

Conductor Sizing and the National Electrical Code

The National Electrical Code requirements for conductor sizing and overcurrent protection have always been confusing and complex. Factors that must be considered include:

1. Continuous loads
2. Terminal temperature ratings
3. Conductor insulation
4. Conductor ampacity
5. Special application
6. System voltage

NEC Section 240-3 requires the branch circuit, feeder, and service conductors to be protected against overcurrent in accordance with their ampacities as specified in Table 310-16. However, Section 240-3 contains twelve rules that modify the general requirement and permit the conductors not to be protected in accordance with their ampacities, they include:

1. Power Loss Hazard
2. Devices Rated 800 Amperes or Less
3. Tap Conductors
4. Motor-Operated Appliance Circuit Conductors
5. Motor and Motor-Control Circuit Conductors
6. Phase Converter Supply Conductors
7. Air-Conditioning and Refrigeration Equipment Circuit Conductors
8. Transformer Secondary Conductors
9. Capacitor Circuit Conductors
10. Electric Welder Circuit Conductors
11. Remote-Control, Signaling, and Power-Limited Circuit Conductors
12. Fire Alarm System Circuit Conductors

With so many different Code rules that modify the general requirements, it does become overwhelming to a circuits conductor and overcurrent protection device. However the following steps and examples should help you understand the basic rules of conductor sizing and protection.

Step 1 - Size the overcurrent protection device in accordance with Sections 210-20(a), 215-3, and 384-16(d). These three NEC rules required the overcurrent protection device (breaker or fuse) be sized no less than 100% of the noncontinuous load, plus 125% of the continuous load. Section 240-6(a) contains the list of standard size overcurrent protection devices.

Step 2 - Select the conductor to comply with Sections 110-14(c), 210-19(a), 215-2, and 230-42
(a). Sections 210-19(a), 215-2 and 230-42(a) required the conductor to be sized no less than 100% of the noncontinuous load, plus 125% of the continuous load. In addition, Section 110-14(c) requires a consideration of the temperature rating of the equipment terminals when sizing conductors. Section 110-14(c) requires the circuit conductors to be sized according to the 60°C column of Table 310-16 for equipment rated 100 amperes and less, unless marked otherwise, and equipment rated over 100 amperes must be sized to the 75°C column of Table 310-16.

Author's Comment. These important Code rules were added to the 1993 and 1996 NEC and are often overlooked. The purpose of these new rules are to insure that the heat generated on the equipment terminals can be properly dissipated without damaging the conductors. For all practical purposes, most electrical equipment is design to accept conductors sized to the 75° C column of Table 310-16.

Step 3 - The selected conductor must be protected against overcurrent in accordance with Section 240-3. Section 240-3. This requires the branch circuit, feeder, and service conductors be protected against overcurrent in accordance with their ampacities as specified in Table 310-16. However, Section 240-3(b) permits "the next size up device" if the conductors are not part of a multioutlet branch circuit supplying receptacles, and the ampacity of the conductors does not correspond with the standard ampere rating of a overcurrent protection fuse or a circuit breaker as listed in Section 240-6(a), and the next higher standard rating selected does not exceed 800 amperes.

Author's Comment. The ampacity of a conductor is it's current rating in amperes that it can carry continuously, after applying conductor ampacity reduction factors for conductor bundling and ambient temperature. In addition, the 1996 clarified in Section 110-14(c), that the ampacity reduction of THHN (90°C) conductor is based on the conductors ampacity as listed in the 90°C column of Table 310-16 and not on the terminal temperature rating.

Branch Circuit Continuous Load Example: What size branch-circuit overcurrent protection device and conductor (THHN) is required for a 19 kVA of nonlinear loads (75°C terminals). The branch-circuit is supplied by a 208/120 volt, 4-wire, 3-phase, Wye connected system.

Step 1 - Size the overcurrent protection device in accordance with Sections 210-20(a) and 384-16(d). The first thing that we must do convert the nonlinear load from kVA to amperes:

Ampères = VA/(Volts x 1.732), Ampères = 19,000/(208 volts x 1.732), Ampères = 52.74 amperes, rounded to 53 amperes

The branch-circuit overcurrent protection device must be sized not less than 125% of 53 amperes, 53 amperes x 125% = 66 amperes. According to Section 240-6(a) we must select a minimum 70 ampere overcurrent protection device.

Step 2 - Select the conductor to comply with Sections 110-14(c) and 210-19(a). Section 210-19(a) also requires the branch-circuit conductor to be sized no less than 125% of the continuous load, 53 amperes x 125% = 66 amperes. We must select the conductor according to the 75°C terminals temperature rating of the equipment terminals. No. 6 THHN has a rating of 65 amperes at 75°C and can not be used, therefore we must select a No. 4 which has a rating of 85 amperes at 75°C.

Step 3 - The No. 4 THHN conductor must be protected against overcurrent in accordance with Section 240-3. We must verify that the No. 4 THHN is properly protected against overcurrent by the 70 ampere overcurrent protection device. Since we have more than three current-carrying conductors in the same raceway, we must correct the No. 4 THHN conductors ampacity as listed in the 90°C column of Table 310-16. Corrected Ampacity No. 4 THHN = Ampacity x Note 8(a) Adjustment Factor
Corrected Ampacity No. 4 THHN = 95 amperes x 80% Corrected Ampacity No. 4 THHN = 76 amperes

The No. 4 THHN which is rated 76 amperes after ampacity correction is properly protected by a 70 ampere overcurrent protection device in compliance with the general requirements of Section 240-3.

Feeder Continuous Load Example: What size feeder overcurrent protection device and conductor (THHN) is required for a 184 ampere continuous load on a panelboard (75°C terminals) that supplies nonlinear loads. The feeder is supplied by a 4-wire, 3-phase, wye connected system.

Step 1 - Size the overcurrent protection device in accordance with Sections 215-3 and 384-16(d). The feeder overcurrent protection device must be sized not less than 125% of 184 amperes, $184 \text{ amperes} \times 125\% = 230 \text{ amperes}$. According to Section 240-6(a) we must select a minimum 250 ampere overcurrent protection device.

Step 2 - Select the conductor to comply with Sections 110-14(c) and 215-2. Section 215-2 also requires the feeder conductor to be sized no less than 125% of the continuous load, $184 \text{ amperes} \times 125\% = 230 \text{ amperes}$. We must select the conductor according to the 75°C temperature rating of the panelboards terminals. No. 4/0 THHN has a rating of 230 amperes at 75°C .

Step 3 - The No. 4/0 conductor must be protected against overcurrent in accordance with Section 240-3. We must verify that the No. 4/0 THHN conductor is properly protected against overcurrent by the 250 ampere overcurrent protection device. Since we have more than three current-carrying conductors in the same raceway, we must correct the No. 4/0 THHN conductors ampacity as listed in the 90°C column of Table 310-16. Corrected Ampacity No. 4/0 THHN = Ampacity x Note 8(a)
Adjustment Factor Corrected Ampacity No. 4/0 THHN = $260 \text{ amperes} \times 80\%$ Corrected Ampacity No. 4/0 THHN = 208 amperes

The No. 4/0 THHN which is rated 208 amperes after ampacity correction is not considered protected by a 250 ampere overcurrent protection device. This is because "the next size up rule" in Section 240-3(b) would only permit a 225 ampere protection device on the 208 ampere conductor [240-6(a)]. Therefor we must increase the conductor size to 250 kcmil in order to comply with the overcurrent protection rules of Section 240-3.

Free Commercial/Industrial Wiring and Raceway Chart

If you have any questions or comments regarding this article, please let me know,
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Circuit Ampacity Wizard™

8/30/05

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<u>Load Amperage</u>		<u>Conductor Ampacity Adjustment Factors</u>			<u>Overcurrent and Conductor Insulation Rating</u>	
Continuous:	80	4-6	Raceway fill adjustment factor: 0.80%	26-30°C	Temperature adjustment factor: 1.00%	Minimum circuit OCPD for load: 100
Noncontinuous:	0					Conductor insulation: 90°C
Circuit Size		NEC Table 310.16	Adjusted Ampacity	Percent of load	Error Warnings	
		60°C	75°C	90°C		
1- #14 AWG Copper		20	20	25	20	400% 1,2,3
1- #12 AWG Copper		25	25	30	24	333% 1,2,3
1- #10 AWG Copper		30	35	40	32	250% 1,2,3
1- #8 AWG Copper		40	50	55	44	182% 1,2,3
1- #6 AWG Copper		55	65	75	60	133% 1,2,3
1- #4 AWG Copper		70	85	95	76	105% 1,2,3
1- #3 AWG Copper		85	100	110	88	91% 1,3
1- #2 AWG Copper		95	115	130	104	77% 1
1- #1 AWG Copper		110	130	150	120	67% None
1- #1/0 AWG Copper		125	150	170	136	59% None
1- #2/0 AWG Copper		145	175	195	156	51% None
1- #3/0 AWG Copper		165	200	225	180	44% None
1- #4/0 AWG Copper		195	230	260	208	38% None
1- 250 kcmil Copper		215	255	290	232	34% None
1- 300 kcmil Copper		240	285	320	256	31% None
1- 350 kcmil Copper		260	310	350	280	29% None
1- 400 kcmil Copper		280	335	380	304	26% None
1- 500 kcmil Copper		320	380	430	344	23% None
1- 600 kcmil Copper		355	420	475	380	21% None
1- 700 kcmil Copper		385	460	520	416	19% None
1- 750 kcmil Copper		400	475	535	428	19% None
1- 800 kcmil Copper		410	490	555	444	18% None
1- 900 kcmil Copper		435	520	585	468	17% None
1- 1000 kcmil Copper		455	545	615	492	16% None
1- 1250 kcmil Copper		495	590	665	532	15% None
1- 1500 kcmil Copper		520	625	705	564	14% None
1- 1750 kcmil Copper		545	650	735	588	14% None
1- 2000 kcmil Copper		560	665	750	600	13% None

Circuit Ampacity Wizard builds a circuit using every conductor size in 2002 NEC table 310.16. When the built circuit fails one of the NEC rules errors are generated. A comma separates each error below is an explanation of each.

Error #1 Circuit terminations may overheat. NEC Sec. 110.14. For a circuit 100A and less: the value is taken from the 60°C column; for a circuit greater than 100A (or wire size #1AWG or greater) the value is taken from the 75°C column. Feeder and branch circuit sizes are determined as 100% of the noncontinuous part of the load plus 125% of the continuous part.

Error #2 Conductor ampacity not adequate for load after adjusted for fill and temperature. The 125% of continuous load rule is NOT used here. The table column value used is based on the conductor insulation rating after any adjustment for the condition-of-use (dry/damp/wet).

Error #3 The OCPD will NOT protect the circuit conductors under their actual condition of use. The conductor ampacity here is determined from the table column that matches the conductor insulation value. This value is then factored for fill and temperature. The 125% of continuous load rule is NOT used here. This is the actual conductor ampacity and it must exceed the rating of a standard OCPD after application of the next-larger-size rule (assuming not over 800A, ect.).

Error #4 Conductor not allowed to be paralleled.

Circuit Ampacity Wizard™

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<u>Load Amperage</u>		<u>Conductor Ampacity Adjustment Factors</u>				<u>Overcurrent and Conductor Insulation Rating</u>
Continuous:	320	4-6 26-30°C	Raceway fill adjustment factor: 0.80%	Temperature adjustment factor: 1.00%		Minimum circuit OCPD for load: 400 Conductor insulation: 90°C
		NEC Table 310.16	Adjusted Ampacity	Percent of load	Error Warnings	
Circuit Size		60°C	75°C	90°C		
1- #14 AWG Copper		20	20	25	20	1600% 1,2,3
1- #12 AWG Copper		25	25	30	24	1333% 1,2,3
1- #10 AWG Copper		30	35	40	32	1000% 1,2,3
1- #8 AWG Copper		40	50	55	44	727% 1,2,3
1- #6 AWG Copper		55	65	75	60	533% 1,2,3
1- #4 AWG Copper		70	85	95	76	421% 1,2,3
1- #3 AWG Copper		85	100	110	88	364% 1,2,3
1- #2 AWG Copper		95	115	130	104	308% 1,2,3
1- #1 AWG Copper		110	130	150	120	267% 1,2,3
1- #1/0 AWG Copper		125	150	170	136	235% 1,2,3
1- #2/0 AWG Copper		145	175	195	156	205% 1,2,3
1- #3/0 AWG Copper		165	200	225	180	178% 1,2,3
1- #4/0 AWG Copper		195	230	260	208	154% 1,2,3
1- 250 kcmil Copper		215	255	290	232	138% 1,2,3
1- 300 kcmil Copper		240	285	320	256	125% 1,2,3
1- 350 kcmil Copper		260	310	350	280	114% 1,2,3
1- 400 kcmil Copper		280	335	380	304	105% 1,2,3
1- 500 kcmil Copper		320	380	430	344	93% 1,3
1- 600 kcmil Copper		355	420	475	380	84% None
1- 700 kcmil Copper		385	460	520	416	77% None
1- 750 kcmil Copper		400	475	535	428	75% None
1- 800 kcmil Copper		410	490	555	444	72% None
1- 900 kcmil Copper		435	520	585	468	68% None
1- 1000 kcmil Copper		455	545	615	492	65% None
1- 1250 kcmil Copper		495	590	665	532	60% None
1- 1500 kcmil Copper		520	625	705	564	57% None
1- 1750 kcmil Copper		545	650	735	588	54% None
1- 2000 kcmil Copper		560	665	750	600	53% None

Circuit Ampacity Wizard builds a circuit using every conductor size in 2002 NEC table 310.16. When the built circuit fails one of the NEC rules errors are generated. A comma separates each error below is an explanation of each.

Error #1 Circuit terminations may overheat. NEC Sec. 110.14. For a circuit 100A and less: the value is taken from the 60°C column; for a circuit greater than 100A (or wire size #1AWG or greater) the value is taken from the 75°C column. Feeder and branch circuit sizes are determined as 100% of the noncontinuous part of the load plus 125% of the continuous part.

Error #2 Conductor ampacity not adequate for load after adjusted for fill and temperature. The 125% of continuous load rule is NOT used here. The table column value used is based on the conductor insulation rating after any adjustment for the condition-of-use (dry/damp/wet).

Error #3 The OCPD will NOT protect the circuit conductors under their actual condition of use. The conductor ampacity here is determined from the table column that matches the conductor insulation value. This value is then factored for fill and temperature. The 125% of continuous load rule is NOT used here. This is the actual conductor ampacity and it must exceed the rating of a standard OCPD after application of the next-larger-size rule (assuming not over 800A, ect.).

Error #4 Conductor not allowed to be paralleled.

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<u>Load Amperage</u>		<u>Conductor Ampacity Adjustment Factors</u>				<u>Overcurrent and Conductor Insulation Rating</u>	
Continuous:	640	4-6 26-30°C	Raceway fill adjustment factor: 0.80%	Temperature adjustment factor: 1.00%		Minimum circuit OCPD for load: 800 Conductor insulation: 90°C	
		NEC Table 310.16			Adjusted Ampacity	Percent of load	Error Warnings
Circuit Size		60°C	75°C	90°C			
1- #14 AWG Copper		20	20	25	20	3200%	1,2,3,4
1- #12 AWG Copper		25	25	30	24	2667%	1,2,3,4
1- #10 AWG Copper		30	35	40	32	2000%	1,2,3,4
1- #8 AWG Copper		40	50	55	44	1455%	1,2,3,4
1- #6 AWG Copper		55	65	75	60	1067%	1,2,3,4
1- #4 AWG Copper		70	85	95	76	842%	1,2,3,4
1- #3 AWG Copper		85	100	110	88	727%	1,2,3,4
1- #2 AWG Copper		95	115	130	104	615%	1,2,3,4
1- #1 AWG Copper		110	130	150	120	533%	1,2,3,4
2- #1/0 AWG Copper		125	150	170	136	471%	1,2,3
2- #2/0 AWG Copper		145	175	195	312	205%	1,2,3
2- #3/0 AWG Copper		165	200	225	360	178%	1,2,3
2- #4/0 AWG Copper		195	230	260	416	154%	1,2,3
2- 250 kcmil Copper		215	255	290	464	138%	1,2,3
2- 300 kcmil Copper		240	285	320	512	125%	1,2,3
2- 350 kcmil Copper		260	310	350	560	114%	1,2,3
2- 400 kcmil Copper		280	335	380	608	105%	1,2,3
2- 500 kcmil Copper		320	380	430	688	93%	1,3
2- 600 kcmil Copper		355	420	475	760	84%	None
2- 700 kcmil Copper		385	460	520	832	77%	None
2- 750 kcmil Copper		400	475	535	856	75%	None
2- 800 kcmil Copper		410	490	555	888	72%	None
2- 900 kcmil Copper		435	520	585	936	68%	None
2- 1000 kcmil Copper		455	545	615	984	65%	None
2- 1250 kcmil Copper		495	590	665	1,064	60%	None
2- 1500 kcmil Copper		520	625	705	1,128	57%	None
2- 1750 kcmil Copper		545	650	735	1,176	54%	None
2- 2000 kcmil Copper		560	665	750	1,200	53%	None

Circuit Ampacity Wizard builds a circuit using every conductor size in 2002 NEC table 310.16. When the built circuit fails one of the NEC rules errors are generated. A comma separates each error below is an explanation of each.

Error #1 Circuit terminations may overheat. NEC Sec. 110.14. For a circuit 100A and less: the value is taken from the 60°C column; for a circuit greater than 100A (or wire size #1AWG or greater) the value is taken from the 75°C column. Feeder and branch circuit sizes are determined as 100% of the noncontinuous part of the load plus 125% of the continuous part.

Error #2 Conductor ampacity not adequate for load after adjusted for fill and temperature. The 125% of continuous load rule is NOT used here. The table column value used is based on the conductor insulation rating after any adjustment for the condition-of-use (dry/damp/wet).

Error #3 The OCPD will NOT protect the circuit conductors under their actual condition of use. The conductor ampacity here is determined from the table column that matches the conductor insulation value. This value is then factored for fill and temperature. The 125% of continuous load rule is NOT used here. This is the actual conductor ampacity and it must exceed the rating of a standard OCPD after application of the next-larger-size rule (assuming not over 800A, ect.).

Error #4 Conductor not allowed to be paralleled.

Conductor Ampacity - Using Lower Rating Section 310.15(A)(2)

Ambient temperature ampacity adjustment for 3/0 AWG THHN (rated 225A at 90°C).

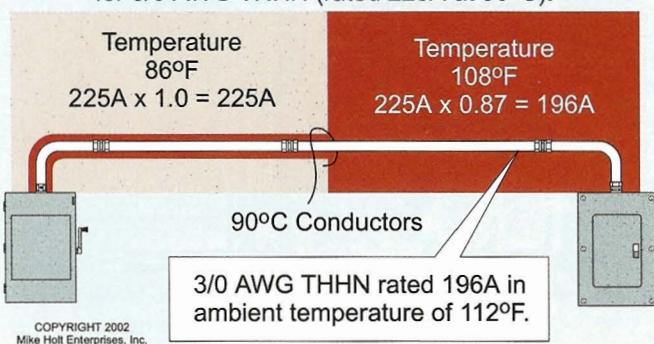


Figure 310-8

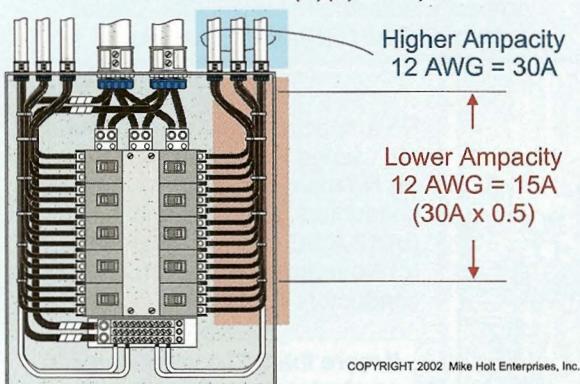
310.15 Conductor Ampacity

(A) General Requirements

- (1) **Tables for Engineering Supervision.** The ampacity of a conductor can be determined by using the table in this article or under engineering supervision.
 - (2) **Conductor Ampacity – Lower Rating.** When two or more ampacities apply to a single conductor length, the lower ampacity value shall be used for the entire circuit. For example, this would occur when a conductor runs through different ambient temperatures. See 310.15(B). Figure 310-8

Exception: When different ampacities apply to a conductor length, the higher ampacity can be used for the entire circuit.

**Conductor Ampacity - Higher Ratios
Section 310.15(A)(2) Exception**



The higher ampacity can be used if the length of the low ampacity is not more than 10 ft, and it is not longer than 10 percent of the higher ampacity length.

if the reduced ampacity length is not in excess of 10 ft and its length does not exceed 10 percent of the length of the higher ampacity. Figure 310-9

- (B) Table Ampacity.** The allowable conductor ampacities listed in Table 310.16 are based on conditions where the ambient temperature is not over 86°F and no more than three current-carrying conductors are bundled together. Figure 310-10

Question: What is the adjusted ampacity of 3/0 AWG THHN conductors if the ambient temperature is 86°F?

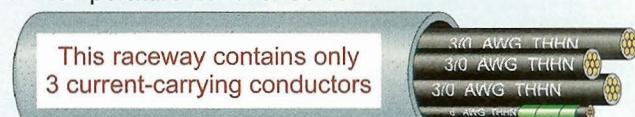
Answer: (c) 225A.

AUTHOR'S COMMENT: When conductors are installed in an ambient temperature other than 78–86°F, the conductors' ampacities, as listed in Table 310.16, shall be adjusted in accordance with the following multipliers at the bottom of Table 310.16 for 90°C conductors such as THHN and XHHW.

Temperature °F	Temperature °C	Multiplier
70–77°F	21–25°C	1.04
78–86°F	26–30°C	1.00
87–95°F	31–35°C	0.96
96–104°F	36–40°C	0.91
105–113°F	41–45°C	0.87
114–122°F	46–50°C	0.82
123–131°F	51–55°C	0.76
132–140°F	56–60°C	0.71
141–158°F	61–70°C	0.58
159–176°F	71–80°C	0.41

Conductor Table Ampacity Section 310.15(B)

The ampacities listed in Table 310.16 are based on 3 or less current-carrying conductors in an ambient temperature not over 86°F.



Conductor Ampacity Adjustment



If the ambient temperature is above 86°F, the conductor ampacity decreases.



If the number of current-carrying conductors exceeds 3, the conductor ampacity decreases.

Figure 310-9

Figure 310-10

cables) are bundled or stacked for more than 24 in., an ampacity adjustment factor of 60 percent shall be applied.

Temperature and Bundling Adjustments. Where there are more than three current-carrying conductors and the ambient temperature is not between 78–86°F, the ampacity listed in Table 310.16 shall be adjusted for both conditions.

Question: What is the adjusted ampacity of 3/0 AWG THHN conductors at an ambient temperature of 108°F if the raceway contains four current-carrying conductors?

Answer: (a) 157A . $225\text{A} \times 0.87 \times 0.80 = 157\text{A}$

Temperature Adjustment [Table 310.16] = 0.87

Bundle Adjustment [310.15(B)(2)(a)] = 0.80

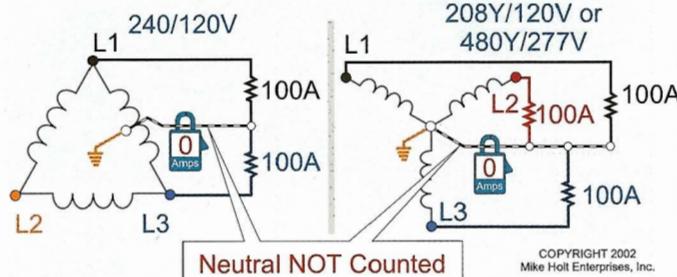
AUTHOR'S COMMENT: When adjusting conductor ampacity, the ampacity of the conductor is based on the 90°C rating of the conductor [110.14(C)].

- (4) **Neutral Conductor.** All ungrounded conductors are considered current-carrying, and some grounded (neutral) conductors are considered current-carrying.

(a) **Balanced Circuits.** The grounded (neutral) conductor of a 3-wire, $1\varnothing$, 120/240V or 4-wire, $3\varnothing$, 208Y/120V or 480Y/277V system is not considered a current-carrying conductor. Figure 310-14

(b) **Wye 3-Wire Circuits.** The grounded (neutral) conductor of a 3-wire circuit from a 4-wire, $3\varnothing$, 208Y/120V or 480Y/277V system is considered a current-carrying conductor.

**Grounded (Neutral) Conductors Supplying Linear Loads
Not Current-Carrying**
Section 310.15(B)(4)(a)



Neutral conductor that carries only the unbalanced current is not considered a current-carrying conductor.

Figure 310-14

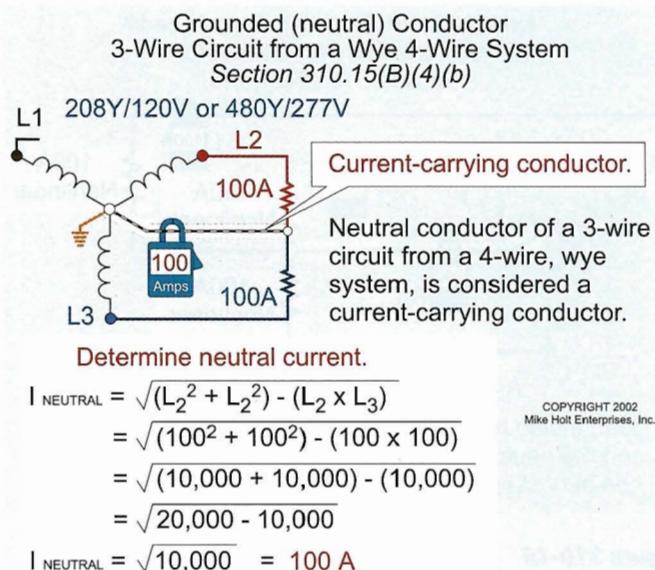


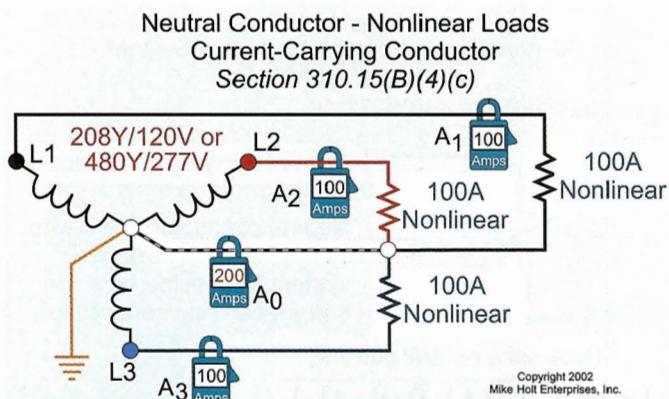
Figure 310-15

AUTHOR'S COMMENT: When a 3-wire circuit is supplied from a 4-wire, 3Ω , wye-connected system, the grounded (neutral) conductor carries approximately the same current as the line-to-neutral current from the ungrounded (hot) conductors. Figure 310-15

- (c) Wye 4-Wire Circuits Supplying Nonlinear Loads.** The neutral conductor of a balanced 4-wire, $3\emptyset$, circuit that is at least 50 percent loaded with nonlinear loads is considered a current-carrying conductor.

AUTHOR'S COMMENT: Nonlinear loads supplied by 3Ø, 4-wire wye-connected power-supply systems such as 208Y/120V or 480Y/277V can produce unwanted and potentially hazardous odd triplen harmonic currents that can add on to the neutral conductor. To prevent a fire, or equipment damage from excessive harmonic neutral current, the designer should consider (1) increasing the size of the neutral conductor, or (2) installing a separate neutral for each phase. For more information, visit <http://www.mikeholt.com/studies/harmonic.htm> and see 210.4(A) FPN, 220.22 FPN 2, and 450.3 FPN 2. Figure 310-16

- (5) **Grounding Conductors.** Grounding and bonding conductors are not considered current-carrying.
 - (6) **Dwelling Unit Feeder/Service Conductors.** One-family, two-family, or multifamily dwelling units can have their ungrounded (hot) conductors sized for 3-wire, $1\varnothing$, 120/240V service-entrance and feeders that serve



Odd triplen harmonic current from nonlinear loads add on the neutral conductor and the actual current could be almost twice the ungrounded conductor's current.

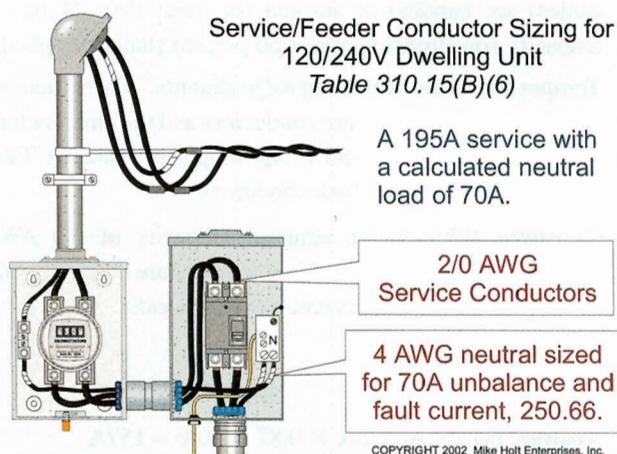
Figure 310-16

as the main power feeder to a dwelling unit in accordance with Table 310.15(B)(6), instead of Table 310.16.

Ampères	Copper	Aluminum
100	4 AWG	2 AWG
110	3 AWG	1 AWG
125	2 AWG	1/0 AWG
150	1 AWG	2/0 AWG
175	1/0 AWG	3/0 AWG
200	2/0 AWG	4/0 AWG
225	3/0 AWG	250 kcmil
250	4/0 AWG	300 kcmil
300	250 kcmil	350 kcmil
350	350 kcmil	500 kcmil
400	400 kcmil	600 kcmil

WARNING: Table 310.15(B)(6) does not apply to 3-wire, 1Ø, 208Y/120V systems, because the grounded (neutral) conductor in these systems carries neutral current even when the load on the phases is balanced [310.15(B)(4)(6)].

Grounded (neutral) Conductor Sizing. The grounded (neutral) conductor for dwelling units can be smaller than the ungrounded conductors, but in no case can it be smaller than required to carry the maximum unbalanced load as determined in 220.22. In addition, the grounded (neutral) conductor shall not be smaller than that required by 250.24(B).



One-family, two-family, or multifamily dwelling units can have their ungrounded (hot) conductors sized to Table 310.15(B)(6), instead of Table 310.16.

Figure 310-17

Question: What size service/feeder conductors would be required if the total adjusted demand load for a dwelling unit equals 195A and the maximum unbalanced neutral load is 70A? Figure 310-17

- (a) 1/0 AWG and 6 AWG (b) 2/0 AWG and 4 AWG
(c) 3/0 AWG and 2 AWG (d) 4/0 AWG and 1 AWG

Answer: (b) 2/0 AWG and 4 AWG

Feeder: 2/0 AWG rated 200A [Table 310.15(B)(6)]

Grounded (neutral) Conductor: 4 AWG, rated 85A at 75°C [110.14(C)(1) and Table 310.16]. 250.24(B) requires the grounded (neutral) conductor to be sized no smaller than 4 AWG based on Table 250.66.

110.13 Mounting and Cooling of Equipment

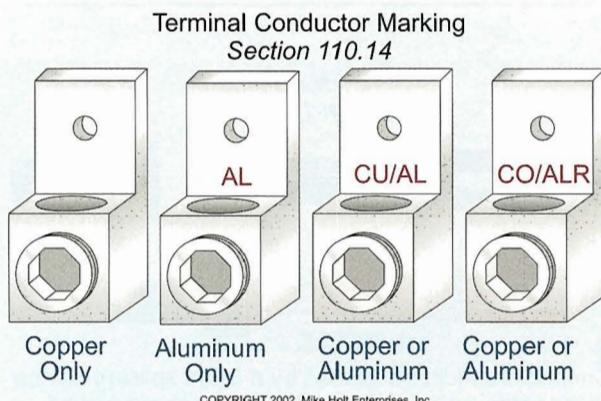
- (A) **Mounting.** Electrical equipment shall be firmly secured to the surface on which it is mounted. See 314.23.
- (B) **Cooling.** Electrical equipment that depends on natural air circulation shall be installed so walls or equipment do not prevent room airflow over such surfaces. The clearance between top surfaces and side surfaces shall be maintained to dissipate rising warm air for equipment designed for floor mounting.

Electrical equipment that is constructed with ventilating openings shall be installed so free air circulation is not inhibited.

110.14 Electrical Conductor Termination

Terminal Conductor Material. Conductor terminals and splicing shall be properly installed, used, and identified for the conductor material. Devices that are suitable only for aluminum shall be marked AL, and devices that are suitable for both copper and aluminum shall be marked as CU/AL or CO/ALR. See 404.14(C), 406.2(C). Figure 110-18

AUTHOR'S COMMENT: Terminations of conductors must be in accordance with manufacturer's instructions as required by 110.3(B). For example, if the terminal device states "Suitable for 18-2 AWG Stranded," only stranded conductors can be used with the terminating device. If it states "Suitable for 18-2 AWG Solid," only solid conductors are permitted to be used with the terminating device, and if it states "Suitable for 18-2 AWG," then either solid or stranded conductors can be used with the terminating device.



Terminals that are suitable only for aluminum shall be marked AL. Terminals suitable for both copper and aluminum shall be marked as CU/AL or CO/ALR.

Figure 110-18

Aluminum: Terminals listed for aluminum conductors are often filled with an antioxidant gel, which is designed to reduce aluminum oxide on the exposed aluminum conductors to reduce the contact resistance between the conductor and the terminal. Split-bolt connectors listed for aluminum-to-aluminum termination will be supplied with instructions that specify how to wire brush the conductors and the requirement for an antioxidant.

Copper: Some terminal manufacturers sell a compound intended to reduce corrosion and heat at terminations, which is especially helpful at high-amperage terminals. This compound is messy, but I have been told that it is effective.

Copper and Aluminum Mixed: Copper and aluminum conductors shall not make contact with each other in a device unless the device is listed and identified for this purpose. Few terminations are listed for use with aluminum wire and copper, but if they are, they will be marked on the product package or terminal device. The reason copper and aluminum cannot be in contact with each other is because corrosion will develop between the conductors, resulting in an increase in contact resistance in the termination or splicing device. This increased resistance can cause overheating of the termination or splice, which could cause a fire. See <http://tis-hq.eh.doe.gov/docs/sn/nsh9001.html> for more information on how to properly terminate aluminum and copper conductors together.

FPN: Many terminations and equipment are marked with a tightening torque.

AUTHOR'S COMMENT: All conductors must terminate in devices that have been properly tightened in accordance with the manufacturer's torque specifications that are included with equipment instructions. Failure to torque terminals is a violation of 110.3(B). Figure 110-19

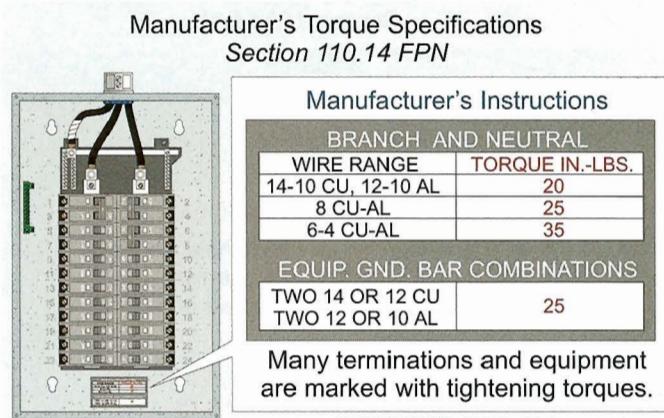


Figure 110-19

Question: What do you do if the torque value is not provided with the device?

Answer: Call the manufacturer, visit their web site, or have the supplier make a copy of the installation instructions.

AUTHOR'S COMMENT: Terminating conductors without a torque tool can result in an improper and unsafe installation. If you are not using a torquing screwdriver, there is a very good chance that you are not terminating the conductors properly.

- (A) **Terminations.** Terminals for conductors shall ensure a good connection without damaging the conductors, and conductors shall terminate to listed pressure connectors.

Question: What do you do if the wire you are terminating is larger than the terminal (upsizing conductors for long runs and for nonlinear loads)?

Answer: This condition needs to be anticipated in advance and the equipment should be ordered with terminals that will accommodate the larger wire. However, if you are in the field, you should:

- Contact the manufacturer and have them express you the proper terminals, bolts, washers and nuts, or
- Order a terminal device that crimps on the end of the larger conductor and reduces the termination size, or splice the conductors to a smaller wire.

One Wire Per Terminal. Terminals are listed to accept no more than one wire per termination, unless marked otherwise. Terminals that are listed for more than one wire shall be identified for this purpose, either within the equipment instructions or on the terminal itself. Figure 110-20

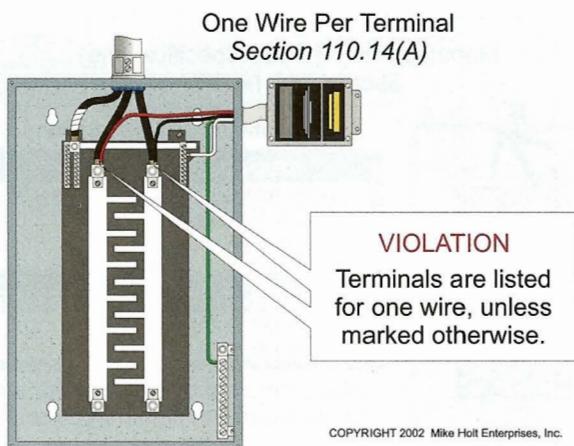
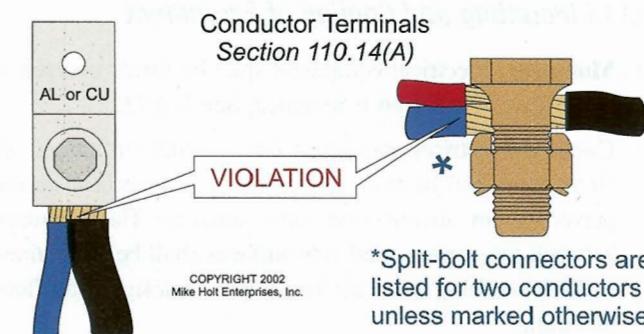


Figure 110-20



The number of conductors in a terminal is limited to that for which the terminal is designed and listed.

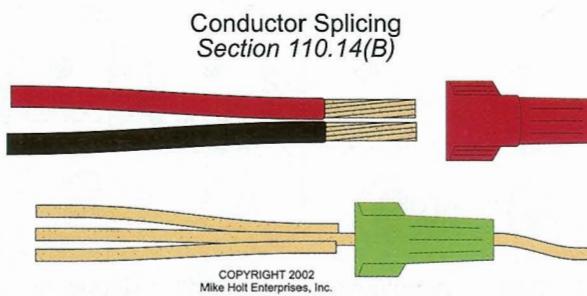
Figure 110-21

Most split-bolt connectors are listed for only two conductors, and it is a common industry practice to terminate more than three conductors. However, some split-bolt connectors are listed for three conductors. Figure 110-21

AUTHOR'S COMMENT: Some split-bolt connectors are listed for aluminum-to-aluminum or aluminum-to-copper; if so, they will be marked for this application.

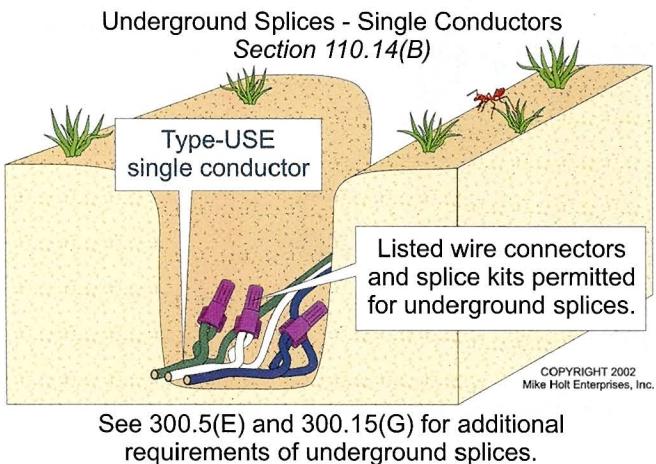
- (B) **Conductor Splices.** Conductors shall be spliced by a listed splicing device or by exothermic welding. Naturally, using a U-bolt fitting for nonelectrical cables would be an improper and unsafe practice.

AUTHOR'S COMMENT: The NEC does not require conductors to be twisted together prior to installing a twist-on wire connector (Wire Nut®), but it is a good practice to twist the grounded (neutral) conductors together for multiwire branch circuits. See 300.13(B). Figure 110-22



Conductors must be spliced by a listed splicing device or by exothermic welding. Wire connectors must be installed in accordance with manufacturer's instructions and twisting the wires together is not required.

Figure 110-22

**Figure 110-23**

Insulation. The free ends of all conductors shall be covered with insulation that is equal to that of the conductor. Spare conductors for future use and conductors that are not currently used can be left, but the free ends of the conductors shall be insulated to prevent the exposed end of the conductor from touching energized parts, which could create an electrical hazard. Both of these requirements can be met by the use of an insulated twist-on or push-on wire connector.

Underground Splices.

Single Conductors. Single direct-burial conductor of Type UF or USE can be spliced underground without the use of a junction box, but the conductors shall be spliced with a splicing device that is listed for direct-burial installation. See 300.5(E) and 300.15(G). Figure 110-23

Multiconductor Cable. Multiconductor Type UF or Type USE cable can be spliced underground with a listed splice kit that encapsulates the conductors and the splice.

(C) Temperature Limitations.

Conductor Size. Conductors are to be sized in accordance with the lowest temperature rating of any terminal, device, or conductor of the circuit in accordance with (1) and (2) below.

Conductors with temperature ratings higher than specified for terminations shall be permitted to be used for ampacity adjustment, correction, or both. This means that conductor ampacity, when required to be adjusted, is based on the conductor insulation temperature rating in accordance with Table 310.16.

For example, the ampacity of each 12 AWG THHN is 30A based on the values listed in the 90°C column of Table 310.16. If we bundle nine current-carrying 12 AWG THHN conductors, the ampacity for each conductor (as listed in

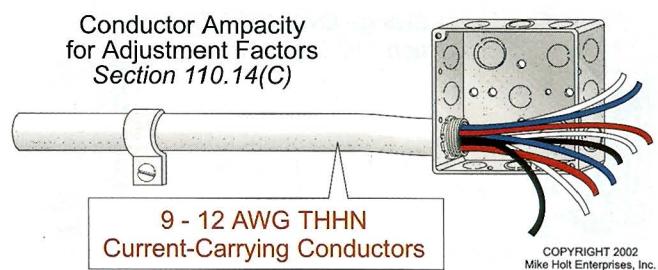
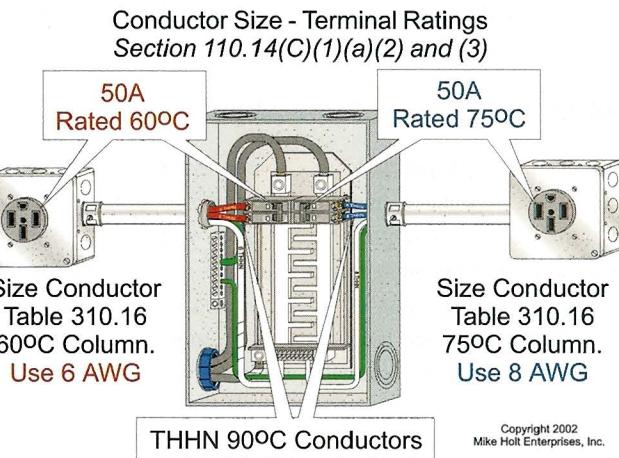


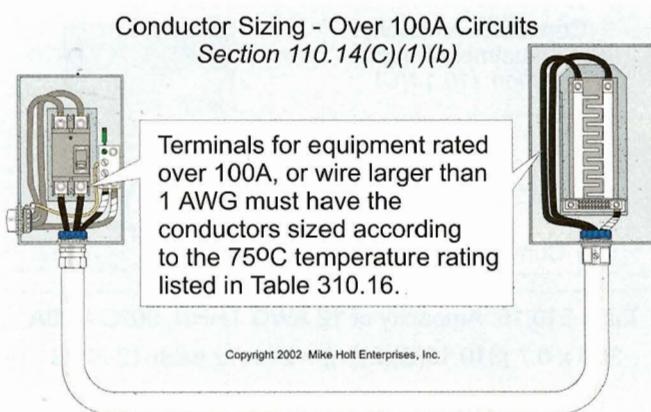
Table 310.16: Ampacity of 12 AWG THHN, 90°C = 30A
30A × 0.7 [310.15(B)(2)(a)] = 21A for each 12 AWG

Figure 110-24

Table 310.16) needs to be adjusted to 21A ($30A \times 0.70$) as specified by Table 310.15(B)(2)(a). Figure 110-24

- (1) **Equipment Provisions.** Unless the equipment is listed and marked otherwise, conductor ampacities used in determining equipment termination provisions shall be based on Table 310.16.
- (a) **Conductor Size for Equipment Rated 100A and Less.**
 - (1) Electrical terminations on equipment rated 100A or less and pressure connector terminals for 14 through 1 AWG conductors are rated for 60°C unless otherwise specified. To keep a 60°C terminal from overheating beyond its rating, the conductor connected to that terminal shall not get hotter than 60°C. This can be done by going to Table 310.16 and selecting a conductor from the 60°C column.
 - (2) Conductors with temperature ratings greater than 60°C can be used on terminals rated 60°C, but the

**Figure 110-25**

**Figure 110-26**

conductor shall be sized based on the 60°C temperature column of Table 310.16. Figure 110-25

- (3) If the terminals are listed and identified for use with terminals rated 75°C, then the conductors can be sized to the 75°C temperature column of Table 310.16. See Figure 110-25

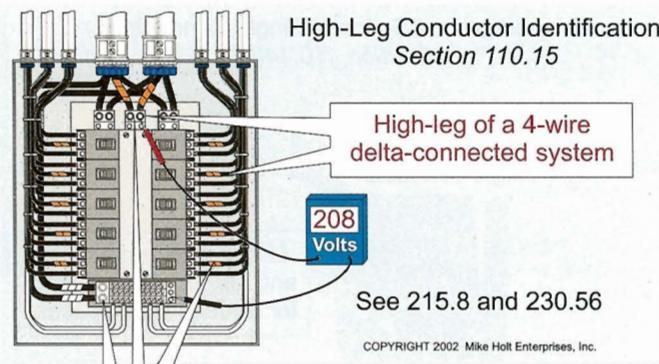
(b) Conductor Size for Equipment Rated Over 100A.

- (1) Conductors for equipment rated over 100A and pressure connector terminals for larger than 1 AWG conductors shall be sized to the 75°C temperature column of Table 310.16. Figure 110-26
- (2) Conductors with temperature ratings greater than 75°C shall be sized based on the 75°C temperature column of Table 310.16.
- (2) **Separate Connector Provisions.** Conductors for separately installed pressure connectors can be sized to the listed temperature rating of the connector. For example, if 90°C pressure connectors are located on busbars, the conductors can be sized to the 90°C temperature column of Table 310.16.

110.15 High-Leg Conductor Identification

On a three-phase (3Ø), 4-wire delta-connected system, where the midpoint of one phase winding is grounded, the conductor or busbar having the higher phase voltage-to-ground shall be durably and permanently marked by an outer finish that is orange in color, or by other effective means. Such identification shall be placed at each point on the system where a connection is made if the grounded (neutral) conductor is also present. Figure 110-27

AUTHOR'S COMMENT: Similar language is contained in 215.8 for feeders and 230.56 for services.

**Figure 110-27**

WARNING: When replacing disconnects, panelboards, meters, switches, or any equipment that contains the high-leg conductor, care must be taken to place the high-leg conductor in the proper location. Failure to install the high-leg properly can result in 120V circuits connected to the 208V high-leg, with disastrous results. See 408.3(E) for proper termination of the high-leg conductor in panelboards and switchboards.

110.16 Flash Protection Warning

Switchboards, panelboards, industrial control panels, and motor control centers in commercial and industrial occupancies, that are likely to require examination, adjustment, servicing, or maintenance while energized, shall be field marked to warn qualified persons of the danger of electric arc flash from a line-to-line or line-to-case fault. The marking shall be clearly visible to qualified persons before they examine, adjust, service, or perform maintenance on the equipment.

The “incident energy” for the selection of personal protective equipment under NFPA 70E is not required, just a sign warning that dangerous electric arc flash could be present. Figure 110-28

AUTHOR'S COMMENT: This rule is to protect qualified persons who work on energized electrical systems, by ensuring that they are alerted that an arc flash hazard exists so they will select proper personal protective equipment. For more information about flash protection, visit <http://www.bussmann.com/safetybasics>.

310.15 Ampacities for Conductors Rated 0–2000 Volts.

(A) General.

Section 310.15 was reorganized for the 1999 *Code*. The notes affecting the ampacity of conductors, previously entitled Article 310, Notes to Ampacity Tables 0 to 2000 Volts, now appear as adjustment factors in 310.15(B)(1) through (6). Although this reorganization was a significant change, no substantive technical changes were made to the requirements.

(1) Tables or Engineering Supervision. Ampacities for conductors shall be permitted to be determined by tables or under engineering supervision, as provided in 310.15(B) and (C).

FPN No. 1:Ampacities provided by this section do not take voltage drop into consideration. See 210.19(A), FPN No. 4, for branch circuits and 215.2(D), FPN No. 2, for feeders.

FPN No. 2:For the allowable ampacities of Type MTW wire, see Table 11 in NFPA 79-1997, *Electrical Standard for Industrial Machinery*.

Section 310.15(A)(1) permits either of two methods of determining conductor ampacity for conductors rated 0 through 2000 volts: to select the ampacity from a table, using correction factors in the table or notes where necessary, or to calculate the ampacity. The latter method can be complex and time consuming and requires engineering supervision. It can, however, result in lower installation costs, in some cases, and if calculated properly, it provides a mathematically exact ampacity. See the commentary following 310.15(C) and accompanying Annex B for further explanation.

(2) Selection of Ampacity. Where more than one calculated or tabulated ampacity could apply for a given circuit length, the lowest value shall be used.

Exception: Where two different ampacities apply to adjacent portions of a circuit, the higher ampacity shall be permitted to be used beyond the point of transition, a distance equal to 3.0 m (10 ft) or 10 percent of the circuit length figured at the higher ampacity, whichever is less.

Example

Three 500-kcmil THW conductors in a rigid conduit are run from a motor control center for 12 ft past a heat-treating furnace to a pump motor located 150 ft from the motor control center. Where run in a 78°F to 86°F ambient, the conductors have an ampacity of 380 amperes, per Table 310.16. The ambient temperature near the furnace, where the conduit is run, is found to be 113°F, and the length of this particular part of the run is greater than 10 ft and more than 10 percent of the total length of the run at the 78°F to 86°F ambient. Determine the ampacity of total run in accordance with 310.15(A)(2).

Solution

In accordance with the correction factors for temperature at the bottom of Table 310.16, the ampacity is 0.82×380 amperes, or 311.6 amperes. This, therefore, is the ampacity of the total run, in accordance with 310.15(A)(2).

Had the run near the furnace at the 113°F ambient been 10 ft or less in length, the ampacity of the entire run would have been 380 amperes, in accordance with the exception to 310.15(A)(2). The heat-sinking effect of the run at the lower ambient temperature would have been sufficient to reduce the temperature of the conductor near the furnace.

FPN:See 110.14(C) for conductor temperature limitations due to termination provisions.

(B) Tables. Ampacities for conductors rated 0 to 2000 volts shall be as specified in the Allowable Ampacity Table 310.16 through Table 310.19 and Ampacity Table 310.20 through 310.23 as modified by (1) through (6).

FPN:Tables Table 310.16 through Table 310.19 are application tables for use in determining conductor sizes on loads calculated in accordance with Article 220. Allowable ampacities result from consideration of one or more of the following:

- (1) Temperature compatibility with connected equipment, especially the connection points.
- (2) Coordination with circuit and system overcurrent protection.
- (3) Compliance with the requirements of product listings or certifications. See 110.3(B).
- (4) Preservation of the safety benefits of established industry practices and standardized procedures.

Ampacity tables, particularly Table 310.16, do not take into account all of the many factors affecting ampacity. See the commentary following 310.15(C) and accompanying Annex B for further explanation. However, experience over many years has proved the table values to be adequate for loads calculated in accordance with Article 220, because not all diversity factors and load factors found in most actual installations are specifically provided for in Article 220. If loads are not calculated in accordance with the requirements of Article 220, the table ampacities, even when corrected in accordance with ambient correction factors and the notes to the tables, might be too high. This result can be particularly true where many cables or raceways are routed close to one another underground. However, load diversity and thermal conductance fill around buried cable could result in increased ampacity. See Annex B for further information.

(1) General. For explanation of type letters used in tables and for recognized sizes of conductors for the various conductor insulations, see 310.13. For installation requirements, see 310.1 through 310.10 and the various articles of this *Code*. For flexible cords, see Table 400.4, Table 400.5(A), and Table 400.5(B).

(2) Adjustment Factors.

(a) More Than Three Current-Carrying Conductors in a Raceway or Cable. Where the number of current-carrying conductors in a raceway or cable exceeds three, or where single conductors or multiconductor cables are stacked or bundled longer than 600 mm (24 in.) without maintaining spacing and are not installed in raceways, the allowable ampacity of each conductor shall be reduced as shown in Table 310.15(B)(2)(a).

FPN:See Annex B, Table B.310.11, for adjustment factors for more than three current-carrying conductors in a raceway or cable with load diversity.

The factors in the second column of Table 310.15(B)(2)(a) are based on no diversity, meaning that all conductors in the raceway or cable are loaded to their maximum rated load. For load diversity, the user is directed to Annex B.

Specific cross references for raceway fill and adjustment factors of 310.15(B)(2) can be found in the fine print note following 300.17. For Class 1 conductors, see 725.28(A); for fire alarm systems, 760.28 and 760.52; for optical fiber cables and raceways, 770.52; and for communications wires and cables within buildings, 800.48.

Exception No. 1: Where conductors of different systems, as provided in 300.3, are installed in a common raceway or cable, the derating factors shown in Table 310.15(B)(2)(a) shall apply to the number of power and lighting conductors only (Articles 210, 215, 220, and 230).

Exception No. 1 assumes that the watt loss (heating) from any control and signal conductors in the same raceway or cable will not be enough to significantly increase the temperature of the power and lighting conductors. See 725.26 and 725.54 for limitations on the installation of control and signal conductors in the same raceway or cable as power and lighting conductors.

Exception No. 2: For conductors installed in cable trays, the provisions of 392.11 shall apply.

Exception No. 3: Derating factors shall not apply to conductors in nipples having a length not exceeding 600 mm (24 in.).

Exception No. 4: Derating factors shall not apply to underground conductors entering or leaving an outdoor trench if those conductors have physical protection in the form of rigid metal conduit, intermediate metal conduit, or rigid nonmetallic conduit having a length not exceeding 3.05 m (10 ft) and if the number of conductors does not exceed four.

Exhibit 310.4 illustrates Exception No. 4 to 310.15(B)(2)(a), in that derating factors do not apply to the conductors because they have physical protection (conduit) that does not exceed 10 ft in length and the number of conductors does not exceed four.

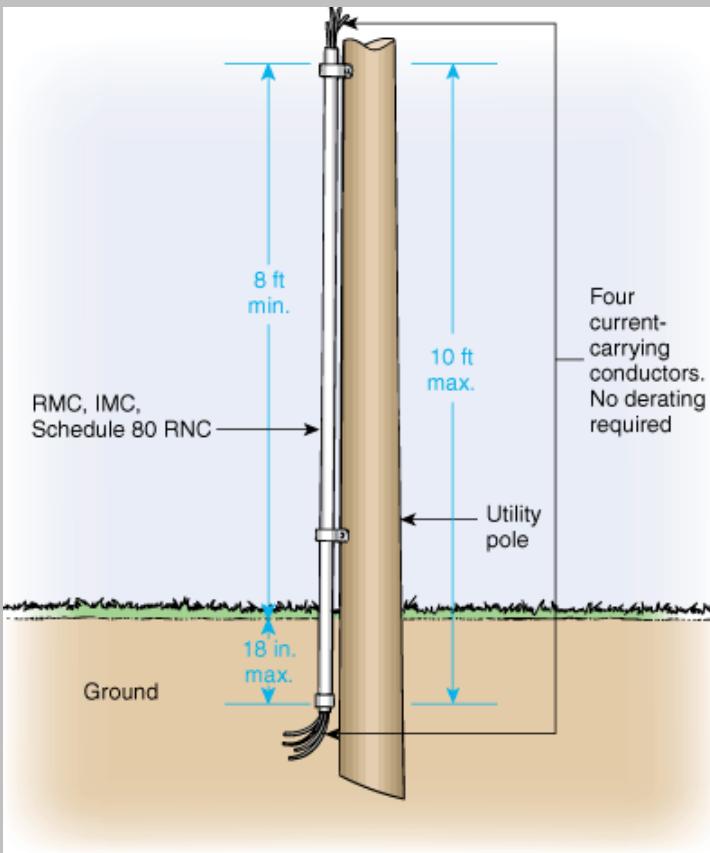


Exhibit 310.4 An application of 310.15(B)(2)(a), Exception No. 4.

Exception No. 5: Adjustment factors shall not apply to Type AC cable or to Type MC cable without an overall outer jacket under the following conditions:

- (a) *Each cable has not more than three current-carrying conductors.*
- (b) *The conductors are 12 AWG copper.*
- (c) *Not more than 20 current-carrying conductors are bundled, stacked, or supported on "bridle rings."*

A 60 percent adjustment factor shall be applied where the current-carrying conductors in these cables that are stacked or bundled longer than 600 mm (24 in.) without maintaining spacing exceeds 20.

Example

A commercial office space will require fourteen 277-volt fluorescent lighting circuits to serve a single open office area. The office area lighting is assumed to be a continuous load, and the office ambient temperature will not exceed 30°C (86°F). Each circuit will be arranged so that it has a computed load not exceeding 16 amperes. The selected wiring method is Type MC cable, 3-conductor (with an additional equipment grounding conductor), 12 AWG THHN copper. Each individual MC cable will contain a 3-wire multiwire branch circuit. To serve the entire area, this arrangement will require a total of seven Type MC cables bundled for a distance of about 25 ft, without maintaining spacing between them where they leave the electrical room and enter the office area.

Determine the ampacity of each circuit conductor in accordance with 310.15, applying Exception No. 5 to 310.15(B)(2)(a) to account for the bundled cables. Then determine the maximum branch-circuit overcurrent protection permitted for these bundled MC cables.

Solution

Step 1.

To apply Exception No. 5, first determine the quantity of current-carrying conductors. According to 310.15(B)(5), equipment grounding conductors are not counted as current-carrying conductors. According to 310.15(B)(4)(c), fluorescent lighting is considered a nonlinear load, so the grounded conductor of each Type MC cable must be counted as a current-carrying conductor.

$$\begin{aligned} & 7 \text{ cables} \times 3 \text{ conductors each} \\ & = 21 \text{ current-carrying conductors} \end{aligned}$$

Because the quantity of current-carrying conductors exceeds 20, a 60 percent adjustment factor is required by 310.15(B)(2)(a), Exception No. 5.

Step 2.

Determine the ampacity of each current-carrying conductor due to these MC cables with more than 20 current-carrying conductors being bundled.

$$\begin{aligned} & \text{From Table 310.16, 12 AWG THHN} = 30 \text{ amps} \\ & 30 \text{ amps} \times 0.60 = 18 \text{ amps} \end{aligned}$$

Because the actual computed load is 16 amperes of continuous load, 210.19(A)(1) is applicable. The conductors must have an ampacity equal to or greater than the load before the adjustment factor is applied. Because the ampacity of the conductors after the adjustment factor is applied is 18 amperes, no further adjustment is necessary and the conductors are suitable for this installation.

Step 3.

Finally, determine the maximum size of overcurrent protection device permitted for these bundled MC cable branch circuits. Section 240.4(B) permits the use of the next higher standard rating of overcurrent protection device. Therefore, although the conductors have a computed ampacity of 18 amperes, a 20-ampere overcurrent protective device is permitted. In addition, and of significance, the 20-ampere overcurrent protective device is in compliance with 210.20(A), given that the actual 16-ampere continuous load would require a 20-ampere overcurrent protective device, based on the listing of the overcurrent device.

Table 310.15(B)(2)(a) Adjustment Factors for More Than Three Current-Carrying Conductors in a Raceway or Cable

Number of Current-Carrying Conductors	Percent of Values in Tables 310.16 through 310.19 as Adjusted for Ambient Temperature if Necessary
4–6	80
7–9	70
10–20	50
21–30	45
31–40	40
41 and above	35

- (b) More Than One Conduit, Tube, or Raceway. Spacing between conduits, tubing, or raceways shall be maintained.

Spacing is normally maintained between individual conduits in groups of conduit runs from junction box to junction box because of the need to separate the conduits where they enter the junction box, to allow room for locknuts and bushings. Field experience has indicated this degree of spacing between runs has not caused any problems.

(3) Bare or Covered Conductors. Where bare or covered conductors are used with insulated conductors, their allowable ampacities shall be limited to those permitted for the adjacent insulated conductors.

(4) Neutral Conductor.

(a) A neutral conductor that carries only the unbalanced current from other conductors of the same circuit shall not be required to be counted when applying the provisions of 310.15(B)(2)(a).

(b) In a 3-wire circuit consisting of two phase wires and the neutral of a 4-wire, 3-phase, wye-connected system, a common conductor carries

approximately the same current as the line-to-neutral load currents of the other conductors and shall be counted when applying the provisions of 310.15(B)(2)(a).

(c) On a 4-wire, 3-phase wye circuit where the major portion of the load consists of nonlinear loads, harmonic currents are present in the neutral conductor; the neutral shall therefore be considered a current-carrying conductor.

During the 1996 *NEC* cycle, a task group composed of interested parties was created to recommend to the National Electrical Code Committee the direction its standards should take to improve the safeguarding of persons and property from conditions that can be introduced by nonlinear loads. This group was designated the NEC Correlating Committee Ad Hoc Subcommittee on Nonlinear Loads. The scope of this subcommittee was as follows:

- (1) To study the effects of electrical loads producing substantial current distortion upon electrical system distribution components including, but not limited to
 - a. Distribution transformers, current transformers, and others
 - b. Switchboards and panelboards
 - c. Phase and neutral feeder conductors
 - d. Phase and neutral branch-circuit conductors
 - e. Proximate data and communications conductors
- (2) To study harmful effects, if any, to the system components from overheating resulting from these load characteristics
- (3) To make recommendations for methods to minimize the harmful effects of nonlinear loads considering all means, including compensating methods at load sources
- (4) To prepare proposals, if necessary, to amend the 1996 *National Electrical Code*, where amelioration to fire safety may be achieved

The subcommittee reviewed technical literature and electrical theory on the fundamental nature of harmonic distortion, as well as the requirements in and proposals for the 1993 *NEC* regarding nonlinear loads. The subcommittee concluded that, while nonlinear loads can cause undesirable operational effects, including additional heating, no significant threat to persons and property has been adequately substantiated.

The subcommittee agreed with the existing *Code* text regarding nonlinear loads. However, the subcommittee submitted many proposals for the 1996 *NEC*, including a definition of nonlinear load, revised text reflecting that definition, fine print notes calling attention to the effects of nonlinear loads, and proposals permitting the paralleling of neutral conductors in existing installations under engineering supervision.

As part of the subcommittee's final report, nine proposals for changes to the 1993 *NEC* were submitted. All were accepted without modification as

changes to the 1996 *NEC*. Also included in this report and now pertinent to the 2002 *NEC* 310.15(B)(4)(c) is the following discussion.

SHOULD NEUTRAL CONDUCTORS BE OVERSIZED?

There is concern that, because the theoretical maximum neutral current is 1.73 times the balanced phase conductor current, a potential exists for neutral conductor overheating in 3-phase, 4-wire, wye-connected power systems. The subcommittee acknowledged this theoretical basis, although a review of documented information could not identify fires attributed to the use of nonlinear loads.

The subcommittee reviewed all available data regarding measurements of circuits that contain nonlinear loads. The data were obtained from consultants, equipment manufacturers, and testing laboratories, and included hundreds of feeder and branch circuits involving 3-phase, 4-wire, wye-connected systems with nonlinear loads. The data revealed that many circuits had neutral conductor current greater than the phase conductor current, and approximately 5 percent of all circuits reported had neutral conductor current exceeding 125 percent of the highest phase conductor current. One documented survey with data collected in 1988 from 146 three-phase computer power system sites determined that 3.4 percent of the sites had neutral current in excess of the rated system full-load current.

According to 384-16(C) of the 1993 *NEC* (for the 2002 *NEC*, refer to 408.16), the total continuous load on any overcurrent device located in a panelboard should not exceed 80 percent of its rating (the exception being assemblies listed for continuous operation at 100 percent of its rating). Because the neutral conductor is usually not connected to an overcurrent device, derating for continuous operation is not necessary. Therefore, neutral conductor ampacity is usually 125 percent of the maximum continuous current allowed by the overcurrent device.

Also important for gathering electrically measured data from existing installations is the following.

Measurement of Nonsinusoidal Voltages and Currents

The measurement of nonsinusoidal voltages and currents may require instruments different from the conventional meters used to measure sinusoidal waveforms. Many voltage and current meters respond only to the peak value of a waveform, and indicate a value that is equivalent to the rms value of a sinusoidal waveform. For a sinusoidal waveform the rms value will be 70.7 percent of the peak value. Meters of this type are known as "average responding meters" and will only give a true indication if the waveform being measured is sinusoidal. Both analog and digital meters may be average responding instruments. Voltages and currents that are nonsinusoidal, such as those with harmonic frequencies, cannot be accurately measured using an average responding meter. Only a meter that measures "true rms" can be used to correctly measure the rms value of a nonsinusoidal waveform.

Exhibit 310.5 shows an example of a clamp-on ammeter that uses true rms measurements. Exhibit 310.6 shows an example of a portable diagnostic analyzer used for more sophisticated power measurements, including measuring harmonic distortion.



Exhibit 310.5 A clamp-on ammeter that uses true rms measurements. (Courtesy of Fluke Corp.)



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Exhibit 310.6 A portable tool for such tasks as diagnostic power analysis including harmonic distortion. (Courtesy of Dranetz-BMI)

(5) Grounding or Bonding Conductor. A grounding or bonding conductor shall not be counted when applying the provisions of 310.15(B)(2)(a).

(6) 120/240-Volt, 3-Wire, Single-Phase Dwelling Services and Feeders. For dwelling units, conductors, as listed in Table 310.15(B)(6), shall be permitted as 120/240-volt, 3-wire, single-phase service-entrance conductors, service lateral conductors, and feeder conductors that serve as the main power feeder to a dwelling unit and are installed in raceway or cable with or without an equipment grounding conductor. For application of this section, the main power feeder shall be the feeder(s) between the main disconnect and the lighting and appliance branch-circuit panelboard(s). The feeder conductors to a dwelling unit shall not be required to be larger than their service-entrance conductors. The grounded conductor shall be permitted to be smaller than the ungrounded conductors, provided the requirements of 215.2, 220.22, and 230.42 are met.

**Table 310.15(B)(6) Conductor Types and Sizes for
120/240-Volt, 3-Wire, Single-Phase Dwelling Services and
Feeders. Conductor Types RHH, RHW, RHW-2, THHN,
THHW, THW, THW-2, THWN, THWN-2, XHHW,
XHHW-2, SE, USE, USE-2**

Conductor (AWG or kcmil)		
Copper	Aluminum or Copper-Clad Aluminum	Service or Feeder Rating (Amperes)
4	2	100
3	1	110
2	1/0	125
1	2/0	150
1/0	3/0	175
2/0	4/0	200
3/0	250	225
4/0	300	250
250	350	300
350	500	350
400	600	400

If a single set of 3-wire, single-phase, service-entrance conductors in raceway or cable supplies a one-family, two-family, or multifamily dwelling, the reduced conductor size permitted by 310.15(B)(6) is applicable to the service-entrance conductors, service-lateral conductors, or any feeder

conductors that supply the main power feeder to a dwelling unit.

This section permits the main feeder to a dwelling unit to be sized according to the conductor sizes in Table 310.15(B)(6) even if other loads, such as ac units and pool loads, are fed from the same service. The feeder conductors to a dwelling unit are not required to be larger than its service-entrance conductors.

Exhibits 310.7 and 310.8 illustrate the application of 310.15(B)(6). In Exhibit 310.7, the reduced conductor size permitted is applicable to the service-entrance conductors run to each apartment from the meters. In Exhibit 310.8, the reduced conductor size permitted is also applicable to the feeder conductors run to each apartment from the service disconnecting means, because these feeders carry the entire load to each apartment.

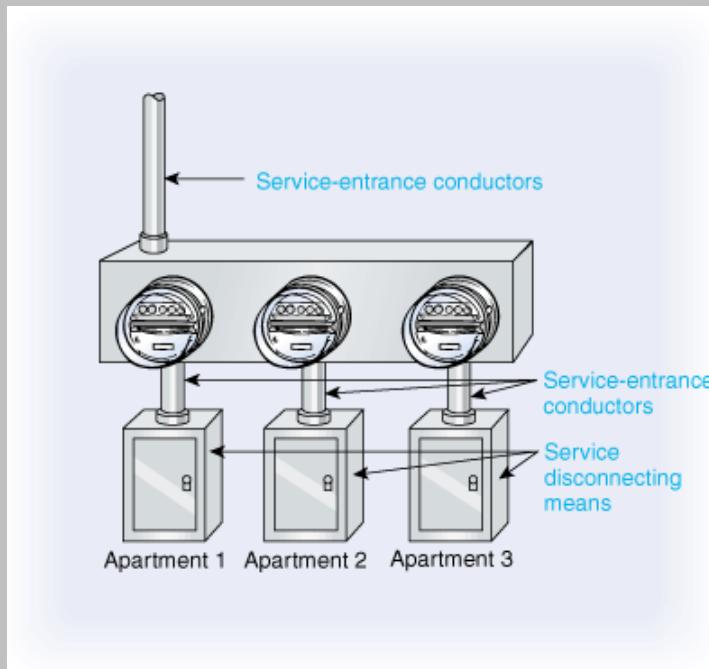


Exhibit 310.7 An application of 310.15(B)(6).

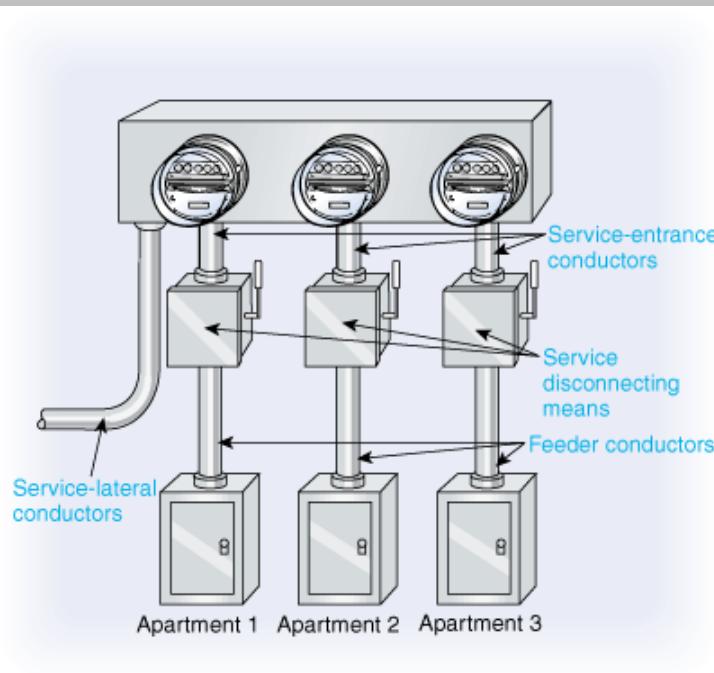


Exhibit 310.8 Another application of 310.15(B)(6).

Previously limited to a two-wire size reduction but changed in the 1996 *Code*, the grounded conductor is now permitted to be reduced more than two sizes. The stipulation is that the requirements from the other applicable *Code* sections are observed, including 250.24(B).

Other sections of the *Code* must also be applied for determining the size of service or feeder conductors. Section 230.42 requires service conductors to be of sufficient size to carry the load calculated in accordance with Article 220. It should not be taken for granted that the grounded (neutral) conductor can be automatically reduced. In addition to the load, the grounded (neutral) conductor must also provide a low-impedance fault path capable of conducting fault current back to the transformer. Section 250.24(B) provides the requirements for determining the minimum size grounded (neutral) conductor.

Section 250.24(B) is not applicable to the grounded (neutral) conductor of feeders; therefore, the minimum size is governed by 220.22. This section requires the grounded (neutral) conductor to be large enough to carry the maximum unbalance of the net computed load connected to the neutral and any one ungrounded conductor. In the event that there are no 240-volt loads, the neutral, under severe unbalanced conditions, carries the same current

as the ungrounded conductor supplying the load.

(C) Engineering Supervision. Under engineering supervision, conductor ampacities shall be permitted to be calculated by means of the following general formula:

$$I = \sqrt{\frac{TC - (TA + \Delta TD)}{RDC(1 + YC)RCA}}$$

where:

TC = conductor temperature in degrees Celsius ($^{\circ}\text{C}$)

TA = ambient temperature in degrees Celsius ($^{\circ}\text{C}$)

ΔTD = dielectric loss temperature rise

RDC = dc resistance of conductor at temperature TC

YC = component ac resistance resulting from skin effect and proximity effect

RCA = effective thermal resistance between conductor and surrounding ambient

FPN: See Annex B for examples of formula applications.

The formula in 310.15(C) was developed by J. H. Neher and M. H. McGrath to determine conductor ampacity. It is actually a composite of a number of separate formulas. A description of this method of calculation was given in AIEE paper No. 5-660, "The Calculation of the Temperature Rise and Load Capability of Cable Systems," by J. H. Neher and M. H. McGrath. This paper was presented to the AIEE general meeting in Montreal, Quebec, on June 24-28, 1956, and was published in *AIEE Transactions, Part III (Power Apparatus and Systems)*, Vol. 76, October 1957, pp. 752-772. AIEE (American Institute of Electrical Engineers) is now IEEE (Institute of Electrical and Electronic Engineers).

The Neher-McGrath formula in 310.15(C) is a heat-transfer formula, composed of a series of heat-transfer calculations, that takes into account all heat sources and the thermal resistances between the heat sources and free air. The most common use for the Neher-McGrath formula is to calculate the ampacity of conductors in underground electrical ducts (raceways), although the formula is applicable to all conductor installations.

It is not the intent of the following discussion to provide instruction on the use of the Neher-McGrath method of calculation. The intent is to identify the many factors affecting the calculations. It is because of these many variables and the complexities of the many formulas involved that the *Code* requires the calculation to be made under engineering supervision.

Current passing through a conductor produces I^2R losses in the form of heat, which results from conductor losses and appears as a temperature rise in the conductor. This heat must pass through the cable insulation, the air in the raceway, and the raceway itself to the surrounding medium, usually earth or concrete, where it is dissipated into the air by radiation and convection. Unless the heat is dissipated, the temperature in the conductor will exceed the rating of the conductor insulation.

The conductor's ampacity is based on the rate of heat dissipation through the thermal resistances surrounding the conductor. Current traveling through a material with a specific resistance at a specified temperature generates this heat. Additional heat is caused by skin and proximity effects, because usually the current is ac and there are other conductors in the same duct.

For conductors in underground electrical ducts, there are several heat sources, as follows, and as illustrated in Exhibit 310.9.

- (1) *Conductor losses due to the load current I^2R .* These losses vary with the load current, conductor material, and conductor cross-sectional area (conductor size).
- (2) *Skin-effect heating if the current is alternating current.* The heat developed by the skin effect is due to the shape of the conductor and is based on the configuration of the conductors (i.e., solid, stranded, or compact).
- (3) *Hysteresis losses if the duct is steel or other magnetic material.* These losses are dependent upon the magnetic properties of the electrical duct and the shape of the duct.
- (4) *Heating from other conductors in the duct.* This heating is based on the number, location, and proximity of other conductors as well as the losses in the other conductors. The more conductors in the raceway, the greater the heating effect from these conductors is likely to be. This factor replaces the adjustment factors in 310.15(B)(2)(a) to the ampacity tables.
- (5) *Mutual heating from other ducts, cables, etc., in the vicinity.* The closer the other heat sources and the more they surround the duct for which calculations are being made, the greater the heating effect. For example, in the case of a symmetrical 9-duct bank, 3 ducts high and 3 ducts wide, the center duct will receive the most heat as a result of mutual heating.

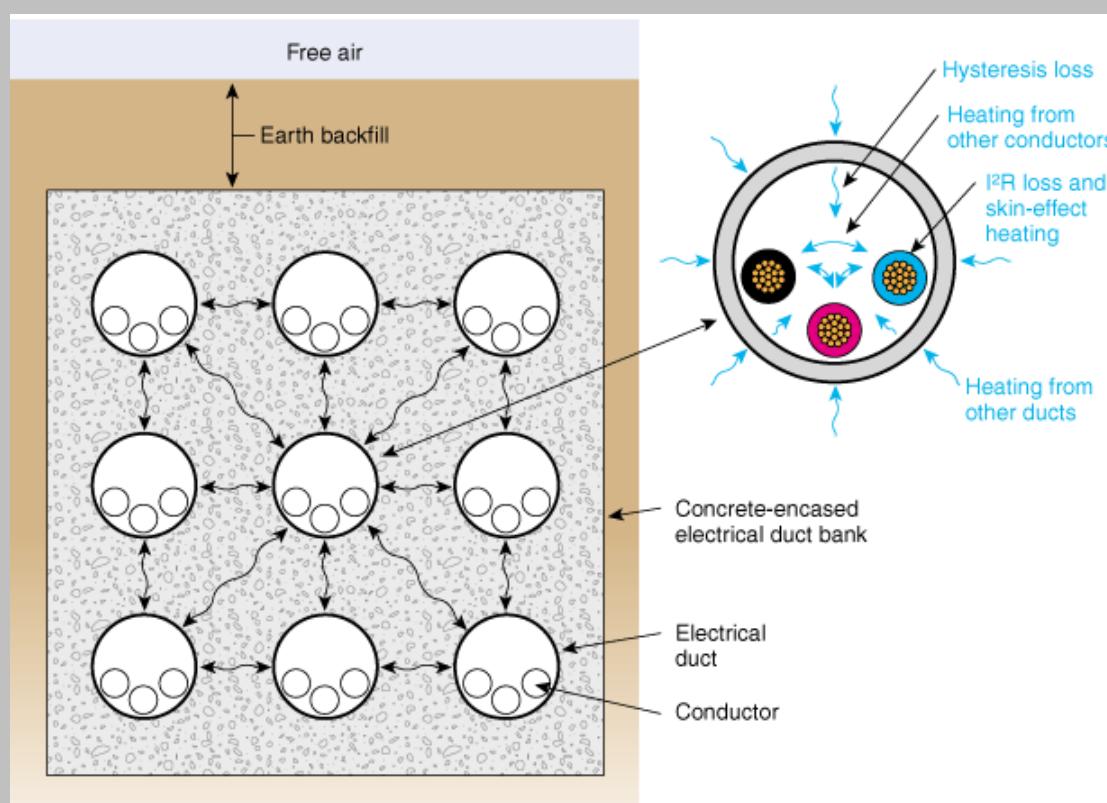


Exhibit 310.9 Heat sources.

Heat generated by the following various types of losses is conducted through the different thermal barriers or resistances, as illustrated in Exhibit 310.10.

Conductor insulation. The conductor insulation, which is designed to perform as a good electrical insulator, also serves as a good thermal insulator. It presents a thermal resistance to heat generated by the conductor due to the I^2R losses, including any dielectric losses. This thermal resistance value depends on the thickness of the insulation and the type of insulating material used. Materials such as polyvinyl chloride, used in Type THW and other conductors; cross-linked polyethylene, used in Type XHHW and other conductors; and rubber, used in Type RHW and other conductors, have different thermal resistivities. In addition, the thickness of the conductor insulation varies from one type of insulation to another, even for the same

size conductor.

Airspace. The next thermal barrier encountered by the heat flow generated in the conductor is the airspace between the conductor insulation and the surrounding wall or raceway. The thermal resistance of this airspace is based on the number of conductors in the duct, the assumed mean value of the temperature of the air in the duct, and the constants provided in the Neher-McGrath paper, which were determined from experimental data.

Duct wall. After it passes through the airspace around the conductors, the heat encounters the thermal resistance of the duct wall. This thermal resistance is based on the thermal resistivity of the type of material used and the thickness of the duct wall. Metallic materials have less thermal resistance than nonmetallic materials. The thicker the wall, the greater the thermal resistance.

Earth backfill. The thermal resistance that must be considered next is that offered by the earth or other backfill material above the duct. This incorporates not only the thermal resistivity and ambient temperature of the earth but also the number of current-carrying conductors within the duct, the outside diameter of the duct, the burial depth, a loss factor, and the mutual heating factor caused by other nearby ducts. The deeper the duct is buried, the greater the thermal resistance.

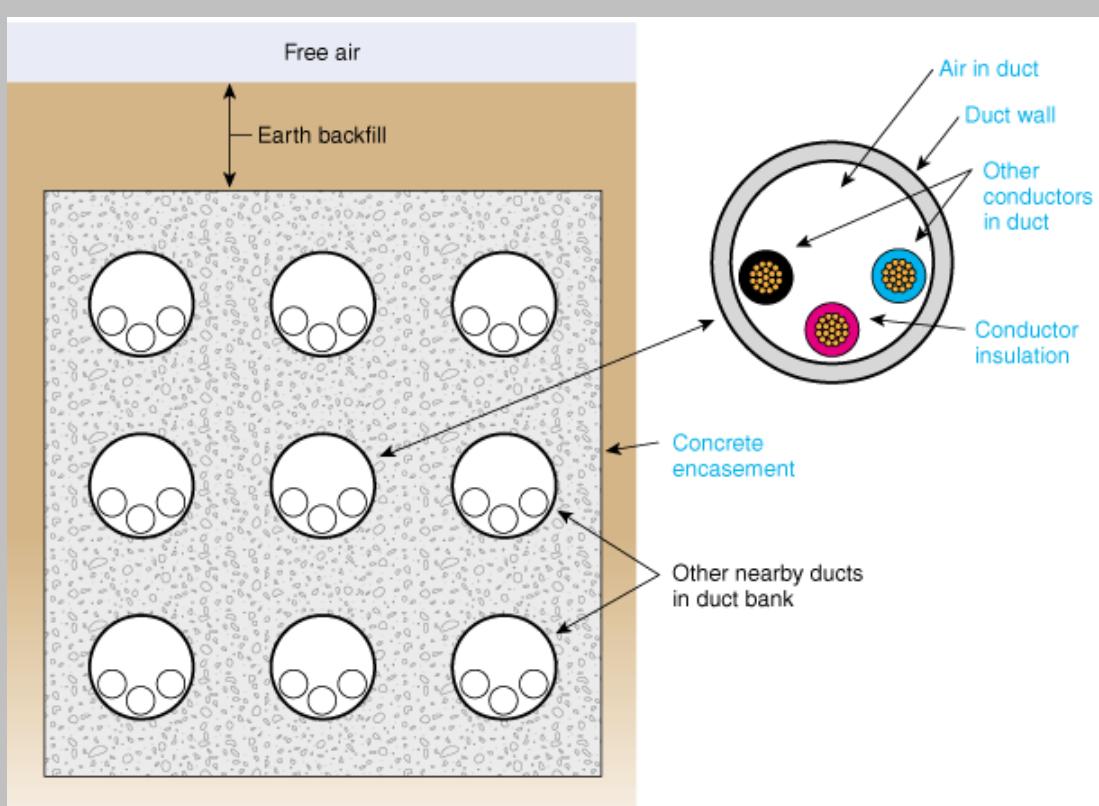


Exhibit 310.10 Thermal barriers (resistances).

To prevent the temperature of the conductors from exceeding the rated temperature of the insulation, heat dissipation through these thermal resistances must be equal to or greater than the heat developed. Thus, the thermal resistances of all the components of a conductor must be determined, and the allowable temperature differential above the ambient temperature and between the conductors and the surface of the earth must be known.

In addition to the Neher-McGrath paper itself, as described in the first paragraph of this commentary, the following references provide more detailed information on the use of this method of calculation:

“Power Cable Ampacity Tables,” Insulated Power Cable Engineers Association, IPCEA P-46-426 (IEEE S-135-1).

"IEEE Standard Power Cable Ampacity Tables," Institute of Electrical and Electronic Engineers, IEEE Standard 835-1994.

"Neher-McGrath Calculations for Insulated Power Cables," Peter Pollak, IEEE Paper No. CH2040-4/84/0000-0172, presented at the 1984 IEEE Industrial and Commercial Power Systems Technical Conference, Atlanta, GA, May 9, 1984.

"Cable Ampacities, the NEC and Computerized Applications," M. T. Brown et al., IEEE Paper No. CH2207-9/85/00000-0323.

"How to Use the Neher-McGrath Method to Calculate Ampacity of Underground Conductors," John M. Caloggero, NFPA *Fire Journal*, pp. 17-18, May/June 1988.

Table 310.16 Allowable Ampacities of Insulated Conductors Rated 0 Through 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)

Size AWG or kcmil	Temperature Rating of Conductor (See Table 310.13.)						Size AWG or kcmil
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
COPPER				ALUMINUM OR COPPER-CLAD ALUMINUM			
18	—	—	14	—	—	—	—
16	—	—	18	—	—	—	—
14*	20	20	25	—	—	—	—
12*	25	25	30	20	20	25	12*
10*	30	35	40	25	30	35	10*
8	40	50	55	30	40	45	8
6	55	65	75	40	50	60	6
4	70	85	95	55	65	75	4
3	85	100	110	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	150	85	100	115	1
1/0	125	150	170	100	120	135	1/0

Table 310.16 Allowable Ampacities of Insulated Conductors Rated 0 Through 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)

Size AWG or kcmil	Temperature Rating of Conductor (See Table 310.13.)						Size AWG or kcmil
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
COPPER							
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	190	230	255	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500
600	355	420	475	285	340	385	600
700	385	460	520	310	375	420	700
750	400	475	535	320	385	435	750
800	410	490	555	330	395	450	800
900	435	520	585	355	425	480	900
1000	455	545	615	375	445	500	1000
1250	495	590	665	405	485	545	1250
1500	520	625	705	435	520	585	1500
1750	545	650	735	455	545	615	1750
2000	560	665	750	470	560	630	2000
CORRECTION FACTORS							
Ambient Temp. (°C)	For ambient temperatures other than 30°C (86°F), multiply the allowable ampacities shown above by the appropriate factor shown below.						Ambient Temp. (°F)

Table 310.16 Allowable Ampacities of Insulated Conductors Rated 0 Through 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)

Size AWG or kcmil	Temperature Rating of Conductor (See Table 310.13.)						Size AWG or kcmil
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
COPPER				ALUMINUM OR COPPER-CLAD ALUMINUM			
21–25	1.08	1.05	1.04	1.08	1.05	1.04	70–77
26–30	1.00	1.00	1.00	1.00	1.00	1.00	78–86
31–35	0.91	0.94	0.96	0.91	0.94	0.96	87–95
36–40	0.82	0.88	0.91	0.82	0.88	0.91	96–104
41–45	0.71	0.82	0.87	0.71	0.82	0.87	105–113
46–50	0.58	0.75	0.82	0.58	0.75	0.82	114–122
51–55	0.41	0.67	0.76	0.41	0.67	0.76	123–131
56–60	—	0.58	0.71	—	0.58	0.71	132–140
61–70	—	0.33	0.58	—	0.33	0.58	141–158
71–80	—	—	0.41	—	—	0.41	159–176

* See 240.4(D).

Table 310.17 Allowable Ampacities of Single-Insulated Conductors Rated 0 Through 2000 Volts in Free Air, Based on Ambient Air Temperature of 30°C (86°F)

Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Size AWG or kcmil
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			

Table 310.17 Allowable Ampacities of Single-Insulated Conductors Rated 0 Through 2000 Volts in Free Air, Based on Ambient Air Temperature of 30°C (86°F)

Size AWG or kcmil	Temperature Rating of Conductor (See Table 310.13.)						Size AWG or kcmil
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Size AWG or kcmil
COPPER	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			
18	—	—	18	—	—	—	—
16	—	—	24	—	—	—	—
14*	25	30	35	—	—	—	—
12*	30	35	40	25	30	35	12*
10*	40	50	55	35	40	40	10*
8	60	70	80	45	55	60	8
6	80	95	105	60	75	80	6
4	105	125	140	80	100	110	4
3	120	145	165	95	115	130	3
2	140	170	190	110	135	150	2
1	165	195	220	130	155	175	1

Table 310.17 Allowable Ampacities of Single-Insulated Conductors Rated 0 Through 2000 Volts in Free Air, Based on Ambient Air Temperature of 30°C (86°F)

Size AWG or kcmil	Temperature Rating of Conductor (See Table 310.13.)						Size AWG or kcmil
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW	Types TBS, SA, SIS, THHN, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
COPPER							
1/0	195	230	260	150	180	205	1/0
2/0	225	265	300	175	210	235	2/0
3/0	260	310	350	200	240	275	3/0
4/0	300	360	405	235	280	315	4/0
250	340	405	455	265	315	355	250
300	375	445	505	290	350	395	300
350	420	505	570	330	395	445	350
400	455	545	615	355	425	480	400
500	515	620	700	405	485	545	500
600	575	690	780	455	540	615	600
700	630	755	855	500	595	675	700
750	655	785	885	515	620	700	750
800	680	815	920	535	645	725	800
900	730	870	985	580	700	785	900
1000	780	935	1055	625	750	845	1000
1250	890	1065	1200	710	855	960	1250
1500	980	1175	1325	795	950	1075	1500
1750	1070	1280	1445	875	1050	1185	1750
2000	1155	1385	1560	960	1150	1335	2000
CORRECTION FACTORS							
Ambient Temp. (°C)	For ambient temperatures other than 30°C (86°F), multiply the allowable ampacities shown above by the appropriate factor shown below.						Ambient Temp. (°F)

Table 310.17 Allowable Ampacities of Single-Insulated Conductors Rated 0 Through 2000 Volts in Free Air, Based on Ambient Air Temperature of 30°C (86°F)

Size AWG or kcmil	Temperature Rating of Conductor (See Table 310.13.)						Size AWG or kcmil
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
COPPER							
21–25	1.08	1.05	1.04	1.08	1.05	1.04	70–77
26–30	1.00	1.00	1.00	1.00	1.00	1.00	78–86
31–35	0.91	0.94	0.96	0.91	0.94	0.96	87–95
36–40	0.82	0.88	0.91	0.82	0.88	0.91	96–104
41–45	0.71	0.82	0.87	0.71	0.82	0.87	105–113
46–50	0.58	0.75	0.82	0.58	0.75	0.82	114–122
51–55	0.41	0.67	0.76	0.41	0.67	0.76	123–131
56–60	—	0.58	0.71	—	0.58	0.71	132–140
61–70	—	0.33	0.58	—	0.33	0.58	141–158
71–80	—	—	0.41	—	—	0.41	159–176

* See 240.4(D).

Table 310.18 Allowable Ampacities of Insulated Conductors Rated 0 Through 2000 Volts, 150°C Through 250°C (302°F Through 482°F). Not More Than Three Current-Carrying Conductors in Raceway or Cable, Based on Ambient Air Temperature of 40°C (104°F)

Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW	THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Size AWG or kcmil
		COPPER				ALUMINUM OR COPPER-CLAD ALUMINUM	

Table 310.18 Allowable Ampacities of Insulated Conductors Rated 0 Through 2000 Volts, 150°C Through 250°C (302°F Through 482°F). Not More Than Three Current-Carrying Conductors in Raceway or Cable, Based on Ambient Air Temperature of 40°C (104°F).

Size AWG or kcmil	Temperature Rating of Conductor (See Table 310.13.)				Size AWG or kcmil
	150°C (302°F)	200°C (392°F)	250°C (482°F)	150°C (302°F)	
	Type Z	Types FEP, FEPB, PFA	Types PFAH, TFE	Type Z	
COPPER		NICKEL OR NICKEL-COATED COPPER		ALUMINUM OR COPPER-CLAD ALUMINUM	
14	34	36	39	—	14
12	43	45	54	30	12
10	55	60	73	44	10
8	76	83	93	57	8
6	96	110	117	75	6
4	120	125	148	94	4
3	143	152	166	109	3
2	160	171	191	124	2
1	186	197	215	145	1
1/0	215	229	244	169	1/0
2/0	251	260	273	198	2/0
3/0	288	297	308	227	3/0
4/0	332	346	361	260	4/0

CORRECTION FACTORS

Ambient Temp. (°C)	For ambient temperatures other than 40°C (104°F), multiply the allowable ampacities shown above by the appropriate factor shown below.			Ambient Temp. (°F)
41–50	0.95	0.97	0.98	105–122
51–60	0.90	0.94	0.95	123–140
61–70	0.85	0.90	0.93	141–158

Table 310.18 Allowable Ampacities of Insulated Conductors Rated 0 Through 2000 Volts, 150°C Through 250°C (302°F Through 482°F). Not More Than Three Current-Carrying Conductors in Raceway or Cable, Based on Ambient Air Temperature of 40°C (104°F)

Size AWG or kcmil	Temperature Rating of Conductor (See Table 310.13.)				Size AWG or kcmil
	150°C (302°F)	200°C (392°F)	250°C (482°F)	150°C (302°F)	
	Type Z	Types FEP, FEPB, PFA	Types PFAH, TFE	Type Z	
	COPPER	NICKEL OR NICKEL-COATED COPPER	ALUMINUM OR COPPER-CLAD ALUMINUM		
71–80	0.80	0.87	0.90	0.80	159–176
81–90	0.74	0.83	0.87	0.74	177–194
91–100	0.67	0.79	0.85	0.67	195–212
101–120	0.52	0.71	0.79	0.52	213–248
121–140	0.30	0.61	0.72	0.30	249–284
141–160	—	0.50	0.65	—	285–320
161–180	—	0.35	0.58	—	321–356
181–200	—	—	0.49	—	357–392
201–225	—	—	0.35	—	393–437

Table 310.19 Allowable Ampacities of Single-Insulated Conductors, Rated 0 Through 2000 Volts, 150°C Through 250°C (302°F Through 482°F), in Free Air, Based on Ambient Air Temperature of 40°C (104°F)

Size AWG or kcmil	Temperature Rating of Conductor (See Table 310.13.)				Size AWG or kcmil
	150°C (302°F)	200°C (392°F)	250°C (482°F)	150°C (302°F)	
	Type Z	Types FEP, FEPB, PFA	Types PFAH, TFE	Type Z	
	COPPER	NICKEL, OR NICKEL-COATED COPPER	ALUMINUM OR COPPER-CLAD ALUMINUM		
14	46	54	59	—	14
12	60	68	78	47	12
10	80	90	107	63	10
8	106	124	142	83	8

Table 310.19 Allowable Ampacities of Single-Insulated Conductors, Rated 0 Through 2000 Volts, 150°C Through 250°C (302°F Through 482°F), in Free Air, Based on Ambient Air Temperature of 40°C (104°F)

Size AWG or kcmil	Temperature Rating of Conductor (See Table 310.13.)				Size AWG or kcmil
	150°C (302°F)	200°C (392°F)	250°C (482°F)	150°C (302°F)	
	Type Z	Types FEP, FEPB, PFA	Types PFAH, TFE	Type Z	
COPPER			NICKEL, OR NICKEL-COATED COPPER	ALUMINUM OR COPPER-CLAD ALUMINUM	
6	155	165	205	112	6
4	190	220	278	148	4
3	214	252	327	170	3
2	255	293	381	198	2
1	293	344	440	228	1
1/0	339	399	532	263	1/0
2/0	390	467	591	305	2/0
3/0	451	546	708	351	3/0
4/0	529	629	830	411	4/0

CORRECTION FACTORS

Ambient Temp. (°C)	For ambient temperatures other than 40°C (104°F), multiply the allowable ampacities shown above by the appropriate factor shown below.			Ambient Temp. (°F)
41–50	0.95	0.97	0.98	105–122
51–60	0.90	0.94	0.95	123–140
61–70	0.85	0.88	0.92	141–150

Table 310.19 Allowable Ampacities of Single-Insulated Conductors, Rated 0 Through 2000 Volts, 150°C Through 250°C (302°F Through 482°F), in Free Air, Based on Ambient Air Temperature of 40°C (104°F)

Size AWG or kcmil	Temperature Rating of Conductor (See Table 310.13.)				Size AWG or kcmil
	150°C (302°F)	200°C (392°F)	250°C (482°F)	150°C (302°F)	
	Type Z	Types FEP, FEPB, PFA	Types PFAH, TFE	Type Z	
	COPPER	NICKEL, OR NICKEL-COATED COPPER	ALUMINUM OR COPPER-CLAD ALUMINUM		
61–70	0.85	0.90	0.93	0.85	141–158
71–80	0.80	0.87	0.90	0.80	159–176
81–90	0.74	0.83	0.87	0.74	177–194
91–100	0.67	0.79	0.85	0.67	195–212
101–120	0.52	0.71	0.79	0.52	213–248
121–140	0.30	0.61	0.72	0.30	249–284
141–160	—	0.50	0.65	—	285–320
161–180	—	0.35	0.58	—	321–356
181–200	—	—	0.49	—	357–392
201–225	—	—	0.35	—	393–437

Table 310.20 Ampacities of Not More Than Three Single Insulated Conductors, Rated 0 Through 2000 Volts, Supported on a Messenger, Based on Ambient Air Temperature of 40°C (104°F)

Table 310.20 Ampacities of Not More Than Three Single Insulated Conductors, Rated 0 Through 2000 Volts, Supported on a Messenger, Based on Ambient Air Temperature of 40°C (104°F)

Size AWG or kcmil	Temperature Rating of Conductor (See Table 310.13.)				Size AWG or kcmil
	75°C (167°F)	90°C (194°F)	75°C (167°F)	90°C (194°F)	
	Types RHW, THHW, THW, THWN, XHHW, ZW	Types MI, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHHW, XHHW-2, ZW-2	Types RHW, THW, THWN, THHW, XHHW	Types THHN, THHW, RHH, XHHW, RHW-2, XHHW-2, THW-2, THWN-2, USE-2, ZW-2	
	COPPER	ALUMINUM OR COPPER-CLAD ALUMINUM		CORRECTION FACTORS	
Ambient Temp. (°C)	For ambient temperatures other than 40°C (104°F), multiply the allowable ampacities shown above by the appropriate factor shown below.				Ambient Temp. (°F)
21–25	1.20	1.14	1.20	1.14	70–77
26–30	1.13	1.10	1.13	1.10	79–86
31–35	1.07	1.05	1.07	1.05	88–95
36–40	1.00	1.00	1.00	1.00	97–104
41–45	0.93	0.95	0.93	0.95	106–113
46–50	0.85	0.89	0.85	0.89	115–122
51–55	0.76	0.84	0.76	0.84	124–131
56–60	0.65	0.77	0.65	0.77	133–140
61–70	0.38	0.63	0.38	0.63	142–158
71–80	—	0.45	—	0.45	160–176

Table 310.21 Ampacities of Bare or Covered Conductors in Free Air, Based on 40°C (104°F) Ambient, 80°C (176°F) Total Conductor Temperature, 610 mm/sec (2 ft/sec) Wind Velocity

Copper Conductors				AAC Aluminum Conductors			
Bare		Covered		Bare		Covered	
AWG or kcmil	Amperes	AWG or kcmil	Amperes	AWG or kcmil	Amperes	AWG or kcmil	Amperes
8	98	8	103	8	76	8	80
6	124	6	130	6	96	6	101
4	155	4	163	4	121	4	127
2	209	2	219	2	163	2	171
1/0	282	1/0	297	1/0	220	1/0	231
2/0	329	2/0	344	2/0	255	2/0	268
3/0	382	3/0	401	3/0	297	3/0	312
4/0	444	4/0	466	4/0	346	4/0	364
250	494	250	519	266.8	403	266.8	423
300	556	300	584	336.4	468	336.4	492
500	773	500	812	397.5	522	397.5	548
750	1000	750	1050	477.0	588	477.0	617
1000	1193	1000	1253	556.5	650	556.5	682
—	—	—	—	636.0	709	636.0	744
—	—	—	—	795.0	819	795.0	860
—	—	—	—	954.0	920	—	—
—	—	—	—	1033.5	968	1033.5	1017
—	—	—	—	1272	1103	1272	1201
—	—	—	—	1590	1267	1590	1381
—	—	—	—	2000	1454	2000	1527

110.14 Electrical Connections.

Because of different characteristics of dissimilar metals, devices such as pressure terminal or pressure splicing connectors and soldering lugs shall be identified for the material of the conductor and shall be properly installed and used. Conductors of dissimilar metals shall not be intermixed in a terminal or splicing connector where physical contact occurs between dissimilar conductors (such as copper and aluminum, copper and copper-clad aluminum, or aluminum and copper-clad aluminum), unless the device is identified for the purpose and conditions of use. Materials such as solder, fluxes, inhibitors, and compounds, where employed, shall be suitable for the use and shall be of a type that will not adversely affect the conductors, installation, or equipment.

FPN: Many terminations and equipment are marked with a tightening torque.

Section 110.3(B) applies where terminations and equipment are marked with tightening torques.

For the testing of wire connectors for which the manufacturer has not assigned another value appropriate for the design, Tables 1.2 through 1.5 provide data on the tightening torques that Underwriters Laboratories uses. These tables should be used for guidance only if no tightening information on the specific wire connector is available. They should not be used to replace the manufacturer's instructions, which should always be followed.

The information in the tables was taken from the edition of UL Standard 486B, *Wire Connections for Use with Aluminum Conductors*, in effect at the time of the printing of the 2002 edition of this handbook. Similar information can be found in UL 486A, *Wire Connections and Solder Lugs for Use with Copper Conductors*.

Table 1.2 Tightening Torques for Screws* in Pound-Inches

Wire Size (AWG or kcmil)	Slotted Head No. 10 and Larger		Hexagonal Head-External Drive Socket Wrench	
	Slot Width to $\frac{3}{64}$ in. or Slot Length to $\frac{1}{4}$ in.	Slot Width Over $\frac{3}{64}$ in. or Slot Length Over $\frac{1}{4}$ in.**	Split-Bolt Connectors	Other Connectors
	in.**	in.**		
30-10	20	35	80	75
8	25	40	80	75
6	35	45	165	110
4	35	45	165	110
3	35	50	275	150
2	40	50	275	150
1	—	50	275	150
1/00	—	50	385	180
2/00	—	50	385	180
3/00	—	50	500	250

Table 1.2 Tightening Torques for Screws* in Pound-Inches

Wire Size (AWG or kcmil)	Slotted Head No. 10 and Larger		Hexagonal Head-External Drive Socket Wrench	
	Slot Width to $\frac{3}{64}$ in. or Slot Length to $\frac{1}{4}$ in.	Slot Width Over $\frac{3}{64}$ in. or Slot Length Over $\frac{1}{4}$ in.**	Split-Bolt Connectors	Other Connectors
	in.**	in.**		
4/00	—	50	500	250
250	—	50	650	325
300	—	50	650	325
350	—	50	650	325
400	—	50	825	325
500	—	50	825	375
600	—	50	1000	375
700	—	50	1000	375
750	—	50	1000	375
800	—	50	1100	500
900	—	50	1100	500
1000	—	50	1100	500
1250	—	—	1100	600
1500	—	—	1100	600
1750	—	—	1100	600
2000	—	—	1100	600

*Clamping screws with multiple tightening means. For example, for a slotted hexagonal head screw, use the torque value associated with the tool used in the installation. UL uses both values when testing.

**For values of slot width or length other than those specified, select the largest torque value associated with conductor size.

Table 1.3 Torques in Pound-Inches for Slotted Head Screws* Smaller Than No. 10, for Use with 8 AWG and Smaller Conductors

Screw-Slot Length (in.)**	Screw-Slot Width Less Than $\frac{3}{64}$ in.	Screw-Slot Width $\frac{3}{64}$ in. and Larger
To $\frac{5}{32}$	7	9
$\frac{5}{32}$	7	12
$\frac{3}{16}$	7	12
$\frac{7}{32}$	7	12

Table 1.3 Torques in Pound-Inches for Slotted Head Screws* Smaller Than No. 10, for Use with 8 AWG and Smaller Conductors

Screw-Slot Length (in.)**	Screw-Slot Width Less Than $\frac{3}{64}$ in.	Screw-Slot Width $\frac{3}{64}$ in. and Larger
$\frac{1}{4}$	9	12
$\frac{9}{32}$	—	15
Above $\frac{9}{32}$	—	20

*Clamping screws with multiple tightening means. For example, for a slotted hexagonal head screw, use the torque value associated with the tool used in the installation. UL uses both values when testing.

**For slot lengths of intermediate values, select torques pertaining to next-shorter slot length.

Table 1.4 Torques for Recessed Allen Head Screws

Socket Size Across Flats (in.)	Torque (lb-in.)
$\frac{1}{8}$	45
$\frac{5}{32}$	100
$\frac{3}{16}$	120
$\frac{7}{32}$	150
$\frac{1}{4}$	200
$\frac{5}{16}$	275
$\frac{3}{8}$	375
$\frac{1}{2}$	500
$\frac{9}{16}$	600

Table 1.5 Lug-Bolting Torques for Connection of Wire Connectors to Busbars

Bolt Diameter	Tightening Torque (lb-ft)
No. 8 or smaller	1.5
No. 10	2
$\frac{1}{4}$ in. or less	6
$\frac{5}{16}$ in.	11

Table 1.5 Lug-Bolting Torques for Connection of Wire Connectors to Busbars

Bolt Diameter	Tightening Torque (lb-ft)
3/8 in.	19
7/16 in.	30
1/2 in.	40
9/16 in. or larger	55

(A) Terminals. Connection of conductors to terminal parts shall ensure a thoroughly good connection without damaging the conductors and shall be made by means of pressure connectors (including set-screw type), solder lugs, or splices to flexible leads. Connection by means of wire-binding screws or studs and nuts that have upturned lugs or the equivalent shall be permitted for 10 AWG or smaller conductors.

Terminals for more than one conductor and terminals used to connect aluminum shall be so identified.

(B) Splices. Conductors shall be spliced or joined with splicing devices identified for the use or by brazing, welding, or soldering with a fusible metal or alloy. Soldered splices shall first be spliced or joined so as to be mechanically and electrically secure without solder and then be soldered. All splices and joints and the free ends of conductors shall be covered with an insulation equivalent to that of the conductors or with an insulating device identified for the purpose.

Wire connectors or splicing means installed on conductors for direct burial shall be listed for such use.

Field observations and trade magazine articles indicate that electrical connection failures have been determined to be the cause of many equipment burnouts and fires. Many of these failures are attributable to improper terminations, poor workmanship, the differing characteristics of dissimilar metals, and improper binding screws or splicing devices.

UL's requirements for listing solid aluminum conductors in 12 AWG and 10 AWG and for listing snap switches and receptacles for use on 15- and 20-ampere branch circuits incorporate stringent tests that take into account the factors listed in the preceding paragraph. For further information regarding receptacles and switches using CO/ALR-rated terminals, refer to 404.14(C) and 406.2(C).

Screwless pressure terminal connectors of the conductor push-in type are for use with solid copper and copper-clad aluminum conductors only.

Instructions that describe proper installation techniques and emphasize the need to follow those techniques and practice good workmanship are required to be included with each coil of 12 AWG and 10 AWG insulated aluminum wire or cable. See also the commentary on tightening torque that follows 110.14, FPN.

New product and material designs that provide for increased levels of safety of aluminum wire terminations have been developed by the electrical

industry. To assist all concerned parties in the proper and safe use of solid aluminum wire in making connections to wiring devices used on 15- and 20-ampere branch circuits, the following information is presented. Understanding and using this information is essential for proper application of materials and devices now available.

For New Installations

The following commentary is based on a report prepared by the Ad Hoc Committee on Aluminum Terminations prior to the 1975 *Code*. This information is still pertinent today and is necessary to comply with 110.14(A) when using aluminum wire in new installations.

New Materials and Devices.

For direct connection, only 15- and 20-ampere receptacles and switches marked “CO/ALR,” and connected as follows in Installation Method, should be used.

The “CO/ALR” marking is on the device mounting yoke or strap. The “CO/ALR” marking means the devices have been tested to stringent heat-cycling requirements to determine their suitability for use with UL-labeled aluminum, copper, or copper-clad aluminum wire.

Listed solid aluminum wire, 12 AWG or 10 AWG, marked with the aluminum insulated wire label should be used. The installation instructions that are packaged with the wire should be used.

Installation Method.

Exhibit 110.2 illustrates the following correct method of connection to be used:

- (1) The freshly stripped end of the wire should be wrapped two-thirds to three-quarters of the distance around the wire-binding screw post, as shown in Step A of Exhibit 110.2. The loop is made so that rotation of the screw during tightening will tend to wrap the wire around the post rather than unwrap it.
- (2) The screw should be tightened until the wire is snugly in contact with the underside of the screw head and with the contact plate on the wiring device, as shown in Step B of Exhibit 110.2.
- (3) The screw should be tightened an additional half-turn, thereby providing a firm connection, as shown in Step C of Exhibit 110.2. Where torque screwdrivers are used, the screw should be tightened to 12 lb-in., as shown in Step C of Exhibit 110.2.

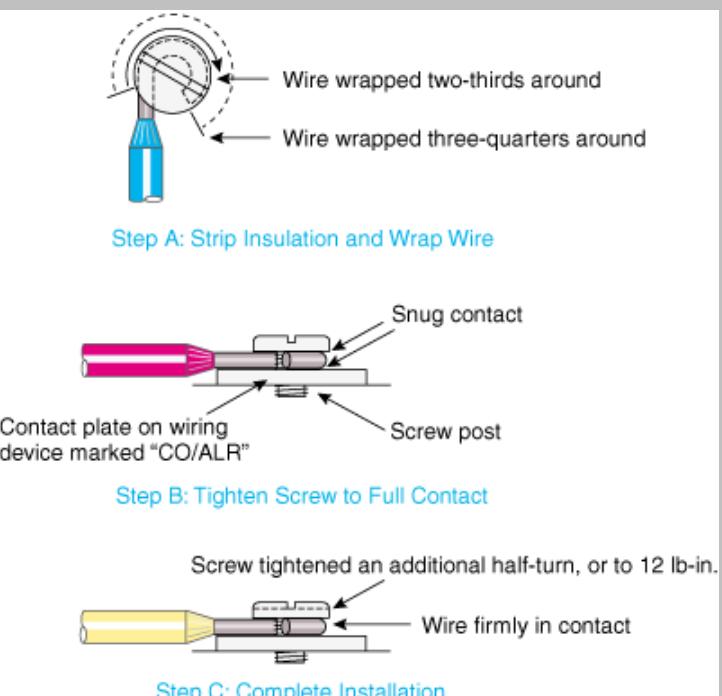


Exhibit 110.2 Correct method of terminating aluminum wire at wire-binding screw terminals of receptacles and snap switches. (Redrawn courtesy of Underwriters Laboratories Inc.)

(4) The wires should be positioned behind the wiring device to decrease the likelihood of the terminal screws loosening when the device is positioned into the outlet box.

Exhibit 110.3 illustrates incorrect methods for connection. These methods should *not* be used.

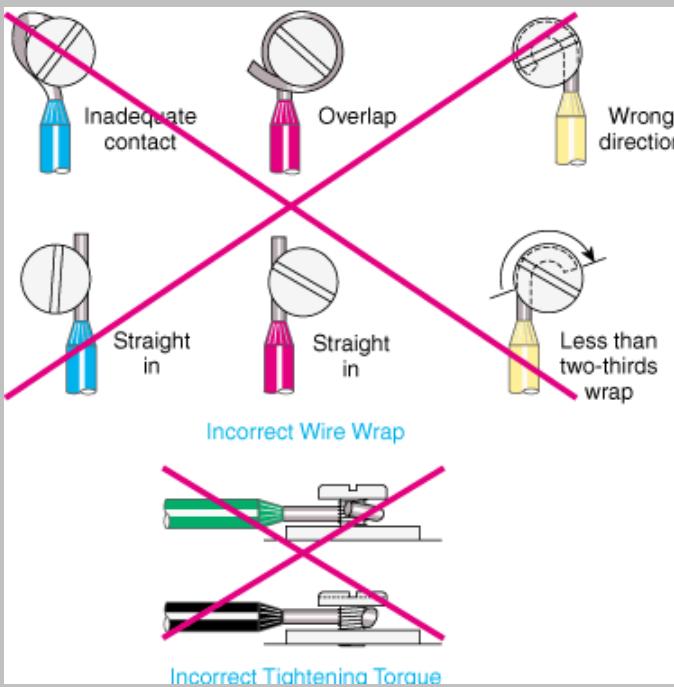


Exhibit 110.3 Incorrect methods of terminating aluminum wire at wire-binding screw terminals of receptacles and snap switches. (Redrawn courtesy of Underwriters Laboratories Inc.)

Existing Inventory.

Labeled 12 AWG or 10 AWG solid aluminum wire that does not bear the new aluminum wire label should be used with wiring devices marked “CO/ALR” and connected as described in the preceding Installation Method. This is the preferred and recommended method for using such wire.

In the following types of devices, the terminals should not be directly connected to aluminum conductors but may be used with labeled copper or copper-clad conductors:

- (1) Receptacles and snap switches marked “AL-CU”
- (2) Receptacles and snap switches having no conductor marking

- (3) Receptacles and snap switches that have back-wired terminals or screwless terminals of the push-in type

For Existing Installations

If examination discloses overheating or loose connections, the recommendations described under Existing Inventory should be followed.

Twist-On Wire Connectors

Because 110.14(B) requires conductors to be spliced with “splicing devices identified for the use,” wire connectors are required to be marked for conductor suitability. Twist-on wire connectors are not suitable for splicing aluminum conductors or copper-clad aluminum to copper conductors unless it is so stated and marked as such on the shipping carton. The marking is typically “AL-CU (dry locations).” Presently, one style of wire nut and one style of crimp-type connector have been listed as having met these requirements.

On February 2, 1995, Underwriters Laboratories announced the listing of a twist-on wire connector suitable for use with aluminum-to-copper conductors, in accordance with UL 486C, *Splicing Wire Connectors*. That was the first listing of a twist-on type connector for aluminum-to-copper conductors since 1987. The UL listing does *not* cover aluminum-to-aluminum combinations. However, more than one aluminum or copper conductor is allowed when used in combination.

These listed wire-connecting devices are available for pigtailing short lengths of copper conductors to the original aluminum branch-circuit conductors, as shown in Exhibit 110.4. Primarily, these pigtailed conductors supply 15- and 20-ampere wiring devices. Pigtailing is permitted, provided there is suitable space within the enclosure.

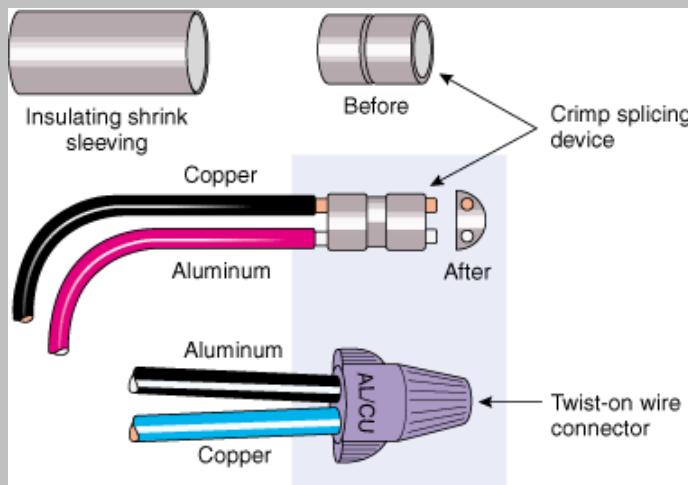


Exhibit 110.4 Pigtailing copper to aluminum conductors using two listed devices.

(C) Temperature Limitations. The temperature rating associated with the ampacity of a conductor shall be selected and coordinated so as not to exceed the lowest temperature rating of any connected termination, conductor, or device. Conductors with temperature ratings higher than specified for terminations shall be permitted to be used for ampacity adjustment, correction, or both.

(1) Equipment Provisions. The determination of termination provisions of equipment shall be based on 110.14(C)(1)(a) or (C)(1)(b). Unless the equipment is listed and marked otherwise, conductor ampacities used in determining equipment termination provisions shall be based on Table 310.16 as appropriately modified by 310.15(B)(1) through (6).

(a) Termination provisions of equipment for circuits rated 100 amperes or less, or marked for 14 AWG through 1 AWG conductors, shall be used only for one of the following:

- (1) Conductors rated 60°C (140°F)
- (2) Conductors with higher temperature ratings, provided the ampacity of such conductors is determined based on the 60°C (140°F) ampacity of the conductor size used
- (3) Conductors with higher temperature ratings if the equipment is listed and identified for use with such conductors
- (4) For motors marked with design letters B, C, D, or E, conductors having an insulation rating of 75°C (167°F) or higher shall be permitted to be used provided the ampacity of such conductors does not exceed the 75°C (167°F) ampacity.

(b) Termination provisions of equipment for circuits rated over 100 amperes, or marked for conductors larger than 1 AWG, shall be used only for one of the following:

- (1) Conductors rated 75°C (167°F)
- (2) Conductors with higher temperature ratings, provided the ampacity of such conductors does not exceed the 75°C (167°F) ampacity of the conductor size used, or up to their ampacity if the equipment is listed and identified for use with such conductors

(2) Separate Connector Provisions. Separately installed pressure connectors shall be used with conductors at the ampacities not exceeding the ampacity at the listed and identified temperature rating of the connector.

FPN:With respect to 110.14(C)(1) and (2), equipment markings or listing information may additionally restrict the sizing and temperature ratings of connected conductors.

Revised for the 2002 *Code*, 110.14(C)(1) now states that where conductors are terminated in equipment, the selected conductor ampacities must be based on Table 310.16, unless the equipment is specifically listed and marked otherwise. The intent of this requirement is to clarify which ampacities are used to determine the proper conductor size at equipment terminations.

When 600-V-and-less equipment is evaluated relative to the appropriate temperature characteristics of the terminations, conductors sized according to

Table 310.16 are required to be used. The UL *General Information Directory* (pages 1 and 2; UL White Book) clearly indicates that the 60°C and 75°C provisions for equipment have been determined using conductors from Table 310.16. However, installers or designers unaware of the UL guide card information might attempt to select conductors based on a table other than 310.16. That is especially true if a wiring method that allows the use of ampacities such as those in Table 310.17 is used. That use can result in overheated terminations at the equipment. Clearly, the ampacities shown in other tables (such as Table 310.17) could be used for various conditions to which the wiring method is subject (ambient, ampacity correction, etc.), but the conductor size at the termination must be based on ampacities from Table 310.16. This change introduces no new impact on the equipment or the wiring methods; it simply adds a rule from the listing information into the *Code* because it is an installation and equipment selection issue.

Section 110.14(C)(1)(a) requires that conductor terminations, as well as conductors, be rated for the operating temperature of the circuit. For example, the load on an 8 AWG THHN, 90°C copper wire is limited to 40 amperes where connected to a disconnect switch with terminals rated at 60°C. This same 8 AWG THHN, 90°C wire is limited to 50 amperes where connected to a fusible switch with terminals rated at 75°C. The conductor ampacities were selected from Table 310.16. Not only does this requirement apply to conductor terminations of breakers and fusible switches, but the equipment enclosure must also permit terminations above 60°C. Exhibit 110.5 shows an example of termination temperature markings.

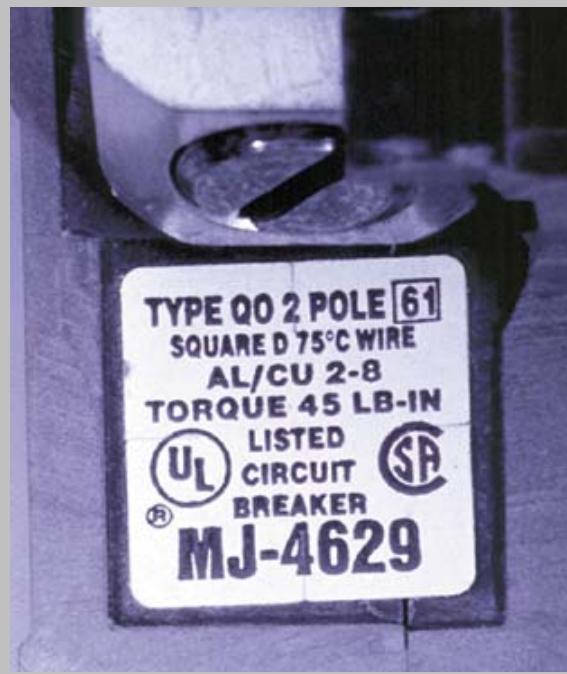


Exhibit 110.5 An example of termination temperature markings on a main circuit breaker. (Courtesy of Square D Co.)