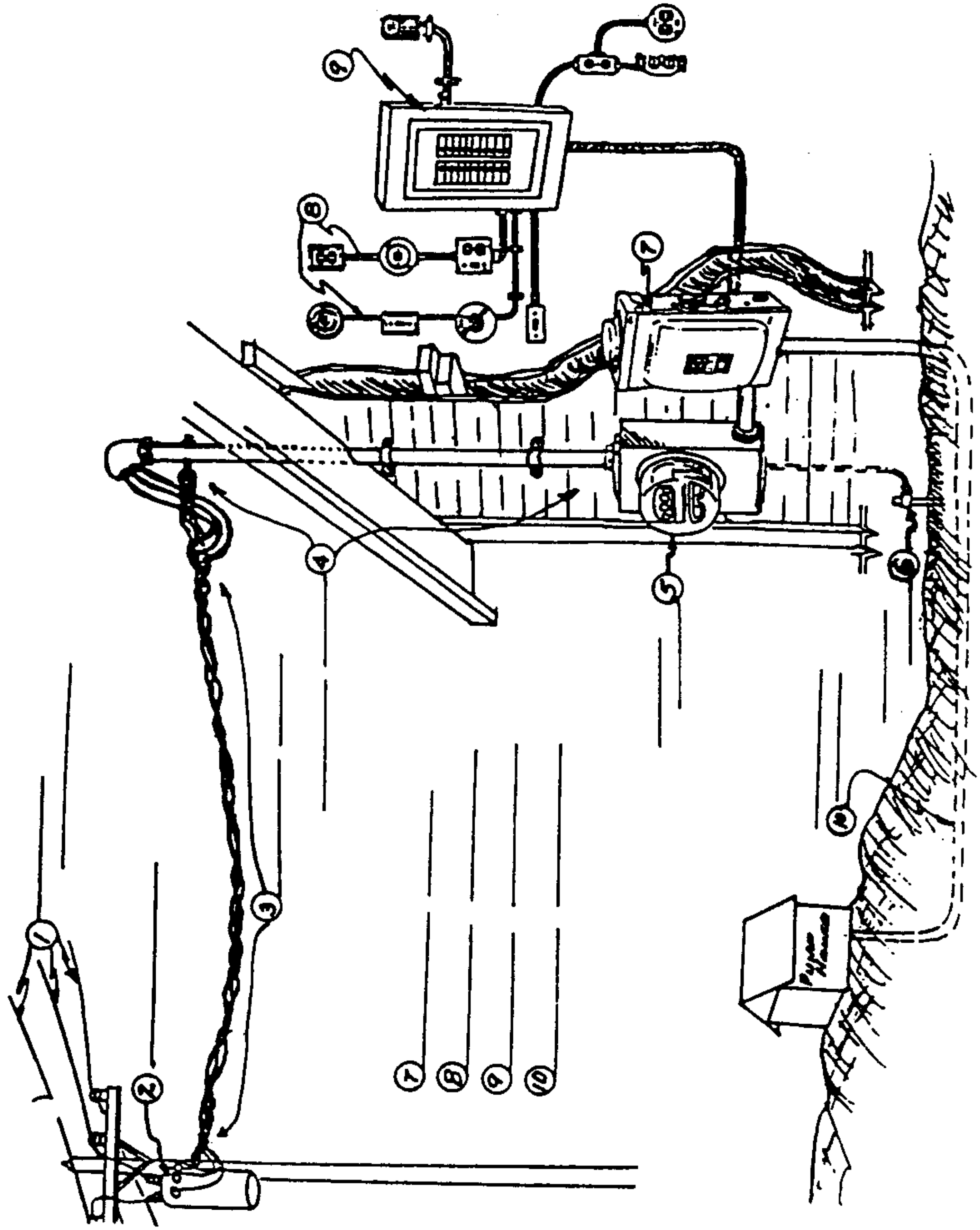
The voltage increases to a peak value then drops back to zero. At this point the electrons change and flow in the opposite direction. This is not negative voltage, it is just shown as negative to indicate the electrons are flowing in the opposite direction. The voltage now increases to a peak value in the opposite direction then drops back to zero. This cycle repeats itself 60 times each second for all electrical systems in North America and 50 times each second in most of Europe and Asia. The speed it repeats is called the system frequency and commonly given in units of hertz or cycles per second.

Peak Voltage
The peak voltage is the maximum value the voltage gets to during any part of the cycle and can be positive or negative. Remember, positive and negative really refer to the direction of current flow. A negative number does not mean that the voltage or current flow are less than zero, only in the opposite direction.

Frequency, Cycles/Second, Hertz
A cycle is one complete repetition of the sine wave pattern. It is produced by one complete revolution (360 degrees) of the generator. In each cycle, their are two peak values (one positive and one negative) and two zero crossing points. This is called the system frequency.

RMS Voltage
RMS stands for Root Mean Square and is the standard way of measuring and reporting AC voltage. It is the *average* voltage available between zero crossing points. The RMS voltage is found by

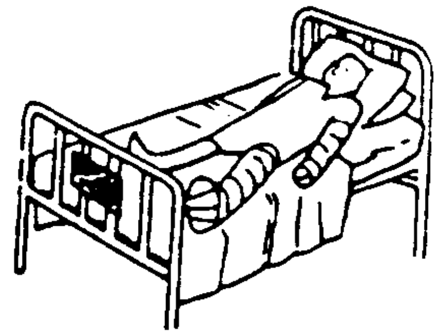
multiplying the peak by the square root of 2 (approximately 1.414).



Electrical Safety

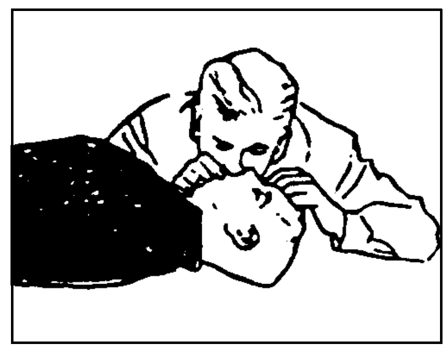
Humans respond to electrical current (amps) and NOT voltage!

Current can cause injury or death by:

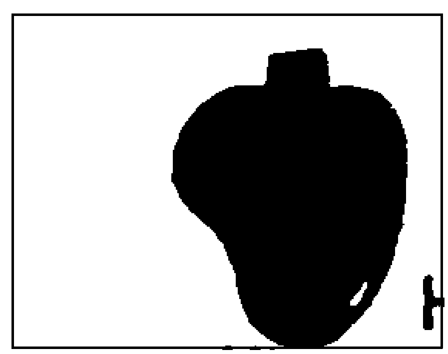


BURNS
(Internal or External)

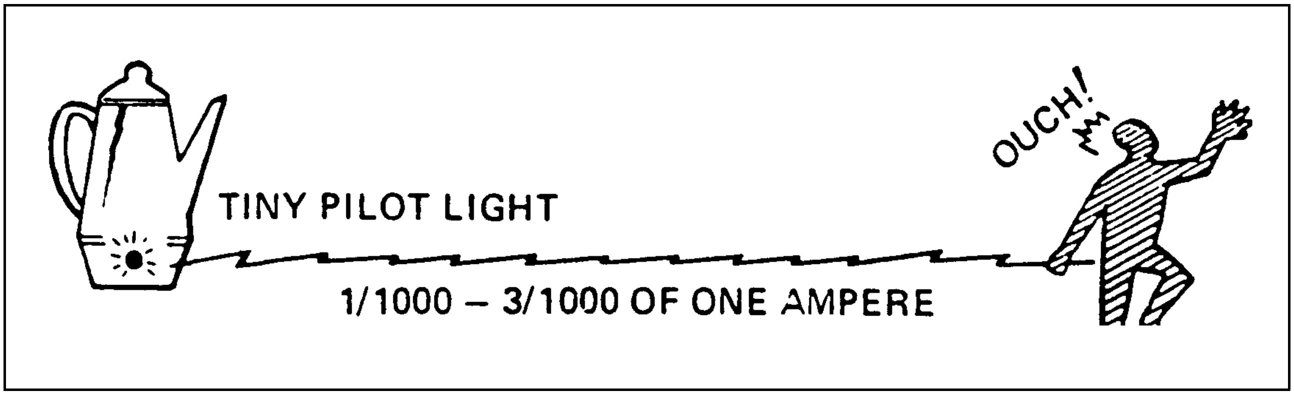
PARALYSIS OF THE LUNGS (lack of oxygen)



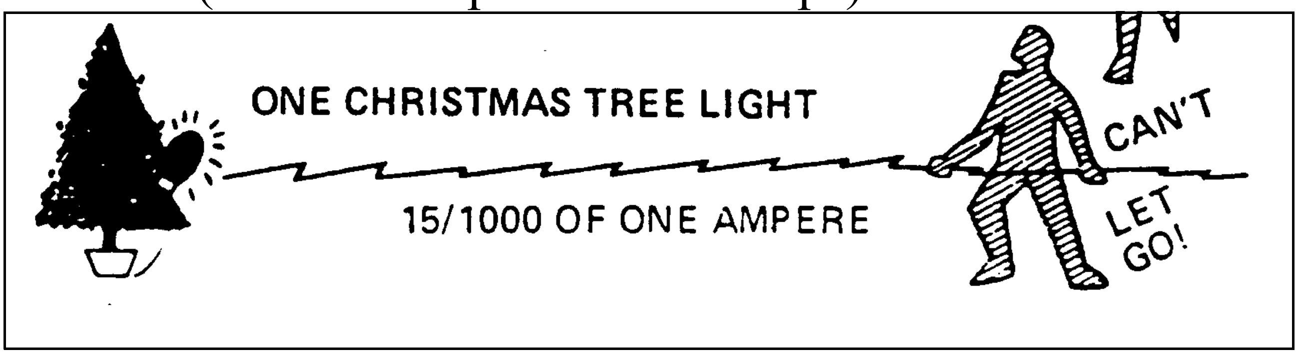
VENTRICULAR FIBRILLATION
(restricted flow of blood)



Typical Human Response Levels to Electrical Current are:

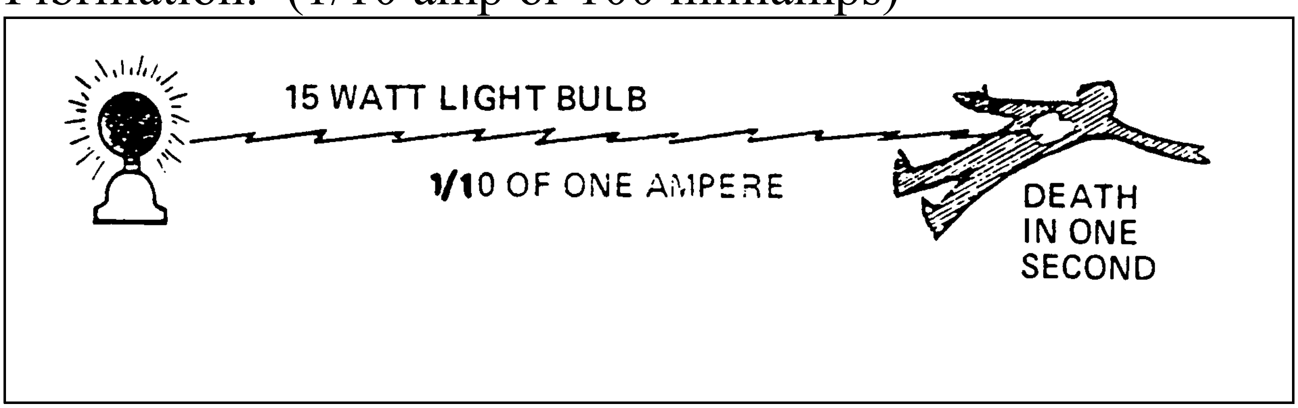


Perception: (1/1000 amp or 1 milliamp)
Let Go: (15/1000 amp or 15 milliamps)

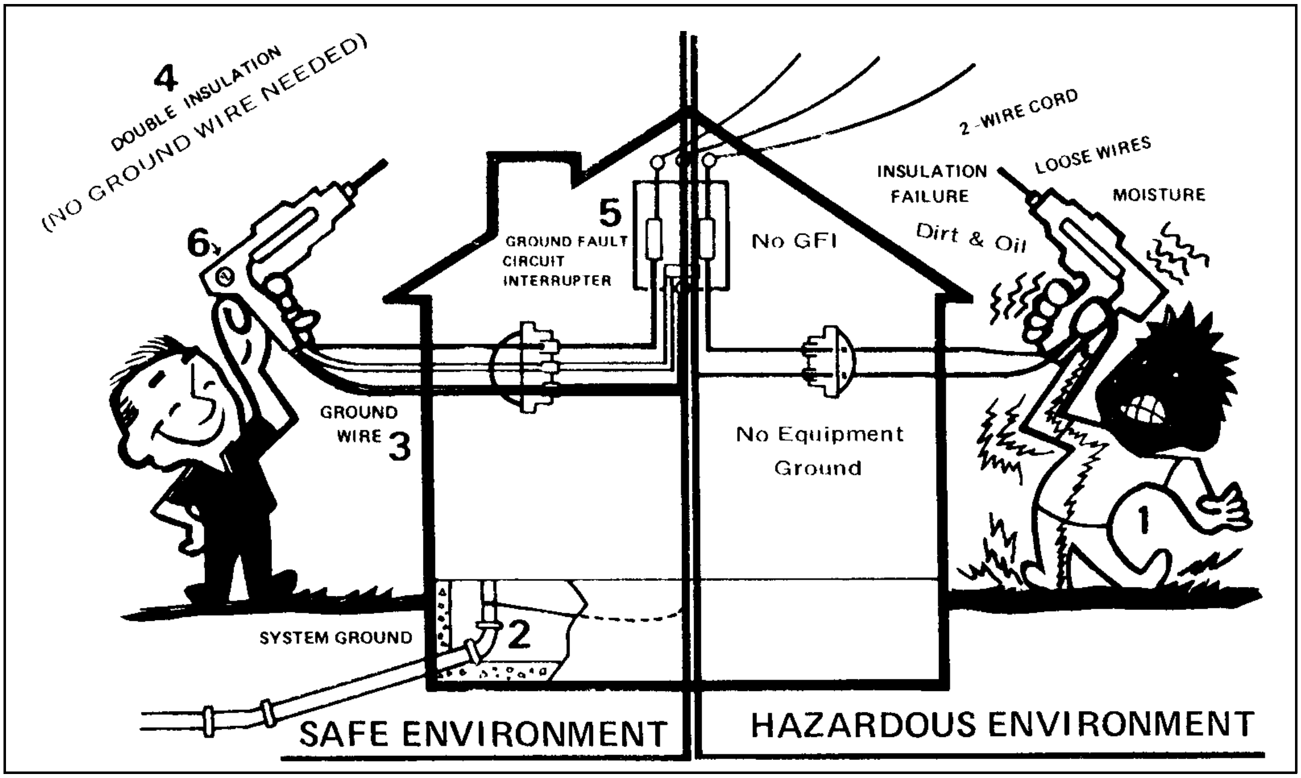


Burns: (50/1000 amp or 50 milliamps)

Fibrillation: (1/10 amp or 100 milliamps)



Several Ways to Prevent Electrical Shocks



1. Don't let your body complete an electrical circuit.

2. Make sure your electrical system is correctly grounded.

3. Ground electrical equipment and appliances correctly.

4. Use "double insulated" portable power tools with non-grounded outlets.

5. Install "GFCI" (Ground Fault Circuit Interrupters) in wet/damp areas.

6. Look for the U_L label to ensure products have been tested for their environment.

GROUNDING

This is a large amount of confusion between the terms grounded and grounding.

GROUNDED

A grounded conductor is a current carrying circuit conductor intentionally and directly connected to earth. It carries current under NORMAL circuit operations. A grounded conductor limits the potential difference to earth of one of the electrical system wires. It is more correctly called a grounded circuit conductor. On most electrical systems, the grounded conductor is also the neutral conductor and is more correctly referred to as the grounded neutral conductor or just "neutral".

GROUNDING

A grounding conductor is a safety wire connected to the metal enclosure of electrical circuits and equipment. A grounding conductor does NOT carry current under NORMAL equipment operation. A grounding conductor carries current under FAULT conditions on the circuit. It is sometimes referred to as the equipment ground or the case ground. It is not required to make the electrical circuit work but is required to make it fail in a safe manner.

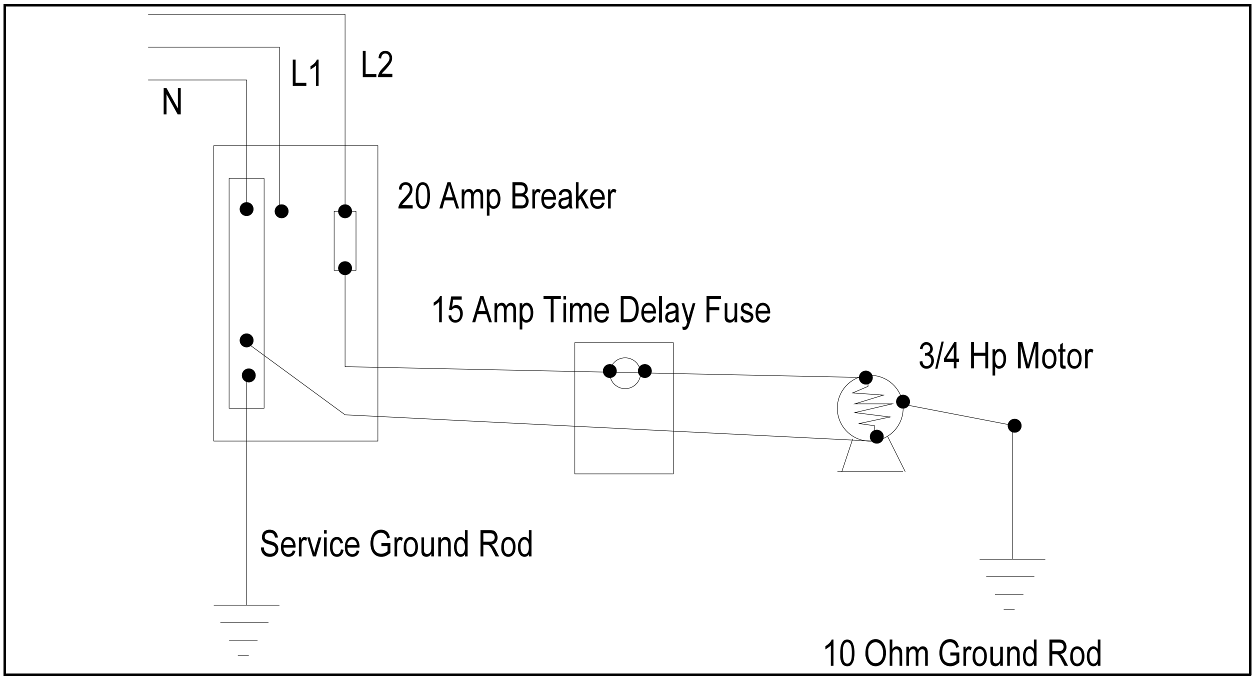
REMEMBER:

Electrical systems are "grounded" by connecting the neutral or grounded wire to earth.

Electrical devices are "grounded" by connecting an equipment grounding conductor from the service panel to non-current carrying parts of the device.

EQUIPMENT GROUNDING WITH GROUND RODS?

A 3/4 horsepower, 120 volt motor draws 13.3 amps and is installed 1000 feet from the breaker box and wired as shown below.



Would the 15 amp fuse installed to protect the wires from overloading blow if the motor directly short circuited to the metal enclosure?

120 volts
----------- = 12.0 amps of fault current through the ground rod.
10 ohms

The 15 amp fuse will **NOT** blow even under a complete direct short circuit of the motor!

If an equipment grounding conductor was correctly installed from the breaker box to the metal enclosure of the motor, would the 15 amp fuse blow if the motor shorted as indicated above?

1000 feet of #12 copper wire = 1.59 ohms

120 volts
---------- = 75.5 amps of current through the equipment grounding conductor.
1.59 ohms

The 15 amp fuse **WILL** blow immediately and de-energize the circuit.

Power Quality

What is Power Quality?

A term used to describe various types/degrees of disturbances that occur in normal electrical systems between the generation plant and the customer's equipment. Power quality broadly encompasses the entire scope of interaction among electrical supplier, the environment, and the electrical system and equipment energized connected to the system.

IEEE (Emerald Book) Power Quality Definition:

The concept of powering and grounding electric equipment in a manner that is suitable to the operation of that equipment.

In other words......doing what it takes to keep the electric service to equipment transparent or un-noticed. Power quality is more than delivery of "clean power" from the electric utility that complies with industry standards. It involves the power and design, selection, and installation of every piece of hardware and software in the electrical energy system.

What is a Power Quality Problem?

Any electrical occurrence or disturbance on an electrical system which causes unwanted or results in unsafe operation of equipment. Electrical utilities and their customers have been experiencing a growing number of problems associated with the apparent quality of electrical power. Power quality problems typically cause equipment malfunction, excessive wear or premature failure of electrical equipment, increased costs from downtime, increased maintenance and repair time and expense, and outside consultant expense.

Why Power Quality Problems Now?

The quality of power in the past was suitable for most resistance and inductance applications such as lighting, motors, and transistor electronics. New electronic equipment technology and increasing customer expectations are changing this situation rapidly. Power quality has been a problem ever since the conception of electricity, but only over the last two decades has it gotten considerable attention.

1980's: large numbers of computers & microprocessors in business and homes.
1990's: the network revolution and ever increasing equipment capability and speed.

Today's high technology electronic environment brings with it the possibility of many new power quality problems. Ever increasing integrated circuit densities, faster processor speeds, and increasingly sensitive equipment will undoubtedly mean that power quality must improve.

Power quality has become more of a concern because:

1. Loads have changed from electro-mechanical to electronic and are more susceptible to power problems. In addition, the sensitivity of electronic loads has increased over the last 10-15 years.

2. Our perceptions and expectations “have changed”. More and more jobs utilize electronic equipment and we used to expect and tolerate computer problems “every so often”.

Example: Computers lock up every so often and the user has no clue why. Users don’t tolerate as many problems as they once did.

<u>500 employees and 10 computers:</u>
If each locks up once a day, who cares..not that many people were affected.

<u>500 employees and 500 computers:</u>
If each locks up once a day, everyone is affected, especially if its mostly at the same time. Add a network and if every machine on the network locks up, more people are affected more times.

3. Widespread use of electronic (non-linear) devices produce power quality problems of their own on the system. Utility systems were designed assuming loads were electromechanical and that voltage and current supplies would always be sine waves. Electronic devices produce harmonic distortion and the proliferation of electronics challenges the sine wave assumption. Many electronic devices are susceptible to power quality problems **AND** a source of power quality problems.

Power Quality Studies:

Electric Utilities are typically blamed for having “dirty power” or causing power “spikes”, “surges” or “glitches”. On the average, about 8 out of 10 power quality problems are caused from within the customer's facility. (This still means 1 out of 5 are caused by something outside the facility). At times, power quality is confusing because historically, there has been a lack of common definitions and terms.

TYPES OF DISTURBANCES

There are several different types of power disturbances and grouping the disturbances into general categories makes for more effective analysis. **IEEE Standard 1159-1995: IEEE Recommended Practice for Monitoring Electrical Power Quality** defines six basic categories of disturbances:

Interruptions
Short Duration Voltage Variations (Sags & Swells)
Long Duration Voltage Variations (Undervoltages & Overvoltages)
Transients
Harmonic Distortion
Frequency Variations

These six disturbances can generally be further subdivided into different types of sub-categories depending on the magnitude of change to the supply voltage and/or length of duration of the event.

Instantaneous Event:	duration less than ½ cycle. (1/120th second)
Momentary Event:	duration between ½ cycle and 3 seconds.
Temporary Event:	duration between 3 seconds and 1 minute.
Long Term Event:	durations longer than 1 minute in length.

Interruptions

Interruptions are defined as events where supply voltage falls below 10% of the nominal circuit voltage. Utilities have historically used the term "outage" to describe events resulting in the absence of voltage over significant time periods. An interruption in the context of power quality has been defined to be more specific regarding the absence of voltage for specific time periods, usually much shorter than what has been historically defined as an "outage". Long term interruptions may qualify as "outages" for utility reporting purposes, however, many short term interruptions do not even though they may have detrimental affects on equipment operation.

Short Duration Voltage Variations

Short duration voltage variations are defined as voltage variations outside the normal supply limits lasting less than 1 minute in time. Lower than normal voltages are called "sags" and higher than normal voltages are called "swells". Other than harmonic distortion, voltage sags are probably one of the most "discussed" power quality problems of the day.

Sags:
Temporary voltage drops lasting less than 1 minute and having a magnitude between 10 and 90% of the nominal supply voltage.

Swells:
Temporary voltage rises lasting less than 1 minute and having a magnitude between 110 and 180% of the nominal supply voltage. The slang term "spike" should be avoided. Sags and swells sometimes precede interruptions.

Long Duration Voltage Variations:

Variations in the RMS supply voltage outside normal limits lasting for longer than one minute in time. Long duration voltage variations include both over or under voltages outside the normal RMS supply voltage limits commonly referred to as Over-voltages and Under-voltages and not qualifying as interruptions.

Undervoltages:

Voltage drops lasting longer than 1 minute and having a magnitude between 10 and 90% of the nominal RMS supply voltage. The term brownout is sometimes used to describe sustained periods of undervoltage. Because there is no formal definition for the term brownout and it is not as clear as the term undervoltage, the term brownout should be avoided.

Overvoltages:

Voltage rises lasting longer than 1 minute and having a magnitude greater than 110 percent of the nominal RMS supply voltage. Overvoltages result because the system is either too weak for the desired voltage regulation or voltage controls are inadequate.

Voltage Transients:

Historically, the term transient has been used in power system analysis to note an undesirable but momentary event. Unfortunately, this definition can be used to describe just about anything unusual that happens on a power system. Many misunderstandings about power quality come from poor terminology used to describe transient disturbances such as bump, glitch, surge, and spike.

A voltage transient is a sub-cycle (less than 1 cycle) disturbance in the RMS voltage AC waveform that is evidenced by a sharp brief discontinuity of the waveform for an extremely short time period, usually measured in microseconds.

Transients have definable beginnings and ends and after the transient has moved through the system, the voltage returns to normal. Transients may be in either polarity, and may be additive or subtractive from the normal waveform and can occur on the phase, neutral or grounding conductors. Transients can occur at a single time or at repetitive intervals. Repetitive disturbances can occur synchronously throughout a single cycle or regularly in multiple cycles.

They are generally not conducted far from the source of where they enter the power system, although they may, in some cases, be conducted for quite some distance along utility lines.

Frequency Variations

On modern interconnected power systems significant frequency variations are rare. The electrical power system frequency is directly related to the rotational speed of the generators supplying the system. There are slight variations in frequency as the dynamic balance between connected load and generation changes. The size of the frequency shift and its duration depends on the load characteristics and the response of the generation control system to load changes. Frequency variations that go outside of accepted limits for normal steady state operation of the power system can be caused by faults on the bulk power transmission system, a large block of load being disconnected, or a large source of generation going off- line.
Frequency variations of consequence are much more likely to occur for loads that are supplied by a generator isolated from the utility system. In such cases, governor response to abrupt load changes may not be adequate to regulate within the narrow bandwidth required by frequency-sensitive equipment.

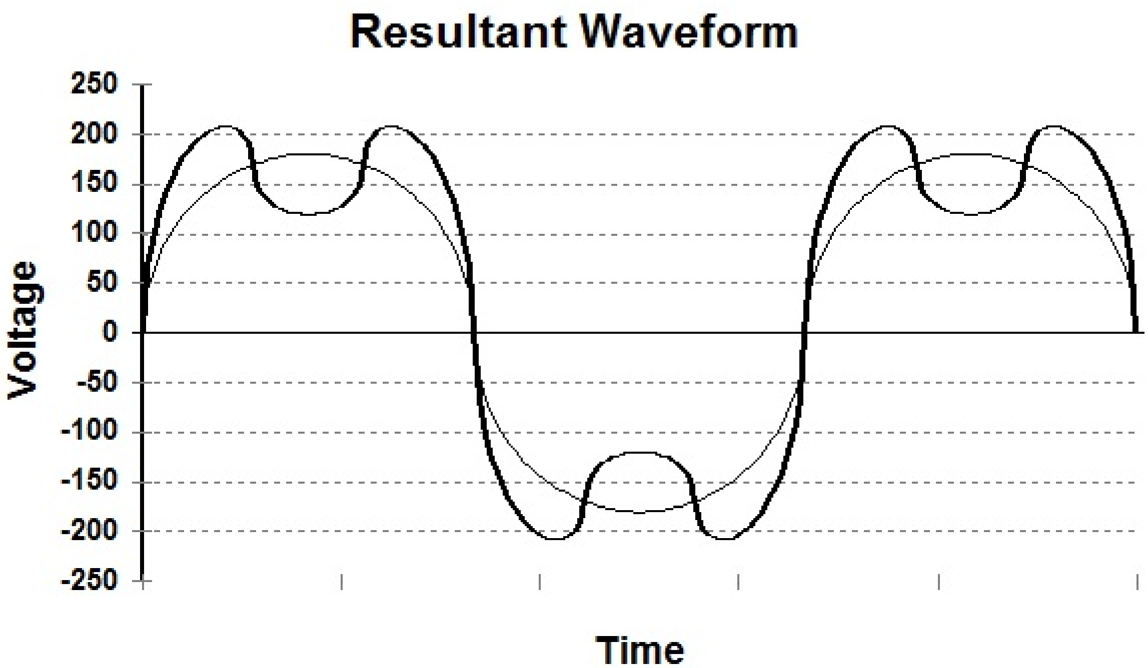
Waveform Distortion:

A steady state deviation from an ideal sine wave of power frequency principally characterized by the spectral content of the deviation. There are five primary types of waveform distortion but the most "discussed" of these in the recent past is Harmonic Distortion. The most common way to judge the severity of harmonics is to measure Total Harmonic Distortion (THD).

Total Harmonic Distortion (THD):

The additional harmonics that exist in a waveform can be measured as a percentage of the fundamental frequency. These percentages are then squared, summed and the square root taken to determine the total harmonic distortion (THD) content.

Harmonics are found as integer multiples of the fundamental frequency. In North America the



fundamental frequency is 60 Hz. Using 60 Hz as the fundamental frequency, the second harmonic would be: 2 X 60 = 120 Hertz, the third harmonic would be: 3 X 60 = 180 Hertz, the fourth would be: 4 X 80 = 240 Hertz and so on.

Multimeters

Voltmeters/Multi-meters or VOM's

Voltmeters can be used to measure voltage, current and resistance.

* Voltmeter checks can detect longer term interruptions, longer term sags & swells, under and over-voltage problems, and voltage imbalances.

Select Meters that Distinguish AC from DC

The meter should be able to distinguish AC from DC voltages.

* Place the meter selector of an analog or digital meter on the AC scale and measure the voltage of a standard battery (9 volt, D cell, etc.).

* If the meter can distinguish between AC and DC it will read zero volts when measuring a DC battery and the switch set on the AC scale.

If the meter shows a voltage reading, then the meter cannot distinguish AC from DC even though it has selector switches for each.

True RMS Voltmeters

* It is important the meter is a "True RMS Meter" so that effects on voltage from nonlinear loads will be accurately registered.

Common Multi-meter Calculation Methods:

All commonly used meters are calibrated to give an RMS indication for the measured signal. However, three different methods are used to calculate the RMS value.

* The three common methods are Peak, Averaging, and True RMS.

* These meters all work fine as long as the AC voltage is a pure sine waveform.

1. Peak Method

The peak responding meter detects the peak value of the sine wave and divides the result by the square root of 2 (1.414) to approximate the RMS voltage value. In other words, it assumes a perfect sine wave and that the peak value of a sine wave is 1.414 times the RMS value.

2. Average Responding Method

The average responding method detects the average of a rectified signal between zero crossings and uses a multiplier of 1.112 to arrive at the RMS value. The 1.112 multiplier is the relationship between the RMS value and average value of a perfectly sinusoidal waveform.

3. True RMS

The True RMS method uses microprocessors to sample many points along the waveform to calculate its true RMS value. Most True RMS digital meters use a digital calculation of the RMS value by squaring the signal on a sample by sample basis, averaging over a period, and then taking the square root of the result. This type of meter will give accurate readings for either pure sine waves or highly distorted complex waveforms.

These methods give the same result for a clean, sinusoidal signal but give significantly different answers for distorted signals.

* The average and peak responding meters don't really measure the RMS voltage, they calculate it based on specific items assuming a pure sinusoidal waveform and then display the calculated RMS reading.

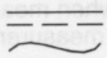
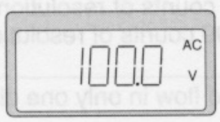
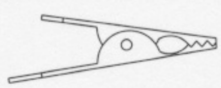
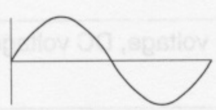
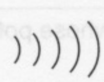
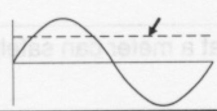
* Large errors will start to develop with both methods when there is distortion in the waveform. Using these types of meters can cause error readings of 25% to 30% below the actual RMS value.

Most true RMS meters usually indicate on their cover that they are true RMS meters. Others will say in their specifications that they are a true RMS sensing meter. A quick check with the vendor or manufacturer can verify any questions.

Meter Symbols

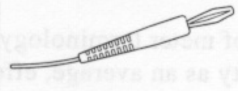
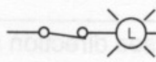
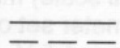
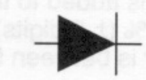
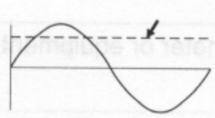
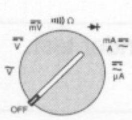
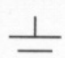
There are a wide variety of meter and electrical terminology and symbols used to indicate various quantities about an electrical meter.

METER TERMINOLOGY

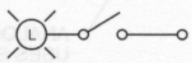
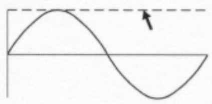
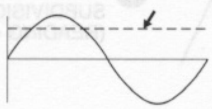
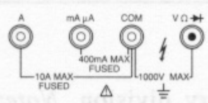
TERM	SYMBOL	DEFINITION
AC		Continually changing current that reverses direction at regular intervals. Standard U.S. voltage is 60 Hz.
AC/DC		Indicates ability to read or operate on alternating and direct current.
ACCURACY ANALOG METER		Largest allowable error (in percent of full scale) made under normal operating conditions. The reading of a meter set on the 250 V range with an accuracy rating of ± 2% could vary ± 5 V. Analog meters have greater accuracy when readings are taken on the upper half of the scale.
ACCURACY DIGITAL METER		Largest allowable error (in percent of reading) made under normal operating conditions. A reading of 100.0 V on a meter with an accuracy of ±2% is between 98.0 V and 102.0 V. Accuracy may also include a specified amount of digits (counts) that is added to the basic accuracy rating. For example, an accuracy of ± 2% (± 2 digits) means that a display reading of 100.0 V on the meter is between 97.8 V and 102.2 V.
ALLIGATOR CLIP		Long-jawed, spring-loaded clamp connected to the end of a test lead. Used to make temporary electrical connections.
AMBIENT TEMPERATURE		Temperature of air surrounding a meter or equipment to which the meter is connected.
AMMETER		Meter that measures electric current.
AMMETER SHUNT		Low-resistance conductor that is connected in parallel with the terminals of an ammeter to extend the range of current values measured by the ammeter.
AMPLITUDE		Highest value reached by a quantity under test.
AUDIBLE		Sound that can be heard.
AUTORANGING		Function that automatically selects a meter's range based on signals received.
AVERAGE VALUE		Value equal to .637 times the amplitude of a measured value.

continued

METER TERMINOLOGY

TERM	SYMBOL	DEFINITION
BANANA PLUG		Long, thick terminal connection on one end of a test lead used to make a connection to a meter.
BANANA JACK		Meter jack that accepts a banana plug.
CELSIUS	°C	Temperature measured on a scale for which the freezing point of water is 0° and the boiling point is 100°.
CLOSED CIRCUIT		Circuit in which two or more points allow a predesigned current to flow.
COUNTS		Unit of measure of meter resolution. A 1999 count meter cannot display a measurement of $\frac{1}{10}$ of a volt when measuring 200 V or more. A 3200 count meter can display a measurement of $\frac{1}{10}$ of a volt up to 320 V.
DC		Current that constantly flows in one direction.
DIGITS		Indication of the resolution of a meter. A $3\frac{1}{2}$ digit meter can display three full digits and one half digit. The three full digits display a number from 0 to 9. The half digit displays a 1 or is left blank. A $3\frac{1}{2}$ digit meter displays readings up to 1999 counts of resolution. A $4\frac{1}{2}$ digit meter displays readings up to 19,999 counts of resolution.
DIODE		Semiconductor that allows current to flow in only one direction.
DISCHARGE		Removal of an electric charge.
EFFECTIVE VALUE		Value equal to .707 of the amplitude of a measured quantity.
FAHRENHEIT	°F	Temperature measured on a scale for which the freezing point of water is 32° and the boiling point is 212°.
FREQUENCY		Number of complete cycles occurring per unit of time.
FUNCTION SWITCH		Switch that selects the function (AC voltage, DC voltage, etc.) that a meter is to measure.
GROUND		Common connection to a point in a circuit whose potential is taken as zero.
HOLD BUTTON	HOLD [H]	Button that allows a meter to capture and hold a stable measurement.
MEASURING RANGE		Minimum and maximum quantity that a meter can safely and accurately measure.

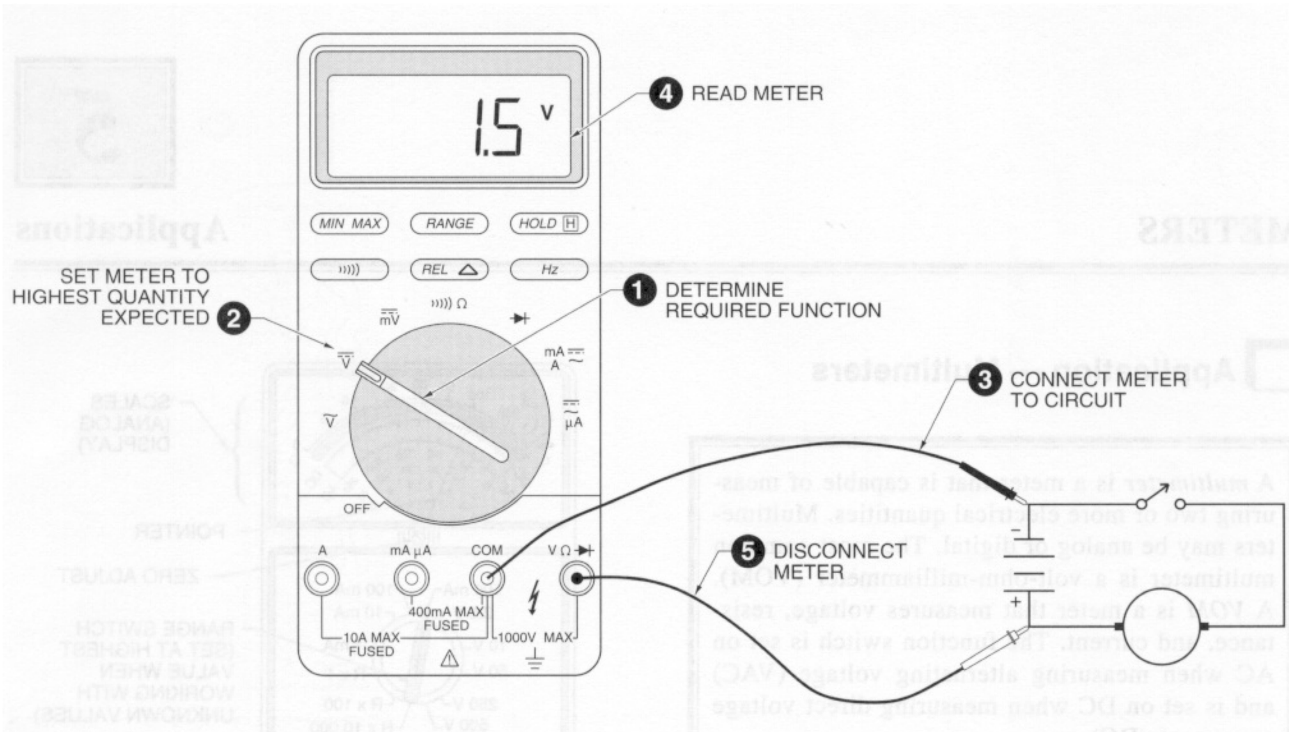
METER TERMINOLOGY

TERM	SYMBOL	DEFINITION
OVERFLOW		Condition of a meter that occurs when a quantity to be measured is greater than the quantity the meter can display.
OVERLOAD	0.L.	Condition of a meter that occurs when a quantity to be measured is greater than the quantity the meter can safely handle for the meter range setting.
OPEN CIRCUIT		Circuit in which two (or more) points do not provide a path for current flow.
PEAK		Highest value reached when measuring.
POLARITY		Orientation of the positive (+) and negative (−) side of direct current or voltage.
PROBE		Pointed metal tip of a test lead used to make contact with the circuit under test.
RESOLUTION		Sensitivity of a meter. A meter may have a resolution of 1 V or 1 mV.
ROOT-MEAN-SQUARE		Value equal to .707 of the amplitude of a measured value.
SHORT CIRCUIT		Two or more points in a circuit that allow an unplanned current flow.
TERMINAL		Point to which meter test leads are connected.
TERMINAL VOLTAGE		Voltage level that meter terminals can safely handle.

Multimeter Use

Multimeters measure many different electrical quantities. Care must be taken to ensure that a inultimeter is set on the correct settings, connected to a circuit correctly, and the scale is read accurately. Ensure that a multimeter is properly set before connecting it to a circuit.

To use a multimeter, apply the procedure:



1. Determine the required function (voltage, current, resistance, etc.) and set the range and/or function switch to the electrical quantity and function required.

Caution: A multimeter is damaged if it is set to measure current but is connected as a voltmeter.

2. Set the meter to the highest quantity expected. Select the highest range for unknown readings.

3. Connect the meter to the circuit per the manufacturer's recommendations. Ensure that the polarity is correct when measuring DC or voltage. Connect one lead when connecting a meter to an unknown circuit. Slowly connect the other lead, observing the meter. Remove the lead immediately if the meter s overloaded.

4. Read the value on the meter.

5. Disconnect the meter from the circuit.

Multimeter Settings

The normal setting for measuring DC voltage or current is +DC which makes the red (+) lead positive.

The alternative setting for measuring DC voltage or current is -DC which makes the red (+) lead negative.

This setting is used when it is preferable to have the test lead with the alligator clip (black) positive and the test lead with the pointer (red) negative.

Ghost Voltages

A meter (especially digital) set to measure voltage may display a reading before the meter is connected to a circuit. The displayed voltage is a ghost voltage that appears as changing number on the digital display or a vibrating analog display needle.

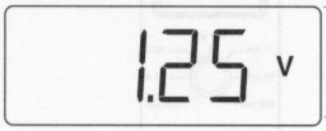
Ghost voltages are produced by the magnetic fields generated by current carrying conductors such as fluorescent lights and other operating electrical equipment. The test leads act as antennae and when moved, a small voltage can be induced by magnetic induction into the leads. These "ghost" voltages do not damage the meter but untrained personnel may misinterpret them or misread a voltage when the meter is connected to a circuit believed to be powered. Circuits that are not powered but can move can also act as antennae for picking up these same types of induced signals. Keep a meter connected to a circuit for a long enough time to ensure the electrical wires/leads are not moving and the display reading is more or less constant.

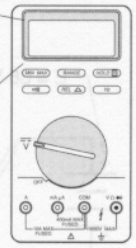
Meter Reading /Conversion Exercise

State the value for each meter reading in the asked for units.

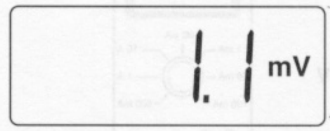
mV = millivolts (0.001) kV= kilovolts (1000) MV=megavolts (1,000,000)

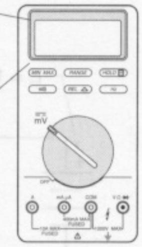
*M*A = microamps(.000001) GV=gigavolts (1 billion)



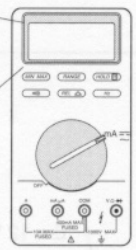


1. ________ mV
2. ________ kV
3. ________ MV

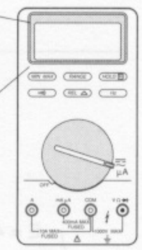




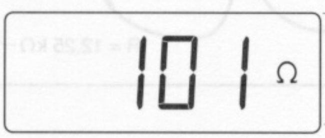
4. ________ V
5. ________ kV
6. ________ GV

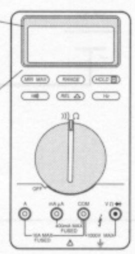


7. ________ A
8. ________ µA
9. ________ kA

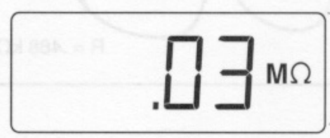


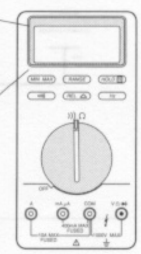
10. ________ A
11. ________ mA
12. ________ kA



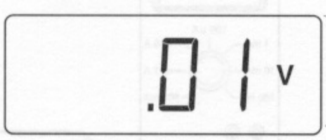


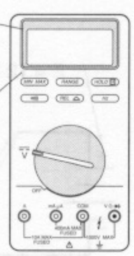
13. ________ kΩ
14. ________ mΩ
15. ________ MΩ



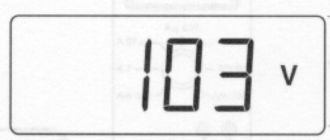


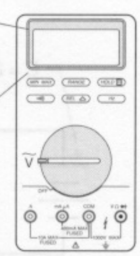
16. ________ Ω
17. ________ kΩ
18. ________ GΩ





19. ________ mV
20. ________ kV
21. ________ µV



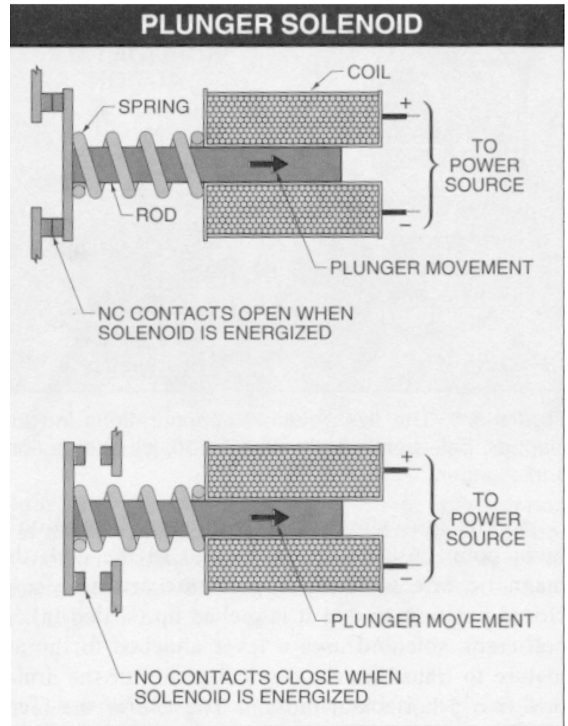


22. ________ kV
23. ________ MV
24. ________ GV

Valves/Solenoids

Many electrical and water control devices like valves rely on either solid state relays or electro-mechanical solenoids to open or close electrical circuits or water systems.

Solenoids



Constructed of many turns of wire wrapped around a magnetic laminate assembly. Passing current through the coil causes the armature to be pulled toward the coil. Various devices can be attached to the end of the armature to open or close electrical contacts or mechanical valves.

Several important factors related to the electrical supply to solenoids used as electrical and pipe flow controls include:

Solenoid "Power"

The power (force) a solenoid produces is related to the number of turns in the coils and the applied voltage and current the device draws. The larger the coil, the greater the force.

The rated power of the solenoid can be an important item when replacing solenoids. It generally takes very little power on the part of the solenoid to close or open electrical contacts in air but closing a water valve with a line at a relatively high pressure requires the valve to work against the pressure of the moving water to close.

Solenoids are generally not rated in watts but a similar rating of "volt-amps" or VA. Most solenoids will have two power ratings including Starting and Sealed.

A solenoid with a 30 volt coil rated at 60 VA sealed would require 2 amps of current when operating.

VA = Volts X Amps,   60 VA divided by 30 volts = 2 amps

If this same coil has an inrush rating of 600 VA, then the current drawn while the coil is starting is:

600 VA divided by 30 volts = 20 amps

Current Ratings

Solenoids controlling valves will have two separate current ratings, the in-rush current and the sealed current.

Sealed Current Rating:

Sealed Current rating of a solenoid coil is the amount of amps the device draws when sealed at rated voltage.

In-Rush Current Rating:

Similar to motors, solenoid coils will draw more current when they are first energized. This initial "starting current" is called the "in-rush current"

The typical inrush current is approximately six to 10 times the sealed current for the device.

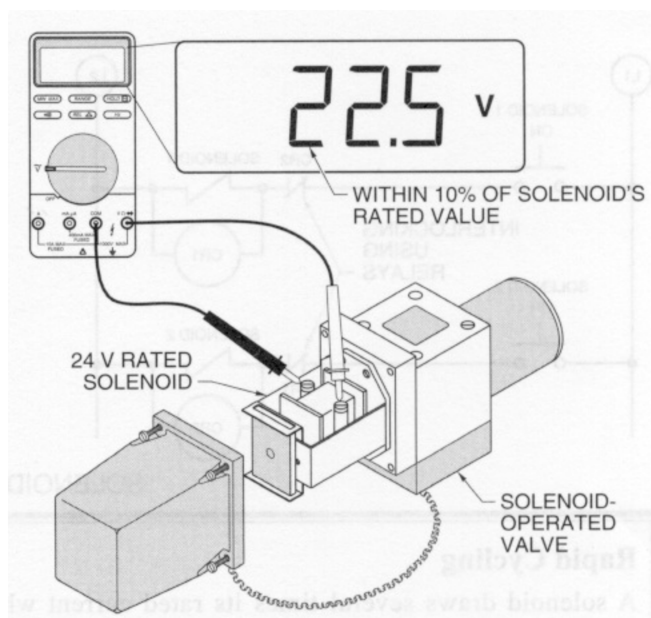
Solenoid Voltage

All electrical equipment is "rated" for operation at a specific voltage (and sometimes a range). Voltage variations are one of the most common causes of solenoid/valve failures as well as operational problems.

Rated Voltage:

The voltage the manufacturer designed the device to be operated. Most electrical system standards accept voltage fluctuations on the electrical supply to plus or minus 10% of nominal voltage.

Acceptable Voltage Range:



* Plus or minus 10% of rated voltage measured at the valve with the valve energized.

There are a number of other voltage ratings on solenoids controlling valves that are also important including:

Pick Up Voltage

The minimum voltage that will start the armature of the solenoid to move.

Seal in Voltage

The minimum voltage required to cause the armature to seal against the pole faces of the magnets.

Drop Out Voltage

The voltage at which the armature can no longer be sealed against the pole faces of the magnets and the device drops out.

Many solenoids can have a lower pick up voltage than seal in voltage. If the voltage happens to be above pick up but below seal in, the device constantly tries to pick up, can't seal in, drops back out, picks back up, and starts to "chatter".

High Voltage Effects

When the voltage applied to a coil is higher than what it is rated for, the coil draws more current than normal.

* This results in excess heating of the coil reduces the life of the insulation on the coil windings and can cause premature catastrophic failure if the current is high enough.

The magnetic force also is higher than what the device was designed for the armature "slams" open and closed with excessive force.

* This commonly results in contact or valve mechanical damage as well as armature damage depending on which if the "weaker" link.

Low Voltage Effects

Low voltage on the coil produces low coil current (amps) and reduces the magnetic strength the armature has to push or pull the intended contacts or valve open or shut.

* The solenoid may pick up but not seal in when the voltage is greater than the pick up rating but less than the seal in rating.

This tends to make the solenoid and device "chatter". Each time the device drops out and then picks up, the coil goes through inrush which can be 6 to 10 times the normal operating current. The coil quickly heats up and burns out because it is not designed to carry this high cycling current. The armature chatter will generally also be damaging to valve seals or contacts connected to them.

Faulty Solenoids

1. Failure to operate when energized
2. Failure to operate when de-energized
3. Noisy Operation
4. Erratic Operation

Troubleshooting Solenoids

A voltmeter and ohmmeter are required when troubleshooting a solenoid.

1. Turn the electrical power to the solenoid or solenoid circuit off.

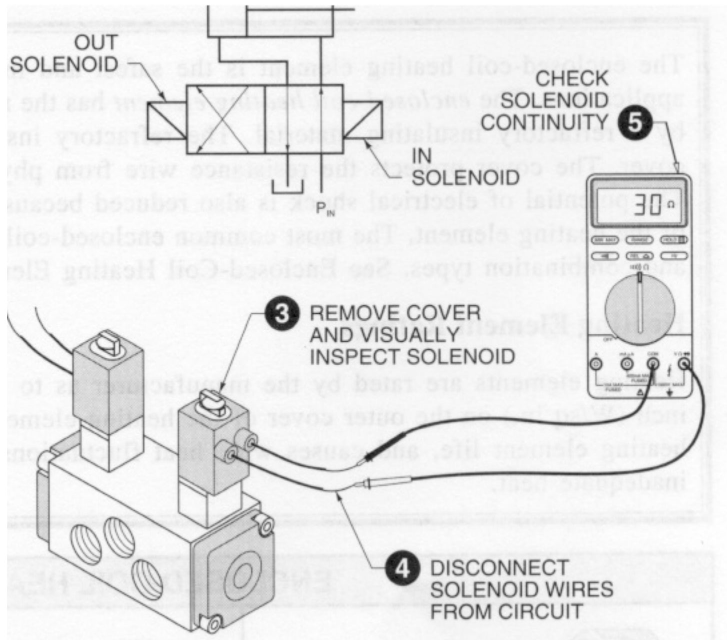
2. Measure the voltage at the solenoid to ensure the power is off.

3. Remove any covers to visually inspect.
    a. Look for burnt coils or broken parts if visible.

b. Determine if new equipment is required.

4. Disconnect the solenoid from the electrical circuit when no obvious problem is observed.

5. Check the solenoid continuity. Usually on the RX100 or lower resistance scale if the device uses smaller wire gauges. Connect the meter leads to the solenoid wires with all power OFF.
The meter should indicate a resistance reading of plus or minus 15% of the coil's normal reading when it was new.



Typical values are found by testing new devices of the same type from the same manufacturer.

* A low or zero reading indicates a short or partial short. Replace the solenoid/valve.

* No movement on an analog meter or infinite resistance (no continuity) on a digital meter means the coil is open and defective.

FAULTY SOLENOID PROBLEMS

Problem	Possible Causes	Comments
Failure to operate when energized	Complete loss of power to the solenoid	Normally caused by blown fuse or control circuit problem
	Low voltage applied to the solenoid	Voltage should be at least 85% of solenoid's rated value
	Burned out solenoid coil	Normally evident by pungent odor caused by burnt insulation
	Shorted coil	Normally a fuse is blown and continues to blow when changed
	Obstruction of plunger movement	Normally caused by a broken part, misalignment, or the presence of a foreign object
	Excessive pressure on solenoid plunger	Normally caused by excessive system pressure in solenoid-operated valves
Failure to operate spring-return solenoids when de-energized	Faulty control circuit	Normally a problem of the control circuit not disengaging the solenoid's hold or memory circuit.
	Obstruction of plunger movement	Normally caused by a broken part, misalignment, or the presence of a foreign object
	Excessive pressure on solenoid plunger	Normally caused by excessive system pressure in solenoid-operated valves
Failure to operate electrically-operated return solenoids when de-energized	Complete loss of power to solenoid	Normally caused by a blown fuse or control circuit problem
	Low voltage applied to solenoid	Voltage should be at least 85% of solenoid's rated value
	Burned out solenoid coil	Normally evident by pungent odor caused by burnt insulation
	Obstruction of plunger movement	Normally caused by broken part, misalignment, or presence of a foreign object
	Excessive pressure on solenoid plunger	Normally caused by excessive system pressure in solenoid-operated valves
Noisy operation	Solenoid housing vibrates	Normally caused by loose mounting screws
	Plunger pole pieces do not make flush contact	An air gap may be present causing the plunger to vibrate. These symptoms are normally caused by foreign matter
Erratic operation	Low voltage applied to the solenoid	Voltage should be at least 85% of the solenoid's rated voltage
	System pressure may be low or excessive	Solenoid size is inadequate for the application
	Control circuit is not operating properly	Conditions on the solenoid have increased to the point where the solenoid cannot deliver the the required force

OSHA Grounding/GFCI Rules

EMPLOYER'S RESPONSIBILITY:

OSHA ground-fault protection rules and regulations have been determined necessary and appropriate for employee safety and health. Therefore, it is the employer's responsibility to provide either:

1. Ground-fault circuit interrupters on construction sites for receptacle outlets in use and not part of the permanent wiring of the building or structure.

2. A scheduled and recorded assured equipment grounding conductor program on construction sites, covering all cord sets and receptacles that are not part of the permanent wiring of the building or structure, and equipment connected by cord and plug that are for use or used by employees.

These requirements are in addition to any other requirements for equipment grounding conductors.

GROUND-FAULT CIRCUIT INTERRUPTERS:

The employer is required to provide approved ground-fault circuit interrupters for all 120-volt, single phase, 15-and 20-ampere receptacle outlets on construction sites that are not a part of the permanent wiring of the building or structure and that are in use by employees.

1. Receptacles on the ends of extension cords are not part of the permanent wiring and, therefore, must be protected by GFCIs whether or not the extension cord is plugged into permanent wiring.

2. This protection is required in addition to, not as a substitute for, the grounding requirements of OSHA safety and health rules and regulations.

ASSURED EQUIPMENT GROUNDING CONDUCTOR PROGRAM:

The assured equipment grounding conductor program covers all cord sets and receptacles that are not a part of the permanent wiring of the building or structure, and equipment connected by cord and plug that is available for use or is used by employees.

1. The requirements the program must meet are stated in 29 CFR 1926.404(b) but employers may provide additional tests or procedures.

2. OSHA requires that a written description of the employer's assured equipment grounding conductor program, including the specific procedures adopted, be kept at the jobsite.

   - The required tests must be recorded, and the record maintained until replaced by a more current record.

   - The written program description and the recorded tests must be made available, at the jobsite, to OSHA and to any affected employee upon request.

   - The employer is required to designate one or more competent persons to implement the program.

3. Electrical equipment noted in the assured equipment grounding conductor program must be visually inspected for damage or defects before each day's use. Any damaged or defective equipment must not be used by the employee until repaired.

4. Tests Required by OSHA.

   A. A continuity test to ensure that the equipment grounding conductor is electrically continuous.

      - It must be performed on all cord sets and on receptacles that are not part of the permanent wiring of the building or structure, and on cord-and plug-connected equipment that is required to be grounded.

      - Tests may be performed using a simple continuity tester, such as a lamp and battery, a bell and battery, an ohmmeter, or a receptacle tester.

   B. Tests of receptacles and plugs to ensure that the equipment grounding conductor is connected to its proper terminal.

      - This test can be performed with the same equipment used in the first test.

These tests are required before first use, after any repairs, after damage is suspected to have occurred, and at 3-month intervals. Cord sets and receptacles that are essentially fixed and not exposed to damage must be tested at regular intervals not to exceed 6 months. Any equipment that fails to pass the required tests shall not be made available or used by employees.

Lockout/Tagout

BACKGROUND:

Machinery or equipment that starts up unexpectedly while someone is performing maintenance or repairs can be a serious safety hazard. Two-thirds of all fatalities occur as a result of improper lockout and/or tagout procedures while performing normal duties. This is usually caused by lack of attention to detail or lack of knowledge.

REGULATIONS / STANDARDS:

Information contained in this training program is summarized from the Code of Federal Regulations (CFR) 1910.147 Control of Hazardous Energy (Lockout/Tagout). Included in this rule is information on applications, servicing and maintenance operations, requirements, inspections, removal, and other related issues.

OSHA LOCKOUT RULING:

1910.147 The employer shall provide training to ensure that the purpose and function of the energy control program are understood by employees and that the knowledge and skills required for the safe application, usage, and removal of energy controls are required by employees. The training includes the following areas:

- Recognizing hazardous energy sources.
- Purpose and use of the energy control procedure.
- Prohibition relating to attempts to restart or energize machines or equipment which are locked out or tagged out.
- Limitations of tags.
- Employee retraining.
- Certify that employee training has been accomplished and is being kept up to date.

DEFINITIONS:

Lockout: Adding a special lock or other device to the normal routine of shutting down the machinery in order to perform maintenance or repairs. When equipment cannot be properly locked out, it must be "tagged out" with a special tag that warns other workers of the danger of starting up the machine.

Tagout: The attachment of a standardized Reg Tag to an isolating device. Red Tags indicate that the equipment must not be operated until the tagout device is properly removed.

Individual Lock/Tag: Lock and/or tag to be attached by an individual and which can only be removed by that individual.

Operations Lock and/or Tag: The first lock and/or tag to be attached to, and the last lock and/or tag to be removed from, an isolating device by a qualified Operations Representative.

One-Plus: The requirement of an additional means of isolation or restraint, when tagout is used without locks, to prevent inadvertent operation of an isolating device. Performed such that two separate unrelated actions must occur to defeat the source isolation. Measures can also be taken (such as removing a valve handle, or using a wrench to tighten the valve) to prevent inadvertent operation of the isolating device.

LOCKOUT / TAGOUT PROCEDURES

Keep in mind that at any time a worker chooses he may put on individual tags, add restraints, apply additional one plus measures or apply a lock to any or all isolating devices. Only authorized employees should perform lockout procedures and remove locks and tags. However, all employees need to understand lockout and tagout procedures. There are nine steps to lock out hazards. Following these simple steps will keep accidents from occurring while maintaining or repairing machinery.

1. **Think, plan and check.** Think through the entire procedure and identify all parts of any systems that need to be shut down. Locate switches, valves or other devices that need to be locked out.

2. **Communicate.** Let other employees working on the equipment know when and why you are shutting down the system.

3. **Locate all power sources.** This includes stored energy in springs or hydraulic systems.

4. **Neutralize all power at its sources.** Disconnect electricity and block any movable parts. Release or block spring energy. Drain all hydraulic and pneumatic lines. Lower suspended parts to rest positions.

5. **Lock-out all power sources.** Use a lock designed only for this purpose. Use a lockout tag that includes your name and the time, date and department.

6. **Test operating controls.** Test all controls to make certain the power is off.

7. **Turn control back off.** Be sure each and every control is in the "off" position before beginning any necessary maintenance or repairs.

8. **Make any necessary repairs.**

9. **Remove locks and restore energy.** Restart equipment only after all other workers are at a safe distance away. Tools should be removed from equipment and machine guards back in place. Notify other workers that the machines are working and back on.

An electrical source is not the only source of energy which will likely cause injury if not properly locked or tagged out. Other sources include:

- hydraulic
- pneumatic
- chemical
- thermal
- mechanical