PDHonline Course E361 (4 PDH)

2011 National Electric Code

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2011 National Electrical Code

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Preface - The 1896 National Electrical Code was created to reduce the insurance losses from fires of electrical origin.

ARTICLE 90, Introduction - The Introduction is a non-enforceable portion of the National Electrical Code (NEC). That means that a Plans Reviewer or Inspector is in error if he cites you for non-compliance with ARTICLE 90. The Fine Prints Notes (FPN) in various sections are also non-enforceable, as are references. Often the NEC references other NFPA publications. This information is offered to aid understanding of the section, but the portion or document referenced is not enforceable as part of the NEC.

The Introduction mentions a goal of the NEC is to "harmonize" with European electrical standards, IEC publications. (IEC is the International Electrotechnical Commission.) This is good for US manufacturers and designers doing business around the world. In addition, it forced the NFPA to address issues that are not interesting to US manufacturers and installers, but have safety importance recognized by a "foreign" viewpoint. For example, IEC has a very different view on electrician safety and explosion-proof installations. These ideas have slowly become part of the NEC and are responsible for several significant changes.

SECTION 90 lists areas covered and excluded by the NEC. Beyond being in a non-enforceable Section of the Code, these lists give a directionally incorrect concept. The NEC is enforced whenever someone in charge chooses to enforce it. Railroads are specifically excluded, but railroad operating companies can choose to enforce it internally as an aid in avoiding liability in lawsuits, since the Judge will look at the NEC as a recognized standard of safe installation. The same reasoning applied to Utilities and military installations.

Further, the NEC is being revised more broadly each year, outside NFPA and within the NFPA committees. For instance, NFPA embraced communications and data wiring several editions ago. This means that the Plans Reviewers can demand details about communications and data equipment and planned wiring and hold up the project until they get it. Similarly, as Inspectors become more sophisticated, they will be closely examining details of communications and data installations. This is a massive change. Communications and data installers come from a different tradition than commercial and industrial electricians, and, in the past, have often paid no attention to fire safety and grounding rules.

This same reasoning applies to photovoltaic, wind power and fuel cell installations. The standards of craftsmanship and circuit safety followed by providers and installing contractors is exceedingly low - as demonstrated by "burn-downs" reported in the media. In response, the 2011 Code addresses these areas. Perhaps unfortunately, because of the widespread problems, local municipalities are writing and enforcing their own rules and standards.

The question of "covered by NEC" or "not covered" frequently comes up in defining the "service point". When you buy electricity from a Utility, at some specific point, responsibility for the installation and maintenance shifts from the Seller to the Buyer. The NEC has vaguely stated opinions, but the matter is decided by State and local regulations and by the Utility's policies. It is common for the Utility to specify overhead wiring from the street or wiring and underground conduit and the meter base, but the Owner's Contractor must install it, subject to Utility inspection. The Utility does the final "hot" tie-in.

The message here is that questions regarding the service point should be discussed with the Utility and the results documented and saved. Experience indicates that different areas within a single Utility in a single city will have different area supervisors and different enforcement of the rules.

Why is this course organized this way and what is this box ?
First, the box. To use your time most effectively, we started paraphrasing and discussing the National Electrical Code immediately. Yes, the introductory material indicates how the course is organized, but not why. To respond to all the associated-but-not-central questions of the course, these boxes, called "sidebars" are used. They are not core material, but supplementary explanations. A critical and fair question is, "What are the important parts of the NEC?" One answer is, "The changes since the last revision. We are all experienced professionals and don't need to discuss the un-changed content." To support this reasoning, a brief chart of changes in the 2011 NEC is provided. The chart was extracted from a very good 2-day course on the 2011 NEC, along with some recent personal experience on design and construction jobs. A very different answer is, "Each table, exception and paragraph of the NEC is critical - when it answers the problem you are having today with a design or installation." That is, essentially, the answer pursued by this course. Many requirements have been overlooked by designers, Plans Reviewers and Inspectors for many revisions of the Code. They become important when your Building Permit is delayed or construction is "red-tagged". For this reason, requirements which the author considers critical are re-stated, even if long-standing, and especially if generally ignored. By following the structure of the NEC publication, it is an easy transition from the course content to the standard. Remember, it is the standard which is enforced, not the course.

Article 100, Definitions

Sometimes we skip over the Definitions section of a document because we are familiar with the terms used in the field. This is an error with the National Electrical Code. The Code writers have a habit of changing the rules by redefining or adding a term. For example, there are critical distinctions among "accessible", "readily accessible (equipment)", and "readily accessible (wiring)".

"Accessible means not guarded by locked doors or elevation. The concept is that a user should be able to get at a disconnect switch when a piece of equipment starts smoking. If the only switch or circuit breaker is in a locked closet, there is a problem. As you would guess, most Owners of public buildings don't want the general public turning off lights or equipment and they lock the electric room. This produces a conflict which is satisfied by normal practice which is not documented in the Code - and varies from location to location. It is almost universal practice to lock the electric room and the Code references this in some places. On the other hand, ASHRAE 90.1, which is enforced by all 50 States, requires individual light switches in each area of use. In commercial occupancies, almost all equipment has a wall plug, which can be used for emergency disconnect. In industrial occupancies, almost all equipment has a nearby safety disconnect switch.

Is "accessible" provided if you need a ladder to get to the device? Yes. That is the difference between "accessible" and "readily accessible".

For wiring, "accessible" means that you don't have to damage the building to get at the connections. This is the reason for access panels, junction boxes and surface-mounted and recessed-mounted equipment. Fully-concealed equipment must have some available screws to get at the innards. This comes up in renovations when a panelboard is replaced. The old panel box, with connections for extension, must be left accessible. It is NOT permissible to make wiring extensions, then mount the new panel on top of the old panel box.

Why are we talking about ASHRAE 90.1 ? This is the NEC course.

Because this is a course on successful design to pass Plans Review and keep Inspectors happy. It is mostly, "NEC", but contains a little more.

The Federal government has forced all 50 States to adopt ASHRAE 90.1, usually referenced by the State Building Code. This course doesn't make you follow it, but does present the rules so that you aren't surprised.

By the way, ASHRAE 90.1-2010 has been forced on the States, effective 2012. It has some really nasty provisions for electrical designers. You might want to look at the PDHonline course on ASHRAE 90.1-2010 (electrical).

Arc-Fault Circuit Interrupter (AFCI) is a new definition for 2011. This is important to you because they are required, don't work and are (largely) unavailable. The wording of the 2008 NEC is that retrofits to locations now requiring AFCI require AFCI for the retrofit - effective 2014. (Many building groups fought this and got State exemptions in 2008). The AFCI don't work because they don't work with vacuum cleaners or tv sets you buy at Wal-Mart. (Some Inspectors recommend buying Dyson vacuum cleaners as a work-around. (There is a promise from NEMA that future AFCI breakers and future Wal-Mart vacuums will, indeed, work). At the time this course was written, there were no commercial AFCI receptacles. Pass and Seymour promises to bring one to market early in 2012.

Ground-fault is first defined in the 2011 NEC. The interesting thing about ground faults is that they are meaningful only as the initiating agent for a line-to-line fault. It is possible to calculate ground fault currents, and sometimes of value. Normally, however, fault modeling assumes that a ground fault will quickly escalate to a line-to-line fault (much more severe) and protection must be sized for the line-to-line fault.

Supplementary overcurrent protective devices are first defined in the 2011 NEC. It has been legal, for a long time, to use a cheap, crummy fuse or circuit breaker downstream of a good fuse or protective device. There are restrictions, however. Now, the cheap, crummy fuses and circuit breakers must be labeled as such, “supplementary overcurrent protective devices”.

Uninterruptible power supply is first defined in the 2011 NEC. Uninterruptable power supplies have problems with power factor, efficiency, grounding and fault-clearing capability. The NEC does not address these, but does require meaningful labels now.

The definition for “authority having jurisdiction” (AHJ) hasn’t changed and isn’t confusing to persons in the electrical trade. It is, however, sometimes confusing to building owners and plant managers. On most commercial and industrial projects, the construction documents must be submitted to a city or county building standards department for approval before a building permit can be issued. The Plans Reviewer at the building standards department and his Electrical Inspector are the “authority having jurisdiction.” These persons can make demands for changes in equipment and materials used and methods used to install them. The “stick” they wave is the building permit and the certificate of occupancy. Sometimes a State official or a military base commander has this responsibility. In very, very rare cases, the building owner or plant manager has the responsibility. The Code refers to insurance inspectors having AHJ responsibility, but this is a contractual relationship, not a legal relationship.

Your author recently suffered significant pain in dealing with a manufacturing facility that didn’t want to put receptacles on the roof at HVAC equipment and ground fault protection on their 2000A, 480Y277V switchboard. When a professional engineer places his seal on a set of construction documents, he is certifying that it complies with applicable Codes and includes provisions to safeguard the public.

The requirement for the receptacle at rooftop HVAC comes from the Building Code, not the NEC, but the ground fault protection requirement is from 215.10 of the NEC.

“Multi-wire circuit” was first defined in 2005, but isn’t understood yet. The wording of the Code is that three single-phase circuits can share a neutral only if a 3-pole circuit breaker feeds the circuits. Almost all designers now send out a separate neutral with each single-phase circuit. They do not recognize, however, that the separate neutral means that the circuit path is 2x that of the common neutral arrangement. If the limit used to be 130-ft for a #12 circuit before you have to upsize it to #10, it is now 65-ft. [The limit for a common neutral 120V, 20A circuit is 130-ft for #12 before you have to upsize it to #10 for voltage drop. The limit for a separate neutral 120V, 20A circuit is 65-ft for #12 before you have to upsize it to #10 for voltage drop.]

“Multi-outlet assembly” was first defined in 2005 and declared legal for use for 90-days, only, if fed by flexible cable. The 2008 NEC changed the wording but kept the 90-day limit. It is still 90-days in the 2011 NEC. There are two major reasons this is not enforced. First, plug-strips are almost always brought in as part of move-in. They don’t show up on the construction documents and the Electrical Inspector never sees them. Second, they meet a real need. Nobody wants a lot of flexible conduit and duplex receptacles on moveable furniture or on the technology data wall.

The 2008 wording for “qualified person” has not changed, but is now being enforced. Engineers do not have documentation of receiving training to open energized equipment or use meters (usually). Only an electrician with a certificate of training can do this.

"Short-circuit rating" has not changed and, in 2011, nobody is yet paying attention to the requirement that equipment be rated for the available short-circuit current.

Everybody in this class will know how to calculate available short-circuit current.
The right way to determine available short-circuit current is to hire a "qualified person" to open equipment doors and write down the ratings of existing equipment and the sizes of existing conductors. You then pay his friend to enter the data into proprietary modeling software and do a "short-circuit study". There are firms and projects that do this. It is rare, however. PDHonline has a course entitled, "Simplified Short Circuit Calculations." It explains how to use a stack of Excel tables that list different transformers and cables. You can download the entire course at no charge. (You pay only if you want to take the test and get PDH credit.) The key concept from that course is, "Look for more than 10,000A available fault current." That is because standard-duty electrical distribution equipment is rated 10,000A withstand. If there is more than 10,000A available where you want to install something, you must buy heavy-duty gear (as 22,000A withstand, or higher). Two tables from that course are offered for your consideration, as follows:

Available Short Circuit Kilo-Amps Using EasyPower ™ ver. 8.0.2.303, ESA								
SC kA	480V, 500 kVA, 5.5%							
	Cable					Busduct		
	4/0	250	350	500	2@500	1200A	1600A	2000A
Feet	10.934							
0								
10								
20	10.551	10.556	10.579	10.597	10.763	10.831	10.879	10.890
50	10.005	10.021	10.081	10.125	10.515	10.667	10.798	10.824
100	9.093	9.143	9.282	9.383	10.103	10.424	10.663	10.715
200	7.746	7.881	8.098	8.251	9.419	9.931	10.394	10.500
500						8.594	9.614	9.878
1000								
2000								
5000								
10000	0.421	0.453	0.529	0.595	1.124			

SC kA	480V, 1000 kVA, 5.5%, 1203FLA							
						Busduct		
	4/0	250	350	500	2@500	1200A	1600A	2000A
Feet	21.865							
0								
10								
20	20.365	20.389	20.483	20.554	21.191	21.455	21.648	21.690
50	18.349	18.428	18.665	18.836	20.248	20.846	21.323	21.429
100	15.389	15.585	16.063	16.406	18.766	19.860	20.786	20.999
200	11.786	12.067	12.713	13.172	16.500	18.026	19.736	20.161
500	6.619	6.926	7.618	8.140	11.953	13.741	16.890	17.864
1000					8.140	9.550	13.283	14.780
2000						5.803	9.040	10.739
5000								5.716
10000	0.427	0.461	0.541	0.610	1.181			

For the first table, consider a 480V, 500kVA, 5.5% transformer (ignore service conductors and switchgear). If you want to run a 4/0 circuit, you can use standard-duty equipment if it is over 50 linear feet away (include up, over and down). If you want parallel 500-kCMIL, you can use standard-duty equipment if it is over 160 linear feet away. These results are not offered as accurate, but they are offered as safe. And, now you understand the problem and the solution.

The definition for "nominal voltage" has not changed. The NEC says to use multiples of 120/240V and 480Y277V. Unfortunately, the world has changed. In assessment work for HUD and local school systems this past year, I never measured less than 123V. My favorite HVAC engineer has 128VAC at his home. Incandescent lamps will not survive this voltage for long. Linear and compact fluorescents do well.

Per wikipedia,
Light from incandescents is proportional to V^3.14.
Lifetime of incandescents is proportional to V^-16.
Or,

Volts	Light	Life
110%	135%	22%
100%	100%	100%
90%	72%	540%

As part of this discussion, be aware that NEC nominal voltage is not the same as incandescent nominal voltage. Read the number on the bulb. It may be 115V, 120V or 130V.

ARTICLE 110, Requirements for Electrical Installations
These are the rules that the Inspector will enforce. Occasionally a Plans Examiner will pick up an inadequate clearance, but it is much more obvious as the equipment is being installed. It is also more expensive to rip gear out and figure a new place to mount it.

Section 110.2 Approval

This section is tightening in each revision of the Code. The intention is that the designer and contractor are supposed to follow the Code. Exceptions are supposed to be rare, well thought-out, and documented in writing. However, this part is enforced in the field, where procedures are different.

The Code is a very solid starting point, but the local Inspector almost certainly enforces some peculiar interpretations, based upon a bad experience in his past. Local contractors know. Out of town contractors learn, painfully. The local Inspector and contractor are used to oral exceptions, which are immediately covered up by the drop ceiling, equipment cover or plaster.

Section 110.3, Examination, Identification and Use of Equipment.
Examination means different things in different jurisdictions. In my experience, examination means that the equipment is UL-listed. Members of my live class on the NEC in New York State report much more participation by Plans reviewers and Inspectors in New York City.

There is a current effort to supplant UL with NRTL (nationally recognized testing laboratory) and ETL (a proprietary laboratory which has received some unfavorable comments). UL is safe, unless an unhappy vendor sues you or when UL doesn't label the particular piece you want to buy. CSA and FM are sometimes offered as equivalents, but not by this course.

This is the section of the Code which incorporates manufacturers' installation instructions into the Code. There is a very real gotcha here. The designer does not get to see the instructions, except in the cases of full-disclosure at the manufacturer's website. That means that there are clearly indicated limitations and requirements which are unknown to the designer and discovered only by diligent contractor foremen. Individual lighting dimmers in switchboxes have been a prominent and painful example. Many have cooling fins larger than the box space. They work fine in a single-gang application, but some fins have to be trimmed off for multi-gang use. This reduces the load capacity. It is clearly explained in the instructions, but a surprise the first time, nonetheless.

Section 110.12, Mechanical Execution of Work
This is another stealth section to the neophyte designer or installer. Materials must be installed in a workmanlike manner. This appears unenforceable in its vagueness, but has been interpreted to mandate following ANSI/NECA 1-2010, *Standard Practices for Good Workmanship in Electrical Construction.*

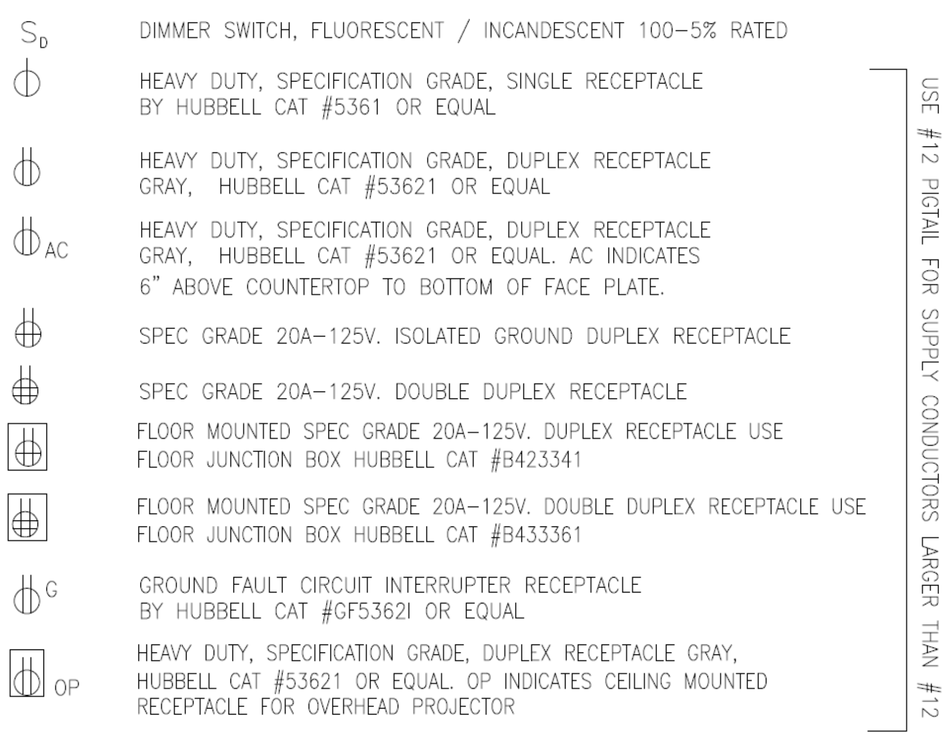
The Standard itself is well-written and has meaningful content and is stringently enforced by Electrical Inspectors and engineers who want to have pride in the appearance of the work. My experience is that good contractors and foreman have the same goal and when shortcuts are taken in appearance, there are also shortcuts present in wiring details.

Section 110.13, Mounting and Cooling of Equipment
This section specifically states that electrical equipment must be mounted so that required cooling is possible. This comes back to the manufacturers' instructions, which you don't get to see until it is uncrated. The wary designer knows which equipment generates a lot of waste heat which must be rejected into the environment. This means side and back clearances. Because of the common requirement for competitive bidding, it is essential to include generous cooling clearances in the plan layout. If a less costly, but larger unit is provided, it will still fit.

Section 110.14, Electrical Connections
There is a field problem that is recognized and addressed by this section - wires into lugs. Previously, electricians often made tee connections by placing incoming and outgoing conductors on a single lug. This is now permitted only when the lug is rated for the count and size of conductors. Another place this shows up is on panel breaker lugs. One circuit per lug is the limit, unless labeled otherwise.

The last place where this shows up is when you choose over-size conductors to avoid voltage drop or provide for future capacity. Big wires into small lugs don't go. There are reducing pin-crimps that handle this (they are intended for aluminum-to-copper) and a box extension ad a pigtail will work. This Code section says that trimming strands to use an unlisted size is not legal.

An earlier discussion related to multi-wire circuits and the new requirement for #10 and #8 wires going to receptacles. The following excerpt from an electrical symbol legend includes a note on use of pigtails. Note also the on-sheet specification for fluorescent dimmers as 100-5%. Many dimmers and dimming ballasts only go to 100-50%.

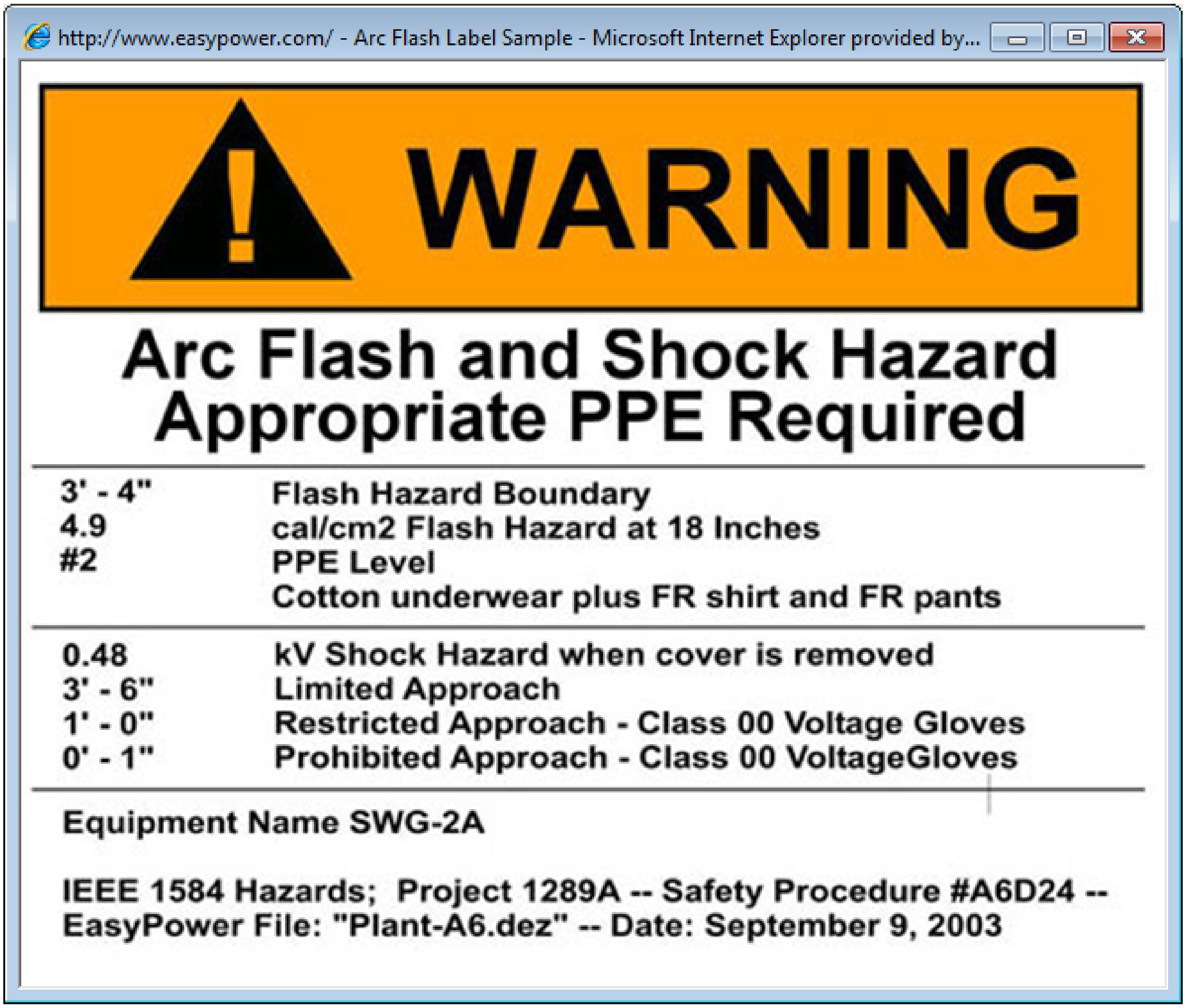


Section 110.14, Electrical Connections
This section specifically allows use of listed direct-burial splice kits. I normally recommend heavy-duty installation, building wire in Schedule 80 PVC conduit or in Schedule 40 conduit in a concrete duct bank. But, there are situations, like a driveway that is constantly being dug up, or a long run to a pump house, that justify direct-burial power cable at the legal depth.

A later paragraph in this section mandates use of wire at its 60C rating for equipment connections. The feeder circuit can be 90C wire, at its 90C rating, with a short, larger pigtail of wire used at its 60C rating. It is not legal to connect the pigtail in the gutter space if this exceeds the cu-in rating of the gutter. To avoid this problem, use 90C wire at its 60C rating.

Section 110.16, Flash Protection (sic – labels)
This is the famous section that requires field-applied arc flash warning labels. To be Code-compliant, the designer must remind the installer to apply are flash warning labels - with no particular wording beyond, "Warning – Arc Flash Hazard".

First, note that this requirement is rarely followed. Second, not that the genuine requirement comes from OSHA, which requires a label similar to the following:



Actually, this sample label, from EasyPower, has more information than required by OSHA. OSHA required "PPE Level #2", but has no requirement to explain what that means.

Nobody else cares about arc flash hazard. Why should you?
Electrical Inspectors are almost universally NOT enforcing the NEC arc-flash label requirement. OSHA starts think about enforcement after someone is killed. Why should you invest the time and money in doing a minimal arc-flash study and printing or hand-writing some OSHA labels?

The answer is at the end of this web link:

http://www.efcog.org/wg/esh_es/events/DOE_Elec_Safety_Workshop-2007/BNL%20Arc-Flash%20Incident%206_19_07%20(Durman).pdf

In this report, you will discover that non-electricians, doing ordinary work, in a safe manner, can be exposed to catastrophic electric failure which causes substantial damage and can injure or kill the Operator. Neither label mitigates the results, but at least, the employee is warned.

110.21, Marking
Equipment (now including control panels, TVSS and such) must carry a label showing the manufacturer, voltage, current and short-circuit withstand. NEMA equipment has been doing this for years, but it is a new idea for panel builders, even when severely arm-twisted by large industrial buyers.

I have been encountering failure of labeling daily of recent times. I have been doing assessments where I must record the rating of the main circuit breaker and feeder breakers. It is only in recent times that this information has been placed where it is accessible. Many of the circuit breakers installed before 1980 require removal of the enclosure cover to get at a sticker with the rating.

110.21,22 Marking and Identification
The Code requires labeling of electrical equipment with manufacturer, voltage and current. Disconnecting means, only, are required to be labeled with their purpose, that is, the equipment that is disconnected. The first requirement is to insure that equipment is applied within its rating - so that you know the rating. The second requirement is so that an operator knows which switch to operate to turn off a particular motor, or whatever. Unfortunately, there is almost no enforcement on the second requirement. You have to trace conduits to find out what the switch controls.

As part of a recent school assessment, an industrial control panel was encountered in the principal's office. No one in the office knew what it did, nor did the maintenance supervisor conducting the tour. It is pictured below:

This is not a Code violation. It is, however, it is bad design and evidence of bad Inspection. The thing with the alarm bell signals some serious problem, that may be remedied by opening the solenoid. But no one knows what the problem is or what the solenoid does.

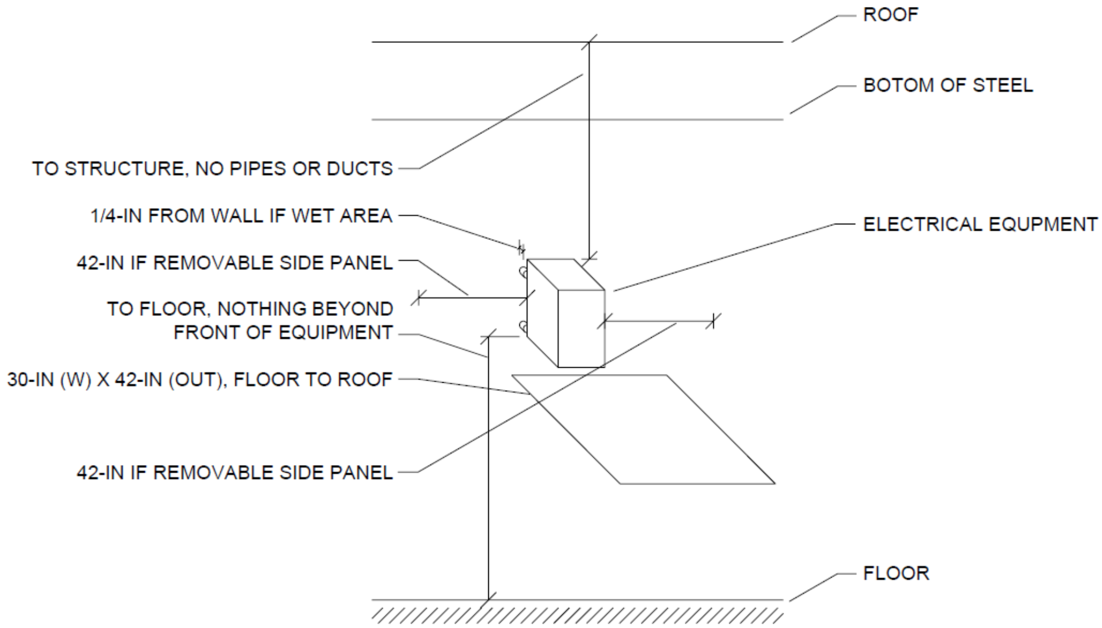
110.22 Identification of Disconnecting Means, (C) Tested Series Combination Systems
This is a peculiarity of the Code which is used without thinking by many designers. The referenced paragraph permits use of circuit breakers that are not able to interrupt the fault current available at the point of installation. The permission stems from use of a faster, more robust circuit breaker upstream. The reasoning is that, so long as the fast, more robust circuit breaker is present, the circuit breaker in question will never see the high fault current - the upstream breaker will interrupt it first. So, I see this on a lot of panelboard specifications and panel directories. Of course, lots of low-rated breakers are less expensive than the same number of high-rated breakers.

The defect in this reasoning is that the faster, more robust breaker can be replaced by a slower, more robust breaker. This is legal. Now, however, the downstream, low-rated breaker sees the full fault current. Your author removes permission for series-rated circuit breakers whenever he sees these words.

110.26, Spaces Around Electrical Equipment
The Code is fairly clear on the requirements. Electrical designers and installers do a good job of following the Code. Inspectors are sensitive to the sections. Mechanical designers and installers, however, don't know the requirements, or, apparently care. They consistently encroach upon the

maintenance space reserved by the Code.

A summary sketch follows:



ACCESS SPACE REQUIRED PER 110.26, 600V OR LESS

Please read the exact wording in the Code to get the exact requirements. This sketch is good, though, to remind you of each of the requirements. The air circulation space behind equipment is not overlooked by Contractors, but often overlooked by maintenance staff. It is rare, today, to find equipment that requires rear access. But, if the back is removable, there must be 42-in access space must be provided.

The 30-in width, in front of equipment, is sometimes a surprise. This applies to light switches, too, beyond normal electrical equipment. Each place the sketch says, “42-in”, you are safe and in compliance with the Code using 42-in. The value is from a table for equipment below 600V. You can reduce this clearance a little bit under some circumstances to meet the minimum requirements.

Note the limitation that nothing above or below the piece of equipment in question may extend beyond the front of the piece in question. You cannot put a big dry transformer below a shallow panelboard. There is an exception, though, permitting big wireway below a shallow panelboard.

There is a requirement that electric rooms containing equipment rated 1200A or more and over 6-ft wide have outward-swinging doors, with panic hardware, at each end. If you take a moment to visualize an arc-flash event and you are in the room, you will immediately agree that you need to get to a door without crossing the field of blowing copper droplets.

Do provide good lighting and battery-powered emergency lights. Motion-sensing switches and energy conservation plans are not permitted. Exhaust fans are implicitly required by the Code to meet the operating temperatures of the equipment as part of complying with the manufacturer’s UL listing.

Article 200, Use and Identification of Grounded Conductors

The basic rule is that there are one or more "hot" conductors which carry electricity from the source to the load. There is often a "neutral", or "grounded power conductor" which carries unbalanced current back to the source. There is one or more "grounds" which keep the voltage down for personnel safety and provide a safety return path for fault current.

Why-for this philosophical excursion?
It's not philosophy. I have worked on systems that don't have a ground. The strangest was a natural gas compression station in west Texas which was fed by two transformers in "open-delta". They were suffering from high, strange voltages from ground. That is, you put one meter lead on a conduit (at ground / earth potential) and the other meter lead on a power conductor (nominally 480V), and you got some strange value, maybe 1,200VAC. This is not a good thing for equipment rated at 600V. It was also not a good thing because bad things were happening to the equipment at the plant. Without going into a lot of detail on a very peculiar electrical system that you will, almost certainly never encounter, please agree with me that "grounding" is something we arbitrarily do for safety reasons. Follow the rules. Do it right. Provide safety. Don't overthink it.

The neutral is not required for 480V power to motors an most large equipment. The ground at the source and at the load are still required for safety. By the magic of balanced three-phase circuitry, all three current flows sum to zero. If they don't sum to zero, the system adjusts and they DO sum to zero. The neutral or grounded conductor is not a problem in these circuits.

In 120/1/60, most 120/240V and most 208Y120V circuits, a neutral is required. The 120V circuit is only supply and return (neutral). The 120/240V circuit may be only 240 supply (hot) and 240 return (also hot), but usually a neutral to handle a small fan or time in the equipment is connected to one hot and the neutral.

Real 208V equipment, like rooftop HVAC units, may be power-only, with no neutral. Again there must be safety grounds at both the source and the load. 208V and 208Y120V are not the same and it costs money to add the neutral later. Most 208Y120V circuits are not balanced and will have a neutral current approaching or EXCEEDING the hot conductor current. (Switching power supplies, like "wall warts" on electronics, pull heavy, short-duration pulses of current that do not balance on three-phase or 120/240V circuits.

You must recognize that current flows in the neutral circuit. Safety precautions in design and installation are necessary to avoid the same shocks that an electrician can get from a hot conductor. If you open the neutral flow on an energized circuit, the line-to-neutral voltage appears on that break and an arc. For this reason, neutrals require the same insulation as hot conductors and as much care in labeling as hot conductors.

The Code requires that a facility containing 120V and 480V circuits use distinctive colors for both systems. The example given in the National Electrical Code Handbook is as follows:

208Y120V			480Y277V	
Phase A	Black		Phase A	Brown
Phase B	Red		Phase B	Orange
Phase C	Blue		Phase C	Yellow
Neutral	White		Neutral	Grey

The text in the National Electrical Code Handbook states that the use of grey for 480Y277V neutral is not required, but common. The wording of the Code permits phase conductors with longitudinal white stripes or lateral white stripes at terminations for either neutral. There must be different neutral colors when there is a liklihood of both appearing in the same equpment or cabinet.

200.6 (D) Grounded Conductors of Different sysems
This section requires that the color codes selected must be readily available or posted at the panels where the different systems originate. I have been calling for these placards since 2005 and have yet to see one installed.

Article 210, Branch Circuits
This article contains requirements for branch circuits, as you might expect. However, it also contains requirements for multi-wire circuits and for residential, commercial and industrial ground fault circuit interrupters (GFCI) and arc-flash circuit interrupters (AFCI).

There is a discussion of multi-wire circuits and the voltage drop problems in the definitions section. It will not be repeated.

There is an extended discussion of AFCI in the definitions section of this course. It will not be repeated. The information here is where GFCI and AFCI are required per the 2011 NEC.

	Commercial / Industrial (Other than Dwelling) 210.8 (B)	Residential / Dwelling, 210.8 (A)
GFCI	Bathrooms Kitchens (broad) Rooftops Outdoors Sinks Boat Hoists	Bathrooms Garages and accessory buildings Outdoors Crawl spaces Unfinished basements Kitchens Sinks Boathouses

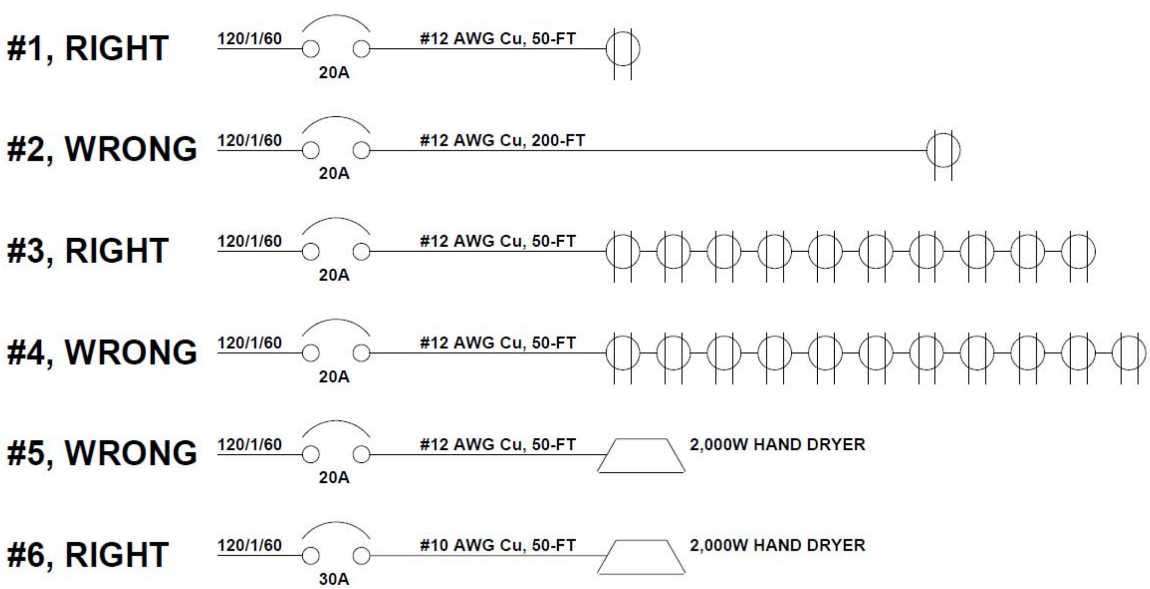
AFCI	Commercial / Industrial (Other than Dwelling)	Residential / Dwelling 210.12 (A)
	No entry	Family rooms Dining Rooms Living Rooms Parlors Libraries

		Dens Bedrooms Sunrooms, recreation rooms, Closets Hallways Or similar rooms

The GFCI requirements have been around a long time but are still causing problems. That is to say, I get calls from Architects who are faced with Change Orders to install GFCI receptacles where they were overlooked in the original design. GFCI receptacles are inexpensive (~$5 trade price) and easily installed. Similar problems for AFCI are much more serious. Please review the AFCI discussion in the definitions section if this doesn't ring a bell.

<u>210.19 Branch Circuit Ratings</u>

There are a tremendous number of detailed limitations on branch circuits. A better approach might be to address correct branch circuits. Please consider the following:



SAMPLE BRANCH CIRCUITS

Sample number one is our base case. We are looking at a 120V, single-phase source, a 20A circuit breaker, 50-ft of #12AWG copper building wire and a receptacle. There are rules which must be complied with here, but mostly relating to limitations on the way the conductors are run, non-metallic cable, building wire in conduit and a range beyond. Basic, simple, it works and it is legal.

Sample number two has excessive voltage drop, as interpreted by the NEC. Yes, the NEC considers a duplex receptacle to be 180va (1.5A), if nothing is plugged in. But, everything about this circuit is nominal 20A, so the NEC looks for voltage drop with 20A flowing. This is arguable, and many good engineers do argue, but Amprobe and Ideal are both selling receptacle testers that apply a 20A momentary load and report the voltage drop. I first saw one of these testers in the hands of an Electrical Inspector.

Voltage drop must not exceed 5%, per ASHRAE 90.1, adopted by all 50 States. A 120V single phase circuit with 20A flow exceeds 5% voltage drop at 65-ft (including up- and down-). See also 310.15 for ampacity ratings of conductors and 210.19 IN 4 for a discussion of voltage drop.

Sample Number three has a lot of receptacles, with nothing connected to them. That is OK. I am guessing that the Code-makes don't expect users to connect too much load using only ten receptacles (10 x 180va = 1800va. 1800va / 120V = 15A. Only 16A are permitted on a 20A breaker, per 210.20.)

Sample number four has too many receptacles, not connected to anything. (1 x 180va = 1980va. 1980va / 120V = 16.5A. 16.5 > 16 and unacceptable.)

Usually receptacles only come in two flavors - nothing connected, or something big connected. "Big" is usually a production copier or a microwave. The rule for known loads is to usually provide a dedicated circuit. The exception, or, actually, a different situation, is a number of known small loads that are not accessible for expansion. For instance, it is common to run a number of take-away conveyor motors off a single motor starter or variable frequency drive controller. A single share circuit for all of them, as long as the load doesn't exceed 80% of the supply. In commercial HVAC, you often have a very large number of VAV terminal boxes. Each needs 120V for a local thermostat and damper motor. You choose some safe number of units, below 80% of the rating of the supply.

Sample number five looks about right and matches wiring I found on a school drawing set about six months ago. Unfortunately, 2000W / 120V = 16.7A. 16.7 > 16 and unacceptable.

Sample number six increases the wire size and circuit breaker and is good.

Article 215, Feeders

The difference between feeder circuits and branch circuits is that feeders are usually big wires going from big panels to smaller panels or to large pieces of equipment. Branch circuits are usually small wires going from small panels to receptacles, or shared circuits or to smaller pieces of equipment. The Article 100 definition of feeder says that it is upstream of the branch circuit device. If you recognize that big pieces of equipment usually have a control transformer and protection for the control circuit, this works. Essentially, they are the same. For instance, we call the wires from a motor starter to its motor the "motor feeder" even though there is no branch circuit protective device in the motor.

Protection for feeder circuits must be sized at 125% the continuous load plus 100% of the non-continuous load. This always works. There is an expensive exception for large loads by using "100%-rated" protective devices. The "100%-rated" devices are available only in electronic trip units, considerably more expensive than simply thermal-magnetic trips. On the other hand, circuits above 1,000A on 480Y277V require ground-fault protection, which is another feature available only on electronic trips.

There are additional rules to permit adding additional load, including non-continuous load de-rating for some machine tools (often misused for general loads) and a demand factor, to reflect loads not operating at rated nameplate. I have used these special calculations when the calculated load is 1% above a circuit breaker frame size, requiring a step increase in enclosure size. Beyond that case, it is consistent with the Code's intent that the designer provide capacity for future.

215.5 Diagrams of Feeders
This section suggests a diagram of feeders, showing sources, loads, square feet of facility served by each and any de-rating factors used. The diagram is discretionary to the designer and Authority Having Jurisdiction. One of my supervisors, in the past, assigned his staff to make such diagrams during a time of light workload. It is interesting how areas of service overlap after years of maintenance. The diagram was very valuable to newly hired maintenance electricians.

Article 230, Services
As with the entire Code, there are many detailed rules, mostly indicating what you cannot do. Contractors and Inspectors are very familiar with these sections and their interpretation. For the designer, you identify the pole that the Utility promised would feed your building and a place in the foundation where you want the conduit to come in to the main switchboard. You show a utility meter on the one-line diagram, but not on the plan. The Contractor does the rest.

However, there are two items which require attention from the electrical designer - number of services and number of service switches. 230.2 is very clear that a building gets only one service. After that, you and the Utility start installing additional services. The first reason is that the building load outgrows the capacity of the incoming cable and main switchboard. Everything works fine, but you need more. Does anyone really want to take the building out of service and make a lot of scrap in order to buy a monster-big new switchboard ? No. Everyone prefers to run a new line into the building, close to the new load, and provide a new moderate-size switchboard. This happens again and again, often accompanied by building expansion matching the new service.

The second reason is to save on transformers. Many older buildings have very strange 240V three phase services. They use the 240/3/60 for pumps and big motors and the strange 120V supply for lights and receptacles. Those strange (and they are very strange) transformers are very difficult to replace. Much easier to put in a 240-delta service along with a 120/240 service.

Why not 208Y120V ?
First, I have seen the 240-delta plus 120/240 again and again. This is what the Utility does where I live and work. Second, going to 208Y120 costs a lot more. The existing 120/240 panels don’t work well on 208Y120. In theory, you could load alternate phases with sequential panels - A-B, B-C, C-A. But, it is a pain, in order to use obsolete equipment. Older 240V pumps and motors won’t run on 208V. Yes, 208-240 is a standard buck-boost transformer connection, but again, a pain in order to use obsolete equipment. Everyone is hoping that money will become available and the entire building can be torn down and replaced, along with a new electrical distribution system.

Regarding how many service switches. The rule is six-maximum, plus one for fire pump and one for fire alarm and one for TVSS. (This means how many switches at each service point.) Most discussions in the Code relate to apartment houses and multi-occupant commercial buildings. These applications are well explained. How to use the rule for rust-belt retrofits is not addressed.

In northern Ohio, and many other places in the country, a need arises to provide more power to a very old industrial building. We hope that it means that someone is making money and expanding, but it is more often the re-purposing of a warehouse for a production activity. The need is the same, however. There is a very, very low budget and they need more power. A legal solution is to tap off the high-side of the service switch and install another service switch with distribution switchboard for the new loads. This is legal up to a total of six service switches.

Of course, the Utility has to decide if they have enough capacity and metering for the new load on their side and there may be an upgrade charge, either directly or through your Contractor.

Architects and most electrical engineers are strongly opposed to this solution. It is not pretty and it is not an excuse to bring the old distribution up to current Code. But, it does bring jobs into the community. And, the difference between an abandoned building with broken windows vs the same old building with a full parking lot and trucks coming and going is a vote for use of the six-switch rule.

Please let me share with you two peculiar service switch situations - accessible service switch and service in the middle of a building. Before we start, let us review the "standard" arrangement. In 99.5%+ of the cases you will encounter, the Utility runs medium voltage power down the street, either overhead or underground. They put in a transformer and you pay for service conductors to a meter on your building. From the meter, more conductors take the power just inside the wall, where you put your service switch and main distribution switchboard.

In some municipalities, it has been decided that fire fighters must be able to turn off all power to the building before they start squirting water on it. In these municipalities, there must be a big service switch on the outside of the building, next to the meter. An alternate, not universally accepted, is to put a shunt-trip circuit breaker in as the service switch and a remote key switch outside, at the meter. I have not been able to talk to local Contractors about how well this works

The second peculiar installation is the result of close reading of the Code and applying good sense. The Code believes that service conductors are not inside the building if they are under the floor, with at least 4-in of concrete. 230.70 says the service disconnect must be readily accessible, either outside or inside nearest the point of entrance. My boss was putting up a new office building. He had the contractor run the service conductors under the floor to the center of the building. Where they popped up, into the switchgear, was nearest the point of entry. This way, his feeders to local lighting and receptacle panels were shorter, with less voltage drop and less length of wire purchased.

Article 240, Overcurrent Protection

It is the characteristic of electrical wires, transformers and most equipment that a small overload can be tolerated for a long time. A large overload can be tolerated for a short time. This relationship is called an inverse time-overcurrent curve. So, when we speak of overcurrent protection, we do not mean, "measure and disconnect if above the setpoint." Rather, we mean, "follow the pattern and when the resulting time-overcurrent function exceeds the time-overcurrent protection curve, then disconnect." Today, this is done by a microprocessor in high-end circuit breakers and the protection curve can be selected. Formerly, and today in molded case breakers and fuses, you pick out a protective device with a single protection curve.

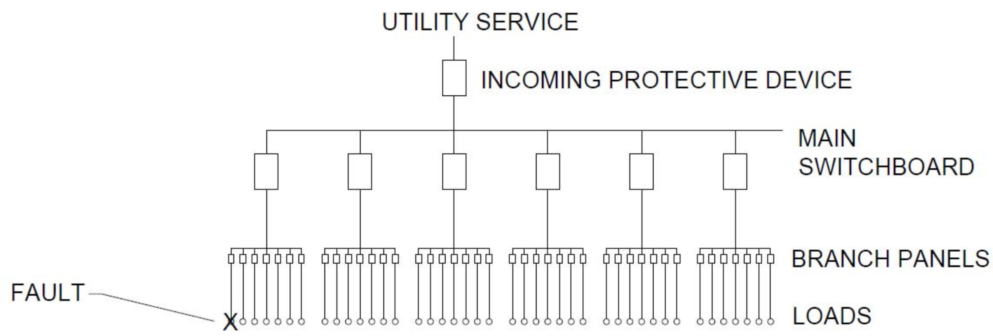
A special case of overcurrent protection is fault protection. A fault is a massive overload. Protective devices are supposed to disconnect as fast as they can. Current limiting fuses do this before the fault current gets to its first half-cycle peak. The best circuit breakers let through about three cycles of fault current. For the most part, there is no intentional delay on instantaneous protection.

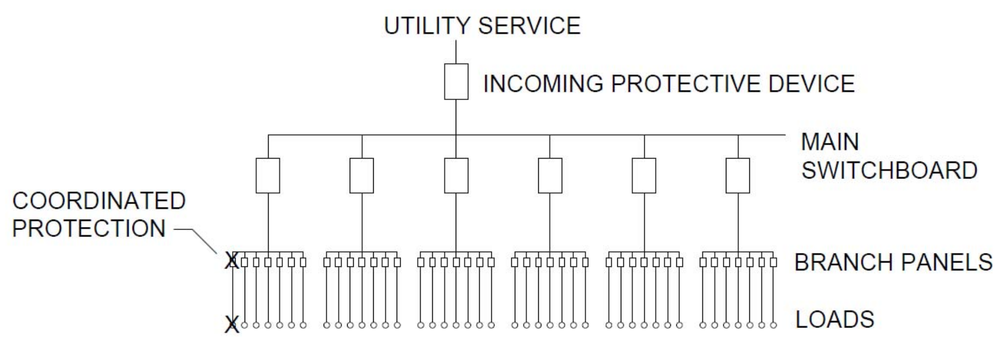
There is a separate set of rules for supervised industrial occupancies with more than 2500 kVA of load. These exceptions will not be addressed here.

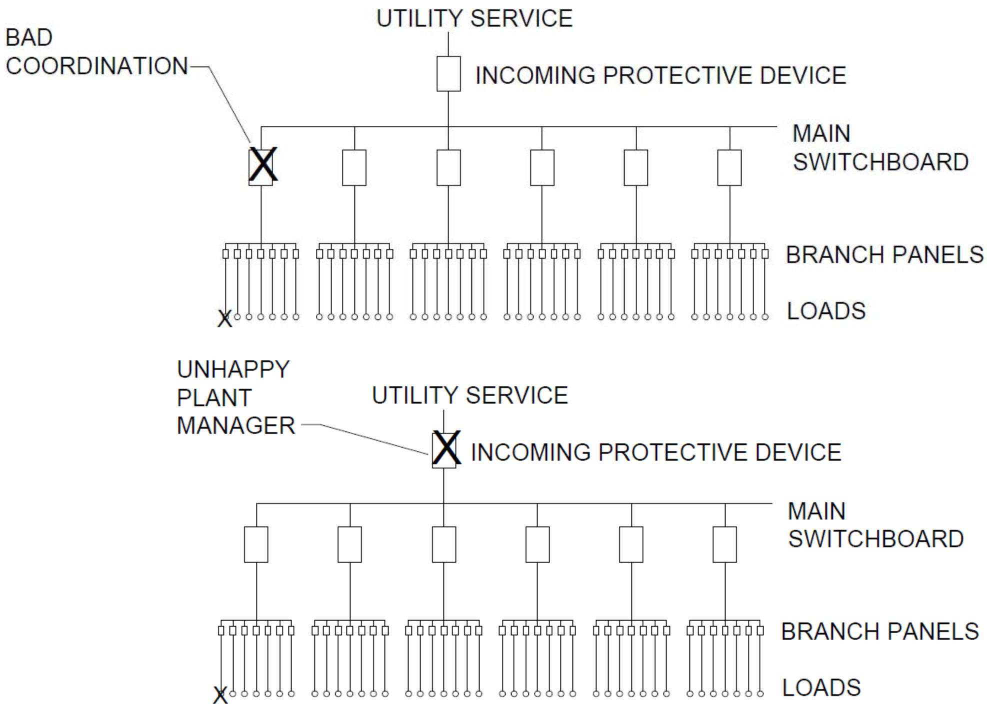
Electrical design means looking at the load you want to connect and choosing wire large enough to supply the load (nameplate or special calculations for motors and transformers). After the wire is chosen, you choose a fuse or circuit breaker to protect the wire selected. There are details following the section 240.4 introduction that let you save a little bit of money.

The people I work with look at the load requirement then choose the next higher standard circuit breaker and pick the wire size that matches that circuit breaker. (And, yes, we use fuses the same way.) This may cost a little more for copper, but we have a table and the process is instantaneous with almost no opportunity for error.

Overload coordination is recommended, but not required, by section 240.12. Almost everyone ignores coordination and people who try, without deep understanding, cause a lot of trouble. It is a simple concept with a tremendous amount of modifying detail. The concept is illustrated in the following:







ILLUSTRATING PROTECTIVE COORDINATION

This illustration follows Exhibit 240.3 in the National Electrical Code Handbook 2011. The lines are electric circuits. The boxes are protective devices. The tiny circles are end-use loads.

The very simple concept is that the protective closes to the load should operate and the rest of the plant should continue to operate. In the bad coordination case, the lowest protective device fails to operate, because of incorrect sizing or lack of maintenance, so the upstream protective device operates and the entire branch panel is removed from service. This is a good reason not to take lighting power or controls from the same panel and process power.

In the unhappy plant manager case, neither the branch panel nor the main switchboard feeder operates and the plant main operates. The entire plant is taken out of service.

One way to achieve selective coordination is to intentionally slow down the high level protective devices. On modern circuit breakers, this is a screwdriver adjustment. This helps assure that low level protective devices will operate first. It also increases the milliseconds for which the fault current flows. Milliseconds x Amps = arc-flash severity.

The "Poor Man's Rule" for circuit breaker coordination is that you need 10x the trip rating between the lower device and next higher device. That is a 20A branch breaker in a panel with the same style 200A main will coordinate. The 20A will trip before the 200A on a short-circuit. By this rule, a 20A branch breaker may or may-not trip before the same style 150A main.

Obviously, if you have a 200A feeder breaker to a branch panel with a 200A main, there is no telling which will trip first, and there is no easy way to fix this without going to an electronic trip unit on the feeder and intentionally delaying or disabling instantaneous trip. And, nobody cares, except one silly electrical engineer at a major auto manufacturer.

You are out of line on that comment about using branch panels with main breakers.
Maybe, maybe not. When a protective device operates, there is something wrong. The proper response is not to reset the breaker, but to find out what is wrong and fix it. It may be that during the walk to the feeder panel, the electrician will remember the last time the breaker tripped and have a good guess what is going to happen when he re-closes into a fault. Your author favors branch panels with a main breaker. There is a hope that the maintenance electrician will take the panel bus bars out of service when he works on the panel. This is not legal, per OSHA. The entire panel must be at zero-energy. Another justification for main breakers is the illustration just presented. It is less likely that two protective devices in series will both malfunction and take out a large part of the plant.

240.21 Location of Protective Devices and Feeder Taps
(That is not the Code wording. They talk about taps here but don't recognize it in the title.)

Consider this, you run an overhead line out to the pump house and later decide it would be good to have a light on one of the poles. Easy to do. Tap the circuit, use a crimp-type inline fuse and power the light. That is the simplest example and the right way to do it.

The first question that comes up is, "How far from the tap can you place the protection?" And, that is the basis of all the tap rules. The three rules most used are as follows:

Unlimited – 10-ft
1/3 – 25-ft
Unlimited – outside

As with all wonderful opportunities offered by the NEC, there are restrictions and some serious consideration is required when you use them. The unlimited – 10-ft rule is only for within equipment, as a switchboard. The idea is that, in the event of a fault, the conductor will burn-clear and damage will be contained in the enclosure. You might not want conductors burning in your switchgear and decide to use an inline fuse, even if not mandated. The most common example of this is tapping a bus for another circuit breaker when there are no spaces available and tapping the bus for metering or a TVSS. A #12 AWG building wire only requires 1A fuse for metering, at a cost of $10 (materials). No. 10 for a TVSS is slightly more.

The 1/3 – 25-ft rule is commonly used. The point is to run conductors from the tap to a place you can mount a fused switch or circuit breaker. The "1/3" refers to the ampacity of the feeder and the tap. The tap isn't supposed to be less than 1/3 the feeder rating. The reasoning is that you get good instantaneous protection and poor overload protection from the feeder protection. There isn't much likelihood of an overload on a piece of wire. The "1/3" limit is because a really small wire can get into a catastrophic short circuit that the protective device on the large wire thinks is just an overload and starts checking its time-overcurrent curve before operating.

The unlimited – outdoor rule is because the hazard from burning clear is considered to be less than the hazard of the same fire inside. Read all the fine print if you decide to use this rule.

A constructive alternative is offered at this point - the full-capacity tap. Because it is at the same rating as the feeder, it is a tap only in configuration. The conductors have the same capacity as the feeder and the existing protection is exactly right. I use this when I fill a panelboard and install another panel for more loads at the same point, from the same feeder. Since I don't know what the actual loads will be, I want the second panel to have the same capacity as the original. Contractors will do this if you buy panels with feed-thru lugs, but they really don't like to make full-capacity gutter-taps. Their preference is a sub-feeder breaker in the original, supplying the new panel.

240.24, Location in or on Premises
Electrical Inspectors enforce these requirements. First, the 6-1/2-ft rule. (Ordinarily) disconnect switches, including switches in panelboards, must not be more than 6-1/2-ft above the floor. The two common exceptions are HVAC disconnects above a drop ceiling, but next to the equipment protected and overhead bus duct switches.

Disconnect switches, including switches in panelboards, must not be mounted on stairs.

Disconnect switches, including switches in panelboards, must be accessible. This comes back to the discussion in the definitions section. For instance, electric panelboards for apartments must be accessible to the residents.

Overcurrent protective devices, including panelboards, must not be exposed to physical damage, located near easily ignitable material or in bathrooms.

240.13, Ground-Fault Protection of Equipment
This section requires a 30mA ground fault sensor and trip unit for 480Y277V devices rated 1,000A or more. It is not required for 208Y120V, 240V or ungrounded 480V-delta. The requirement can be avoided for small loads by using multiple 800A-frame devices. It cannot be avoided by using 1,000A-frame and an 800A trip unit.

As with the rest of the Code, there are restrictions and exceptions. 30-mA is most common, and presented to contrast the 5-mA personnel protection GFCI on receptacles and vending machines. 50-mA and 70-mA, and possibly others, are available, with restrictions. A time-delay can be applied between the sensor and the trip unit to permit a downstream GFP to operate before the main. Upstream-inhibit can also be used, but will not be discussed here.

There is no implication that the fault magnitude is 30-mA; that is just the threshold at which the sensor starts paying attention. A 600A ground fault is quite possible on a 2000A feeder and would not be picked up by either instantaneous or overload protection, but could be very destructive.

Article 250, Grounding and Bonding

This article states very clearly that “all metallic systems must be grounded”, and explains this means that there must be an intentional copper conductor back to the service ground. Usually the common tie-point for downstream grounds is the ground bar for the main distribution. Recently, vendors are offering nice little ground bars with plastic covers to meet the grounding requirements for CATV, data and telephone. Commercial and industrial occupancies usually put a crimp lug on the tiny wire and a machine screw into the power ground bus. Connection of the ground bar to the ground rods is a special topic. Another special topic is grounding of the utility service transformer. These will be addressed later.

Of course, intermediate points and systems may get their ground connection from any particular ground wire going back to the service ground. There are only two real restrictions relating to equipment ground with accompany feeder or branch supply conductors - they must closely accompany the supply conductors and they must be of sufficient size to safely carry the fault current in the event of a line-to-ground fault at the equipment served.

Ground conductors for incidental systems, such as HVAC duct, CATV or data systems can be anything larger than #56 AWG copper. There are other sections which require a larger conductor for expected grounding of lightning strikes. Is is common to use bare 500 kCMIL or 4/0 AWG for a perimeter loop, with #2 AWG connections to individual building steel columns and motor bases. These are auxiliary ground fault return paths, but present primarily for equalization of voltage for a lightning event. They are intended to minimize the voltage present rather than trip the supply circuit breaker.

Beyond these concepts, the Code is dedicated to listing mistakes to avoid and a few good practices to avoid problems. The lists are mandatory and make up a good part of the Electrical Inspector’s job - to find violations.

There is a very specialized field of hospital patient-area grounding. That will not be addressed here, but be aware that the requirements are much more stringent and the methods applied are much more complex.

Section 250.8 addresses legal ways of connecting the ground wire. Hose clamps and self-tapping metal screws are forbidden. There are special “three-lobe” thread-forming machine screws that are legal (and don’t drop the shavings into the electrical equipment).

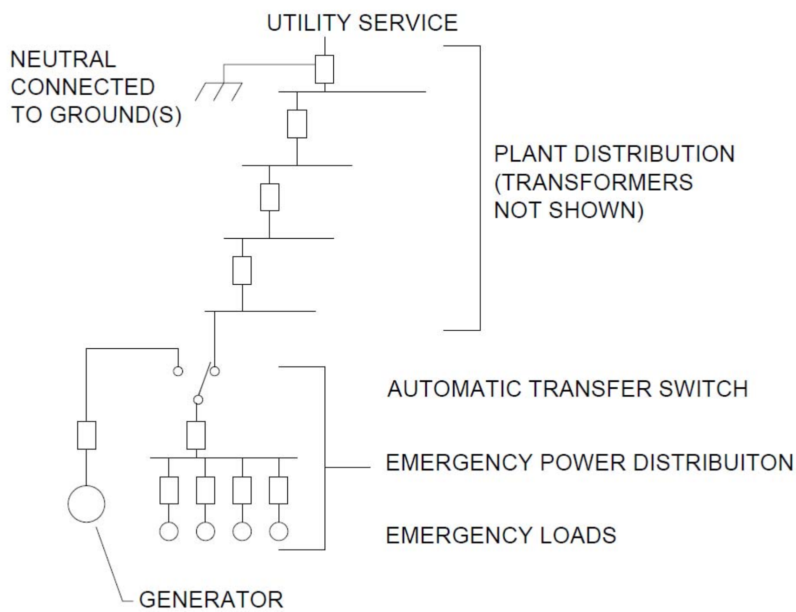
The best electrical connection results from a “double-lug, double-crimp” lug on a wire-brushed surface with no-ox paste. The code permits spring-connectors (wire nuts) and there are special wire-nut-plus-green-pigtails that make very tidy connections in wall boxes. Exothermic welded connections are very good, but labor-intensive. Approved crimp connections work very well. As always, “UL-approved for the application” is a key specification entry.

Section 250.20 lists various systems that must be grounded or may be ungrounded. Be warned, however, that systems that are ungrounded must be in grounded raceway and all other metal items still need to be grounded.

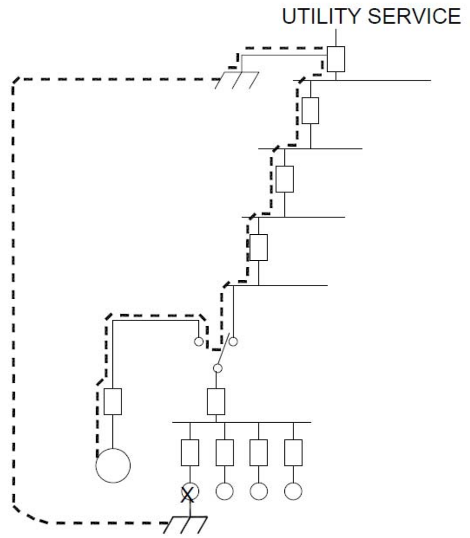
Legal ungrounded systems that you may run into are low-voltage controls, legacy industrial power systems and chemical processes using extremely high currents. The legacy industrial systems (240Vdelta, 480V-delta and 575V-delta) require ground alarms, but do not require automatic action result from alarm activation. It is very common to have ground alarms on these specialized systems and perform maintenance to keep them ground-free.

Separately derived systems are discussed in this article. A transformer, generator and some static devices are separately derived sources - they create new electricity. The general rule is that the new source must be grounded. This works well for a separately derived source with a permanent distribution system. The question arises when it is connected to the plant or office electrical system with a transfer switch - sometimes normal power and sometimes generator power. Only one ground connection is permitted for the building service. What to do?

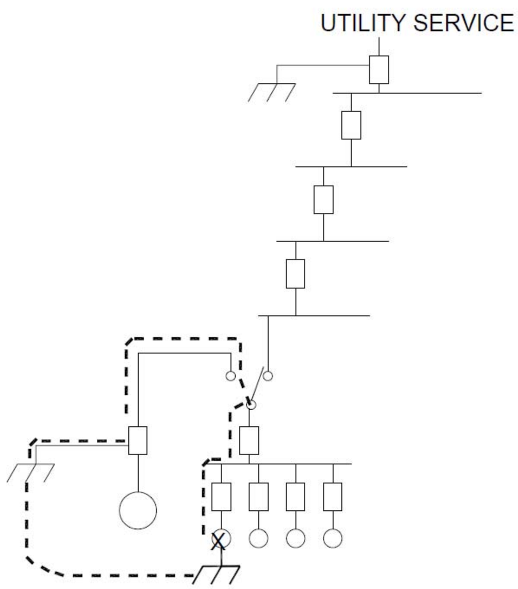
There are two answers and very strong opinions on both sides. One is to ground the generator and switch the system neutral to the generator with a 4-pole transfer switch. The other is to solidly connect the generator neutral to the building neutral, but not to earth, and have fault current go back to the building bonding connection, then back thru the neutral to the generator. See the sketch below:



TRANSFER SWITCH ILLUSTRATION



FAULT PATH WITH 3-POLE SWITCH



FAULT PATH WITH 4-POLE SWITCH

Slow down, Hoss, there are a lot of things wrong with those illustrations.
Well, kinda-yes, kinda-no. You are correct that we run a lot of copper equipment ground wires so that the fault current doesn't have to go through the earth from the fault back to the neutral-earth connection. On the other hand, for the fault current to get from the failure back to the source, it must travel roughly the path shown, only, following the circuit conductors rather than out in the earth around the

plant. The point was the length of the fault return path. It is much shorter with the four-pole transfer switch.

Regarding the implied transformers and new earth-neutral connection at the secondary of each. Yes, this is true. However, a 480V line-to-ground fault on a plant with 480V service will have a return path similar to that shown (using equipment ground wires). A 208V line-to-ground fault will have the fault return current only go back to the transformer to get on the neutral for the generator.

Section 250.50 addresses the utility service ground. As stated previously, the reasons for grounding the electrical distribution system are to stabilize it from voltage swings, shunt lightning before it gets into the building, provide a fault return path to trip protective devices and to provide safe surfaces for staff and visitors.

The Code says that all seven grounding electrodes that are present must be bonded together to form a grounding electrode system. This is not confusing, but interpretations are. It is not onerously expensive to actually create and bond all seven and I recommend this (and seem them all frequently on construction drawings). The only one that gets serious complain is number 3), tying to foundation reinforcing steel. This requires coordination with the foundation contractor and a visit, at the right time, by an electrician.

The seven grounding electrodes are as follows:

1) Metal Underground Water Pipe
2) Metal Frame of the Building or Structure, with daisy-chains if not inherently tied together
3) Concrete-Encased Electrode
4) Perimeter Ground Ring
5) Ground Rod
6) Other Listed Electrode
7) Ground Plate
8) Other Metal Underground Systems or Structures

I added the caveat about daisy-chains on the building steel in response to a Change Order caused by one Electrical Inspector's interpretation. More bare ground wire is easy to add before the drywall goes up.

You might notice that there are eight items in the list of seven. Well, neither number 8 nor 6 really says anything.

There are details on the sizes and installation details in the National Electrical Code Handbook for each of these electrodes. It is important for the field inspector to be aware of these details, but the designer only has to say, "per NEC". He should leave wire size selection, connectors and piece selection to the Contractor under "means and methods". One exception is the basic ground electrode. For years, this was the only earth ground and got a lot of attention. Careful designers call for a minimum of three 10-ft (fully covered) driven rods, spaced at least 10-ft apart (often in a triangle.

Ungrounded systems are used in mining, marine and Utility applications. You were enticed to take this course with a reference to "cold ironing". That means running a ship's power off a land-side power source while doing maintenance on the ship's generator. The grounding required for "cold ironing" requires close attention and may involve different interpretations from the ship people and land people and various regulatory bodies.

Grounding was a question for electric cars for some time, but appears to have been resolved by a widely accepted NEMA connector. This is addressed by the Code in section 625 but not reported here.

A very difficult grounding question relates to vehicle block heaters. Section 210.8 (remember the matrix of GRCI and AFCI requirements?) requires ground fault protection on outdoor receptacles. The block heater, on a school bus, for instance, plugs into an outdoor receptacle. Block heaters have huge leakage current and trip a GFCI. Designers put in GFCI; maintenance people take them out. The good thing is that they are never used when the kids are using the bus.

Section 250.102 discusses equipment bonding jumpers. What we are talking about is the equipment ground conductor which accompanies the power conductors from the panel to the load. This section includes a provision that you can wrap a short section of green-insulated conductor around the outside of an oiltight flexible steel conduit going up to a motor junction box. It is common to find an entire plant, often a water or waste water plant, with all the motor connections displaying an external green wire at the motor junction box.

It is also common in large plants to find a discrete bonding system between building steel and motor bases. It is required by the design standards for firms over 100-years old but not so common in start-ups. As long as everything is bonded together, per the "8 of 7 rule", there is nothing wrong. If the ground accompanying the power conductors is intact and the protective devices work, there is not benefit for the additional ground.

Flash! Lincoln Electric recommends a discrete ground wire from building steel to each welding power sources!
This recommendation is in response to warranty calls. A great many controls mis-operations are eliminated by this ground connection. The newest welders are invertor-based, with microprocessor-control. And then, there are robotic welders.

Section 250.106 requires that if a lightning protection system is present, it must be bonded to the electric service ground. This is also the source of the perimeter ring ground. The ring is especially effective for lightning protection on high-rise buildings.

Section 250.118 says that it is still legal to use rigid steel, intermediate steel, thinwall and flexible metallic conduit as a grounding conductor - with limitations. All specifications I have read in the last twenty years call for a separate grounding conductor. Too many times, I see conduit connections pulled loose in the field. Sometimes the equipment sinks because of inadequate foundation. Sometime the conduit "rots away" because of chlorine in the air. It is a bad idea to use the raceway as the ground.

Section 250.122.F requires that the grounds for parallel conductors each be sized for the entire load.

This applies only to individual conduits, where the ground impedance will be different for each run of the circuit and fault current may choose to follow only the lowest impedance path. (If you think fault currents can be quirky, check into lightning currents.)

The equipment grounding conductor is selected from Table 250.122, based upon the size of the protective device for the circuit. Note that the ground is not a current-carrying conductor. It is intended to carry fault current for a few one-thousandths of a second only.

Section 250.170 discusses grounding of meter and protective relay circuits - voltage transformers and current transformers. It would be nice if we could just let the factory install metering and relaying for the switchboard or motor control center. Unfortunately, these circuits are capable of very dangerous mis-operations and catastrophic failure if mis-wired. Also, someday, business leaders will notice how much money they are spending on electric power each month and they have no ideas where it is going. We will be retrofitting check-metering wholesale.

I thought LEED had a "Measurement and Verification" point to encourage sub-metering.
This is awkward. Architects handle LEED. Architects don't understand electricity. When they seek the M&V point (EA c5), they don't want to buy meters, just get the EE to sign off that they bought them. I put sub-metering into three LEED schools recently. The LEED person was the HVAC designer on the project. He has more ethics than an Architect and really wants to see how his energy use models compare with reality. The State-hired Construction Manager may delete the meters from the project as a cost-saving, though the State demands LEED certification. The adder for submetering was ~$10,000. An underlying conflict is that you need $200 kWD / kWH meters, but all the advertising is for $10,000 kWD / kWH / transient / THD … meters. Obviously, the fellow who specifies Italian marble facing wants only the best meter, or none at all.

Back to metering and protective relaying, we ground one side of the secondary of a voltage transformer and (mostly) we ground one side of the secondary of a current transformer. If we do this, then any wiring fault will make a big spark and blow a fuse or melt the conductor. The exceptions relate to special three-phase connections.

Section 280, Surge Arrestors

Section 280 is for surge arrestors on systems over 1,000V. This is very meaningful for plant internal medium voltage power distribution and for large motors. Typically, switchboard and unit substation manufacturers are very careful, because their technicians will be doing startup and they will have liability for associated injuries for the life of the equipment.

Section 285, Surge-Protective Devices

Section 285 is surge protective devices for systems of 1,000V or less. (1,000V systems are common in surface and underground mining and are getting some attention from large international manufacturers.) For the rest of us, that is 120V, 208Y120V and 480Y277V, surge protectors are needed, not surge arrestors. I use the term "transient voltage surge suppressors" (TVSS), since that seems more descriptive and is standard in catalogs.

There are a lot of details regarding TVSS, but only two important concepts - labeling Type and that they are a collection of 10-cent metal oxide varistors (MOV). Labeling Types and restrictions are as follows:

Type 1 - Supply-side of main disconnecting means, or any location downstream. These are also permitted to be labeled as surge arrestors.

Type 2 - Load-side of main disconnecting means and protection, or any location downstream.

Type 3 - Load-side of a protective device at least 30-ft from the service entrance.

Type 4 - Point-of-use, as a TVSS receptacle or power strip with TVSS or a simple plug-in MOV.

If you open almost any commercial TVSS, you find several rows of discs the size of a penny, with an insulating cover, usually wired in parallel. There will be a strip for each phase to neutral, there may be a strip for each phase to ground and there may be a strip from neutral to ground. Everything else is marketing value-added.

Surge Protective Devices – Smoke-and-Mirrors vs Functionality
The kind of surge protectors we are talking about are sacrificial devices. That is, they function by shunting the energy of a lightning strike or switching surge through themselves to ground. This implies several things, as follows: 1) In a high-lightning area, even the best surge protector will eventually fail (months, not decades). 2) In a low-lightning area, the likelihood of surge protector operation is low. This certainly means than an effective salesman can point to success on installations of his special product. 3) Because they are sacrificial, you should buy units with out-of-service lights. 4) It is of critical importance to follow IEEE guidelines and put a Type 1 or 2 unit at the service and a Type 2 or 3 at each panel. I say again, "Put a Type 1 or 2 unit at the service **AND** a Type 2 or 3 at **EACH** panel." The benefits of TVSS are cumulative. The surge that gets past the service TVSS gets attenuated further by the panel TVSS and again attenuated by the UPS TVSS in the computer room.

5) Because they are shunt devices on an energized line, simple surge protectors are limited to about 600V clipping on 120V and about 1200V clipping on 277V. This means that electronic devices still need withstand ratings and the need for isolations and UPS is not eliminated.

Article 300, Wiring Methods

Article 300 lists available wiring methods and identifies proper uses and forbidden uses. As technology keeps advancing, innovations are offered to the marketplace to reduce materials costs and labor. This describes most of the additions to Article 300 in the last 50-years.

The old methods are individual conductors in raceways of rigid steel, intermediate steel, thinwall tubing, flexible conduit and liquidtight flexible conduit. For institutional and industrial occupancies with an expected life exceeding 20-yr, these are still the preferred methods. For speculative office buildings and warehouses or retail buildings, the innovative methods often make the difference between financial success and failure.

With the understanding that many of the innovations trade low first-cost for higher life-cycle-cost, the decision resolves to the risk tolerance of the Owner, designer and Building Standards Office. Some Building Standards Offices are extremely risk-adverse. This is usually well-known in the community, but may be a surprise to outside investors or an out-of-town low-bid contractor.

Section 300.4 is worthy of note. It has always required protection of conductors from damage, but is getting more attention from Inspectors in my part of the country.

A requirement that I have rarely seen followed is to place residential type NM (nonmetallic, or Romex™) cable at least 1-1/4-in from the edge of a stud or joist. If closer, there is supposed to be a UL-approved metal plate to protect the conductors.

A change for 2011, 3004.E, is protection of conduit-encased conductors and boxes under a roof deck. The requirement is 1-1/2" and the conduit and boxes must not be concealed. For 2011, expansion joints in conduit runs are required wherever the Architect has a building expansion joint. Also, 300.11, above-ceiling support wires for electrical must be tagged or colored to differentiate them from grid supports.

Section 310, Conductors

The content of the text and tables in section 310 are unchanged, but the wording is revised and a great many additional tables are included. Table 310.15.B.16 lists not more than three current carrying conductors in raceway, cable or direct-buried. Content is the same as the old Table 310.16. Listed are 60C, 75C and 90C insulations over copper or aluminum conductors.

Note the requirements for upsizing conductors if there is high ambient temperature (Table 310.15.B.2.A), more than three current-carrying conductors (Table 310.15.B.3.a) or sufficient to give 5% voltage drop (no Table).

Table 1, Chapter 9, lists maximum fill and hasn't changed. It is 40% for everything you will likely encounter. Table 4, Chapter 9, lists total cross-sectional area for heavy-wall steel conduits. Table 5, Chapter 9 lists conductor cross-sectional areas.

Annex C Table C.8 lists permissible conduit fill for common insulations on building wire in common rigid conduit sizes. Adjacent tables list different conductor types and different raceway types.

A very powerful design aid is a table with columns for circuit breaker, power conductor size, ground conductor size and conduit size. A further aid is to include a key, perhaps in a hex box, and use the key on one-line diagrams instead of repeating information on each 10HP motor. A sample is included below:

FEEDER SCHEDULE

	HTR 208V KW	HTR 460V KW	3 PH 208V HP	3 PH 460V HP	MAX AMPS	#	# OF PARALLEL RUNS	ø WIRES AND NEUTRAL PER CONDUIT	PHASE CONDUCTOR SIZE	GROUND SIZE	CONDUIT SIZE
SINGLE PHASE	3KW	7KW			20	1	1	2	12	12	3/4"
SINGLE PHASE	5KW	11KW			30	2	1	2	10	10	3/4"
SINGLE PHASE	6KW	15KW			40	3	1	2	8	10	3/4"
SINGLE PHASE	8KW	19KW			50	4	1	2	6	10	1"
SINGLE PHASE	11KW	26KW			70	5	1	2	4	8	1"-1/4"
	5KW	13KW	3	10	20	6	1	3	12	12	3/4"
					20	7	1	4			
	8KW	20KW	5	15	30	8	1	3	10	10	3/4"
					30	9	1	4			
	11KW	26KW	10	20	40	10	1	3	8	10	3/4"
					40	11	1	4			
	14KW	33KW	–	30	50	12	1	3	6	10	3/4"
					50	13	1	4			1"
	20KW	46KW	15	40	70	14	1	3	4	8	1-1/4"
					70	15	1	4			
	28KW	66KW	25	60	100	16	1	3	1	8	1-1/4"
					100	17	1	4			
	36KW	83KW	–	75	125	18	1	3	1/0	6	1-1/2"
					125	19	1	4			
	43KW	100KW	40	–	150	20	1	3	1/0	6	1-1/2"
					150	21	1	4			2"
			–	100	175	22	1	3	2/0	6	2"
					175	23	1	4			
			50	125	200	24	1	3	3/0	6	2"
					200	25	1	4			
			60	150	225	26	1	3	4/0	4	2"
					225	27	1	4			2-1/2"
			–	–	250	28	1	3	250KCMIL	4	2-1/2"
					250	29	1	4			3"
			75	200	300	30	1	3	350KCMIL	4	3"
					300	31	1	4			4"

		300	31	1	4	350KCMIL	4	4"
100	250	400	32	1	3	500KCMIL	3	4"
		400	33	1	4			
150	300	500	34	2	3	250KCMIL	2	2-1/2"
		500	35	2	4			3"
–	400	600	36	2	3	350KCMIL	1	3"
		600	37	2	4			4"
200	450	700	38	2	3	500KCMIL	1/0	4"
		700	39	2	4			
–	500	800	40	2	3	600KCMIL	1/0	3"
		800	41	2	4			4"
		1000	42	3	3	500KCMIL	2/0	4"
		1000	43	3	4			
		1200	44	4	3	350KCMIL	3/0	3"
		1200	45	4	4			4"
		1600	46	5	3	500KCMIL	4/0	4"
		1600	47	5	4			
		2000	48	6	3	500KCMIL	250KCMIL	4"
		2000	49	6	4			

I keep expanding this chart when I run into a repetitive job and don't want to re-do the calculations again-and-again. The first addition was the motor size. I size breakers and conductors by the load. Showing the load makes it easier.

Then, I added the single-phase list for a job that had a lot of single phase loads and copying hex-# was easier than copying a string of letters and numbers. Finally, I added the single-phase and three phase heaters when I worked with an HVAC designer who listed kW but didn't list AMPS.

For a long time, I plotted only the Hex-# and circuit information. More recently, I need to check that the right size circuit was designed for the load delivered to the construction site. I need the connection between kW and AMPS, or must do some calculator-work. It seems reasonable to let the Contractor help with QA. If I got the wrong size, let's find it and correct it early in the job, not after the wires have been pulled.

Flight of fancy - more tables
Following the reasoning presented above, of late, I have been putting my circuit information (panel, breaker, wire size and conduit size) right on the Kitchen Equipment Schedule and on an Excel ™ take-off of the HVAC schedule. It involves a lot less copying of information for me (and reduced likelihood of error). This gives the Contractor the best available information. Examples follow:

ELECTRICAL CONNECTION SCHEDULE

CIRCUIT	KPA1–cb	ITEM	CONN#	DESCRIPTION
2–#12#12G–3/4"C	39	DCO		(1) REQUIRED .. DUPLEX CONVENIENCE OUTLET; 120V–1; ON 20 AMP CIRCUIT; HEIGHT AS INDICATED.
2–#12#12G–3/4"C	26	2	(1)	(1) REQUIRED .. E.C.; 120V–1; 6.3 AMPS; DOWN FROM ABOVE TO TOP OF WALK–IN AT APPROX. 102" AFF. ELECTRICAL CONTRACTOR TO INSTALL ADDITIONAL LIGHT FIXTURES PROVIDED LOOSE WITH WALK–IN ASSEMBLY. NOTE: SEE WALK–IN PENETRATION DETAIL THIS SHEET. (WALK–IN FREEZER LIGHTS AND DOOR FRAME HEATER)
2–#12#12G–3/4"C	24	2	(2)	(1) REQUIRED .. E.C.; 120V–1; 6.3 AMPS; DOWN FROM ABOVE TO TOP OF WALK–IN AT APPROX. 102" AFF. ELECTRICAL CONTRACTOR TO INSTALL ADDITIONAL LIGHT FIXTURES PROVIDED LOOSE WITH WALK–IN ASSEMBLY. NOTE: SEE WALK–IN PENETRATION DETAIL THIS SHEET. (WALK–IN COOLER LIGHTS AND DOOR FRAME HEATER)
3–#12#12G–3/4"C	14,16	2A	(1)	(1) REQUIRED .. SERVICE TO FREEZER EVAPORATOR COIL WIRED THROUGH TIME CLOCK LOCATED AT CONDENSING UNIT. (208V–1); SEE CONNECTION 2A (2).
3–#12#12G–3/4"C	2,4,6	2A	(2)	(1) REQUIRED .. E.C.; SERVICE TO ACCOMMODATE THE FOLLOWING: FREEZER CONDENSING UNIT.. 208V–3; 7.1 AMPS FREEZER EVAPORATOR COIL.. 208V–1; 7.0 AMPS NOTE: FREEZER CONDENSING UNIT LOCATED ON FLAT ROOF ABOVE WALK–IN BOX. ELECTRICAL CONTRACTOR TO VERIFY LOCATION WITH ARCHITECT PRIOR TO ROUGH–IN. THE FREEZER EVAPORATOR COIL IS WIRED THROUGH TIME CLOCK LOCATED AT FREEZER CONDENSING UNIT.

	HVAC EQUIPMENT LOAD SCHEDULE - ORCHARD SCHOOL						
CIRCUIT	PANEL	CIRCUIT	AMPS	TAG	NO.	VOLT/PH	AMP/HP
	FAN POWER BOXES						
2-#12,#12G-3/4"C	**LPB1**	**44**	**20**	**FPB-2-**	**1**	**277/1**	**3/4, .8kVA**
2-#12,#12G-3/4"C	**LPB1**	**46**	**20**	**FPB-2-**	**2**	**277/1**	**1/3, .45kVA**
2-#12,#12G-3/4"C	**LPB1**	**48**	**20**	**FPB-2-**	**3**	**277/1**	**1/2, .6kVA**
2-#12,#12G-3/4"C	**LPB1**	**50**	**20**	**FPB-2-**	**4**	**277/1**	**3/4**
2-#12,#12G-3/4"C	**LPB1**	**52**	**20**	**FPB-2-**	**5**	**277/1**	**3/4**
2-#12,#12G-3/4"C	**LPB1**	**54**	**20**	**FPB-2-**	**6**	**277/1**	**1/3**
2-#12,#12G-3/4"C	**LPB1**	**56**	**20**	**FPB-2-**	**7**	**277/1**	**1/3**
2-#12,#12G-3/4"C	**LPB1**	**58**	**20**	**FPB-2-**	**8**	**277/1**	**1/3**
2-#12,#12G-3/4"C	**LPE1**	64	**20**	**FPB-2-**	**44**	**277/1**	**1/2**
	PUMPS						
3-#6,#1G-3/4"C	MDP1	FU SW	50	**HWP-**	**1**	**460/3**	**30**
3-#6,#1G-3/4"C	MDP1	FU SW	50	**HWP-**	**2**	**460/3**	**30**
3-#12,#12G-3/4"C	MDP1	FU SW	20	**CWP-**	**1**	**460/3**	**5**
3-#10,#10G-3/4"C	MDP1	FU SW	30	**CWS-**	**1**	**460/3**	**15**
	CHILLER						
3-#600,#1/0G-3"C	MDP1	FU SW	500	**CH-**	**1**	**460/3**	**350**
	EXHAUST FANS						
2-#12,#12G-3/4"C	RPE1	48	**20**	**EF-**	**1**	**120/1**	**.1kVA**
2-#12,#12G-3/4"C	RPE1	50	**20**	**EF-**	**2**	**120/1**	**.4kVA**
2-#12,#12G-3/4"C	RPB1	52	**20**	**EF-**	**3**	**120/1**	**.4kVA**

Special Case of WireMold ™ 4000

Section 376.22 provides an exception for medium-large wireway, similar to Wiremold ™ 4000. Up to 30 conductors can be used without derating. This is extremely powerful for situations where you must relocate a panelboard or must accommodate especially intractable interferences.

Diversity and Sizing Circuits

There are several sections in the Code that permit "overloading" a feeder for non-coincident loads (not on at the same time). If you read the wording closely, they almost never apply. If you have two pumps, you must lock-out the second while the first is operating. This means that you can never respond to a hydraulic need for both pumps simultaneously. There is a section in cranes that has been quoted for reduced supply capacity. It applies only to cranes.

The correct way is to size your motor control center for expected loads, plus a reasonable future capacity, then size the feeder to the motor control center by the nameplate you chose for the motor control center. There is a hidden "diversity" here, but you are following the exact wording of the Code.

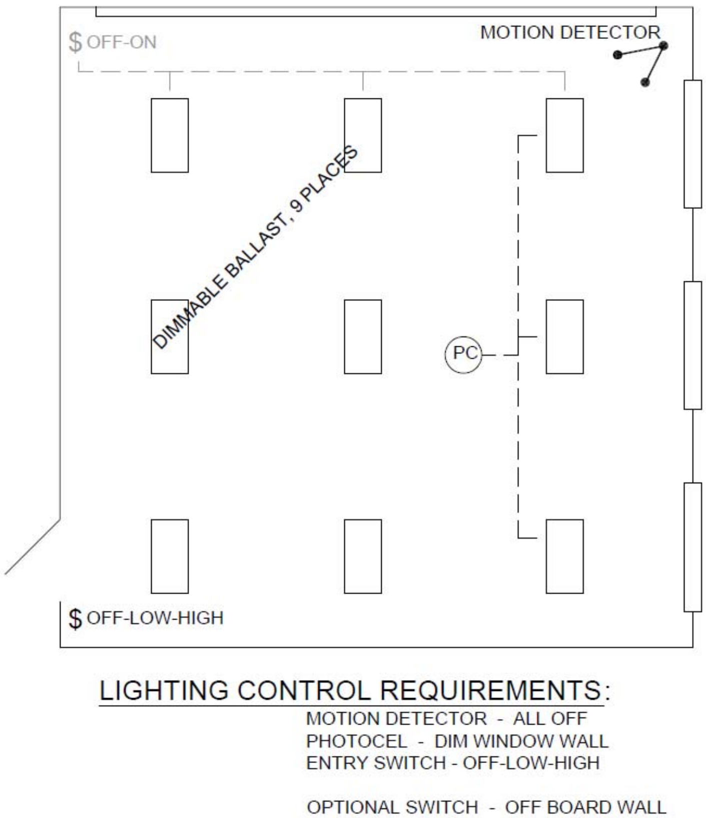
Similarly, when you size the main distribution panel for a building, you do not sum the installed circuit breakers and use that for the main. We know that it is rare for a feeder to run at 50% load, and less than 20% is common. This has been verified by field measurements consistently for many decades. After you tell the Utility you have 500kVA of load, they have you share a 200kVA transformer with the next guy in the industrial park. They know and they don't have to follow the NEC.

Article 404, Switches

Article 404 discusses switches, mostly light switches. There are rules which must be followed, but no hidden problems for the designer. The very real problem in my design world is lighting control and energy conservation.

The present energy codes presently require dual-level switching and motion detectors. Both are doable but not widely adopted. The new energy codes, which take effect in 2012, require daylight harvesting in rooms with more than 250 sq-ft of outside windows. I am presently working on five schools. The state school funding agency requires separate lighting control over the "board wall" for video projection use. Elementary classrooms have to have outside doors, so they need emergency egress lighting. This is an awful lot of control for six ceiling fixtures.

Let's limit our discussion to 2012 requirements - dual-level switching, motion detectors and daylight harvesting. Daylight harvesting, as you might expect, is the biggest problem. First, we must upgrade to dimmable fixtures. It is not good for students or employees to have lights turning on and off as clouds cover and clear. The following illustration attempts to illustrate this:



There are two forms of continuously dimming ballasts - 0-10V control and dimmed line voltage. Dimmed line voltage works with a Lutron ™ wall dimmer or with an architectural lighting dimmer for a restaurant or casino. A 0-10V dimmer reflects an archaic theatrical dimming scheme. Unfortunately, only the 0-10V dimming ballast is supported by currently available daylight harvesting controls.

This discussion affects the National Electrical Code only in so far as the controls are implemented badly. If a conventional dimming ballast is used, not much can go wrong. If an integrated control computer handles the range of commands from the photocell, motion detector and multiple switches, again, it should work or you change out the computer. On the other hand, if you competitively bid the ballasts, photocell, and motion detector, and try to get by without a computer, it becomes a monstrosity. These amalgam forms are what the NEC should be regulating.

Article 409, Industrial Control Panels

This section is not changed, but slightly clarified in the 2011 NEC. The requirement for labeling with fault-current withstand is unchanged. Added is wording that a panel must not be applied where the available fault-current exceeds this value. Also added is a requirement that if operation of more than one disconnect switch is required to disconnect all power, then labeling is needed to say so. The older, voluntary industrial panel standard, NFPA-79, had this and a requirement for a different color for wires carrying different external voltage sources.

Still missing from the NEC is the requirement for “touch-safe connections”. This has been a European requirement for many revisions of our Code. I specified this on sports lighting equipment recently and the supplier complied without complaining. It is a BIG DEAL in providing safety for later maintenance people.

Also missing is the requirement for a sub-panel and adequate wireways. NEMA figured this out many years ago. UL certainly knows. Established panel fabricators know. New engineers, just out of college, don't know and a firm just starting out in panel fabrication may see a Value Engineering opportunity. Controls devices should be mounted on one or more sub-panels that bolt into the main panel on stand-offs. A line in the purchase specification gives you something to talk about when you review the shop drawings.

Article 410, Lighting Fixtures

Article 410 is about lighting fixtures, mostly residential. Do pay close attention if you are involved in hotels or apartments.

Section 410.30 relates to pole-mounted outside lighting fixtures. There are several little-known requirements, as follows:

1) A non-hinged pole must have a hand-hole giving access to the incoming conductors and ground lug. A hinged pole still needs a ground lug.

2) You can put a security CCTV camera on a light pole but you must maintain separation between the power and low-voltage conductors. The Code vaguely suggests a raceway or cabled power conductors instead of loose conductors. It also mandates vertical support of all conductors, per Section 300.19. [Have you seen the highway fixtures that lower for re-lamping? Want to bet whether the conductors are vertically supported?]

3) It is good design to provide a local ground rod for each light pole. Some State highway departments require two ground rods for each pole.

4) Metal-halide lamps must have a lens. The Code reports fries from arc-tube failures.

5) 410.130 requires individual disconnects for non-dwelling fluorescent fixtures. Most manufacturers are not including separable connectors with the fixture, lamps and ballast.

6) 410.141 requires locking disconnects or a disconnect within view of the fixture for outdoor electric discharge lighting over 1000V at the lamp.

7) Section 600.6 requires a disconnect with locking means on outside signs.

8) Section 600.21 says that a (neon sign) ballast located in an attic or soffit requires a worklight.

But why is it here?
While we are talking about outdoor and mast lighting, please let me share an observation. One of the schools I was assessing put a generic compact fluorescent screw-base lamp in a self-ballasted light fixture in the bus parking area. It has been in service for three years and they are very pleased with it. This uses the original photocell on the fixture. I was amazed with replacing a 150W lamp with a 26W lamp and being happy with the result.

Article 430, Motors

Article 430 is about installing motors. Nothing much has changed for 50-years and Contractors are still skipping local safety disconnect switches and it is still rare to find labeling identifying voltage, load served or power source. Worse, firms with strong specifications accompany them with un-readable alpha-numeric sequences which are supposed to communicate. I feel very differently about a 208V Size 1 motor starter and a 480V Size 1 motor starter. Actually, most interpretations of OSHA arc-flash regulations feel very differently about 208V and 480V.

Section 480.120 is titled "Adjustable-Speed Drive Systems". This is wrong. The picture in the NEC Handbook is of "Variable Frequency Drives". The difference is that an adjustable drive has a single speed, that you can change. Mechanical belt drives do this. A variable frequency drive is continuously variable - both in speed of response and range. The boxes we are installing today are variable frequency drives (VFD), but we find the rules following 480.120.

I will relate here only three rules, which solve most of the problems I have encountered with VFD's. First, a VFD is a motor controller, but not a motor starter. Second, you usually need a bigger VFD than they tell you. Third, beware of harmonics on the incoming outgoing power leads.

You use a different set of rules for a VFD. The first difference is ratings. A starter has a NEMA or IEC horsepower rating. A VFD has a continuous current rating and smoke-and-mirrors regarding inrush and starting current capability. I buy at least one rating higher than it looks like I need and then I don't have problems. Two charts follow. One is sales literature from a major manufacturer. The second is my comparison of the VFD ratings and the NEC full-load currents.

Motor		Line supply				Altivar 71				
Power indicated on plate *(1)*		Line current *(2)*		Apparent power	Max. prospective line Isc	Maximum continuous current *(1)*	Max. transient current for		Catalog number	Weight
		380 V	480 V	380 V			60 s	2 s		
kW	*HP*	A	A	kVA	kA	A	A	A		kg
3-phase supply voltage: 380…480 V 50/60 Hz										
0.75	*1*	3.7	3	2.4	5	2.3	3.5	3.8	**ATV 71H075N4** *(3) (4)*	3.000
1.5	*2*	5.8	5.3	3.8	5	4.1	6.2	6.8	**ATV 71HU15N4** *(3) (4)*	3.000
2.2	*3*	8.2	7.1	5.4	5	5.8	8.7	9.6	**ATV 71HU22N4** *(3) (4)*	3.000
3	–	10.7	9	7	5	7.8	11.7	12.9	**ATV 71HU30N4** *(3) (4)*	4.000
4	*5*	14.1	11.5	9.3	5	10.5	15.8	17.3	**ATV 71HU40N4** *(3) (4)*	4.000
5.5	*7.5*	20.3	17	13.4	22	14.3	21.5	23.6	**ATV 71HU55N4** *(3) (4)*	5.500
7.5	*10*	27	22.2	17.8	22	17.6	26.4	29	**ATV 71HU75N4** *(3) (4)*	5.500
11	*15*	36.6	30	24.1	22	27.7	41.6	45.7	**ATV 71HD11N4** *(3) (4)*	7.000
15	*20*	48	39	31.6	22	33	49.5	54.5	**ATV 71HD15N4** *(3) (4)*	9.000
18.5	*25*	45.5	37.5	29.9	22	41	61.5	67.7	**ATV 71HD18N4** *(3)*	9.000
22	*30*	50	42	32.9	22	48	72	79.2	**ATV 71HD22N4** *(3)*	19.000
30	*40*	66	56	43.4	22	66	99	109	**ATV 71HD30N4** *(3)*	26.000
37	*50*	84	69	55.3	22	79	118.5	130	**ATV 71HD37N4** *(3)*	26.000
45	*60*	104	85	68.5	22	94	141	155	**ATV 71HD45N4** *(3)*	44.000
55	*75*	120	101	79	22	116	174	191	**ATV 71HD55N4** *(3)*	44.000
75	*100*	167	137	109.9	22	160	240	264	**ATV 71HD75N4** *(3)*	44.000
90	*125*	166	134	109.3	35	179	269	295	**ATV 71HD90N4** *(5) (6)*	60.000
110	*150*	202	163	133	35	215	323	355	**ATV 71HC11N4** *(5) (6)*	74.000
132	*200*	239	192	157.3	35	259	388	427	**ATV 71HC13N4** *(5) (6)*	80.000
160	*250*	289	233	190.2	50	314	471	518	**ATV 71HC16N4** *(5) (6)*	110.000
200	*300*	357	286	235	50	387	580	638	**ATV 71HC20N4** *(5) (6)*	140.000

Catalog Data										Calculated Ratio	
		480V				460V, NEC 430.250				1 Size offset	2 Size offset
kW	HP	Line A	Max A	60s A	2s A	NEC FL	6x FL	Max / FL	2s / 6x	2s / 6x	2s / 6x
0.75	1	3	2.3	3.5	3.8	1.6	9.6	1.4375	0.395833	0.70833333	1
1.5	2	5.3	4.1	6.2	6.8	3	18	1.366667	0.377778	0.53333333	0.71666667
2.2	3	7.1	5.8	8.7	9.6	4.8	28.8	1.208333	0.333333	0.44791667	0.60069444
3	-	9	7.8	11.1	12.9	6.2	37.2	1.258065	0.346774	0.46505376	0.6344086
4	5	11.5	10.5	15.8	17.3	7.6	45.6	1.381579	0.379386	0.51754386	0.63596491
5.4	7.5	17	14.3	21.5	23.6	11	66	1.3	0.357576	0.43939394	0.69242424
7.5	10	22.2	17.6	26.4	29	14	84	1.257143	0.345238	0.54404762	0.64880952
11	15	30	27.7	41.6	45.7	21	126	1.319048	0.362698	0.43253968	0.53730159
15	20	39	33	49.5	54.5	27	162	1.222222	0.33642	0.41790123	0.48888889
18.5	25	37.5	41	61.5	67.7	34	204	1.205882	0.331863	0.38823529	0.53431373
22	30	42	48	72	79.2	40	240	1.2	0.33	0.45416667	0.54166667
30	40	56	66	99	109	52	312	1.269231	0.349359	0.41666667	0.49679487
37	50	69	79	118.5	130	65	390	1.215385	0.333333	0.3974359	0.48974359
45	60	85	94	141	155	77	462	1.220779	0.335498	0.41341991	0.57142857
55	75	101	116	174	191	96	576	1.208333	0.331597	0.45833333	0.51215278
75	100	137	160	240	264	124	744	1.290323	0.354839	0.39650538	0.47715054
90	125	134	179	269	295	156	936	1.147436	0.315171	0.3792735	0.45619658
110	150	163	215	323	355	180	1080	1.194444	0.328704	0.39537037	0.47962963
132	200	192	259	388	427	240	1440	1.079167	0.296528	0.35972222	0.44305556
160	250	233	314	471	518	302	1812	1.039735	0.285872	0.35209713	0
200	300	286	387	580	638	361	2166	1.072022	0.294552	0	0

VFD Calculations

Now, why don't you use the motor horsepower and buy the VFD from the table ? If we look at the NEC continuous full load amps of the motor and the Max Amps of the VFD, we see a good fit. For instance, the 10HP Catalog Data offers 17.6 Max Amps. The NEC FL for 10HP is 14A. There should be no problem running the motor at rating. In fact, Max / FL = 1.25, so, you could run an industrial motor at its 125% service factor without problems.

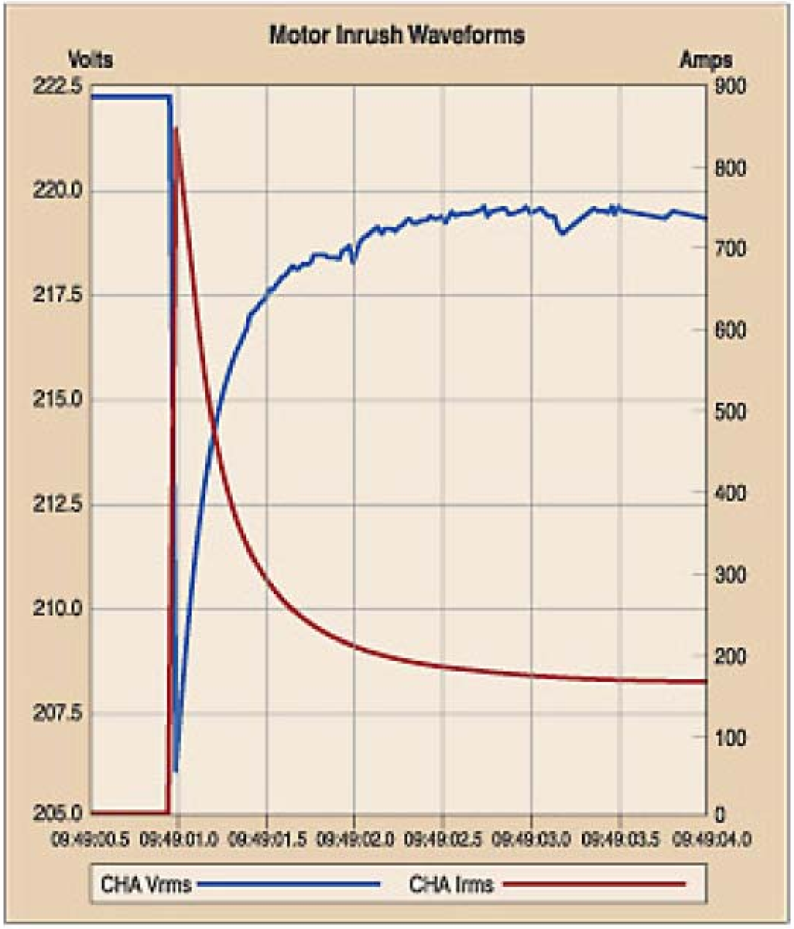
However, look at the starting situation. The 10HP motor needs 6x FL for 10 seconds for a worst-case start without damage. For the 10HP motor, 6s FL = 84A. The two second (2s A) rating of the recommended VFD is 29A. 2s/6x = .34. That means that the VFD will self-protect to 29A. It will not deliver the 84A that the motor wants. It will deliver 29A and the motor will start slowly. It may or may-not reach running speed in 10 seconds. Also, the manufacturer isn't offering 29A for 10 seconds, only 2 seconds. Depending upon the load characteristics, the VFD doesn't look big enough for the motor.

If we go up one size, that is, select a 15HP VFD for the 10HP motor, then 2s/6x = .54. We are still current limiting to protect the VFD. Go up two sizes, 20HP for a 10HP motor, 2s/6x = .65, still current limiting and slow start.

What to do? First, there is published data for the starting requirements for typical loads - fans with cold air, fans with hot air, unloaded pumps, loaded pumps, punch presses. If you search the internet a little, you can make a reasonable guess. In the old days, each VFD vendor had one specialist at the factory who did system design for customers and knew more about your loads than your mechanical engineer does. I think he retired. You can ask your mechanical engineer. Make sure you talk to him about upsizing the VFD.

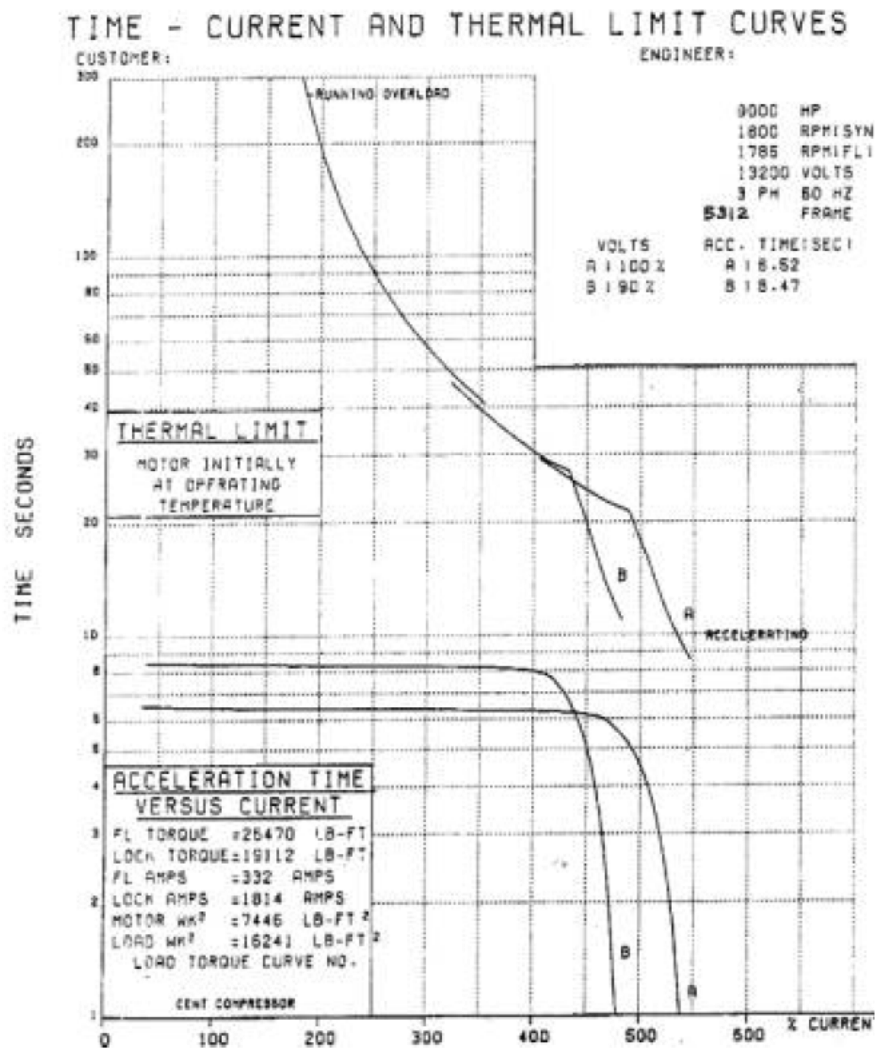
Just another caveat at this point. When you put a 10HP motor on a 20HP VFD, you might have trouble with the no-brainer motor protection set-up. Buy a thermal overload relay and put it in the emergency stop circuit. (A lot of designers always add a thermal overload relay, anyway, because they don't totally trust electronics and set-up technicians.)

Why do you think a NEMA B motor needs 6x full-load current for 10-seconds?
I was born knowing that a NEMA B motor needs 6x full-load current for 10-seconds. Seriously, I couldn't remember where that rule-of-thumb came from, so I did an internet search and confirmed it. For 6x inrush current, I found a link from Electrical Construction and Maintenance Magazine, by Dranetz, [See links in Course Description.] with the following chart:



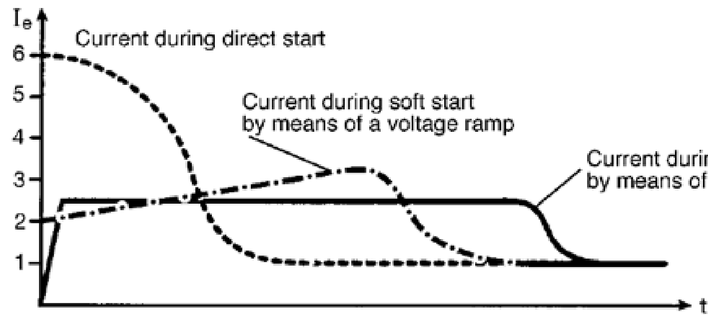
The horizontal scale is seconds, shown as clock-time. From 9:49.01.0 to 9:49.02.0 is one second. The motor they show has 860A/160A = 5.4x, and starts in less than two seconds. (Believe me, big motors, on big loads, using across-the-line starters, get up to speed in eight seconds.

Regarding start time, Timothy O'Hearn published information way beyond my understanding. [See links in Course Description.] He included the following time-overcurrent curve (TOC), which I vaguely remember from college and the Terman book (no longer available):



The two curves at the bottom are the motor-withstand capability. One says 6.5 seconds and the other says 8.5 seconds.

Regarding VFD's current-limiting for self-protection, producing slow starts, I found an Allen Bradley, Rockwell publication [See links in Course Description.] with the following chart:



Current curves during run up

This chart has two glaring defects. First, it says “Soft Start” and we are talking about “VFD”. Second, it is essential to get a hard “kick” initially to break-away from static friction. The point, though, was reduced motor current goes along with longer starting time.

The first two rules kinda ran together. A VFD is not a motor starter. We get deeply involved in motor inrush when we talk about motors and starters. A VFD is a solid state device, not an electro-mechanical connection between the motor and the line. For a VFD, the motor doesn’t matter. The VFD determines the current. The wire size to feed a VFD is the full load current on the nameplate (x 1.25). As we select a larger VFD because we know we have an inrush problem, then the nameplate of the bigger VFD tells us to put larger wire and breaker upstream.

Regarding harmonics on the line and load sides. Consider a 5% line reactor on the line side and another 5% line reactor on the load side. You DON’t need the reactor on the line side if you do not have a lineup of VFD’s. You DON’T need the reactor on the load side if your motor is VFD-rated (4,000V) and within 30 wire-feet of the VFD.

Article 445 Generators

Article 445 discusses generators. The world is presently changing rapidly and generators are being used differently than they were 10 years ago. Important considerations are different than they were 10 years ago. The products are much better than they were 10 years ago.

Article 445 is very bare-bones in requirements for safe installation of a generator. We will address emergency systems later, in Article 700.

Use the vendor service you are paying for.
Not long ago, there were problems with generators. The solution was to specify the engine, generator, exciter, voltage regulator and automatic transfer switch separately. Since then, the major generator manufacturers have adopted microcomputers and integrated them into the controls. Today, you don’t dare separate the exciter, regulator and transfer switch. The distribution channel for generators protects the local salesman. You can’t buy an industrial unit from Amazon (though you can buy a used generator from a broker). The local salesman has sizing software and experience in small and large generator application. Each of the major vendors will help you in return for a chance to bid on the purchase.

The following checklist will be sufficient to get a budgetary quote at the start a project:

Generator Checklist

____ Emergency
____ Standby
____ Fire Pump

____ Voltage / Phase

____ Present Guess on Full Load Amps
____ HP Largest Single Motor
____ Largest Motor Starts Alone
____ Largest Motor Starts with Genset Lo

____ Required Hours of Operation

____ Three-Pole Transfer Switch
____ Four-Pole Transfer Switch

____ Computer Interface

____ Diesel, Sub-Base Fuel Tank
____ Natural Gas

The first question establishes the UL standards that the generator must meet. Emergency duty requires 10-second start and costs more. Fire pump is more than the pump motor horsepower, and costs more also.

Voltage and phase are a bigger problem than they appear. You usually think of the generator and the load, but it may be desirable to generate at a higher voltage to minimize voltage drop for a distant load. You may have both 480V and 120V loads. You need to think this through before asking for a quote.

The size of the generator is based upon the total load and how it is started. The most economical generator starts the biggest load first, then the rest.

Hours of operation is for sizing the fuel tank on a diesel. Remember, old fuel oil is a hazardous waste, so do not oversize the tank. Similarly, EPA has become very restrictive on permitted annual hours of operation. You can't just burn off the reserve before a delivery, if you are following the rules.

Three-pole and four-pole transfer switches have been discussed previously. It is listed here mostly as a reminder that you want to spend an extra $15,000 right now. You need the transfer switch for automatic starting and for the computer interface.

The computer interface is for large organizations with central maintenance monitoring. You must specify the digital interface. ModBus is most common, with a gateway to Lon Bus or TCP/IP, if needed.

The diesel sub-base fuel tank is almost universal now, because of EPA tank rules. But, you have to mention it to get it. Natural gas used to be forbidden for emergency generators, but has become widespread. It may require a written waiver from the Building Department, though.

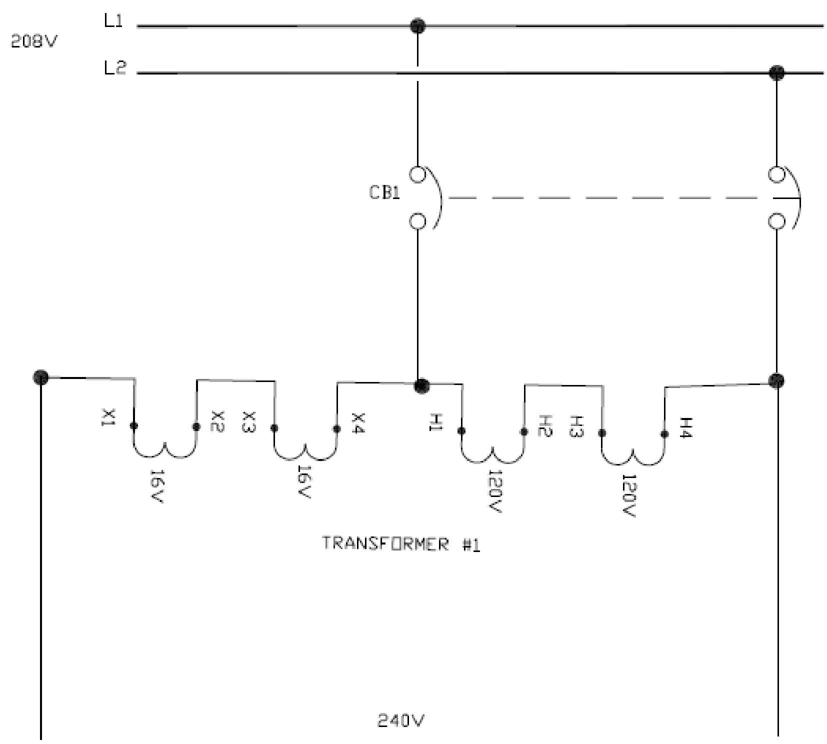
Article 450, Transformers

Article 450 discusses transformers. The hard part of specifying transformers is to provide protection but not trip out on inrush. The Code addresses this in many and confusing ways. For small, general-purpose transformers, the manufacturer will give you a table of recommended protection. Ignore this at your own risk. The NEC requires UL listing, which includes the requirement of installing the equipment per the manufacturer's instructions.

For larger transformers, perhaps 30kVA and larger, the inrush is a bigger problem and the hardship of a trip on inrush is bigger. Table 450.3 requires a maximum of 125% protection on the secondary (separate protection or main on a downstream panel) and a maximum of 250% protection on the primary.

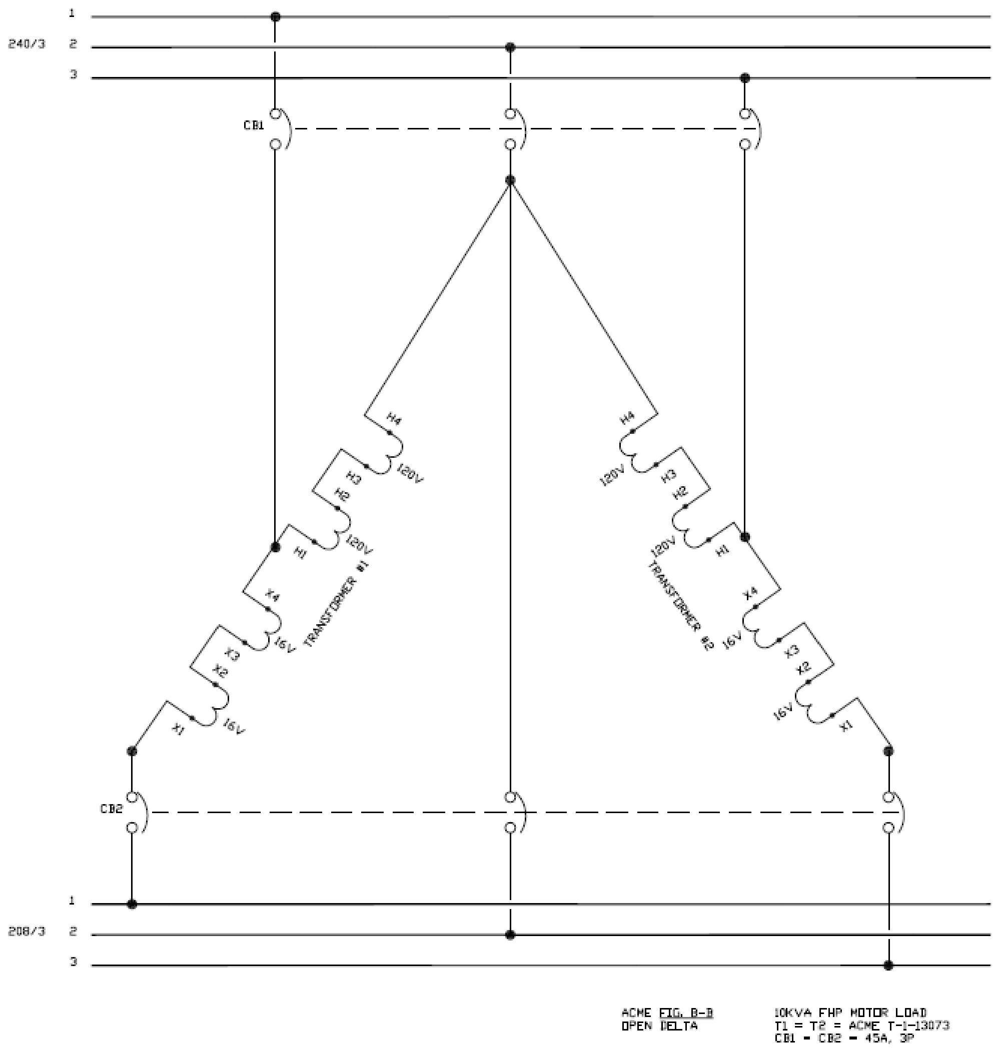
A 30kVA, 480V transformer has 36A full load. 250% of 36A is 90A. Do you think 450.3 means that you use a 90A circuit breaker on #8 wire? Yes. The 90A breaker provides short-circuit protection on the feeder and it is unlikely-to-impossible to get an overload from circuit failure or transformer failure.

Section 450.4 presents autotransformers. Autotransformers are sufficiently confusing that a separate PDHonline course is offered on connecting 230V motors on 208V systems using an autotransformer. Surprisingly, a properly sized autotransformer does not need separate protection. It is a series element. If the supply is sized fort he load and the autotransformer is sized for the load, no extra protection is required. Two illustrations from PDHonline Course #E1-62 are included below:



SINGLE PHASE BUCK-BOOST
TRANSFORMER CONNECTION DETAIL

2.5KW HEATER LOAD
T1 = .75KVA, 120/240-16/32V
CB1 = 20A, 1P



THREE-PHASE BUCK-BOOST TRANSFORMER CONNECTION DETAIL

Article 460, Capacitors

Article 460 discusses capacitors. During the first energy shortage, ~1973, building owners became excited about energy savings and monthly billing savings by installing power factor correction capacitors. Ten years later, most of the installations had at least one leg open, due to a blown fuse. This does bad things to the electrical system, but nobody cared then or now.

The Code gives rules for installing power factor capacitors. Vendor guides give very detailed instructions for sizing and installing them. Nobody emphasizes the importance of maintenance. You can check the operation of a capacitor bank by having an electrician use a clamp-on ammeter on each leg. Equal currents are good.

Large industrials may require individual capacitors for each large fixed-speed motor or buy step-capacitors with controllers for installation at the motor control center or substation. Both are good plans. However, a fixed capacitor at the motor control center or substation will cause leading power factor when the plant is down. This can be very bad.

Article 480, Storage Batteries

Article 480 discusses the installation of storage batteries. This started with large substations operated their protective relays and circuit breakers on 125 VDC. This application is still vitally important. However, you are more likely to see storage batteries as part of and Information Technology (IT) uninterruptable power supply (UPS) or as part of a photovoltaic (PV) generating system.

Both IT and PV are smoke-and-mirrors applications. The IT guys start out arrogant and secretive and really, really like to think they are doing something special because a Nice Salesman who buys a good lunch tells them. UPS today have protection and disconnect switches, but you still have to watch them. On a big system, the batteries will be remote from the inverter and MUST have fuses or circuit breakers. Within the battery bank, fusing is desirable, but not required.

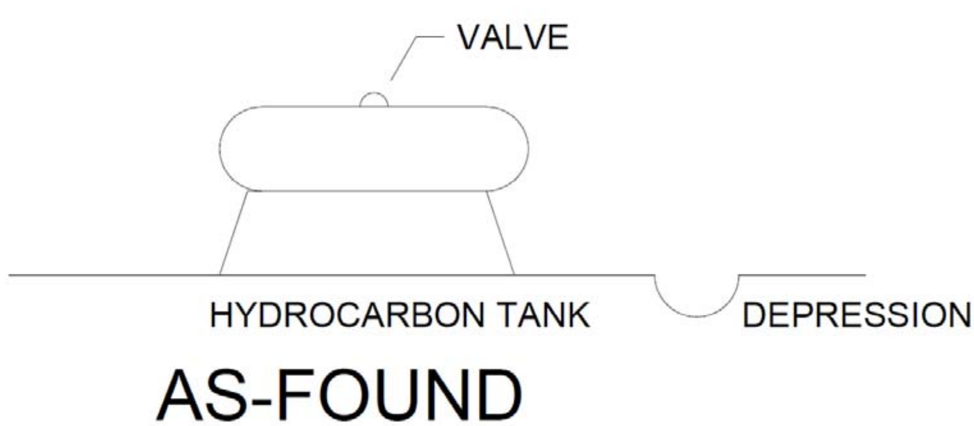
PV systems today rarely include disconnects and fuses or circuit breakers. A separate Article, 690, addresses photovoltaic systems and is not included in this course. Be aware, however, that good practice on electric sources and loads is the same as good practice on photovoltaic sources, converters, batteries, more converters and load connections. Use disconnect switches and fuses or circuit breakers - even if they don't come from the factory that way and the installer has never seen a fuse used.

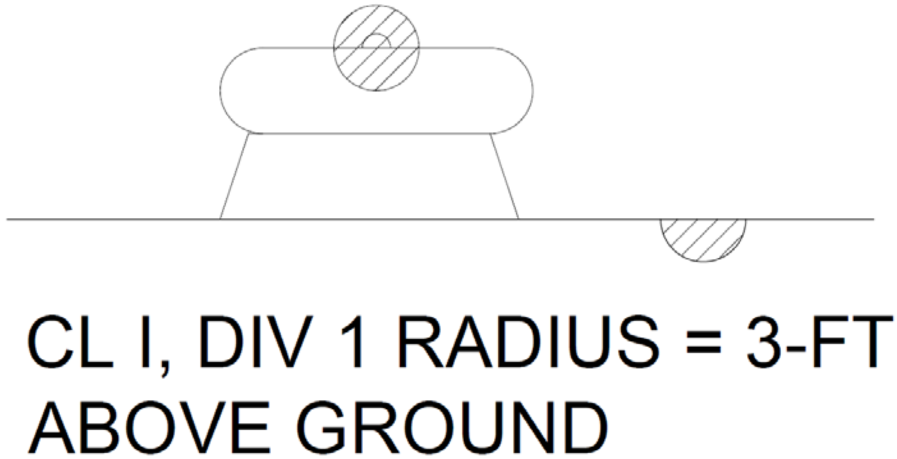
Article 500, Hazardous Locations

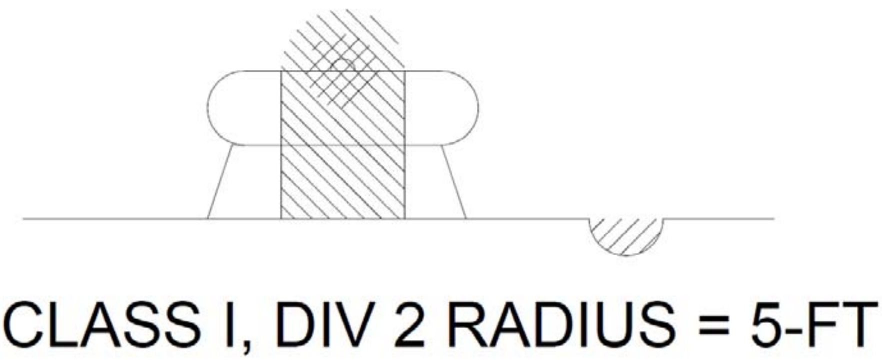
Article 500 discusses hazardous locations. This deserves close attention, beyond the scope of this course. If you are new to designing electric power, controls and lighting in hazardous areas, a good starting point is the application guides from Crouse-Hinds and Appleton. The only consistent error I encounter in the field is ignoring the Div 2 buffer between Div 1 and non-hazardous areas. Typically, there should be a 3-ft buffer - just where Architects put the light switch. (Must be explosion-proof switch, even though outside the Div 1 hazardous area.)

If the nomenclature for hazardous areas is confusing to you, start with Class I, Div 2, Group D. This is, by far, the most common. It means "bad stuff not normally present, but nearby, of the gasoline type." Class I, Div 1 means "bad stuff always present."

An illustration copied from the NEC Handbook follows:







Article 517, Health Care Facilities

Article 517 discusses details of health care facilities. It is grouped under hazardous locations because of explosive anesthetics and oxygen, but an equal or greater hazard is leakage currents to devices contacting or penetrating the patient. There are a wide range of special health care requirements, in the NEC, In IEEE publications, in government publications relating to licensing the institutions and in voluntary oversight agencies and insurance companies.

The key to electrical design in health care facilities is a definition and plan drawing of the different "areas" within the regulatory definitions and the electrical requirements for each area. In my experience, the Architect on the job spent a lot of time with hospital personnel making the area definitions and there were a very great many reviews of the design by personnel and agencies.

Article 518, Assembly Occupancies

Article 518 relates to assembly occupancies. For the most part, this means spaces intended for 50 or more persons (per the International Building Code, but, 100, per the 2011 NEC and, in some cases, 30 or more persons). The National Electrical Code Handbook includes a table to convert room sq-ft to expectected occupancy, but it is an explicit responsibility of the Architect on the job to make these determinations and prepare a Code Compliance sheet for inclusion in the construction document set.

A quirk in both the Building Code and the NEC regards stages. If a permant stage is present, the space is automatically deemed a place of assembly and Article 520 applies. If portable risers are used, it will still be a place of assembly, but the special fire rules for theaters and NEC 520 do not apply.

Conference centers are a special problem, because individula vendor booths usually want power and temporary flexible cords damage easily and can be trip hazards, beyond fire hazards. The nec responds to this in 518.3 with in-floor heavy-duty receptacles, temporary power distribution units which may be 480/3V-in and 208Y120V panelboard out. A treale (hard rubber short ramp over floor flexible cord) is illustrated in the NEC Handbook.

New to the 2011 NEC is the SUSPENSION of the requirement for ground fault circuit interrupters, now mandated in 290.6 for temporary wiring.

Article 520, Theatres, ….

Article 520 relates to theaters, motion picture studios, tv studios and performing arts. It is specialized and detailed and not coverd here except for the warning in the Article 518 discussion that a permanent stage invokes these rules.

Chapter 6, Special Equipment

Special equipment, in the meaning of the National Electrical Code, includes 25 very different types of equpment, many emerging technologies. The rules for electric signs are stringently enforced in some parts of the country, but ignored elsewhere. Electric vehicle charging systems are being led by the automotive companies and charger providers, but the NEC has opinions. Electrified truck parking spaces are an idea to run an over-the-road truck auxiliaries off land power and shut down the engine. It hasn't caught on. Swimming pool rules change with each revision but only apply to persons installing pools. Solar photovoltaic, fuel cells and small wind systems are covered here, along with guidance on Unility interconnection. [Better to talk to the Utility.]

Article 695, Fire Pumps

First, what is NOT covered by Article 695 - feeder reliability and jockey pumps. Within the NFPA feeding zone, the electrical feeder to the fire pump and the pressure maintenance pump, or jockey pump, are part of NFPA 20-2010, *Standard for the Installation of Stationary Pumps for Fire Protection.*

Second, per the NEC, a fire pump does NOT need two sources of power. A single RELIABLE source capable of delivering continuous locked-rotor current along with pressure maintenance pump current is adequate. That source can be any one of the following

1) Electric utility dedicated service connection.

2) On-site generation as long as the generator is located and protected to minimize the posibility of damage by the fire.

3) [New for 2011] A dedicated feeder fed from a different switchboard cubicle than the main.

The nuances of the fire pump feeder are tricky. As I understand it, the protective fuse or breaker must be above the locked-rotor current of the pump, but the wire size is for 1.25x full-load current and does

NOT have to match the fuse or breaker. This makes me very uncomfortable, so I always put in wire size to match the breaker, even though Inspectors have told me it is excessive.

Each disconnect along the feeder is critical and must be labeled in 1-in (min) letters, "Fire Pump Disconnecting Means."Each disconnecting means must carry UL service-equipment rating, be lockable in the closed position, located away from other distribution equipment and be located away from other fire pump disconnects. Red-painted conduits and junction boxes are required in some localities.

The pressure maintenance pump (jockey pump) is the only thing that is permitted to be connected to the fire pump feeder.

What is a "jockey pump"?
Most sprinkler systems are wet systems. That means that there is always water in the pipe at the sprinkler head. It is the nature of hydraulic systems to leak, so a tiny bit more water must be added to the system periodically. Not the huge flow of spraying through one or more sprinkler, just a tiny bit. An auxiliary pump is provided for the tiny flow. It is the jockey pump. The reason this is important and the connection of the jockey pump is important is because if the jockey pump is out of service, then the main fire pump "short-cycles". That is, the tiny leaks take place until the pressure in the system drops. The pressure switch thinks a sprinkler is dumping and turns on the fire pump. But, there is no large flow and the pressure returns and the fire pumps resets to "ready". Therefore, the jockey pump, with a pressure switch set higher than the main pump switch is needed. Short-cycling is very not-good for the fire pump. Unfortunately, maintenance response to trouble alarms often takes weeks for first inspection.

Chapter 7, Special Conditons

There are five Articles in Chapter 7 that deserve close attention. They are 700, 701 and 70, emergency and standby generators; 725, low-voltage control circuits; and, 760, fire alarms.

As mentioned in the introduction, "Emergency Systems", including the emergency generator involve life safety. The present interpretation of life-safety loads is fire alarm, medicine storage, exit signs, egress lighting, communications and security. Some Owners and Architects are trying to include computer-room airconditioning, since, without it, the VOIP phone and IP-PA go down. I have insisted on using a second automatic transfer switch for airconditioning and shed it if there are any generator problems. IT equipment is is rated for continuous operation at 104F, and there should be reduced graphics and financial transfers during a fire, earthquake, toxic spill or terrorist invasion.

An emergency generator must start within 10-seconds and comply with stringent UL requirements. The life-safety electric distribution system must be completely isolated from the general electrical distribution system, except at the source (automatic transfer switch) and at some loads (some loads internally switch from normal to emergency, as UPS). Conductors for emergency circuits must not be in the same conduit or junction box as general electrical distribution conductors.

Testing the generator under load
People who know generators insist that they need load. That is, starting up a generator and

running it with nothing connected is not good for the drive engine and does not accurately indicate that the generator will work when needed.

On the other hand, Owners with critical loads don't want even a momentary transition from normal power to generator power. They won't let you test the generator with the buildiing as the load.

The solution is to buy a load bank. This works, but can be a $10,000 investment, to use for 30-minutes each month, with arguable contribution to the benefit provided by the generator.

The answer is for NFPA to mandate either using the building as the test load or the purchase of a load bank. Section 700.3.E says that means for testing under load shall be provided. I have never seen a building used for testing and very, very rarely seen a load bank installed.

Section 700.4.B says that you can connect standby loads to the emergency generator if load-shedding is implemented to drop the standby load as current approaches nameplate. Use of emergency the generator is supported, in hopes that it will encourage under-load testing and maintenance.

Section 701 ,is for legally required standby systems, including standby generators. Section 702 is for optional standby systems. In each case, the requirements losen slightly. I always specify the generator for emergency service, hopefully, to get the best performance, even though there is a cost premium.

Article 725, Class 1, 2 and 3 Circuits

This article started out as rules for telephone wires, thermostats and doorbell transformers. It soon expanded into security alarm low-voltage wiring and garage door openers. For a short time, data wiring was here, but it moved to Chapter 8, along with telephone, when that chapter was added.

Class 1 circuits are line-voltage remote control devices, without power limiting, such as motor pushbuttons, limit switches and light curtains. This would include 24VDC safeties also, if not power-limited. Wiring methods for Class 1 circuits are nearly identical to general purpose wiring - conduit or heavy-jacketed cables.

Power-limited means tiny transformer or intentional impedance in source

Back to doorbells, security alarms, thermostats and garage door openers, you can use #22 wire and not protect it if it has a power-limited source. The reasoning is that, if you can't get enough power from a short circuit to start a fire, then nothing bad can happen from a short-circuit.

Power limited means less than one ampere. A 10VA 120/24VAC transformer is self-limited to .42A. If you put a diode bridge on it, then it is limited to .42 ADC. A 25VA transformer calculates to 1.04A, but commercial units are less than 1.00A and legal. The common form of such control transformers is one end with a conduit fitting that goes into a junction box and the other end has two screw terminals.

Class 2 circuits use the power-limited source. Class 3 circuits have a slightly different set of requirements and permissions and are rarely used.

Wiring for Class 2 circuits is jacketed or unjacketed telephone wire (#22 or larger). Bare conductors are permitted in UL-approved security devices, as break-glass tapes.

In the NEC Handbook, Section 725.139, an illustration shows telephone and data circuits in the same cable. (This was before VOIP telephone.) This section forbids audio cables sharing cable or raceway with other Class 2 or 3 circuits, even though audio cables are considered Class 2.

The 2008 revision to the NEC introduced the requirement for separate support of Class 2 and data wiring and the requirement for removal of abandoned Class 2 and data wiring.

Article 760, Fire Alarms

Article 760 refers to fire alarms. PDHonline offers a separate course exclusively dedicated to fire alarms (E-207, NFPA 72). Because that topic is too important for a superficial review, your attention is drawn to that specialized course and it will not be addressed here.

Chapter 9, Tables

The key tables for use of the National Electrical Code are as follows:

Wire Ampacity - 310.13
Conduit Fill - C.8
Motor FLA - 430.250
Equipment Grounding Conductor - 250.122
and,
Conductor Characteristics - Table 9

Table 9 in Chapter 9 is emphasized because it presents alternating-current impedance for copper and aluminum conductors. These values can be used to do back-of-envelope calculations and get meaningful results.