Equipment Grounding Conductor

NEC 250.122 Calculations

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Executive Summary

Observing proper grounding and bonding processes and employing reliable materials are essential considerations that contribute to the safety of personnel and equipment over the lifetime of an electrical system.

Properly following the general requirements for grounding and bonding articulated in Section 250.4 (A) of the National Electric Code (NEC) can prevent injuries by limiting the voltage imposed by incidents such as lightning strikes, line surges, or unintentional contact with higher voltage lines.

While the processes for grounding and bonding are straightforward, well known, and commonly practiced, material selection for equipment grounding conductor (EGC) is not such a cut-and-dry affair. Where copper was formerly the universally approved choice, the performance of aluminum alloy in EGC has earned the respect it deserves.

Within the context provided by Section 250.122 of the NEC, this paper will examine the functionality, effectiveness, and practicality of combining an aluminum alloy EGC with aluminum phase conductors.

Types of Equipment Grounding Conductors

Since the late 1960s, technology used in electrical components has improved tremendously. In particular, advancements in aluminum alloy manufacturing have resulted in more secure and reliable electrical systems at reduced material cost. In the late 1970s, improved dual-rated (ALCU, AL7CU, and AL9CU) connectors that could be used with both aluminum and copper conductors became widely available. Simultaneously, the range of EGC options opened up considerably.

NEC Section 250.118 provides a list of possible EGC options. In many cases, the requirements in this list articulate a need for the EGC to run with or enclosing the circuit conductors. Acceptable EGCs shall consist of any of the following:

- A copper, aluminum, or copper-clad aluminum conductor. This conductor shall be solid or stranded; insulated, covered, or bare; and in the form of a wire or a busbar of any shape.
- Rigid metal conduit (RMC)
- Intermediate metal conduit(IMC)
- Electrical metallic tubing (EMT)
- Listed flexible metal conduit (FMC)
- Flexible metal tubing (FMT)
- Type AC cable (BX)
- Listed liquidtight flexible metal conduit (LTFC)
- Mineral insulated sheathed cable (MI)
- Type MC Cable
- Cable trays
- Cablebus framework
- Other listed electrically continuous metal raceways
- Surface metal raceways listed for grounding

Notable in this list is the opportunity represented by the inclusion of aluminum alloy EGCs. Indeed, the advances in the 1960s and 1970s enabled a more harmonized system using similar metals for both the conductor and connector. The connector body itself is made of aluminum alloy with a tinplating to mitigate galvanic corrosion when copper conductor terminations are made on aluminum alloy connectors.

The NEC acknowledges these advancements and recognizes the use of aluminum alloy conductors such as STABILOY® AA-8030 conductors. Section 310.106(B) in the 2011 NEC, states that solid aluminum conductors size 8 AWG, 10 AWG, and 12 AWG shall be made of an AA-8000 series electrical-grade aluminum alloy conductor material, and stranded aluminum conductors 8 AWG through 1000 kcmil shall be made of AA-8000 series electrical-grade aluminum alloy conductor material for most insulation types.

It is clear in the NEC that aluminum alloy conductors are an acceptable and equal choice for equipment grounding conductors. Table 250.122 includes both copper and aluminum conductor sizing for equipment grounding conductors.

Despite this affirmation by the NEC, and the fact that the AA-8000 series aluminum alloy has been in use for more than 40 years, a tendency toward choosing copper EGCs for use with aluminum phase conductors persists within the industry. However, it is likely that the perception of copper as the default choice for EGCs will continue to fade over time as awareness of the NEC compliance of aluminum alloy EGCs and the economic benefits of choosing aluminum alloy become better known. There is no engineering benefit to using a copper EGC with aluminum phase conductors, and it simply adds cost without benefit.

Identification of Equipment Grounding Conductors

Being able to visually isolate and identify EGCs is a very important safety consideration, and is key to prevention of electrical accidents. Section 250.119 of the NEC explains the identification of EGCs for use with conductors larger than 6 AWG (250.119 (A)), multi-conductor cable (250.119 (B)), and flexible cords (250.119 (C)). According to the NEC, EGCs can be bare, insulated, or covered, unless stipulated otherwise elsewhere in the NEC. Individually covered or insulated EGCs should have a continuous outer finish that is either green or green with one or more yellow stripes – and to accentuate differentiation – this color scheme is not permitted for ungrounded or grounded circuit conductors.

EGCs larger than 6 AWG, whether aluminum or copper, that are insulated or covered, shall be color-coded at each end and at every point where the conductor is accessible.

Installation of Equipment Grounding Conductors

Optimal location is a crucial factor in achieving minimal impedance in an AC grounding system. Even if a sufficiently sized EGC is used, electrical hazard can manifest if it is not properly located and installed. To this end, Section 250.134 (B) requires that EGCs be installed in the same raceway, cable or cord as the circuit conductors. This requirement, in similar form, is again reiterated in Section 300.3 (B), which expresses the need for EGCs to be installed in the same raceway, cable, trench, etc. with the other circuit conductors.

The purpose of the EGC is to bond non-current carrying parts of the electrical system and provide a low impedance path for ground fault current, allowing for effective clearing of ground faults. Routing the EGC with the circuit conductors is required by the NEC in most cases.

EGCs should be installed in accordance with Section 250.120 (A), (B), and (C). These NEC entries require that installation within a raceway, cable tray, cable armor, cablebus framework, or cable sheath be installed with applicable code provisions, and that all terminations and joints be listed, approved, and tightly secured with appropriate tools.

While both bare and insulated aluminum or copper-clad aluminum EGCs are permitted, Section 250.120(B), requires that bare conductors not come into direct contact with masonry, earth or any region where they may be subjected to corrosive conditions. Further, aluminum or copper-clad aluminum should not be terminated within 18 inches of the earth's surface – the intention of this restriction is to avoid corrosion of the aluminum by contact with certain types of soil (for example, soils that contain certain salts and/or alkaline pH levels).

Sizing of Equipment Grounding Conductors

The purpose of EGCs is to provide a low-impedance, ground-fault current path that reduces equipment to as close to zero potential as possible. NEC Table 250.122 relates the selection of size-appropriate EGC to the size of the over-current device ahead of the conductor. Section 250.122 (A) clearly states that aluminum and copper EGCs shall not be smaller than the values presented in this table, but also states that they are not required to be larger than the circuit conductors supplying the equipment.

As a rule-of-thumb (using calculations for verification), EGCs should not be less than 25 percent of the capacity of the phase conductors or the over-current device.

Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size (AWG or kcmil)	
	Copper	Aluminum or Copper-Clad Aluminum*
15	14	12
20	12	10
60	10	8
100	8	6
200	6	4
300	4	2
400	3	1
500	2	1/0
600	1	2/0
800	1/0	3/0
1000	2/0	4/0
1200	3/0	250
1600	4/0	350
2000	250	400
2500	350	600
3000	400	600
4000	500	750
5000	700	1200
6000	800	1200

Note: Where necessary to comply with 250.4(A)(5) or (B)(4), the equipment grounding conductor shall be sized larger than given in this table.
**See installation restrictions in 250.120.*

Example 1 shows an EGC's minimum size based on the over-current protection device (OCPD).

Example 1:

What size aluminum equipment grounding conductor is needed for a 400A circuit breaker protecting the feeder circuit?

Solution:

Referencing NEC Table 250.122, listing of minimum sizes of EGCs based on the over-current device rating, we see under the over-current device column, that a 1 AWG aluminum EGC meets the minimum requirement for a 400A circuit breaker.

Size Increase Requirements

Sometimes higher voltage drop or other adjustments or correction factors require that phase conductors be increased in size. Under these circumstances, Section 250.122 (B) requires a proportional increase in the size of the EGC. The National Electrical Code Chapter 9, Table 8 contains information that can be used to determine the appropriate size EGCs based on the circular mil area of the ungrounded conductors.

Example 2:

For a 100A load, what size of aluminum EGC should be used when the phase conductors are increased in size to compensate for a higher voltage drop?

Solution:

Step 1: Considering a voltage drop, select phase conductor from Table 310.15(B)(16) for a100A load.

As per Table 250.122, a 100A OCPD requires a 6 AWG aluminum conductor. From Table 310.5(B)(16), a 100A load will need 1 AWG aluminum conductors. To compensate for a voltage drop, the conductor size is increased to 1/0 AWG aluminum.

Step 2: Find circular mils of conductors from Table 8 in Chapter 9.

Required conductor area (CM) = original wire size without VD = 1 AWG Al = 83,690 CM

Selected conductor area (CM) = increased wire size with VD = 1/0 AWG Al = 105,600 CM

Minimum EGC wire size = 6 AWG Al = 26,240 CM

Step 3: Calculate which new EGC is to be used by taking into account the size increase of the phase conductors.

$$\text{Ratio} = \frac{\text{Selected conductor area (CM)}}{\text{Required conductor area (CM)}}$$

Ratio = 105,600 / 83,690 = 1.262

*New equipment grounding conductor = Conductor area of original EGC * Ratio*
*= 26240 * 1.262*
= 33,115 CM

NEC Table 8 in Chapter 9 shows us the circular mil area of the smallest conductor that is larger than the calculated value is a 4 AWG aluminum at 41,740 CM. So, the size of the new EGC is 4 AWG aluminum.

Multiple Circuits

Section 250.122 (C) mentions that when a single EGC is run within a raceway with multiple circuits, it should be sized for the largest over-current device present.

Example 3:

Find the EGC for a conduit that contains multiple circuits with over-current protections ratings of 20A, 30A, 40A, and 50A.

Solution:

OCPD are 20A, 30A, 40A, and 50A. Per 250.122 (C) the size of the EGC should be for the largest over-current device.

In this example the largest OCPD ahead of the circuit is 50A. Since a 50A designation is not provided in Table 250.122, we reference the next larger size, which is 60A. Minimum aluminum EGC is 8 AWG.

Conductors in Parallel

When using EGCs for conductors in parallel runs, Section 250.122 (F) is our point of reference. Whether or not to install parallel conductors is largely determined by design and economic considerations. Ampacities for aluminum and copper conductors are given in Table 310.15(B)(16). Notice that they do not increase in direct proportion to the size of the conductors. The general requirements of parallel conductor installations are given in Section 310.10(H) of the NEC, where it is required that each set of conductors must be comprised of the same conductor material and insulation type, must be of the same dimensions in both circular mil area and length, and must be terminated in the same manner. Also, each run should have separate EGCs in each conduit. The reason for this is to ensure that each EGC is adequately sized to facilitate low impedance values during a ground fault in order to prevent damage due to overloading. And remember, EGCs never have to be larger than the phase conductors of the circuit according to Section 250.122(A).

The rationale behind the requirements in Section 310.10(H) is to keep equal current in parallel sets and avoid insulation damage from severe current imbalances. Please notice again, referencing Table 250.122, that there is no need to use copper EGCs if the phase conductors are aluminum. The only requirement here is that parallel EGCs must be of the same material.

Cable assemblies, such as Metal Clad (MC) Cable, are manufactured in standard conductor configurations, and while the EGCs in cable assemblies are sized for many circuit arrangements, it is not safe to assume that they are suitable for all parallel circuit arrangements. It is very important to confirm that the EGC in each assembly is sized according to Table 250.122 using the size of the over-current device as the determining factor.

Example 4:

> ***A 2000A feeder is installed in parallel using 6 Metal Clad (MC) type cables. Each set contains four 600 kcmil aluminum alloy conductors. What is the minimum size EGC that can be used?***

Solution:

> ***From Table 250.122, we see that a 2000A OCPD requires – at a minimum – that a 400 kcmil aluminum EGC be installed in each MC Cable assembly.***

Section 250.122 (G), which refers to the selection of EGC for feeder taps, shows the EGC run with feeder taps shall not be smaller than the values presented in Table 250.122 that reference the rating of the over-current device ahead of the feeder. It also shows that they are not required to be larger than the tap conductor.

Conclusion

EGCs are an indispensable aspect of grounding and bonding safeguards in electrical installation projects. They not only protect circuits and equipment, but also help eliminate the risk of electrical shock. In order to achieve the desired level of impedance, sizing of EGCs is very important and can be accomplished using the details in Section 250.122 of the NEC. Ultimately, the proper grounding of electrical equipment requires adherence to three fundamentals: the grounding path should be permanent; it should be electrically continuous; and it should facilitate the lowest possible impedance.

Due to pervasive and persistent misunderstandings about the suitability of aluminum alloy EGCs for use with aluminum phase conductors, many designers still unnecessarily specify the use of copper EGCs. Section 250.118 clearly accepts the use of aluminum EGCs and reaffirms it in Table 250.122. Both copper and aluminum EGCs facilitate sufficiently low impedance path levels provided they are of the appropriate size, which is determined by the over-current device ahead of the circuit.

All aluminum alloy conductors, including EGCs, must terminate on connectors listed for use with aluminum. These connectors are typically dual-rated for both aluminum and copper. In 1978, dual-rated (ALCU, AL7CU, and AL9CU) aluminum body lugs were introduced and tested in accordance with UL 486B. These dual-rated connectors are suitable for both copper and aluminum conductors and are made of an aluminum alloy.

Considering more than a century of withstanding nature's harshest conditions in electrical transmission line systems, decades of use for EGCs in buildings, and growing awareness of the economic value it offers, aluminum finally appears to be getting the attention it deserves on the drafting table – and on the job site.

References

Simmons, Philip J., Electrical Grounding and Bonding, 2nd ed:199-227
National Electrical Code NFPA: 2011 ed..

[Soares]. Book on Grounding and Bonding, IAEI: 9th edition: 160-207
Michael Johnston.,"Equipment Grounding Conductors for Parallel Runs."

Hunter, Christel. "Aluminum Building Wire Installation and Terminations." IAEI News (January/February 2006)

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