A SunCam online continuing education course

What every Engineer should know about Power Engineering fundamentals

by

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1. INTRODUCTION: All too often I speak to recently graduated electrical engineers and sadly they have no idea what a conductor or conduit is or looks like. I'll ask them, "have you ever seen an electrical panelboard?" It is a fact that many engineering students study calculus, physics, chemistry etc, and never actually get to see or learn about actual physical electrical equipment like panelboards, circuit breakers, conduit and conductors. I was lucky to have my Dad and brothers build their houses, so I was introduced to panelboards, conduits, conductors, Romex etc. I now too have just recently built my own house, installing all of the electrical, plumbing and HVAC. This brief course will educate you on some fundamental electrical design components which you will find in everyday life and will see at every construction site. This is by far not all inclusive of all aspects of power electrical engineering as each project has its own equipment and design issues. This is meant to cover the typical equipment and appurtenances on a typical industrial, commercial or residential engineering project. My field of expertise is in the heavy industrial wastewater, water, commercial, municipal, government, power and residential industries. I have more than 16 years' experience as a professional electrical power engineer. I am licensed in 5 states and have worked on several projects across the US.

2. PANELBOARDS: Have you ever lost power at your house after using a hair dryer or vacuum? Chances are you tripped a circuit breaker that was located inside your main panelboard. Panelboards come in many different shapes and sizes, but all of them contain circuit breakers for all the circuits inside your house. The majority of residential houses today will have a 240/120v panelboard located near the Utility incoming line. Panelboards can be located outside or inside. They sometimes contain the main Utility meter and usually will have a main breaker for protection and shutoff.

In the USA, all household receptacles are 120v, with some appliances requiring 240v. In the panelboard, there are circuit breakers, which can be rated from 15A to 200+A. The circuit breakers can be 1-pole type, which are for 120v loads or 2-pole types, which would be for 240v loads. An electric dryer is a good example of an appliance that would typically require a 30A or 40A, 2-pole circuit breaker, as it can use a good amount of power. When you go home tonight, take a good look at your existing panelboard at your house or apartment, open it up and look at the circuit breakers.

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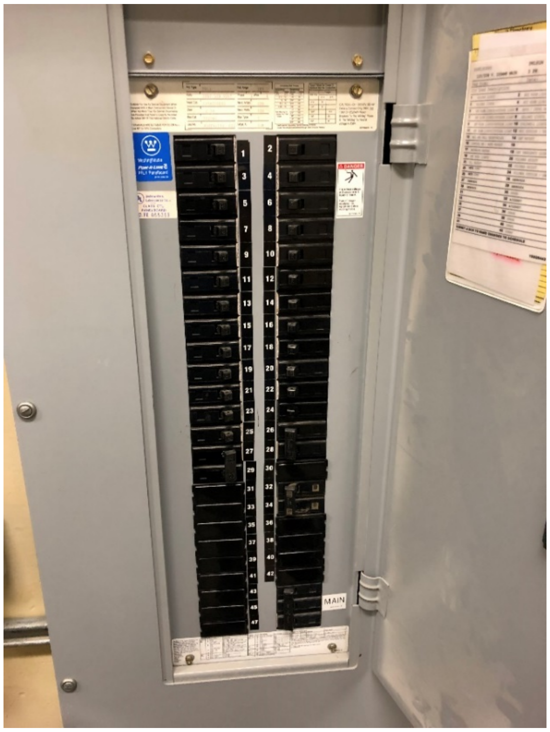
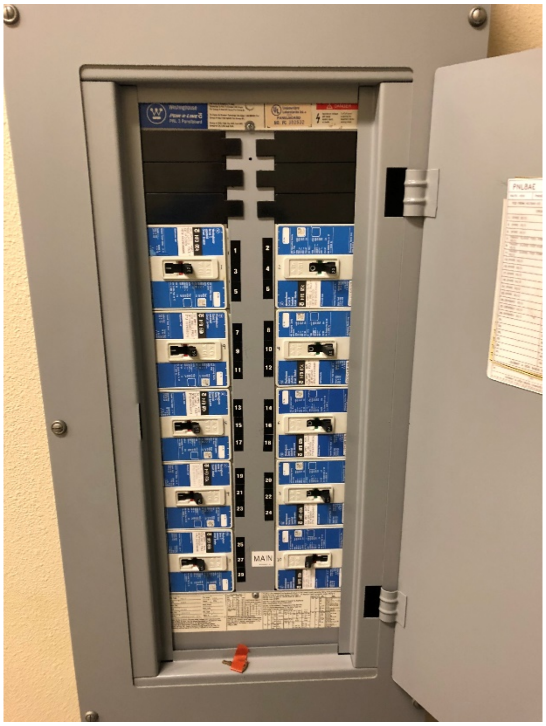


240/120V panelboard and circuit breakers



480v, three phase panelboard and circuit breakers

Residential Meter/Mains

Takeaways: Panelboards are used everywhere from your own house or apartment, to commercial buildings, and large plants. There are many different voltages and sizes. Some have room for 12 1-pole circuit breakers and some have room for 42 1-pole circuit breakers. Some also have the Utility main circuit breaker and the Utility watt-hour meter inside the panel.

3. CIRCUIT BREAKERS: Circuit breakers are seen in every panelboard, motor control center, switchboard and control panels. They protect the conductors and panel from over current and short circuit. The circuit breakers not only protect the conductors but also serve as disconnect for the power circuit. Circuit breakers can be push on or bolt-on with the bolt-on being more expensive. Circuit breakers are sized per the National Electric Code (NEC) and depend on the load they are protecting. You can also use fused switches in lieu of circuit breakers. However with fuses, once the fuse blows, they will need to be replaced. With a circuit breaker, if the breaker trips, it can be reset. Typically, a tripped breaker means a fault or short happened somewhere in the circuit. It is best to check out the circuit if the circuit breaker trips. There are many different types of breakers with many different ratings, so engineering calculations for a properly designed system is important. There are trip curves for each breaker as well that should be looked at for coordination.

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1-pole circuit breaker and 2-pole, 20A circuit breaker

Larger molded case circuit breakers are used in motor control centers and switchboards for protecting the feeder conductors and have ampere ratings from 20A to 2000A. These breakers can also have relay protection units with them for coordinating with upstream protection. There are many different types of breakers for different voltages and are beyond the scope of this course.

Molded case circuit breaker

Takeaways: Circuit breakers come in all shapes and sizes. For residential, arc-fault rated breakers are becoming the code standard. Push on breakers are for residential type panelboards. For commercial and industrial, I recommend bolt on breakers as they are more secure. Be sure to match the short circuit rating of the breakers with the rating of the main equipment. Always make sure the breaker or protection device is sized correctly.

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4. CONDUITS: The definition of conduit is "a tube or trough for protecting electric wiring." If you ever visit a commercial building or industrial building, take a look around and you will see hundreds of conduits. In residential houses, conduits are not used as often. A type of conductor called Romex is used in houses and does not require the use of conduits. Refer to Romex in the Conductors paragraph. Conduits are used to route conductors from equipment to equipment and often used for protection of the conductors inside. Conduits for residential and light commercial are usually type EMT, which stands for electrical metallic tubing. EMT conduit is extremely thin and can easily be bent.

The main conduits utilized in construction are PVC schedule 40, PVC schedule 80, Galvanized Rigid Steel (GRS), Rigid Aluminum, Fiberglass and PVC-coated conduits. Along with conduits, there are many types of fittings. Boxes, couplers, straps, reducers, condulets etc. Conduits come in several different sizes ranging from ½" to 6" in diameter. For industrial type projects, typically ½" is only allowed for lighting circuits. When designing conduits for a project, you must size the conduits per the NEC fill limitations. I will leave the NEC code and tables for another paper, as it can get pretty detailed for engineering. Just remember that there are a myriad of situations that require proper electrical engineering for specifying the conduits.

EMT Conduit Couplings

PVC conduit, which stands for Poly-Vinyl-Chloride, is a plastic conduit used primary in underground ductbanks. PVC conduit is UV resistant, but if you leave it out in the sun for a

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while, it will discolor and become brittle. If you install PVC at home, it is a good practice to paint it black to protect it. In fact, while building a recent house in Northern California, all the water pipes installed outside the house had to be painted black per the building code.

PVC comes in many different types, but the majority of conduit used in construction is type Schedule 40 and 80. The schedule refers to the wall thickness of the PVC conduit. Schedule 40 is thinner than schedule 80. Schedule 80 PVC would typically be used for commercial or industrial where a greater degree of protection is desired, such as under a roadway or construction path. There is another type sometimes used for water, called CPVC, which has a thinner wall that schedule 40. For industrial type projects, PVC schedule 40 and schedule 80 are specified.

PVC Schedule 40, Belled end

Takeaways: PVC conduit will not last in the sun after a couple of years. Suggest any PVC conduit left outside be painted black for protection. Conduit should always be strapped and secured, as it will sag over time. Best to use in ductbanks and concrete encased ductbanks. Long 20’ sticks of PVC can be ordered with bell ends so couplers are not required. All couplers should be primed and glued with PVC glue.

GRS, Galvanized Rigid Steel is a rugged steel conduit that offers a lot of protection. Also called Rigid metal conduit (RMC). GRS is used on exposed conduit above ground and is usually installed with threaded ends. The conduit is extremely robust and cannot be easily dented. GRS

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is used in heavy commercial and industrial construction. It is a lot more costly to install since field bends and cuts require a special tooling machine to cut and thread the ends.

Galvanized Rigid Steel Conduit, 2" threaded end

IMC, Intermediate metal Conduit, is like GRS except has a thinner wall and weighs about 1/3 less than GRS. You can read more about this conduit on the WWW. However, I do not specify or use since GRS is the standard for heavy Industrial.

EMT, Electrical Metallic Tubing conduit is a thin walled conduit which can be easily bent. It is usually installed in residential and light commercial projects. I often see this at restaurants, breweries, stores, etc. Usually the fittings are screw type offering a less rugged connection point which can come apart much easier than threaded GRS. EMT can be field bent with a bender rather easily, making installation much cheaper. EMT is used in industrial type construction for lighting, receptacles or inside CMU Brick walls. It should not be allowed for process areas in industrial where subject to damage from machines or atmosphere.

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EMT Thin wall

ARC, Aluminum Rigid Conduit, is like GRS except it is made out of Aluminum instead of steel. It is a good alternative when you may need non-sparking, non-magnetic, and non-corrosive protection for conductors. It is not quite as rugged as GRS, but will offer more protection than EMT. One thing to watch out for with ARC is dissimilar metals and corrosion in concrete. The aluminum coupled with any ferrous metals can cause galvanic corrosion and erode the conduit over time. The ARC in concrete can cause significant corrosion. Use caution when specifying ARC.

PVC-Coated conduits offer a greater degree of protection from corrosive environments. PVC-coated GRS is typically specified at waste water treatment plants for corrosive environments like Aeration basins, Bar screens and Digesters. PVC-coated raceways are generally installed as a system, meaning the fittings, conduit bodies, straps, hangers, boxes etc., are also coated. PVC-coated GRS elbows are often used for conduit bends emerging from concrete of ductbanks to protect conductors from "burning" or cutting into the conduit. When just PVC conduit is used, the conductors can actually cut thru the 90 degree bend when pulling the conductors thru. When the runs are long and conductors are larger, a PVC-coated GRS elbows are specified or detailed.

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Another tip when specifying this conduit is to make sure when installed, the installer is trained and certified to install. It takes careful tooling to make sure the outer PVC coating is not marred. When marred, the inner GRS is exposed to the atmosphere and will rust and corrode. It is good practice to make sure all marred conduits during construction are painted with sealant to insure conduit is protected.

Takeaways: PVC-coated conduit is expensive to purchase and expensive to install. I see PVC-coated GRS installed in highly corrosive environments like wastewater treatment plants. PVC-coated is used on heavy industrial and less on commercial or residential. Remember to have a qualified electrician install and to cover up scuffs on the conduits with paint or sealant.

Liquid tight flexible conduit, is extra flexible conduit providing mechanical and moisture protection for conductors. It is usually used for final connections to motor, light fixtures and equipment. It offers some movement in equipment and not so rigid. There used to be a limit to 6' in length in the NEC, however, now there is no limit. I like to limit the length to 6' as longer installations of Flex look sloppy with the conduit not being straight and neat. There are some exceptions in the NEC, so be sure to look it up and know the rules. This outline is simply bringing up construction ideas and issues I have seen in the past.

Liquid tight Flexible Conduit, (semiconduits.com, internet)

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Takeaways: Do not overuse flex, it will look sloppy on installations. Limit the length allowed. Sometimes these are sold as whips, with the conductors already installed in the flex conduit. You can buy these at Home depot or Lowes for connection power to pumps and motors.

Fiberglass Conduit. Fiberglass conduit is useful in highly corrosive locations. It does not rust. Fiberglass conduits are UV resistant and can be installed outdoors. They make "hot-boxes" so that field bends can be made on site. I would say that fiberglass conduit is an alternative to using PVC-Coated GRS and would typically cost about the same.

Cable Tray. Cable trays are used to protect and provide a raceway for conductors. Cable trays are useful for when there would be several conduits required for the same routing. Cable trays would be used over Motor Control Centers (MCCs) and Switchgears. They are installed over the power distribution equipment and out to the electrical equipment, motors, valves and control panels. They are usually seen in equipment galleries on large projects. The cable tray can be ventilated ladder type and solid bottom or top type. Cable tray can be made out of aluminum and steel and even stainless steel. It can range from 6" wide to 36" wide. A UL rated type CT conductor should be specified for cable tray use. Cable trays are used in lieu of conduits for the main run, however, conduits are utilized to route the conductors in and out of the cable tray to the equipment.

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Ladder type ventilated cable tray

Takeaways: Cable tray is a great option where large MCCs and switchgears and electrical equipment will be installed in an electrical room and fed out to equipment. Instead of hundreds of conduits, a cable tray will route all the conductors going to the same locations. Tray rated conductors must be used with cable tray.

5. CONDUCTORS: Also called wires, cables, feeders etc. I will use conductors following, since they are conducting the electricity to power the equipment or motors. Conductors come in many different sizes and have different types of insulations. Conductors come stranded and solid cores. Solid cores are usually reserved for the smaller conductors for wiring to devices. For bendability, stranded core is recommended for the larger sizes. I usually specify XHHW-2 type insulation conductors for all power and control feeders and THWN-2 or THHN for lighting and receptacles conductors. There are also copper conductors and aluminum conductors, which

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have their purpose and place. For the majority of projects, copper is used. Aluminum conductors are used by Utility companies and sometimes for residential feeders.

Colored THHN conductors

THHN/THWN-2 insulation: This is the most common type of conductors used in commercial and industrial type projects. THHN insulated conductors have a PVC insulation and a Nylon jacket. The conductor is rated for a maximum conductor temperature of 90° C in dry locations and 75° C in wet locations. THHN is usually specified in dry locations for lighting and receptacles only. Utilize THWN-2 insulation, which is good for 90° C in dry and wet locations. This is usually specified for light industrial or commercial. Anytime you have conductors being installed underground, they should be specified for 90° C when wet. THHN or THWN-2 conductors are the least expensive and have the least service life, typically around 20 to 25 years.

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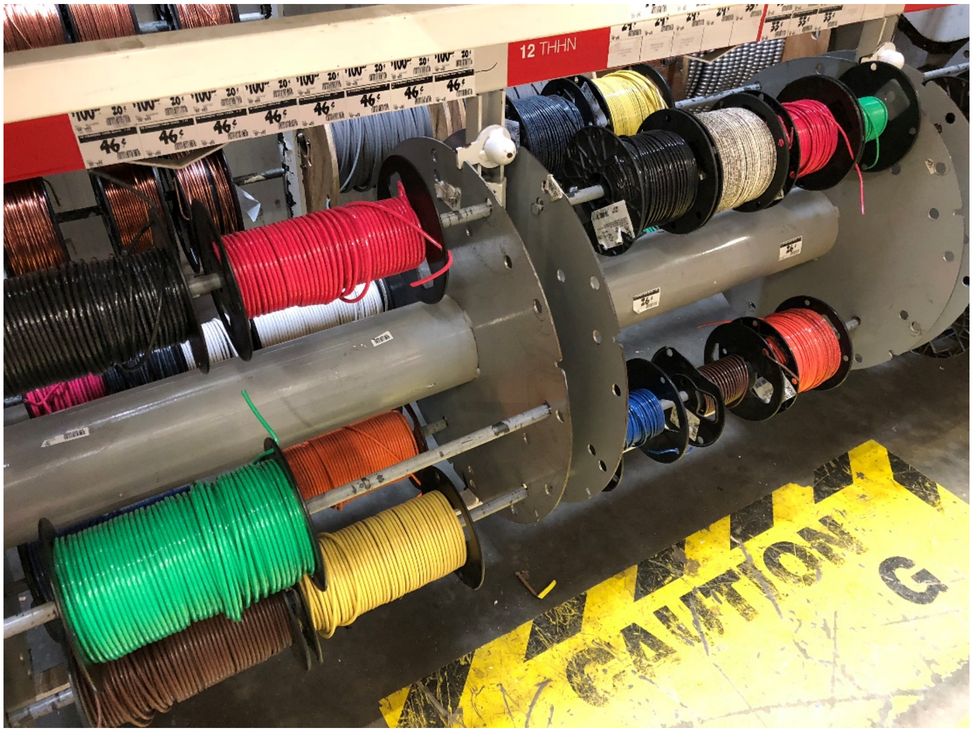

Variety of conductors

XHHW-2 insulation: XHHW-2 is a heavier duty insulated conductor with a rating of 90° C wet or dry. The insulation is XLPE, cross linked polyethylene, which offers more protection than the THHN PVC insulation. This conductor is typically specified for heavy industrial. Its service life is 25 to 30 years and more expensive than THHN.

RHW-2 insulation: RHW-2 insulation conductors are the most expensive conductors and have the longest service life of over 30 years. They have XLP insulation, but with a rubber outer layer offering more protection for the conductor. This conductor can be more difficult to install. I see this wire specified on heavy industrial, corrosive atmospheres.

ROMEX: Romex is a brand name similar to Kleenex and Jacuzzi. The wire itself is a type NM conductor and owned by Southwire. This conductor is sold in every home improvement store and can be seen in different colors. Type NM-b, 12/2 Yellow Romex is rated for 25A and usually specified for lighting and receptacles in residential. The 12/2 is #12 AWG wire, 2 each, plus a ground. There is also 12/3, which has 3 conductor plus a ground. White is reserved for #14 conductors which is good for only 20A at 75° C. This conductor is usually run with 15A circuit breakers. Orange Romex is for #10 conductors. You will see these conductors rolled up in the electrical sections of Home Depot and Lowes.

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Takeaways: Romex is used in residential houses and light construction. In residential, it is run in the walls without conduits, with exceptions. Romex conductor should be secured to the walls or ceiling with staples or straps.

Romex wire rolls

Conductor sizes: There are standard sizes for conductors ranging from #18 AWG to 2,000 KCMIL. The NEC table 310.15 (B)(16) is used for sizing conductors during design. One can see that the larger American Wire Gauge (AWG), the smaller the conductor. Therefore, a #16 AWG is smaller in circular mils than a #12 AWG conductor. Also, the larger the conductor size, the more amps the conductor can carry. Therefore, a #12 AWG conductor can carry 25A at 75° C, per NEC table 310.15 (B)(16), and a #8 AWG conductor can carry 50A. Be sure to study the NEC table to see the standard sizes and their available amp capacity. Don't forget that this is an overview of the sizes and types of conductors and there is much more engineering to learn in another course. After the size of wires get to #1 AWG, they change and go to #1/0, #2/0, #3/0 and #4/0 respectively. These sometimes can be seen as 0, 00, 000, and 0000. Once the wire size gets larger still, they change to KCMILs or MCM. So the next size larger than #4/0 AWG is 250Kcmils. Learning the different wire sizes will come with practice and engineering projects.

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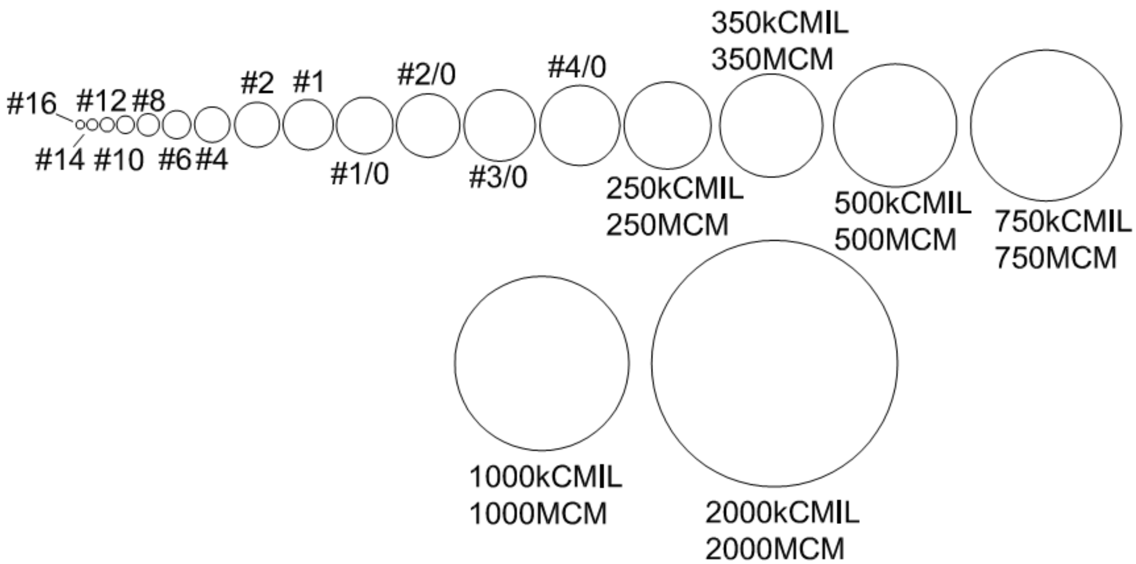

Standard conductor sizes, to scale 1:1

Takeaways: Conductor sizes are always dictated by the NEC and are sized at 125% of the full load amps (FLA) of the motor or equipment. In industrial projects, #14AWG conductor is the smallest allowed for control and #12AWG is the smallest conductor allowed for power. When sizing conductors, make sure the conductor amperage rating is larger than the breaker or protection device ahead of it.

6. ENCLOSURE TYPES: There are several NEMA ratings for control panels and electrical enclosures, see tables below. The typical panels specified for industrial and residential are NEMA 1, NEMA 3R, NEMA 4X, NEMA 7, NEMA 12. For panelboards at your house or any equipment that will be installed outside and subject to rain, a NEMA 3R is specified. For corrosive environments, like waste water treatment plants, NEMA 4X stainless steel is specified. There are also different grades of stainless steel like 304 and 316 and others. As a guide to practical engineering, I will say that for highly corrosive environments, type 316 is specified. Type 304 offers less protection from corrosion and may be seen in light commercial.

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There are also ratings for hazardous enclosures, which I will leave for another course. There is a lot to learn about hazardous locations, per the NFPA 820. There are articles in the NEC, article 500 and 501, 502 and 503 which deal with classified or hazardous locations as well. To learn more about these, I suggest taking a course on classified areas.
There are also plastic and fiberglass enclosures. Do not allow fiberglass enclosures to be installed outdoors in the sun. After a couple of years, it will begin to break down. Use plastic, steel or stainless steel.

Takeaways: The most common enclosure ratings are NEMA 1, NEMA 3R, NEMA 4X, and NEMA 12. NEMA 7 is specified for explosion proof enclosures, and where possible, should be avoided. NEMA 4X is for outdoors or corrosive environment and is usually specified as 316 Stainless Steel. NEMA 1 and 12 are for indoors clean environment and NEMA 3R is for outdoors, non-corrosive.

7. MOTOR CONTROL CENTERS (MCCS): There are two classifications for MCCs, low voltage and medium voltage. Any MCC lower than 1000V is considered to be low voltage. Medium voltage, 1000v to 21000v are not covered here.

A low voltage MCC is an assembly of one or more enclosed sections having a common power bus and principally containing motor control units. MCCs provide the most suitable method for grouping electrical motor control, automation, and power distribution in a compact package. MCCs consist of totally enclosed, freestanding sections bolted together. These sections support and house control units, a common bus bar for distributing power to the control units, and a network of wire trough and conductor entrance areas for accommodating incoming and outgoing load, control and signal wires. The control units or buckets consist of components such as motor starters, branch feeder circuit breakers, variable frequency drives (VFDs), reduced voltage solid state (RVSS) starters, main circuit breakers, meters and surge protection devices (SPD). All of this equipment can be arranged in one motor control center or several depending on size and locations.

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Motor Control Center

A typical MCC is rated NEMA 1 or 12 for indoor clean electrical room locations. If located outdoors, NEMA 3R is specified, non-walk in. They also make walk-in types, with room to house equipment and panelboards. I have also seen Stainless Steel MCCs near the ocean, which would be very costly but good for corrosive environments. As stated earlier, MCCs house starters, Full Voltage Non-Reversing (FVNR), soft starters (RVSS) and VFDs. VFDs 50HP and larger are usually installed outside the MCC in their own enclosure. Note that VFDs generate a lot of heat, and therefore require either an air conditioned room or air conditioned enclosure.

MCCs come in all different sizes, however off the shelf standard sizes are 21" deep, 20" wide and 90" tall. 60" tall MCCs can be fabricated for low profile depending on locations. Panel fabrication shops can make MCCs all different sizes per specifications. Depending on the size of starters and breakers, sections can be 30" to 40" wide and may be deeper.

They make different types of MCCs as well, such as arc resistant or flash resistant. These are designed to increase the safety of the MCC during an arc flash event. Arc flash or shock can

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happen at any time with any piece of electrified equipment and should be learned about through another course. Arc Flash is complicated and very dangerous and safety is number one with any plant or business. Typically there are arc flash labels on the MCC or equipment warning of the hazard and distances to stay away. If there are no arc flash warning labels, then a study should be performed and the equipment labeled accordingly.

MCCs can also house dry-type lighting transformers and panelboards. Typically a 15kVA or 30 kVA dry-type transformer will be specified in the MCC for 240/120v panelboards. The panelboards are used for most of the 120v loads, such as lighting, receptacles, PLCs and instruments. The panelboards can also be located inside the MCC. This is a good way to house the equipment when there is not much room in the electrical room or the MCC is located outside. However, remember that there are typically a lot of conduits that go to and from the panelboard. Therefore, if there is ample room in the electrical room, I suggest to install the dry-type transformer and panelboard outside the MCC for ease of installation and future connections. *Takeaways: MCCs will most likely be used on a lot of projects varying in size. When there are a lot of starters and smaller VFDs, MCCs are good to use. If all the starters are local to the motors or pumps, consider a panelboard or switchboard.*

8. REDUCED VOLTAGE SOLID STATE (RVSS) STARTERS: These starters are typically used on constant speed motors over 50HP or so. They are used to reduce the inrush and voltage drop which occurs on starting of the pump or motor. They offer more control than the standard across-the-line type FVNR starter. Typically they are called soft starters and can be seen in the MCC's or standalone enclosures. Soft starters will have signals or communication ports to bring back lots of information to the plant SCADA. SCADA stands for supervisory control and data acquisition. It is a control system architecture that uses computers, networked data communications and a graphical user interface for high-level process management. Other devices such as PLCs or DCS's interface with the process plant or equipment.

Takeaways: Soft starters are used to limit the inrush created by large motors. Some utilities require soft starters for large motors, typically over 50HP or so. Soft starters do not vary the speed, so they are used for constant speed applications. Soft starters have full voltage bypass contactors to bypass the electronics after reaching full speed, so they essentially act as a FVNR starter after the motor is at 100% load.

9. VARIABLE FREQUENCY DRIVES (VFDs): A VFD is a type of motor controller that drives an electric motor by varying the frequency and voltage supplied to the electric motor.

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Other names used for VFD's are variable speed drive (VSD), adjustable speed drive (ASD), adjustable frequency drive (AFD) or AC drive. I prefer to use VFD, since the frequency varies depending on the speed of the motor. Frequency (Hz) is directly related to the motor's speed (RPMs). The faster the frequency, the faster the motor turns. 0 – 60Hz is the typical range for VFDs, with 0 being stopped and 60Hz running full speed. VFDs come in three standard variations, 6-pulse, 12-pulse and 18-pulse. The pulses depend on the internal configuration of the VFD and dictates how clean the VFD will be.

VFDs generate a lot of harmonics which distort the waveforms of current and voltage. This causes issues that can harm motors and the rest of the plant. The harmonics can cause current and voltage surges, and distorted sine waves of current and voltage. To clean up this distorted power, a higher pulse (18-pulse) drive would be specified. This cleans up the harmful harmonics created by the VFD. However, it is much more expensive. There is a lot more information on harmonics and VFDs which should be looked up by the reader. All that you should know now is that VFDs create harmful harmonics to the power system and motors, and create a lot of heat, therefore, when designing the power system with VFDs, you need to consider filters, type of VFDs and air conditioning. They also make harmonic filters that will clean up the power and make dV/dt filters that will clean up the load side of the drives. All of these terms and equipment will be learned in time, as there is a lot to know about VFDs. More and more VFDs are being installed and used as they are efficient to use when variable speeds or flows are required. However, they require a lot more engineering, designing, and filtering equipment to install, so make sure they are indeed required for the process application.

As stated earlier, VFDs 50HP and smaller could be installed inside the MCC. Larger VFDs will be in their own free-standing enclosure and take up a lot of room. Any VFD enclosure outdoors should be installed with air conditioning. As with any electrical engineering design, there should be a harmonic study performed at some point to make sure the harmonic distortion is below IEEE 519 limits. This endures the harmonics are limited and the power company does not have to deal with high harmonic content.

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Open air 6-pulse VFDs

Enclosed VFD cabinet, NEMA 12

Takeaways: VFDs are being used more and more to control pumps and motors. VFDs create harmonics on the electrical system which can be harmful to the utility power, and motors connected to the VFD, and sensitive electrical equipment. VFDs always require air conditioned rooms or enclosures. Clean drives are 18-pulse and typically specified for large motors above 50HP. Harmonic filters can be utilized depending on the design.

10. SWITCHBOARDS AND SWITCHGEAR: **Switchboards and Switchgear:**

Switchboards and switchgear are similar pieces of electrical power distribution equipment. Switchboards are power distribution equipment that is typically used for service metering, main breaker and large feeder breakers. Starters, VFDs or smaller circuit breakers are not typically installed in switchboards and installed in MCCs instead.

Switchboards are good for distributing the power all over the plant to panelboards, MCCs and equipment. Switchboards are generally front only accessible and much less deep than switchgear. The ratings for switchboards are also less robust than for switchgear. Switchgear is typically used for heavy industrial type projects where reliability is very important. Typical switchgear can be as much as 10’ deep and have rear access. Again, like all topics, there is a ton of information to be learned about by the reader or engineer. This is an overview of the equipment and how it is used on projects. There are several new arc-flash reduction products coming out for switchboards and switchgear. You will find a ton of switchboards outside commercial buildings, generally near the service transformers. They are typically large outdoor NEMA 3R cabinets and are always locked. You will also find indoor ones in the main electrical room for small commercial buildings.

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Typical Switchboard

Notice the main breaker in the first section, followed by feeder breakers in the second section. This is a NEMA 1 or NEMA 12 rated indoor switchboard.

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Typical indoor metal-clad switchgear

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You can see how deep the switchgear is and how much room it can take up. When designing electrical rooms, make sure you tell the architect how much room you will need, as the gear can be quite large. Per NEC, there are also minimum clearances in front and rear of the equipment, which makes even more room required. Also note that there are a lot of protection metering and relays on the breaker sections. Switchgear typically houses a lot more relay protection that switchboards.

Takeaways: MCCs, Switchboards, and Switchgear are all used for power distribution. Depending on size, location, reliability, safety depends on what type of gear is specified. Electrical engineering will determine the best equipment for the planned project or upgrade.

11. TRANSFORMERS: There are dry-type, pole mounted, pad mount, substation and oil-filled type transformers. The dry-type transformers are typically utilized for small loads, under 45kva, and used for 240/120v or 208/120v panelboards. The panelboards are used for all the 120v loads and some 240 or 208v loads at the plant or building. The dry-type transformers rely on ambient air to cool the transformer. Transformers are utilized to transform the voltage either up from a lower to higher or step-down from a higher voltage to lower voltage. For example, distribution voltage from the local Utility can be 21,000v. To step that voltage down to a safer usable voltage, a transformer is installed that will step down the voltage from 21,000v to 240v/120v. The 120v power is then used in residential houses for power.

Dry-type transformers are mostly seen in electrical rooms in commercial buildings and industrial buildings. They supply all the 120v, 208/240/ and some 480v power at the plant. They are typically pretty small compared to the larger 1000kVA transformers. Typical sizes for dry-type transformers are 3kVA to 45kVA. These transformers can heat up and you will often see them piled with papers or equipment on them in the electrical rooms. If you put your hand on top, it will feel hot. I have seen some smaller ones located outside in the sun that would burn you. These are obviously overloaded and should be replaced. Almost always, a panelboard will be located next to the transformer.

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Dry-type transformer feeding panelboards

Pole mounted transformers are almost exclusively used by the Utilities and are mounted on the utility poles. You will see these outside of everyone's house feeding each house or several houses. These can be one transformer for single phase power typically used for residential households or could be a bank of three for three phase, which would be used at factories and plants.

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Pole mounted transformer

Pad mount transformers are typically ground mounted electric power distribution transformers in a locked steel cabinet mounted on a concrete pad. These are seen everywhere outside the commercial buildings at shopping centers. They are usually painted green. These transformers are typically air-cooled, see the fins on the back of the transformer pictured below.

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Typical Pad mount transformer

Substation transformers are usually much larger and filled with a cooling oil. These are large kVA transformers seen at a substations and on large industrial plants. These transformers will also have fans for cooling as well.

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Substation transformer

Oil-filled transformers are as the name implied, filled with oil. The oil is used to insulate and cool the transformer. With the use of oil, there will need to be some type of containment for the oil and the oil could catch fire. Generally, oil-filled are used for the larger transformers, above 500kVA. The decision on what transformer to use is part of the engineering and design. *Takeaways: Transformers are used on every project and everywhere power is required. They can be very small or very big. Sizing transformers takes a load study of the plant. Smaller pole mounted transformers are used by the Utility for residential houses.*

12. LIGHTING: Lighting has evolved a lot over the recent years with the use of LEDs. Almost 99% of new lighting today will be LED and more control over the lights are available today. I recently learned about wireless lighting control, where you can program what each light will do. You can have the lights dim according to occupancy, daylight and time of day. Any switch is a smart switch and can control whatever light you program it to. All of the lights will also work off an application from your phone on device. Typically electrical engineers will design the lighting and receptacles. As for each topic, there is a ton to learn about lighting and will be saved for another time. There are many software packages that help with laying out fixtures and can calculate how much foot candles each light puts off. I utilize a software add-in package called ELUM which works with the software REVIT. This allows all the fixtures to be

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put into the 3D model and then rendered to show how the lights will look in the room or area when turned on. The foot candles are calculated as well.
Takeaways: LED lights are the future of lighting and controls for the lights as well. LEDs take less wattage than traditional lighting. Some LED fixtures can be expensive, so check with manufacturer. Lighting calculations must be performed to ensure even lighting is achieved, as well as minimum foot-candle levels as required by the building code.

13. GENERATORS: Generators provide back-up power if the utility power should fail. Some places, like hospitals and wastewater treatment plants require generators. They are legally required to have generators for back-up power per the building code. Generators can be diesel fueled or natural gas fueled. I find that diesel fuel is the better alternative. However, if natural gas is nearby and fuel deliveries could pose an issue, natural gas is desired. Natural gas generators tend to be larger and cost more.

Generators can be as small as 500W and go all the way up to 5MW. Generators come in different tiers depending on how clean the generator will run. In some places, the generators are limited to how much they can run to keep the air clean. Generators can be sized to run the entire plant or office or just to run certain loads during a power outage. Typically generators are sized for emergency loads, as the larger the generator the more the cost. Generators can be installed inside the electrical buildings or outside with weather enclosure. They also make sound attenuated enclosures to limit the sound of the generator. Generators are usually connected to the power system via an automatic transfer switch, which will transfer power from the utility source to the generator, automatically. When the utility power comes back online, the generator is switched off. This provides continuous power for places like a hospital or wastewater treatment plant where you can't go without power for even 10 seconds.
Takeaways: Generators are very important pieces of electrical equipment and must be designed for each location depending on site requirements. Fuel tanks can be external or belly mounted. Air pollution is a huge issue with generators, be sure to discuss with generator manufacturer about air permits. If noise is an issue, sound attenuated enclosures are available.

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Outdoor generator

14. PROGRAMMABLE LOGIC CONTROLSERS (PLCs): Almost every project you will see or interface with has a PLC panel and PLC. The PLC is the heart of the plant and controls everything. The PLC itself is a controller that can be programmed with ladder logic to record data, read data, read signals, send commands etc. The PLC rack I/O, which is input and output, collects the controls and signals from the electrical equipment. Conductors are landed on the I/O cards and the PLC program will read the data and control the equipment. PLCs and the I/O racks are housed in PLC panels. These panels have the terminal blocks, wiring, controls, relays, timers, power supplies, HMIs and more. They house all the equipment for the control system. Human machine interfaces (HMIs) are similar to the display at your computer. They allow a way to communicate with the PLC. There are many different types of PLCs and configurations and networks, so this will be left to another topic of discussion.

Takeaways: PLC panels are typically located in the main electrical room close to the MCCs. The PLCs can control a piece of equipment, like a sump pump, or the entire plant. PLCs are part of the SCADA system.

This had been an overview and general discussion of electrical power engineering, construction elements and electrical fundamentals. I have barely scratched the surface of electrical power

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engineering. This was meant to educate on some aspects of electrical power engineering and construction and to introduce you how much there is to know about electrical engineering. There are so many design issues and techniques that hundreds of books have been written on single topics alone. If I have missed a major topic or you have any questions, please feel free to contact me. Thank you for reading.

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