EE 101

An Introduction to Electrical Engineering Concepts… for the non – Electrical Engineer

Produced and Distributed by
PDH Now, LLC
857 East Park Avenue
Tallahassee, FL 32301

EE 101 - An Introduction to Electrical Engineering Concepts … for the non – Electrical Engineer

Course Description

Electricity as a power source is omnipresent, powering the vast majority of our nation's residential, industrial and commercial loads. A loss of electricity, no matter how brief, is all it takes to reveal our near total dependence on the invisible power source and to leave us feeling "powerless", both figuratively and literally. For many non-electrical engineers, understanding how electricity "works" and knowing how to specify equipment that utilizes electricity can be confusing. This course is intended to guide non-electrical engineers (you civil, mechanical, structural, fire protection and other design professionals) through the many questions that arise when non-electrical engineers must interact with and understand the subject of electrical power in the course of their work as design professionals.

1.0 ELECTRICITY AND THE STRUCTURE OF THE ELECTRIC POWER SYSTEM

Electricity can't be pumped out of the ground like oil or captured from moving air like wind energy. So it is called a secondary source of energy, meaning that it is produced by the use of primary energy sources such as coal, natural gas, or nuclear reactions. Although it is a secondary source, electricity plays such an essential role in contemporary America that its supply and demand are often examined separately from the primary sources used to produce it.

An electric power system is a network of electrical components used to supply, transmit and utilize electric power. An example of an electric power system is the network that supplies a region's homes and industry with power - for large regions, this power system is sometimes referred to as *the grid*.

An Electric Power system consists of the following subsystems:

- Generation Subsystem
- Transmission Subsystem
- Distribution Subsystem
- Utilization Subsystem

Generation Subsystem – This is the part of the electric power system that generates and supplies the power. Electricity or electrical power can be generated in a number of ways.

Transmission Subsystem – These are the components that carry the power, often long distances, from the generating centers or power plants to the load centers (cities, towns, etc) where the power is utilized. This subsystem typically operates at what are referred to as “high voltages” ranging from 115,000 Volts and higher.

Distribution Subsystem – This is the subsystem that feeds the power to nearby homes and industries within a city or town. This subsystem typically operates at what are referred to as “medium voltages” ranging from 2,400 Volts to 69,000 Volts.

Utilization Subsystem – This is the part of the electric system dealing with the electrical loads/the devices and equipment that utilize electricity. It consists of the electrical components that exist between the utility transformer (or the owner’s transformer in a plant / large property environment in which the owner operates the distribution subsystem) and actual equipment that utilizes electricity. In this environment we are dealing with low voltages – typically less than 600 Volts.

This course will focus on the electrical system and the use of electricity at the load level within the utilization subsystem at less than 600 Volts.

2.0 BASICS OF ELECTRICITY (note 1)

From power lines to computer chips, electrical circuits are ubiquitous in the modern world, and yet, because we don't actually see the electricity moving through them, most people have only a vague idea of what the electricity is actually doing in a circuit. This lack of intuition, of the "common sense" about a subject that comes from everyday familiarity - can be a problem when students first begin to try to understand electricity and circuits. The extended analogy presented here should help, by comparing the flow of electricity to the more-familiar flow of water.

Flow

Electricity and water are very different things, and they flow for different reasons, but there are enough similarities that comparing the two can help you imagine, understand, and remember what is happening in an electrical circuit. For example, water will flow from a high place to a low place, if there's nothing blocking it from doing so. It flows for the same reason - gravity - that a rock in a high place will fall to a low place, as long as there's nothing in the way that blocks it from falling.

You may remember, from basic mechanics in physics class, that when the water (or rock) is the high place, ready to fall, it is said to have *potential energy*. This just means that it is capable of releasing energy, or doing work, simply because of its position. As the water (or rock) moves down through the gravitational field, the potential energy changes to kinetic energy, the energy of the movement of the water (or rock). When it reaches the bottom the potential energy is gone, "used up" by the movement; but meanwhile, you might have been able to use it to do work, having the falling water turn a water wheel, for example (or using the falling rock to break open a nut).

Electrical charge also flows when it can move from someplace with a higher potential energy to someplace where it will have a lower potential energy. This change in potential energy is due to an electrical field, instead of a gravitational field. The fact that electrical charges will move, if they can, to a place with a lower electrical potential energy is one of those basic laws of the universe, like gravity. And, just as with the flowing water, we can use the flow of charge - electricity - to do work as it moves.

But, just as many things can block water from flowing, many things can block electricity from flowing, too. Water flows well through air, but not through solid materials such as metal. Electricity does not flow well through air, or through many solid materials, such as rubber and plastic. Picture these *non-conductors* as high river banks or walls that block the flow. Electricity does flow well through metal, so picture such *conductors* as open spaces that the electrons can flow freely in. A long, thin, metal wire, then, surrounded by a rubber coating, is like a water channel with high banks; if it's "higher" at one end than the other, the water (electrons) will flow freely from one end of the channel (wire) to the other with very little leakage as shown in Figure 1.

(a) **(b)**

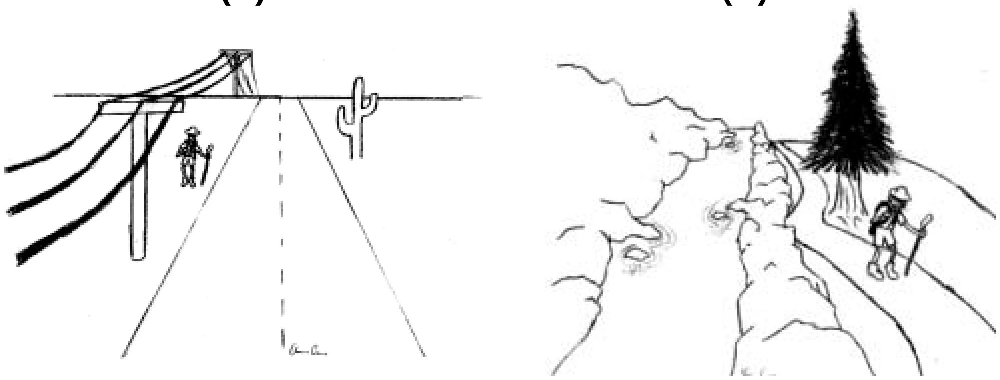


Figure 1: A wire surrounded by a non-conductive coating is analogous to a river flowing between high banks.

What if there's a breach in the banks as shown in Figure 2 below? Remember, air is not a good conductor, so simply removing a section of the rubber coating may not hurt anything. But if a good conductor does touch the wire at the bare spot (and remember, *you* are a good conductor), the result is about the same as digging a hole in the riverbank; if the hole gives the water (electrons) a chance to flow to a "lower" spot, the result can be a catastrophic flood! You can consider any connection that allows the electricity to spread out over a large area (a *grounding* wire, for example) the same as a direct outlet to the sea; both water and electricity will "prefer" any short-cut to the "lowest" place.

(a) **(b)**

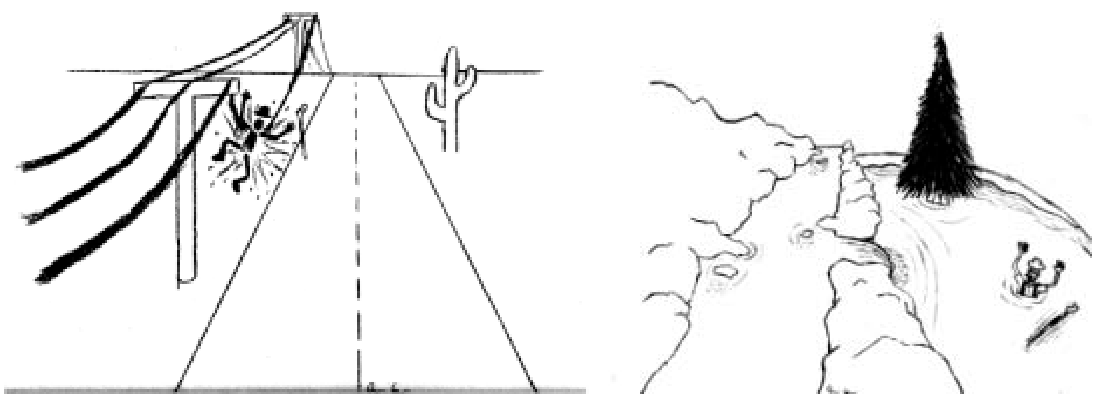


Figure 2

Figure 2 depicts when a breach in the banks, or in the non-conductive coating, allows the flow to "escape". The escaped flow is no longer available to do work in the circuit. Before trying to repair any breaches, turn off the flow! You don't want to be in the way when it tries to go to a "lower" place. Remember, for electricity, "lower" does not mean "closer to the ground"; it means any place (including the ground) where it will have a lower potential energy.

Power

We make electrical circuits in order to do something with the electricity flowing through them, so one of the questions you might have about a circuit is: how much work can it do? The answer depends on two different things: voltage and current.

When you measure the current of a river, you are measuring how much water is flowing past a certain point in a certain amount of time. If you watch a small brook, for example, you may see only a few cubic feet of water go by every second. A big river, on the other hand, can move thousands of cubic feet of water past you in one second. Similarly, the *current* in a wire is a measure of how much electricity is going through it per second. Electrical current is measured in *amperes*; one ampere is one *coulomb* of electrical charge going through any particular point every second. That's a lot of electrons (more than a billion billion) going by every second, just as a cubic foot of water is an awful lot of drops of water going by.

Obviously, a bigger current can do more work. Picture the current of a big river pushing barges from one town to another, or generating a lot of electricity by turning some big turbines in a dam. You might get a little work out of the small brook, by putting a water wheel in it, but you're not going to light up an entire city that way. But current is not the only issue. Picture two power-generating dams on that big river. In one dam, the water only falls ten feet from one side of the dam to the other; in the other dam, it falls one hundred feet. Same river, same current, but the second dam can generate more power because the water falls through a much greater height. There is a greater "difference" in the potential energy of the water entering and leaving the higher dam. *Voltage* is the difference in electrical potential energy. So a 12-volt battery comes with a bigger built-in "height" than a 9-volt battery and a 480 volt power system comes with more electrical potential than a 208 volt system.

Volts are just a measure of the difference in the potential energy, not a direct measure of potential energy, rather like measuring the height from the base to the top of a waterfall. It would be much harder to measure the absolute height of the top of the waterfall above sea level, or from the center of the earth, and it wouldn't give you any more useful information about power, anyway. Being high in the mountains doesn't make a waterfall more powerful; what matters is the change in potential energy (height) from the beginning to the end of the waterfall. In electricity, even this change is difficult to measure directly, so a volt is measured and defined in terms of how much work it can do.

A *volt* can be defined as "the amount of change in potential that will cause a one-ampere current to give one *watt* of power. Another way of saying this is: *Power is voltage times current*. So as the current gets bigger, so does the power, and when the voltage gets higher the power also increases.

It's useful to understand what it means physically that "power is voltage times current". For example, will touching a particular wire hurt you? If it has a very high voltage but a very low current, it might hurt you about as much as standing under a very high waterfall (high voltage) that has almost no water in it (low current). The small sparks caused by static electricity in cool dry weather, are high-voltage, low-current flows. The voltage has to be pretty high to get the electricity to jump through the air, since air is not a good conductor, but the small current involved means the "shock" it will give you will be pretty small.

A circuit with a very high current but a low voltage, on the other hand, is about as dangerous as a fairly flat section of a big river. The river has a lot of current, but its height (voltage) from one end to the other is small. Try standing in such a river, and it may have enough power to sweep you far away; but a trained swimmer can negotiate it safely. A welding machine uses a high-current, low-voltage flow. It has enough current to melt the metal it touches, but its voltage is low enough that it can be safely handled by people trained to do so. Car batteries also have a lot of current but a low voltage.

Electricity - like water - is most dangerous when both the current and the voltage are high. Consider how quickly things can change with multiplication: if either the voltage or the current is "one", and the other is "ten", then the power is only "ten". But if both are "ten", the power is "one hundred"! You don't want to stand under Niagara Falls - lots of current, big height (potential difference) - and you don't want to touch a power line or stick your finger in a socket - also high current, and high voltage (potential difference). But that high power also means lots of energy is available to do work.

Circuit Components

So to get things moving in your circuit, you're going to need to create that *electrical potential difference*. One easy way to do this is with a *battery*. You can picture the battery as two water reservoirs, one higher than the other. A high battery voltage represents a top reservoir that's much higher than the bottom reservoir. If the battery voltage is low, the top reservoir is not that much higher than the bottom one. If the battery is charged, there is plenty of water behind a dam in the upper reservoir. If the battery is "dead", too much of the water has run down to the low reservoir already. Some batteries you can recharge, just as you can refill the upper reservoir, but of course it takes energy to do so. (You can wait for rain to fill the upper reservoir, but that is just relying on the sun's energy to move the water.) Inside the battery, the two reservoirs are kept separate, so the only way for the electricity to move is for you to provide a channel (a wire) from the upper reservoir (the *anode*) to the lower reservoir (the *cathode*).

Now, if you just connect the two reservoirs with a wire made out of a good conductor, you're just opening the floodgates and letting the water run unimpeded - whoosh - in a waterfall from high to low. This is not useful. In the electrical world, this is analogous to a short circuit. In order to begin to make it useful, you may want to add some resistance to the flow. A *resistor* slows down the flow without stopping it. It's used to adjust the current and voltage in the circuit. Instead of the water pouring straight down, you've added an obstacle - maybe a platform filled with rocks, that the water has to pass before it can continue to fall. The water keeps falling, but it has slowed down. Note that this also means it has lost energy; a resistor does use up electrical energy. This can be necessary so that other objects in the circuit aren't damaged by a current or by a voltage that is too high. You might want the waterfall to lose some energy if you're going to stand underneath it to take a shower, for example. It's also possible to use the energy loss from the resistor in a useful way; this is how filament light-bulbs work. In this type of bulb, part of the circuit is a length of wire that is not such a good conductor. Its resistance to the electricity moving through it heats it up to the point of glowing brightly. It is as if you put those rocks in the way of the waterfall because you wanted to use the moving water to clean them.

Note 1: This entire section is attributed to and adapted from:

Schmidt-Jones C, Jones D. Electricity/Water Analogy [Connexions Web site]. January 30, 2009. Available at: http://cnx.org/content/m17281/1.2/.

Summary of Useful Analogies to Visualize the Behavior of Electrical System Quantities and Components

Wires: A relatively wide pipe completely filled with water is equivalent to a piece of wire. When comparing to a piece of wire, the pipe should be thought of as having semi-permanent caps on the ends. Connecting one end of a wire to a circuit is equivalent to forcibly un-capping one end of the pipe and attaching it to another pipe. With few exceptions (such as a high-voltage power source), a wire with only one end attached to a circuit will do nothing; the pipe remains capped on the free end, and thus adds nothing to the circuit for no flow can occur.

Electric potential or voltage: For the discussion above we referenced elevated water in a reservoir or tank. We could also think of a closed system where the pressure source is a pump. Either way, electric potential or voltage is analogous to pressure. Voltage is measured in volts.

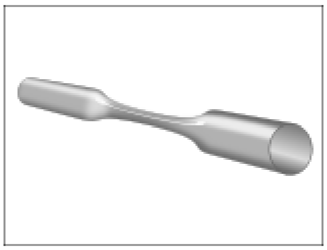
Voltage Drop or potential difference is analogous to a difference in pressure between two points or pressure drop. Voltage drop is measured in volts.

Electric charge is analogous to a quantity of water.

Current is analogous to a hydraulic volume flow rate; that is, the volumetric quantity of flowing water over time. Current is measured in amperes.

In a pipe tee (T) filled with flowing water, the total amount of water flowing into the tee is equal to the total amount flowing out of it. This fact corresponds to Kirchhoff's junction rule.

Resistance is analogous to a constriction in the bore of the pipe which requires more pressure to pass the same amount of water. All pipes have some resistance to flow, just as all wires have some resistance to current.

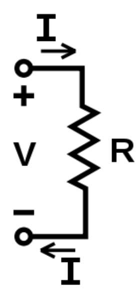


A simple pipe with a constricted region

Ohms law

Ohm's law states that the current through a conductor between two points is directly proportional to the potential difference across the two points. Introducing the constant of proportionality, the resistance, one arrives at the usual mathematical equation that describes this relationship

$$I = \frac{V}{R},$$



where I is the current through the conductor in units of amperes, V is the potential difference measured across the conductor in units of volts, and R is the resistance of the conductor in units of ohms. More specifically, Ohm's law states that the R in this relation is constant, independent of the current.

So if a potential difference of 120V (V) is applied to a resistance of 120 Ohms (R) then 120 volts/120 ohms or 1 ampere will flow.   If the voltage is doubled to 240 volts (V) and the resistance remains at 120 Ohms (R) then 240 volts/120 ohms or 2 amperes will flow.

It is important to note that not all electrical components have constant resistance as assumed in ohms law. In fact, there is a more advanced but similar concept of impedance, that includes capacitance and inductance in addition to resistance, which is outside the scope of this course. When you see the term impedance used in this course, think “resistance”.

Electrical Frequency

Utility frequency or (power) line frequency is the frequency of the oscillations of alternating current (AC) in an electric power grid transmitted from a power plant to the end-user. In the United States it is typically 60 Hertz or Hz (A hertz is a cycle per second), although elsewhere in the world 50 Hz is the more common frequency. In the US, one cycle is 1/60 second.

During the development of commercial electric power systems in the late 19th and early 20th centuries, many different frequencies (and voltages) had been used. Large investment in equipment at one frequency made standardization a slow process.

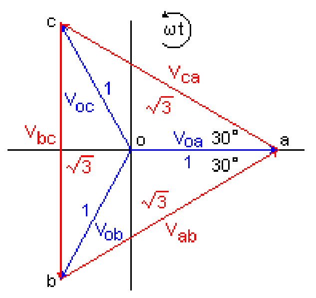
Around the world both frequencies (50 Hz and 60 Hz) exist today with no particular technical reason to prefer one over the other and no apparent desire for complete worldwide standardization. There would be significant expense involved to convert a system from one frequency to another.

Unless specified by the manufacturer to operate on both 50 and 60 Hz, equipment cannot be assumed to operate efficiently or even safely if used on anything other than the intended frequency.

Why are there different voltages / number of phases?

In a typical building or plant system the most common voltages are 480/277V three phase systems and 208/120V three phase systems. The two numbers separated by a slash indicate the different voltages that exist in a multi phase system. The first number is the larger number and it represents the voltage or potential difference between each phase or each live conductor on the system. This is called the phase Voltage or the Line to Line Voltage, V_{LL}. The second and lower number represents the voltage or potential difference between a phase and neutral (and ground for a grounded system – we will discuss grounding later in the course).This second lower voltage is the Line to Neutral Voltage or V_{LN} The figures below present the various voltages that exist within a multi phase system. The algebraic relationship between phase to voltage (line to line voltage V_{LL}) and the line to neutral voltage (V_{LN}) is dependent on the geometric relationships in the windings of the transformer (or generator) that serves the power. For a three phase system the line to line voltage V_{LL} is 1.732 (the square root of three) times the line to neutral voltage $V_{LN.}$ So on a 480V three phase system where the line to line voltage is 480V, the line to neutral voltage is 480 volts divided by 1.732 or 277V. On a three phase 208 volt system, the line to neutral voltage is 208 volts divided by 1.732 or 120 volts.

In the figure below V_{ca}, V_{bc} and V_{ab} are Line to Line voltages and V_{oa}, V_{ob} and V_{oc} are Line to Neutral voltages shown in phasor representation – which demonstrates geometrically why there is a factor of 1.732 (square root of three) between line to neutral voltage and line to line voltage.



Three-Phase Wye and Delta

Voltage at point of use

When discussing voltage we need to keep in mind that the system voltage at the point of service will not be the same as the voltage at the point of utilization (where equipment receives electricity). Because there are system losses due to resistance (impedance) there is voltage drop (or loss of electrical pressure) as the electrical energy flows from the source to the load.

For this reason, equipment (motors for example) on a 480V system are often rated as 460V motors). Loads on a 120V single phase circuit are often called 110 or 115 Volt loads).

Benefits of the various voltage and phase options

When given an option – using electricity at a higher voltage is typically more economical. Since power equals voltage and current – the same power can be delivered at a higher voltage using less amperes. Conductors and panels and circuit breakers are all rated in amperes. Less amperes require less copper / less material and therefore cost less and since most utilization level electrical components are rated for up to 600V there is little increased cost for choosing a higher voltage. The decision process is similar to using higher pressure to distribute liquid or gas but without a cost increase for material that can accommodate a higher pressure.

Phases

Single-phase electric power refers to the distribution of alternating current electric power using a system in which all the voltages of the supply vary in unison. Single-phase distribution is used when loads are mostly lighting and heating, with few large electric motors.

In contrast, in a three-phase system, the currents in each conductor reach their peak instantaneous values sequentially, not simultaneously; in each cycle of the power frequency, first one, then the second, then the third current reaches its maximum value. The waveforms of the three supply conductors are offset from one another in time (delayed in phase) by one-third of their period. When the three phases are connected to windings around the interior of a motor stator, they produce a revolving magnetic field; such motors are self-starting.

A single-phase supply connected to an alternating current electric motor does not produce a revolving magnetic field; single-phase motors need additional circuits for starting (involving capacitors to provide phase shift and resultant torque to cause rotation), and such motors are uncommon above 10 or 20 kW in rating.

Three-phase electric power is a common method of alternating-current electric power generation, transmission, and distribution. It is a type of polyphase system and is the most common method used by electrical grids worldwide to transfer power. It is also used to power large motors and other heavy loads. A three-phase system is usually more economical than an equivalent single-phase or two-phase system at the same voltage because it uses less conductor material to transmit electrical power

3.0 OVERCURRENT CONCEPTS

There are two basic types of abnormal over current electrical conditions to which protective devices are designed to respond. **Overloads** and **Short Circuits**.

Overloads to circuits or components can be caused by:

- Connecting larger or additional equipment to a circuit in excess of its rated capacity.
- Improper mechanical equipment installation and/maintenance resulting in misaligned shafts and worn bearings
- Improper procedures such as too frequent starting, extended accelerating periods, and obstructed ventilation.

Short circuits may be caused in many ways including:

- Failure of insulation due to excessive moisture
- Mechanical damage to electrical distribution equipment
- Failure of utilization equipment as a result of over loading or other abuse

The isolation of overloads and short circuits requires the application of protective devices that will both sense that an abnormal current flow exists and then act to remove the affected portion from the system.

Overloads

Overloads are most often between one and six times the normal current level. Usually, they are caused by harmless temporary surge currents that occur when motors start up or transformers are energized. Such overload currents, or transients, are normal occurrences. Since they are of brief duration, any temperature rise is trivial and has no harmful effect on the circuit components. (It is important that protective devices do not react to them.)

Continuous overloads can result from defective motors (such as worn motor bearings), overloaded equipment, or too many loads on one circuit. Such sustained overloads are destructive and must be cut off by protective devices before they damage the distribution system or system loads. However, since they are of relatively low magnitude compared to short-circuit currents, removal of the overload current within a few seconds to many minutes will generally prevent equipment damage. A sustained overload current results in overheating of conductors and other components and will cause deterioration of insulation, which may eventually result in severe damage and short circuits if not interrupted.

Short Circuits

Whereas overload currents occur at rather modest levels, the short-circuit or fault current can be many hundred times larger than the normal operating current. A high level fault may be 50,000A (or larger). If not cut off within a matter of a few

thousandths of a second, damage and destruction can become rampant–there can be severe insulation damage, melting of conductors, vaporization of metal, ionization of gases, arcing, and fires.
Simultaneously, high level short-circuit currents can develop huge magnetic field stresses. The magnetic forces between bus bars and other conductors can be many hundreds of pounds per linear foot; even heavy bracing may not be adequate to keep them from being warped or distorted beyond repair.

Short circuits may occur between two phase conductors, between all phases of a multi phase system, or between one of more phases and ground. The short circuit may be solid (called “bolted”), in which case the short circuit is permanent and solidly connected having low impedance. For under 240V volts, the short circuit may burn itself clear, probably opening one or more conductors in the process. The short circuit may involve an arc (current flowing through air) having a relatively high impedance. Such an arcing short circuit (or fault) can do extensive damage without producing exceptionally high current. Different types of short circuits produce somewhat different conditions in the electrical system. Electrical systems need to be protected against the highest short circuit that can occur.

4.0 PROTECTIVE DEVICES (CIRCUIT BREAKERS AND FUSES) (note 2)

System protection is one of the most important aspects of an electrical system. Properly selected over current protective devices will clear a fault in time to minimize system damage while also limiting the extent of electrical outage caused by the fault being cleared. Without proper over current protection, system reliability and availability are reduced, causing unnecessary downtime. The most common protective devices are circuit breakers and fuses.

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Its basic function is to detect a fault condition and interrupt current flow. Unlike a fuse, which operates once and then must be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation. Circuit breakers are made in varying sizes, from small devices that protect an individual household appliance up to large switchgear designed to protect high voltage circuits feeding an entire city.

Circuit Breaker Operation Basics

Circuit breakers are mechanical over current protective devices. All circuit breakers share three common operating functions:

1. Current sensing means:
    A. Thermal
    B. Magnetic
2. Unlatching mechanism: mechanical
3. Current/voltage interruption means (both)

The circuit breaker’s physics of operation is significantly different from that of a fuse. First, the circuit breaker senses the over current. If the over current persists for too long, the sensing means causes or signals the unlatching of the contact mechanism. The unlatching function permits a mechanism to start the contacts to part. As the contacts start to part, the current is stretched through the air and arcing between the contacts commences. The further the contacts separate the longer the arc, which aids in interrupting the over current. However, in most cases, especially for fault current, the contacts alone are not sufficient to interrupt. The arcing is thrown to the arc chute which aids in stretching and cooling the arc so that interruption can be made. Figure 3 shows a simplified model with the three operating functions shown for a thermal magnetic circuit breaker, which is the most commonly used circuit breaker. Also, it should be noted that there are various contact mechanism designs that can significantly affect the interruption process.

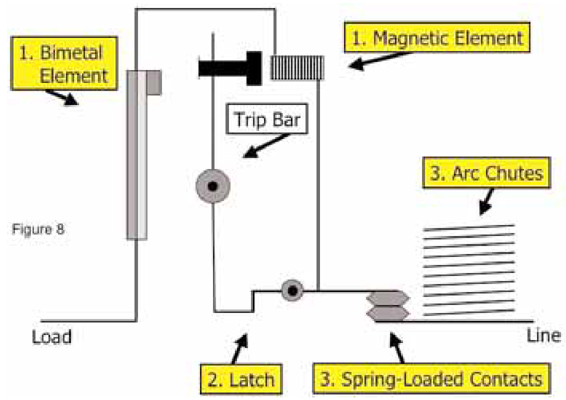


Figure 3

Circuit Breaker Overload Operation

Figures 4 and 5 illustrate circuit breaker operation by a thermal bimetal element sensing a persistent overload. The bimetal element senses overload conditions. In some circuit breakers, the overload sensing function is performed by electronic means. In either case, the unlatching and interruption process is the same. Figure 4 illustrates that as the overload persists, the bimetal sensing element bends. If the overload persists for too long, the force exerted by the bimetal sensor on the trip bar becomes sufficient to unlatch the circuit breaker. Figure 5 shows that once a circuit breaker is unlatched, it is on its way to opening. The spring-loaded contacts separate and the overload is cleared. There can be some arcing as the contacts open, but the arcing is not as prominent as when a short-circuit current is interrupted.

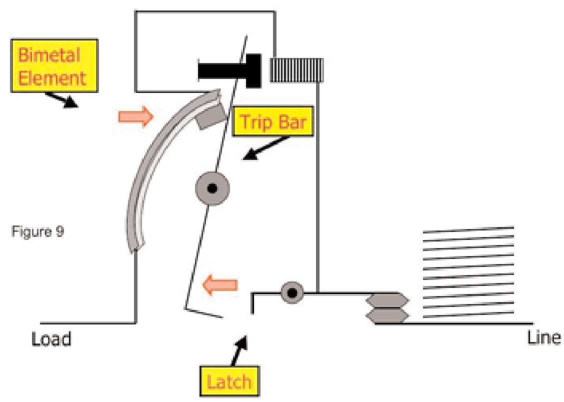


Figure 4

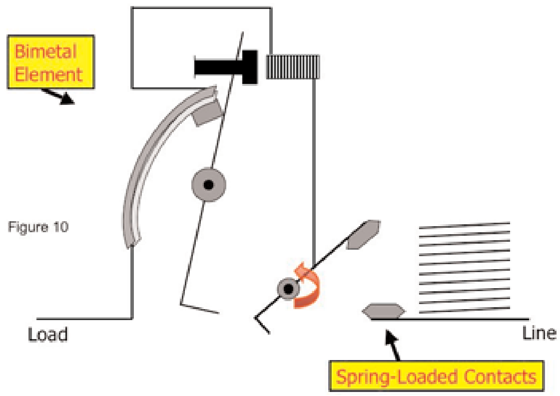


Figure 5

Circuit Breaker Instantaneous Trip Operation

Figures 6, 7 and 8 illustrate circuit breaker instantaneous trip operation due to a short-circuit current. The magnetic element senses higher level over current conditions. This element is often referred to as the instantaneous trip, which means the circuit breaker is opening without intentional delay. In some circuit breakers, the instantaneous trip sensing is performed by electronic means. In either case, the unlatching and interruption process is the same as illustrated in Figures 7 and 8. Figure 6 illustrates the high rate of change of current due to a short-circuit causing the trip bar to be pulled toward the magnetic element. If the fault current is high enough, the strong force causes the trip bar to exert enough force to unlatch the circuit breaker. This is a rapid event and is referred to as instantaneous trip. Figure 7 shows that once unlatched, the contacts are permitted to start to part. It is important to understand that once a circuit breaker is unlatched it will open. However, the current interruption does not commence until the contacts start to part. As the contacts start to part, the current continues to flow through the air (arcing current) between the stationary contact and the movable contact. At some point, the arc is thrown to the arc chute, which stretches and cools the arc. The speed of opening the contacts depends on the circuit breaker design. The total time of the current interruption for circuit breaker instantaneous tripping is dependent on the specific design and condition of the mechanisms. Smaller amp rated circuit breakers may clear in 1⁄2 to 1 cycle or less. Larger amp rated circuit breakers may clear in a range typically from 1 to 3 cycles, depending on the design. Circuit breakers that are listed and marked as current-limiting can interrupt in 1⁄2 cycle or less when the fault current is in the circuit breaker's current-limiting range.

With the assistance of the arc chute, as well as the alternating current running its normal course of crossing zero, and the contacts traveling a sufficient distance, the fault current is interrupted (see Figure 8). There can be a tremendous amount of energy released in the contact interruption path and arc chute during the current interruption process.

As a consequence, circuit breakers are designed to have specific interrupting ratings at specific voltage ratings. For instance, a circuit breaker may have a 14,000A interrupting rating at 480Vac and 25,000A interrupting rating at 240Vac.

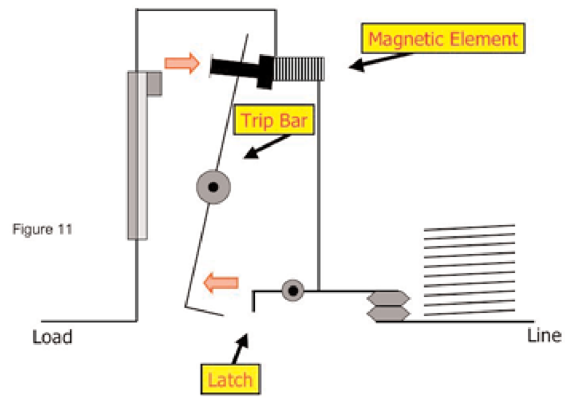


Figure 6

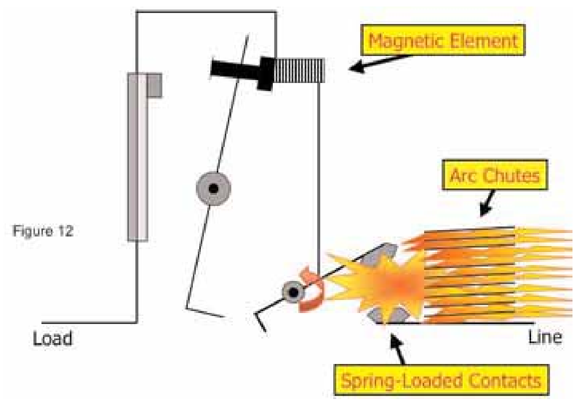


Figure 7

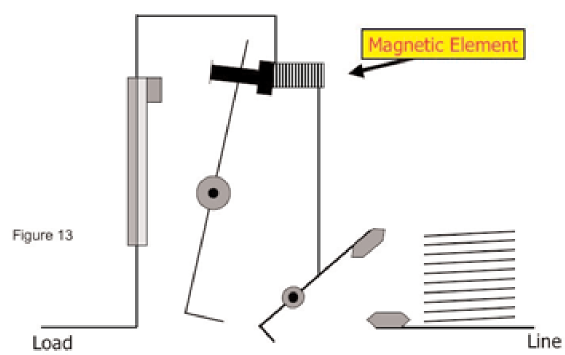


Figure 8

Note 2: This entire section is attributed to and adapted from Cooper BUSSMAN selective coordination literature.

5.0 ARC FLASH HAZARDS

What is Arc Flash?

An arc flash is the light and heat produced from an electrical arc or arcing fault supplied with sufficient electrical energy to cause substantial damage or harm, fire or injury. Electrical arcs, when fed by limited energy and well controlled, produce very bright light (as in arc lamps—enclosed, or with open electrodes), and are also used for welding and other industrial applications.

An arcing fault is a release of electricity between two or more conducting surfaces. The release of electrical energy becomes heat, which can break down a wire's insulation and possibly trigger an electrical fire. The magnitude of arcing faults can range in power from a few amps up to several thousands of amps and can vary dramatically in terms of energy level and duration.

Arc flash temperatures can reach or exceed 35,000 °F (19,400 °C) at the arc terminals. The massive energy released in the fault rapidly vaporizes the metal conductors and other materials involved, blasting molten metal and expanding plasma outward with extraordinary force. A typical arc flash incident can be inconsequential but could conceivably easily produce a more severe explosion. The result of the violent event can cause destruction of equipment involved, fire, and injury not only to an electrical worker but also to bystanders. During the arc flash, electrical energy vaporizes the metal, which changes from solid state to gas vapor expanding by a factor nearly 70,000 times in terms of volume.

In addition to the explosive blast, called arc blast, destruction also arises from the intense radiant heat produced by the arc. The metal plasma arc produces tremendous amounts of light energy ranging in the energy spectrum from far infrared to ultraviolet. Surfaces of nearby objects, including people absorb this energy and can be instantly heated to vaporizing temperatures.

In general, arc flash incidents which ignite clothing are highly improbable on systems operating at less than 208 volts phase to phase (120 V to ground) and when fed by less than a 125 kVA transformer, as 120 volts does not provide sufficient potential to cause an arc flash hazard. Most 480 V electrical services have sufficient capacity to cause an arc flash hazard. Medium-voltage equipment (above 600 V) is higher energy and therefore a higher potential for an arc flash hazard.

In the National Electrical Code, Article 100 defines Arc Flash Hazard as:

- A dangerous condition associated with the possible release of energy caused by an electric arc.

- Informational Note No. 1: An arc flash hazard may exist when energized electrical conductors or circuit parts are exposed or when they are within equipment in a guarded or enclosed condition, provided a person is interacting with the equipment in such a manner that could cause an electric arc. Under normal operating conditions, enclosed energized equipment that has been properly installed and maintained is not likely to pose an arc flash hazard.

How does one determine the arc flash hazard?

Due to the basic nature of this course, we are not able to delve into the nuts and bolts of arc flash hazard calculations. However, in very basic terms, the magnitude of the arc flash hazard at a piece of energized electrical equipment is a function of three variables:

- Time (duration of the fault determined by the time upstream protective devices take to clear the fault). Direct relationship.
- Power available at the location of a possible arc flash event – measured in arcing fault current. Direct relationship.
- Distance (the distance a person is from the arcing equipment components). Inverse relationship.

There are complex calculations that can be performed (usually with software) to determine the arc flash hazard at a given working distance for various scenarios associated with energized electrical panels and components. Such calculations should only be performed under the guidance of a qualified electrical professional.

How to protect against arc flash hazard?

For the purposes of this course – be aware that just being exposed (and not in contact with) to live electrical components can present a lethal threat. It comes as a surprise to many, that Arc flash hazard is not related to the threat of shock or electrocution through contact with live electric components. As such, unless you are a qualified and trained electrician or electrical professional, never open or access a panel or piece of electrical equipment without FIRST removing power from it by opening an upstream device (breaker or switch). It is important to note that even the act of verifying (with a meter) that power has been removed from inside a panel can be dangerous if the power hasn't actually been removed.

How to reduce or mitigate the arc flash hazard?

Reducing or mitigating arc flash hazard requires the services of an electrical professional. Again in general terms, we learned that the arc flash hazard is directly related to the duration of the arc flash event and the power available and indirectly related to the distance from the arc. Techniques to reduce or mitigate arc flash hazard associated with an installation focus on reducing the time that an arc flash event lasts by using faster acting protective devices or decreasing the power available (not as easy). The distance of trained personnel can be increased by the use of remote racking / switching devices during switching operations.

6.0 SPECIFYING CONTROL PANELS IN A NON-ELECTRICAL SPECIFICATION

Equipment and systems that use electrical power need to a) receive the power from the electrical distribution system, b) have the power distributed from the incoming electrical circuit to sub-feed the different components and finally c) components need to be controlled, often requiring that electrical power be switched on and off in a controlled manner to accomplish certain goals or to support a desired process.

So, it is not uncommon for civil or mechanical engineer to have to specify a control panel associated with their water or air moving equipment (Pumps, Fans, Air Handling equipment, and other packaged equipment) in a non-electrical specification section.

When specifying control panels that use, distribute, and/or control electrical power there are several electrical features that need to be both understood and coordinated with regard to the electrical system from which the panel will be fed.

The electrical items that typically need to be coordinated include:

Voltage/Phases – check with the electrical engineer on the project or the owner's electrical staff to determine what voltage and phases are present and available in sufficient quantity to feed your load. Typically US utilization voltages are 480, 230 or 208 volts three phase or 480, 277, 230, 208 or 120V single phase. The electrical engineer or electrician will need to determine the point at the electrical system that has sufficient unutilized electrical capacity and physical circuit breaker space from which to feed your load.

The rated Amps – what the full load amperes (the load) the equipment or control panel with impose on the electrical system.

Maximum over current protective device (MOCP) – the electrical engineer or electrician will need to know what size circuit breaker or fuse is required to protect your control panel or equipment from an electrical overload if it is relying on upstream circuit protection.

Environment – the temperature and humidity the equipment is to operate in. Will the panel be located indoors, outdoors, is it a corrosive environment? The panel and its components need to be appropriately rated.

Motor controlling means - how will motors be started and controlled. They are several options from starting and controlling motors. Each option has pros and cons as is the case with any engineering decision. You will need to specify the motor controller means and determine the motor control sequence of operation in terms of what field devices (located outside the control panel) will provide start/stop signals and in some cases speed signals. Some motor controlling options are:

- Across the line, full voltage starters
- Solid state soft starters (SSSS)

- Variable speed or variable frequency drives (VFD)
- Reduced voltage auto transformer starters (RVAT)
- Delta-wye starters

Panel materials and construction – The panel materials and its construction needs to be suitable for operation in its intended environment. The assembled panel and all its components will need to be UL listed individually and as a system for building dept inspection purposes. This requires that the panel be assembled in a UL panel shop and not someone's garage. It is possible for UL listed components to be integrated into a control panel in a manner that is not safe – this is what drives the requirement for panels being UL listed as an assembled system.

Short Circuit Current Rating (SCCR)

In section 3 Over-current Concepts we discussed short circuits. Short circuits are electrical faults which are characterized by extremely high current (thousands of amperes) and lasting for a brief duration (milliseconds).

Whenever equipment that utilizes electrical power is connected to the electrical system it becomes a candidate to present a fault or short circuit condition to the electrical distribution system. So it follows that any equipment connected to an electrical system needs to be able to not only operate properly when connected, but it also needs not fail catastrophically due to an equipment failure while connected to the electrical system.

Short-Circuit Current Rating (SCCR) is the maximum short-circuit current a component or assembly can safely withstand when protected by a specific over current protective device(s) or for a specified time. "Short-circuit current rating" is not the same as "interrupting rating" (which we learned about in section 4 and the two must not be confused. Interrupting rating is the maximum short-circuit current that an over current protective device can safely interrupt under standard test conditions; it does not ensure protection of the circuit components or equipment.

When analyzing control panels or other assemblies for short-circuit current rating, the interrupting rating of over current protective devices and the short-circuit current rating of all other components affect the overall equipment/assembly short-circuit current rating. For instance, the short-circuit current rating of an industrial control panel typically cannot be greater than the lowest interrupting rating of any fuse or circuit breaker, or the lowest short-circuit current rating of all other components in the enclosure.

If an over-current situation arises, the energy level may be higher than the lowest level SCCR on a component within the panel. When ratings on components are less than the available fault current, the safe performance of the panel comes into question.

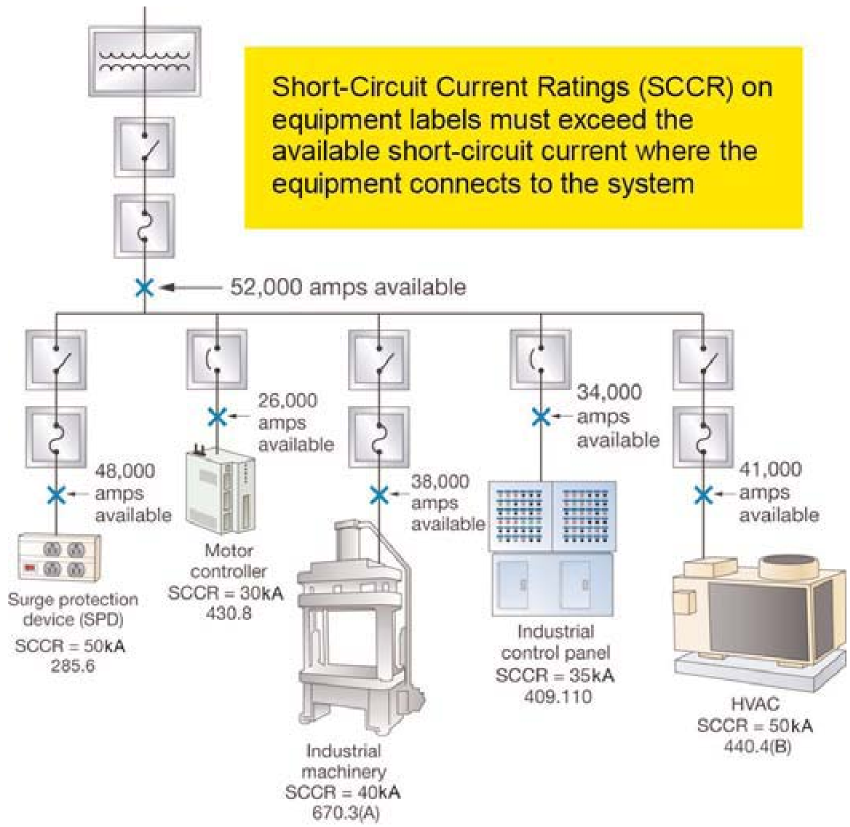


Figure 9

References under each device are to the National Electrical Code sections

In section 4 we learned that over current protection devices must be designed to open and interrupt the fault current that is available to pass through the device. The analogy we discussed was short circuit current being like a rush of flowing water from an elevated water tank through an open duct (aqua duct) over a “draw bridge like gate” that could be pulled up to interrupt and stop the flow of water. The more water flow available from the water tank, the more difficult it would be to construct a draw bridge type gate that could a) open against the raging waters and b) stop the flow without the water shooting over the gate or worse totally destroying the gate due to the force of the flowing water. We learned that an over current protective device’s Interrupting Rating tells us whether a device is rated for and can actually open the circuit and interrupt the fault current that is flowing through it during a short circuit. Remember that opening an electrical circuit is like closing a water circuit with a valve or gate – both actions stop the flow.

Just like a circuit breaker needs to interrupt the available short circuit current, all components that are subject to the thermal and magnetic forces associated with a short circuit should be able to withstand those same forces without failing catastrophically.

In order to specify the appropriate SCCR rating for a control panel or piece of manufactured equipment, you will need to coordinate with the electrical engineer to find out the calculated short circuit current at the point in the electrical distribution system where the panel or equipment will be installed.

Service entrance rated – when equipment receives electrical power directly from a utility transformer rather than from a power panel of some type which itself is fed by a utility transformer somewhere upstream (toward the utility), that equipment must be "service entrance rated".

In order to qualify as a service entrance the equipment must a) have a neutral – ground bond connected to a grounding electrode system (electrical term for a ground rod or similar devices often connected or bonded together), b) a disconnect device and c) and an over current protective device.

So when you are specifying a control panel (for lift station pumps for example) that is to be fed directly from a utility transformer, you will need to specify that it be "service entrance rated". The alternative to a service entrance rated control panel is to locate a service entrance rated fused switch or circuit breaker between the control panel and the utility service.

Arc Flash hazard – Just being in the presence of energized electrical components can present an arc flash hazard. Energized equipment and control panels should have a lockable disconnect switch outside and upstream of the device utilizing electricity to allow electrical power and the threat of arc flash to be removed from the interior of the device or panel prior to opening any doors or covers for inspection or maintenance. Often appliances and control panels are furnished with an integral disconnect switch that is located inside the equipment itself. Relying on integral disconnect switches to remove power from a device doesn't remove the arc flash hazard since operating (opening) such an integral switch doesn't remove power from the incoming or line side of the switch. When you open a switch located inside a panel, it only prevents power from passing through the switch from its input to the output or load side of the switch leaving live parts (the incoming line terminations ahead of the switch) energized after the switch is open and panel covers are opened or removed. It is best to avoid relying on integral disconnect switches as the only means of removing power from inside the device since they leave live power inside the device!

7.0 PROTECTIVE DEVICE COORDINATION

Each type of over current protective equipment (i.e. circuit breakers, fuses, and other related devices not covered in this course) has definite operating characteristics which must be chosen in order to provide the protection that was discussed in the previous section. The devices sometimes have settings that must be "set" to provide proper protection to the associated equipment, and to also coordinate with other protective devices located immediately upstream and downstream. The goal is selective coordination among protective devices while properly protecting equipment.

Examples of uncoordinated and coordinated protective devices are shown in the diagrams below. In the diagram, the boxes represent protective devices feeding panels or equipment. The goal of a system with selective coordination is for the one protective device closest to a fault (short circuit) to trip and only for that device to trip. When devices further upstream or more than one device trips other parts of the electrical system lose power and are unnecessarily affected.

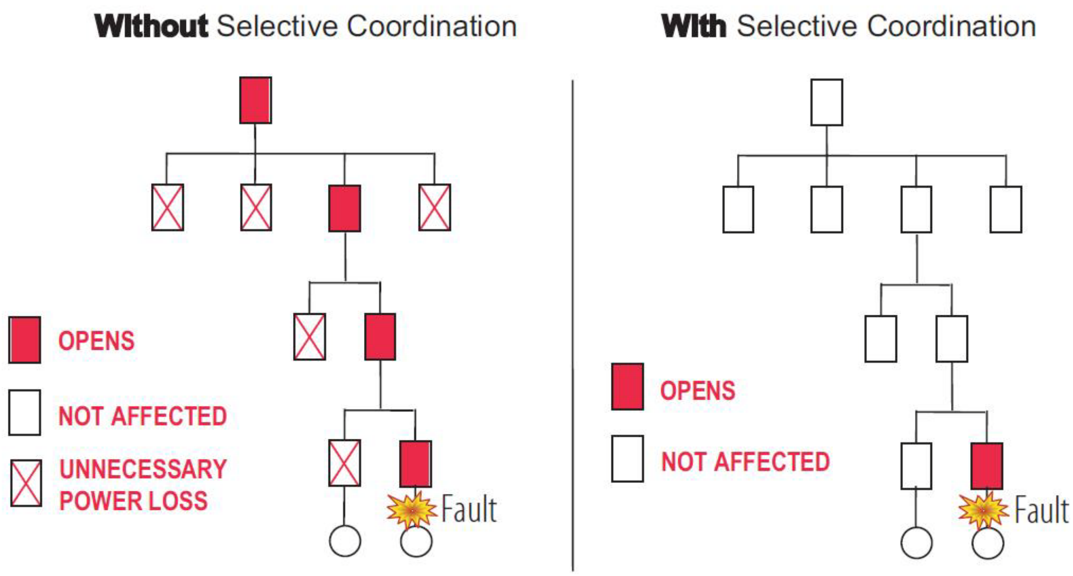


Figure 10

Electrical Systems with and without Selective Coordination

The interruption caused by an electrical outage can be extremely expensive. Imagine a manufacturing facility where a controlled process is required and all products on the line are ruined if the process is interrupted (pharmaceuticals or solid state integrated circuits/chips) or a reservation call center for a theme park….

a hospital operating room…or just the cost of employees sitting around unable to work. The costs of downtime can be staggering and can often be calculated.

Properly set over current protective equipment (circuit breakers and fuses) will operate at the appropriate time, if the fault occurs downstream of this equipment, such that the device upstream will not operate. This offers quick isolation of the faulted circuit, without affecting the upstream system.

In the time current curve shown below, you can see the operating or trip curves for several devices plotted on log – log scale. If the current flowing through a device (during an electrical anomaly) when plotted on the graph versus time, is to the left and below a curve then the device will remain closed and not clear the anomaly. If, however, the current is to the right and above the device's curve, the device would open and clear the fault. Inside the curve is within the manufacturing tolerance of the device and it may or may not open until the current has cleared the curve.

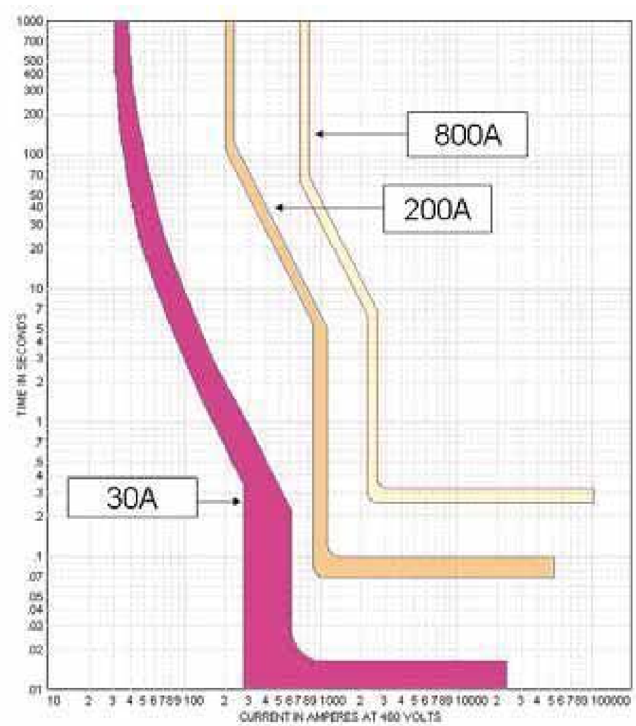


Figure 11

Protective devices exhibiting good selective coordination

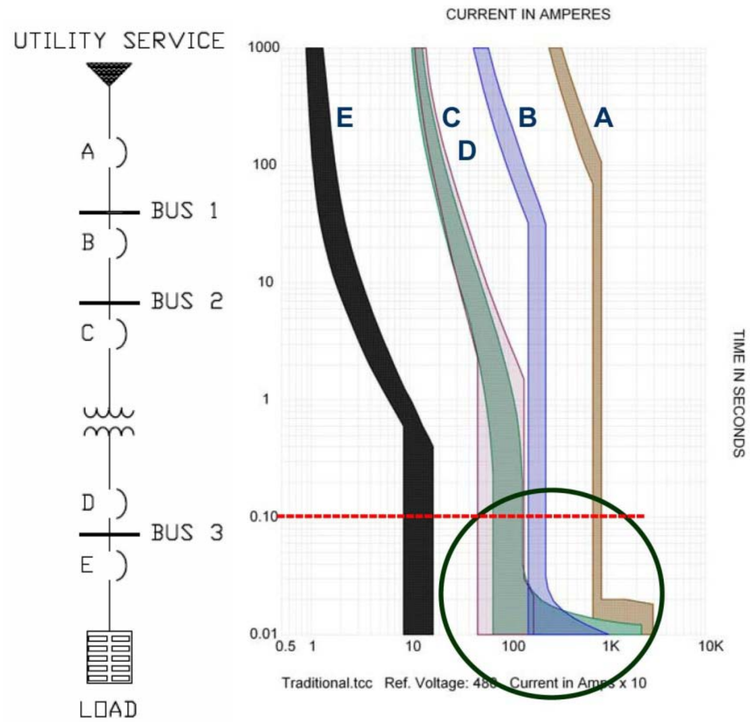


Figure 12

Protective devices exhibiting poor selective coordination

In general terms, where the trip curves do not cross each other and have space in between adjacent curves, then the devices will selectively coordinate with each other. In other words, the device closest to a fault (short circuit) will open or trip first to clear the fault prior to any upstream devices opening or tripping. Proper coordination of protective devices rarely happens by chance. Moving the curves so that they do coordinate requires either changing device sizes or ratings (where possible while still providing the required protection) or changing the model or manufacture to another device of the same rating that offers a different shaped curve or that offers more adjustments to the curves. These changes must be made while providing the required protection to the equipment (panel boards, wires, transformers, etc) that the device is protecting.

Coordination, selectivity or selective coordination: According to ANSI/IEEE C37.100-1981, the term "selectivity" is defined as "a general term describing the interrelated performance of relays and other protective devices, whereby a minimum amount of equipment is removed from service for isolation of a fault or other abnormality".

Selectivity, though desirable, is not the entire goal of a protection system. While striving for as much selectivity as practical, a protection system must provide adequate protection against overloads and interrupt faults as rapidly as possible. Protection and selectivity are often contradictory in their objectives. Fast removal of a fault in a power system can trigger nuisance tripping in adjacent portions of the system or simply not allow the closest device to interrupt the fault so that the largest part of the system may continue operating.

The way to assure that an electrical system's protective devices are properly coordinated is through a protective device coordination study which looks at the concepts we've discussed and selects and sets the devices to achieve the best available balance of selective coordination and protection.

The goals of any protective device coordination study are to:

1. Select the proper operating characteristics of circuit breakers, fuses, relays, etc. to provide required protection while limiting the extent of outages.
2. Provide a backup protection system; that is, if the over current device closest to the fault fails to interrupt the fault for any reason, the next upstream device will operate before any major equipment is damaged.
3. Provide the means to quickly locate a fault after it occurs.
4. Avoid a "cascade" type failure in any part of the system. A cascade type failure is when the larger upstream breaker starts to open before the smaller downstream breaker has fully opened and cleared the fault. This means that for certain faults a main breaker may open in addition to downstream breakers when it would be desirable for only the breaker closest to the fault to have opened.

It is important to note that there are some situations where it is inconsequential if a pair of upstream and downstream protective devices selectively coordinates with each other or not. When the devices protective what is essentially the same circuit.

The hashed protective devices in both circuits shown below do not have to be selectively coordinated with each other because whether one, the other or both devices open the extent of the outage is the same.

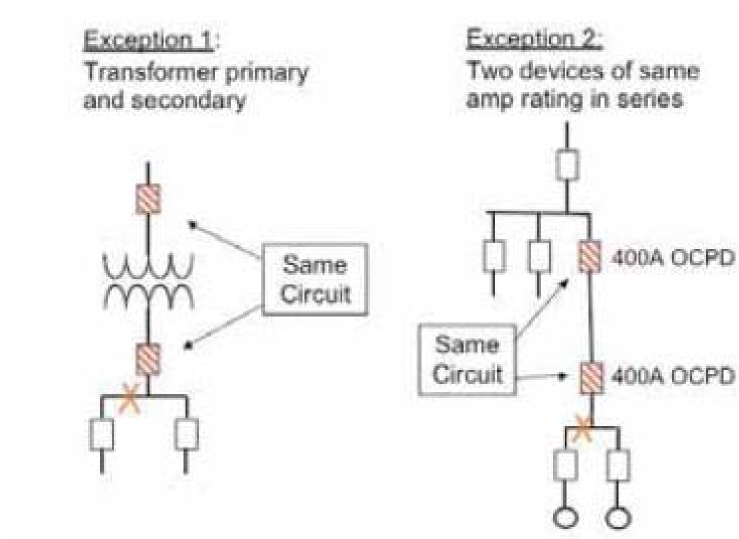


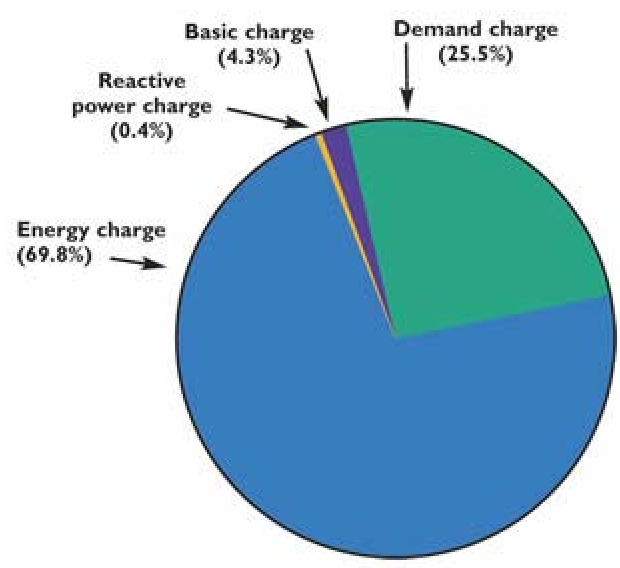
Figure 13

8.0 ELECTRICAL UTILITY BILLING

The following will help you understand how charges are determined for commercial and industrial electric service. Residential services typically do not have charges for Demand or Reactive Power.

How a customer's electricity costs might break down

This chart shows several components that may go into figuring a customer's total electricity costs.

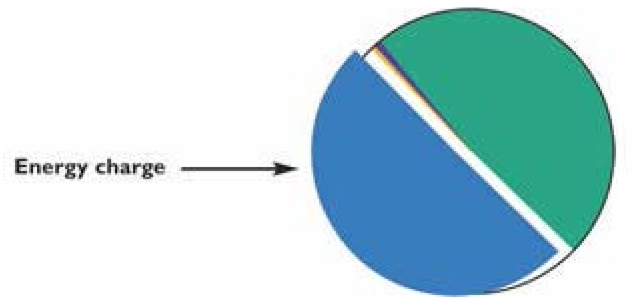


This customer used 190 kilowatts of demand and 62,500 kilowatt-hours of energy this month and had 18 excess kVar this month.

What is an energy charge?

Electricity or electrical energy is measured in kilowatt-hours (kwh). Specifically, one kwh is 1,000 watts used steadily for one hour – a measurement of the rate of electrical energy used multiplied by the length of time it is used.

The larger the power rating of your electrical equipment (kw) and the longer you use the equipment (hours), the more kilowatt-hours you will consume.



For example, a small 5 kw motor running for 10 hours would use 50 kwh, while a large 50 kw motor operating for only one hour would also use 50 kwh.

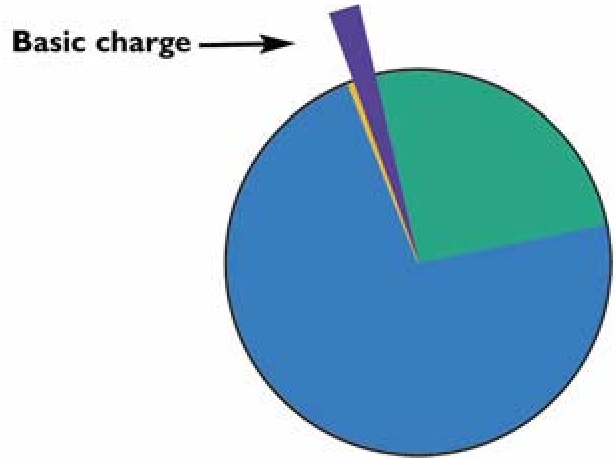
A kwh meter keeps track of the energy used in a billing period, which is normally 30 days. The energy charge is designed to recover variable costs. On some tariff or pricing schedules, you could be billed at different prices for different "blocks" of energy. (A "block" of kwh can be thought of as different increments of kwh, such as the first 10,000 kwh, the next 90,000 kwh, etc.)

What is a minimum charge?

Even if you use no energy during the month, a minimum charge is imposed to cover some of the costs we incur for "standing by in readiness." The minimum charge is often the same as the basic charge that is designed to recover the distribution and billing-related costs. Besides the basic charge, the minimum charge could also include a charge per kw of demand based on a minimum monthly demand for the schedule. Under certain circumstances, a special minimum charge may be required by contract.

What is a basic charge?

The basic charge or customer service charge is intended to recover the distribution and billing-related costs, which include having an electrical distribution system in place, plus the cost of the meter, servicing and reading the meter, mailing the bills and maintaining customer records.

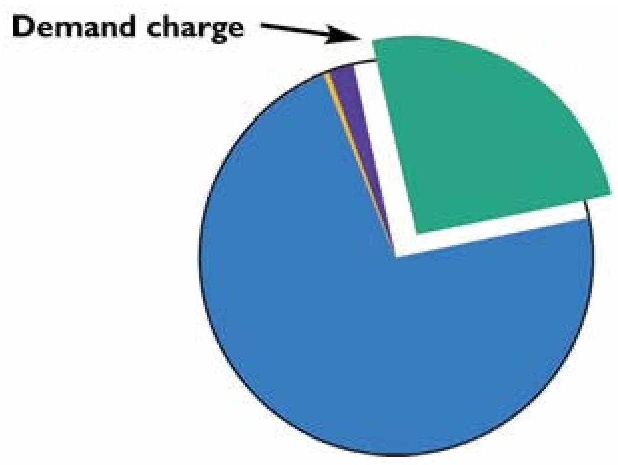


The basic charge may include a per-kilowatt charge based on the load size. Load size is calculated as the average of the two greatest non-zero monthly demands of the last twelve months (see the definition of demand below). This charge is designed to tailor the basic charge to the size of the customer.

What is a demand charge?

Sometimes called a power charge, demand charge is measured in kilowatts (kw). This is a measurement of capacity or the rate at which you use energy. Demand represents the greatest amount of energy used in 15-minute intervals during a billing cycle.

To measure demand, electric meters record the average demand usage over each 15-minute period and record the highest (peak) period for the month.



Within a customer class, if two customers use the same amount of energy but one has higher demands, the customer with higher demands will see higher bills.

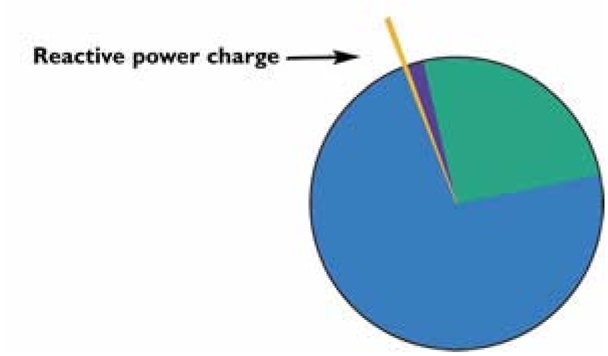
For example, suppose two businesses both use 2,400 kwh per day. One uses energy uniformly during an eight hour day at a constant demand rate of 300 kw (300 kw X 8 hours = 2,400 kwh). The other business operates 24 hours a day at a constant rate of 100 kw (100 kw X 24 hours = 2,400 kwh). Although both businesses use the same amount of energy (2,400 kwh), the first places three times the demand on the electrical system and needs three times the generating capacity and possibly a larger transformer and conductors to meet its demand.

Through the demand charge, each business pays its share of the utility's investment in generation, transmission and distribution equipment standing by to serve.

What is a reactive power charge?

Reactive power, measured in kilovolt-amperes (kvar), results from equipment that draws reactive current. High levels of reactive power are associated with what is called “poor” power factor.

Examples of the type of equipment that draw high amounts of reactive power are motors, older lights with magnetic ballasts and induction furnaces. Many utilities have a reactive power clause in their rate agreements for industrial services and charge a penalty when excessive reactive power is used by the facility. Reactive power consumes transformer and cable capacity but is not billed as energy used – so it uses capacity but provides no revenue to the utility.



You can reduce this charge by turning off unused motors and other equipment and sometimes by installing power factor correction capacitors.

Keep in mind that power factor or reactive power charges are rarely levied on a customer so be wary of energy consultants who recommend power factor correction capacitors to “Save” energy since reactive power is not billed as an energy charge.

9.0 LIGHTING DESIGN CONCEPTS

Lighting design is a unique topic within the practice of engineering. Light plays essential role in our ability to perceive the world around us. Lighting design is part science and part art. It is a science because the behavior of light is ruled by the laws of physics. Artistically, lighting designers can use light and shadows to create a mood and influence feeling…they literally “paint with light” to create the environment we perceive. Lighting has a tremendous influence not only on how we perceive a space but it can even influence how we feel in that space. When it comes to lighting, the adage “perception is reality” absolutely applies!

We will explore some lighting design definitions and characteristics of light and light sources to equip you with a basic understanding of the factors that go into deciding what type of light is recommended for people to do what they need to do in a given environment.

Definitions and how they apply to lighting decisions

From Pegasus Lighting) read more at: http://www.pegasuslighting.com/glossary.html

Color Rendering Index (CRI): a measure of a lamp’s ability to render colors accurately. The scale ranges from 1 (low pressure sodium) to 100 (the sun). A CRI of 85 is considered to be very good. The color rendering index of a light resource tells generally how well a source will render or reveal an illuminated object's natural colors. Light sources with a low or poor color rendering index indicate that some colors may appear unnatural when illuminated by the light source.

Color Temperature: a measure of the color appearance or hue of a light source which helps describe the apparent "warmth" (reddish) or "coolness" (bluish) of that light source. Generally, light sources below 3200K are considered "warm;" while those above 4000K are considered "cool" light sources. The color temperature of a lamp has nothing to do with how hot the lamp will get or how much heat is given off by the lamp. The letter, K, stands for Kelvin. This term is also referred to as the Correlated Color Temperature (CCT).

APPROX. COLOR TEMPERATURE	ASSOCIATED EFFECTS & MOODS	APPROPRIATE APPLICATIONS
2700K	Friendly, Personal, Intimate	Homes, Libraries, Restaurants
3500K	Friendly, Inviting, Non-threatening	New Offices,Public Reception Areas

4100K	Neat, Clean, Efficient	Older Offices, Classrooms, Mass Merchandisers
5000K	Bright, Alert, Exacting Coloration	Graphics, Jewelry Stores, Medical Exam Areas, Photography

APPROX. COLOR TEMPERATURE	LIGHT SOURCE
1600K	Sunrise or Sunset
1800K	Candlelight
1800K	Gaslight
2800K	Household Incandescent Lamp
3000K	Warm White Fluorescent Lamp
3500K	Neutral White Fluorescent Lamp
4100K	Cool White Fluorescent Lamp
5000K	Professional Light Booth
5200K	Bright Midday Sun
6500K	Heavily Overcast Sky

Foot-Candle (fc): the USA unit of measurement of lighting level (illumination or the amount of light reaching a subject) and sometimes spelled footcandle. The international unit of measurement of lighting level (Illumination) is the lux (lx). The relationship between the lux and the foot-candle is 1 fc = 10.76 lux. One goal of lighting design is to put the appropriate illumination or foot – candles on a work plane. The quantity of light is measured by foot-candles. In general terms, the quality of the light is related to the uniformity of the foot candles on a space.

Inverse Square Law: a law that states that the illuminance (E) at a point on a plane perpendicular to the line joining the point and a source is inversely proportional to the square of the distance (d) between the source and the plane, $E = I/d^2$. This means, for example, that if the distance between a light source and the object being lit is doubled or tripled, that the object being lit receives 1/4 or 1/9 illumination (respectively) as it did originally.

Light Loss Factor: a factor used to estimate the illumination lost to a variety of factors such as dirt and dust accumulation, voltage fluctuations, and lamp depreciation to name a few. When lighting calculations are performed – the initial light available from a fixture is de-rated to account for the degradation of the light levels out of the fixture over time. BY using a light loss factor the calculation will yield the proper lighting over time and not just when first installed.

Uniformity: the degree of variation of illuminance over a given plane. Greater uniformity means less variation of illuminance. In addition to providing a certain level of illumination over a plane (e.g. the desk in a classroom or the floor of a parking garage, etc), proper lighting design concerns itself with the uniformity of the lighting. Lighting a space with single high output lamp can provide the same average illumination as many lower output fixtures. The single large fixture in the middle of the space would have a bright hotpot under the fixture and lower illumination levels at the perimeter of the space away from the single fixture. A typical measure of uniformity is the ratio between maximum illumination and minimum illumination in a space. A ratio of 1.0 is perfect uniformity. The higher the ratio is, the less uniform the lighting is. The more fixtures you have to achieve the lighting goals and the further the distance of the lighting source from the plane that the light is being measured, the more uniform the lighting will be.

Basics of Lighting Design

It is beyond the scope of this course to go step by step through the process of producing a lighting design. Instead, we will review the several ways that lighting professionals look at lighting design, from the simple to the sophisticated.

One way to approach lighting design is to ensure that the lighting system 1) provides ambient illumination for orientation and general tasks in the space, 2) task illumination for local, more demanding tasks, and 3) accent illumination to highlight special objects of interest or to guide occupants. An example of this scheme is an open office plan with workstations; a lighting designer might provide one type of ceiling fixture to provide ambient illumination, task lighting at the workstations for detailed work lighting, and accent lighting to highlight pieces of corporate art on the walls.

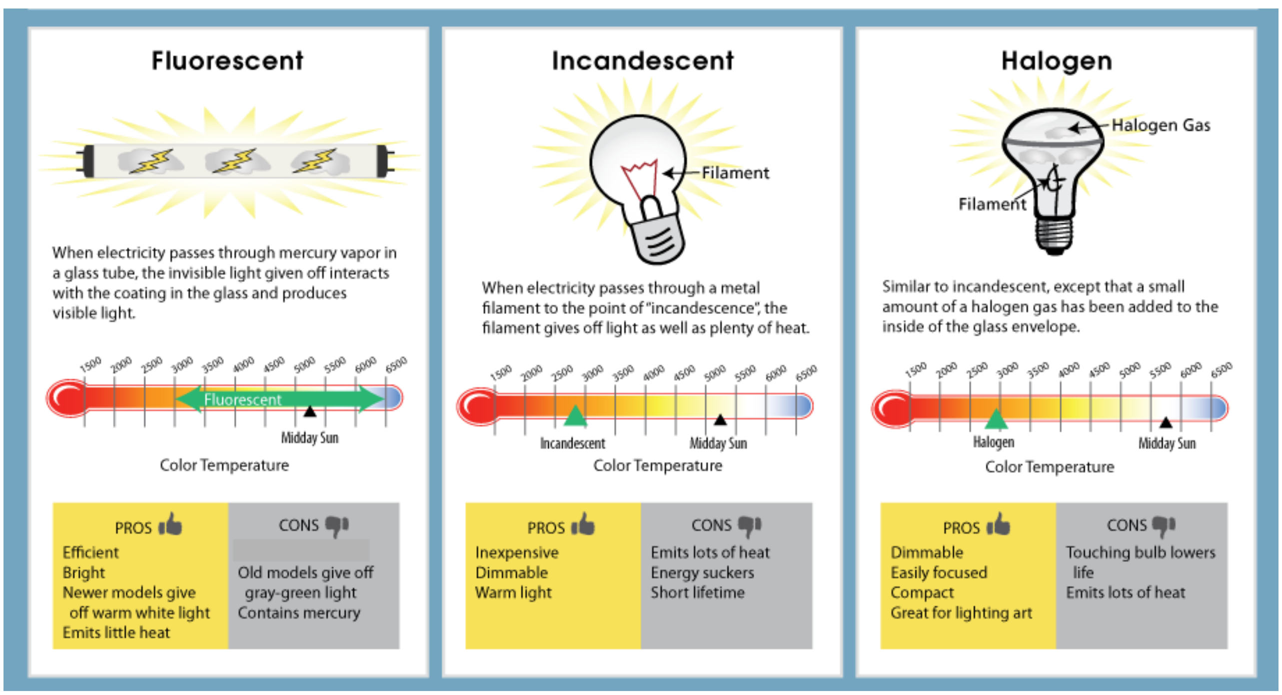
A typical approach to lighting design is, after determining how the space is used, to provide in order, 1) general lighting, 2) localized general, and 3) task illumination to meet these needs. General lighting provides a generally uniform light level on the work plane throughout the lighted space. Localized general lighting is similar but is tailored more to the location of tasks in the lighted space. Localized or taks lighting, also called supplemental lighting, is used to provide light to a specific area. Task lighting delivers light for the purpose of accomplishing a specific task. Like doing work at a desk at school, reading construction drawings, maintaining equipment, etc...

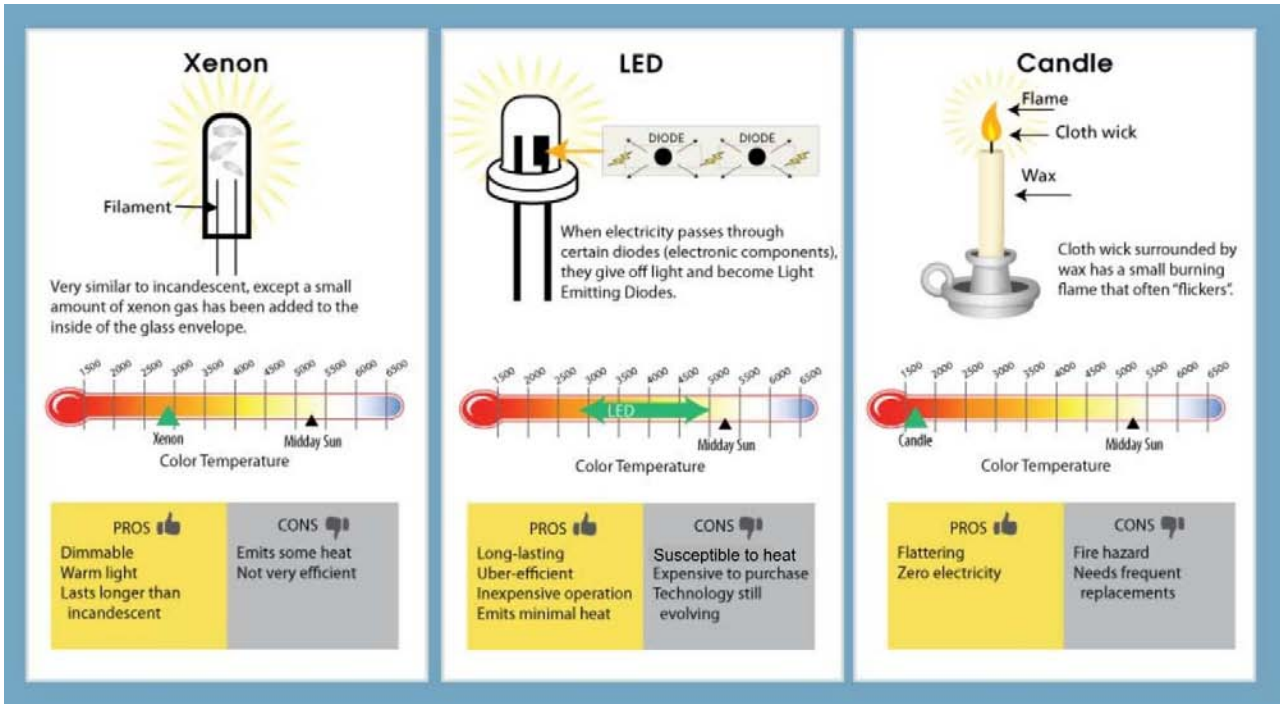
A final way of looking at lighting design is more sophisticated, focused not only on simply providing quantity of footcandles for tasks with accent illumination for highlighting, but also on the art of using light to produce a desired effect.

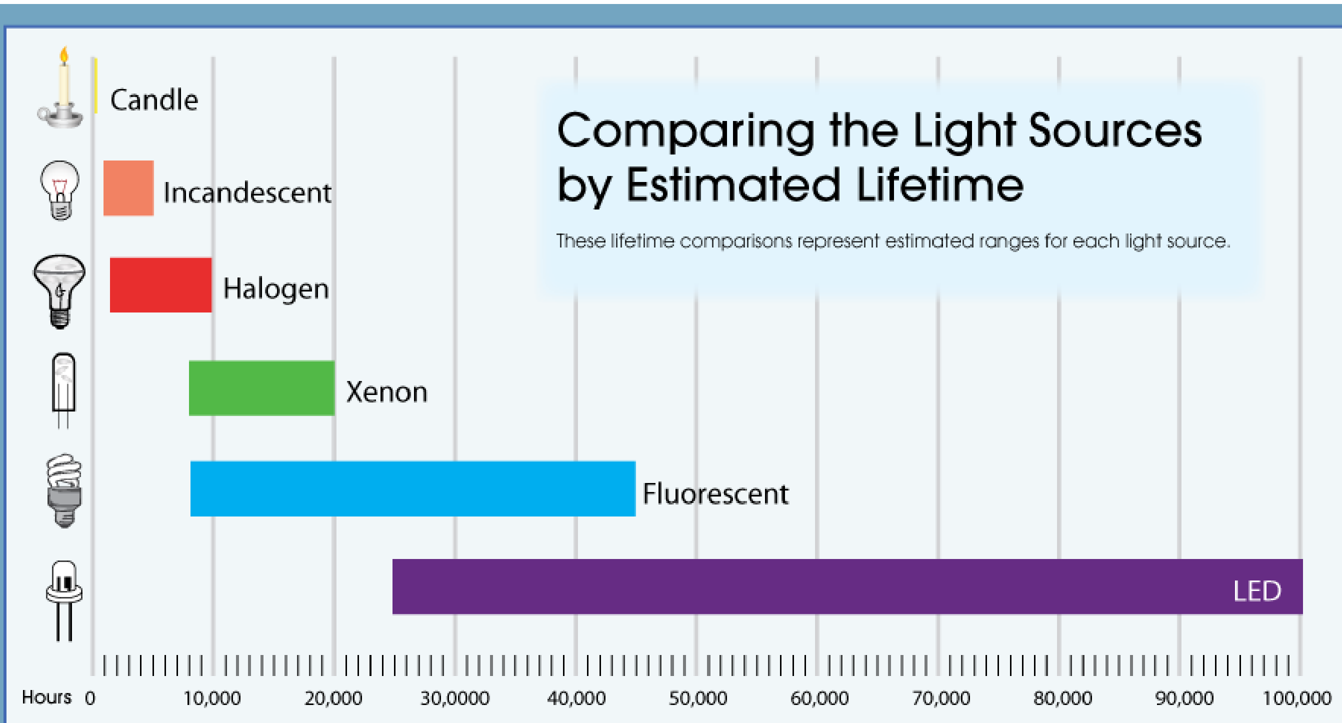
Lighting can affect performance, mood, morale, safety, security and our decision making process. The first step in producing an appropriate lighting design is to ask and understand what the space is used for. The lighting designer can then determine quantity of light, color quality, brightness and other factors.

Light Source

Choosing a light source can be a daunting task. Each different type of light source has pros and cons associated with it in terms of first cost, energy efficiency (operating cost), expected life (which impacts repair, replacement, and maintenance costs), color rendition, color of the light, susceptibility to hot, cold, and changes in temperature. The charts presented below (also compliments of Pegasus Lighting, Inc) presents color temperature, expected life, pros and cons of several common lighting sources.




Xenon
Filament
Very similar to incandescent, except a small amount of xenon gas has been added to the inside of the glass envelope.
Xenon
Midday Sun
Color Temperature
PROS
Dimmable
Warm light
Lasts longer than incandescent
CONS
Emits some heat
Not very efficient
LED
DIODE
DIODE
When electricity passes through certain diodes (electronic components), they give off light and become Light Emitting Diodes.
LED
Midday Sun
Color Temperature
PROS
Long-lasting
Uber-efficient
Inexpensive operation
Emits minimal heat
CONS
Susceptible to heat
Expensive to purchase
Technology still evolving
Candle
Flame
Cloth wick
Wax
Cloth wick surrounded by wax has a small burning flame that often "flickers".
Candle
Midday Sun
Color Temperature
PROS
Flattering
Zero electricity
CONS
Fire hazard
Needs frequent replacements



Which light to choose?

Now that you are familiar with each light source, the next step is to choose the best type of light to use for your project.

Choose Fluorescent...

When you want to be blown away by the amount of light output generated by very little electricity. If you're looking for low-profile, very bright, long-lasting lights, go with fluorescent.

Choose Xenon...

When you want the "warm look" of incandescent lighting but would prefer a bit more efficiency in your light source. Very popular in under cabinet lighting; plus, xenon is dimmable which is a great benefit.

Choose Halogen...

When you need crisp lighting that renders colors perfectly. Often the light source of choice for illuminating artwork and displays, and very popular in recessed lighting.

Choose LED...

When you want your light to be ultra-energy efficient, long-lasting, and cool to the touch. It seems like every day there are more and more choices in LED lighting so it is probably a good idea to look at your LED options for your situation.

Choose Incandescent...

When you want to stick with what you know best. Also, incandescent light bulbs are available in decorative styles (i.e, clear globes) that you can't always find in other light sources.

Choose a Candle...

When you're going for romantic appeal – or pretending you live in the 19th century.

10.0 GROUNDING AND BONDING

- A common misconception among engineers is that grounding and bonding are the same topic. Though they are related, they are not the same. A goal of this course is to clarify each topic.

- The 2005 edition of the National Electrical Code recognized this and changed the title of its Article 250 (which was formerly titled "Grounding") to Grounding and Bonding to reinforce that grounding and bonding are two separate concepts. While distinct. they are directly interrelated through the requirements of Article 250.

- Bonding is the connection of two or more conductive objects to one another by means of a conductor such as a wire.

- Grounding, also referred to as "earthing", is a specific form of bonding wherein one or more conductive objects are connected to the ground or earth by means of a conductor such as a wire or rod.

- Proper grounding of objects (conductors) in the field will normally incorporate both bonds between objects and a specific bond to the earth (ground).

> Grounding, for the purposes of this course, is making an intentional connection to the earth or another conductive body of relatively large extent that serves in the place of the earth. Another word for grounding is "earthing". If we keep this in mind and use the term "earthing" whenever we use the term "grounding" it will help us understand what grounding (or earthing) is and what it isn't.

> Bonding is the interconnecting of conductive parts for the purpose of maintaining a common electrical potential and to provide an electrical conductive path that will assure electrical continuity and capacity to conduct safely any current likely to be imposed. *IEEE Std. 1100-1999.*

According to the National Electrical Code Article 250.4(A), the following are the

> The following general requirements identify what grounding and bonding of electrical systems are required to accomplish. The prescriptive methods contained in National Electrical Code Article 250 shall be followed to comply with the performance requirements of this section.
>
> **(1) Electrical System Grounding** Electrical systems that are grounded shall be connected to earth in a manner that will limit the voltage imposed by lightning, line surges, or unintentional contact with higher-voltage lines and that will stabilize the voltage to earth during normal operation.
>
> **(2) Grounding of Electrical Equipment** Non–current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, shall be connected to earth so as to limit the voltage to ground on these materials.
>
> **(3) Bonding of Electrical Equipment** Non–current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, shall be connected together and to the electrical supply source in a manner that establishes an effective ground-fault current path.
>
> **(4) Bonding of Electrically Conductive Materials and Other Equipment** Electrically conductive materials that are likely to become energized shall be connected together and to the electrical supply source in a manner that establishes an effective ground-fault current path.
>
> **(5) Effective Ground-Fault Current Path** Electrical equipment and wiring and other electrically conductive material likely to become energized shall be installed in a manner that creates a permanent, low-impedance circuit facilitating the operation of the overcurrent device or ground detector for high-impedance grounded systems. It shall be capable of safely carrying the maximum ground-fault current likely to be imposed on it from any point on the wiring system where a ground fault may occur to the electrical supply source. The earth shall not be considered as an effective ground-fault current path.

General Requirements for Grounding and Bonding for Grounded Systems.

Let's review these general requirements presented in the National Electrical Code for grounding and bonding to better understand which requirements are addressed through grounding (earthing) and which are addressed through bonding techniques.

- Requirements (1) and (2) are grounding issues – they specifically reference "connection to earth".

- Requirement (1) is system grounding or the intentional connection of a system conductor on a grounded system to earth. The stated purpose of this intentional connection to earth is to limit the voltage imposed by lightning, line surges, or unintentional contact with higher-voltage lines and that will stabilize the voltage to earth during normal operation.

- Requirement (2) is accomplished by bonding non-current carrying metal objects to the equipment grounding conductor which is bonded to the grounding electrode conductor at the service entrance and on the load side of each separately derived system.

- Requirements (3), (4), and (5) are bonding issues. By bonding all metal items likely to become energized in the event of a fault (and by providing an equipment grounding conductor bonded to these items and to the source), an effective ground current path is provided facilitating the operation of over current protective devices. Simply put – the fault current path must be of sufficiently low resistance to allow fault current of sufficiently high magnitude to cause the protective device upstream to trip. Bonding also helps assure personnel safety, so that someone touching two pieces of equipment at the same time does not receive a shock by becoming the path of equalization if they happen to be at different potentials. Potential equalization is realized by the bonding of metal objects. For the same reason that bonding protects people, it protects equipment, by reducing current flow on power and data conductors between pieces of equipment at different potentials.

It is important to understand the difference between bonding and grounding (earthing). Keep in mind that earth (soil) is a poor conductor and should never be relied on as part of the ground fault current return path – that is the path intended to clear a fault. The reason that earth/soil should never be relied upon as part of the ground fault return path is due to its high resistance.

The resistance of earth is on the order of one billion times that of copper (according to IEEE standard 142 Section 2.2.8) and will only allow a few amperes (1-10) back to the source.

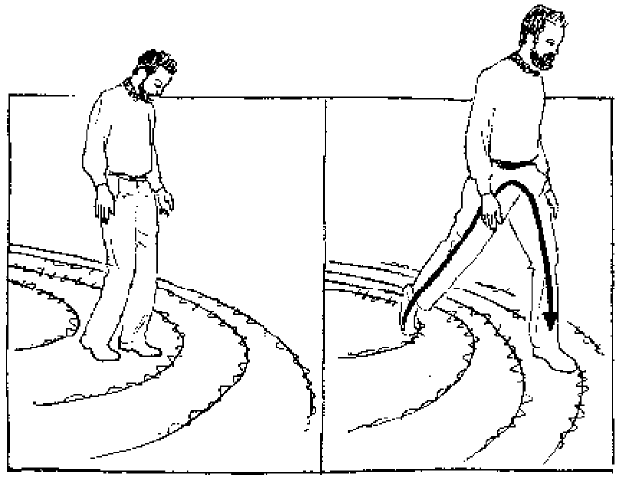
The Institute of Electrical and Electronics Engineers Standard 142 states "The most elaborate grounding system that can be designed may prove to be inadequate unless the connection of the system to the earth is adequate and has a low resistance. It follows, therefore, that the earth connection is one of the most important parts of the whole grounding system. It is also the most difficult part to design and to obtain... For small substations and industrial plants in general, a resistance of less than 5 ohms should be obtained if practicable."

However, from a practical standpoint, a grounding electrode, no matter how low its resistance cannot be depended upon to clear a ground fault. If equipment is effectively grounded and bonded, then a path of low impedance (not through the grounding electrode to earth and through the earth back to the source) must be provided to facilitate the operation of the over current devices in the circuit. While the lowest practical resistance of a grounding electrode is desirable and will better limit the potential of equipment frames above ground, it is more important to provide a low-impedance path to clear a fault promptly to ensure safety. To obtain the lowest practical impedance, the equipment grounding circuit must be connected to the grounded conductor within the service equipment.

Neither grounding (earthing) nor the grounding electrode system helps clear electrical faults. It is the bonding of the metal objects to the equipment grounding conductor back to the source that provides the path of sufficiently low impedance to allow over current protective devices to operate and clear faults. If the ground fault path relies on the earth there will not be enough fault current (due to the high impedance) to trip the protective device.

Remember Ohm’s Law, V = I x R? Consider the following example. A 120 Volt phase conductor is intentionally connected directly to the ground (if a live, bare wire were terminated to a ground rod in the dirt) and the ground rod has 25 ohms resistance back to the grounded power source (transformer) the earth. This scenario would yield just less than 5 Amperes (4.8A) of ground fault current. This intentional connection to earth would not yield enough fault current to trip even a 20A circuit breaker since a 20A circuit breaker can carry as much as 16 Amperes continuously.

The same high impedance of the earth that limits the fault current to levels less than what is required to open protective devices will create dangerous step or touch voltages in the vicinity of the ground rod that can be deadly. A step voltage occurs when charge current disperses and passes through resistive earth or other material and a voltage drop (voltage difference) occurs between two points and that voltage is equal to the current (amperes) flowing times the resistance (impedance). The voltage potential from the point of electrical contact with the earth radiates in concentric rings with a voltage difference between the rings as shown in the figure below.



Several people have died from this very condition – where street lighting poles were grounded (earthed) with ground rods but had no equipment grounding conductors to serve as an effective fault current path back to the power source. The key point to take away from this discussion is that the earth, in general, is not a good grounding path. This is especially true in places where sand or sandy soil is prevalent with sand being more like an insulator than a conductive material.

An Introduction to Electrical Engineering Concepts for the non – Electrical Engineer

Examination

After you have completed answering all of the questions, go back and check your work. Make certain that you have marked only one answer for each question. There is only one correct answer to each question. Make certain that you have answered each question. Any question that is left blank will be counted as incorrect.

A score of 70% is required to complete the course. Failing to achieve a 70% score all your answers will be erased. You will have three opportunities to achieve a passing grade. Failing to score a passing grade on the third attempt will block you from further attempts and your course fee returned to you.

Once you have successfully completed exam you will be able to print out your completion certificate. We suggest you file it electronically or print it out should you be audited by your licensure board for compliance with continuing education requirements. At that time you will also be able to compare your answers to the school answers on questions you may have missed.

1. The inverse square law states which of the following about illuminance?

   a. The illuminance at a point on a plane perpendicular to the line joining the point and a source is inversely proportional to the square of the distance between the source and the plane.
   b. The illuminance is most uniform when square fixtures are inverted, or hung upside down.
   c. The illuminance at a point on a plane perpendicular to the line joining the point and a source is inversely proportional to the square root of 2 times the distance between the source and the plane.
   d. None of the above

2. What are the purposes of bonding?

   a. To equalize potential between metal objects.
   b. To provide a low resistance path back to the power source to facilitate the operation of overcurrent protective devices in the event of a ground fault.
   c. Limit system voltage imposed by lightning, line surges, and unintentional contact with high voltage lines.
   d. a and b

3. According to the text, if you connect a live 120 volt, 20A circuit conductor (protected by a 20A circuit breaker) to a ground rod that has a resistance of 60 ohms through the earth back to the source (grounded transformer), ohms law tells us that?

   a. 1/2 amp of current will flow, enough to trip the circuit breaker because it is a ground fault.
   b. 2 amps of current with flow, enough to trip the circuit breaker because it is a ground fault.
   c. ½ amps of current will flow, not enough to trip the circuit breaker.
   d. 2 amps of current will flow, not enough to trip the circuit breaker.

4. The goals of a protective device coordination study include which of the following?

   a. Selecting the proper operating characteristics of circuit breakers, fuses, relays, etc. to provide required protection while limiting the extent of outages.
   b. Provide a backup protection system; that is, if the over current device closest to the fault fails to interrupt the fault for any reason, the next upstream device will operate before any major equipment is damaged.
   c. Avoid a “cascade” type failure in any part of the system.

d. All of the above.

5. Which of the following are true?

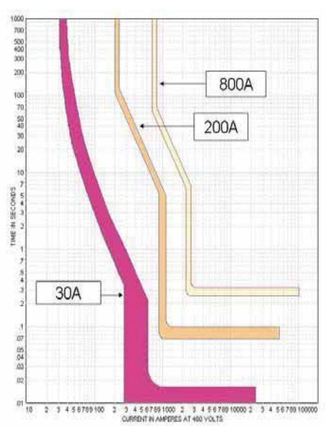
a. Overloads are typically greater than six times the normal current level.
b. Short circuits are typically measured in thousands of amperes and if not cut off in a matter of a few thousands of a second, very bad things happen.
c. Both a and b
d. None of the above.

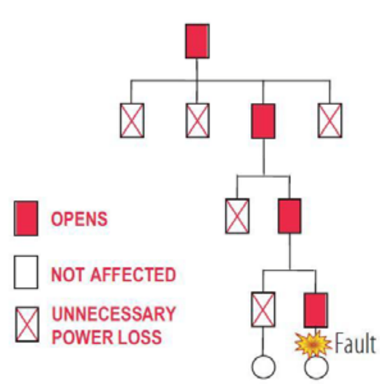
6. Which is true according to the National Electrical Code?

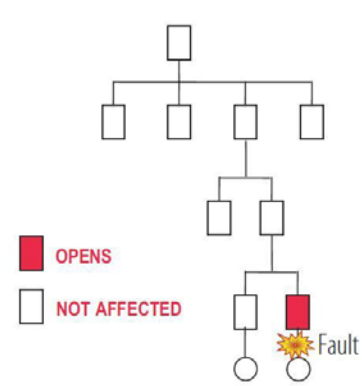
a. Arc Flash Hazard is defined as “A dangerous condition associated with the possible release of energy caused by an electric arc.”
b. Arc flash hazard will not exist when energized electrical conductors or circuit parts are within equipment in a guarded or enclosed condition provided a person is interacting with the equipment in such a manner that could cause an electric arc.
c. Even ender normal operating conditions, enclosed energized equipment that has been properly installed and maintained is likely to pose an arc flash hazard.
d. None of the above

7. Of the following three figures, which can be said to illustrate selective coordination between protective devices?

a. None of them
b. All of them
c. Two of them
d. One of them







8. According to the text, lighting uniformity is which of the following?

   a. Is often achieved by using fewer lighting fixtures with higher individual output rather than by using more evenly spaced lighting fixtures of less individual output.
   b. Can be expressed by the ratio of maximum to minimum illuminance with a lower number indicating more uniform lighting.
   c. Both a and b
   d. None of the above

9. Which type of lighting is the base lighting addressed first in a lighting design?

   a. General lighting
   b. Localized task lighting
   c. Accent lighting
   d. Shadow lighting

10. To which of the following mechanical quantities is voltage analogous?

   a. Rate of flow
   b. Volume of flow
   c. Pressure produced by an elevated water tank
   d. Cross section and smoothness of a pipe's interior

11. To which of the following mechanical quantities is electrical system resistance analogous?

   a. A gate valve.
   b. A paddle wheel or turbine.
   c. A membrane in a water tank.
   d. A reduced diameter or restriction in a pipe's interior.

12. Which of the following is true regarding the color temperature of light?

   a. The color temperature of a light source is a measurement of its radiated heat in degrees Kelvin.
   b. The lower the degrees Kelvin of a light source, the "cooler" the light.
   c. The 1800K light from a candle is considered warmer than the 5000K light from an LED fixture
   d. Medical exam areas typically warrant "warm" lighting.

13. Arc Flashes are characterized by all of the following, except which one?

   a. Temperatures that can exceed 25,000 degrees F.
   b. Vaporized metal that can expand by a factor of nearly 70,000 times by volume.
   c. Accompanied by intense radiant heat.
   d. Require a person to physically contact a live electrical part.

14. Which of the following are not benefits of LED lighting?

   a. Long lasting
   b. Very energy efficient costing little to operate
   c. Emit little heat
   d. Can survive with no problems in extremely hot environments.

15. Which is not a subsystem of the electrical power system?

   a. Transmission Subsystem
   b. Distribution Subsystem
   c. Utilization Subsystem
   d. Fuel delivery Subsystem

16. According to the text, which of the following is correct?

   a. The magnitude of arc flash energy is directly related to time (duration of fault) of the arc flash event.
   b. The magnitude of arc flash energy is directly related to the distance from the arc squared.
   c. The magnitude of arc flash energy is indirectly related to the power (fault current) available at the arc.
   d. All of the above

17. Which of the following charges are NOT typically associated with utility electrical billing for commercial occupancies?

   a. Energy charges
   b. Basic charges
   c. Demand charges
   d. Reactive power or poor power factor charges

18. Which of the following are not components of a typical thermal magnetic circuit breaker?

   a. Arc chute
   b. Brake fluid

c. Trip bar
d. Magnetic element

19. With regard to power system frequency which of the following is false?

a. Most US equipment will operate properly when powered by any frequency power as long as it less than 60 Hz.
b. In the United States, the frequency of electrical power is 60 Hz.
c. A hertz is one cycle per second.
d. It is an expensive undertaking to convert a power system from one frequency to another.

20. What are the purposes of grounding (earthing)?

a. Limit system voltage imposed by lightning, line surges, and unintentional contact with high voltage lines.
b. Stabilize voltage to earth during normal operation.
c. To equalize potential between metal objects.
d. a and b