involved, it is important for the engineer to investigate such conductor enclosures to determine that their impedance is sufficiently low to provide an effective ground-fault current path.

In general, the minimum size of equipment grounding conductor is provided in Table 250.122 and is based on the rating of the overcurrent device ahead of the conductors. (An analysis of Table 250.122 is provided in table 7 of chapter twenty.) The rule of thumb may be applied, but it should be verified by calculation that the equipment grounding conductor should not be less than 25 percent of the capacity of the phase conductors or the overcurrent device that supply the circuit. A note has been added to the table indicating that the size of equipment grounding conductor given in the table must be increased if necessary to comply with 250.4(A)(5). This adds emphasis to the heading of Table 250.122 because it indicates that equipment grounding conductors given in the table are the minimum size.

An analysis of Table 250.122 shows the relation of the equipment grounding conductor to the size of the overcurrent device (based on the continuous rating of 75°C-rated wire). It is from 50 to 125 percent of the phase conductor for overcurrent devices up to 100-ampere rating. The rating varies from 33 to 25 percent for overcurrent devices rated up to 400 amperes and is from 22 percent for 600-ampere overcurrent devices to a low of only 8 percent for an overcurrent device of 6000 amperes.

Obviously, the equipment grounding conductor must be large enough to carry that amount of current, for the amount of time necessary to clear the overcurrent device with which it is associated, and not result in extensive damage. In addition, it is vital that the equipment grounding conductor be run with the circuit conductors or enclose the circuit conductors. This was covered extensively in chapter nine.

Section 110.9 states, "Equipment intended to interrupt current at fault levels shall have an interrupting rating sufficient for the nominal circuit voltage and the current which is available at the line terminals of the equipment." [11] This includes fuses, circuit breakers, disconnect switches and similar equipment.

Section 110.10 reads in part, "The overcurrent protective devices, the total impedance, the component short-circuit current ratings, and other characteristics of the circuit to be protected shall be selected and coordinated to permit the circuit protective devices used to clear a fault to do so without extensive damage to the electrical components of the circuit. This fault shall be assumed to be either between two or more of the circuit conductors, or between any circuit conductor and the grounding conductor or enclosing raceway." [12]

Grounding conductors, circuit conductors, busbars, bonding jumpers, and so forth, are not intended to break current. These conductors must be large enough to safely carry any short-circuit and ground-fault current for the time it takes the overcurrent protective device to clear the fault. This is clearly stated in 110.10, 240.1 FPN, 250.4, 250.90 and 250.96. Section 310.10 also provides details for the temperature limitations of conductors.

The integrity of equipment grounding conductors, grounding electrode conductors, main bonding jumpers and other circuit conductors must be ensured by sizing them properly. Equipment grounding conductors that are too small are of little value in clearing a fault and can, in fact, give one a false sense of security. Grounding conductors must not burn off during ground-fault conditions, leaving the equipment enclosure energized, in many cases, creating a shock hazard that can cause serious injury or even be fatal. Safety should not be compromised. In fact, the first sentence of the *Code* states that, "the purpose of this *Code* is the practical safeguarding of persons and property from hazards arising from the use of electricity." [13]

It can be calculated, using values from the Insulated Cable Engineers Association publication P32-382 (1994), that an insulated copper conductor with a bolted connection can safely carry one ampere for every 42.25 circular mils for five seconds without destroying its validity (see figures 11-11 and 11-12). That will be the short-time rating or I^2t (amperes x amperes x time) value of the conductor. Then, from the time-current characteristic curves of various approved overcurrent devices, the amount of current necessary to clear the overcurrent device in five seconds can be determined.

Using that formula, the size of the equipment grounding conductors that will be proportional to those given in Table 250.122, as analyzed in table 7 of chapter twenty, can be determined. Grounding conductors are permitted to be bare, and, in most cases, are pulled into the same raceway as the insulated phase conductors. This presents a potential problem. When an equipment grounding conductor is carrying ground-fault current, an extreme rise in its temperature can cause the insulation on the adjacent phase conductors to melt, causing further damage. Again, the potential for equipment damage and electrical shock hazard to personnel is increased. It is desirable to limit the heat of the faulted circuit to reduce damage to adjacent insulated conductors.

Thus, as discussed in this chapter, for copper conductors, the clearing time and short-circuit current must be limited to:

- One ampere...
- for five seconds...
- for every 42.25 circular mils.

This can be expressed by the formula ampere squared seconds (I^2t).

For example, from Table 8 of *NEC* chapter nine, an 8 AWG conductor has a cross-sectional area of 16,510 circular mils. By dividing the circular mil area of the conductor by 42.25, the conductor's five-second withstand rating can be calculated (16,510 ÷ 42.25 = 391).

Stated another way, this conductor has an I^2t five-second withstand rating of:

391 x 391 x 5 = 764,405 ampere squared seconds.

From this five-second withstand rating value, it is easy to calculate the conductor's withstand rating for other values of time and/or for other values of current.

Example 1: How many amperes will the 8 AWG copper conductor be able to safely carry if the impedance of the circuit along with the operating characteristics of the overcurrent device protecting the circuit results in a 2-cycle (0.0333 seconds) opening time? Example 1 is solved as follows:

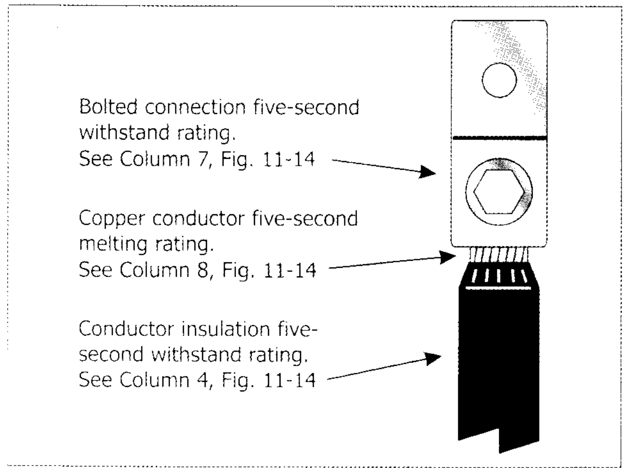

Figure 11-11. Wire, insulation and connection withstand ratings

I^2t = 764.405 ampere squared seconds

$I^2 = \frac{764.405}{t}$

$I = \sqrt{\frac{764.405}{0.0333}}$

I = 4.791 amperes

Example 2: How many amperes will the 8 AWG copper conductor be able to safely carry if the impedance of the circuit along with the operating characteristics of the overcurrent device protecting the circuit results in a $\frac{1}{4}$ cycle (0.0042) opening time? Example 2 is solved as follows:

I^2t = 764.405 ampere squared seconds

$I^2 = \frac{764.405}{t}$

$I = \sqrt{\frac{764.405}{0.0042}}$

I = 13.491 amperes

Note that in the example above, because a much faster total clearing time is achieved, the allowable fault current that the conductor will be subjected to can be increased. This is a result of substituting different time values in the I^2t formula.

Generally, where current-limiting overcurrent devices are protecting the circuit, the equipment grounding conductor sizes are determined directly from Table 250.122. Where available fault currents are high and the overcurrent protective device takes longer than .25 cycle to clear the fault, it is suggested

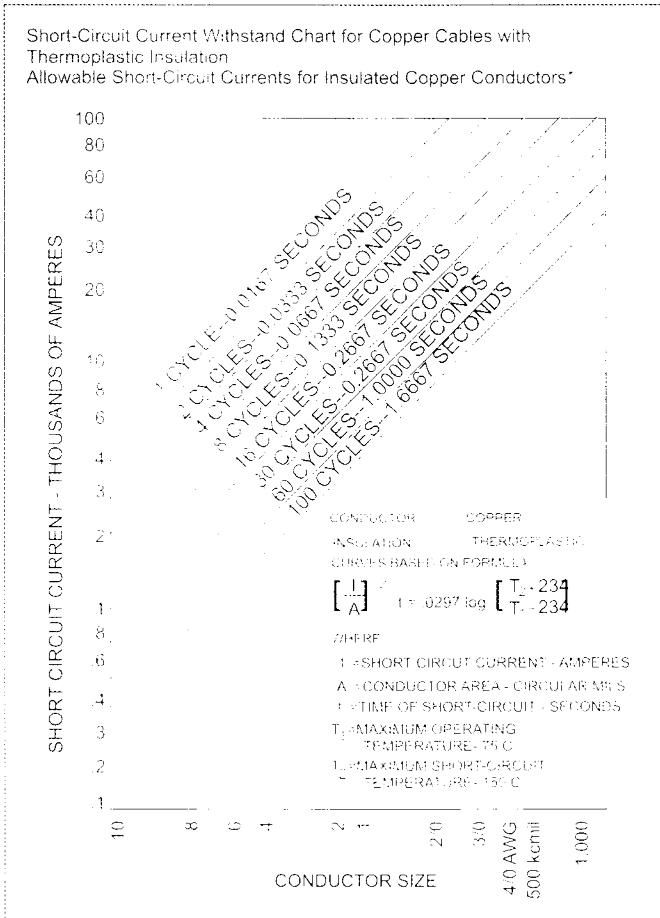

Figure 11-12. Short-circuit current withstand chart
Courtesy of the Insulated Cable Engineers Association

that the equipment grounding conductor be sized per figure 11-12, to be on the safe side.

Figure 11-14 provides information to assist the installer in the proper selection of equipment grounding conductors. Among other information, it includes:

1. safe values for 75°C thermoplastic insulated conductors,

2. safe values for bolted connections,

3. unsafe (melting) values for the copper conductor itself.

Because the weakest link in any system is the insulation short-circuit withstand rating as found in columns 4, 5, and 6 of figure 11-14, it is recommended that column 4 be the deciding factor where selecting equipment grounding conductors. The Insulated Cable Engineers Association data, figure 11-14, column 4 calculates out to the previously discussed: *Do not exceed one ampere... for five seconds...for every 42.25 circular mils of copper conductor.*

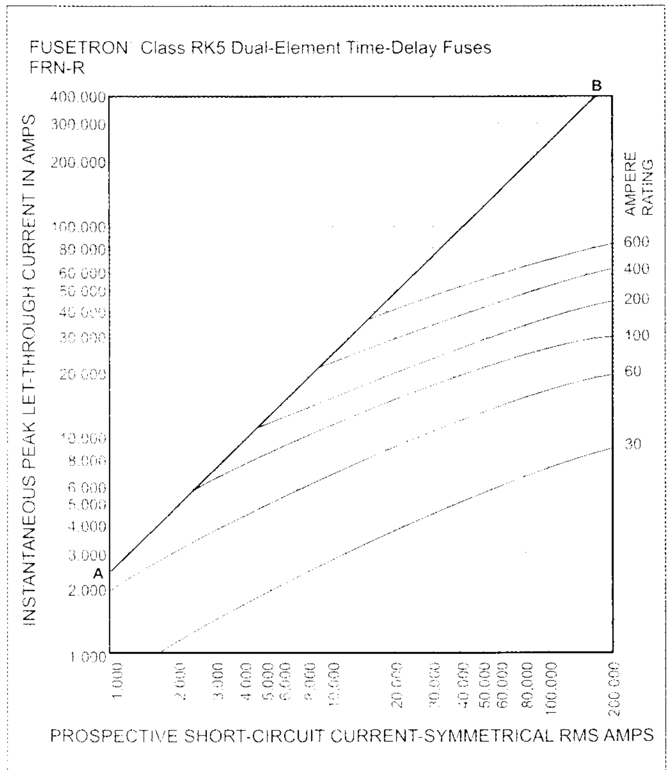

Figure 11-13. Typical time current curves for fuses. Courtesy of Cooper Bussman, Cooper Industries

This chart also shows the 8 AWG conductor used in the above text examples. Where you are absolutely certain that the equipment grounding conductor will not come into contact with any of the current-carrying insulated circuit conductors, the withstand rating of the grounding conductor, for every 29.1 circular mils of copper conductor, cannot exceed one ampere for five seconds (see column seven, figure 11-14).

This is the standard previously referred to in this text as the "Do not exceed one ampere for five seconds for every thirty circular mils of conductor area."

This value is only to be used where bare equipment grounding conductors are used in such a manner that they will not come in contact with insulated conductors. In this application, the limiting element of the circuit is the bolted connection of the lug.

Column 8 of figure 11-14 gives the current in amperes at which the melting temperature of copper conductors is reached. Of course, you never want to reach the current shown because the equipment grounding conductor will burn off leaving the equipment ungrounded and a possible shock hazard.

Copper 75° C. Thermoplastic Insulated Conductor, Bare Conductor, Bolted Connection Five Second Withstand Rating In Amperes and Melting of Copper Wire

1	2	3	4	5	6	7	8
Wire size	Area in circular mils	Area in square mm	ICEA Amperes	IEC Amperes	IEE Amperes	Bolted connection 250°C. Amperes	Melting of conductor 1,083°C. Amperes
14	4,110	2.080	97	107	107	141	254
12	6,530	3.310	155	170	170	224	403
10	10.380	5.261	246	271	271	357	641
8	16.510	8.367	391	430	430	567	1,020
6	26.240	13.300	621	684	684	902	1,621
4	41.740	21.150	988	1,088	1.088	1,435	2,578
3	52.620	26.670	1.245	1.372	1.372	1,808	3,251
2	66.360	33.620	1.571	1.729	1.729	2,281	4,099
1	83 690	42.410	1.981	2.181	2.181	2,876	5,170
1/0	105 600	53.490	2.499	2.751	2,751	3 629	6,523
2/0	133.100	67.430	3.150	3.468	3,468	4,574	8,222
3/0	167.800	85.010	3.972	4,372	4,372	5,767	10,366
4/0	211.600	107.200	5.009	5,513	5,513	7,272	13,071
250	250.000	126.700	5.918	6,516	6,516	8,592	15,443
300	300.000	152.000	7.101	7.818	7,818	10,310	18,532
350	350.000	177.300	8.285	9.119	9.119	12.029	21.621
400	400.000	202.700	9.467	10.425	10.425	13.747	24.709
500	500,000	253.300	11.834	13.027	13.027	17.184	30,887
600	600,000	304.000	14,201	15,636	15.636	20,621	37,064
700	700,000	354.700	16,568	18,243	18,243	24,057	43,241
750	750,000	380.000	17,752	19,544	19,544	25,776	46,330
800	800,000	405.400	18,935	20,850	20.850	27.494	49,419
900	900,000	456.000	21,302	23.453	23.453	30,931	55,596
1,000	1,000,000	506.700	23,669	26,060	26.060	34,368	61,773

Column 4 - Insulated Cable Engineers Association publication P32-382. One ampere for five seconds for every 42.25 circular mils of conductor area.

Column 5 - International Electrotechnical Commission publication 364-4-43.

Column 6 - Institute of Electrical Engineers publication 434-6.

Column 7 - Calculated from data in Electrical Engineers Handbook (75°C ambient). One ampere for five seconds for every 29.1 circular mils of conductor area.

Column 8 - Calculated from data in Electrical Engineers Handbook (75°C ambient). One ampere for five seconds for every 16.19 circular mils of conductor area.

Figure 11-14. Five-second withstand ratings for insulated conductors, bare conductors with bolted connections.

Courtesy of the ICEA

For a grounded system, it is vital to safety that a low-impedance equipment grounding conductor path be provided in addition to a good grounding electrode system with as low a resistance as practical. This allows sufficient current to clear a ground fault automatically in a limited time, which would be as quickly as is practical, without undue interruption of service.

The I^2t values found in column 7 of figure 11-14 are based on the adequacy of a copper conductor and its bolted joints to carry the current values without destroying its validity. The values are obtained from an IEEE committee report in "A Guide to Safety in AC Substation Grounding." The value expressed in amperes per circular mil is one ampere for every 29.1 circular mils cross section. The time of five seconds was used to provide a safety factor and was considered a reasonable approach for distribution systems of 600 volts or less protected by high-interrupting-capacity current-limiting fuses and having equipment ground-fault protection.

As previously stated, where grounding conductors might come into contact with insulated phase conductors, use the values found in column four of figure 11-14. This column is based on one ampere for every 42.25 circular mils of conductor for five seconds. Figure 11-14 has all the calculations done and is much easier to use than performing complicated calculations.

The short-time rating of the equipment grounding conductor bears an approximately constant relation to the size of the overcurrent device. The I^2t values of the conductors given in Table 250.122 are between about 13 and 28 times their nominal continuous rating based on one ampere for every 42.25 circular mils cross section.

[1] Electric Power Distribution for Industrial Plants. The Institute of Electrical and Electronics Engineers, Inc., © 1954 AIEE, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

[2] "Some Fundamentals of Equipment-Grounding Circuit Design" by R. H. Kaufmann, Paper 54-244 presented at the AIEE Summer and Pacific General Meeting, Los Angeles, California, June 24-25, 1954, © 1954 AIEE, (now IEEE), 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331.

[3] Kaufmann, ibid. 4 Kaufmann, ibid.5 Kaufmann, ibid.

[6] Fuses (JCQR), General Information for Electrical Equipment 2004, (Underwriters Laboratories, Northbrook, IL, 2004), p. 54.

Circuit Breakers, Moulded-Case and Circuit Breaker Enclosures (DIVQ), General Information for Electrical Equipment 2004, (Underwriters Laboratories, Northbrook, IL, 2004), p. 14.

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NFPA 70, 110.10, p. 70-34.

NFPA 70, Front page, p. 70-1.