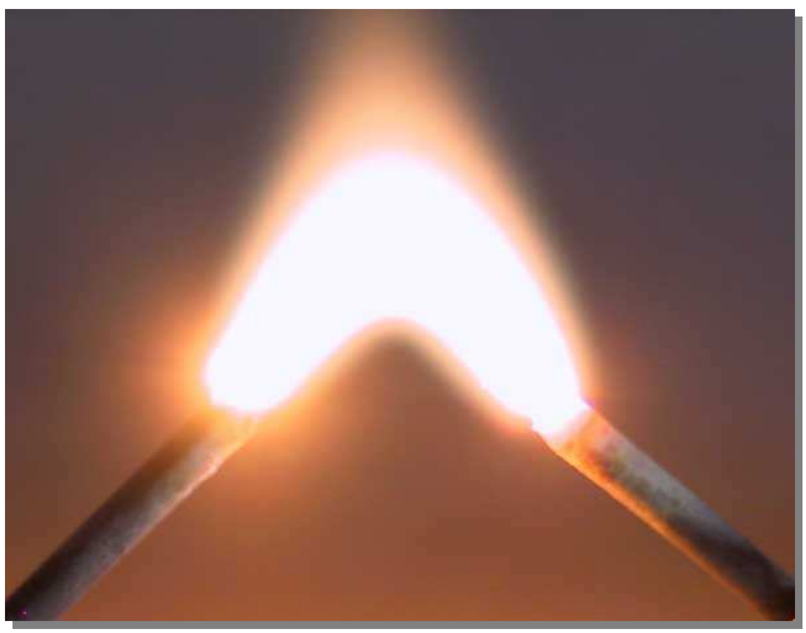
Kriz-Davis Co.
WHOLESALE ELECTRICAL SUPPLIES
"An Employee Owned Company"

ELECTRICAL TRAINING COURSE
VERSION 4



Thank you for requesting or downloading this copy of our electrical training course. The primary goal is to teach you about products as well as application. All examples and descriptions used throughout the course are to be used as an aid in understanding the individual subject(s) being covered. Some will be shown in the extreme and should not be construed as the only way to accomplish a task. We may not always show the proper grounding of a circuit and may not always show a complete circuit. Some examples in the course may be of the extreme and not necessarily the only proper method of installation or design. Our main goal is to offer examples and explanation of that particular product or application.

We will not be responsible for the use, misuse, misunderstanding, errors or misapplication of the information contained in this training course. We will not attempt to train you on the NEC except, where necessary, for clarificationUse of this information is entirely the responsibility of the participant(s).

In order to properly present this course, we start with basics of electricity and the premise of zero knowledge of electrical equipment. This concept, however, does present a variety of problems. We have had engineers, journeymen electricians, maintenance, and plant supervisors, machine operators, maintenance mechanics, and electrical distributor personnel participate. Obviously, the engineer will understand fault currents and Ohms Law where others may not. To produce an overall understanding of electricity and electrical equipment, we will attempt to include as much subject matter as possible. You will be asked to study a variety of subjects products as shown in the chapter outline in the following pages. This chapter outline, however, does not show the secondary side of each chapter. Some portion of the subject matter may not interest you. If this is the case, we ask that you review that section to get an overall feel and continue on.

A variety of questions regarding the course have been asked over the years, and, to help clarify some questions you may have, we will list a few below.

- As a machine operator, why do I have to understand Ohms Law and voltage drop when all I will probably ever do is change fuses?
    - A fuse is a fuse…correct? Not at all. What happens when you mix interrupting capacities in a switch?

  - **What is the difference between interrupting ratings of fuses and equipment?**
  - **Does it matter how long your feeder conductor is?**
- **Can you use a breaker in place of a fused switch? What about interrupting capacities, ampere sizing, voltage rating etc.**
- **What is the NEC derating requirement for multiconductor cables installed on a cord reel?**
- **Do calculations of voltage drop change with usage of an aluminum conductor?**
- **Even though the course is written using Square D Schneider Electric products, sizing starters, utilization of relays and usage of controls is universal. Catalog numbers may change but usage remains the same. How do you choose a proper thermal overload unit? Does ambient temperature have an effect on equipment? What is the amperage rating percentage, plus or minus, based upon placement of the controller?**
- **What is RMS currents?**

Ohms Law is basically the same as the introduction to a book or the beginning of a movie. Without it, nothing else makes sense. As you will see, we attempt to instill a sense of *reading the fine print*. This will reduce your company's expenses and help you achieve a better understanding. As previously mentioned, Square D is the vehicle used throughout the course. There will also be a Schneider Electric Digest that is used as reference for the class which is available for download free of charge. Catalog numbers shown are also for reference to allow you to locate product in the Square D Digest. Searching the Digest is also the fastest way to locate a device. Regardless the manufacturer that could have been used, the theme and message would remain the same. Understanding Ohms Law, fault current, voltage drop is not exclusive to one manufacturer and understanding available fault current and effects on equipment is also universal to all equipment.

What is the length of the course? It all depends on you. There are 14 chapters which could take several months to complete. The number of chapters and the content could be modified somewhat in the future, depending on changes by the manufacturer. We appreciate your endeavor and hope it proves to be a benefit to all those involved.

Our training course was created in 1995 and it has been evolving ever since. Over this period, we have been privileged to have over 500 participants throughout the world and we hope to include you.

The complete course has since been updated and all chapters have been merged together. This provides a more contiguous presentation, less download times, and easier subject search. The class is protected with a password to insure registration via email letting us know who you are and your state or country. This will help us to determine whether future expansion of the course is a viable option due to usage and interest. You

have our assurance that your email address will be retained in a secure database and will not be furnished or sold to any third party. Use of this information will be strictly limited to the course and any future updates. Again, there are no hidden costs or requirements. Simply send an email to Gary Jackson at gjackson@krizdavis.com

We again, thank you for your interest .

Regards:
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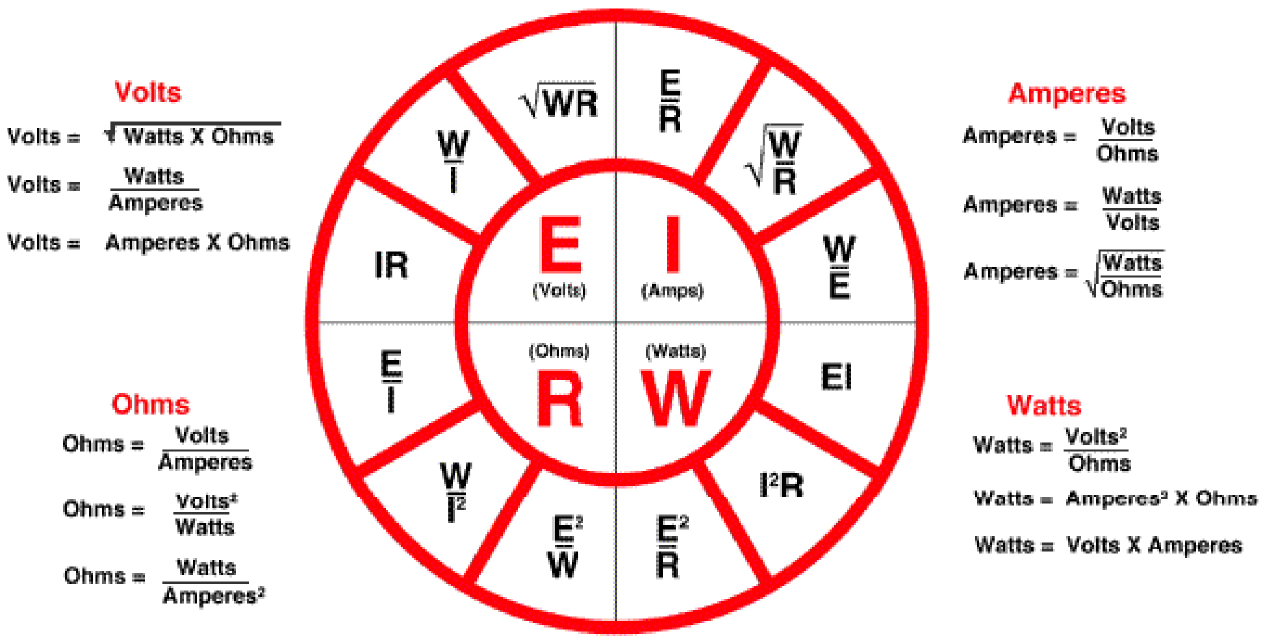
CHAPTER 1

OHMS LAW

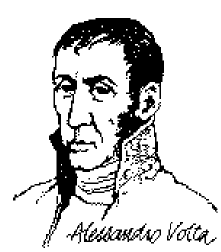


The starting point for any electrical study is a review of Ohms Law. It is absolutely necessary you have a complete and clear understanding of Ohms Law to help you choose and/or install the proper equipment.

But first a little history of electricity. Some of our ancient ancestors, digging along the seashores in Asia found a yellow, glass-like rock that, when rubbed with a cloth or fur, developed the power to attract straw, paper etc. The pebbles were a fossilized type of resin, called *amber,* left over from extinct pine trees. Amber is particularly abundant along the shores of the Baltic Sea where it is mined extensively from Tertiary glauconite sands. Around 600 B.C., the Greek philosopher, Thales of Miletus, published articles of experiments with *amber*, which the Greeks called *elektron* or *electrum*. From this word our modern terms *electricity*, *electron*, and *electronics* are derived. (see notes last page regarding the amber pict.)

Louis Bloomfield, Professor of Physics at the University of Virginia is always asked by his new students why alternating current (AC) is more prevalent in present society and whether it is a better alternative to direct current (DC). Professor Bloomfield gives the answer in his book *The Physics of Everyday Life*: the genius of George Westinghouse and Nikola Telsa, in the late 1800's, was to realize that producing alternating current (AC) makes it possible to transfer power easily from one electric circuit to another with the help of an electromagnetic device better known as a transformer. When an alternating electric (AC) current passes through the primary wire coil or the windings of a transformer, a current is induced in the secondary coil of the transformer, producing power in the output terminals of the transformer. While no electric charges move between these two coils, electric power does move by the magnetic flux. A transformer cannot transfer power between two circuits if the circuits operate on direct current (DC) Thomas Edison tried to use direct current (DC) in his power delivery systems, and fought George Westinghouse and Nikola Telsa for years. To prove that alternating current (AC) was much more dangerous to the public than his direct current system, Edison, as a last ditch effort, invented the alternating current (AC) electric chair to prove his point. As we all now know, George Westinghouse and Nikola Telsa won out in the end.

Now…. On to Ohms Law:



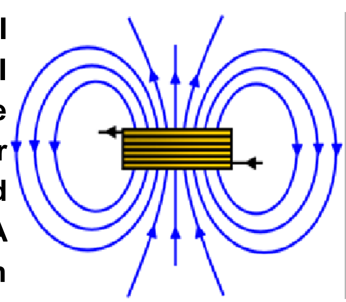
We will, in this section, primarily be concerned with volts, amperes, watts and ohms. The unit of electric potential, the volt (E) is named for Italian physicist Count Alessandro Giuseppe Antonio Anastasio Volta. As stated in the book *Electricity for Technicians*, voltage is the

electromotive force, which creates the electric pressure that causes the current to flow through a conductor. The volt is defined as that electromotive force necessary to cause one ampere of current to flow through a resistance of one ohm. Where the volt is too large a unit, you would use the millivolt (1/1000 of a volt) or the microvolt (1/1,000,000 of a volt). Where the volt is too small you would use kilovolt (1000 volts). To use the analogy of a water hose, voltage measures the pressure (energy) of the water in the hose. If voltage shocks you, why does current kill you? Your skin is an excellent electric insulator, preventing any current from passing through your body, as long as that current and voltage is very low. A higher voltage (the electric equivalent of pressure) is required to push charge through your skin. But once the charge is inside your body, it moves through your system quite easily. This movement is perpetuated because your body fluids are essentially salt solutions and is a relatively good conductor of electricity. However, a small current passing through your body won't cause injury. It takes about 0.010 amperes or 10 milliamperes to cause a life-threatening disturbance to your electric system.

Small currents associated with static electricity are not enough to cause trouble, even though they easily pass through your skin. So high voltages are needed to break through your protective barrier, the skin, in order to give you a shock, but large currents are needed to injure or kill you.

What is the relationship between electric fields, magnetic fields, and current?
1] Currents cause magnetic fields.
2] Currents that change with time cause magnetic fields that change with time.
3] Magnetic fields that change with time cause electric fields.
4] Electric fields cause currents to flow in an electrical conductor.

This is all done due to a phenomenon known as mutual inductance and magnetic flux. From these relationships, you will see that any time you have a changing current through one circuit, you can end up with a current flowing through another nearby circuit. Power moves from the first circuit to the second circuit with the help of a magnetic field and an electric field. A moving magnet also produces a magnetic field that changes with time, and can also send a current through a nearby circuit.



One of the more common circuits is parallel AC. This type of circuit is found in the home, where the loads behave primarily as resistors. Lamps, stove elements, toasters, and irons are examples of resistive loads. Fluorescent lamps, refrigerator motors and furnaces are

a combination of resistance and inductance. In industry, the load will most likely be inductive due to the large number of induction motors used.

Ampere (I) is the unit for *measuring* electric current force in a circuit. Formerly, the definition involved the force produced between parallel wires carrying a current; still earlier, the ampere was defined as a flow of one coulomb per second, where the coulomb, a quantity of electrical charge, was taken as the basic unit.

The ampere is named for French physicist and mathematician Andre Ampere, who laid the foundations for the science of electrodynamics. Andre proved, through demonstrations, that electric currents do produce magnetic fields. His two most notable achievements were his independent determination of Avogadro's law and his work on Oersted's discovery, announced in 1820, that a magnetic needle moves in the vicinity of an electric current. Andre demonstrated the direction of the magnetic field is determined by the direction of the current. Using the above demonstration as a guide, Andre eventually developed a quantitative relationship for the strength of a magnetic field in relation to an electric current (Ampere's theorem) and put forth a theory as to how iron becomes magnetized. Andre also devised a rule governing the mutual interaction of current carrying wires (Ampere's law) and produced a definition of the unit of measurement of current flow, now known as the ampere or the symbol (I). The variation of actual currents is enormous. A modern electrometer can detect currents as low as 1/100,000,000,000,000,000 amp, which is a mere 63 electrons per second. The current in

a nerve impulse is approximately 1/100,000 amp; a 100-watt light bulb at 120v carries 0.83 amperes, a lightning bolt peaks at about 20,000 amps and a 1,200-megawatt nuclear power plant can deliver 10,000,000 amps at 115-volt. There are some similarities in measuring water flow and electrical flow. For example, the flow of water can be measured by determining the amount of time it takes to fill a gallon bucket with water. Similarly, electrical flow can be measured by the amount of current that flows past a certain point in a certain amount of time. This rate of electrical current flow is the amperage (I).

This electric flow through a transformer, for example, is usually rated at its maximum kVA rating. This is the product of kilovolts (kV) times amperes (A), and is a measure of power. If you multiply the voltage in volts delivered to an electric heater by the current in amperes sent through that heater, you would obtain the electric power in watts consumed by the heater. Thus the heater's power consumption in watts is the same as the product of its voltage times its current, or its kVA. However, there are many devices that do not behave like an electric heater. An electric heater for example, is a purely resistive device, while many other products such as electric motors are both resistive and reactive. Reactive devices do not obey Ohm's law and may draw their peak currents at times of peak voltage. Therefore, the power in watts consumed by a reactive device is not the same as the product of its current times its voltage or its kVA.

When this current flows through a conductor, resistance in the circuit attempts to reduce current flow. In other words, the higher the resistance, the lower the current flow. The Ohm (R) is the measurement or unit of this electrical *resistance* in a circuit or conductor. The international ohm has been defined since 1893 as the resistance of a standard column of mercury.

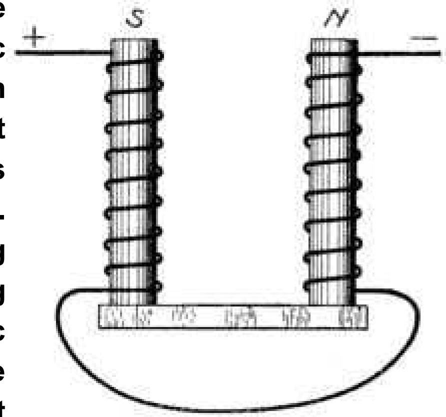
In 1827 a German teacher named Georg Simon Ohm demonstrated that current in a wire increases in a direct proportion to the voltage (V) and the cross-sectional areas of the wire (A), and in inverse proportion to the length (L). The same example of water in amperage equates to when water flow is decreased in a water hose by the friction, or resistance, created by the water hose material. Similarly, the composition of an electrical conductor creates resistance to the flow of electric current. If the length of a conductor is increased, resistance increases, which can result in less current flow. Increasing the diameter increases the capability of the conductor to carry current, because there is more area through which the current can flow.

Although a conductor permits the flow of charge, it is not without a cost in energy. Electrons are accelerated by the electric field. Before the electrons move far, however, they collide with one of the conductor atoms, slowing them down, or even reversing their direction. As a result, the electrons lose energy to the atoms. This energy appears as heat, and the scattering is a resistance to the current.

Since 1948, the standard has been the absolute ohm, defined in terms of the wave impedance of a vacuum. When a steady current of 1 ampere flowing through a conductor produces a potential difference of 1 volt, the resistance of the conductor is 1 ohm. The ohm is also the unit of reactance and impedance. Stated by Georg Simon Ohm in 1826, Ohm's law establishes the mathematical relationship between voltage (V), current (I), and resistance (R) as V = IR, for both alternating and direct currents (AC and DC).

As you will see in chapter 2, direct current (DC) cannot be converted with a standard AC transformer due to a lack of the magnetic induction between fields or windings. One way to produce a DC output voltage is to use a power supply.

The understanding of electricity has led to the invention of motors, generators, telephones, radio and television, X-ray devices, computers, and nuclear energy systems. Electricity is a definite necessity to our modern civilization. Can you make electricity with magnets? You can by moving a magnet past a wire. The magnetic field around the

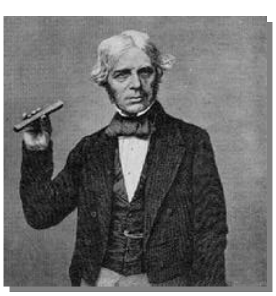


magnet exerts a force on the positive and negative magnetic poles. If you move the magnet and its magnetic field, you create an electric field, exerting a force on electrical charges. Whenever a magnetic field changes, it changes with time and will produce an electric field. This electric field will push on the mobile electrons in a wire. When you move a magnet past a wire, you are producing a changing magnetic field in the wire. This changing magnetic field produces an electric field, and the electric field causes the electrons in the wire to accelerate. The moving electrons are electricity. This is exactly what happens when a generator is used to produce power.

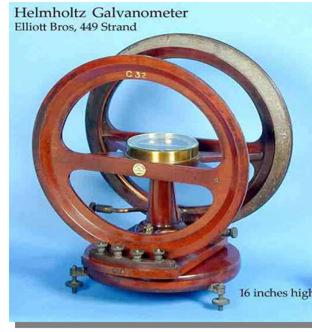
An electromagnet is a coil of wire, usually wound around an iron core, which produces magnetism as long as an electric current flows through the coil. Because electromagnets act like permanent magnets, they are used, as an example, to lift and load scrap iron. An electromagnet's magnetism, however, unlike a permanent magnet, can be turned on and off, making it useful in operating electrical devices with movable magnetic parts, such as generators, motors, brakes, clutches, relays, and solenoids.

In a solenoid, an iron core held away from the center of the coil is rapidly pulled into the center position when the coil is energized, completing the circuit. In the relay, the coil is wound on, and insulated from, a stationary core. When current flows through the coil, the core becomes magnetized, causing a hinged, soft-iron armature located near the electromagnet to be attracted to it. As the armature moves, it makes or breaks a separate electric circuit. Relays are used in such devices as circuit breakers, doorbells, regulators, and telephone receivers.

This magnetic field produces an electromagnetic induction from the field. Electromagnetic induction is the creation of an electric field by a time-varying magnetic field. The electric field may be produced, according to Faraday's law of induction, in two ways: by the motion of a conductor cutting across lines of magnetic flux of a magnetic field, or by a change in the magnetic flux passing through a coil immersed in a non-constant magnetic field.

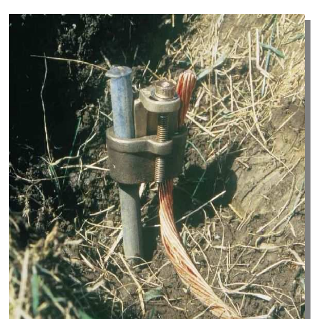


Michael Faraday (left) and Joseph Henry (right) both independently observed (1831) that when a magnet is moved through a closed coil of wire, a current is induced in that wire. The direction of current flow creates a magnetic field opposite in direction to the field produced by the magnet. Faraday then replaced



the magnet with an electromagnet. Two coils were wound closely together, the first being connected to a battery and the second to a galvanometer, which measures small currents. Faraday noticed deflections of the galvanometer needle when the connection between the first coil and the battery was made or broken. The currents induced at those two moments flowed in opposite directions. No current flowed in the second coil when a large steady current flowed in the first. The significant feature of the previous experiment, therefore, was the change in the magnetic field. What Faraday had done was to build the first transformer. The changing current in the first coil (the primary winding) set up a time-varying magnetic field that penetrated the second coil (the secondary winding) and set up an electromotive force in that coil, causing a current to flow. Transformers were not put into practical use until the introduction of alternating currents. The most important result of electromagnetic induction is the occurrence of electromagnetic radiation. A time-oscillatory magnetic field, traveling through a medium or empty space, gives rise to an oscillating electric field perpendicular to it. This field in turn gives rise, in accordance with Maxwell's equations, to an oscillating magnetic field whose direction and phase reinforce the original magnetic field. In this way, a self-perpetuating, traveling electromagnetic disturbance (wave) is set up.

WATTS: (P) The watt is the unit of *power* ordinarily employed in mechanics and electricity. One watt equals 1 joule per second, or 10 million ergs, and 746 watts equal 1 horsepower (h.p.). The power in watts developed in an electrical circuit is equal to the potential (volts) or (V) times the current (amperes) or (I). In heat measurement, which customarily uses calories and BTUs as energy units, 1 watt equals 0.239 calories per second or 3.4192 Btu/h. Multiplying a unit of power by a time unit, such as that done to obtain kilowatt hours (kWH), will furnish the units of energy. The following is an example, furnished by the Physics Professor of the University of Virginia of how a donut equates to wattage: The watt is the standard unit of power, and is the way we measure how much energy is being transferred to or from a device each second. 1 watt is equivalent to 1 joule of energy per second. A 100 watt light bulb consumes 100 joules of electric energy each second. Anytime energy moves from one place to another, you can determine how much power is following. For example, the food energy in a jelly donut is about 1 million joules, so if you eat 1 jelly donut in 100 seconds, you received 10,000 watts of power. Since your body only consumes about 100 watts of power while you are resting, it will take you 10,000 seconds (166.6 minutes or 2.78 hours) to use up all that food energy.



And finally, a system has to be grounded. Always remember that voltage flow will take the path of least resistance. What happens to an electrical device during a short circuit when installed without a ground? If you are holding the device, you become the path of least resistance. With a ground wire attached, overflow voltage is drained to the earth. The higher the voltage level, the more dangerous it is. The safest voltage is *zero voltage*. The earth, or ground, is considered to be at a zero voltage level. Anything that touches or connects with the earth will take on zero voltage level and is said to be *grounded*. The neutral wire entering a building at its service entrance and the neutral wires in all electrical circuits must always be at zero voltage. In a service entrance load center in your home for example, the incoming neutral wire is grounded by attaching it to the neutral bar, which is attached to the load center. The neutral wire accompanying each *hot* wire in each 120-volt circuit is also connected to the neutral bar. The neutral bar is connected to the ground through a wire extending from the neutral bar to a grounding rod or metal water pipe system buried in the ground. Connecting the neutral bar to the ground ensures the voltage of the neutral wires connected to the neutral bar will always be zero. This neutral conductor is not the ground wire, but utilizes the ground wire from the panel neutral to the ground rod.

Now that we are through with the preface, lets begin by looking at Ohms Law and how it applies to electricity, and electrical equipment. First we have to ask the question *Why do you need to understand Ohms Law* if all you are doing is selling or installing equipment? Three reasons – your customer, your company and your self. Without this understanding you will experience equipment failure, possible employee injury, and higher maintenance bills, besides understanding will make each day you have to work that much easier. Ohms Law involves every aspect of electrical supply, installation and purchasing. If you can't choose the correct equipment then everyone suffers.

The Ohm's Law wheel shown on the next page will simplify most electrical calculations. To calculate your formula, choose E, I, R or W and read the formula shown in the appropriate formula grouping. Understanding the differences between single and three phase circuits will allow you to decide whether it is more advantageous to pay the additional dollars for three phase equipment verses the difference in energy costs involved. Utilizing three phase circuits over single-phase circuits will allow you to install smaller conduit and cable and allow the reduction of fuse and/or breaker capacity. A reduction in size of equipment and current usage will reduce your power consumption, thereby reducing your company's operating and production costs.

A relationship exists between amperage and voltage for a given amount of electrical power being transmitted. If power is transmitted at low voltage, its amperage is high, if it

is transmitted at a higher voltage, then its amperage is lower. The higher the transmission at a higher voltage, used for an amount of power, the lower its amperage will be. This relationship is called the *power formula*: P = I x E Power = amperage times voltage.

The size of a wire used as an electrical conductor is determined by the amount of amperage that will flow through it. For a given amount of power, the lower the amperage, the smaller the conductor.

VOLTS (E) = Electromotive force.

AMPS (I) = Current.

OHMS (R) = Resistance to current flow.

WATTS (W) = Power consumed and/or used by the application.

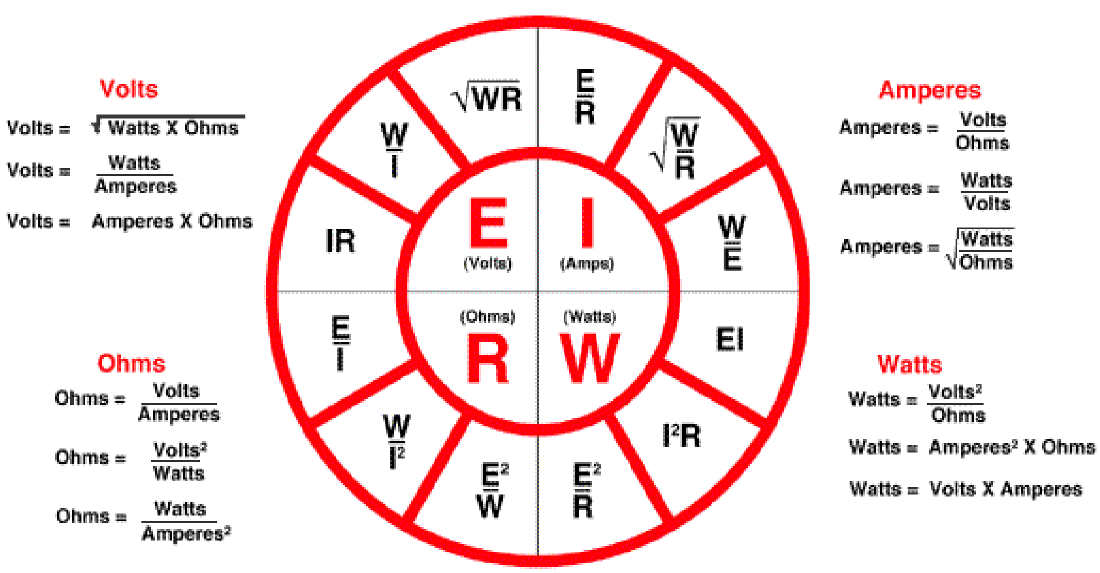
IR = Voltage drop.

kV = 1,000 volts. (Kilovolt)

kW = 1,000 watts. (Kilowatt).

kVA = 1,000 voltamps. (Kilovoltamp)

1.73 = the square root of 3 is used when figuring three phase circuits.



VOLTS (E)

Amps (I) x Ohms (R) = Volts
Amps (I) divided into Watts (W) = Volts

AMPS (I)

Ohms (R) divided into Volts (E) = Amps
Volts (E) divided into Watts (W) = amps

OHMS (R)

Amps (I) divided into Volts (E) = Ohms
Amps squared (I) divided into watts = Ohms
Watts (W) divided into Volts (E) Squared = Ohms

WATTS (W)

Ohms (R) divided into Volts (E) squared = Watts
Volts (E) x Amps (I) = Watts
Amps (I) squared x ohms (R) = Watts

The above listing of Ohms Law is for use with single-phase circuits only. To obtain three phase results, you would need to utilize the square root or 1.73 as shown later.

The Ohms law wheel above shows twelve different formulas for four different factors. Some of which you probably won't ever use.. Everyday use of Ohms law probably will only involve three....watts (W), amps (I), and volts (E). For one of our in-house training classes we were trying to figure a way to help everyone remember Omhs Law for everyday use. If you can remember the phrase "Who's Al Volta" you have the problem solved. (Volts was named after Alessandro Giuseppe Antonio Anastasio Volta.)

To fin **V. To**

International technology continues to make inroads into the American market and understanding the kilowatt will take on more importance than ever. As you know, all U.S. manufactured motors normally have a nameplate indicating the voltage rating, the full load currents in amperes, and the insulation class of the motor. Sizing a cable system utilizing kW instead of full load amperes could present few problems in sizing your load. Most or all imported IEC controls and motors are usually rated according to IEC specifications. This changes the ampere rating on the motor nameplate to kW. Visualize how you would order and install the necessary cables for an 18.5 kW 3-phase 480-volt motor if you could not determine the correct full load amperes. Any ampere chart or motor slide rule will give you the proper cable sizes to use IF you know the motor horsepower, but will not convert kW to horsepower. In the spring of 1998, Square D came out with an IEC Motor Slide Rule to help in sizing your IEC product. However, if the product you are using is not Square D, you will still have the same problem. The following formulas will be useful in helping you to arrive at the amperes of the motor. Bear in mind, however, all motors will vary in amperes due to bearing losses, age, and / or manufacturer. The figures obtained from this formula will provide you with the amperes for the kW indicated on the nameplate. Using, as an example, the 18.5 kW motor discussed above, we need to calculate the ampere rating for the three phase applications. The constant of 0.746 shown in the formula is the kW rating of a 1 horsepower motor.

THREE PHASE kW TO HORSEPOWER

First you have to figure the amperes of your kW load.

$$\frac{\text{Kilowatts} \times 1{,}000}{\text{Volts} \times 1.73} = \text{Amperes}$$

$$\frac{18.5\text{ kW} \times 1{,}000}{480\text{-volt} \times 1.73} = \frac{= 18{,}500}{= \ 830.4} \ 22.27\text{ amperes}$$

Then use the 22.27 amperes to calculate the H.P. rating of your motor.

$$\frac{\text{Volts} \times \text{Amperes} \times 1.73}{746} = \text{Horsepower}$$

$$\frac{480\text{-volt} \times 22.27 \times 1.73 = 18{,}493}{746} \quad \frac{}{746} = 24.8 \text{ Horsepower}$$

1kW = 1.34 horsepower
1 hp = 0.746 kW

To find any single-phase answer from the above calculation, just remove the 1.73 from your equation.

The following will show examples of some of the above formulas to indicate their proper usage.

FINDING THE AMPS OF A 5kW UNIT HEATER @ 480-VOLT SINGLE PHASE

$$\frac{\text{Watts (W)} \quad 5{,}000 \text{ watts (5kW)}}{\text{Volts (E)} \quad 480\text{-volts (E)}} = 10.42 \text{ amperes}$$

To illustrate the differences between single phase and three phase for the above application, we will figure the amp requirement based on three phase. Remember that three phase circuits vary directly and the square root of three must be used to obtain the proper amperes. The same heater in three phase would yield the following results.

$$\frac{\text{Watts (W)} \quad 5{,}000 \text{ watts (5kW)}}{\text{Volts (E)} \times 1.73 \quad 480\text{-volts (E)} \times 1.73} \quad \frac{5{,}000}{830.4} \quad 6.02 \text{ amperes}$$

How do we know the previous two figures are correct? As shown above, *volts x amps* will equal the *watts* of the unit.

SINGLE PHASE

480-volts (E) x 10.42 Amperes (I) = 5,001.6 Watts

THREE PHASE

480-volts (E) x 1.73 x 6.02 Amperes (I) = 4,999 watts.

As the example on the previous page illustrates, if you used a three phase unit over a single phase you would save 4.4 amperes per unit resulting in a per unit power savings of 58%. The problem of not understanding phasing is the possibility of equipment purchase errors and production down time.

AMPERE RATING FROM A GENERATOR

How many amperes will a 2 kVA, 115-volt single phase generator deliver at full load?

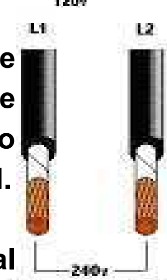
$$\frac{2 \times 1000}{115\text{-volt}} = \frac{2{,}000}{115\text{-volt}} = 17.4 \text{ amperes}$$

What are the amps if the generator changes to 240-volt three phase?

$$\frac{2 \times 1000}{240\text{-volt} \times 1.73} = \frac{2{,}000}{415.2} = 4.82 \text{ amperes}$$

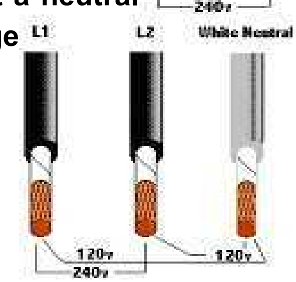
Before we proceed any further, we need to examine the different types of standard phasing. In the first example, you are shown a 120-volt single-phase circuit used for normal 120-volt loads. The black L1 feeder cable is attached to the single pole breaker, feeding power to the load, and returns through the white conductor to the neutral bar mounted inside the panel.

This graphic shows a 240-volt single phase circuit being fed from a 2 pole circuit breaker without a neutral conductor. Without the white neutral conductor attached to the neutral bar, you are unable to obtain 120-volt from this circuit. Usage could be for a single phase bar heater, baseboard heater, water heater, or a 240-volt single phase motor.



This is the same as the previous, with the white neutral feeding back to the neutral bar. With this arrangement, you are able to use L1 and L2 in the same manner as the 240-volt single-phase circuit shown above, and still able to obtain 120-volt between L1 and the white neutral, or L2 and the white neutral.

All three-phase Delta circuits consist of three power feeds without a neutral conductor. On a three phase 3 wire 240-volt system, voltage between the above wires would be:



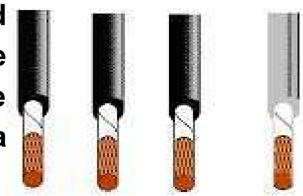
(1) and (2) = 240-volt
(1) and (3) = 240-volt

(2) and (3) = 240-volt

(1) (2) (3)

A Wye circuit consists of three power feeds, L1, L2, L3, and a solid neutral conductor feeding back to the solid neutral bar in the panel. A Wye circuit will become a Delta circuit when all three black conductors are connected to a motor or heat load <u>without</u> a neutral.

208-volt Wye / 120-volt system



(1) (2) (3) (4)

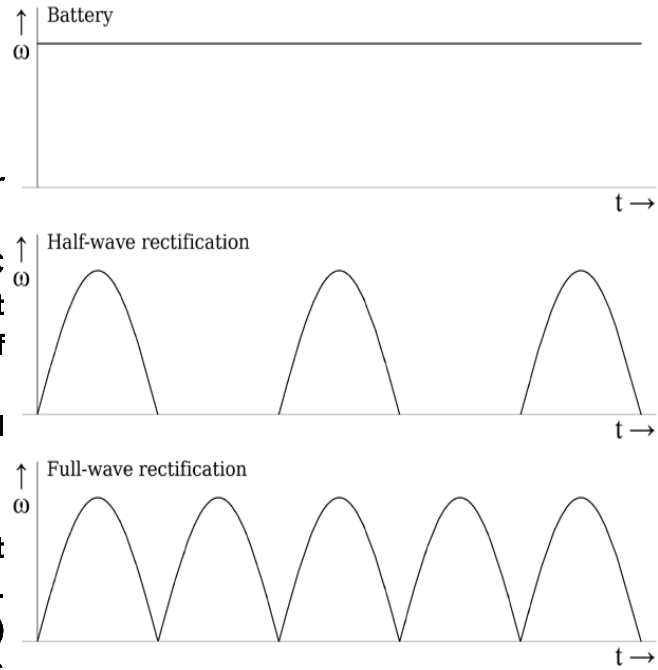
(1) and (4) = 120-volt
(2) and (4) = 120-volt
(3) and (4) = 120-volt
(1) and (2) = 208-volt
(2) and (3) = 208-volt
(1) and (3) = 208-volt

- **120/240-volt systems are most commonly used in residential applications. 120-volt is available between phase and neutral. 240-volts is available phase-to-phase.**
- **240-volt delta system: This is used in light industrial applications and motor loads. This is a 3 phase 3 wire system which provides 240-volts phase-to-phase. The NEC requires most of these systems to be grounded, hence the name “Grounded B phase”.**
- **240/120-volt delta system. This is most commonly referred to as a “Wild Leg” system. (3 phase 4 wire) 240-volts is available between phases and 120-volts is available between two of the phases plus the neutral which grounded (usually the A and C phases). It should be noted that between the B phase and ground 208 volts is available.**
- **208Y/120-volt Wye system are common for commercial applications. By using this 3 phase 4 wire system you will have 120-volts available for lighting and receptacle loads which is available between any phase and neutral; and 208-volts for motors and heating loads available phase to phase.**
- **480-volt Delta system is very common system in large industrial applications. This 3 phase 3 wire system is usually installed ungrounded. Electrical equipment installed on this system must be rated 480-volt phase to ground as well as phase to phase.**
- **480Y/277-volt Wye system is the most common system in large commercial and industrial applications. By using this 3 phase 4 wire system, 277-volts for lighting loads is available between any phase and neutral and 480-volts for motors and heating loads is available phase-to-phase.**

DIRECT CURRENT (DC)

We won't go into a deep examination of DC current however, it does need to be reviewed by asking three questions:

- How does DC or direct current differ from AC or alternating current?
- Does Ohms law used for AC applications apply to DC or does it utilize a completely separate of mathematical equations?
- Can DC voltage be created or changed using a transformer?

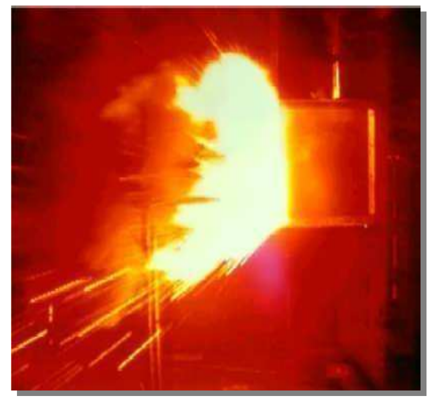


DC current differs from AC because it does not produce a variable sine wave. There is a constant flow of voltage (DC) from high to low potential. This is typically in a conductor such as a wire, but can also be through semiconductors, insulators, or even through a vacuum as in electron or ion beams. In direct current, the electric charges flow in the same direction, distinguishing it from alternating current. A term formerly used for direct current was Galvanic current. As we read in the first part of this chapter, the first commercial electric power transmission (developed by Thomas Edison in the late nineteenth century) used direct current. Because alternating current is more convenient than direct current for electric power distribution and transmission, nearly all electric power transmission uses alternating current. Direct current can exists in many forms for example the battery (both wet and dry), and DC power supplies which create DC from an AC input being the most common.

Electric current is electrons in motion, and when the electrons flow in one direction only, the current is called DC or direct current. The same is true for AC except the electrons follow an alternating sequence. Regardless the type of current, AC or DC, you are measuring electrons in motion. Ohms Law formulas are used interchangeably in calculations for AC and DC circuits. As you will learn later in Chapter 2, transformers use the magnetic flux produced by the alternating current to produce or actually induce a voltage in a secondary windings of the transformer. This magnetic flux cannot be produced by a DC source therefore, transformers cannot produce a DC current. DC current can be rectified to produce a fake AC output known as half-wave or full-wave rectification. Otherwise, the output of a DC circuit is graphically shown as a straight line.

FAULT CURRENTS

This section will explain the differences and relationships of overloads, short circuits, and fault currents. We will also explore how to figure the impedance of a fault, examine overload and short circuit protection of fuses, breakers, and thermal overload relays.



Fault currents and short circuits are primarily the same thing. Short circuits can occur by human error, a wrench dropped across two wires, hooking up conductors incorrectly, etc., and are normally momentary. Fault currents caused by mechanical failure are excessive currents produced by an electrical device during a short circuit. Mechanical faults are usually worse, due to the short not correcting itself, and continuing to produce excessive currents until the device eventually burns up.

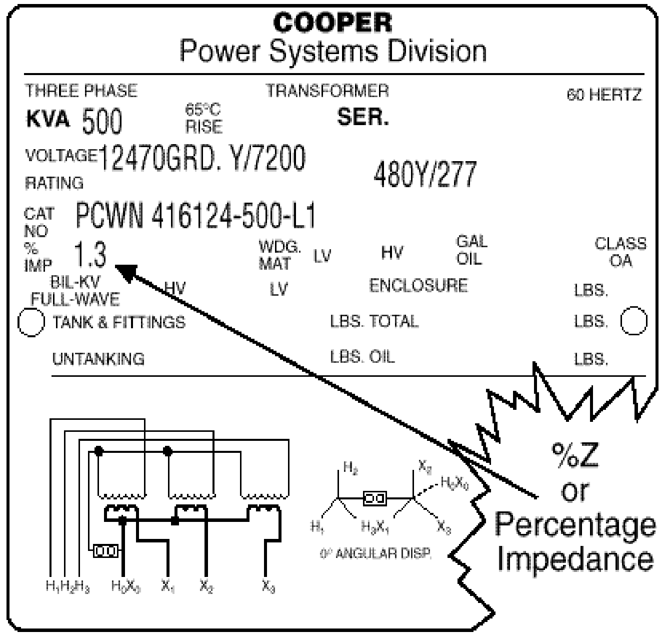
Where do short circuits come from, and where should we look for possible fault currents? Some would check the spot where sparks fly, and assume this is the only part of the electrical system involved in a short circuit fault. Normally the fault does not originate at the point of arcing, but is poured into the fault from other sources. The amount of short circuit current delivered by a transformer is dependent upon the following factors:

A) The primary source (available kVA).
B) The secondary voltage.
C) The size of the transformer.
D) The impedance of the transformer.

The largest possible primary source is called an "infinite bus". A 500 mVA primary source is generally considered the largest encountered in any practical system. (1 mVA = 1,000 kVA = 1,000,000 VA). Any source greater than 500 mVA is considered "unlimited".

Any method for determining secondary short circuit currents of transformers should include a range of available primary mVA.

Impedance is the opposition that a short circuit current encounters in passing through a transformer. Since it represents an opposition to the flow of current, it has the same unit of measurement as resistance, the ohm, and is represented by the symbol Z. It normally only occurs in AC circuits. Since the current is changing constantly, so is the magnetic field. This changing magnetic field, constantly cutting across the turns of a coil, induces in it an electromotive force. From Lenz's law, we know this force acts in a direction counter to the force that set the original current flowing through the coil. This is a counter force opposing the flow of the original current. Alternating current flowing through such a circuit encounters the opposition of both the resistance and the induced counter of electromotive force. Impedance is usually expressed in per-unit or percent of the rated voltage of the winding in which the voltage is measured.



You will remember we previously discussed the relationship between current (I), voltage (E) and resistance (R) expressed in the following equations:

$$I = \frac{E}{R} \qquad E = I \times R \qquad \text{and } R = \frac{E}{I}$$

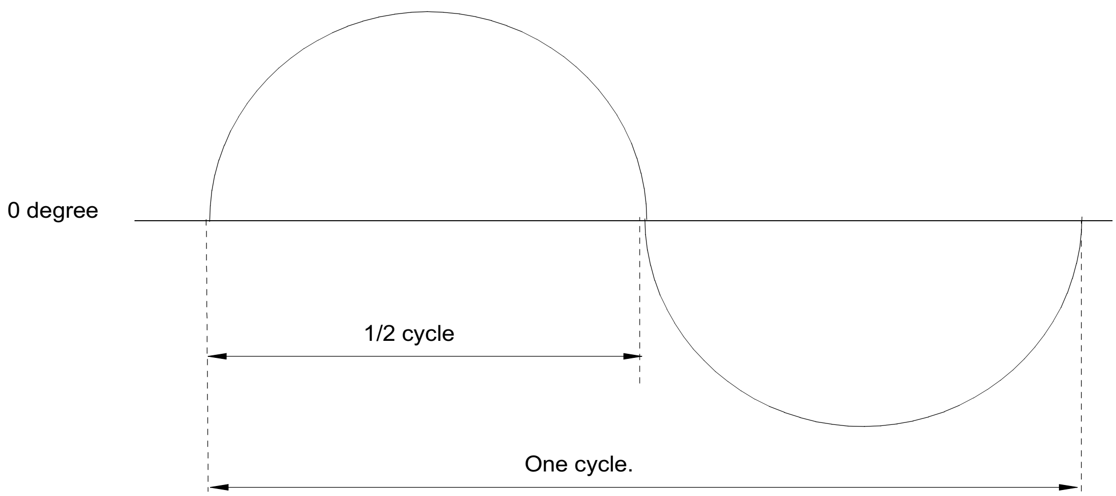
If we now substitute impedance (Z) for resistance (R), our Ohm's law equations apply equally well:

$$I = \frac{E}{Z} \qquad E = I \times Z \qquad \text{and } Z = \frac{E}{I}$$

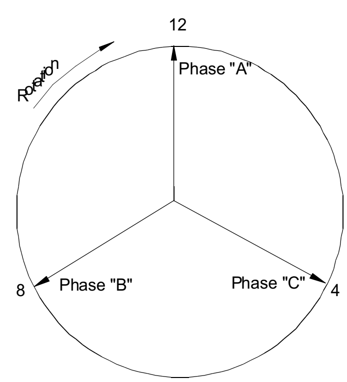
Impedance varies with the many types and design of transformers. The only way to be absolutely certain of the exact impedance is to check the nameplate on the transformer. Impedance for three phase transformers having ratings of 500 kVA and less varies from 1.6% to 4.5%. Larger transformers are approximately 5-½ % impedance. For transformers of the same rating, the one with the lowest impedance will put out the highest short circuit current.

Fault currents in an induction motor cannot be ignored in any short circuit study. The short circuit current produced by induction motors will vary widely from motor to motor. On a new installation, thermal overload units are chosen according to the nameplate rating and fault currents are figured accordingly for the incoming feeders and distribution equipment. Over the years, as motors are removed, repaired, changed, or added in any large installation, their fault current capacities will change dramatically. An approximate value for the instantaneous short circuit current from a motor at an instant ½ cycle after the short circuit occurs is 3.6 times the full load current. It does not vary appreciably whether the motor is lightly loaded or fully loaded when the fault occurs.

<u>Cycles per second: 1 Phase</u>

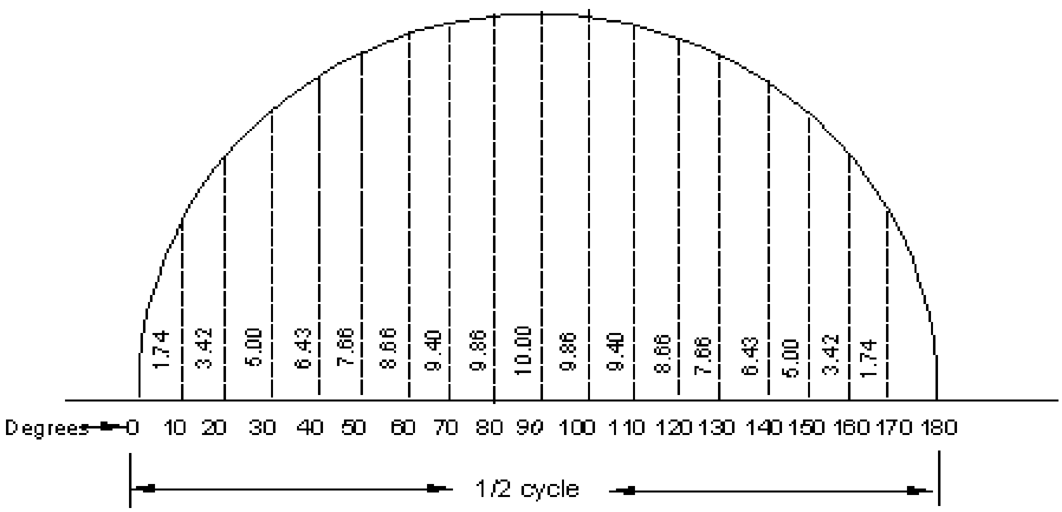


Alternating current alternates or changes state continuously, from 0 degree on high to 0 degree on low. 60 cycle AC currents change direction 60 times per second and one cycle = 1/60 second (0.0167 seconds). A three phase current cycle may be pictured as a clock with three hands with *Phase A* starting at 12, *Phase C* starting at 4 and *Phase B* starting at 8. Each of the phases produces its own sine wave 120 degrees apart.



There are four different factors to current, the first being the *effective* current. Alternating current varies continuously from 0 degree to a maximum at 90-degree back to low of 0 at 180 degree and then reverses itself on the low side of the sine wave. Stating a current is X does not necessarily state the accurate current values. Effective current is where 1 ampere of alternating current does the same work as 1 ampere of direct current.

Current at any point on a sine wave is called the *instantaneous current.* Current at the top of the wave is called *peak or crest current.* *RMS current* means *root mean square* and is the average of all the instantaneous currents squared. The following *half* of a single cycle, having a 10 ampere maximum or peak value will illustrate RMS currents. You can see in the example, at 90 degrees, the ampere load is 10 amps. Each degree of the drawing indicates the *instantaneous* amperes at each degree of angle in 10-degree increments. The second half of the sine wave would be exactly the same and the total combined ampere of the full cycle would be 20 amperes. The *combined* total is one full cycle. The value of instantaneous currents can be easily measured. The average instantaneous currents are found by dividing the totals by 18.



DEGREES ½ CYCLE	INSTANTANEOUS AMPERES	INSTANTANEOUS AMPERES SQUARED
0	0	0
10	1.74	3.03
20	3.42	11.79
30	5.00	25.00
40	6.43	41.35
50	7.66	58.67
60	8.66	75.00
70	9.40	88.36
80	9.86	97.22
90	10.00	100.00
100	9.86	97.22
110	9.40	88.36
120	8.66	75.00
130	7.66	58.67
140	6.43	41.35
150	5.00	25.00
160	3.42	11.79
170	1.74	3.03
180	0	0
AVERAGE CURRENTS	6.36 AMPERES	50.0 AMPERES

The magnitude and symmetry of the current wave on a short circuit depends on the point on the wave at which the short occurs. In real life, faults can occur at any and every point on the voltage sine wave. In laboratory tests it is possible to pick the point on the voltage wave where the fault occurs by closing the circuit at any desired angle on the voltage wave. We can pick the closing angle to produce the current conditions we desire. This is called *controlled closing*. Fuse manufacturers use controlled closing to design different classes of fuses. For instance, rectifier fuses require a considerably faster clearing time than a standard fuse.

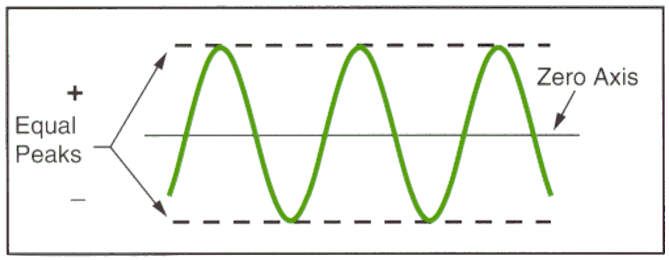


Figure 8
Symmetrical Current

Random closing* faults may occur at any point on the voltage wave and laboratory duplications can be made by closing the circuit at random. The following is true of a short circuit having negligible resistance: If the fault occurs at zero voltage on the sine wave, the current wave is fully asymmetrical, thus a maximum value of short circuit current is obtained. If the fault occurs at maximum voltage the current wave is completely symmetrical, and a minimum value of short circuit current is obtained. Most neutral faults occur somewhere between these two extremes, in other words, random *closing.

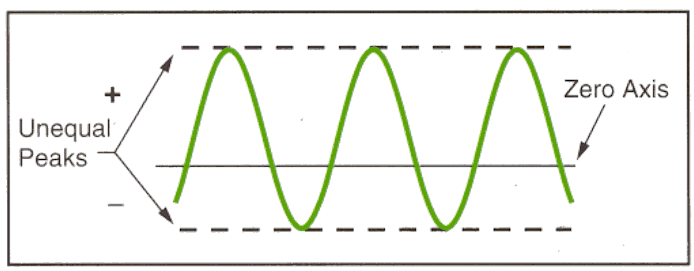


Figure 7
Asymmetrical Current

Polarity in an AC system is constantly changing every 1/60th of a second. The electrons are actually moving forward and backward in the cable and their speed is graphically represented by the height of the sine wave. Symmetrical and asymmetrical current describes the AC sine wave's symmetry or relationship around the zero axis. When the peak currents above (positive) and below (negative) (see Figure 8) the zero axis of the sine wave are equal in value, the current of the AC sine wave is symmetrical. If the peak currents are not equal (see Figure 7), the current is asymmetrical. The change in power factor and the point in the voltage wave determine the degree of asymmetry during a fault when the fault occurs. Generally, a lower short-circuit power factor increases the degree of asymmetry or change above zero axis.

Power factor, when used in over current protection calculations, is the relationship between the inductive reactance and the resistance in the system during a fault. Under normal conditions, a system may be operating at a 0.85% power factor. When a fault

occurs, much of the system resistance is shorted out and the power factor may drop to 25% of less. This may cause the current to become asymmetrical. UL fuse testing of circuits with interrupting ratings exceeding 10,000 amperes are required to have a power factor of 20% or less. Since the power factor of test circuits tends to vary during testing procedures, actual test circuits are usually set to 15% power factor. Short circuit currents normally assume an asymmetrical characteristic during the first few cycles of duration. The first half of the first wave is almost at zero at the end of the 180-degree of the first cycle. It then decays to zero after a few cycles due to I^2R losses in the system, at which the short circuit current is symmetrical about the zero axis.

For current limiting devices such as fuses, the current limiting range begins at the lowest value of RMS symmetrical current at which the device becomes current limiting and extends to the maximum interrupting capacity of the device. (See Figure 3). Current limiting fuses have time current characteristics to determine how fast a fuse acts to over currents.

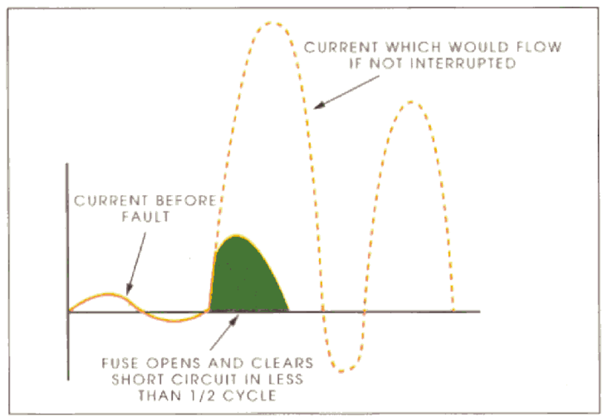


Figure 3

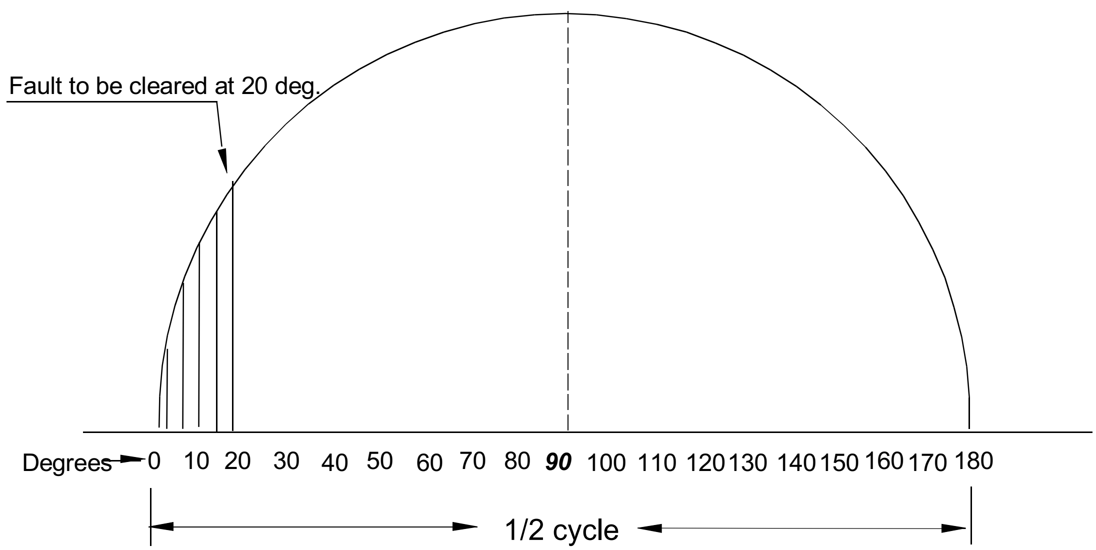
Time current characteristics are inverse time, where the opening time of a fuse *decreases* as the amperes *increase*. When a fault current surpasses the fuses threshold current, it must open the circuit in less than 180 electrical degrees or ½ cycle after the start of the fault. Low voltage fuse interrupting rating are based on RMS symmetrical at a specific power factor. Fuses are designed to interrupt any asymmetrical current associated with its rating.

If the fault occurred at zero axis on an existing asymmetrical or distorted sine wave, it would allow the fault to produce a maximum short circuit current. Poor power factor in the system would look like Figure 7, having the sine wave above its zero axis. This additional current will increase proportionally if the circuit has poor power factor. The greater the sine wave change, the greater the amperes due to additional time available to reach the first 180 degree of the first half cycle. So the lower the power factor, the greater the change above zero axis and the greater the increase in fault currents.

If the short circuit occurred where the sine wave was perfectly symmetrical, the peak fault current would occur during the first 1/2 cycle and continue to degrade until it is almost perfectly symmetrical at the end of the forth cycle.

Current limitations: The significant reduction of available short circuit current, in a circuit, by use of a device that prevents this short circuit

current from reaching its maximum value, called current limitation. Fuses that perform this function are known as current limiting fuses. Current limiting fuses operate in less than ½ cycle, interrupting the short circuit current before it can achieve its maximum value. On normal electrical equipment, the fault should be halted at 20 degrees or less of the first ½ cycle. The longer the time span between the fault and the fault clearing, the more current let-through and the greater the damage to equipment and personnel.



The fault cleared at 20 degrees, as shown above, indicating current and time variation when a current limiting fuse or breaker interrupts a high fault current. The current starts to rise but the fuse element melts or the thermal sensor in the breaker trips before the available current can get through. The current drops to zero in the time between 0 and 20 degrees. The peak of the 20 degrees shows the peak current that the fuse lets through. This current is expressed in RMS amperes.

How does all of this relate to everyday life? Lets examine the differences between an overload of a 150 horsepower, 3-phase 480-volt motor and a fault in a 150-kVA 3-phase 480-volt transformer.

480-volt 3 phase	150 horsepower motor	150 kVA transformer
Amperes / capacity	180 amps	180 amps
BTU Hour	511,950	511,950
kW	150	150
Fault Current Available		16,759

As you can see, usage of amperes, BTU hours and kW are the same for both the motor and transformer. The drawing example on page 22 shows that as long as the motor does not reach a continuous overload condition for more than 20 seconds, the motor will continue to operate. When a motor senses the overload condition (not a fault) for 20 seconds, a trip occurs.

Clarification needs to be made in relation to the 20 seconds. The thermal unit, as mentioned, is designed to trip in an overload condition of 20 continuous seconds. The *designed* ampere temperature times the 20 seconds trip range of the thermal unit can change however, and produce a shorter trip range. This will happen if the resulting totaled required ampere temperature is reached in a shorter time span.

This 20 seconds equates to 1,200 full cycles or 2,400, ½ cycles of voltage. A fault in a transformer is considerably different in amperes and time. Accepted practice is to use the current available ½ cycle after the short circuit starts. For a fully offset wave, maximum current does occur at the end of the first half cycle of time. Because this is the worst case, we need to determine peak and RMS currents at this point.

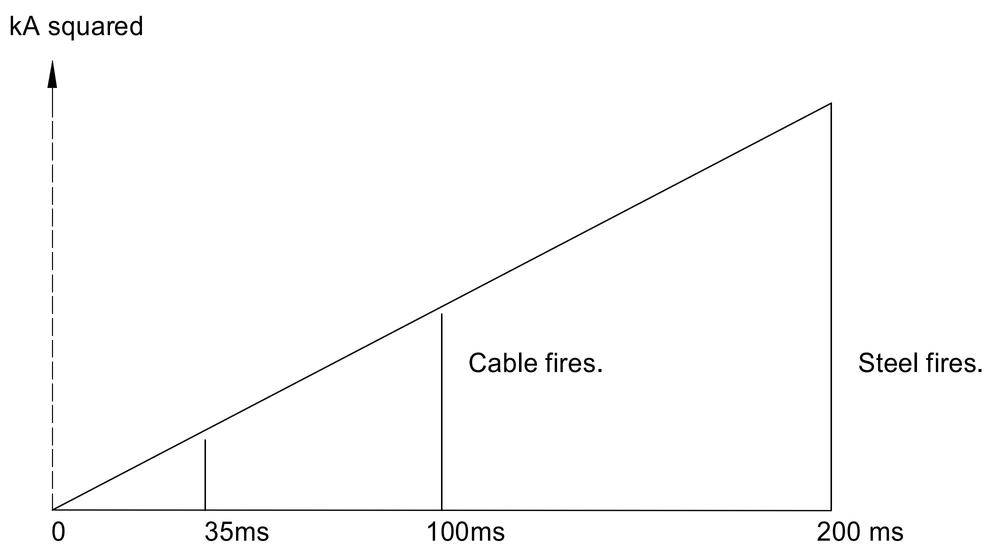
The rate of decay in ampere faults of 600 volts or less is that the proper ½ cycle value for the RMS asymmetrical current is 1.4 times the RMS symmetrical currents, and the peak instantaneous current is 1.7 times the RMS asymmetrical current. 1.7 x 1.4 equals 2.4 RMS symmetrical currents will be produced in the first half cycle current. Peak fault current is reached in the first ½ cycle. Optimum protection would be to stop the fault current before the peak is reached. 20 degrees for standard circuits is the normal. Discounting the many variables available in an installation, the average fault current, as indicated on page 19, is 16,759 amperes. This fault is reached in a ½ cycle. Compare this with an overload where the overload condition is reached in 2,400 cycles. A ½ cycle is reached in 0.00835 seconds.

To interrupt the fault within the 20 degrees as indicated, you would have to accomplish this in 0.002783333333333 seconds. As you can see, closing a switch on a fault will leave no time to react. How does this equate to damage to equipment and personnel? The following will illustrate mechanical force and thermal energy in a fault. You will see I^2 and I^2T listed in fuse and breaker catalogs, their definitions given below.

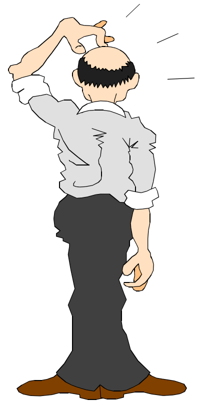
I^2 is a measure of the mechanical force caused by peak current (LP). This is the electro-magnetic force, which mechanically damages bus structures, cable supports and equipment enclosures. Ampere bus bracing in electrical equipment is the capability of equipment to withstand a certain ampacity fault stress. Specifications for projects may list bus-bracing requirements, as an example, as 15

kAIR (AIC). Insulators and bus supports will withstand a fault up to 15,000 amperes without damage. Example; a motor control center with a spacing of 2 ½ inches between bus bars, receiving a 16,000 amp fault, would receive a peak wave of 15 tons + of force *per foot of bus* for *each phase*. Needless to say, if this happened and the fault was not cleared in time, the bus bars would be destroyed, and human life could be lost. The longer it takes for the fault to start to degrade in power, the worse the damage incurred. At 35 milliseconds of the beginning of the fault, bus bars and steel starts to spark and melt, at 500 milliseconds the peak of the fault at the ½ cycle is reached, exploding and disintegrating all equipment.

I^2T is a measure of the heating effect or thermal energy of a fault current and uses RMS amperes instead of peak amperes used for mechanical forces. Copper bus bars (bare) melt at 1,981 degree F and iron melts at 2,795 degree F. The heating effect from the 16,759 amperes of fault current amperes listed in the previous chart would be an instantaneous 13,916,673.6 watts. You can see by the following chart, copper cables begin to melt at 100 milliseconds and the iron/steel enclosure burns at 200 milliseconds.



The picture of the controlled ABB fault at the beginning of this section shows an example of a controlled fault created in the laboratory by the ABB Control Corporation. As shown in the small photograph at the bottom left, at 35 milliseconds the switch is arcing and starting to melt and at 500 millisecond, this small switch was completely destroyed. The enclosure was no larger than a standard 40-circuit load center.



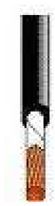
What causes voltage drop? The Grolier Encyclopedia gives the meaning of resistance in an electrical circuit as: *electrical resistance being a property of an electrical circuit that opposes the flow of current.* Resistance is analogous to friction in hydraulic or mechanical systems and causes energy dissipation in the form of heat. A physical device displaying these properties is called a resistor. Heat generated by the resistance of the circuit is the cause and effect requiring de-rating of the ampere ratings of cables in a system. The more resistance in a circuit, the more opposition to current flow in that circuit. This electrical resistance, caused by the collisions of electrons in motion, is responsible for converting electrical energy into some other form, such as heat or light.

The bottom line question is why is voltage drop important and if it is so important, why do more people not utilize it in electrical design? Voltage drop calculations are a necessary evil when figuring installation of equipment. Under voltage conditions affect the life of equipment, increase utility bills due to increased amperes and the potential for harm to people. The NEC states that voltage drop shall be no more than 3% for lighting loads or feeders for power and heating loads. Combined lighting heating and power loads shall be no more than 5% for feeder and branch circuits.

Low voltage, as a result of voltage drop can create and promote cable failure, motor damage, When alternating currents flow through a conductor, an inductive effect occurs, tending to force the current to the surface of the conductor, a process better known as the *skin effect.* This produces a voltage loss, and also affects the current carrying capacity of the conductor. For open wires, or wires in nonmetallic sheathed cable, this effect is neglected until the size 1/0 is reached. In metallic sheathed cables and metallic raceways, the skin effect is neglected until size 2 is reached.

The circular mil is the unit of cross section used in the American Wire Gauge (AWG). The term mil means one thousandth of an inch (0.001 inch). A circular mil is the area of a circular wire with a diameter of 1 mil (0.001 inch). The circular mil area of any solid cylindrical wire is equal to its diameter expressed in mils, written CM or circular mil. A wire having a diameter of 3/8 inch (0.375) equals 375 X 375 (or 375 squared) = 140,625 CM. The diameter in mils of a solid circular wire is equal to the square root of its circular mil area. Assuming that a conductor has an area of 500,000 CM, its diameter in mils is the square root of 500,000, which is equal to 707 mils or 0.707 inches.

The mil foot is a unit of a circular conductor that is one foot in length and one mil in diameter. The resistance of such a unit of copper has been found experimentally to be 10.4 ohms at 20 degree C. A mil foot of copper at 20 degree C offers 10.4 ohms resistance; 11.2 ohms at 30 degree C, 11.6 at 40 degree C, 11.8 at 50 degree C 12.3 at 60 degree C and 12.3 at 70 degree C. In all voltage drop calculations, 12 is generally used as the constant "K" unless otherwise specified. The number 12 allows some additional factors for safety.



The resistance of a wire is directly proportional to its length and inversely proportional to its cross sectional area. Therefore, if the resistance given in ohms of a mil foot of wire is multiplied by the total length in feet and divided by its cross sectional area in circular mils, the result will be the total resistance of the wire in ohms. Remember there are usually always two wires; so if the distance is given in feet, multiply it by 2 to get the total resistance of both wires.

The following formulas will give an average voltage drop for copper and aluminum circuits. There are four (4) primary and three (3) sub-categories we must consider in order to figure voltage drop for any application.

D = Cross section area (circular mils) of the conductor.

I = Current (amperes) in the conductor.

K = Resistivity of the conductor.

(a) K = 11 is the constant for circuits loaded less than 50% of the allowable carrying capacities of the copper conductor.
(b) K = 12 is the constant for circuits loaded more than 50% of the allowable carrying capacities of the copper conductor.
(c) K = 20 for all aluminum conductors. (60 degree C). Some suggest the use of 18 as a standard K factor for aluminum. The factor of 18 would equate to 30 degree C for the cable installation or 86 degree F. However, the K factor of 20 will always provide a safety factor.

L = Length of the circuit one-way in feet

R = resistance per foot of conductor (ohms / foot)

V = Drop in circuit voltage.

The voltage drop between one outside conductor and the neutral equals ½ of the drop calculated by the formula for two wire circuits. This is for lighting loads. Motor leads voltage drop between any two outside conductors equals 0.866 times the drop determined by the formula for two wire circuits.

Table 1

Two wire single phase circuits.	$V = \frac{2 \times K \times L \times I}{D}$
Three wire single phase circuits.	$V = \frac{2 \times K \times L \times I}{D}$
Three phase three wire circuits.	$V = \frac{2 \times K \times L \times I}{D} \times 0.866$
Three phase four wire balanced circuits.	$V = \frac{2 \times K \times L \times I}{D} \times \frac{1}{2}$

Note: Whether the cable is stranded or solid, the circular mils (CM) are the same.

Table 2

SIZE / AWG	CIRCULAR MILS	SIZE / AWG	CIRCULAR MILS
18	1620	250MCM	250000
16	2580	300MCM	300000
14	4110	350MCM	350000
12	6530	400MCM	400000
10	10380	500MCM	500000
8	16510	600MCM	600000
6	26240	700MCM	700000
4	41740	750MCM	750000
3	52620	800MCM	800000
2	66360	900MCM	900000
1	83690	1000MCM	1000000
1/0	105600	1250MCM	1250000
2/0	133100	1500MCM	1500000
3/0	167800	1750MCM	1750000
4/0	211600	2000MCM	2000000

Lets examine the various voltage drops and percentages for a 10 horsepower motor for a new pump located 276 feet from the power source using three different voltages; 230-volt single phase, 230-volt three phase and 480-volt three phase. The cable will be copper and sized for the largest load in the examples below.

	230-volt Single Phase	230-volt Three Phase	480-volt Three Phase
Full Load Amperes	50	28	14

230-volt single phase (using #6 copper cable rated at 55 amps)

$$\frac{2 \times 12 \times 276 \text{ feet} \times 50 \text{ amps}}{26240 \text{ cm}} = \frac{331{,}200}{26240} = 12.6 \text{ volt drop}$$

230 volts
- 12.6 volt drop

217.4 remaining volts

$$\frac{217.4}{230.0} = .945 \text{ minus } 1.0 = 0.055\ (5.5\%) \text{ volt drop}$$

(please see note ① two charts below)

(for aluminum conductors - change 12 to 20 in the formula)

230-volt three phase (using #6 copper cable rated at 55 amps)

$$\frac{2 \times 12 \times 276 \text{ feet} \times 28 \text{ amps}}{26240 \text{ cm}} = \frac{185{,}472}{26240} = 7.07\text{-volt drop} \times 0.866 = 6.12\text{-volt drop}$$

230-volt
- 6.12-volt drop

223.9 remaining volts

$$\frac{223.9}{230.0} = .973 \text{ minus } 1.0 = 0.027\ (2.7\%) \text{ volt drop}$$

(please see note ① next chart)

(for aluminum conductors - change 12 to 20 in the formula)

480-volt three phase (using #6 copper cable rated at 55 amps)

$$\frac{2 \times 12 \times 276 \text{ feet} \times 14 \text{ amps}}{26240 \text{ cm}} = \frac{92{,}736}{26240} = 3.53\text{-volt drop} \times 0.866 = 3.06\text{-volt drop}$$

480-volt
- 3.06-volt drop

476.9 remaining volts

$$\frac{476.9}{480.0} = .994 \text{ minus } 1.0 = 0.006\%\ (.6\ \%) \text{ volt drop}$$

(please see note ① below)

(for aluminum conductors - change 12 to 20 in the formula)

①Note: when calculating a percentage, your answer will always be provide in a decimal format when dividing a lower number by a higher number. Move the decimal point *2 places* to the right to view the percentage.

How does low voltage affect equipment? Consider the examples in the next charts:

MOTORS

EXISTING LOAD	5% LOW VOLTAGE	10% LOW VOLTAGE	15% LOW VOLTAGE
73 AMPS	76.8 AMPS	81.1	85.8
MOTOR WINDING TEMPERATURE 165F	173.9F	183.3F	194.1F
MOTOR TORQUE	8.5% DECREASE	19% DECREASE	38% DECREASE

HEATING EQUIPMENT

	5% LOW VOLTAGE	10% LOW VOLTAGE	15% LOW VOLTAGE
4000 WATT UNIT HEATER	3,800 WATTS	3,600 WATTS	3,400 WATTS

LIGHTING OUTPUT

	5% LOW VOLTAGE	10% LOW VOLTAGE	15% LOW VOLTAGE
LIGHTING LUMEN OUTPUT	8.5% DECREASE	19% DECREASE	38% DECREASE

Underwriters Laboratories stipulates the maximum ballast case temperature for fluorescent ballast is 90 degree C (194F) at its hottest spot. The case temperature will increase proportionally to the degree of under or over voltage in the feed. Complicating the above are the additional factors relating to multiple conductors and multiple cord wrap on reels.

MULTIPLE CONDUCTOR CABLE DERATING FACTORS PER NEC

When the number of conductors in a raceway or cable exceeds 3, the allowable ampacity of each conductor shall be reduced as shown in the following tables.

Number of conductors	Multiply the ampere rating by the following
4 to 6	.80
7-24	.70
25-42	.60
43 above	.50

CORDS WOUND ON REELS

Number of layers (wraps)	Multiply the ampere rating by the following
1	.85
2	.65
3	.45
4	.35

As you can see, the excess heat generated by over lapping conductors will reduce the ampere capacity of the conductor. The end result is that there is only five ways to reduce voltage drop in a system.

1. **Decreasing the length of the circuit, thereby reducing the resistance of the cable.**
2. **Increasing the size of the conductor to lower the resistance of the cable.**
3. **Lower the load by decreasing the amperes consumed in the circuit.**
4. **Increasing the voltage, this in turn decreases the amperes needed to do the same amount of work.**
5. **Lower the temperature of the conductor.**

CHAPTER 1 TEST

1. 1,000 watts (W) is the same as 1kV. True or False? ______________.

2. If you have a load of 2 amperes and 600 ohms, what would your voltage be?

___________________________.

3. What is resistance (R) of a 16.7 amp load at 240-volt single phase?

____

4. V divided into W = amperes. True or False? ________________

5. What is the wattage of a 65 ohms and 480-volt circuit? __________________

6. There are three heaters on a single *series* circuit, each unit is 10kW, 10kW and 15kW. What is the total combined three phase amperes at 480-volt? __________________

7. A Wye voltage system can produce a Delta voltage source. True or False? _________

8. What is the ampere load of a 100 watt 120-volt light bulb? ______________________

9. Resistance increases in a circuit as the length of the cable increases. True or False?

____

10. The earth's voltage is considered _____ volts. (A) –120-volts (B) 0-volts (C) -20-volts.

11. What is the voltage between lines L1 and L3 on a 240-volt 3-phase 3-wire system?

____

12. What is the ampere of a three-phase 480-volt 2 horsepower motor? _____________

13. What would the ampere be if the same motor in question 12 were single-phase?

____

14. What is the watts consumed by a 120-volt AC circuit drawing a current of 5 amperes.

____

15. What are the amps of a 2.5 kW unit heater operating on 480-volt single-phase?

____

16. What would the amperes be if you changed the heater in question 15 to three-phase?

____

17. If you multiply single-phase amperes (I) by ohms (R) you will receive the volts of your system. True or False? ______________

18. Single-phase amperes (I) divided into watts will furnish you the volts of the unit. True or False? ______________

19. Single-phase watts divided into volts will give you the amperes of your system. True or False? _______________

20. If we use the following formula and find the horsepower of a three phase 460-volt motor is 52 amps, is the answer and formula correct? Yes or No? _________

460-volt x 52 amps x 1.73 = 41,381.6

================== ======== = 55.47 horsepower

746 746

21. The rate of electric current flow is the ampere. True or False? _____________

22. DC voltage can be used with a transformer. True or False? ______________

23. A 480-volt Delta circuit will produce 480-volt single-phase between either lines L1 & L2, L1 & L3 or L2 & L3. True or False? ______________

24. 1.73 is used in all three-phase formulas. True or False? ____________

25. A Class 20 thermal overload unit will trip in less than 20 seconds under certain overload conditions. True or False ______________

26. Impedance and ohms basically means the same thing. True or False _______________

27. A fault current occurring at maximum voltage is completely symmetrical. True or False?

____

28. To find Z you would divide E into I. True or False ____________

29. Current at 90 degree of ½ of a sine wave is called the *peak* or *crest* current. True or False

____

30. Impedance can be substituted for ohms in fault currents. True False _____________

31. Colder ambient temperatures will increase the range of a thermal overload relay. True or False ___________

32. I^2T uses amperes to measure the thermal energy of a fault. What type of current is it?

A) RMS B) Peak amperes C) Controlled amperes. _______________

33. Is the following statement true or false? For 1.15 to 1.25 service factor motors with the motor and controller in the same ambient, you would use 100% of the motor full load current to select your thermal unit. True or False

34. What is the full load current multiplier for an instantaneous short circuit current at ½ cycle? _________________

35. If you have a 5-conductor cable with a capacity of 40 amperes, what would the NEC allowable ampacity be for each conductor?

(A) 32 amperes (B) 35 amperes (C) 30 amperes (D) 40 amperes __________________

36. What is the maximum allowable voltage drop, in percentage, for combined lighting and heating loads? (A) 3% (B) 5% (C) 4% ____________________

37. What would the answer be for question 36 if it were a lighting load only? ____________

38. What is the ohms resistance of a 21.3 ampere load at 120-volt single phase? (A) 5.9 ohms (B) 5.3 ohms (C) 15.6 ohms (D) 5.6 ohms __________________

39. The service factor of a motor is the *extra* capacity built into the windings of the motor, thereby allowing it to handle overloading conditions and providing horsepower above the nameplate rating. True or False? _____________

40. You have a 5 Kw unit heater operating on a 230-volt single phase feed and need to choose the proper cable size for the application. What is the amperes of the load? (Voltage drop is not a factor).(A) 23.5 (B) 20.74 (C) 21.74 (D) 35 (E) 26 ________________

41. A cord reel with four wraps of 16 gauge, 10 ampere cord requires replacement monthly even though the load is only 5 amperes. What is the actual NEC capacity of the cord? (A) 3.5 amperes (B) 3.25 amperes (C) 3.75 amperes (D) 3.0 amperes _________________

42. A 23-ampere load with a resistance of 5 ohms is powered by a ___volt power source. Which of the following are correct? (A) 115-volt (B) 120-volt (C) 230-volt (D) 130-volt

____

43. What is the voltage drop of the following circuit? 15-ampere lighting load, 168 feet from the breaker to the load using a 14 gauge copper wire and a 120-volt source? __________