CONSTRUCTION ELECTRICIAN APPRENTICESHIP PROGRAM

Level 3 Line G: Install Low Voltage Distribution Systems



LEARNING GUIDE G-1

APPLY CODES, REGULATIONS AND STANDARDS

ita
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THE RIGHT SKILLS ▶ A PROVEN ADVANTAGE

BRITISH COLUMBIA

Foreword

The Industry Training Authority (ITA) is pleased to release this major update of learning resources to support the delivery of the BC Electrician Apprenticeship Program. It was made possible by the dedicated efforts of the Electrical Articulation Committee of BC (EAC).

The EAC is a working group of electrical instructors from institutions across the province and is one of the key stakeholder groups that supports and strengthens industry training in BC. It was the driving force behind the update of the Electrician Apprenticeship Program Learning Guides, supplying the specialized expertise required to incorporate technological, procedural and industry-driven changes. The EAC plays an important role in the province's post-secondary public institutions. As discipline specialists the committee's members share information and engage in discussions of curriculum matters, particularly those affecting student mobility.

ITA would also like to acknowledge the Construction Industry Training Organization (CITO), which provides direction for improving industry training in the construction sector. CITO is responsible for organizing industry and instructor representatives within BC to consult and provide changes related to the BC Construction Electrician Training Program.

We are grateful to EAC for their contributions to the ongoing development of BC Construction Electrician Training Program Learning Guides (materials whose ownership and copyright are maintained by the Province of British Columbia through ITA).

Industry Training Authority
January 2011

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Learning Task 1:	
Figure 3—Sheath currents	*CEC Handbook 2015,* Figure 4-4, Induced sheath current flow (p. 44)
Figure 5—Use of identified conductor in switching	*CEC Handbook 2015,* p. 51, Figure 4-8
Figure 6—Neutral conductor applications	*CEC Handbook 2015*, p. 51, Figure 4-9

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LEVEL 3, LEARNING GUIDE G-1:

APPLY CODES, REGULATIONS AND STANDARDS

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Learning Objectives

The learner will be able to:

- apply the CEC to three-phase installations.

Activities

- Read and study the topics of Competency G-1.
- Complete Self-Tests 1 and 2. Check your answers with the answer key provided at the end of this Learning Guide

Resources

You are encouraged to consult the following to obtain supplemental learning information:

- *Canadian Electrical Code, Part 1,* Current Edition. Canadian Standards Association
- *Requirements for Secondary Metering Installations*. BC Hydro
- *Canadian Electrical Code Handbook*. Canadian Standards Association

Courses:

British Columbia Institute of Technology, CESA 0158: Introduction to Solar Electricity

British Columbia Institute of Technology, CESA 0159: Solar Electric Design

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Industry Training Authority
January 2011

Learning Task 1:

Interpret Applicable CEC Rules and Regulations for Three-phase Wiring Installations

By now you should be fairly familiar with the various sections of the Code and many of the CEC rules within those sections. In this Learning Task you will learn to apply CEC rules and regulations from those sections of the CEC as they pertain to three-phase equipment and wiring installations.

Section 0, Definitions

A working knowledge of terms and definitions is an important tool in understanding the Electrical Code. Listed below are some simplified explanations of terms that are particularly important at this level of technical training.

Compare the following explanations with the actual Code definitions listed in Section 0.

Bonding conductor	That conductor which interconnects the metallic, non-current-carrying parts of all electrical equipment to the main service (or system) grounding conductor.
Branch circuit	The portion of wiring between a load device and its individual overcurrent protection device.
Bus	A conductor (usually larger) used to provide a common connecting point for two or more similar circuits.
Duty	The time and load conditions placed on a piece of electrical equipment.
Ground	A direct connection to earth through a grounding electrode.
Grounded	Somehow connected to ground through a low-impedance path.
Grounding	Purposely providing a permanent and continuous path to earth.
Identified	The colour (or other means) used to distinguish the grounded side of a circuit: for conductors, usually a white or natural grey covering; or a raised longitudinal ridge on the surface of some flexible cords; for equipment terminals, usually tinned, nickel-plated, or suitably marked.
Isolating switch	A switch that is **not** to be operated (opened or closed) when it is carrying current.
Motor-circuit switch	A manually operated disconnect switch (either fused or unfused) that is horsepower or kilowatt rated for the motor it serves.
Multi-winding motor	A motor with multiple sets of coils that can be connected in various configurations; designed for operation at either different speeds or different voltages.
Neutral	The identified conductor in a single-phase, three-wire circuit or three-phase, four-wire circuit that is intended to carry zero current under a balanced load situation. It has the same voltage between it and all of the other line conductors in the system.

Splitter	A wiring enclosure housing busbars and/or terminals intended for supplying a number of branch circuits.
Starter	A device that is designed for starting, stopping and providing overload protection for a motor.

Not all definitions are found in Section 0 of the CEC. Some terms are explained in other sections of the Code, while others are usually considered "trade knowledge." A few examples are as follows:

Code fuse	A standard cartridge fuse with non-time delay characteristics certified to have an interrupting capacity of 10 000-A symmetrical maximum at the specified voltage rating. In accordance with CSA standards, it is known as a *Class H fuse*.
Common conductor	The "identified conductor" when used to supply loads connected between two phase (line) wires and the neutral in a three-phase, four-wire system. (It carries the line current.)
Guarding	Using enclosures, fences, or elevated platforms to prevent accidental contact with live parts.
Harmonics	Electrical energy (often caused by unbalanced user loads) that is at a frequency other than 60 Hz.
HRC fuse	A "high rupturing capacity" fuse intended for circuits where the available fault current exceeds the interrupting capacity of standard cartridge fuses. In accordance with CSA standards, they are now identified by a specific class designation.
Integral devices	Individual devices that are incorporated to form part of a complete unit, such as HRC fuses integrated within a circuit breaker enclosure, or overload relays integrated with a contactor to form a motor starter.
Motor supply conductors	Those conductors entering the motor connection box.
Service factor	A multiplier applied to the full-load rating of a motor to indicate its continuous operating capability.
Standard fuse	Another name for Code fuse (see above).
Tap conductor	A conductor that usually has an ampacity rating smaller than the ampacity of the bus, splitter, or conductor feeding it.
Transformer	Can be interpreted as either a single transformer, or a group of two or more transformers operating as a three-phase bank.
Ventilation	Providing for sufficient air movement, usually to prevent overheating of conductors or equipment.

Activity 1

Various types of cables, such as NMD90, AC90, TECK90, etc., have a bare, uninsulated conductor in addition to the insulated conductors. Would these bare wires be best defined as a ground wire or as a bond wire?

What are the differences (if any) between the neutral conductor, the common conductor and the identified conductor?

Section 2, General CEC Rules

As you already know, this section provides general CEC Rules dealing with technical regulations and maintenance/operation regulations. Two CEC Rules from this section are of particular significance for the installation of three-phase motors:

- Rule 2-100 Marking of equipment
- Rule 2-404 Marking of motors

Rule 2-100 Marking of equipment

The nameplate of electrical equipment contains special information that is important for both installing and troubleshooting the equipment. The CEC provides tables that act as guides for the full-load currents of various motors. However, where exact values are required, such as for motor protection, then the nameplate ratings should always be used.

Rule 2-404 Marking of motors

Markings that are used to identify special motor enclosures include:

- DP = drip-proof
- WP = weatherproof
- TE = totally enclosed

Section 4, Conductors

Although this section deals with the general application of conductors, you have probably spent most of your time applying CEC Rules for calculating ampacities and conductor sizes. You will be applying the same CEC Rules for three-phase installations.

Rule 4-006 Temperature limitations

It is the intention of this rule that the ampacity of conductors is to be selected from the temperature column in Tables 1, 2, 3, or 4 that corresponds to the temperature rating marked on the electrical equipment.

When the CSA and UL test apparatuses for certification, the testing is performed using 60°C and/or more commonly 75°C conductors, and the equipment is approved as a system (the equipment and conductor combined). The use of conductors with higher temperature ratings is permissible, provided that the ampacity of the conductor is de-rated to a 60/75°C rating by selecting the allowable ampacity from the column that corresponds to the marking on the electrical equipment.

Using a conductor with a 90°C temperature rating with a 90°C ampacity may cause nuisance tripping or overheating of the device and conductor.

Using a conductor with a 60°C temperature rating where a 75°C insulation rating is called for may overheat the conductor and cause its insulation to fail.

As an example, where a conductor is terminated on a breaker with a 75°C rating, the minimum insulation rating would be 75°C, and the maximum conductor ampacity would be based on the 75°C column of the table.

Some equipment does not have a maximum conductor termination temperature rating marked on the equipment. In these cases the maximum conductor termination temperature shall be:

- 60°C for equipment rated at not more than 100 A, or marked for use with #1 AWG or smaller conductors.
- 75°C for equipment rated for more than 100 A, or marked for use with larger than #1 AWG conductors.

Subrules 1 and 2 apply to the first 1.2 m of the conductor from where it is terminated. This rule has caused numerous Code revisions to be implemented.

When high-voltage equipment is not marked with a conductor termination temperature, Subrule 3 permits consultation with the manufacturer to determine the acceptable termination temperature ratings.

It should be noted that if a termination temperature rating is not indicated on a given piece of equipment, a consultation with the manufacturer should provide the necessary information.

Example 1: A 50-A load that has a 60°C termination temperature rating is fed with NMD90 copper cable from a circuit breaker with a 75°C termination temperature rating. What minimum size of conductor is required, and what is the maximum ampacity allowed by the Code?

Solution: In this example, the maximum conductor termination temperature would be determined from the temperature rating marked on the electrical equipment having the lowest rating, which is the 60°C load. The NMD90 may be used, but the maximum conductor ampacity would be based on the 60°C column of the table.

Table 2, column 2 lists #6 AWG (55 A) as the minimum size conductor for a load ampacity of 50 A.

Activity 2

In Table 1 in Figure 1 below, indicate (as per examples) if the conductor insulation ratings are permitted for the given termination temperature ratings, and whether any de-rating is required.

Termination rating (°C)	Conductor insulation rating		
	60°C	75°C	90°C
60°C	OK		
75°C		OK (at 60°C or 75°C rating)	
60/75°C			OK (at 60°C or 75°C rating)
90°C			

Figure 1—Table 1, Maximum conductor termination temperatures

Rule 4-004 Ampacity of wires and cables

This rule defines various factors that affect the ampacity of a conductor. The basic concepts behind this rule are:

- All conductors have resistance (for a given length and size, aluminum is higher than copper).
- All current-carrying conductors produce heat (I2R loss).
- Heat can break down conductor insulation.

As a result, Subrule 1 generally allows single copper conductors in free air a higher ampacity than when installed in raceway (or as cable assembly).

Example 2: Three copper conductors with RW90 XLPE insulation, fed from a circuit breaker with a 75°C termination temperature rating, are to be installed in a conduit to supply a three-phase, 600-V demand load of 145 kVA. What is the minimum size conductor required by Code?

Solution: The calculated ampacity is: $\frac{145\,000\text{ VA}}{\sqrt{3}\times 600\text{ V}} = 139.5\text{ A}$

The key words **copper**, **three**, **in conduit** lead us to Subrule 1(b), which refers us to Table 2.

Table 2, column 4 (90°C) lists #1 AWG (145 A) as the minimum size conductor for an ampacity of 139.5 A.

However, because the equipment is marked with maximum conductor termination temperature of 75°C, we must use column 3 (75°C), which permits only 130 A for a #1 AWG. Therefore we must install #1/0 AWG (150 A).

Example 3: Three copper conductors with RW75 insulation are to be installed in a conduit to supply the same demand load as in Example 2. What is the minimum size of conductor required?

Solution: For this example the insulation type from Example 2 has been changed. Using the previous calculated ampacity of 139.5 A:

Table 2, column 3 lists #1/0 AWG (150 A) as the minimum size of conductor for an ampacity of 139.5 A.

Example 4: Find the ampacity of four #1/0 AWG copper conductors with RW75 insulation when installed in conduit.

Solution: This example is similar to Example 3, except that a fourth conductor has been added. If it carries current, then it produces heat in addition to the heat produced by the other three conductors. Subrule 1(c) refers to Table 5C for a reduction in ampacity by using a "correction factor."

Table 2, column 3 lists ampacity of #1/0 AWG copper RW75 conductors as 150 A.

Table 5C requires a correction factor for four conductors of 0.80.

Therefore, the ampacity of each conductor = 150 A $\times$ 0.80 = 120 A.

Example 5: Three aluminum conductors with RW90 XLPE insulation, fed from a junction box not less than 1.2 m from the point of termination on the equipment, are to be installed in a conduit to supply a three-phase, 600 V, demand load of 145 kVA. What is the minimum size of conductor required by Code?

Solution: This example is similar to Example 2, except that the conductor is fed from a junction box not less than 1.2 m from the point of termination and has been changed to aluminum instead of copper. Subrule 2 requires you to treat aluminum conductors differently than copper by using Table 3 or Table 4.

The calculated ampacity of 139.5 A must be applied to Table 4.

Table 4, column 4 lists #2/0 AWG (150 A) as the correct conductor size, as the cable transition is made not less than 1.2 m from the point of termination on the equipment.

Example 6: A four-wire aluminum TECK90 cable, fed from a circuit breaker with a 75°C termination temperature rating, is to be used to supply a demand load of 210 kVA, 600/347 V, from a three-phase system at an ambient temperature of 30°C. What is the minimum conductor size permitted by the Code?

Solution: In this example, since the fourth conductor is a neutral, its current (if any) will only be the unbalanced current from the other three conductors.

Subrule 3 does not require you to count the neutral for de-rating purposes. Therefore, we would consider three current-carrying conductors for determining conductor size and ampacity.

The calculated ampacity is: $\dfrac{210\,000\text{ VA}}{\sqrt{3}\times 600\text{ V}} = 202\text{ A}$

Notice that we are using aluminum and the insulation temperature rating is 90°C. However, because the equipment is marked with maximum conductor termination temperature of 75°C, we must once again use column 3 (75°C).

Using Table 4, column 3, the size of conductor required is 250 kcmil AWG (205 A).

Subrule 4 states that there are two conditions where the neutral is counted as a current-carrying conductor:

- when it is used with a single line conductor to feed a two-wire circuit, in which case it is normally called the identified conductor, or
- when it is used with two of the three-phase line conductors to feed a three-wire circuit, in which case it is called the common conductor.

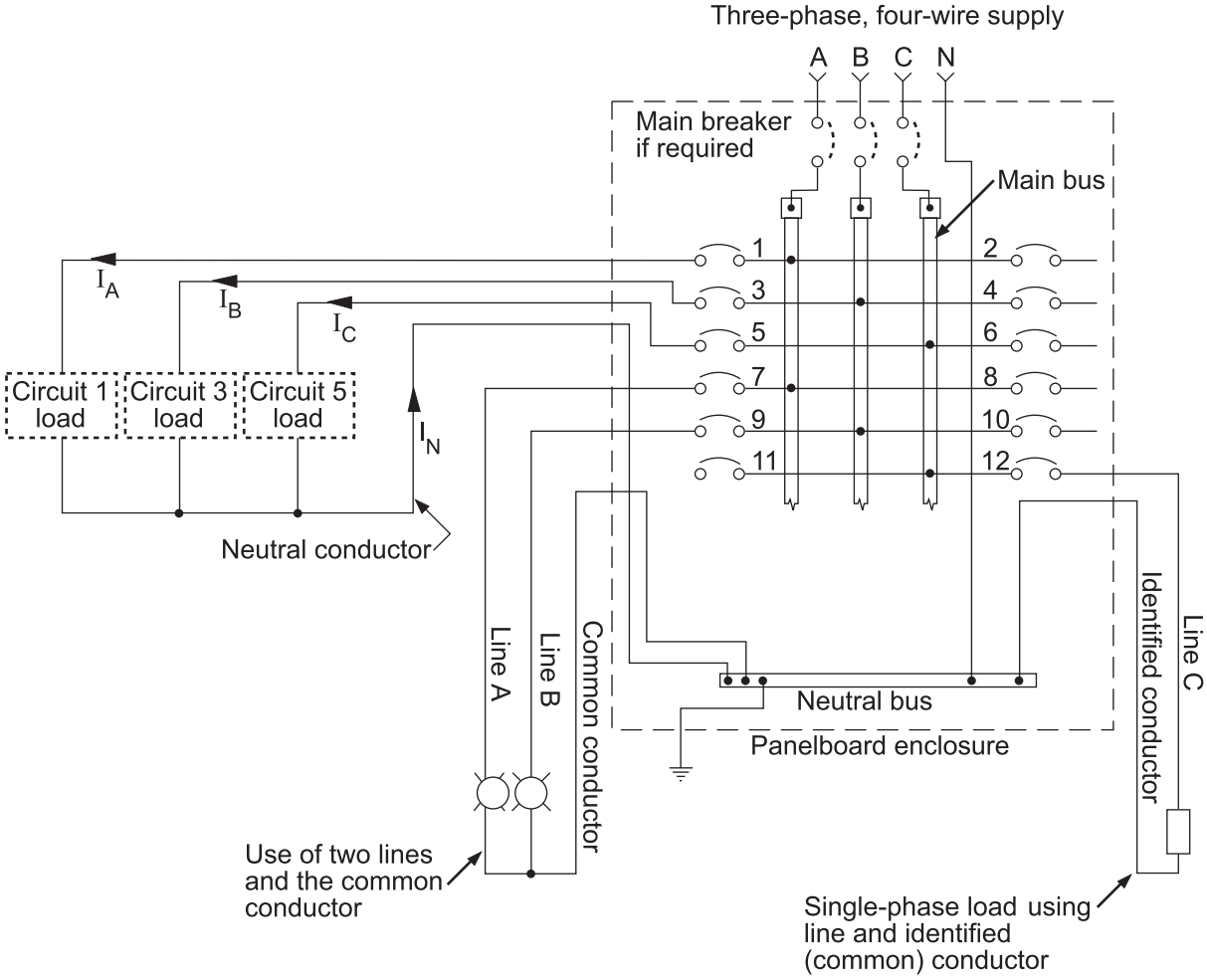


Figure 2—Neutral conductor applications

Example 7: Three copper conductors with RW90 XLPE insulation, fed from a circuit breaker with a 75°C termination temperature rating, are to be installed in conduit to supply a three-phase, 600 V, demand load of 145 kVA. The ambient temperature can rise to 38°C. What is the minimum size conductor required by Code?

Solution: This example is different from Example 2 in that the surrounding temperature is over 30°C. Subrule 8 requires the use of a correction factor from Table 5A.

For the insulation type used, column 4 of Table 5A applies a correction factor of 0.91 for an ambient temperature up to 40°C.

Since the demand load is 139.5 A and the correction factor is 0.91, the calculated ampacity equals:

$$\frac{139.5\,\text{A}}{0.91} = 153\,\text{A}$$

Table 2, column 3 lists #2/0 AWG (175 A) as the required minimum size conductor.

Activity 3

If the four conductors in Example 4 were installed where the ambient temperature could rise to 40°C, would a Table 5A de-rating be required in addition to the Table 5C de-rating?

If the four conductors in Example 4 were feeding a 120/208 V, three-phase load, would a Table 5C de-rating be required?

Rule 4-024 Size of neutral conductor

Generally, to supply a three-phase load, the neutral conductor is the same size as the line conductors. We usually attempt to distribute the load equally between all three phases. Therefore, when the load is balanced, there is no current flow in the neutral; and in the worst situation to create unbalancing, if two phases were disconnected, the neutral would have to carry the same current as the one line conductor.

Subrule 2 does permit a reduction in the size of the neutral in some instances where the unbalanced load is more than 200 A.

However, there is no reduction of conductor ampacity permitted for any electric-discharge lighting loads, nor for any harmonic-producing non-linear loads such as computers, printers, electronic ballasts, variable-speed drives, etc.

Example 8: What ampacity would be required for the neutral conductor for a feeder supplying a three-phase incandescent lighting load of 500 A and a three-phase motor load of 500 A?

Solution: In this example, the motor is considered as a balanced load, and the incandescent lamps could be considered as the maximum unbalanced load:

total load	=	1000 A
balanced load	=	– 500 A
unbalanced load	=	500 A

The neutral may be sized by applying Rule 4-024(2)(b), where the:

first 200 A @ 100%	=	200 A
remaining 300 A @ 70%	=	210 A
the neutral is sized for	=	410 A

(The motor load is not added back into the neutral ampacity since it is a balanced load.)

Example 9: What ampacity is required for the neutral conductor for a feeder supplying a 200-A three-phase motor load and 800 A of discharge lighting?

Solution: In this example:

total load	=	1000 A
balanced load	=	– 200A
unbalanced load	=	800 A

Since no reduction is permitted for discharge lighting, using Rule 4-024(2)(a), the neutral must be sized for 800 A.

In residential applications, most 120/240-V single-family dwellings are not usually sized over 200 A in total demand, so there would be no opportunity to reduce the size of the neutral as in the previous examples. However, many loads in a residential installation will be 240 V, and therefore they will have no required attachment to the neutral. And as with the preceding examples, we usually attempt to distribute the load equally between the incoming lines. Therefore, when the load is balanced, there is no current flow in the neutral; but once again, if one line was disconnected, the neutral would have to carry the same current as the remaining line conductor.

Subrule 1 is adamant that the neutral must have sufficient ampacity to carry the unbalanced load. Subrule 3(b) states that a service neutral must not be sized smaller than required by Subrule 1 and Subrule 10-204(2). Subrule 10-204(2) requires the grounded conductor, or the neutral, to have a minimum size as required for bonding conductors as directed by Rule 10-814, which refers to the sizing of bonding conductors in Tables 16A and 16B.

Example 10: What is the required ampacity of neutral conductor for a 120/240-V 1Ø supply to a 120 m^2 single dwelling with a 12-kW range, 5-kW dryer, 3-kW hot water tank, and 10 kW of electric baseboard heat?

Solution: The calculation of the minimum service size is done using the appropriate demand factors from Rule 8-200.

Basic	5000
	1000
Range	6000
Dryer	1250
HWT	750
Ht	10 000
	24 000 ÷ 240 = 100 A

The minimum neutral size is calculated by subtracting the 240-V loads with the appropriate demand factors from the service size. It should be noted that the BC Safety Authority Electrical Information Bulletins consider 240-V cord-connected electric dryers and ranges to be permanently connected 240-V loads, which may also be subtracted from the service ampacity.

Range	6000
Dryer	1250
HWT	750
Ht	10 000
	18 000 ÷ 240 = 75 A

Neutral = 100 – 75 = 25 A

Subrule 3(b) requires the minimum neutral size to be not smaller than 25 A **and** to be sized not smaller than required by Table 16A or 16B, which is based on the size of the largest ungrounded conductor. In this case, the service conductor required is 100 A, and therefore a minimum #6 AWG copper or #4 AWG aluminum neutral is required.

It should be noted that most modern households have numerous electronic, non-linear loads that have rectified inputs or electronically switched power supplies. Loads such as computers, electronic ballasts, battery chargers, machines using variable-speed drives and other "smart" appliances produce harmonic currents that tend to add up arithmetically on the neutral. Therefore, caution should be used when selecting the neutral conductor size.

Rule 4-010 Induced voltages and sheath currents in single-conductor metal-sheathed cables

In many large electrical installations it is preferred to use single-conductor cables due to their ability to carry much larger currents than multi-conductor cables. The downside, however, is that the magnetic field produced around these individual conductors isn't entirely cancelled by the other phase and neutral conductors, and as a result certain problems arise.

One problem is that voltages are induced in the metal armour by the alternating magnetic field. If the metallic sheath is not bonded to ground, the induced voltage may become high enough to produce a hazardous, perhaps even fatal shock. These induced voltages can be reduced in cables carrying up to 425 A by spacing the cables approximately a diameter apart, producing the three-phase field cancellation effect at close spacing. For cables carrying over 425 A it is generally necessary to de-rate the cables' current-carrying rating.

In addition, the magnetic field around a single-conductor cable can create eddy current and hysteresis heating in the ferrous materials of the enclosure wall, connectors and locknuts, straps and supports, etc., through which it passes. For single-conductor cables carrying more than 200 A, a preferred method to prevent the inductive heating of ferrous metal boxes is to cut out a section of the enclosure larger than required for the conductors and replace it with a non-ferrous plate.

However, another problem arises when the metallic sheath is bonded to ground. Sheath currents will flow as a result of the voltages that are induced in the metal armour if the sheath circuit is completed. These sheath currents that are generated when using a single-conductor metallic armour cable may produce enough heat to cause deterioration of the conductor insulation. It may be necessary to de-rate all such installations to avoid overheating of the cable, or else eliminate the sheath currents.

To prevent the flow of sheath currents, it is necessary to ensure that all paths by which they may circulate are kept open. Cable sheaths shall be grounded at the supply end and thereafter isolated from ground and each other. Isolation may be attained by installing the cables in individual ducts of insulating material or by employing cables jacketed with PVC or other insulated supports. Refer to Figure 3 for examples of how sheath currents can flow through a completed sheath circuit.

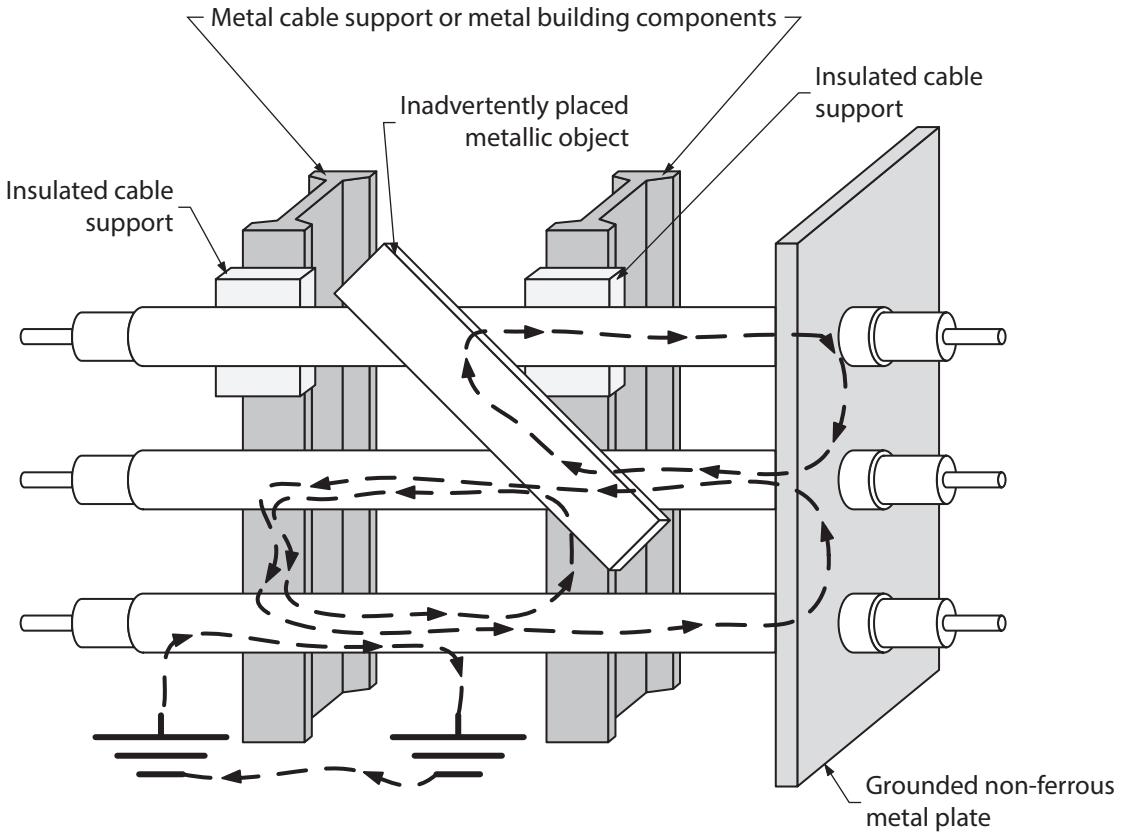


Figure 3—Sheath currents

The sheath (or sheaths) should be isolated at the load end with insulating material such as mica board. Since the cable sheaths in such circumstances cannot be used for bonding the electrical system, it will be necessary to provide a bonding conductor of adequate size for this purpose. See Rule 10-304(2) and Table 16A or 16B.

Figure 4 shows a common method of eliminating sheath currents. See also Rule 12–3022(7).

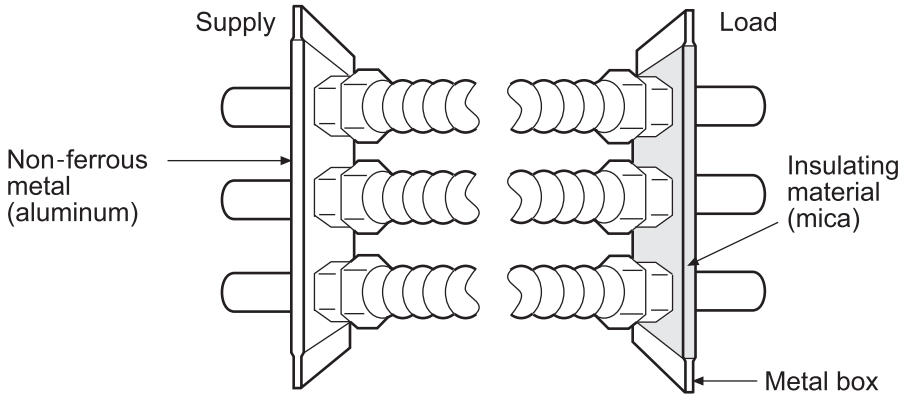
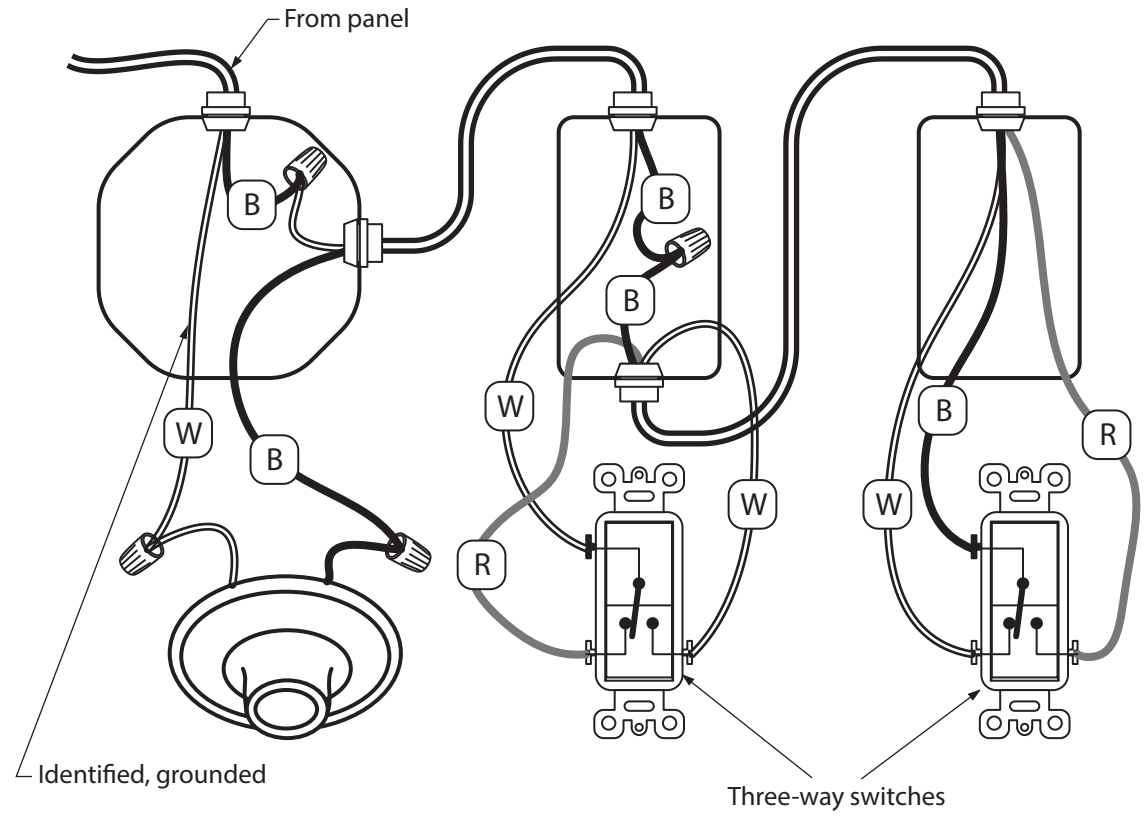


Figure 4—Method of eliminating sheath currents

Rule 4-036 Use of identified conductors

Identified conductors are just that: identified by the white or natural grey covering or other distinguishing features. As such, the CEC is very strict about its use. Subrule 1 allows the use of these conductors as *other than identified* if they form part of a manufactured cable such as armoured cable, aluminum and/or copper sheathed cable, or non-metallic sheathed cable. However, these identified conductors must be permanently un-identified by painting, taping, or otherwise disguised where accessible.

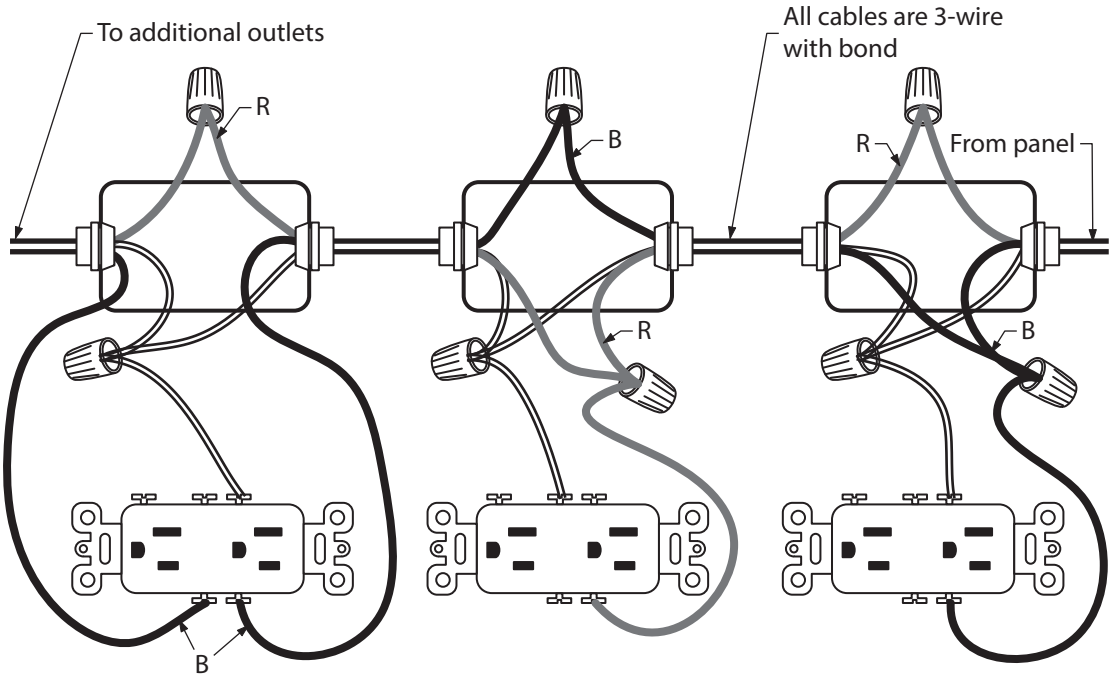
Subrule 2 essentially permits a "notwithstanding" or "never mind what you just read" permission with the use of the identified conductors in these aforementioned cable types if they form part of a single-pole, three-way or four-way switch loop. In these cases it is not required to "camouflage" the identified conductor at the switch as long as this conductor is not the switch leg, as depicted in Figure 5.



Note: bonding conductors not shown

Figure 5—Use of identified conductor in switching

Subrule 4 requires continuity of the identified conductor when it is used as the common in a multi-wire branch circuit, similar to the depiction in Figure 6. These types of installations require "pigtailing" of the identified conductor to permit removal of a device without interrupting the return path for the devices on the other branch(es).



Notes:
1. Bonding wires not shown
2. "Hot" conductors may be either pigtailed or connected on the device
3. Neutral must always be pigtailed

Figure 6—Neutral conductor applications

Rule 4-038 Colour of conductors

You should already be familiar with the standard colour coding of three-phase conductors: red (phase A), black (phase B), blue (phase C), and white/natural grey for the neutral, when required.

In three-phase, four-wire delta-connected systems, where one phase is used to supply single-phase lighting loads, the phase A conductor (red) must be identified as the conductor having the highest voltage to ground. See Figure 7.

Subrule 5 requires that the phase A conductor be suitably barriered from any compartment provided for the single-phase distribution where the grounded conductor is present.

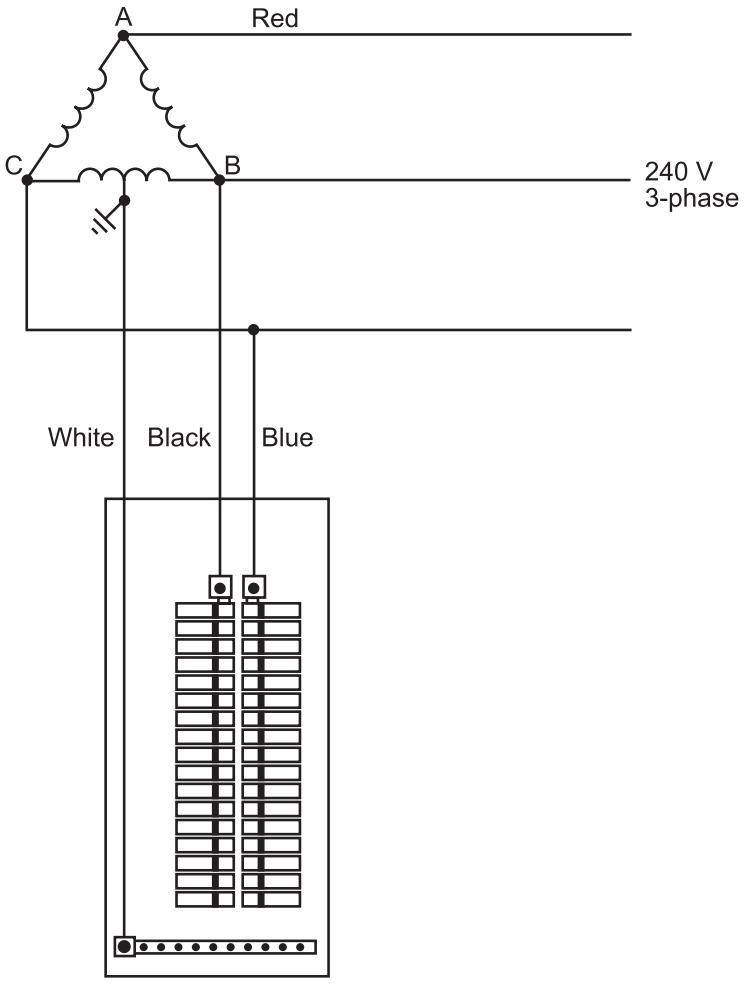


Figure 7—Three-phase, four-wire delta system

Section 6, Services and service equipment

The integrity of all electrical installations begins at the incoming service. Although the distribution of three-phase energy may vary with different installations, the fundamental service requirements are the same.

Figure 8 illustrates some important Section 6 rules for three-phase services.

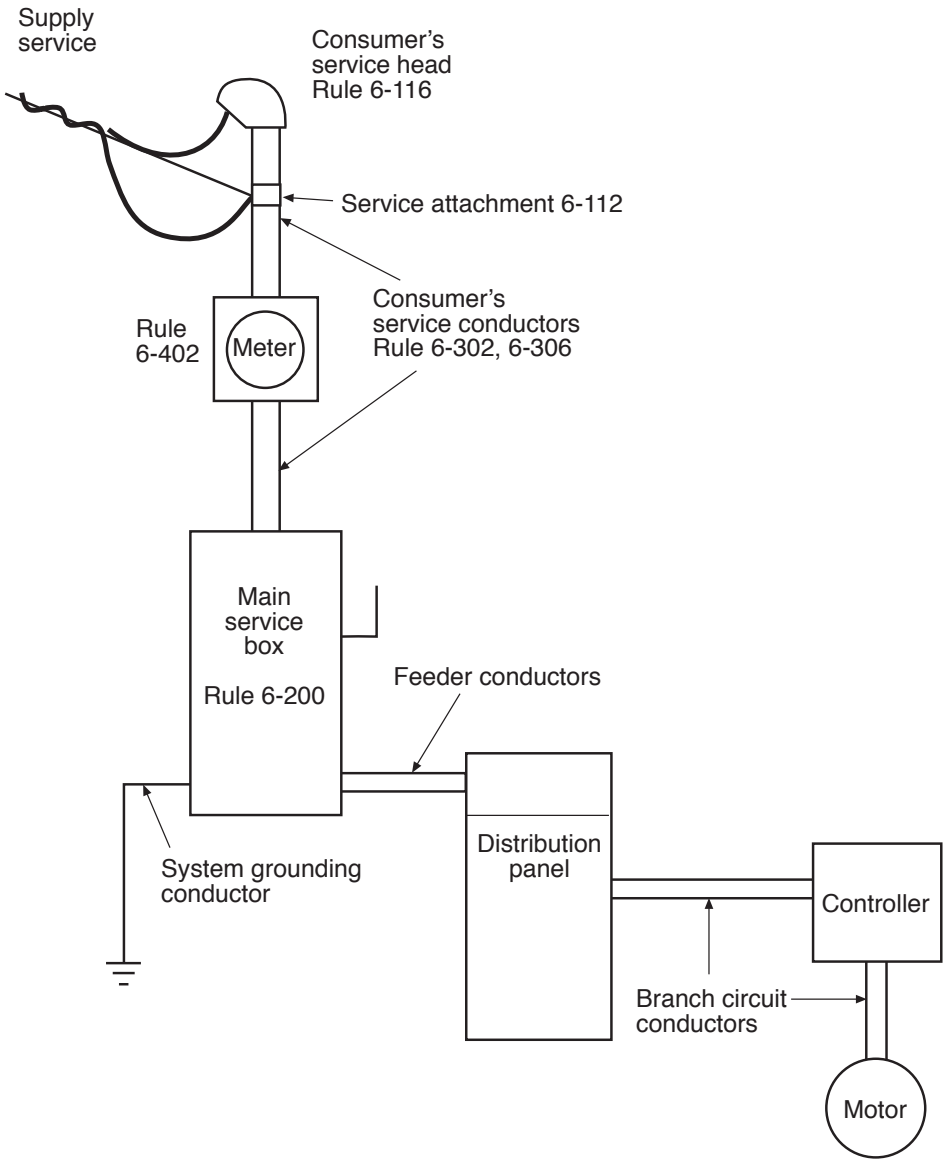


Figure 8—Features of three-phase service and distribution

Recognize that the supply service is that portion of wiring from the power authority to the point of connection, while the consumer's service continues from the point of supply connection through to the service box, which includes the overcurrent protection and main disconnect for the wiring system.

Section 8, Circuit loading and demand factors

In previous studies, you used Section 8 to determine the requirements for a variety of services and feeders. Later in this Learning Guide, you will be dealing with the installation requirements for three-phase motors, capacitors and transformers. Remember, however, that Section 8 is considered a "general" section. The CEC Rules for sizing conductors and overcurrent protection for motors (Section 28) and for capacitors and transformers (Section 26) take precedence over the requirements of Section 8.

Section 10, Grounding and bonding

You have previously studied the reasons for grounding and bonding, and by now you should be fairly familiar with the content of Section 10. You will be applying many of the same CEC Rules for three-phase installations as you did for single-phase installations.

Grounding of systems (and circuits)

System grounding connects one of the conductors of the distribution system to earth. The conductor that is grounded is normally the neutral, or the identified circuit conductor. There are three fundamental CEC Rules to consider for system grounding:

- Rule 10-106 Alternating current systems
- Rule 10-206 Grounding connections for different systems at a facility
- Rule 10-806 Installation of system grounding conductors

Rule 10-106 Alternating current systems

When dealing with three-phase systems, the system must be grounded if the voltage-to-ground does not exceed 150 V, or if the system contains a neutral conductor.

This implies that three-phase, four-wire wye-connected systems must always be grounded. Although typically we think of delta-connected systems as being ungrounded (in which case they must be provided with a ground detection device), certain three-phase delta systems may be grounded, as shown in Figure 9.

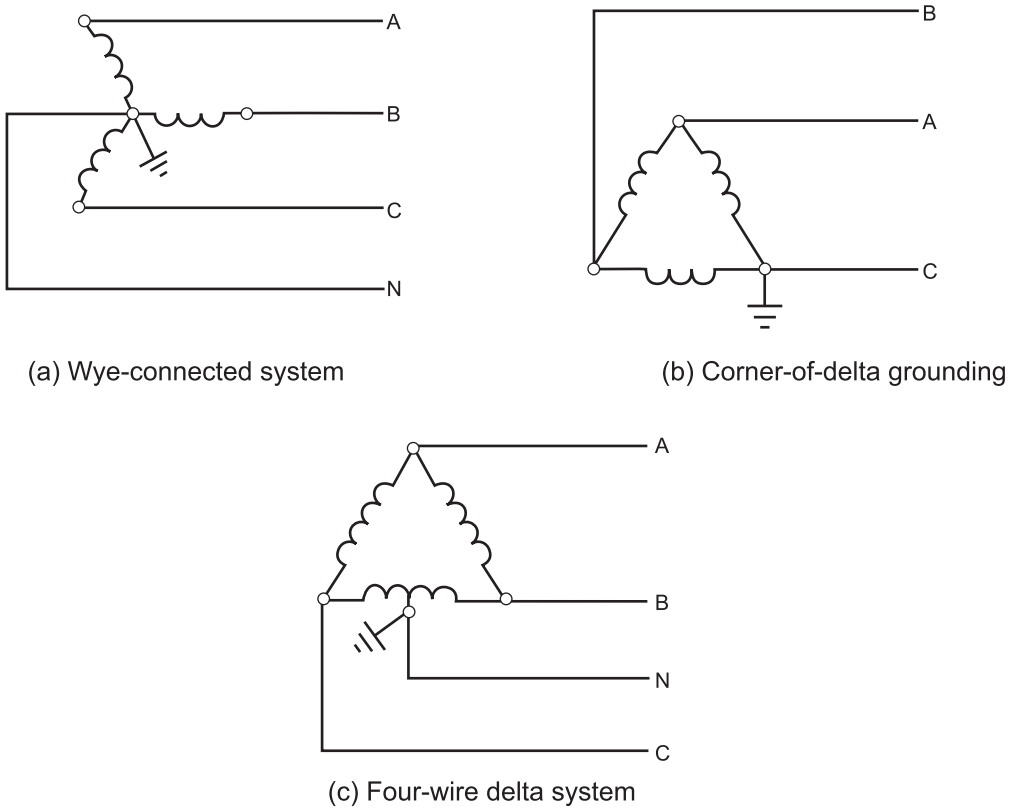


Figure 9—Three-phase system grounding

Rule 10-210 states which conductor must be grounded in AC wiring systems. For ungrounded delta systems, the service equipment must still be connected to earth, or grounded:

Rule 10-206 Grounding connections for different systems at a facility

Some three-phase systems (say, 600 V) may use separate single-phase transformers to supply 120-V lighting circuits. This is referred to as an *isolated* system. See Figure 10.

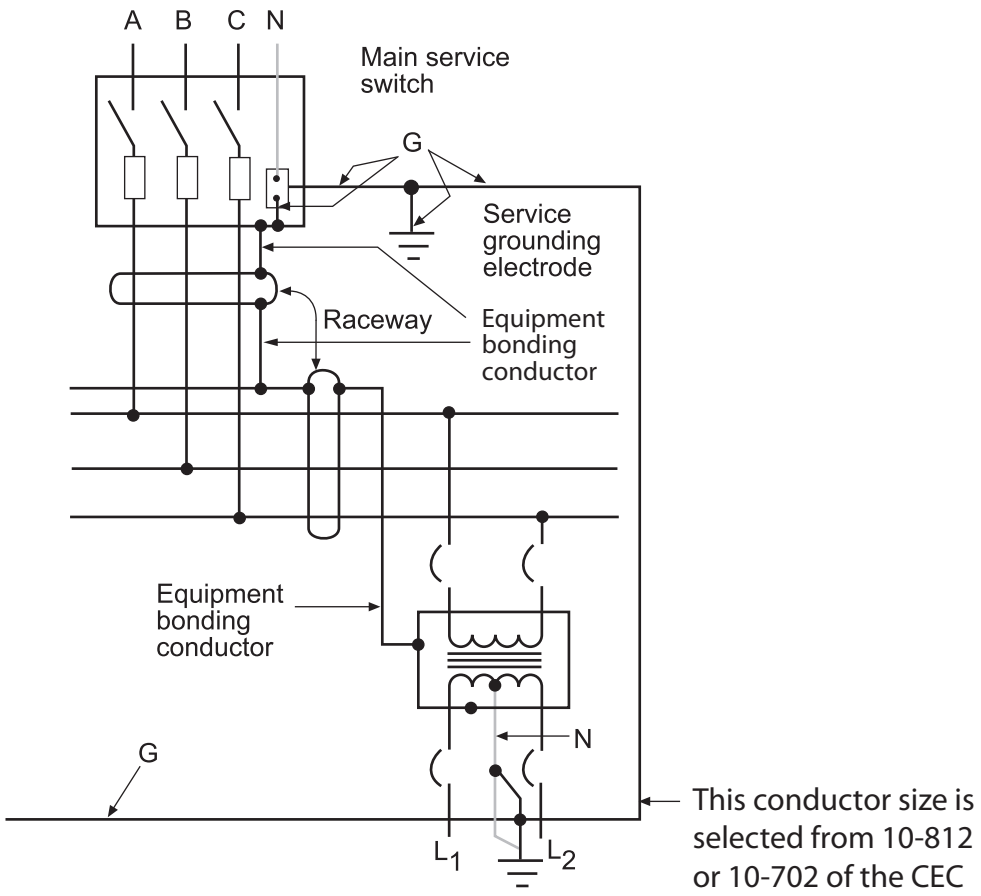


Figure 10—Grounding of isolated systems

In this case, the grounding connection can be made at the single-phase transformer (based on the requirements of Rules 10-700, 10-806 and 10-812), at the main service switch, or on the supply side of the first switch controlling the system. If two or more systems are used, then the grounding for the individual systems must be interconnected, as per Rule 10-702.

Rule 10-806 Installation of system grounding conductors

This rule establishes the requirements for the installation of grounding conductors and tries to ensure that the integrity of the grounding path is complete. This is essential for safety in the event of a system fault.

Subrule 1 states that the grounding conductor for a system must be "without joint or splice" throughout its length, except in the case of busbars, thermite-welded joints and compression connectors applied with proper tools. This means no bolted connectors.

Anytime a grounding conductor may be subjected to physical damage, mechanical protection must be assured by means of metal enclosures. Where this is not the case, grounding conductors #6 AWG and larger may be run without mechanical protection. The metal enclosure used must be attached to the cabinet or equipment at one end, and to the ground electrode at the other end. This makes the enclosure a part of the grounding path.

Grounding conductors #6 AWG and larger may be run bare in concrete provided that they are suitably protected from mechanical damage where they enter and exit the concrete (Rule 10-806(6)). This may be a short piece of conduit.

Rule 10-812 is used for sizing the grounding conductor for grounded three-phase systems and for sizing the grounding conductor for service equipment in ungrounded three-phase systems. It should be noted in Rule 10-802 that in addition to copper, aluminum or other acceptable material is now a recognized means of grounding.

Example 11: A three-phase, four-wire service with a marked maximum conductor termination temperature rating of 75°C has a demand load of 355 A. If using TECK90 copper conductors for the service, determine the minimum size of:

a. main service conductor required
b. system grounding conductor required

Solution:

a. Using Table 2, column 3, the minimum size of service conductor for the demand load is 500 kcmil (which has an ampacity of 380 A).

b. Using Rule 10-812, for the service conductor ampacity of 380 A, the minimum size of grounding conductor is #6 AWG copper or #4 AWG aluminum.

Example 12: A three-phase, three-wire, ungrounded service with a marked maximum conductor termination temperature rating of 60/75°C has a demand load of 195 A. If using TECK90 copper conductors for the service, determine the minimum size of:

a. main service conductor required
b. service grounding conductor required

Solution:

a. Using Table 2, column 3, the minimum size of service conductor for the demand load is #000 AWG (which has an ampacity of 200 A).

b. Using Rule 10-812, for the service conductor ampacity of 200 A, the minimum size of grounding conductor is #6 AWG copper or #4 AWG aluminum.

Bonding of equipment

The CEC essentially requires that all non-current-carrying metal parts of electrical equipment (and conductor enclosures) must be joined together to assure electrical continuity to ground. This is known as bonding. Rules 10-300, 10-302, 10-304, 10-400, and 10-402 identify specific types of conductor enclosures and equipment that must be bonded to ground.

The metal parts of non-electrical equipment within buildings, such as gas piping, water piping, or sewer lines, must be bonded in accordance with Rule 10-406. This is usually done by running a #6 copper conductor to all of the non-electrical equipment to be bonded. See Figure 11.

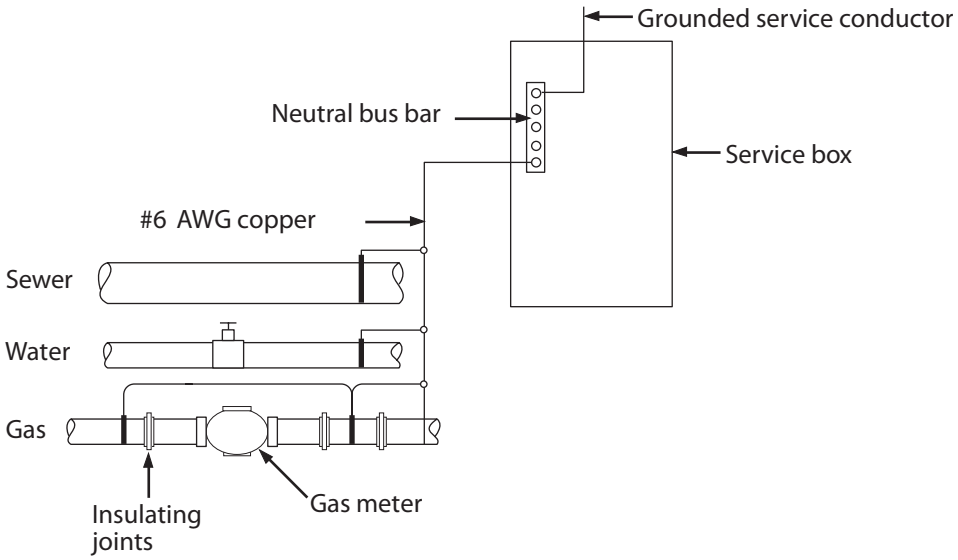


Figure 11—Bonding of non-electrical equipment

The CEC is much less stringent about the type of material that may be used for bonding conductors than for grounding conductors. See Rule 10-804.

Rule 10-814 Bonding conductor size

Consideration must be given to the impedance of the bonding path to ensure that, in the event of an equipment fault, enough fault current will flow to quickly operate the overcurrent device. Also, in the case of a fault occurring, this impedance must be low enough to limit the voltage above ground.

Bonding conductors are sized based on the size of the largest ungrounded conductor or the ampacity of the largest ungrounded busbar, as listed in Table 16A or Table 16B respectively. Where a raceway or cable sheath is permitted to be used as the bonding conductor, it is deemed to be of the proper size.

Example 13: Three #10 AWG TW75 copper conductors are in trade size 16 (1/2") EMT to supply a balanced 208 V, three-phase load that is protected with a 30-A, three-pole circuit breaker. What is the minimum size of bonding conductor that is required?

Solution: Table 16A is used to determine the minimum size of bonding conductor required for the #10 TW75 (35 A). A #12 AWG copper or a #10 AWG aluminum bonding conductor would be needed based on the size of the largest ungrounded conductor. In this instance, since the size of EMT satisfies the requirements of Tables 10A, 8, and 9I for conduit fill, Rule 10-814, Appendix B indicates that it may also serve as the bonding conductor (if properly installed).

Section 12, Wiring methods

This section of the Code details the uses and installation requirements for various low-voltage wiring methods. Conductors, raceways and equipment must be installed in a safe manner so that they do not represent mechanical, electrical, or fire hazards.

Rule 12-012 Underground installations

Underground installations must use approved cables and raceways. Table 19 lists the types of cable that are approved for direct earth burial. Table 53 specifies the minimum cover requirements for underground installations.

Figure 12 illustrates the various methods of protection that are required for type TWU conductors under a pedestrian area.

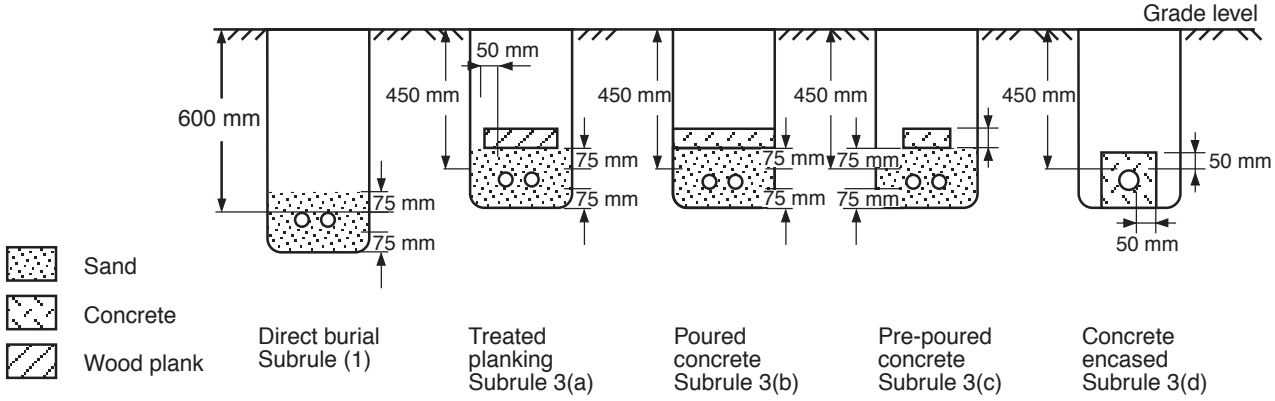


Figure 12—Mechanical protection for underground conductors

Rule 12-108 Conductors in parallel

The decision to run parallel conductors is usually for the ease of installation. Smaller conductors are obviously easier to handle than large ones. High currents are usually associated with this procedure, and it is important to keep in mind that the current is to be equally divided between all the parallel conductors involved.

The rule specifies that only conductors in sizes #1/0 AWG and larger are allowed to be paralleled. The following conditions must also be complied with:

- no splices throughout the total length (notwithstanding, a single splice per conductor shall be permitted to meet the requirements of Rule 4-006)
- the same circular mil area
- the same type of insulation
- terminated in the same manner
- the same conductor material
- the same length

One phase, polarity, or grounded circuit conductor shall not be required to have the same characteristics as those of another. The neutral (grounded circuit conductors) and the bonding conductors must also be paralleled (see Rules 10-204(2) and 10-814). Appendix B provides information and clarification for the arrangement of parallel single-conductor cables.

If parallel conductors are all run in the same conduit, you must apply the de-rating factors from Section 4. However, when larger power conductors are run in parallel, they are usually installed in separate conduits so that there is no need for de-rating of the conductor ampacity. As illustrated in Figure 13, each conduit must contain an equal number of all three-phase conductors. See Rule 12-904.

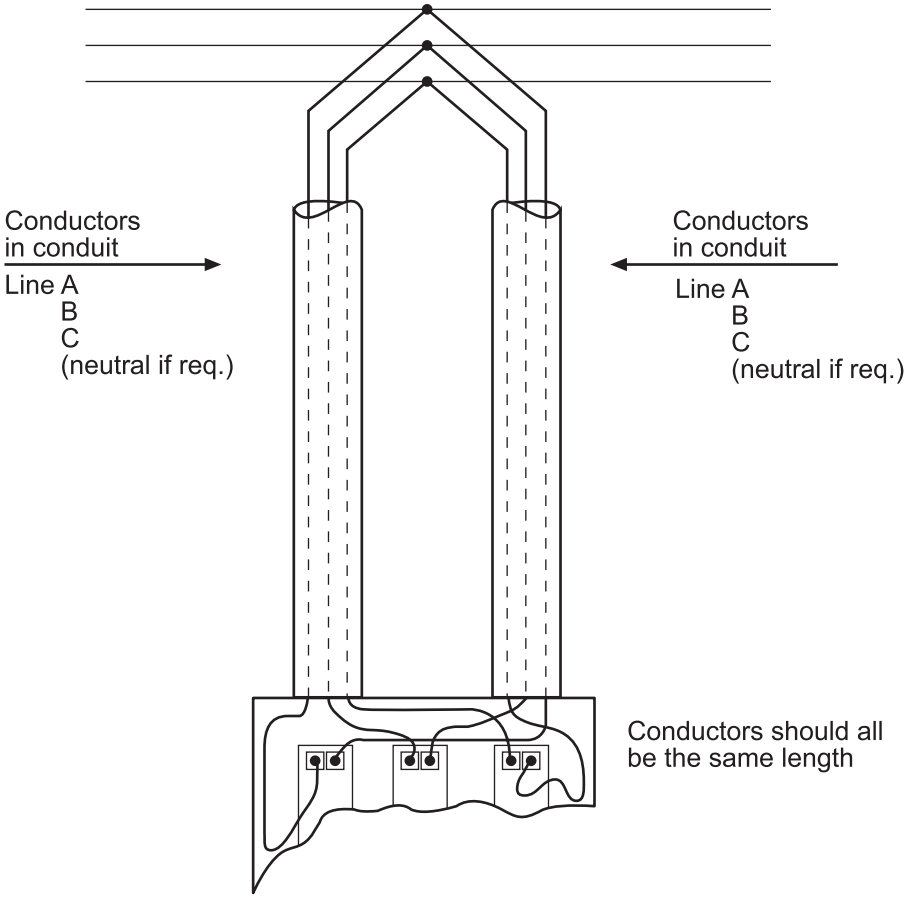


Figure 13—Large power conductors run in parallel

Rule 12-900 Raceway rules

By simple definition, a raceway is any channel designed for housing conductors (wires, cables, or busbars). The types of conductors used and the method of installation depend largely on the type of raceway selected. Rules 12-902 to 12-944 offer some general considerations for raceway systems. Specific rules must be applied when dealing with:

- rigid and flexible metal conduit (Rules 12-1000 to 12-1014)
- rigid PVC and rigid HFT conduit (Rules 12-1100 to 12-1124)
- rigid types EB1 and DB2/ES2 PVC conduit (Rules 12-1150 to 12-1166)
- rigid RTRC conduit (Rules 12-1200 to 12-1220)
- liquid-tight flexible conduit (Rules 12-1300 to 12-1308)
- electrical metallic tubing (Rules 12-1400 to 12-1414)
- electrical non-metallic tubing (Rules 12-1500 to 12-1514)
- surface raceways (Rules 12-1600 to 12-1614)
- underfloor raceways (Rules 12-1700 to 12-1718)
- cellular floors (Rules 12-1800 to 12-1820)
- auxiliary gutters (Rules 12-1900 to 12-1904)
- busways and splitters (Rules 12-2000 to 12-2020)
- wireways (Rules 12-2100 to 12-2112)
- cable trays (Rules 12-2200 to 12-2210)
- cablebus (Rules 12-2250 to 12-2260)
- manufactured wiring systems (Rules 12-2500 to 12-2502)

Rule 12-910 Conductors in conduit

Conduit must be sized to allow the conductors to be easily installed without damage and to allow sufficient air space for heat dissipation. This rule provides some guidelines for properly sizing conduits.

When all of the conductors in a single conduit are the same size and insulation type, the trade size of conduit or tubing is easily determined by applying Subrule 5. Note that all of Tables 6A to 6K are predetermined based on the smallest size of conduit available.

Example 14: What minimum size of conduit is necessary to install 12 #14 AWG RW90 XLPE, 600-V (unjacketed) copper conductors?

Solution: Step 1: Referring to Tables 6A to 6K, use the table heading to find the specific table that includes the appropriate conductor insulation type—in this case, type RW90 XLPE (600 V without jacket) found on Table 6A.

Step 2: Using the far-left column of Table 6A, select the wire size—in this case, #14 AWG.

Step 3: Read across the columns with the wire size and locate the number of conductors listed that is equal to or greater than your requirement—in this case, use the column that shows 21 (since 11 is too few).

Step 4: Now follow the column straight up and read the size of conduit suitable for that quantity of wires—in this case, 27 (1).

In this example, you will require a metric 27 (1-inch) conduit.

However, when installing conductors into a specific type of conduit or tubing, you would be advised to follow the procedure outlined in Subrule 4, using Tables 9A to 9J. This involves:

- determining the total cross-sectional area of all of the conductors using dimensions from Table 10A, 10B, or 10C
- identifying the allowable percent fill of the conduit (usually 40%) using Table 8
- selecting the type of conduit and size (using the appropriate percent fill) from Tables 9A to 9J

Example 15: What minimum size of electrical metallic tubing is necessary to install 12 #14 AWG RW90 XLPE, 600-V (unjacketed) stranded copper conductors?

Solution: Step 1: Use Table 10A to determine the area of each of the conductors. In the RW90XLPE* 600 V column, each #14 RW90 XLPE wire has an area of 8.89 mm^2.

Step 2: Determine the total area of all of the wires:

$12 \times 8.89\ mm^2 = 106.68\ mm^2$ total area

Step 3: Refer to Table 8, which identifies the maximum allowable conduit fill as being 40%, since we have over four conductors.

Step 4: Go to Table 9I and look under the 40% column to locate an area that is equal to or greater than the total conductor area of 106.68 mm^2—in this case, Table 9I shows 132 mm^2.

Read across to the far-left column to select the size of conduit—in this case, 21 (¾ inch).

In this example, you will only require a metric 21 (¾ inch) electrical metallic tubing (instead of the 27 (1) conduit from the previous example).

Note, if these conductors were solid AWG No. 14 RW90, you would be required to defer to Table 10C to determine the total area of all the wires.

When installing conductors of mixed wire sizes into various sizes of conduit or tubing, you must follow the procedure outlined in Subrule 4. Once again this involves:

- determining the total cross-sectional area of all of the conductors using dimensions from Table 10A, 10B, or 10C
- identifying the allowable percent fill of the conduit (usually 40%) using Table 8
- selecting the type of conduit and size (using the appropriate percent fill) from Tables 9A to 9J

Example 16: What size of single rigid metal conduit is necessary to contain six #8 AWG TW75 and six #14 AWG TW75 stranded copper conductors?

Solution: Step 1: Use Table 10A to determine the area of each of the conductors. In the TW75 column, each #14 TW75 wire has an area of 8.89 mm^2 and each #8 TW75 wire has an area of 28.17 mm^2.

Step 2: Determine the total area of all of the wires:

$6 \times 8.89\ mm^2 = 53.34\ mm^2$ (#14 wires)
$6 \times 28.17\ mm^2 = 169.02\ mm^2$ (#8 wires)
Total area = $222.36\ mm^2$

Step 3: Refer to Table 8, which identifies the maximum allowable conduit fill as being 40%, since we have more than four conductors.

Step 4: Go to Table 9A and look under the 40% column to locate an area that is equal to or greater than the total conductor area of 222.36 mm^2—in this case, Table 9A shows 229 mm^2.

Read across to the far-left column to select the size of conduit—in this case, 27 (1).

In this example, you will require a trade size 27 (1 inch) conduit.

Note, if these AWG No. 14 conductors were solid TW75, you would be required to defer to Table 10C, and Table 10A for the No. 8 TW75 to determine the total area of all the wires.

Note that any grounding and bonding conductors must also be included whenever computing conduit fill. Dimensions of bare bonding or grounding conductors may be obtained from Table D5 (or by actual measurement).

Rule 12-3022 Entrance of conductors into boxes, cabinets and fittings

Bushings are used primarily to protect conductor insulation from abrasion by a conduit and are required for conductors #8 AWG and larger. See Figure 14. Bushings are made from plastic or steel, and some bushings have a plastic insert.

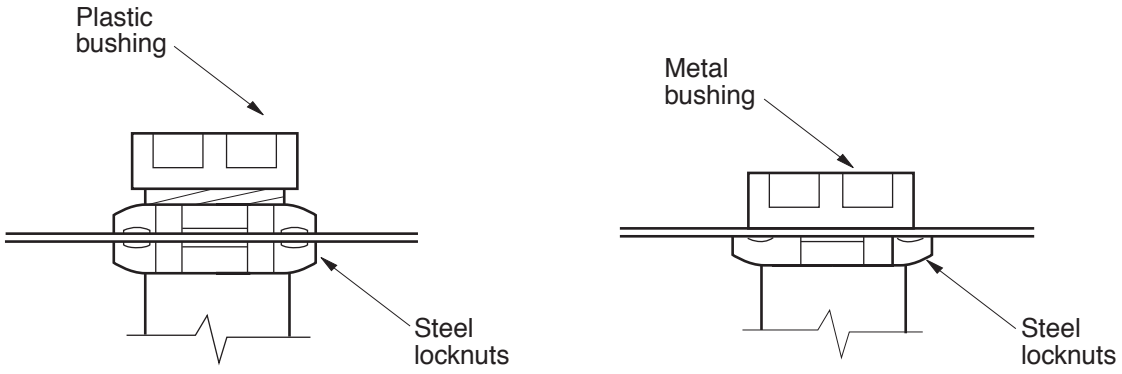


Figure 14—Terminating rigid conduit

Subrule 4 identifies that conduits shall be secured in place with the requirements of Section 10. Although it is good practice to use two locknuts and a bushing for securing rigid conduit, smaller conduit sizes may use a single locknut and one bushing. When no second locknut is used, the bushing must be metal. Read Rule 10-610.

Rule 12-3034 Maximum number of conductors in a box

When too many conductors are contained in a box, they may be physically damaged or overheating could occur. As a result:

- Table 22 specifies the volume required for each insulated conductor in any box.
- Table 23 lists the capacity of standard boxes and the maximum number of insulated conductors permitted in each.

Subject to the conditions given in Subrule 1 and except as specified in Subrule 3, the number of conductors listed in Table 23 are typically reduced based on:

- whether the box contains fixture studs or hickeys
- how many wire connectors with insulating caps are within the box
- the size of flush devices (receptacles or switches) mounted on the box

Conductors that do not leave a box (e.g., pigtails to terminals) and fixture wires supplying a lighting fixture are not counted.

Example 17: Two NMD90 (two-wire-plus-bond) #14 AWG cables enter an octagon box. Two of the wires are spliced together using a wire connector with insulating caps (marrettes); the other two go to the terminals of a keyless plastic lampholder (see Figure 15). How many conductors are counted for box fill? Is a 4 × 1½ octagon box appropriate for this job?

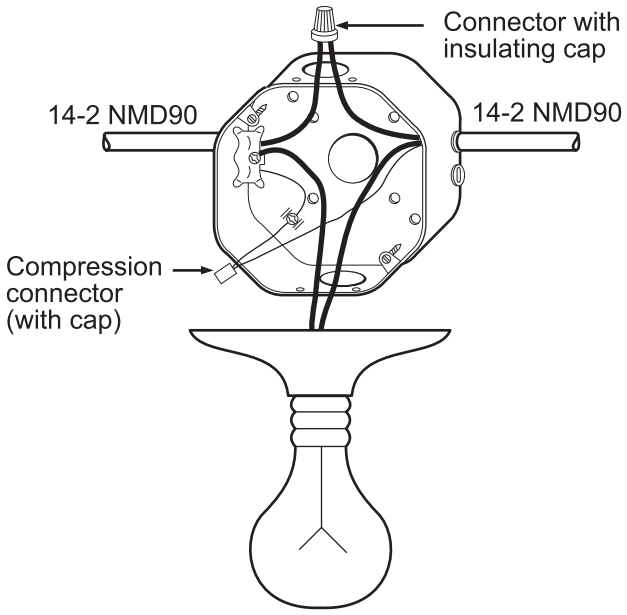


Figure 15—Use of octagonal box

Solution: In accordance with Rule 12-3034(1)(b), each insulated wire in each cable is counted. Notice that bare grounding wires are not counted.

No. of insulated conductors = 2 × 2 wires = 4 wires counted.

In accordance with Rule 12-3034(2)(b), we require "no reduction" for a one-wire connector with an insulating cap.

Therefore = 0 wires counted.

Since the lampholder is a surface-mounted device, there is "no reduction" necessary.

Therefore = 0 wires counted.

The total number of wires counted for box fill = 4 + 0 + 0 = 4 conductors.

From Table 23, a 4 × 1½ octagonal box permits up to 10 #14 AWG wires.

Example 18: Two NMD90 (two-wire-plus-bond) #14 AWG cables enter a standard receptacle box. The black wires are spliced together (using a marrette connector), as are the white wires and the ground wires. A duplex receptacle is connected by pigtailing. See Figure 16. How many conductors are counted for box fill? What standard size of device box is adequate for this job?

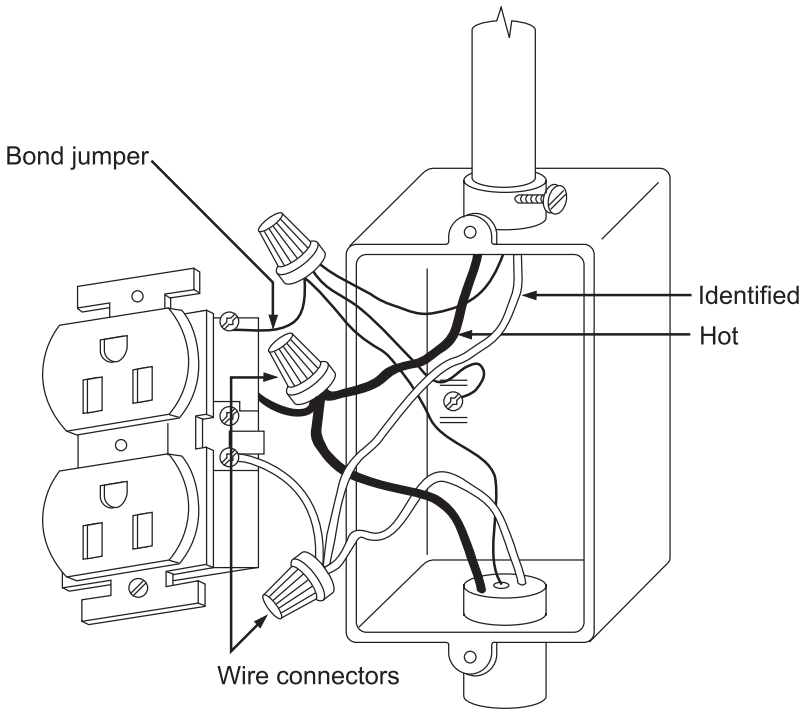


Figure 16—Use of device box

Solution: No. of insulated conductors = 2 × 2 wires = 4 wires counted.

In accordance with Rule 12-3034(2)(b), since we have three wire connectors with insulating caps, we count 1 wire.

Therefore = 1 wire counted.

In accordance with Rule 12-3034(2)(c), we must count the receptacle as two wires.

Therefore = 2 wires counted.

The total number of wires counted for box fill = 4 + 1 + 2 = 7 conductors.

From Table 23, a 3 × 2 × 2½ device box (eight wires permitted) is adequate for this installation.

Rule 12-3036 Pull box or junction box sizes

A pull box or junction box is often used in conduit work where the distance between outlets becomes too great for easy conductor installation. They may also be used when a change in direction of a conduit run is required.

For straight pulls utilizing #4 AWG or larger conductors, the minimum length of the box is eight times the largest pipe diameter (or equivalent cable). See Subrule 2(b).

Example 19: In Figure 17, what is the overall length required for the pull box?

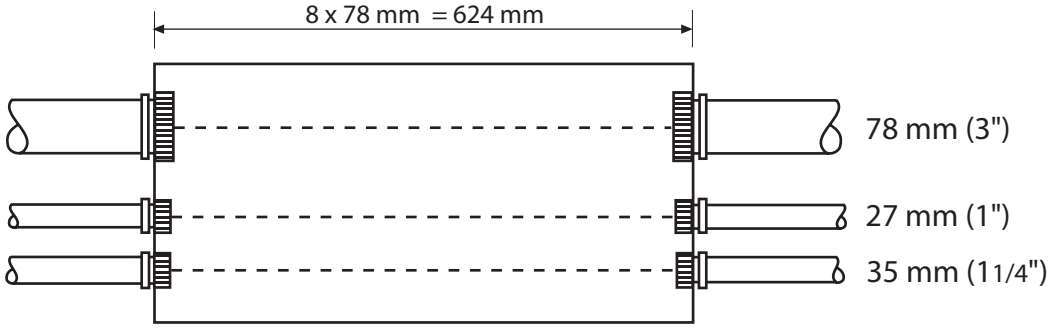


Figure 17—A straight pull

Solution: The minimum length of the box = 8 × 78 mm = 624 mm

Note that the width is not governed by this rule, so the box width must be sufficient to accept all of the conduits plus space for locknuts and bushings.

For angle or U-pulls:

- The distance between each raceway entry inside the box and the opposite wall of the box must not be less than six times the trade size of the largest conduit (see Figure 18).
- The distance must be increased for additional raceways by the amount of the sum of the diameters of all other raceway entries on the same wall of the pull box.
- The distance between raceway entries shall not be less than six times the trade diameter of the largest conduit.

Example 20: In Figure 18, determine the minimum distances (A, B, C) for the angle pulls.

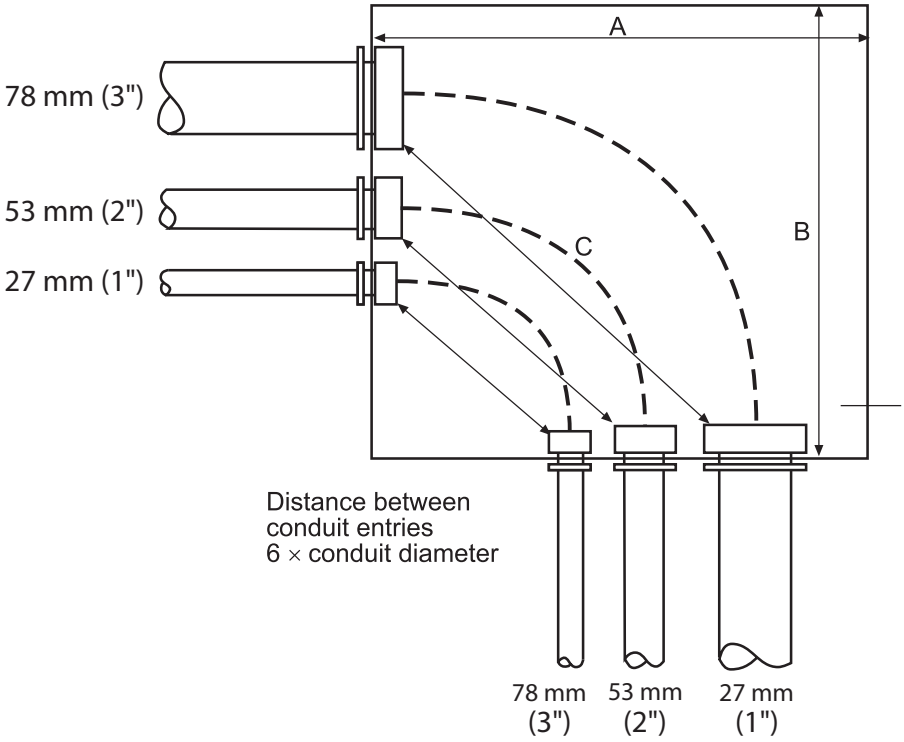


Figure 18—Angle pulls

Solution:

$$\text{Length A} = 6 \times 78 + (53 + 27)$$
$$= 548 \text{ minimum inside dimension}$$
$$\text{Length B} = 6 \times 78 + (53 + 27)$$
$$= 548 \text{ minimum inside dimension}$$

Minimum distance between conduit entries (C):

- for 78 mm (3") conduit = 6 × 78 = 468 mm
- for 53 mm (2") conduit = 6 × 53 = 318 mm
- for 27 mm (1") conduit = 6 × 27 = 162 mm

Example 21: In Figure 19, determine the minimum distances (A and B) for the U-pull.

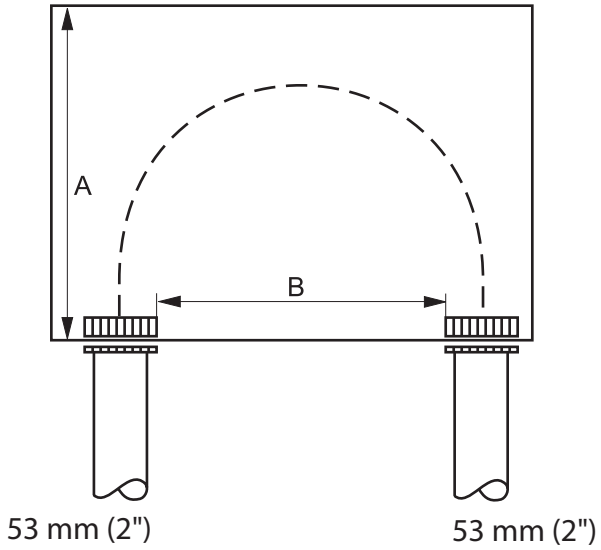


Figure 19—U-pull

Solution: Length A = 6 × 53 + 53 = 371 mm minimum inside dimension

Minimum distance between conduit entries (B) = 6 × 53 = 318 mm minimum

Note that the width of the box must be sufficient to accommodate the two conduits and to maintain the required distance apart.

Activity 4

If one of the trade size 78 (3") conduits in Example 20 (Figure 15) was installed opposite the other trade size 78 conduit, resulting in a straight pull, while the remaining five conduits were left as is on the existing walls, would a different size pull-box be required?

Section 14, Protection and control

Section 14 deals with the protection and control of electrical circuits and apparatuses. You have previously studied specific protective devices, such as fuses and circuit breakers, and recognize how they protect against overload and overcurrent hazards.

Rule 14-012 Ratings of protective and control equipment

A lot of attention is devoted to calculating branch circuit overcurrent protection throughout this Learning Guide. Rule 14-012 is provided to protect equipment against available fault currents.

Consider the example in Figure 20.

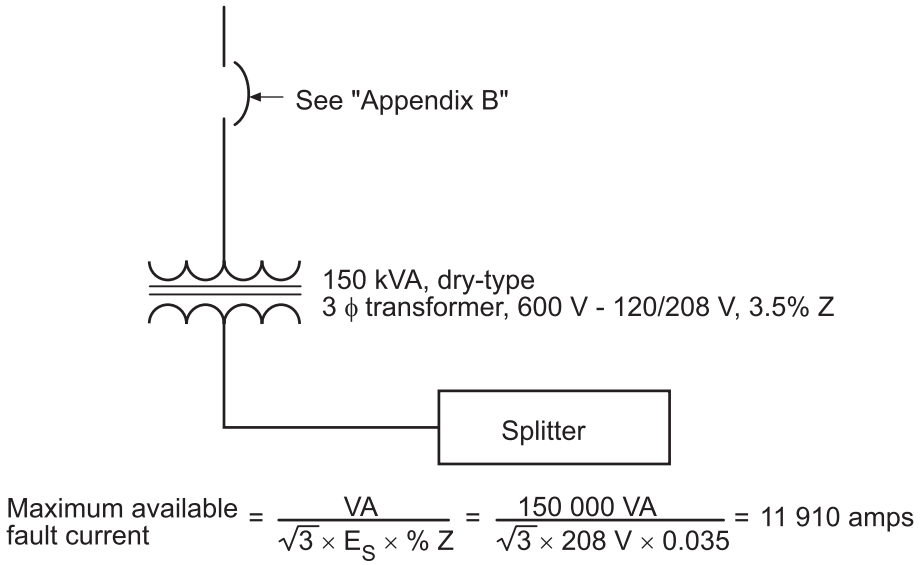


Figure 20—Fault current calculation

When selecting overcurrent devices, care must be taken to ensure that the available fault current can be safely interrupted and limited. Without this, we can see that the magnetic flux generated by these high currents can whip about unsecured conductors and cause mechanical/magnetic stresses on terminations that can exceed the bracing for which the equipment is designed. This can result in added phase-to-phase and phase-to-ground shorts when the bracing fails, releasing even more stored energy from load devices. Under the worst conditions the surrounding air can become ionized, with fire and explosion enveloping persons in the area as well as causing major equipment damage.

Rule 14-100 Overcurrent devices required

As the conductors in an electrical distribution system branch out from the main service to feeders, subfeeders and branch circuits, they generally get smaller in size. All conductors are sized to safely carry the current to the load(s) they supply, and the Code requires that the associated overcurrent device properly protects the conductor. However, when a smaller conductor "taps" into a larger conductor, the overcurrent protection for the larger conductor may sometimes exceed the ampacity of the smaller conductor.

Within certain limitations, this rule permits this reduction in tap conductors. Refer to Figure 21 and read paragraphs (b) and (c) of this rule.

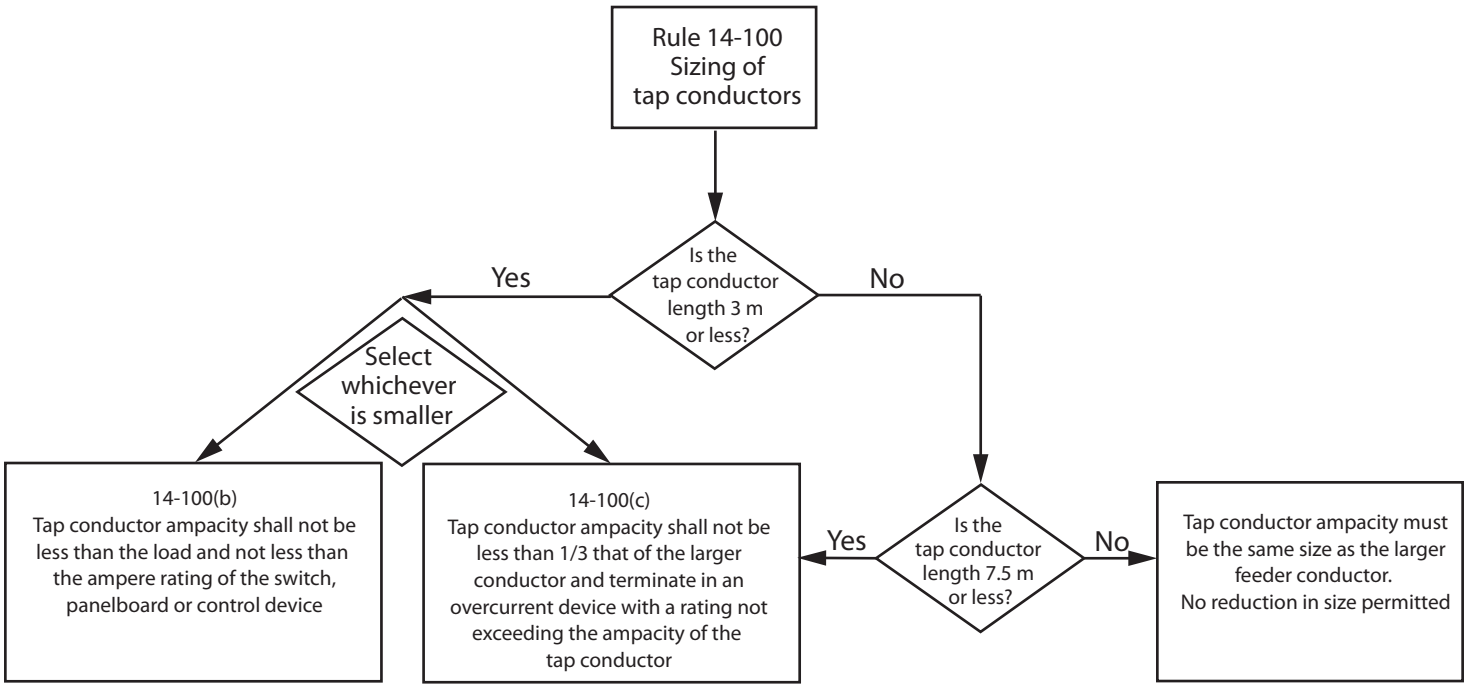


Figure 21—Guide for tap conductors

By keeping the tap conductors short in length and physically protected, it is anticipated that the possibility of a fault condition in the underprotected length is very unlikely. Tap conductors that exceed 7.5 m in length would require the same ampacity as the larger feeder, or be provided with separate overcurrent protection at the point of the tap (within 7.5 m).

Example 22: Determine the minimum ampacity permitted for the tap conductors shown in Figure 22. The maximum tap conductor length is as marked, and all wires are installed in rigid conduit.

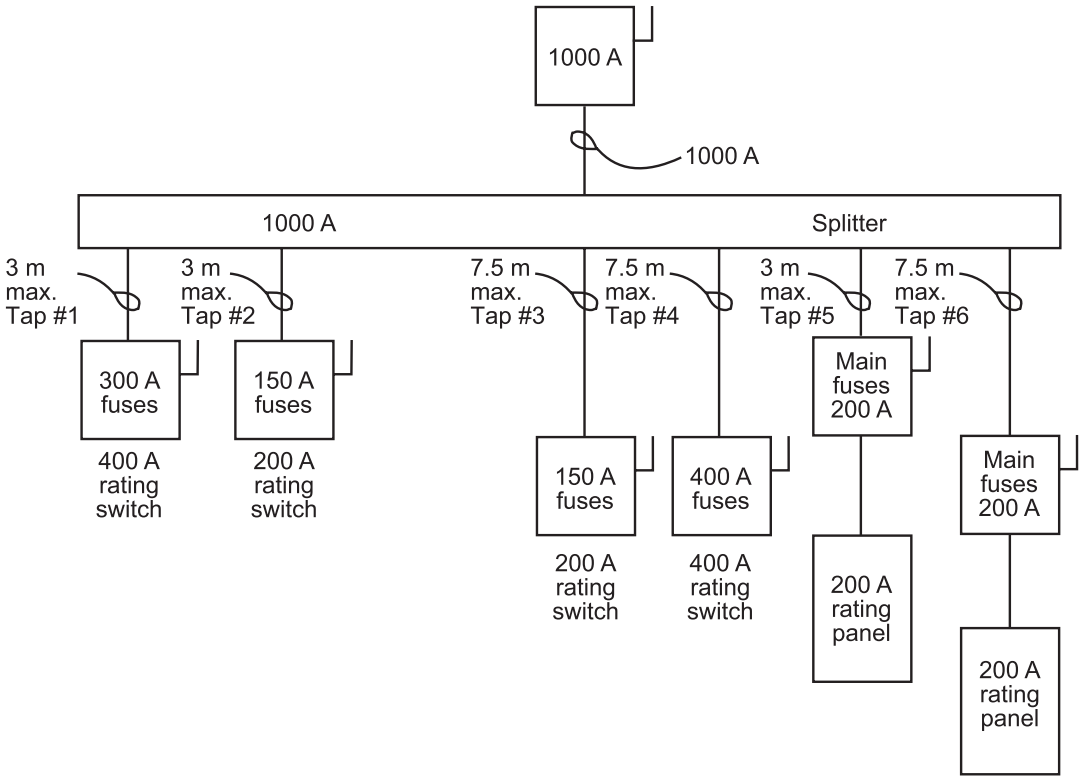


Figure 22—Sizing of tap conductors

Solution: Tap #1: Using CEC Rule 14-100(b) requires tap conductor to be sized using the 400-A switch ampacity rating. Answer = 400 A

Tap #2: Using CEC Rule 14-100(b) requires tap conductor to be sized using the 200-A switch ampacity rating. Answer = 200 A

Tap #3: Using CEC Rule 14-100(c) because of tap length, which overrides the 150-A fuse & 200-A switch rating. Requires conductor to be sized on ⅓ the ampacity of the 1000-A conductor feeding the splitter. 1000/3 = 333.33 A: therefore the minimum tap conductor is based on a minimum of 333 A. Answer = 333.33 A

Tap #4: Using CEC Rule 14-100(c), can't be less than ⅓ the ampacity of the 1000-A conductor feeding the splitter. In this case the load is being supplied using a 400-A switch, with 400-A fuses. Minimum Tap requirement based on 400 A. Answer = 400 A

Tap #5: Using CEC Rule 14-100(b) requires tap conductor to be sized using the 200-A switch ampacity rating. Answer = 200 A

Tap #6: Using CEC Rule 14-100(c) because of tap length, which overrides the 200-A fuse & 200-A switch rating. Requires conductor to be sized on ⅓ the ampacity of the 1000A conductor feeding the splitter. 1000/3 = 333.33 A: therefore the minimum tap conductor is based on a minimum of 333 A. Answer = 333.33 A

When dealing with motor control circuits, paragraph (e) of this rule allows the conductors for remote control to "tap off" the power circuit (see Figure 18) without requiring separate overcurrent protection, provided that the control circuit conductors:

- are #14 AWG or larger, and
- have an ampacity of at least ⅓ the rating of the branch circuit overcurrent device.

In any event, separate overcurrent protection is not required where the control circuit performs a critical function (e.g., fire pump operation) and its opening may create a hazard.

Rule 14-104 Rating of overcurrent devices

The addition of Subrule 2 now restricts the allowable overcurrent protection of copper and aluminum wire, as follows:

- 15 A for #14 AWG copper
- 20 A for #12 AWG copper
- 30 A for #10 AWG copper
- 15 A for #12 AWG aluminum
- 25 A for #10 AWG aluminum

This subrule and its restrictions have been inserted into the Code to make sure that when these common conductor sizes are used, one understands the conductor ampacity limitations of Tables 1, 2, 3, and 4, and the minimum protection that is required.

Subrule 1(c) refers to other rules of the Code that specifically allow these conductors to have overcurrent protection greater than the protection required by Subrule 2(a), (b), and (c). Electrical apparatus such as capacitors, transformers, motors, arc welders, etc., would meet this criterion.

Section 16, Class 1 and Class 2 circuits

You have dealt with applications of Class 1 and Class 2 circuits in past studies (see Competency G-1 and Level 2 Competency G-2). In this Learning Guide, you will apply rules that deal primarily with motor control circuits. These are usually Class 1 circuits.

Rule 16-010 Circuits to safety control devices

This rule requires that remote-control circuits for the operation of safety-type devices (e.g., fire alarm circuits) must be installed in compliance with the rules for Class 1 circuits.

Rule 16-100 Limitations of Class 1 circuits

Subrule 2 requires that remote-control and signal circuits be no higher than 600 V. One example of a Class 1 circuit (600 V or less) is the control wiring used to control magnetic motor starters. See Figure 23.

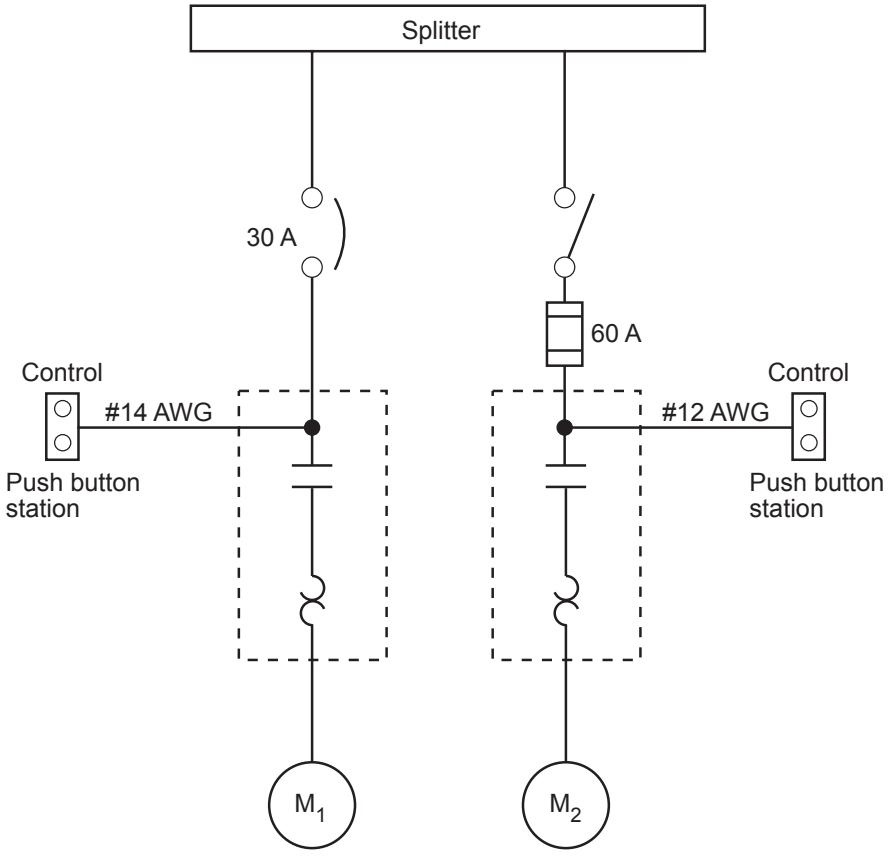


Figure 23—Motor control circuit conductors

Rule 16-114 Conductors of different circuits in the same enclosure, cable, or raceway

In the control of three-phase motors, this rule permits the control circuit and power circuit conductors to be in the same raceway or junction box, provided that all conductors are insulated for the highest voltage.

Section 26, Installation of electrical equipment

Section 26 addresses the installation of two types of three-phase equipment that you have learned about:

- power factor correction capacitors
- transformers

Rules 26-200 to 26-222 Capacitors

As you are aware, there are several different methods of connecting capacitors for power factor correction:

- as individual units at each inductive load
- as large banks on main feeders
- as a combination of both these methods

Figure 24 shows a diagram of a capacitor branch circuit.

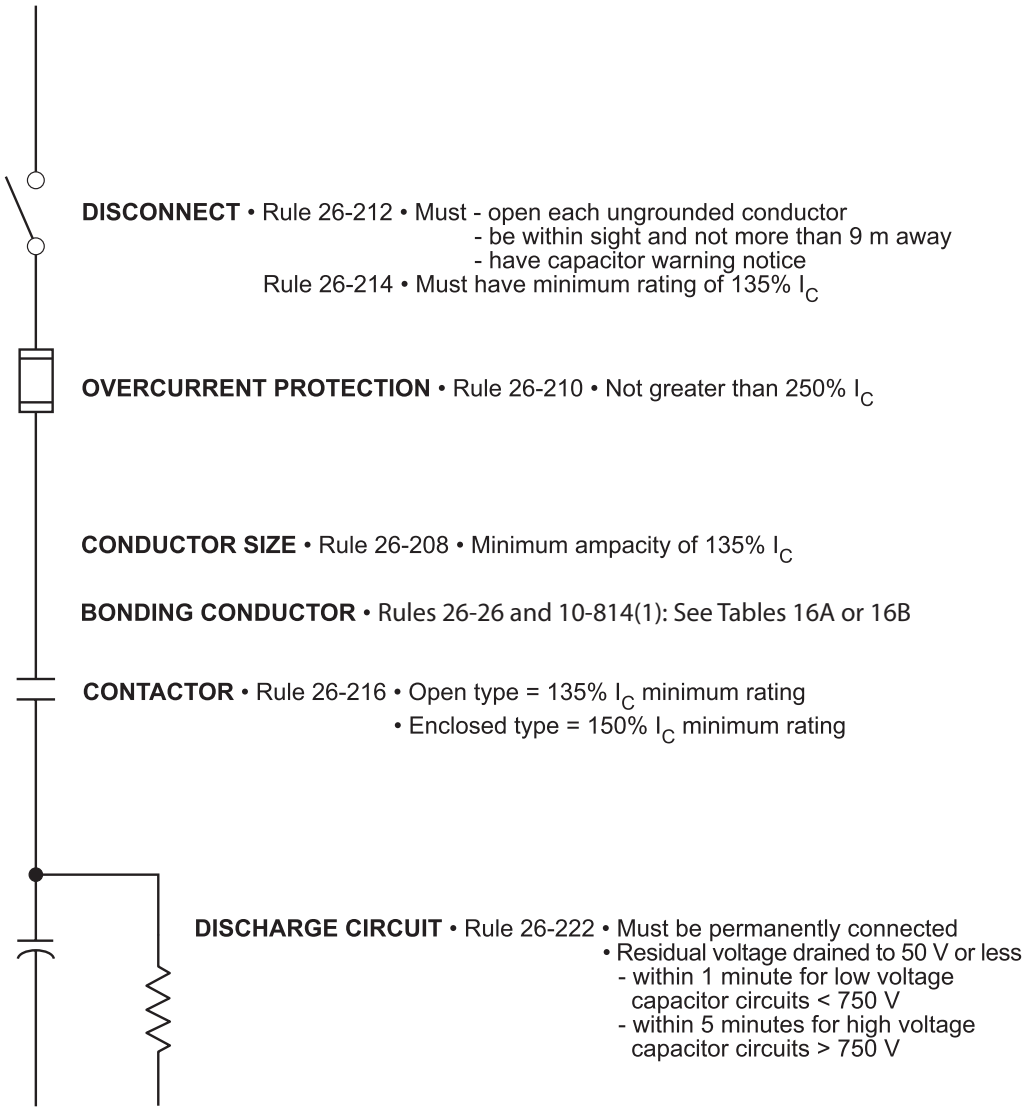


Figure 24—Capacitor branch circuit

Example 23: A 45-kVAR, 480-V, three-phase capacitor is to be installed on a separate branch circuit where all the equipment is marked with a maximum conductor termination temperature of 75°C. For this capacitor, determine the following:

- minimum size of TW75 copper conductors
- maximum fuse size
- disconnect switch rating

Solution: The rated current of the capacitor is:

$$I_C = \frac{45\,000 \text{ VARS}}{\sqrt{3} \times 480 \text{ V}} = 54.13 \text{ A}$$

Using Rule 26-208(1), the minimum conductor ampacity equals:

54.13 A × 1.35 = 73.1 A

and from Table 2, we require three #4 TW75 (85 A).

Using Rule 26-210, the maximum calculated fuse size = 54.13 A × 2.5 = 135 A, and therefore a maximum standard fuse size of 125 A is permitted.

Appendix B suggests that the manufacturer's recommendations should be followed with regard to protection for capacitors, in which case the actual fuse selected may be smaller than the maximum permitted by Code.

Using Rule 26-214, the minimum disconnect rating equals:

54.13 A × 1.35 = 73.1 A

This would require the use of a 100-A (standard size) disconnect switch. However, if the maximum fuse of 125 A is used, the disconnect switch size must be increased to accommodate the fuse. Therefore, a 200 A (standard size) disconnect switch would have to be used. Again, using a smaller fuse would offer an advantage.

Rule 26-218 Special provisions for motor circuit capacitors

Whenever capacitors are installed directly at motors, there are several important considerations to be observed. Figure 25 identifies the application of rules dealing specifically with capacitors that are connected on the load side of the motor controller.

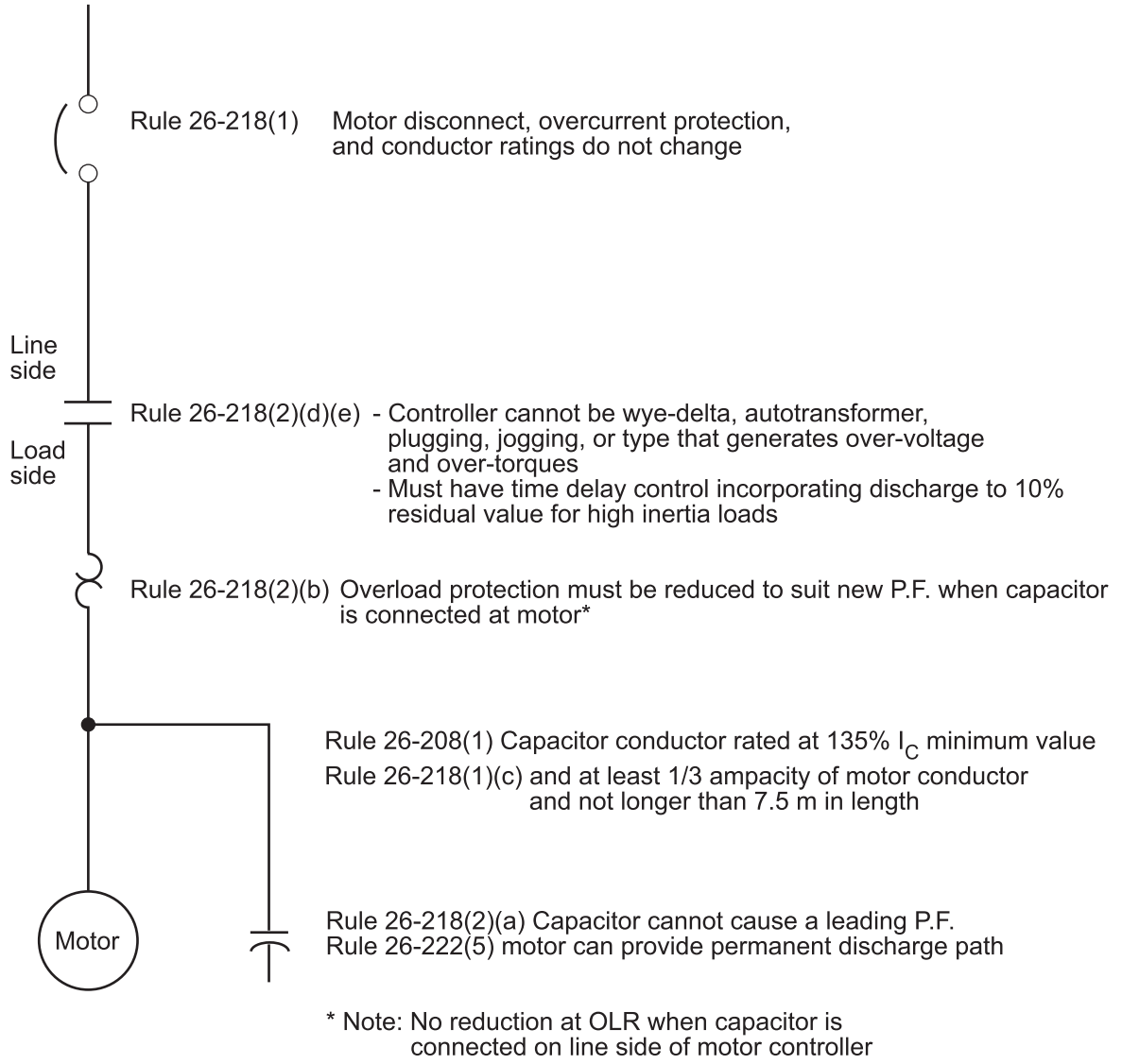


Figure 25—Capacitors in motor circuits

Example 24: A 75-hp, 480-V, three-phase induction motor draws a full-load current of 100 A. The motor is protected with 300-A fuses in a 400-A disconnect switch, and all equipment is marked with a maximum conductor termination temperature of 75°C. The motor supply conductors used are #1 R90 (130-A) copper. A 25-kVAR, 480-V, three-phase capacitor is to be installed on the load side of the motor controller, also marked with maximum conductor termination temperature of 75°C. If the capacitor improves the circuit PF to 94% lag and reduces the overall line current to 86 A, determine the following:

a. size of R90 XLPE copper for the capacitor (tap length less than 7.5 m)

b. size of EMT to the capacitor

c. value of current through the overload relay heaters

Solution: a. The rated current of the capacitor is

$$I_C = \frac{25\,000 \text{ VARS}}{\sqrt{3} \times 480 \text{ V}} = 30.1 \text{ A}$$

Using Rule 26-208(1), the minimum conductor ampacity calculates as:

$1.35 \times 30.1 \text{ A} = 40.6 \text{ A}$

However, Rule 26-218(1)(c) requires that the capacitor conductors be at least $⅓ \times 130 \text{ A} = 43.3 \text{ A}$ when the tap is less than 7.5 m long.

Using Table 2, the capacitor requires #8 AWG R90XLPE 600-V unjacketed (50-A) conductors.

b. From Table 6A, the size of EMT (based on three conductors) = ¾" (21 mm). (Rule 12-910 and Tables 10A, 8, and 9I require equivalent sizes.)

c. The actual value of current through the overload relay heaters = 86 A.

Rules 26-240 to 26-268 Transformers

When the CEC refers to *transformers*, it means single-phase transformers, three-phase transformers, or single-phase transformers operated as a three-phase bank.

Rule 26-242 Outdoor transformer installations

This rule deals essentially with two main requirements:

1. The inaccessibility to live parts by unauthorized persons. This rule specifies a minimum height if the transformer is to be isolated by elevation. It also refers to rules regarding isolation fences. When live parts are exposed, there must be suitable warning signs indicating the highest voltage employed.

2. The fire hazard requirements of Rule 26-014 have been relaxed for liquid-filled transformers installed outdoors. Transformers may be located as close as *3 metres from combustible surfaces* and at least *6 metres from any window, door, or ventilation opening* of a building, unless a non-combustible wall or barrier is constructed between the transformer and the opening.

Rule 26-246 Dielectric liquid-filled transformers indoors

The requirements of this rule and Rule 26-012 are primarily intended to prevent the spread of fire. Appendix B offers criteria for the installation of liquid-filled transformers in electrical equipment vaults.

Rule 26-248 Dry-core, open-ventilated type transformers

Dry-core, open-ventilated transformers rely on air flow around the transformer to provide cooling. Figure 26 illustrates the clearance requirements for floor-mounted transformers in accordance with this rule.

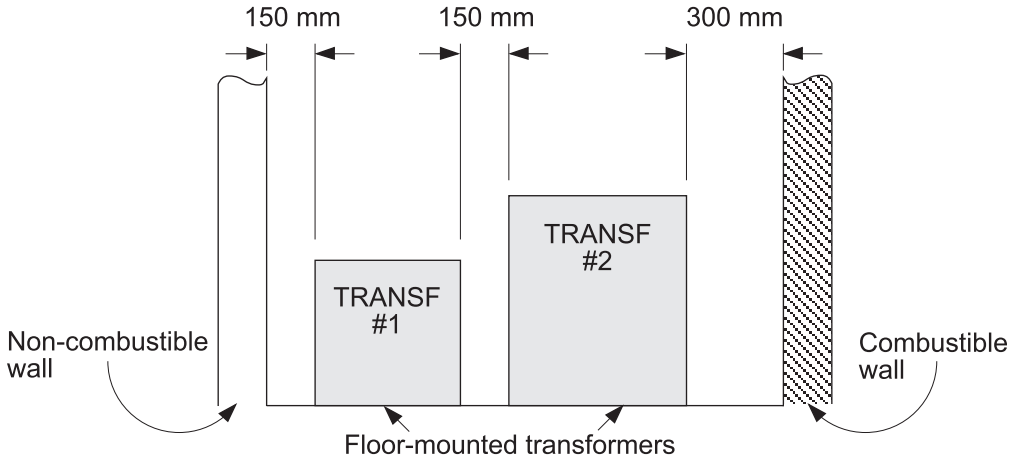


Figure 26—Floor-mounted transformers

Figure 27 shows the clearance requirements for wall-mounted transformers in accordance with this rule.

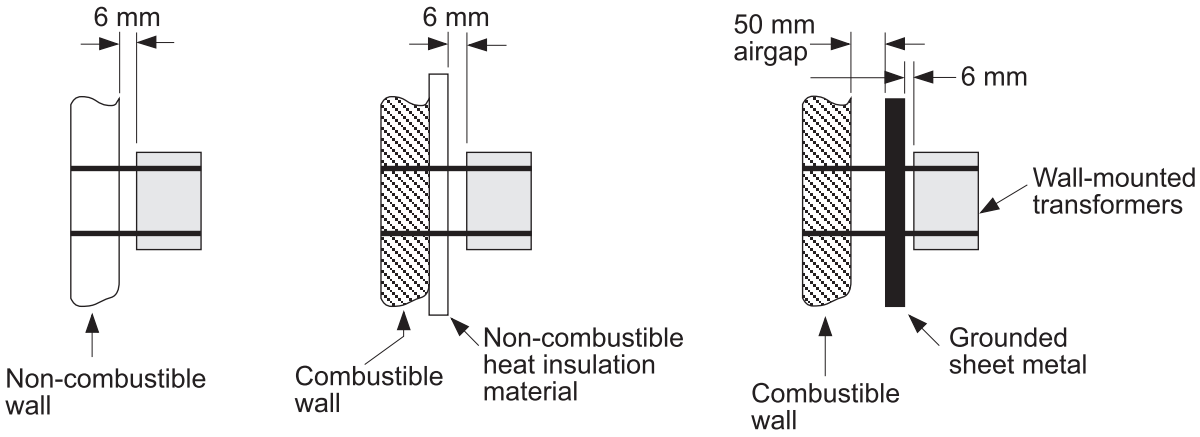


Figure 27—Wall-mounted transformers

Rule 26-250 Disconnecting means for transformers

To facilitate maintenance, a disconnecting means must be installed in the primary circuit of each power and distribution transformer. In low-voltage installations, the disconnecting means is normally a circuit breaker or a fused switch. The size of the disconnecting means is determined by the overcurrent protection specified by the CEC.

In installations where the primary circuit is high voltage, the disconnecting means must meet the requirements of Rule 36-214. Similarly, Rule 36-210 requires a suitable disconnecting means on the supply side of fuses for instrument voltage transformers.

Rule 26-252 Overcurrent protection for power and distribution transformers rated over 750 V

This rule describes the overcurrent protection requirements for high-voltage power and distribution-type transformers. Since the voltage level is over 750 V, the rules in Section 36 must also be followed.

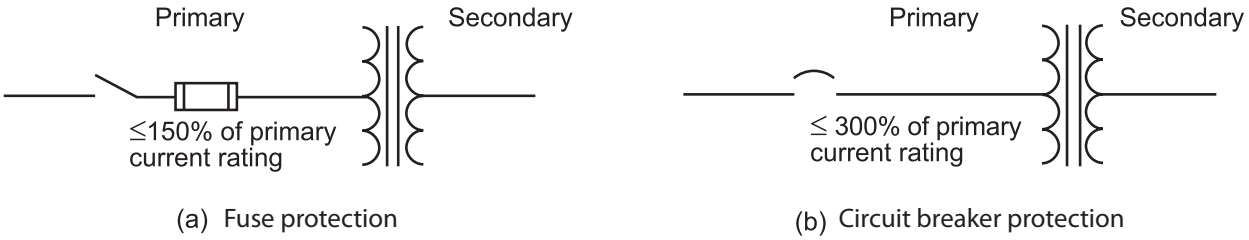


Figure 28—Individual transformer overcurrent protection

Figure 28 illustrates the use of either fuses or circuit breakers on the primary side for providing short-circuit protection. The difference in ratings is based on the operating characteristics of high-voltage fuses compared with high-voltage circuit breakers. In either case, the calculated value may be increased to the next standard size available.

In some instances, individual overcurrent protection on the primary side may not be required. This is the case when the transformer:

- is provided with overcurrent protection on the secondary side, or
- is equipped with coordinated thermal overload protection by the manufacturer, and
- the feeder overcurrent device does not exceed the values listed in Table 50. See Figure 29.

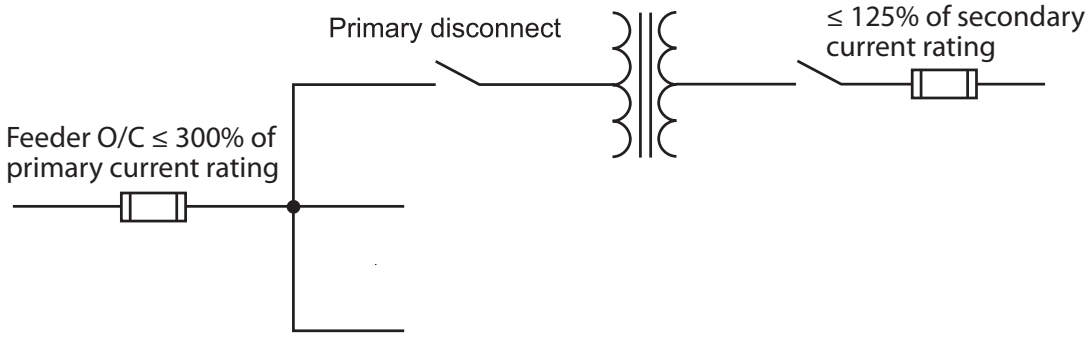


Figure 29—Primary feeder overcurrent protection

Rule 26-254 Overcurrent protection for power and distribution transformers rated 750 V or less (other than dry-type transformers)

This rule generally requires that the primary side of each transformer be provided with overcurrent protection (either fuses or circuit breaker) not exceeding 150% of the rated primary current. See Figure 30.

The intent of this rule is similar to the previous rule dealing with high-voltage transformers, except that fuses and circuit breakers are treated the same. Also, this rule is somewhat relaxed, depending on the actual value of rated primary current.

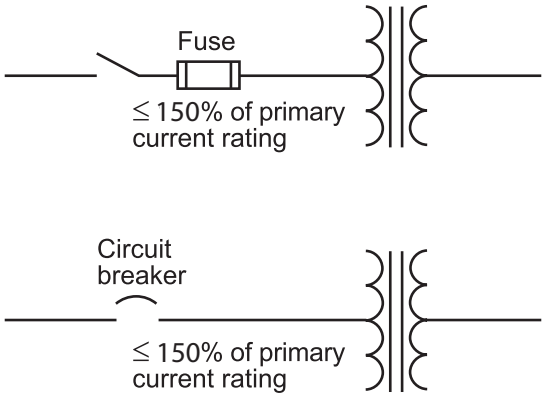


Figure 30—Individual transformer overcurrent protection

Where the feeder provides the required value of overcurrent protection, a separate overcurrent device may not be required on the primary side. See Figure 31.

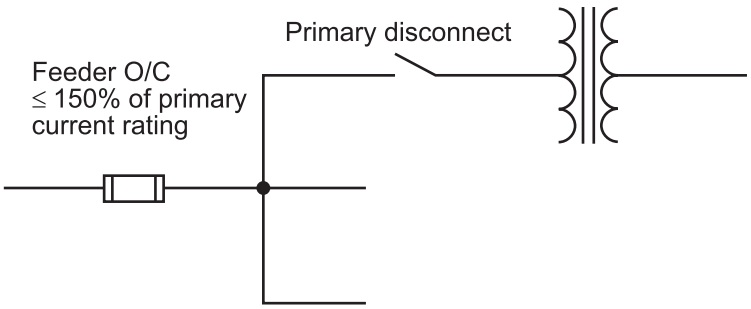


Figure 31—Primary feeder overcurrent protection

Furthermore, if the transformer has secondary overcurrent protection not exceeding 125% of the rated secondary current, then the feeder overcurrent protection on the primary side may be as high as 300% of the rated primary current. See Figure 32.

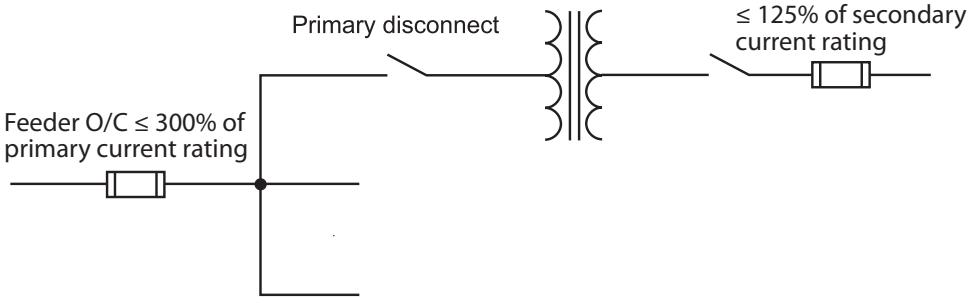


Figure 32—Transformer with individual secondary overcurrent protection

Again, the rating of overcurrent protection on the secondary side is somewhat relaxed, depending on the actual value of rated secondary current.

A transformer that is equipped with coordinated thermal overload protection by the manufacturer may not be required to have individual primary overcurrent protection. See Figure 33.

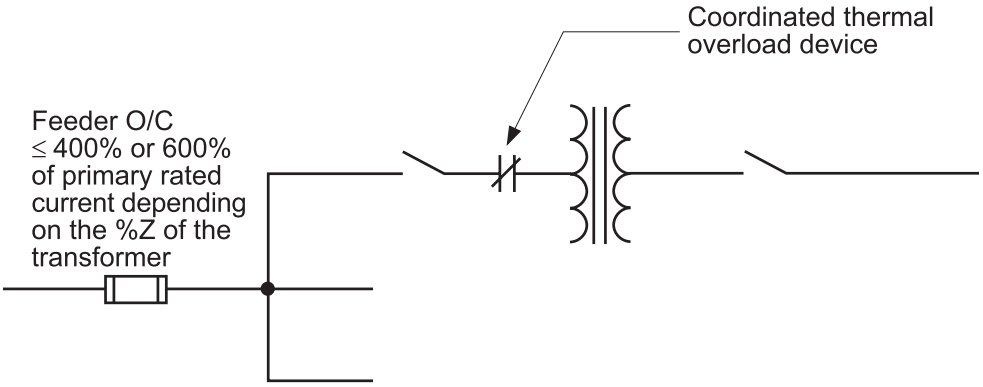


Figure 33—Transformer with coordinated thermal overload protection

Rule 26-256 Overcurrent protection for dry-type transformers rated 750 V or less

Dry-type transformers generally operate at higher temperatures and are not considered to withstand overloads as well as liquid-filled transformers. Therefore, the requirements for overcurrent protection are stricter. See Figure 34.

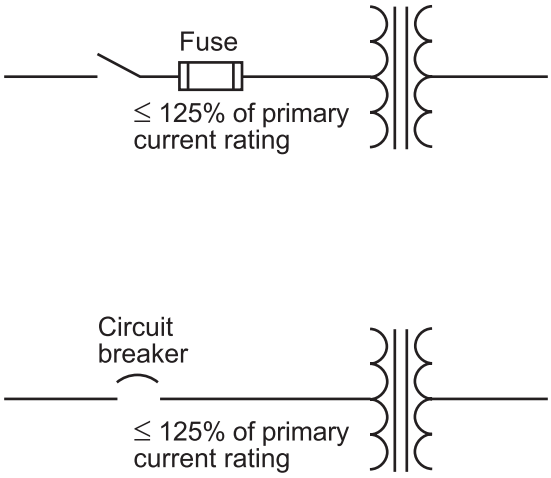


Figure 34—Individual primary overcurrent protection for dry-type transformers

If equipped with proper overcurrent protection on the secondary, the primary feeder overcurrent protection may replace the individual transformer primary overcurrent device. See Figure 35.

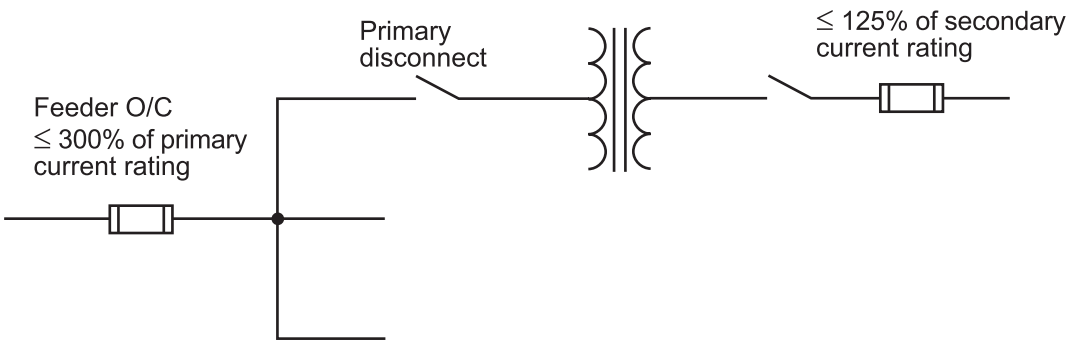


Figure 35—Feeder overcurrent protection for dry-type transformers

Rule 26-256(3) allows for an overcurrent device of the next higher standard to be used where 125% of the rated primary current does not correspond to the standard rating of the overcurrent device used.

Rule 26-262 Overcurrent protection of instrument voltage transformers

The main purpose for installing fuses in the primary circuits of instrument PTs (as described in Appendix B) is to protect the power system in the event of an insulation failure between primary and secondary windings within the transformer. These fuses must have adequate interrupting capacity for the power system that they are connected to. Generally, these fuses are 10 A maximum for low-voltage circuits and 3-A maximum for high-voltage circuits.

Rule 26-258 Conductor size for transformers

When sizing the conductors for a single transformer, the ampacity of both primary and secondary conductors is based on 125% of the rated transformer values.

Example 25: Figure 36 shows a 75-kVA, 600-V – 120-V/208-V, three-phase transformer. Determine:

a. the minimum ampacity for the primary conductors supplying this transformer

b. the minimum ampacity for the secondary conductors connected to this transformer

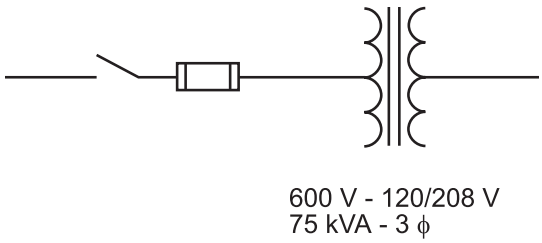


Figure 36—Three-phase transformer (Example 25)

Solution: a. The rated primary current calculates as:

$$I_p = \frac{75\,000\ \text{VA}}{\sqrt{3} \times 600\ \text{V}} = 72.2\ \text{A}$$

The ampacity required for the primary conductors equals:

$1.25 \times 72.2\ \text{A} = 90.2\ \text{A}$

b. The rated secondary current calculates as:

$$I_S = \frac{75\,000\,\text{VA}}{\sqrt{3} \times 208\ \text{V}} = 208.2\ \text{A}$$

The ampacity required for the secondary conductors equals:

$1.25 \times 208.2\ \text{A} = 260.2\ \text{A}$

In some instances, the primary and secondary conductors may be sized for the demand load, in which case they must be properly protected in accordance with Rules 14-100 and 14-104.

The following example demonstrates the various requirements for a transformer installation.

Example 26: You are required to supply a 120-V/208-V, 200-A, three-phase lighting panel from a 347-V/600-V, 400-A splitter supplied by a 400-A service. A delta-to-wye connected, dry-type, step-down transformer is to be used. All equipment is marked with a maximum conductor termination temperature of 60/75°C. The wiring method is to be R90 XLPE (600 V unjacketed) installed in EMT. Figure 37 shows a diagram of this application. Determine the following:

a. kVA rating of the transformer required for this application
- 45 kVA
- 50 kVA
- 75 kVA
- 100 kVA

b. rating of the primary overcurrent protection if required

c. rating of the secondary overcurrent device if required

d. sizes of the primary and secondary R90 XLPE (600-V unjacketed) copper conductors required

e. size of the primary disconnecting means required

f. sizes of the EMT required to contain the primary and secondary conductors

g. size of the grounding conductor required to ground the secondary AC system of the transformer

h. size of the interconnection conductor between the two grounding electrodes if a separate ground electrode is installed for the transformer

i. available fault current at the secondary terminals of the transformer if it has a 3% Z

Several solutions maybe used for this same problem. The following will be calculated without taking into account Rule 14-100.

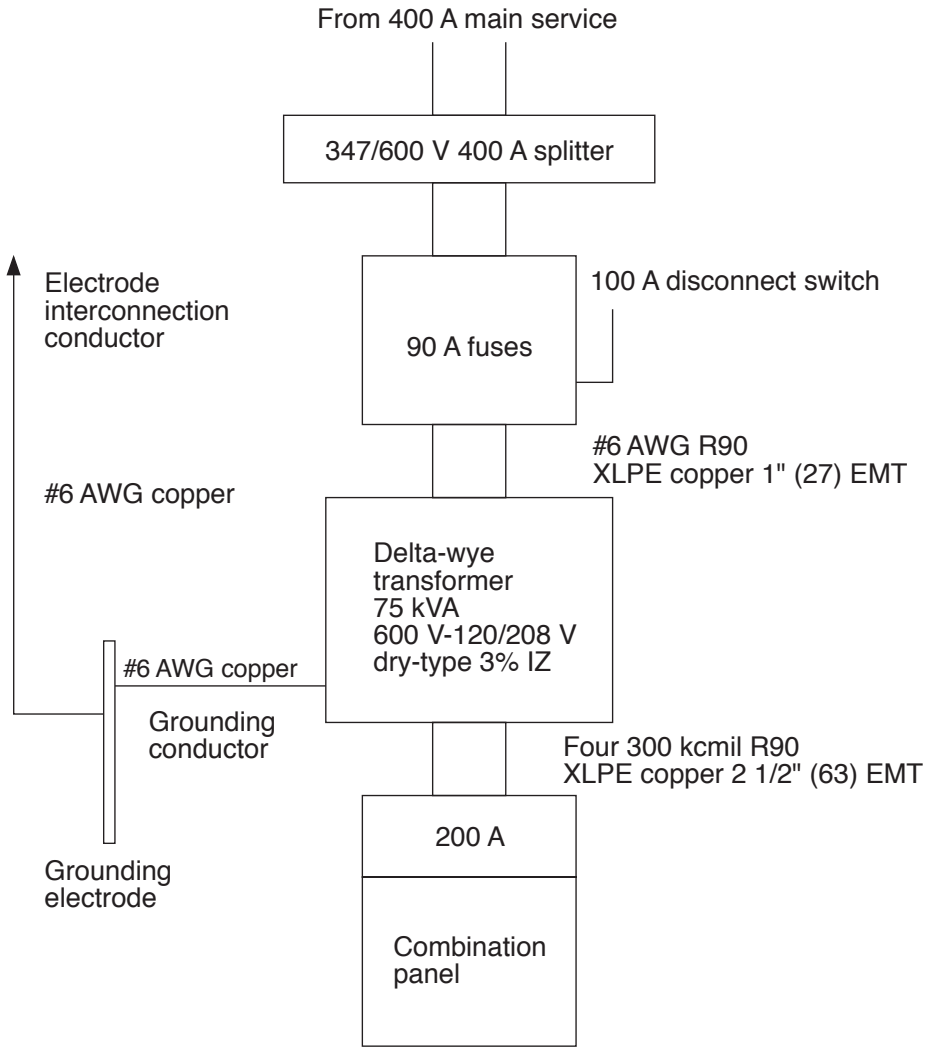


Figure 37—Transformer installation for three-phase lighting panel (Example 26)

Solution: a. First, calculate the required transformer rating. There is no specific rule for determining the load that may be placed on a transformer. However, the transformer should never be loaded to more than 100% of its rated current. Use the load current to determine the required VA rating of the transformer:

$$VA = \sqrt{3} \times E_L \times I_L$$

$$= \sqrt{3} \times 208\ V \times 200\ A$$

$$= 72053\ VA$$

The closest standard-size transformer that could handle this load is a 75 kVA transformer.

b. Rated primary and secondary current ratings for this transformer are as follows:

$$I_P = \frac{75\,000\ \text{VA}}{\sqrt{3} \times 600\ \text{V}} = 72\ \text{A}$$

$$I_S = \frac{75\,000\ \text{VA}}{\sqrt{3} \times 208\ \text{V}} = 208\ \text{A}$$

To calculate the size of the primary overcurrent protection, choose the rule that applies. This depends on a number of things:

- voltage rating of the transformer
- whether it is a dry-type or liquid-filled
- what other protective devices might be present in either the primary or secondary circuit

In this case the transformer is rated less than 750 V and has a dry-type construction, so Rule 26-256 applies.

The rating of the overcurrent device for the splitter exceeds 300% of the primary current rating of the transformer. Therefore, a separate overcurrent device must be installed in the primary circuit of the transformer. This is true whether or not an overcurrent device is installed in the secondary circuit.

This overcurrent device must have a rating not exceeding 125% of the rated primary current (IP) of the transformer:

72 A × 1.25 = 90 A

Since this corresponds to a standard fuse size, a 90-A fuse is required.

c. Rating or setting of the secondary overcurrent protection, if required:

The primary is to be protected by an overcurrent device rated at not more than 125% of the rated primary current. Therefore, no separate overcurrent protection is required on the secondary side of the transformer.

This is permitted as long as the primary overcurrent protection meets the requirements of Rules 26-256(1) and 26-256(3).

Notice that a 200-A combination panel (with 200-A main breaker) is used rather than just a 200-A panelboard. This is required by Rule 14-606(2). The main breaker is required to protect the 200-A busbars in the panelboard.

d. Rule 26-258 specifies that the ratings of both the primary and secondary conductors must be at least 125% of the transformer primary and secondary rating respectively:
   - primary conductor ampacity = 72 A × 1.25 = 90 A
   - secondary conductor ampacity = 208 A × 1.25 = 260 A
   - according to Rule 4-004, Rule 4-006 and Table 2, column 3 (75°C), the size of the primary conductors must be #3 AWG R90 XLPE (100-A) copper and the secondary conductors must be AWG 300-kcm R90 XLPE (285-A) copper, due to the equipment being marked with maximum conductor termination temperature of 75°C.

e. The primary disconnecting means must be large enough to house the 90-A fuse holders. The fused disconnect can serve as the disconnecting means required by Rule 26-250. Therefore a 100-A fused disconnect is required.

f. The conduit serves both as a raceway for the conductors and as a suitable bonding conductor for the transformer. Refer to Rule 10-814, Appendix B:
   - EMT for primary conductors will contain three #3 AWG (100-A) R90 XLPE (600-V unjacketed) copper conductors. Rule 12-910 and Table 6A specify a trade size 27 (1") EMT. (Rule 12-910 and Tables 10A, 8, and 9I require equivalent sizes.)
   - EMT for secondary conductors will contain four AWG 300-kcm (285-A) R90 XLPE (600-V unjacketed) copper conductors. Rule 12-910 and Table 6A specify a trade size 63 (2½") EMT. (Rule 12-910 and Tables 10A, 8, and 9I require equivalent sizes.)

g. To determine the size of the grounding conductor required to ground the secondary AC system of the transformer:
   - The secondary of the transformer is wye-connected and contains a neutral.
   - Rule 10-106 requires that this system be grounded.
   - Rule 10-206 requires that it be grounded either at the transformer or on the supply side of the first switch controlling the system.
   - Rule 10-210(c) requires that the neutral conductor be grounded.
   - Use Rule 10-812(a) or (b) to determine the size of the grounding conductor that both grounds the system and bonds the electrical equipment and raceways to ground. This requires a grounding conductor sized at #6 AWG if of copper or a #4 AWG if of aluminum.

h. The system may be grounded in one of two ways in accordance with Rule 10-206 and Appendix B:
   - The grounding conductor may be run all the way back to the main service ground electrode as shown in Figure 38.

- Alternatively, the grounding conductor may run to its own ground electrode. The two grounding systems must be interconnected by a conductor sized according to Rule 10-702(b). The size is #6 AWG if of copper, or #4 AWG if of aluminum. This is shown in Figure 39.

The ground conductor must run directly from the system to the ground electrode and be free of splices. Therefore, the ground conductor connection is made at the X0 terminal. A bonding conductor must then connect the transformer enclosure to this point, sized according to CEC Rule 10-814 (1). Therefore, using Table 16A, a #4 AWG copper or a #2 AWG aluminium bonding conductor would be required (based on the size of largest ungrounded conductor, which is 300 kcmil).

Note: Do **NOT** make the grounding connection to the enclosure and run to the X0 point with a separate required.

i. Available fault current at the secondary terminals of the transformer equals:

$$I_{Short-circuit} = \frac{I_{full-load}}{\%Z}$$

$$= \frac{208\,A}{0.03}$$

$$= 6933\,A$$

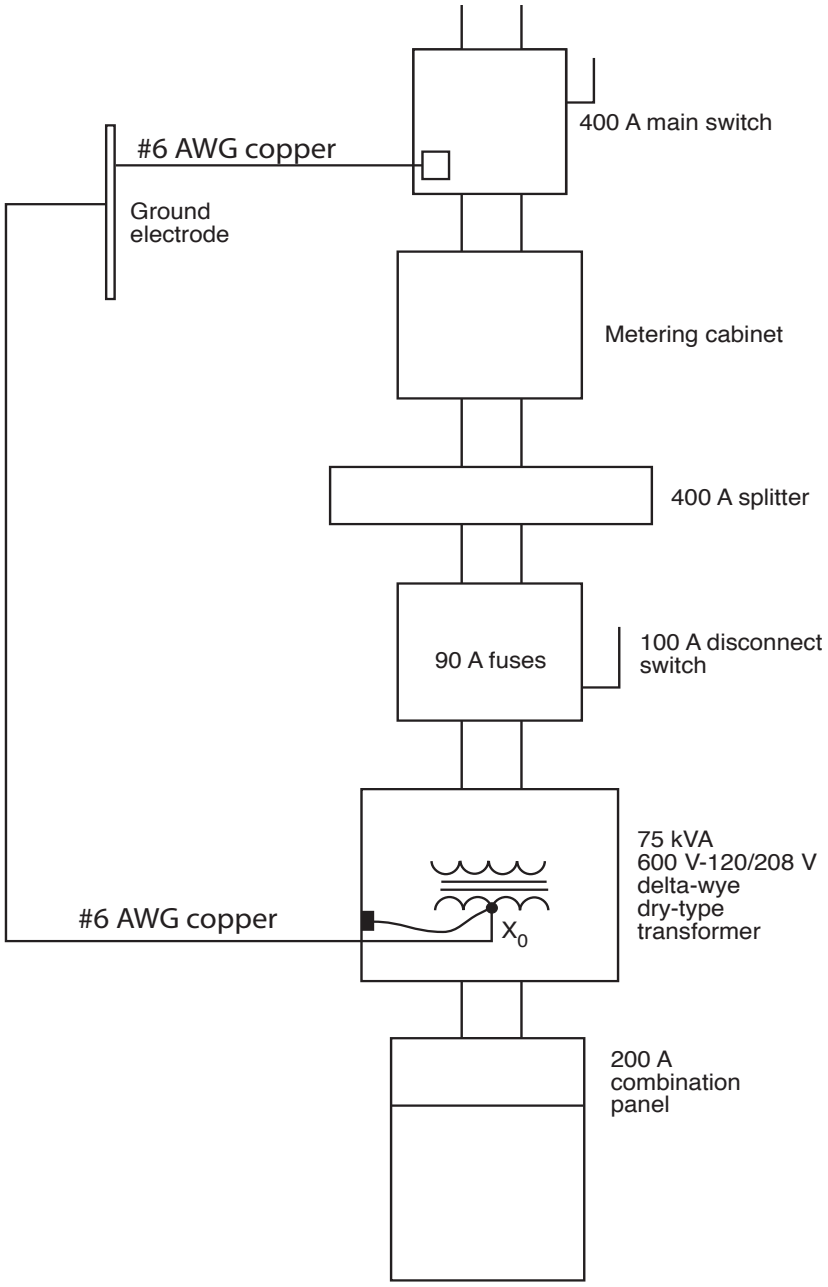


Figure 38—One ground electrode (Example 26)

Since the available fault current at the secondary terminals of the transformer is 6933 A, the circuit breaker in the combination panel must have an interrupting rating of at least 6933 A. In fact, the available fault current at the breaker would be slightly less due to the impedance of the secondary conductors.

Rule 14-012, Appendix B states that unless otherwise marked, circuit breakers rated 100 A or less and 250 V or less are considered to have an interrupting capacity of only 5000 A symmetrical, and circuit breakers rated above 100 A or above 250 V have a 10 000-A maximum symmetrical interrupting rating. Therefore, be careful in selecting 100-A breakers for this application. The interrupting rating of fuses is 10 000-A maximum unless otherwise marked.

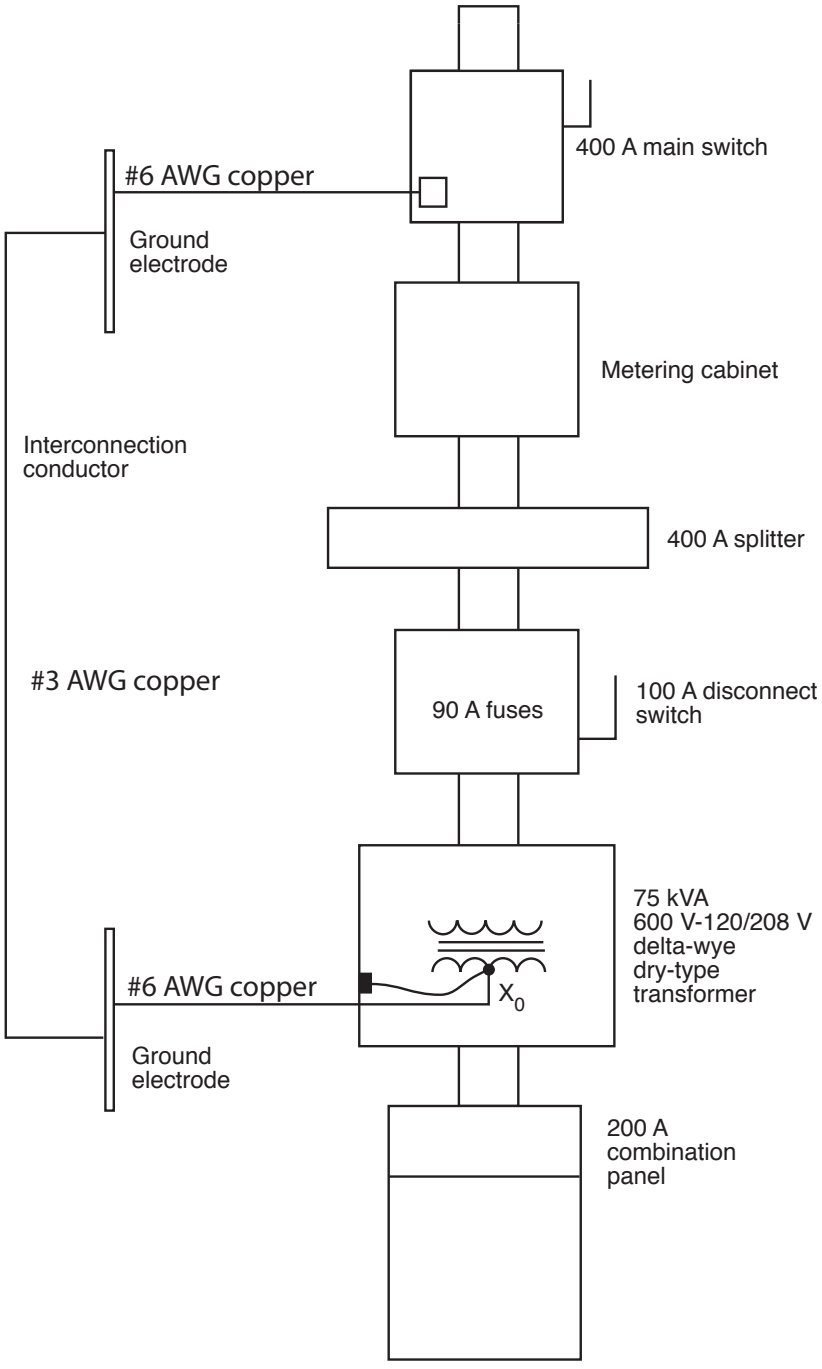


Figure 39—More than one ground electrode (Example 26)

Activity 5

If the transformer rated over 750 V in Figure 28 was a 225-kVA, 14.4 kV: 25 kV single-phase, step-up transformer, what difference (if any) of maximum overcurrent protection would there be on a fuse versus a circuit breaker?

If the other-than-dry-type of transformer in Figure 30 was a 37.5 kVA, 600 V: 240 V single-phase, step-down transformer, what difference (if any) of maximum overcurrent protection would there be on a fuse versus a circuit breaker?

Section 28, Motors and generators

Section 28 deals with the installation requirements for motors and generators. In this Learning Guide, you will be applying rules for motors that deal with the following:

- wiring methods and conductors
- overcurrent protection
- overload and overheating protection
- undervoltage protection
- control
- disconnecting means

Rules 28-100 to 28-112 Wiring methods and conductors

You must consider several factors in selecting the conductors supplying electric motors:

- The conductors must have sufficient ampacity for the load they are supplying. With a motor, this load may be higher than the rated full-load current of the motor. (Many motors are designed to handle overloads, determined by the service factor of the motor.)
- The current drawn by the motor during its starting period may be as high as six times the full-load current of the motor. If the motor is started frequently, this higher current can cause the branch circuit conductors to overheat.
- The insulation temperature rating must be high enough to handle the heat to which the conductor will be exposed. The insulation temperature rating of the conductors near the motor may have to be increased due to the heat produced by the motor itself.
- The type of insulation used must possess the mechanical resistance required by the type of service to which it will be subjected. For example, conductors supplying portable motors are less easy to protect from mechanical abuse than conductors supplying stationary motors.
- The length and size of the conductor must be sufficient to limit the line drop. This is the same for a motor circuit as it is for any other circuit. The resistance of the conductors causes a drop in voltage across the conductors. This may be reduced in longer runs by increasing the cross-sectional area of the conductors selected. Section 8 of the CEC specifies the maximum line drop permitted.

Rules 28-200 to 28-212 Overcurrent protection

The inrush current to a motor when it is being started may be as high as six times the full-load current of the motor. Therefore, the overcurrent protective device must be set at a current higher than the full-load current rating of the motor. Table 29 in the Code gives the maximum permitted percentage of full load at which the overcurrent device may be rated. This rating will vary with the type of overcurrent protection selected because of different response characteristics of overcurrent protection devices.



If the equipment is marked with its own rating requirements for overcurrent protective devices, this rating must not be exceeded (Rule 28-202).

Note too that branch circuits and feeders are treated differently when determining the rating of overcurrent devices.

Overcurrent protection will protect the motor and circuit components against damage by short-circuits. However, this will not provide protection against overloads or overheating.

Rules 28-300 to 28-318 Overload and overheating protection

This subsection deals with the types of overload protection permitted and the numbers and location required to provide proper protection of the motor.

- *Overloading* is caused by excessive mechanical load on the motor.
- *Overheating* may be caused by excessive current due to overload. It may also be caused by other things such as high ambient temperature around the motor or poor air circulation around the motor.

The subsection also deals with the safety aspects of the motor restarting automatically after the overload device has cooled down. In some cases (such as in sump pumps) automatic restart would likely be desirable. In other cases (such as on grinders or lathes) where there could be danger to people working close to the equipment, the automatic restart is not permissible (Rule 28-312).

When dealing with three-phase AC motors, you must provide current responsive elements (fuses or overload relays) in series with each of the three line conductors to the motor.

The rating, or trip, selection of overload devices depends upon the full-load current rating and the service factor on the motor nameplate. The service factor indicates how much overload the motor can withstand on a continuous basis.

Rule 28-400 Undervoltage protection

Magnetic motor control circuits may be divided into two categories:

- circuits that provide undervoltage or low-voltage *protection*
- circuits that provide undervoltage or low-voltage *release*

The Code tries to ensure that the proper type of protection is applied when it is required. *Undervoltage protection* involves a device that operates on the reduction or failure of voltage to cause and maintain the interruption of power to the main circuit. This type of circuit stops the motor when the voltage drops below a predetermined level and does not restart the motor automatically when the voltage rises again.

Undervoltage release involves a device that operates on the reduction or failure of voltage to cause interruption of power to the main circuit, but not to prevent its re-establishment on the return of voltage to a safe operating value. This type of circuit stops the motor when the voltage drops below a predetermined level but allows the motor to restart automatically when the voltage rises again. Both types of protection are shown in Figure 40.

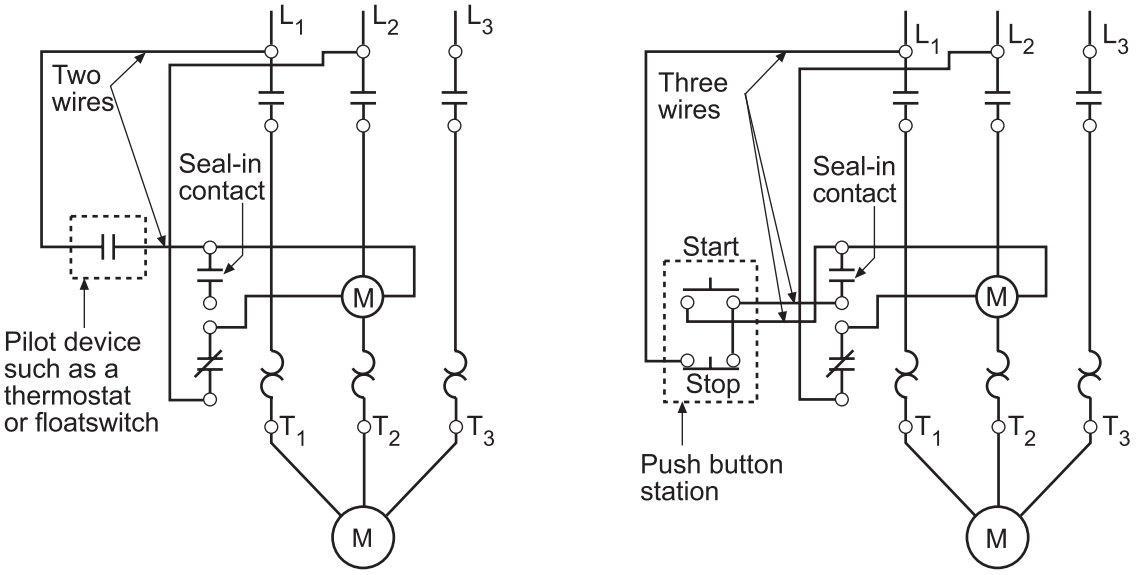


Figure 40—Undervoltage protection in two-wire and three-wire control circuits

Rules 28-500 to 28-506 Control

The starter or controller must be capable of safely starting and stopping the motor. This means it must be able to interrupt the locked rotor current of the motor. For this reason, the CEC requires that the starter or controller be horsepower-rated. Manufacturers' associations (both NEMA and EEMAC) set standards for starters and contactors. Each starter or contactor is given a size number that corresponds to a horsepower rating at a given supply voltage and number of phases. The table of starter sizes and hp ratings is not located in the Code and must be looked up in some other source such as suppliers' catalogues (see the example in Figure 41 on the following page).

There are a few exceptions listed in this subsection where starters or controllers are not required. The subsection also tries to ensure that the control equipment is installed so that the machinery it controls may be operated safely. Some motors have starting methods other than simply connecting the motor straight across the line and applying full voltage to the motor. The Code requires that these motor controllers never be left in the start position, as this could be damaging to the control equipment, the motor, or possibly the load itself.

NEMA Size	Continuous Ampere Rating	Maximum UL Horsepower					
		1-Phase		3-Phase			
		115 V	230 V	208 V	240 V	480 V	600 V
00	9	⅓	1	1½	1½	2	2
0	18	1	2	3	3	5	5
1	27	2	3	7½	7½	10	10
2	45	3	7½	10	15	25	25
3	90			25	30	50	50
4	135			40	50	100	100
5	270			75	100	200	200
6	540			150	200	400	400
7	810			200	300	600	600
8	1215			400	450	900	900

Figure 41—NEMA and EEMAC motor starter chart

When a control circuit receives its power from a grounded circuit, it is essential to safety that the control circuit components be so connected as to:

- avoid causing the motor to start
- prevent it from stopping

In the event of an accidental ground in the control wiring, refer to Rule 28-506.

Figure 42 shows how one wire connected in the wrong place could cause a hazardous situation in a grounded control circuit.

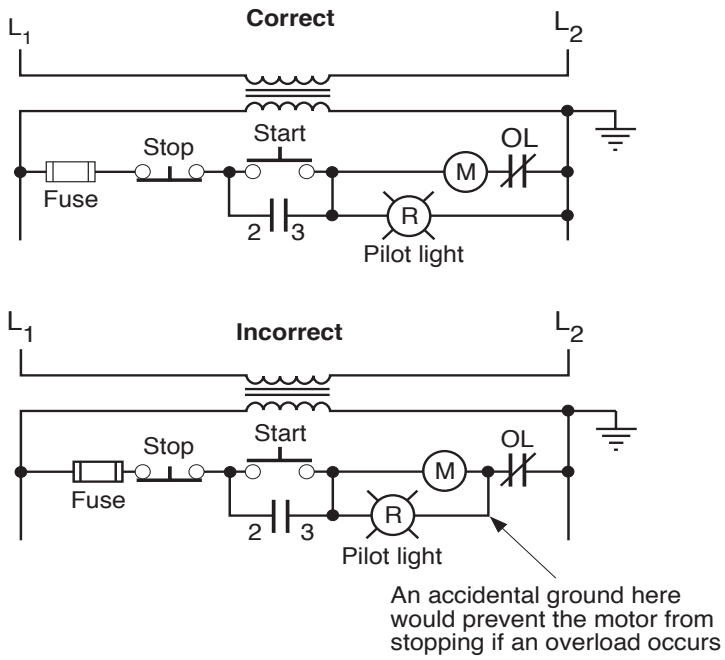


Figure 42—Correct and incorrect connection of control circuit components

Normally, there is very little chance of a ground taking place between the magnetic coil and the overload relay contacts, because they are located in the same enclosure. However, when the remote indicator light is added, the wires to this lamp are installed outside the enclosure and may be subjected to a possible ground connection. In this case, the connection would prevent the overload relay contacts from being able to stop the motor if an overload occurred.

Rules 28-600 to 28-604 Disconnecting means

A *disconnecting means* is a device, group of devices, or other means whereby the conductors of a circuit can be disconnected from their source of supply. It is used to provide safety when working on electrical equipment. Therefore, the disconnecting means must be installed where it is accessible or where the means for operating it is accessible.

This subsection deals with the types of disconnecting means permitted. It also deals with the location of the disconnecting means. The disconnecting means should be located within sight and within 9 m of the motor (and machinery it drives) and the controller. If this is not feasible, it must be capable of being locked in the open position and clearly labelled as to the equipment it supplies.

A disconnecting means is required for each motor branch circuit, each starter or controller, and each motor. However, one disconnecting means may provide more than one of three functions. If the disconnecting means is required to interrupt current, it should be horsepower-rated or capable of interrupting the locked rotor current of the motor. If it is not, it should be marked in such a way as to warn people not to try.

Note that a disconnecting means shall not be of a type that is electrically operated, either automatically or by remote control.

Appendix B in the CEC illustrates a "Diagram of Circuits, Control and Protective Devices for Motors." This riser diagram identifies rules that correspond to various components in motor circuits.

Example 27: Figure 43 shows a simplified motor branch-circuit riser diagram (Motor 1).

The specifications for Motor 1 are as follows:

- operates a slinger on the end of a conveyor
- operates in an ambient temperature not exceeding 30°C
- totally enclosed
- fan cooled
- to be operated on 480-V, three-phase system
- all equipment is marked with a maximum conductor termination temperature of 60/75°C.

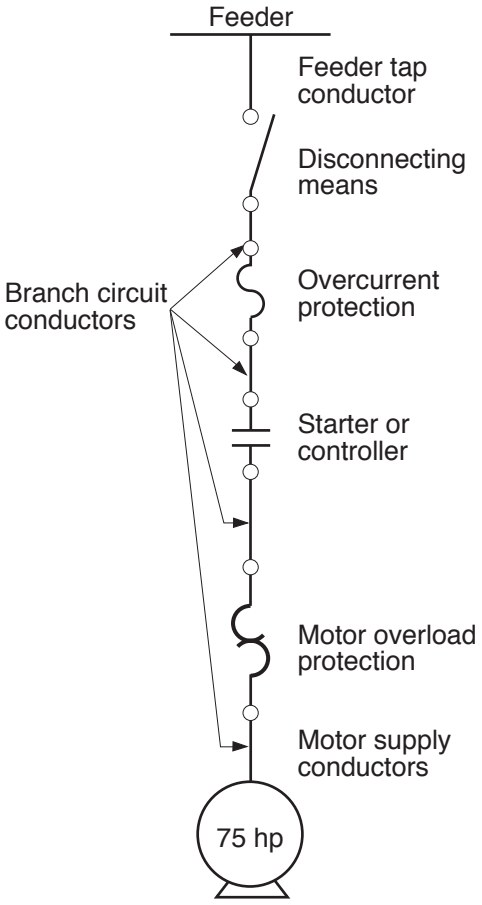


Figure 43—Simplified branch circuit riser diagram – Motor 1

In making the calculations described, refer to the Motor 1 nameplate shown in Figure 44.

Determine the following:

a. minimum ampacity of the branch circuit conductors (TW75 copper conductors are to be used)

b. minimum insulation temperature rating of the motor supply conductors

c. minimum size of the motor starter

d. maximum ampacity of the branch circuit overcurrent protection if non-time-delay fuses are used

e. maximum ampacity of the overload protection for the motor

f. rating of the branch circuit disconnect if the fused safety switch is to be used

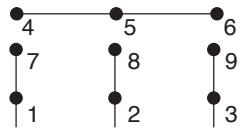
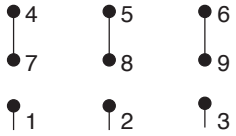
HIGH TORQUE ELECTRIC Cat # 13572468			
Hp 125	Frame 444TS	IJKL	Model
3 Phase	Cycle 60	F	Locked Kva Code
Volts 230/460	Design Class C	H	Ins. Class
Amps 312/156		40°C	Max. Ambient
Rpm 1740	Time Rating Cont.	1.15	Service Factor
Drive End Bearing			
Front End Bearing			
Serial Number 1235 - 4678			
 Lower Voltage Line	AC Motor	 High Voltage Line	

Figure 44—Motor 1 nameplate

Solution: a. Minimum ampacity of the branch circuit conductors

The branch circuit conductors are those conductors between the last overcurrent device in the circuit and the motor.

Rule 28-106(1) applies here. The branch circuit conductors shall have an ampacity of 125% of the full-load current rating. The full-load current rating of the motor is taken from the motor nameplate at 96 A. If this is not available, the full load current rating may be looked up in Table 44 of the Code using the horsepower rating of the motor and its rated voltage.

$1.25 \times 96\ \text{A} = 120\ \text{A}$

It is stated in the problem that TW75 copper conductors are to be used for the branch circuit conductors. Table 2 requires a #1 AWG conductor.

Since the motor supply conductors are a part of the branch circuit, they must also have a minimum ampacity rating of 120 A. However, the insulation temperature rating may be higher.

b. Minimum insulation temperature rating of the motor supply conductors

Motor supply conductors are those conductors that actually enter the motor terminal box. They are considered to be a part of the branch circuit conductors but have a special rule (Rule 28-104) dealing with their insulation temperature rating and ampacity.

The motor produces heat when it is operating because of such things as copper and core losses. The conductors that enter the connection box on the motor or pass in close proximity to the motor are subjected to this heat. Therefore, when determining the required insulation temperature rating of these conductors, this heat must be taken into consideration.

Rule 28-104 determines not just the insulation temperature rating of the conductors, but also how far away from the motor these conductors must extend before the insulation temperature rating may be reduced. The insulation temperature rating takes into account the insulation class of the motor and the ambient temperature of the surrounding air.

Both Rule 28-104 and Table 37 apply.

First, find the insulation class on the motor nameplate. In this case it is Class F. In Table 37 find the column headed F. Next, find the row corresponding to the type of motor enclosure the motor has and follow this across to the Class F column to determine the minimum insulation temperature rating. The details listed for Motor 1 describe the motor as totally enclosed and fan-cooled.

Table 37 requires a 90°C insulation temperature rating. Since the details show that the ambient temperature will not exceed 30°C, no further increase in insulation temperature is required.

The conductors used here could be #1 R90 XLPE where the ampacity is based on 75°C insulation (130 A) in accordance with Rule 28-104(1).

In accordance with Rule 28-104(2) these #1 R90 XLPE motor supply conductors must be a minimum of 1.2 m long and terminate in a location not less than 600 mm from any part of the motor, as shown in Figure 45. Ahead of this location, the conductors could be of less expensive TW75 copper.

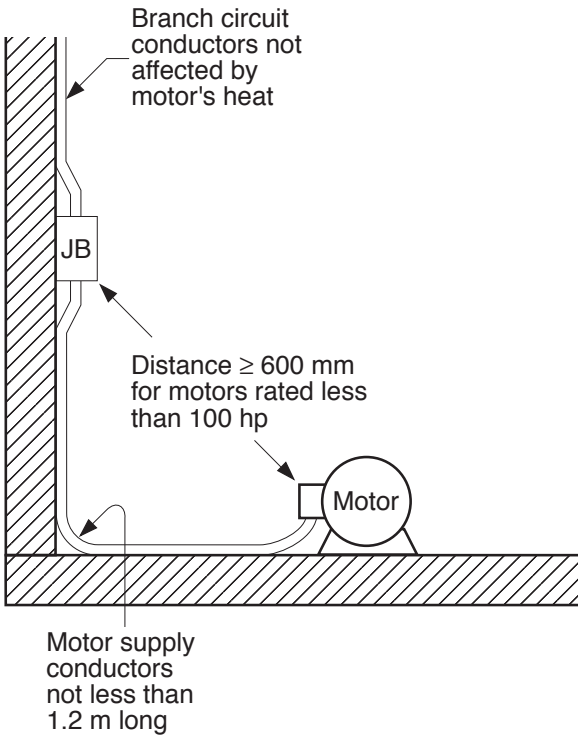


Figure 45—Length and termination distance for motor supply conductors

If the motor had been 100 hp or larger, the R90 XLPE conductors would have had to terminate not less than 1.2 m from any part of the motor.

c. Minimum size of the motor starter

Rule 28-500 requires that the motor have a motor starter or controller for starting and stopping it with a horsepower rating not less than the rating of the motor it serves.

Magnetic starters and contactors are sized for motor loads using the NEMA/EEMAC standards (see Figure 41 in this learning task).

If the motor is rated at 75 hp and 460 V, three-phase, this application would require a size 4 starter.

d. Maximum ampacity of the branch circuit overcurrent protection if non-time-delay fuses are used

Rule 28-200(a) requires that Table 29 be applied to the rated full-load current of the motor to determine the maximum permitted rating for the branch circuit overcurrent device. Table 29 requires that the full load current be multiplied by 300%.

$$96\ \text{A} \times 3.00 = 288\ \text{A}$$

Since this is the maximum rating permitted and it is not a standard-size fuse, you must select the next lowest standard size: a 250-A fuse. Table 13 lists the standard sizes of fuses and circuit breakers.

Rule 28-200(e) would allow an increase in the maximum permitted rating for the branch circuit overcurrent device to 400% of full-load current only if 300% will not permit the motor to start.

e. Maximum ampacity of the overload protection for the motor

In accordance with Rule 28-306(1), both the full-load current rating of the motor and its service factor are required to determine the rating or trip selection of the overload device. Since the service factor on this motor is listed at 1.15, the rating or selection shall be not more than 125% of the full-load current of the motor.

$96\ A \times 1.25 = 120\ A$

f. Rating of the branch circuit disconnect if the fused safety switch is to be used

Switches are available with both 250-V and 600-V ratings. The common current ratings are 30, 60, 100, 200, 400, 600, 800, and 1200 A. However, the 600-V switches are hp-rated at 240 V, 480 V, and 600 V.

Rule 28-602(1)(a) requires that the fused safety switch be a motor circuit switch with a horsepower rating not less than that of the motor it serves.

In addition, Rule 28-208 requires that the fuseholders in the switch be large enough to accommodate fuses of the maximum rating permitted in Table 29.

In this case the disconnecting means would be a 400-A, 600-V motor circuit switch rated for at least 7 hp at 480 V, three-phase. The next smaller switch available is a 200-A switch, which would not have fuseholders large enough for the 250-A fuse.

Figure 46 shows the completed motor branch circuit riser for Motor 1.

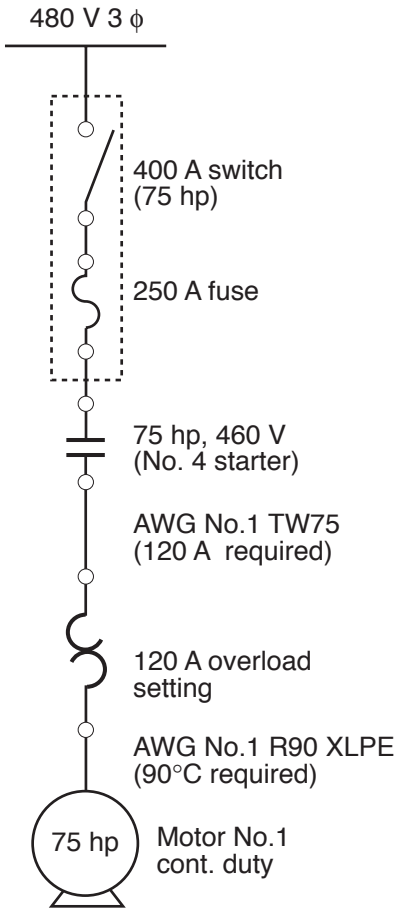


Figure 46—Motor 1 branch circuit riser

Example 28: The simplified motor branch-circuit riser diagram previously shown in Figure 43 also applies to Motor 2.

The specifications for Motor 2 are as follows:

- operates an air compressor
- operates in an ambient temperature that may be as high as 35°C
- open type
- to be operated on 480-V, three-phase system
- all equipment is marked with a maximum conductor termination temperature of 60/75°C.

In making the calculations described, refer to the Motor 2 nameplate shown in Figure 47.

Determine the following:

a. minimum ampacity of the branch circuit conductors (TW75 copper conductors are to be used)

b. minimum insulation temperature rating of the motor supply conductors

c. minimum size of the motor starter

d. maximum ampacity of the branch circuit overcurrent protection if non-time-delay fuses are used

e. maximum ampacity of the overload protection for the motor

f. rating of the branch circuit disconnect if the fused safety switch is to be used

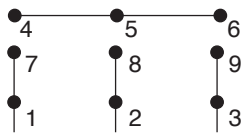
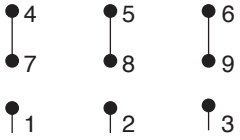
HIGH TORQUE ELECTRIC Cat # 12345678					
Hp	20	Frame	254T	ABCD	Model
	3 Phase	Cycle	60	F	Locked Kva Code
Volts	230/460	Design Class B		B	Ins. Class
Amps	54/27			40°C	Max. Ambient
Rpm	3480	Time Rating Cont.			Service Factor
Drive End Bearing					
Front End Bearing					
Serial Number	3579 - 8642				
 Lower Voltage Line		AC Motor		 High Voltage Line	

Figure 47—Motor 2 nameplate

Solution: a. Minimum ampacity of the branch circuit conductors

The branch circuit conductors are those conductors between the last overcurrent device in the circuit and the motor.

Rule 28-106(1) applies here. The full-load current rating of the motor is taken from the nameplate at 27 A.

$27 \text{ A} \times 1.25 \div 0.94 = 35.9 \text{ A}$

It was stated in the problem that TW75 copper conductors are to be used for the branch circuit conductors. Table 2 requires a TW75 #8 AWG conductor.

Since the motor supply conductors are part of the branch circuit, they must also have a minimum ampacity rating of 33.75 A. The insulation temperature rating, however, may be higher.

b. Minimum insulation temperature rating of the motor supply conductors

Motor 2 is an open type, rated with insulation Class B. In accordance with Rule 28-104, use this information to look up the required insulation temperature rating for the motor supply conductors in no more than a 30°C ambient temperature. Table 37 requires a minimum 75°C insulation rating for the supply conductors.

Note that the ambient temperature around the motor is 35°C. This means that, in accordance with Rule 28-104(3), the minimum insulation temperature will have to be increased by at least the difference between 30°C and 35°C. This makes the minimum insulation temperature:

75°C + (35°C – 30°C) = 80°C
27 A × 1.25 = 33.75 A

The conductors used here could be #10 R90 XLPE (35 A), where the ampacity is still based on 75°C insulation in accordance with Rule 28-104(1).

c. Minimum size of the motor starter

In this case, the motor is rated at 20 hp and 460 V, three-phase. This application would require a size 2 starter. (See Figure 41 in this learning task.)

d. Maximum ampacity of the branch circuit overcurrent protection if non-time-delay fuses are used

Rule 28-200(a) and Table 29 require that the full-load current be multiplied by 300%.

27 A × 3.00 = 81 A

Since this is the maximum rating permitted, and it is not a standard-size fuse, you must select the next lowest standard size: an 80-A fuse. (Table 13 lists the standard sizes of fuses and circuit breakers.)

Rule 28-200(e) would allow an increase in the maximum permitted rating for the branch circuit overcurrent device to 400% of the full-load current only if 300% will not permit the motor to start.

e. Maximum ampacity of the overload protection for the motor

Rule 28-306(1)(b) applies here, since no service factor is listed on the nameplate.

27 A × 1.15 = 31.05 A

f. Rating of the branch circuit disconnect if the fused safety switch is to be used

Rule 2-602(1)(a) requires that the fused safety switch be a motor circuit switch with a horsepower rating not less than that of the motor it serves.

In addition, Rule 28-208 requires that the fuseholders in the switch be large enough to accommodate fuses of the maximum rating permitted in Table 29.

In this case the disconnecting means would be a 100-A motor circuit switch rated for at least 20 hp at 480 V, 600 V three-phase. The next smaller switch available is a 60-A switch, which would not have fuseholders large enough for the 80-A fuse.

Figure 48 shows the completed motor branch circuit riser for Motor 2.

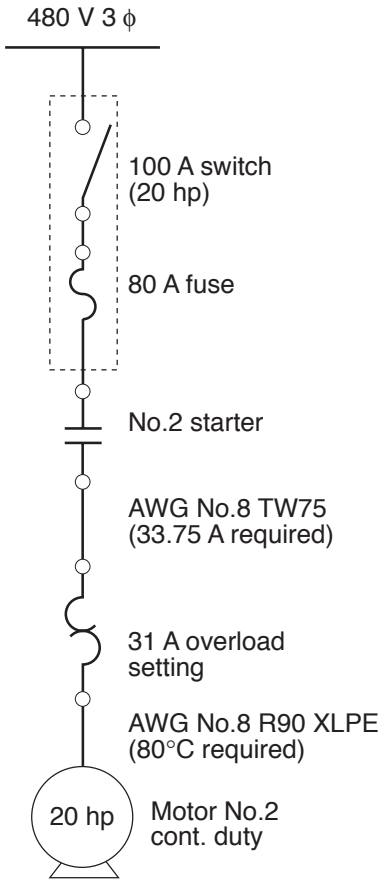


Figure 48—Motor 2 branch circuit riser

Example 29: The simplified motor branch-circuit riser diagram previously shown in Figure 43 also applies to Motor 3.

The specifications for Motor 3 are as follows:

- operates a conveyor
- operates in an ambient temperature that will not exceed 30°C
- totally enclosed, fan cooled
- to be operated on 480-V, three-phase system
- all equipment is marked with a maximum conductor termination temperature of 60/75°C

In making the calculations described below, refer to the Motor 3 nameplate shown in Figure 49.

Determine the following:

a. minimum ampacity of the branch circuit conductors (TW75 copper conductors are to be used)

b. minimum insulation temperature rating of the motor supply conductors

c. minimum size of the motor starter

d. maximum ampacity of the branch circuit overcurrent protection if non-time-delay fuses are used

e. maximum ampacity of the overload protection for the motor

f. rating of the branch circuit disconnect if the fused safety switch is to be used

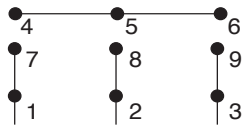
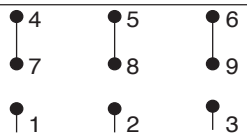
HIGH TORQUE ELECTRIC Cat # 13572468					
Hp	125	Frame	444TS	IJKL	Model
	3 Phase	Cycle	60	F	Locked Kva Code
Volts	230/460	Design Class C		H	Ins. Class
Amps	312/156			40°C	Max. Ambient
Rpm	1740	Time Rating Cont.		1.15	Service Factor
Drive End Bearing					
Front End Bearing					
Serial Number	1235 - 4678				
 Lower Voltage Line		AC Motor		 High Voltage Line	

Figure 49—Motor 3 nameplate

Solution: a. Minimum ampacity of the branch circuit conductors

Rule 28-106(1) applies here. The full-load current rating of the motor is taken from the nameplate at 156 A.

$156\ A \times 1.25 = 195\ A$

It was stated in the problem that TW75 copper conductors are to be used for the branch circuit conductors. Table 2 requires a #3/0 AWG TW75 conductor.

Since the motor supply conductors are part of the branch circuit, they must also have a minimum ampacity rating of 195 A. However, the insulation temperature rating may be higher.

b. Minimum insulation temperature rating of the motor supply conductors

Motor 3 is a totally enclosed, fan-cooled type and is rated with insulation Class H. In accordance with Rule 28-104, use this information to look up the required insulation temperature rating for the motor supply conductors in no more than a 30°C ambient temperature. Table 37 requires a minimum 110°C insulation rating for the supply conductors.

c. Minimum size of the motor starter

In this case, the motor is rated at 125 hp and 480 V, three-phase. This application would require a size 5 starter. (See Figure 41 in this learning task.)

d. Maximum ampacity of the branch circuit overcurrent protection if non-time-delay fuses are used

Rule 28-200(a) and Table 29 require that the full-load current be multiplied by 300%.

$156\ \text{A} \times 3.00 = 468\ \text{A}$

Since this is the maximum rating permitted and it is not a standard size of fuse, you must select the next lower standard size: a 450-A fuse. Table 13 lists the standard sizes of fuses and circuit breakers.

Rule 28-200(e) would allow an increase in the maximum permitted rating for the branch circuit overcurrent device to 400% of the full-load current only if 300% will not permit the motor to start.

e. Maximum ampacity of the overload protection for the motor

Rule 2-306(1)(a) applies here, since a 1.15 service factor is listed on the nameplate.

$156\ \text{A} \times 1.25 = 195\ \text{A}$

f. Rating of the branch circuit disconnect if the fused safety switch is to be used

Rule 28-602(a) requires that the fused safety switch be a motor circuit switch with a horsepower rating not less than that of the motor it serves. However, switches are not horsepower-rated higher than 100 hp, three-phase, and 50 hp, single-phase. If the motor rating is higher than these ratings, Rule 28-602(3) applies. In this case, the switch serves as an isolating switch and must have a current rating not less than 115% of the full-load current rating of the motor it serves. As well, the switch must be plainly marked in accordance with Rule 26-100(2) so as to make it unlikely that it will be operated under load.

Rule 28-208 requires that the fuseholders in the switch be large enough to accommodate fuses of the maximum rating permitted in Table 29.

This application would require the disconnecting means to be a 600-A, 600-V, three-phase safety switch. The next smaller switch available is rated for 400 A. While this switch would be of sufficient size to meet the 115% requirement of Rule 28-602(3), it would not have fuseholders large enough for the 450-A fuse.

Figure 50 shows the completed motor branch circuit riser for Motor 3.

You must also be able to apply the Code in determining the installation requirements for a feeder supplying more than one motor. The following example utilizes the motors used in the previous three examples.

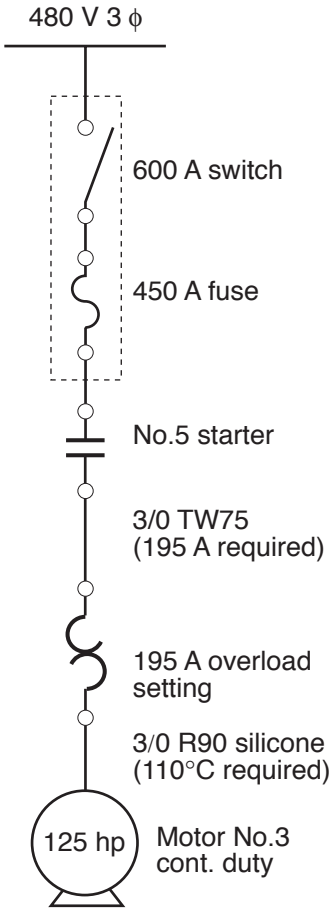


Figure 50—Motor 3 branch circuit riser

Example 30: Figure 51 shows a riser diagram for a feeder supplying three motors. The three motors are all classified and rated continuous service. Once again, all equipment is marked with a maximum conductor termination temperature of 60/75°C. To complete the riser the following must be determined:

a. minimum ampacity of the feeder conductors (TW75 copper is to be used)

b. maximum ampacity of the feeder overcurrent protection if non-time-delay fuses are used

c. minimum rating of the feeder disconnect

d. size and restrictions of feeder tap conductors. (Use TW75 copper.)

Solution: a. Minimum ampacity of the feeder conductors

Rule 28-18(1)(a) applies here because the feeder supplies continuous-duty service motor loads only. The three full-load currents (FLA) of the motors are:

Motor 1 96 A
Motor 2 27 A
Motor 3 156 A

According to the rule, you must add 125% of the largest full-load current of the motor to the full-load currents of the other motors being fed by the same feeder.

$$(156\ \text{A} \times 1.25) + 96\ \text{A} + 27\ \text{A} = 318\ \text{A}$$

The minimum feeder conductor ampacity is 318 A. According to Table 2, a 400-kcmil TW75 conductor is required.

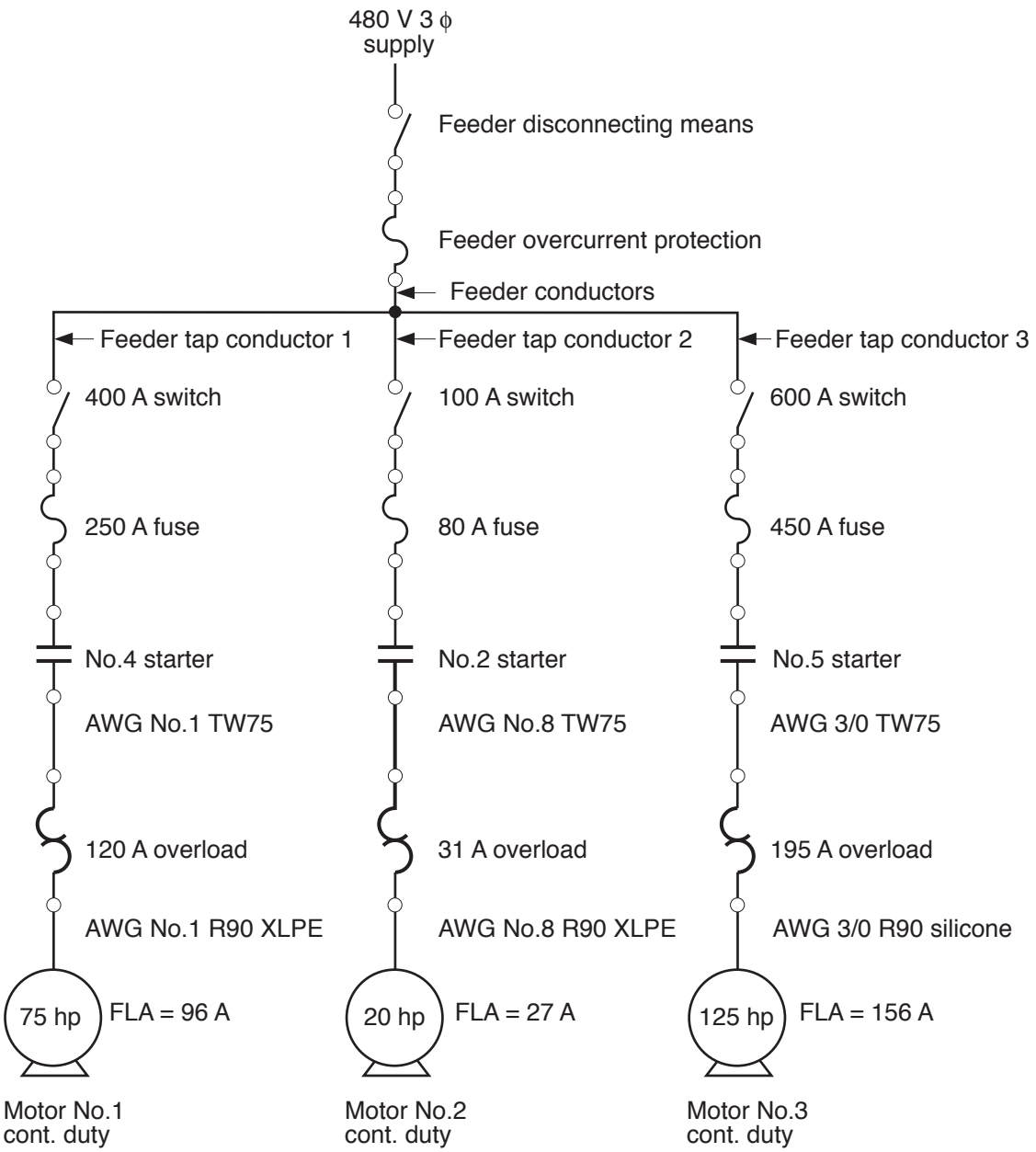


Figure 51—Riser for motors 1, 2, and 3.

b. Maximum ampacity of the feeder overcurrent protection if non-time-delay fuses are used

Rule 28-204(1) applies here because the feeder supplies motor branch circuits only and none of the motors is required to start simultaneously.

First, you must determine which of the motors is permitted the highest rated overcurrent device. The rating of this device is added to the full-load current ratings of the other motors. The maximum non-time-delay fuse rating permitted for Motor 3 was 450 A (156 A × 300% = 468 A).

468 A + 96 A + 27 A = 591 A

Since this is the maximum rating permitted and is not a standard size of fuse, the next lower standard-size fuse must be selected. This is a 500-A fuse. (Table 13 lists the standard sizes of fuses and circuit breakers.)

c. Minimum rating of the feeder disconnect

There is no specific rule in Section 28 dealing with the feeder disconnect. However, it must comply with Rules 14-010 (b), 14-402 and 28-208.

A fused safety switch rated at 600-A, 600-V, three-phase will meet the requirements of these three rules by:

i. disconnecting all ungrounded conductors simultaneously at the point of supply (Rule 14-010(b))
ii. providing a disconnecting means, integral with the fuseholders (Rule 14-402)
iii. providing fuseholders with the proper rating for the fuses required (Rule 28-208).

d. Size and restrictions of feeder tap conductors

A *feeder tap* is the conductor between the main feeder and a branch circuit overcurrent protective device. There are three feeder taps in this system, one between the feeder and each motor branch circuit overcurrent device. These taps are labelled on the diagram in Figure 45.

In accordance with Rule 28-110(2), the feeder tap conductors must have an ampacity not less than that of the feeder unless the tap meets one or both of the following requirements:

i. The feeder tap does not exceed 3 m in length and is enclosed in metal.
ii. The feeder tap does not exceed 7.5 m in length, has an ampacity not less than one-third that of the feeder and is suitably protected from mechanical damage.

If the requirements of (a) above are met, the feeder tap conductors may have the same ampacity as the branch circuit conductors the tap is supplying.

If the requirements of (b) above are met, the feeder tap conductors may have an ampacity of the larger of the following:

- the ampacity of the branch circuit conductors the tap is supplying
- one-third the ampacity of the feeder

The ampacity of the feeder is considered to be the ampere rating of the feeder overcurrent protection or the ampacity of the feeder conductors, whichever is smaller. See Rule 8-104(1). In this case, the feeder ampacity would be the 335-A ampacity of the 400-kcmil TW75 conductors, since this is lower than the 500-A feeder overcurrent device rating.

Feeder Tap 1 Feeder Tap 1 must have an ampacity of:

- 335 A (400 kcmil TW75 copper) if it does not meet the requirements of Rule 28-110(2)(a) or (b)
- 120 A (#1 AWG TW75 copper) if it meets the requirements of Rule 28-110(2)(a). **Note:** The branch circuit ampacity was calculated previously, using Rule 28-106(1).
- 120 A (#1 AWG TW75 copper) if it meets the requirements of Rule 28-110(2)(b). Note that one-third the ampacity of the feeder is 112 A (335 A · ⅓). This is lower than the ampacity of the branch circuit, so the branch circuit ampacity is used.

Feeder Tap 2 Feeder Tap 2 must have an ampacity of:

- 335 A (400 kcmil TW75 copper) if it does not meet the requirements of Rule 28-110(2)(a) or (b)
- 33.75 A (#8 AWG TW75 copper) if it meets the requirements of Rule 28-110(2)(a). **Note:** The branch circuit ampacity was calculated previously, using Rule 28-106(1).
- 112 A (#2 AWG TW75 copper) if it meets the requirements of Rule 28-110(2)(b). Note that one-third the ampacity of the feeder is 112 A (335 A · ⅓). This is higher than the ampacity of the branch circuit, which is 33.75 A.

Feeder Tap 3 Feeder Tap 3 must have an ampacity of:

- 335 A (400 kcmil TW75 copper) if it does not meet the requirements of Rule 28-110(2)(a) or (b).
- 195 A (3/0 TW75 copper) if it meets the requirements of Rule 28-110(2)(a). **Note:** The branch circuit ampacity was calculated previously, using Rule 28-106.
- 195 A (3/0 TW75 copper) if it meets the requirements of Rule 28-110(2)(b). Note that one-third the ampacity of the feeder is 112 A (335 A · ⅓). This is lower than the ampacity of the branch circuit conductor, so the branch circuit ampacity is used.

Activity 6

If Motor 1 in Example 27 (Figure 46) was for use in a varying duty service with a 30-minute rating, what difference (if any) would be required of its **branch** circuit minimum conductor size and/or its maximum overcurrent protection?

If Motor 1 in Example 30 (Figure 51) was for use in a varying duty service with a 30-minute rating, what difference (if any) would be required of the feeder circuit minimum conductor size and/or the **feeder** circuit maximum overcurrent protection?

Synchronous motors

The application of the Code to the installation of synchronous motors is essentially the same as for squirrel-cage induction motors. However, you should be aware of two footnotes in the following tables:

- Table 44, Footnote 3
- Table 29, Footnote 1

Table 44 is used as a guide to determine the full-load current ratings of three-phase motors when the motor nameplate data is not available. For synchronous motors, the values listed are for "unity PF" type. If the motor operates at a power factor less than unity, then the values listed in the table will have to be increased accordingly.

Table 29 is used to determine the maximum rating of overcurrent devices for motor circuits. When installing synchronous motors of the low-torque, or low-speed type, then the rating of the overcurrent device should not exceed 200% of the full-load current.

Example 31: If a 200-hp, 575-V, synchronous motor is rated for 168 A at unity power factor (according to Table 44), what is its full-load current rating if operated at:

a. 90% leading PF?
b. 80% leading PF?

Solution:

a. From Table 44, Footnote 3, the current must be adjusted by a factor of 1.1 for an operating power factor between 90% and 100%. Therefore:

   168 A × 1.1 = 184.8 A at 90% PF

b. From Table 44, Footnote 3, the current must be adjusted by a factor of 1.25 for an operating power factor between 80% and 90%. Therefore:

   168 A × 1.25 = 210 A at 80% PF

Wound-rotor motors

A wound-rotor induction motor is normally started with resistance inserted in its secondary (rotor) circuit. As a result, the starting inrush current in the primary circuit is significantly reduced, and the rating of the overcurrent device may also be reduced (see Table 29). Since wound-rotor motors are often used in "different classifications of service," you must refer to Table 27 for other than continuous-duty ratings.

Figure 52 illustrates a one-line diagram for a wound-rotor motor circuit.

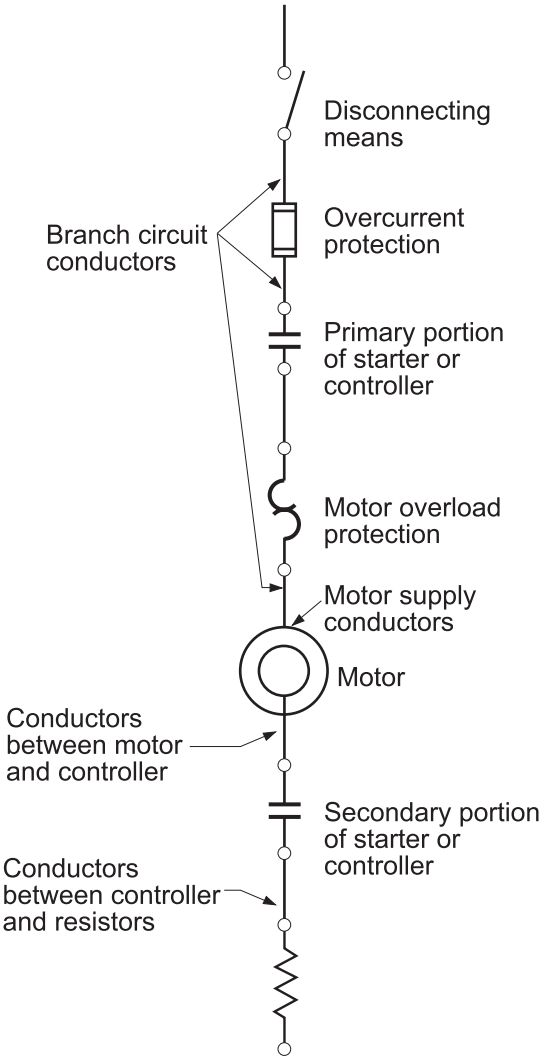


Figure 52—One-line diagram for wound-rotor motor circuit

Rule 28-112 deals specifically with the secondary (rotor) conductors for wound-rotor motors. This rule deals with the secondary conductors between:

- the rotor and the controller
- the controller and the secondary resistors

The conductors between the rotor and the controller are essentially sized in accordance with Rule 28-106, as for other motors. See Figure 53.

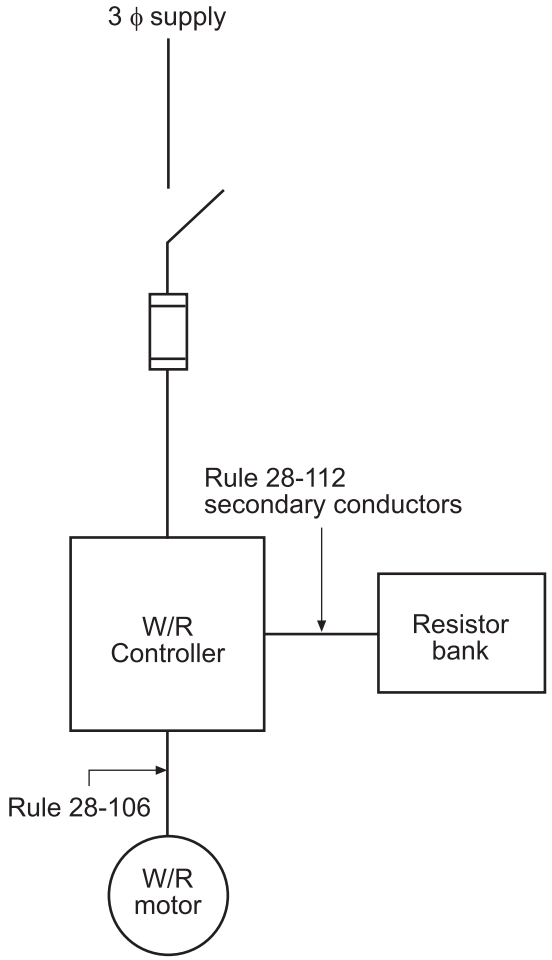


Figure 53—Secondary conductors for wound-rotor motors

The conductors between the controller and the resistor bank are sized by using Table 28. This considers the inrush current of the rotor as well as the duty classification of the resistors used.

Hermetic refrigerant motor compressors

Hermetic refrigerant motor compressors are sealed units in that both compressor and motor are sealed together in one housing. The atmosphere around the motor is the refrigerant, which is used to cool the motor. Therefore, the motor operates in a very low ambient temperature.

Because it operates in a very low ambient temperature, the motor may be overloaded beyond its rated capacity, which permits the manufacturers to reduce the physical size of these units. For example, a 7½ hp motor may be used where a 10 hp motor would otherwise be needed.

These motor compressors must be marked with both rated full-load current and rated locked-rotor current. They are not normally rated in horsepower, since there is tremendous variation between the current ratings for a given horsepower rating of motor.

Selection of equipment used in circuits supplying hermetic refrigerant motor compressors is based on either the full-load current rating or the locked-rotor current rating of the motor, because the horsepower rating does not give a good indication of what the actual current ratings would be.

Where the full-load current rating is not marked on the equipment nameplate, it may be looked up in Table 44 or 45 using the horsepower rating. Table 44 is for polyphase equipment and Table 45 is for single-phase equipment.

When the locked-rotor current rating is not marked on equipment, it may be calculated by multiplying the full-load current rating six times.

Conductor ampacity

The conductor ampacity is determined in the same way as for any other motor. It is generally based on 125% of the full-load current rating.

Overcurrent protection

The rating or setting of the overcurrent protection is based on the locked-rotor current rating of the motor. Normally it must not exceed 50% of the locked-rotor current rating, but if this will not allow the motor to start, the maximum rating may be increased to 65%.

Overload protection

These types of motors are designed to withstand overloads of 140%, which is higher than regular motors. Rule 28-710 allows a rating or setting of not more than 140% of the full-load current rating of the motor if an overload relay is used. However, if other types of overload protection are used, the maximum rating or setting must not exceed 125% of the full-load current rating.

Control equipment

Control equipment must have both a marked full-load current rating and marked locked-rotor current rating not less than that of the motor compressor. In all other respects, the control equipment is the same as for other motors.

Disconnecting means

Disconnecting means must have a continuous-duty current rating of at least 115% of the full-load current rating of the motor compressor and an interrupting capacity at least equal to the locked-rotor current rating of the motor compressor.

If the disconnect also serves other loads, it must have a continuous-duty current rating equal to 115% of the motor compressor having the largest load plus the full-load currents of all the other loads. As well, it must have an interrupting capacity at least equal to the locked-rotor rating of the motor compressor with the largest locked-rotor rating.

Reduced-voltage starting

Reduced-voltage starting is used where full-voltage starting may cause problems. Since reducing the starting voltage reduces the current, the main function of the reduced-voltage starter is to lower the inrush current drawn by induction motors. Commonly, all deviations

from full-voltage starting have been placed in the category of reduced-voltage starting. Not all starting schemes grouped under this method actually reduce the voltage at the motor terminals; however, they all reduce the line current during starting.

Note: See Table 29 for the setting of overcurrent devices using reduced-voltage starters.

Rule 28-504 Starters having different starting and running positions

Since the controller is used for starting and stopping the motor, it must be adequately rated for the motor it serves. The Code states that

> "magnetic starters having different starting and running positions shall be constructed so that they cannot remain in the starting position under normal operating conditions."

This rule must be observed for reduced-voltage starters.

Rules 28-800 to 28-812 Multi-winding and part-winding start motors

Multi-winding motors include dual-voltage motors and multi-speed (consequent pole) motors. Some dual-voltage motors may be started as part-winding motors.

Each connection configuration of multi-winding motors draws a different current from the source. Rule 28-804 ensures that the conductors supplying the controller have sufficient ampacity for the largest current to which they will be subjected. Since the conductors between the controller and the motor may not be subjected to such high current, they may be reduced in size so that they only have sufficient ampacity for the current to which they will be subjected. The size of these conductors is to be based on Rule 28-106.

The overcurrent devices in the circuit are designed to protect the conductors from overcurrents. Since the conductors on the motor side of the controller may be smaller than those on the supply side of the controller, separate overcurrent protection may be required on the motor side of the controller. Rule 28-806 deals with the overcurrent protection.

Since each winding configuration draws a different current from the source, separate overload protection may be required for each different connection. Rule 28-808 deals with overload protection.

Rule 28-810 deals with the controls for the motors. The controls must be either horsepower-rated or rated for the locked-rotor current of the motor it supplies. The controls must also be interlocked so that it not possible to energize the motor in more than one configuration simultaneously.

As with other motors, a disconnecting means is required for the motor and its controls. The same disconnecting means may serve both purposes. This disconnecting means must have a continuous-current rating equal to or exceeding that of the highest full-load current rating for any configuration the motor will be connected at. Where the disconnecting means is required to be horsepower-rated or rated for the locked-rotor current, it must be rated for the highest possible in any of the configurations.

Dual-voltage motors are normally connected in a "permanent configuration" to one supply. The Code states that, in this case, the motor shall be treated as a single-winding motor with ratings that correspond to the winding configuration used. See Rule 28-802.

Multi-winding motors

Figure 54 shows a nameplate from a dual-voltage motor. If it is connected properly to a three-phase 480-V supply, it must be treated as a 460-V motor with a full-load current of 96 A. If it is connected properly to a three-phase, 240-V supply, it must be treated as a single-voltage 230-V motor with a full-load current of 192 A.

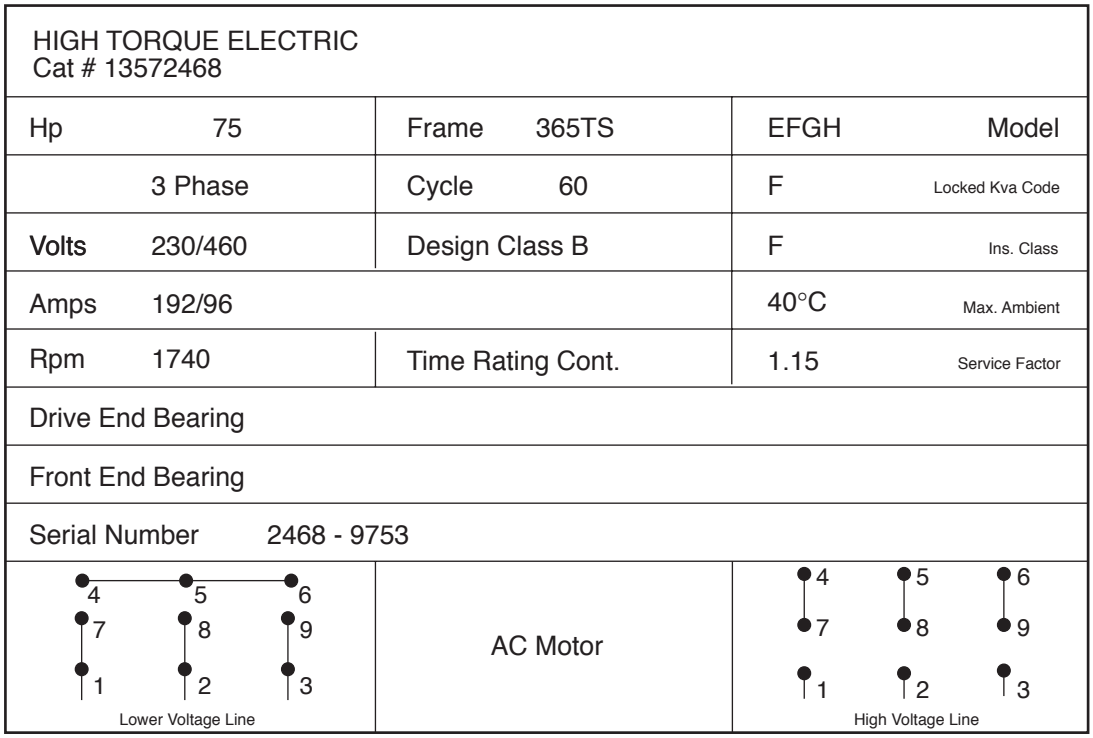


Figure 54—Nameplate from a dual-voltage motor

Section 30, Installation of lighting equipment

By now, you are aware that three-phase systems are used extensively for electrical power distribution. Since its introduction, lighting equipment has been possibly the largest user and most commonly found load device using electrical energy. We use electricity to provide light everywhere.

A brief review of lighting with respect to three-phase systems follows.

Rule 30-102 Voltage

By restricting voltages to 150 volts-to-ground in dwelling units, and voltages in other than dwelling units to 600 V/347 V, the Code serves the purpose of safety. Since only trained and qualified persons are intended to work on electrical equipment, the restricting voltage limits the availability of the unqualified person to come into contact with electrical circuits and danger.

Rule 30-104 Protection

The higher voltage-to-ground in commercial and industrial circuits is considerably dangerous. This is supported by the restrictions on dwelling units.

This rule limits the branch circuit overcurrent protection as follows:

- Subrule (b): over 347 volts-to-ground to15 amps
- Subrule (c): up to 347 volts-to-ground to 20 amps
- Subrule (d): to 40 amps as listed in the Code

Limiting the overcurrent device limits any excessive current flow that can generate heat, causing fires and equipment damage.

Rule 30-302 Supports

In larger installations, lighting designs and requirements sometimes need substantially sized fixtures. Care is required to ensure that light fixtures are supported adequately so that they don't fall. Some concerns are seismic restraint, building vibration and physical weight of light fixtures.

Rule 30-310 Luminaries as a raceway

In many commercial installations, light fixtures marked for continuous-row mounting are designed to be connected together to provide uniform light in a large area. This provides a raceway integral with the fixtures for the wiring. Here, it must be recognized that lighting ballasts produce heat and have high secondary voltages. Rule 30-310 requires that voltage and temperature ratings are satisfied.

Balanced three-phase, four-wire circuits are used to provide more than one circuit in the area. Two reasons for this are:

- failure of one circuit will not result in complete lighting blackout in that area
- higher efficiencies in copper and equipment utilization

Rule 30-412 Tap connection conductors

When the lighting circuit overcurrent device is 20 A, you can tap off the branch circuit conductor with a #14 AWG conductor. This can only be done, however, with a few restrictions, including the following:

- The rating of the luminaire or luminaires does not exceed the rating of the tap conductor.
- The tap conductor is not more than 7.5 m in length. (**Note:** This 7.5 m tap is just like using Rule 14-100.)

Rule 30-710 Control

When working with three-phase installations, it is common to find electric discharge lighting. Remember that discharge lighting uses ballasts. Ballasts are inductors with the ability to store and release energy when they are switched. Arcing wear on switch contacts is the result, so we must watch out for this when using switches, breakers and contactors.

Note: See Appendix B. When using 347-V switches, the mounting boxes must be larger than standard device boxes.

Rule 30-712 Branch circuit capacity

Electric discharge lighting at 1000 V or less may load the circuit overcurrent device to 80% of the rating. The loading is based on the rating of the fixture and not on the watts of the lamp. Again, you find that the general rule, 8-104, is followed.

Section 62, Electric heating systems

Electric heating systems are most commonly connected as single-phase loads. These single-phase loads are, however, supplied by three-phase systems in commercial and industrial installations.

The Scope of Section 62 mentions that heating systems are provided for pipe heating applications. This would be considered when:

- installing heat tracing to prohibit freezing of plumbing systems in unheated areas in buildings or outdoors
- fluid or gas viscosity is a criteria or a concern in industrial locations

Following are some other rules for consideration.

Rule 62-104 Special terminology

Special definitions are provided to clarify the different systems or heating units covered in this section.

Rule 62-110 Branch circuits

Generally, heating equipment is kept separate from other circuits, with special attention given at terminations where the supply conductors will not be damaged by the heat produced.

Rule 62-114 Overcurrent protection and grouping

Subrule 3 states that when in locations other than residential occupancy (i.e., commercial and industrial), the branch circuit overcurrent devices may be rated at 60 A. Some heating loads are three-phase supplied; examples are a central unit or a kiln.

Note: If heat fixtures are configured as a balanced three-phase load (wye or delta), then overcurrent devices larger than 60 A may be used.

Subrule 6 considers heating loads to be continuous loads. As a result, the overcurrent protection and conductor requirements are patterned after Rule 8-104, where:

- If the overcurrent device is marked for 100% continuous operation, the load can be 100% of the device rating.

The conductor must be rated not less than the load (load amps = device rating = conductor ampacity).

Example 32: Figure 55 shows a 40-kW, 240-V, three-phase heater circuit. If the overcurrent device being used is a circuit breaker marked for 100% continuous operation and marked with a maximum conductor termination temperature rating of 75°C, determine the following:

a. the circuit breaker setting

b. the size of type R90 XLPE copper conductor required

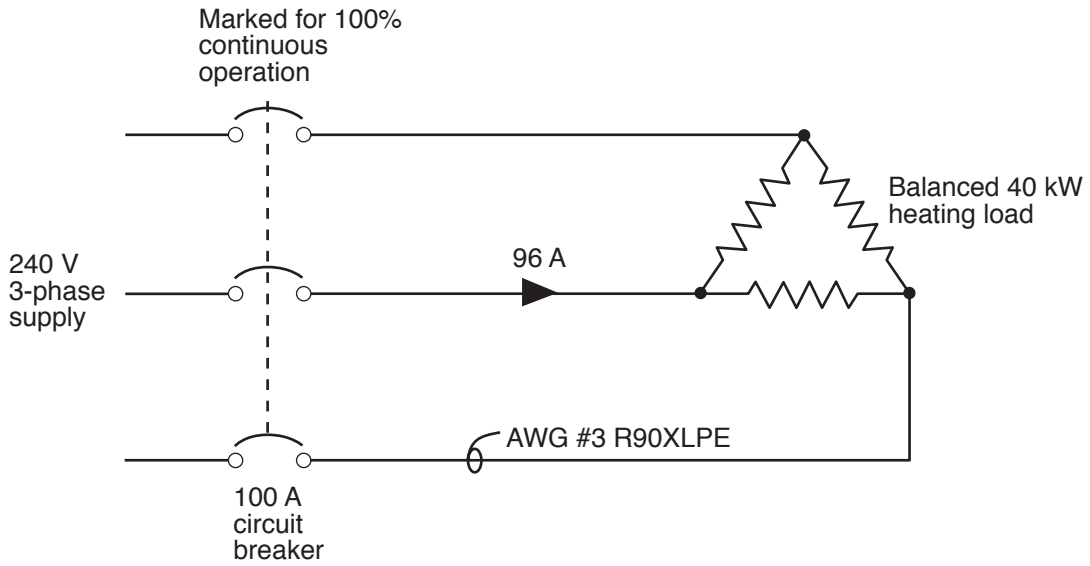


Figure 55—Three-phase, balanced resistance heating load

Solution: a. The line current calculates as:

$$\frac{40\,000\ \text{W}}{\sqrt{3}\times 240\,\text{V}} = 96\ \text{A}$$

From Rule 62-114(6)(a): With a 96-A load, we can use a 100-A circuit breaker when the breaker is marked for 100% continuous operation.

b. From Rule 62-114(7)(a): The conductor ampacity must not be less than the load, i.e., 96 A. From Table 2, using the 75° column for the R90 XLPE, we would require 3# AWG (rated 100 A).

More commonly:

- If the overcurrent device is not marked or is marked for continuous operation at 80%, then the load can be only 80% of the overcurrent device rating.
- The conductor ampacity must be at least 80% of the overcurrent device (80% overcurrent device rating = load amps = 80% conductor ampacity).

Example 33: Figure 56 shows a 40-kW, 240-V, three-phase heater circuit. If the overcurrent device is a circuit breaker not marked for 100% continuous operation but is marked with a maximum conductor termination temperature rating of 75°C, determine the following:

a. the circuit breaker setting

b. the size of type R90 XLPE copper conductor required

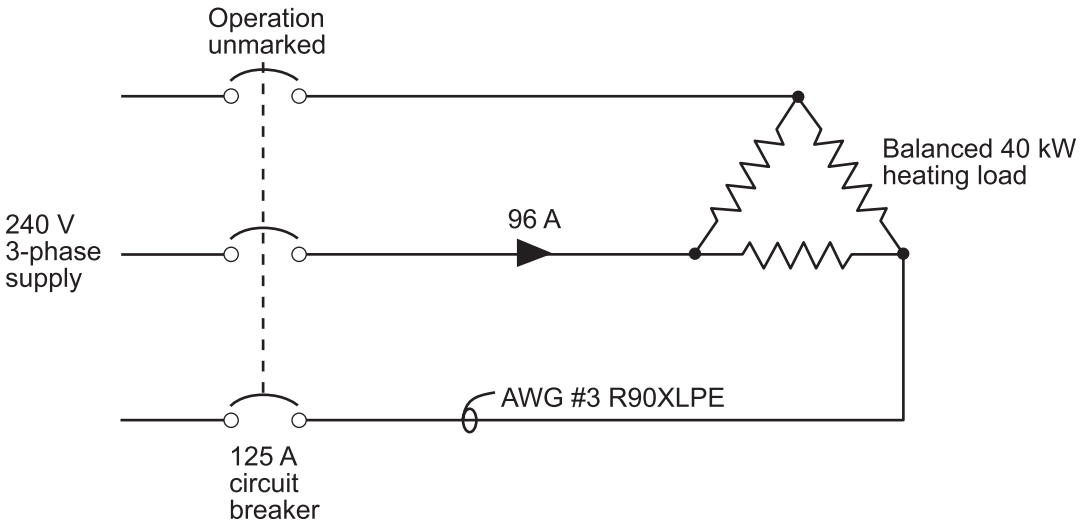


Figure 56—Three-phase, balanced resistance heating load

As in the preceding example, the line current calculates to 96 A.

Solution: a. From Rule 62-114(6)(b): We can only load the circuit breaker to 80% of its setting; i.e., 96 A load = 80% × O/C setting. Therefore, we would require O/C setting = 96 A ÷ 0.8 = 120-A "calculated" circuit breaker size.

We would use a standard-size 125-A circuit breaker.

b. From Rule 62-114(7): The conductor ampacity must satisfy the load requirement and must be at least the circuit breaker setting of 125 A · 80% = 100 A.

From Table 2, using the 75° column for the R90 XLPE, we would require #3 AWG (rated 100 A).

Subrule 8 permits the overcurrent device to be increased to the next higher standard value for some circuits where the 80% conductor loading does not correspond with a standard overcurrent device. If this rule is utilized, the conductor would not be required to be 80% of the rating of the circuit breaker, but it must not be less than the load.

Now do Self-Test 1 and check your answers.

Self-Test 1

In answering each of the following questions, also identify the applicable Rule(s).

1. Three copper conductors with RW90 XLPE 600-V unjacketed insulation are to be installed in a single conduit to supply a demand load of 150 kW, 480 V, three-phase with a maximum ambient temperature of 40 °C. What is the minimum conductor size permitted by Code?

2. What is the minimum size conduit for the three conductors in Question 1?

3. What is the minimum size electrical metallic tubing for the three conductors in Question 1?

4. Three copper conductors with RW90 XLPE 600-V unjacketed insulation are to be installed in a single conduit to supply a demand load of 150 kW, 480 V, three-phase with a maximum ambient temperature of 40°C. If this load was fed from a circuit breaker with a maximum conductor termination temperature rating of 75°, what is the minimum conductor size permitted by the Code.

5. A 120/208-V three-phase 100 A load centre, that is not marked, is fed with copper AC90 from a three-pole circuit breaker that is marked with a 75°C termination temperature rating. What is the

   a. minimum size copper R90 XLPE branch circuit conductors required

   b. maximum overcurrent ampacity allowed

6. A three-phase feeder supplies a neutral demand load of 1000 A, of which 300 A is discharge lighting. Calculate the minimum ampacity permitted for the neutral conductor.

7. A three-phase four-wire splitter is tapped to supply a single-phase, three-wire circuit. What is the name given to the neutral in this application?

8. A certain three-phase induction motor requires a separate bonding conductor to be installed in raceway. The motor disconnect contains three 600 A fuses for overcurrent protection, and there are three 225 A overload devices in the motor controller. The three line conductors to the motor are #4/0 AWG copper R90 XLPE. What is the minimum size of copper bonding conductor permitted?

9. Are bonding conductors necessary on expansion joints for rigid steel conduit?

10. What is the minimum size of copper grounding conductor required for a 400 A, three-phase, three-wire delta service which uses TECK 90 cable?

11. What is the minimum size of copper grounding conductor required for a three-phase, four-wire service which uses TECK 90 cable with a demand load of 355 A?

12. Determine the minimum size of electrical metallic tubing for three #3/0 AWG R90 XLPE (with jacket) and one #2 AWG bare copper bonding conductor.

13. If the conduits contain #4 AWG or larger conductors, calculate the minimum length "A" required for the pull box shown in Figure 1.

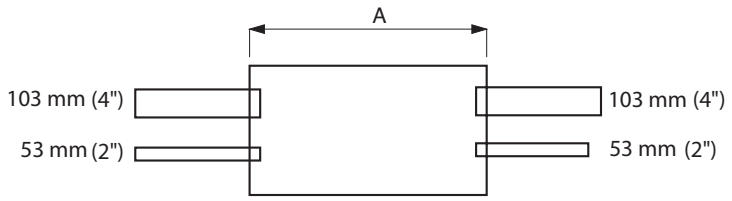


Figure 1—Diagram for Question 13

14. If the conduits in Figure 2 contain #4 AWG or larger conductors, calculate the minimum dimensions "A", "B", and "C" required for Figure 2.

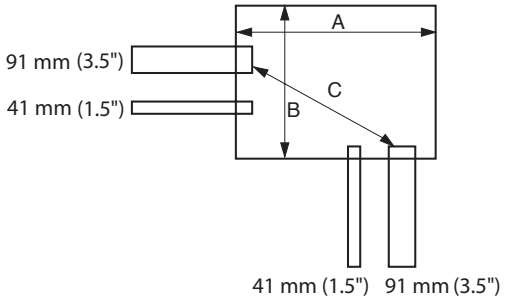


Figure 2—Diagram for Question 14

15. A branch circuit supplies a three-phase capacitor bank rated at 18 kVAR, 480 V. What is the minimum conductor ampacity required to supply this capacitor bank?

16. What is the maximum fuse size (standard) permitted for the branch circuit in Question 15?

17. What are two important considerations when installing PF capacitors directly at the motor terminals?

18. What is the maximum (standard) fuse size permitted for a 150-kVA, 600-V – 120 V/208 V, liquid-filled transformer with no secondary overcurrent protection?

19. What is the maximum (standard) fuse size permitted for a 75-kVA, 480-V – 120 V/208 V, dry-type transformer with no secondary overcurrent protection?

20. What is the maximum current rating of a fuse used to protect the primary of a 600-V – 120 V potential (metering) transformer?

21. A 75-kVA, 600-V – 277-V/480-V, dry-type transformer is fed from a splitter protected by a 200 A overcurrent device. The secondary conductors are protected by 110-A fuses. Does the transformer require its own overcurrent device in the primary circuit?

22. What is the minimum size of TW75 copper conductors that may be used to supply a 37.5-kVA, 600-V – 120-V/208-V, dry-type transformer? (All equipment is marked with a maximum conductor termination temperature of 60/75°C.)

23. Two oil-filled transformers are supplied by a common feeder. The ratings of the transformers are:

    - 75 kVA, 600V – 120 V/208 V
    - 30 kVA, 600V – 277 V/480 V

    What is the minimum size of TW75 aluminum conductors that may be used for the primary feeder? (All equipment is marked with a maximum conductor termination temperature of 60/75°C.)

24. You are required to install a 120-V/208-V, 100-A, three-phase lighting panel from a 277-V/480-V, 200-A splitter on the load side of a 200-A fuse (Figure 3). You are to use a delta-to-wye, dry-type transformer. The wiring method is TW75 copper installed in EMT, and all equipment is marked with a maximum conductor termination temperature of 60/75°C.

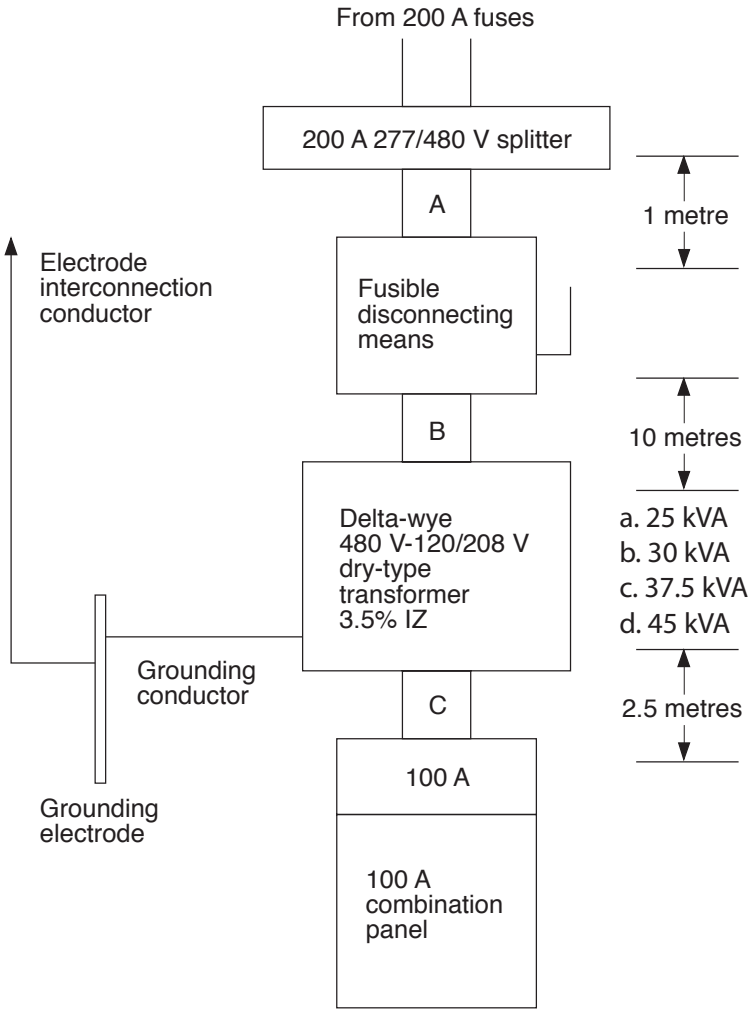


Figure 3—Circuit diagram for Question 24

Determine the:

a. kVA (standard) rating of transformer required (a. b. c. or d. in Figure 3)

_____

b. rating of the secondary overcurrent protection, if required

_____

c. rating of the primary overcurrent (standard) fuse, if required

_____

d. size of the primary disconnect means

_____

e. size of primary and secondary TW75 copper conductors required at points A, B and C in Figure 3

f. sizes of EMT at points A, B and C in Figure 3

g. size of grounding conductor to ground the secondary AC system of the transformer

h. size of the inter-connection conductor between the two grounding electrodes if a separate ground electrode is installed for the transformer

i. the calculated available fault current at the secondary terminals of the transformer.

25. Table 37 provides the insulation requirements of motor supply conductors based on the motor enclosure and _____ .

26. What Table in the CEC sets the maximum rating/setting of overcurrent devices used to protect DC motor branch circuits?

27. Where the full-load current rating is not available, which Table in the CEC would you use to determine the FLA for a:
    a. DC motor?
    b. Single-phase AC motor?
    c. Three-phase AC motor? _____

28. Motor 1 has the following specifications:
    - drives a conveyor
    - operates in a 30°C ambient
    - is totally-enclosed, fan-cooled
    - operates on a 600-V, three-phase system
    - has continuous service classification
    - all equipment is marked with a maximum conductor termination temperature of 60/75°C

    Determine the following from the Motor 1 nameplate shown in Figure 4:

    a. minimum size of copper TW75 branch circuit conductors

    _____

    b. minimum insulation temperature rating of the motor supply conductors

    _____

    c. maximum non-time delay fuse (standard) size for overcurrent protection

    _____

    d. maximum setting of overload protection for the motor

    _____

    e. rating of branch circuit disconnect (fused safety switch).

    _____

HIGH TORQUE ELECTRIC Cat # 13572468		
Hp 20	Frame 256T	EFGH Model
3 Phase	Cycle 60	F Locked Kva Code
Volts 575	Design Class C	F Ins. Class
Amps 22		40°C Max. Ambient
Rpm 1740	Time Rating Cont.	1.15 Service Factor
Drive End Bearing		
Front End Bearing		
Serial Number 2468 - 9753		
	AC Motor	

Figure 4—Motor 1 nameplate for Question 28

29. Motor 2 has the following specifications:
    - drives a pump
    - operates in a 40°C ambient
    - is an open type
    - operates on a 600-V, three-phase system
    - has continuous service classification
    - all equipment is marked with a maximum conductor termination temperature of 60/75°C.

    Determine the following from the Motor 2 nameplate shown in Figure 5:

    a. minimum size of copper TW75 branch circuit conductors

    _____

    b. minimum insulation temperature rating of the motor supply conductors

    _____

    c. maximum non-time delay fuse (standard) size for overcurrent protection

    _____

    d. maximum setting of overload protection for the motor

    _____

    e. rating of branch circuit disconnect (fused safety switch).

    _____

HIGH TORQUE ELECTRIC Cat # 13572468			
Hp 10	Frame 215T	EFGH	Model
3 Phase	Cycle 60	F	Locked Kva Code
Volts 575	Design Class B	F	Ins. Class
Amps 11		40°C	Max. Ambient
Rpm 1740	Time Rating Cont.	1.15	Service Factor
Drive End Bearing			
Front End Bearing			
Serial Number 2468 - 9753			
	AC Motor		

Figure 5—Motor 2 nameplate for Question 29

30. Motor 3 has the following specifications:
    - drives a freight elevator
    - operates in a 30°C ambient
    - is an open type
    - operates on a 600-V, three-phase system
    - has intermittent-duty service classification
    - all equipment is marked with a maximum conductor termination temperature of 60/75°C

    Determine the following from the Motor 3 nameplate shown in Figure 6:

    a. minimum size of copper TW75 branch circuit conductors

    _____

    b. minimum insulation temperature rating of the motor supply conductors

    _____

    c. maximum non-time delay fuse (standard) size for overcurrent protection

    _____

    d. maximum setting of overload protection for the motor

    _____

    e. rating of branch circuit disconnect (fused safety switch).

    _____

HIGH TORQUE ELECTRIC Cat # 13572468					
Hp	30	Frame	286T	EFGH	Model
	3 Phase	Cycle	60	F	Locked Kva Code
Volts	575	Design Class C		F	Ins. Class
Amps	32			40°C	Max. Ambient
Rpm	1740	Time Rating 30 min		1.15	Service Factor
Drive End Bearing					
Front End Bearing					
Serial Number	2468 - 9753				
		AC Motor			

Figure 6—Motor 3 nameplate for Question 30

31. For a feeder to supply the three motors in Questions 28, 29 and 30, where all the equipment is marked with a maximum conductor termination temperature of 60/75°C, determine the following:

    a. minimum size of copper TW75 feeder conductors

    b. maximum feeder overcurrent protection using non-time-delay (standard) fuses

    c. minimum rating of the feeder disconnect.

32. What percentage overload are hermetic refrigerant compressor motors normally designed to withstand?

33. Knowing the horsepower and voltage rating for the motors in Question 32, how are the full-load and locked-rotor currents determined for control equipment?

34. In a commercial three-phase, 120/208-V lighting installation, what is the maximum overcurrent protection permitted for:

    a. fluorescent lighting branch circuits

    b. HID lighting branch circuits?

35. If a circuit breaker only is used to control a 15 A/347 V fluorescent lighting circuit, how shall it be marked?

36. You are asked to install a 30-kW, 208-V, three-phase resistance heater from a circuit breaker panelboard. If the circuit breaker used is marked for 100% continuous operation and there is no marked maximum conductor termination temperature rating, what is the:

    a. current rating of the three-pole circuit breaker required

    _____

    b. size of copper R90 XLPE branch circuit conductors?

    _____

37. If the circuit breaker in Question 36 was **not marked** for 100% continuous operation, and there is no marked maximum conductor termination temperature rating, what is the:

    a. current rating of the three-pole circuit breaker required

    _____

    b. size of copper R90 XLPE branch circuit conductors?

    _____

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 2:

Calculate service equipment requirements

In this learning task you will learn how to calculate the service equipment requirements for the following types of installations:

- apartments
- schools
- hospitals
- hotels and motels
- other occupancies

Apartments

Example 1: An apartment building consists of 10 suites. Each suite has 65 m^2 of living area, and each contains one 12-kW range. The house load consists of 5-kW for miscellaneous lighting loads, two 5-kW dryers and one 5 kW domestic hot water tank. The supply voltage used for the service and house panel is 120 V/208 V, three-phase, four-wire. All suites are supplied at 120 V/208 V, single phase.

What is the ampacity of service or feeder conductors from the main service?

Solution: The minimum ampacity of service or feeder conductors from the main service must be determined by applying Rule 8-202.

Suite Demand: Each suite is 65 m^2

First 45 m^2	3500 W	Rule 8-202(1)(a)(i)
Remaining 20 m^2	1500 W	Rule 8-202(1)(a)(ii)
12-kW range	6000 W	Rule 8-202(1)(a)(v)
Total	11 000 W	

$$I = \frac{11\,000\ W}{208\ V} = 53\ A$$

Each suite feeder must be rated for the greater of Rule 8-202(1)(a) or Rule 8-202(1)(b). Note that Rule 8-202(1)(b) requires that 60 A is the minimum ampacity for each suite feeder.

House load sub-feed: Rule 8-202(4)

One 5-kW miscellaneous lighting	5000 W
Two 5-kW dryers	10 000 W
One 5-kW domestic hot water tank	5000 W
Total	20 000 W

$$I = \frac{20\ 000\ W}{208\ V \times \sqrt{3}} = 55.5\ A$$

The feeder conductors from a service supplying these loads that are not located in dwelling units must have an ampacity not less than 55.5 A. Note that if the fused switches or circuit breakers are marked for continuous operation at 80% of their ampere rating, the ampacity rating of this circuit must not be less than 69.4 A. (Rules 8-202(2) and 8-104(6)(a))

Main Service: Rule 8-202(3)

1 unit 11 000 W at 100%	11 000 W	Rule 8-202(3)(a)(i)
2 units 11 000 W at 65%	14 300 W	Rule 8-202(3)(a)(ii)
2 units 11 000 W at 40%	8800 W	Rule 8-202(3)(a)(iii)
5 units 11 000 W at 25%	13 750 W	Rule 8-202(3)(a)(iv)
Total	47 850 W	
House demand @ 75%	15 000 W	Rule 8-202(3)(e) (18 750 W demand if 80% rated switches or breakers installed (Rules 8-202(2) and 8-104(6)(a))
Total	62 850 W	

$$I = \frac{62\,850\ W}{\sqrt{3} \times 208\ V} = 175\ A$$

The minimum ampacity of the main service conductors must be 175 A.

Example 2: An apartment building consists of 9 suites. Each suite has 80 m^2 of living area, and each contains one 14-kW range, one 3-kW domestic hot water tank, and 6 kW of electric space heating. The house load consists of 4 kW for miscellaneous lighting loads, two 6-kW dryers, one 6-kW domestic hot water tank and 16 kW of electric space heating. The supply voltage used for the service and house panel is 120 V/208 V, three-phase, four-wire. All suites are supplied at 120 V/208 V, single phase. Determine the main service requirements and the sub-service requirements for the suites and house panel.

Solution: **Suite Demand:** Each suite is 80m^2

First 45 m^2	3500 W	Rule 8-202(1)(a)(i)
Remaining 35 m^2	1500 W	Rule 8-202(1)(a)(ii)
14-kW range	6000 W	Rule 8-202(1)(a)(v)
with 2 kW @ 40%	800 W	
3-kW hot water tank @ 25%	750 W	Rule 8-202(1)(a)(vi)
6-kW heating @ 100%	6000 W	Rule 62-116(2)(a)
Total	18 550 W	

$$I = \frac{18\,550\,W}{208\,V} = 89.2\ A$$

Each suite feeder must be rated for the greater of either Rule 8-202(1)(a) or Rule 8-202 (1)(b). Note that Rule 8-202(1)(a) requires that 89.2 A is the minimum ampacity for each suite feeder.

House load sub-feed: Rule 8-202(4)

One 4-kW miscellaneous lighting	4000 W	
Two 6-kW dryers	12 000 W	
One 6-kW DHWT	6 000 W	
16-kW heating @ 75%	12 000 W	Rule 62-116(3)(b)
Total	34 000 W	

$$I = \frac{34\,000\ W}{\sqrt{3} \times 208\ V} = 94.4\ A$$

The feeder conductors from the service supplying these loads that are not located in dwelling units must have an ampacity not less than 94.4 A. Note again that if the fused switches or circuit breakers are marked for continuous operation at 80% of their ampere rating, the ampacity rating of this circuit must not be less than 118 A (Rules 8-202(2) and 8-104(6)(a)).

Main Service: Rule 8-202(3)

Suite Demand

1 unit 12 550 W at 100%	12 550 W	Rule 8-202(3)(a)(i)
2 units 12 550 W at 65%	16 315 W	Rule 8-202(3)(a)(ii)
2 units 12 550 W at 40%	10 040 W	Rule 8-202(3)(a)(iii)
4 units 12 550 W at 25%	12 550 W	Rule 8-202(3)(a)(iv)
Total	51 455 W	

To calculate the electric heating load demand see Rules 8-202(3)(b) and 62-118(3)(a) and(b).

9 units @ 6000 W =	54 000 W	
First 10 kW @ 100%	10 000 W	
Remaining 44 kW @ 75%	33 000 W	
Total	43 000 W	

House load: Rule 8-202(3)(e)

One 4-kW miscellaneous lighting @ 75%	3000 W	
Two 6-kW dryers @ 75 %	9000 W	
One 6-kW DHWT @ 75%	4500 W	
16-kW heating @ 75%	12 000 W	
Total	28 500 W	(35 625 W demand if 80% rated switches or breakers installed (Rules 8-202(2) and 8-104(6)(a))

Total load demand (a + b + c) = 122 955 W

$$I = \frac{122\,955\ W}{\sqrt{3} \times 208\ V} = 341.3\ A$$

The minimum ampacity of the main service conductors must be 341.3 A.

Activity 7

All of the overcurrent devices for Example 1 are marked with a maximum conductor termination temperature of 60/75°C and also marked for continuous operation at 80%. Would the total suite feed calculated need any adjustment for the circuit breaker and wire sizing if NMD90 copper was used as the feeder?

Would the total house load sub-feed calculated need any adjustment for the circuit breaker and wire sizing if NMD90 copper was used as the feeder?

Would the total main service feed calculated need any adjustment for the circuit breaker and wire sizing if R90XLPE 600-V unjacketed copper was used as the feeders?

All of the overcurrent devices for Example 2 are marked with a maximum conductor termination temperature of 60/75°C and also marked for continuous operation at 80%. Would the total suite feed calculated need any adjustment for the circuit breaker and wire sizing if TW75 copper was used in electrical non-metallic tubing as the feeder?

Would the total house load sub-feed calculated need any adjustment for the circuit breaker and wire sizing if TW75 copper was used in electrical non-metallic tubing as the feeder?

Would the total main service feed calculated need any adjustment for the circuit breaker and wire sizing if TW75 copper was used as the feeders?

Schools

Example 3: Determine the minimum service conductor ampacity for a school that has an outside dimension of 80 m by 60 m. The total classroom area of the school is 3000 m^2. The supply service voltage is 120 V/208 V, three-phase, four-wire. The school also has the following loads:

- four 12-kW electric ranges
- one 4-kW clothes dryer
- three 9-kW electric hot water tanks

Solution: Determine the total building area based on the outside dimensions of the building.

80 m × 60 m = 4800 m^2
classroom area = 3000 m^2
remaining area = (4800 m^2 – 3000 m^2) = 1800 m^2

Determine the load for the classroom areas using Rule 8-204(1)(a):

50 W/m^2 × 3000 m^2 = 150 000 W

Determine the load for the remaining area of 1800 m^2 using Rule 8-204(1)(b):

10 W/m^2 × 1800 m^2 = 18 000 W

Determine the total of other loads in the school using Rule 8-204(1)(c):

Electric ranges	4 × 12 000 W =	48 000 W
Clothes dryer	1 × 4000 W =	4000 W
Electric hot water tanks	3 × 9000 W =	27 000 W
Total other loads		79 000 W

The total load can now be determined as 150 000 W + 18 000 W + 79 000 W = 247 000 W.

Rule 8-204(2)(b) specifies how demand factors must be applied to schools when the total building area exceeds 900 m^2 (based on the outside dimensions of the school).

Determine the load-per-square-metre using Rule 8-204(2)(b)(ii):

$$\frac{\text{Load}}{m^2} = \frac{247\,000\,\text{W}}{4800\,m^2} = 51.46\ \text{W/m}^2$$

Calculate the load for the first 900 m^2 using Rule 8-204(2)(b)(ii)(A):

75% × 51.46 W/m^2 × 900 m^2 = 34 734 W

Calculate the load for the remaining area using Rule 8-204(2)(b)(ii)(B):

50% × 51.46 W/m^2 × 3900 m^2 = 100 344 W

Calculate the minimum service conductor ampacity required for this school:

$$I = \frac{(34\,734\,\text{W} + 100\,344\,\text{W})}{\sqrt{3} \times 208\,\text{V}} = 375\,\text{A}$$

Example 4: Determine the minimum service conductor ampacity for a school that has an outside dimension of 35 m by 40 m. The total classroom area of the school is 1000 m^2. The supply service voltage is 120 V/208 V, three-phase, four-wire. The school also has the following loads:

- 24 kW of electric baseboard heating
- two 3-kW electric hot water heaters
- 5 kW of parking lot lighting
- four 12-kW electric ranges
- 20 kW of miscellaneous machinery in the workshop

Solution: Determine the total building area based on the outside dimensions of the building:

35 m × 40 m = 1400 m^2
classroom area = 1000 m^2
remaining area = (1400 m^2 – 1000 m^2) = 400 m^2

Determine the load for the classroom areas using Rule 8-204(1)(a):

50 W/m^2 × 1000 m^2 = 50 000 W

Determine the load for the remaining area of 400 m^2 using Rule 8-204(1)(b):

10 W/m^2 × 400 m^2 = 4000 W

Determine the total of other loads in the school using Rule 8-204(1)(c) and/or (d):

Two hot water tanks 2 × 3000 W	=	6000 W
Parking lot lighting	=	5000 W
Four ranges 4 × 12 000 W	=	48 000 W
Machinery	=	20 000 W
Total other loads	=	79 000 W
Heating load	=	24 000 W

Rule 8-204(2)(b) specifies how demand factors must be applied to schools when the total building area exceeds 900 m^2, based on the outside dimensions of the school.

Calculate heating load as:

24 000 W × 75% = 18 000 W Rule 62-118(5)(b)

The balance of the load (i.e., other than heating) can now be determined to be 50 000 W + 4000 W + 79 000 W = 133 000 W.

Determine the load-per-square-metre using Rule 8-204(2)(b)(ii):

$$\frac{\text{Load}}{m^2} = \frac{133\,000\,\text{W}}{1400\,m^2} = 95\ \text{W/m}^2$$

Calculate the load for the first 900 m^2 using Rule 8-204(2)(b)(ii)(A):

75% × 95 W/m^2 × 900 m^2 = 64 125 W

Calculate the load for the remaining area using Rule 8-204(2)(b)(ii)(B):

50% × 95 W/m^2 × 500 m^2 = 23 750 W

Calculate the minimum service conductor ampacity required for this school:

$$I = \frac{(18\,000\ \Omega + 64\,125\ \Omega + 23\,750\ \Omega)}{\sqrt{3} \times 208\,\varsigma} = 294\ \text{A}$$

Hospitals

Example 5: Determine the minimum service conductor ampacity for a hospital that has a total area, based on the outside dimensions, of 7600 m^2. There are 210 m^2 used as operating rooms. The supply service voltage is 120 V/208 V, three-phase, four-wire. The hospital also has the following loads:

- electric space heating 500 000 W
- air conditioning 140 000 W
- additional power loads 105 000 W

The electric space heating and the air-conditioning loads will not be used simultaneously.

Solution: Determine the basic load of the hospital Rule 8-206(1)(a):

7600 m^2 × 20 W/m^2 = 152 000 W

Determine the load for the high intensity areas Rule 8-206(1)(b):

$210\ m^2 \times 100\ W/m^2 = 21\,000\ W$

Determine the total of all other loads in the hospital. Rule 8-206(1)(c):

Applying Rule 8-106(4), we will use the heating load but not the air-conditioning load since these loads will not be used simultaneously.

Electric space heating	500 000 W
Additional power loads	105 000 W
Total	605 000 W

Determine the total building load:

152 000 W + 21 000 W + 605 000 W = 778 000 W

Determine the total building load less any electric space heating loads:

778 000 W – 500 000 W = 278 000 W

For a hospital with an area exceeding 900 m^2 based on the outside dimensions, the demand factors that may be applied are specified in Rule 8-206(2)(b).

Space heating loads:

500 000 W × 75% = 375 000 W (Rule 62-116(3)(b))

Determine the load per square meter (Rule 8-206(2)(b)(ii)):

$$\frac{\text{Load}}{m^2} = \frac{278\,000\,W}{7600\,m^2} = 36.58\ W/m^2$$

Determine the load for the first 900 m^2 of area (Rule 8-206(2)(b)(ii)(A)):

$80\% \times 36.58\ W/m^2 \times 900\ m^2 = 26\,338\ W$

Determine the load for the remaining area of the hospital (Rule 8-206(2)(b)(ii)(B)):

$65\% \times 36.58\ W/m^2 \times (7600\ m^2 - 900\ m^2) = 159\,306\ W$

Calculate the minimum service conductor ampacity:

$$I = \frac{(375\,000\,W + 26\,338\,W + 159\,306\,W)}{\sqrt{3} \times 208\,V}$$

$$= 1556\ A$$

Hotels

Example 6: Determine the minimum service conductor ampacity for a hotel that has a total area, based on the outside dimensions, of 5600 m^2. The supply service voltage is 120 V/208 V, three-phase, four-wire. The hotel also has the following loads:

- specialized lighting 24 000 W
- electric space heating 500 000 W
- air conditioning 105 000 W
- additional power loads 140 000 W

The electric space heating and the air-conditioning loads will not be used simultaneously.

Solution: Determine the basic load of the hotel (Rule 8-208(1)(a)):

5600 m^2 × 20 W/m^2 = 112 000 W

The specialized lighting loads are 24 000 W (Rule 8-208(1)(b))

Determine the total of all other loads in the hotel using Rule 8-208(1)(c) and/or (d):

Applying Rule 8-106(4), we will use the heating load but not the air-conditioning load, since these loads will not be used simultaneously.

Electric space heating	500 000 W
Additional power loads	140 000 W
Total	640 000 W

Determine the total building load:

112 000 W + 24 000 W + 640 000 W = 776 000 W

Determine the total building load less any electric space heating loads:

776 000 W – 500 000 W = 276 000 W

For a hotel with an area exceeding 900 m^2 based on the outside dimensions, the demand factors that may be applied are specified in Rule 8-208(2)(b).

Space heating loads:

500 000 W × 75% = 375 000 W (Rule 62-118(5)(b))

Determine the load per square meter using Rule 8-208(2)(b)(ii):

$$\frac{\text{Load}}{\text{m}^2} = \frac{276\,000\,\text{W}}{5600\,\text{m}^2} = 49.3\,\text{W/m}^2$$

Determine the load for the first 900 m^2 of area using Rule 8-208(2)(b)(ii)(A):

80% × 49.3 W/m^2 × 900 m^2 = 35 496 W

Determine the load for the remaining area of the hotel using Rule 8-208(2)(b)(ii)(B):

65% × 49.3 W/m^2 × (5600 m^2 – 900 m^2) = 150 612 W

Calculate the minimum service conductor ampacity:

$$I = \frac{(375\,000\,\text{W} + 35\,496\,\text{W} + 150\,612\,\text{W})}{\sqrt{3} \times 208\,\text{V}} = 1557\,\text{A}$$

Commercial and apartment complexes

It is not unusual to have dwelling units on top of offices and retail stores. Rule 8-210 and Table 14 apply to these complexes; they deal with occupancies other than schools, hospitals and hotels. The load requirements for these buildings are calculated as follows:

- Basic load demand factors are specified in Table 14.
- Heating load demand factors are specified by Rule 62-118(5)(b).
- Unless other load demand factors are specified in particular parts of the Code (such as for motor circuits), calculate all other loads at 100%.
- For the dwelling units at the top of the complex, use Rule 8-202 to calculate the feeder ampacity, adding it to the other load requirements.

Example 7: Calculate the current ratings of the main service conductors and overcurrent protection for the following 48-suite apartment and shopping complex. Each suite is 56 m^2 and has a 10.8-kW range and 8 kW of electric baseboard heaters. House loads include 25 kW of miscellaneous loads and lighting, two 10-kW hot water heaters, five 6-kW electric dryers, a 6-kW sauna, 20-kW electric baseboard heating and two 15 hp, three-phase continuous-duty elevator motors supplied at 208 V.

The other facilities in the building are as follows:

Facility	Area	Heating	Motor
Restaurant	200 m^2	16 kW	2 hp fan, 3 ø
Three offices, each	100 m^2	9 kW	-
Barber shop	80 m^2	7 kW	-
Beauty parlor	100 m^2	9 kW	-
Bank	120 m^2	10 kW	-
Theater	500 m^2	20 kW	
Store	150 m^2	12 kW	Four 3 hp cooler fans, 3ø
Service supply to the complex is 120 V/208 V, three-phase, four-wire			

Solution: Calculate service demand by dividing it into three sections:

- dwelling complex, using Rule 8-202
- commercial/shopping complex, using Rule 8-210 and Table 14
- other motor loads

Dwelling complex: Rule 8-202

Total basic load for each of the 56 m^2 suites

Basic load for first 45 m^2 of living space	=	3500 W
Remaining 11 m^2 of area	=	1500 W
Range	=	6000 W
Subtotal	=	11 000 W

Apartment basic demand: Rule 8-202(3)(a)

Based on 48 suites:

1 × 11 000 W × 100%	=	11 000 W
2 × 11 000 W × 65%	=	14 300 W
2 × 11 000 W × 40%	=	8800 W
15 × 11 000 W × 25%	=	41 250 W
28 × 11 000 W × 10%	=	30 800 W
Subtotal	=	106 150 W

Suite heating: Rules 8-202(3)(b) and 62-118(5)(a)

For 48 suites, heating load is 8 kW × 48 = 384 kW

First 10 kW × 100%	=	10 000 W
Remaining 374 kW × 75%	=	280 500 W
Subtotal	=	290 500 W

According to Rule 8-202(2), this total load calculated according to Rule 8-202(3)(a), (b), and (c) shall not be considered to be a continuous load.

House loads: Rule 8-202(3)(e)

Miscellaneous and lighting 25 kW × 75%	=	18 750 W
Two hot water tanks 2 × 10 kW × 75%	=	15 000 W
Five dryers 5 × 6 kW × 75%	=	22 500 W
Sauna 6 kW × 75%	=	4500 W
Heating 20 kW × 75%	=	15 000 W
Subtotal	=	75 750 W

However, since Subrules (d) and (e) of Rule 8-202(3) are not referenced by Rule 8-202(2), this total calculated load would have to be considered a continuous load for the application of Rule 8-104.

Total dwelling-complex load (no motors)

(106 150 W + 290 500 W + 75 750 W) = 472 400 W

$$\text{Current load} = \frac{472\,400\ \text{W}}{\sqrt{3} \times 208\ \text{V}} = 1311\ \text{A}$$

Where a fused switch or circuit breaker is marked for continuous operation at 80% (or not marked at either 80% or 100%), it is considered to be suitable for continuous operation at 80% for the application of Rule 8-104 and Appendix B.

Total dwelling-complex load (no motors)

(106 150 W + 290 500 W + (75 750 W ÷ 0.8)) = 491 338 W

$$\text{Current load} = \frac{491\,338\ \text{W}}{\sqrt{3} \times 208\ \text{V}} = 1364\ \text{A}$$

Shopping complex: Rule 8-210 and Table 14

Omitting the motor loads, each part of the shopping complex has a basic load whose demand factors vary and a heating load that has a demand factor of 75%. It is helpful to list each facility individually before finding their total loads.

Facility	Basic service (CEC Table 14)		
Restaurant	200 m^2 × 30 W/m^2 × 100%	=	6000 W
Office 1	100 m^2 × 50 W/m^2 × 90%	=	4500 W
Office 2	100 m^2 × 50 W/m^2 × 90%	=	4500 W
Office 3	100 m^2 × 50 W/m^2 × 90%	=	4500 W
Barber shop	80 m^2 × 30 W/m^2 × 90%	=	2160 W
Beauty parlor	100 m^2 × 30 W/m^2 × 90%	=	2700 W
Bank	120 m^2 × 50 W/m^2 × 100%	=	6000 W
Theater	500 m^2 × 30 W/m^2 × 75%	=	11 250 W
Store	150 m^2 × 30 W/m^2 × 100%	=	4500 W
Subtotal		=	46 110 W

Facility	Heating
Restaurant	16 000 W
Office 1	9000 W
Office 2	9000 W
Office 3	9000 W
Barber shop	7000 W
Beauty parlor	9000 W
Bank	10 000 W
Theater	20 000 W
Store	12 000 W
Subtotal	101 000 W x 75% = 75 750 W

Total shopping-complex load (no motors)
(46 110 W + 75 750 W) = 121 860 W

According to Rule 8-104, this total load calculated in accordance with the demand factors permitted by Rule 8-208 would have to be considered a continuous load.

$$\text{Current load} = \frac{121\,860\ \text{W}}{\sqrt{3} \times 208\ \text{V}} = 338\ \text{A}$$

Again, where a fused switch or circuit breaker is marked for continuous operation at 80% (or not marked at either 80% or 100%), it is considered to be suitable for continuous operation at 80% for the application of Rule 8-104 and Appendix B.

$$\text{Current load} = \frac{121\,860\ \text{W}}{\sqrt{3} \times 208\ \text{V}} = 338\ \text{A}$$

$338\ \text{A} \div 0.8 = 423\text{A}$

Motor Loads: Rule 8-202(3)(e) and 28-108 and 28-204(1):

Location	hp	FLA	Service demand	Total O/C
Apartments	15	46.2	46.2 × 0.75 = 34.7 A	34.7 A (75% FLA)
Apartments	15	46.2	46.2 × 0.75 = 34.7 A	34.7 A (75% FLA)
Store	3	10.6	10.6 × 1.25 = 13.2 A	31.7 A (300% FLA)
Store	3	10.6	10.6 × 1.00 = 10.6 A	10.6 A
Store	3	10.6	10.6 × 1.00 = 10.6 A	10.6 A
Store	3	10.6	10.6 × 1.00 = 10.6 A	10.6 A
Restaurant	2	7.5	7.5 × 1.00 = 7.5 A	7.5 A
Totals			= 121.9 A	140.4 A

Note:

- Since the above motor current calculations are for the main service, consider the two elevator motors for the apartment with a demand factor of 75% (according to Rule 8-202(3)(e)). The remaining motors are not part of the apartment, so base their service contribution on the rating of the equipment with demand factors as permitted (according to Rule 8-210(b)).
- When motors are involved, determine the overcurrent protection using Rule 28-204(3). Since the two elevator motors are considered part of the apartment, according to Rule 8-202(3)(e), their demand factor for overcurrent protection is the same as for their conductor ampacity, which is 75%. For the remaining motors, determine the maximum rating of the overcurrent device permitted by Rule 28-200 for the motor that is permitted the highest rated overcurrent device of any motor supplied by the feeder, and then add to it the sum of the full-load current ratings of all other motors that will be in operation at the same time.

For the **whole** apartment/shopping complex:

Main Service	Conductor ampacity	Overcurrent value
Motors only	122 A	140 A
Apartments only	1311 A	1311 A
Shopping only	338 A	338 A
Whole complex	1771 A	1789 A
Note that standard fuses are not time delay.		

Once again, where a fused switch or circuit breaker is marked for continuous operation at 80% (or not marked at either 80% or 100%), it is considered to be suitable for continuous operation at 80% for the application of Rule 8-104 and Appendix B.

Main Service	Conductor ampacity	Overcurrent value
Motors only	122 A	140 A
Apartments only	1364 A	1364 A
Shopping only	423 A	423 A
Whole complex	1909 A	1927 A
Note that standard fuses are not time delay.		

 Now do Self-Test 2 and check your answers.

Self-Test 2

1. An apartment building consists of 20 suites. Each suite has 45 m^2 of living area, and each contains one 12-kW range and 5 kW of electric space heating. The house load consists of 7 kW for miscellaneous lighting loads, two 6-kW dryers and 7 kW of electric space heating loads. The supply voltage used for the service and house panel is 120 V/208 V, three-phase, four-wire. All suites are supplied at 120 V/208 V, single-phase, three-wire. Determine the main service requirements and the sub-service requirements for the suites and house panel.

2. Determine the minimum service conductor ampacity for a school with a total building area of 4500 m^2. The total classroom area of the school is 2700 m^2. The supply service voltage is 120 V/208 V, three-phase, four-wire. The school also has the following loads:
   - 75 kW of electric baseboard heating
   - six 12-kW electric ranges
   - one 4-kW clothes dryer
   - four 9-kW electric hot water tanks
   - one 6-kW electric kiln
   - 30 flood lighting fixtures at 0.5 kW each
   - 30 parking stalls at 1.2 kW each

3. Determine the minimum service conductor ampacity for a hospital that has a total area, based on outside dimensions, of 12 000 m^2. There are 300 m^2 used as operating rooms. The supply service voltage is 120 V/208 V, three-phase, four-wire. The hospital also has the following loads:

   - electric space heating 1 200 000 W
   - air conditioning 100 000 W
   - additional power loads 165 000 W

   The electric space heating and the air-conditioning loads will not be used simultaneously.

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4. Determine the minimum service conductor ampacity for a hotel that has a total area, based on outside dimensions, of 4800 m^2. The supply service voltage is 120 V/208 V, three-phase, four-wire. The hotel also has the following loads:

   - specialized lighting 22 000 W
   - electric space heating 500 000 W
   - air conditioning 300 000 W
   - additional power loads 340 000 W

   The electric space heating and the air-conditioning loads will not be used simultaneously.

Go to the Answer Key at the end of the Learning Guide to check your answers.

Answer Key

Self-Test 1

1. #000 AWG — Rules 4-004(1)(b); 4-004(8)
2. 53 (2") — Rule 12-910(5)
3. 41 (1½") — Rule 12-910(4)
4. #0000 AWG — Rules 4-004(1)(b); 4-004(8); 4-006(1)
5. In this example, where the maximum conductor termination temperature for equipment is not marked (on the load centre), it would be based on Rule 4-006(2)(a), where it is considered to be 60°C for equipment rated at not more than 100 A.
   a. #1 AWG
   b. 100 A
6. 850 A — Rule 4-024(2)
7. Common conductor — Rule 4-004(4)
8. #4 AWG copper — Rule 10-814(1); Table 16A
9. Yes — Rule 10-612(1)
10. #6 AWG — Rule 10-812(a)
11. #6 AWG — Rule 10-812(a)
12. 53 (2") — Rule 12-910(4); Tables 10A, D5, 8 and 9I
13. 824 mm — Rule 12-3036(2)(b)
14. A = 587 mm
    B = 587 mm
    C = 546 mm — Rule 12-3036(2)(c)
15. 29.3 A — Rule 26-208(1)
16. 50 A — Rule 26-210
17. • The rating of the capacitor must not exceed the value to raise the motor's no-load PF to unity. — Rule 26-218(2)(a)
    • The setting of the overload device must be reduced to correspond to the new current at the improved PF. — Rule 26-218(2)(b)
18. 225 A — Rule 26-254(1), (2)(a)
19. 125 A — Rule 26-256(1), (3)

20. 10 A — Rule 26-262(1)(a)

21. No — Rule 26-256(2)

22. #8 AWG — Rule 26-258(1)(a) and Table 2

23. #1/0 AWG — Rule 26-258(1)(b) and Table 4

24. a. 37.5 kVA standard size $\left(\sqrt{3} \times 208\ \text{V} \times 100\ \text{A} = 36\,027\ \text{VA}\right)$

    b. 100 A main breaker on the combination panel provides the necessary protection. Rule 14-100(b)

    c. 60 A — Rule 26-256(1), (3)

    d. 60 A — Rule 26-250

    e. Point A = three #6 AWG TW75 (65 A) copper — Rules 14-100(b) and 4-004
    Point B = three #6 AWG TW75 (65 A) copper — Rules 26-258 and 4-004
    Point C = four #3 AWG TW75 (100A) copper — Rules 26-258, 14-100(b) and 4-004

    f. Point A = 27 (1") — Rules 12-910 and 10-814(1), App. B
    Point B = 27 (1") — Rules 12-910 and 10-814(1), App. B
    Point C = 35 (1¼") — Rules 12-910 and 10-814(1), App. B

    g. AWG #6 copper — Rule 10-812

    h. AWG #6 copper — Rule 10-702(b)

    i. 2971 A 37 500 ÷ (208 × $\sqrt{3}$) ÷ 0.035

25. insulation class rating — Rule 28-104

26. Table 29 — Rule 28-200

27. a. Table D2
    b. Table 45
    c. Table 44

28. a. #10 AWG TW75 (27.5 A) — Rules 28-106(1) and 4-006, and Table 2
    b. 90°C — Rule 28-104 and Table 37
    c. 60 A (66 A calculated) — Rule 28-200(a) and Table 29
    d. 27.5 A — Rule 28-306(1)(a)
    e. 60 A @ 20 hp – 600 V — Rule 28-602(1)(a)

29. a. #14 AWG TW75 (15.6 A) (as Q. 28 above) plus Rule 4-004(8) and Table 5A
    b. 100°C
    c. 30 A (33 A calculated)

d. 13.75 A

e. 30 A @ 10 hp – 600 V

30. a. #10 AWG TW75 (28.8 A) Rule 28-106(2), Rule 4-006, Table 27 and Table 2

b. 90°C (as Q. 28 above)

c. 90 A (96 A calculated)

d. 40 A

e. 100 A @ 30 hp – 600 V

31. a. #4 AWG TW75 (67.3 A) Rule 28-108(1)(c)

b. 125 A (129 A calculated) Rule 28-204(1)

c. 200 A @ 30 hp – 600 V Rule 28-602

32. 140% Rule 28-710(a)

33. The full-load current may be determined using Table 44 or 45, and the locked-rotor current may be determined by multiplying the FLA by six times.
Rule 28-704

34. a. 20 A Rule 30-104(c)

b. 40 A Rule 30-104(d)

35. SWD Rule 30-710(3)

36. a. 90 A (83.3 A calculated)

b. #3 AWG
Rule 4-006(2)(a) states that where the maximum conductor termination temperature for equipment is not marked, it shall be considered to be 60°C.

37. a. 110 A (104 A calculated)

b. #1 AWG (as above)

Self-Test 2

1. Suite Demand: Each suite is 45 m^2.

45 m^2	3500 W		Rule 8-202(1)(a)(i)
12-kW range	6000 W		Rule 8-202(1)(a)(v)
5-kW heating @ 100%	5000 W		Rule 8-202(1)(a)(iv) and 62-116(2)(a)
Total	14 500 W		

$$I = \frac{14\,500\ W}{208\ V} = 69.7\ A$$ **69.6 A**

House load sub-feed: Rule 8-202(4)

One 7-kW miscellaneous lighting	7000 W	
Two 6-kW driers	12 000 W	
7-kW heating @75%	5250 W	Rule 62-116(30)(b)
Total	24 250 W	

$$I = \frac{24\ 250\ W}{\sqrt{3} \times 208} = 67.3\ A$$ **67.3 A**

Main Service: Rule 8-202(3)

Suite Demand:

1 unit 9500 W @ 100%	9500 W		Rule 8-202(3)(a)(i)
2 unit 9500 W @ 65%	12 350 W		Rule 8-202(3)(a)(ii)
2 unit 9500 W @ 40%	7600 W		Rule 8-202(3)(a)(iii)
15 unit 9500 W @ 25%	35 625 W		Rule 8-202(3)(a)(iv)
Sub Total	65 075 W	**65 075 W**	

Electric Heating Demand: Rules 8-202(3)(b)

20 units @ 5000 W =	100 000 W	
First 10 000 @ 100%	10 000 W	
remainder @ 75 %	67 500 W	
Sub Total	77 500 W	**77 500 W**

House Load: Rule 8-202(3)(d)

1 × 7000 W @ 75 %	5250 W	
2 × 6000 W @ 75 %	9000 W	
1 × 7000 W @ 75 %	5250 W	
Sub Total	19 500 W	**19 500 W**

Main Service Total:

$$I = \frac{162\ 075\ W}{\sqrt{3} \times 208\ V} 449.9\ A$$ **449.9 A**

2. Electric heating load demand = 56 250 W
   The load for the first 900 m^2 = 48 303 W
   The load for the remaining area = 128 808 W
   ∴ The minimum service conductor ampacity = 648 A

3. Total building load = 1 635 000 W
   Total building load less electric space heating = 435 000 W
   Electric space heating demand = 900 000 W
   The load per square meter = 36.25 W/m^2
   The load for the first 900 m^2 = 26 100 W
   The load for the remaining area = 261 544 W
   ∴ The minimum service conductor ampacity = 3297 A

4. Total building load = 958 000 W
   Total building load less electric space heating = 458 000 W
   Electric space heating demand = 375 000 W
   The load per square meter = 95.417 W/m^2
   The load for the first 900 m^2 = 68 700 W
   The load for the remaining area = 241 881 W
   ∴ The minimum service conductor ampacity = 1903 A



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