Equipment Grounding Conductors: Sizing & Methods

by Ryan Mayfield

The subject of grounding photovoltaic systems can lead to some very heated conversations. It is not uncommon for multiple interpretations of the same rule to come out during the course of a discussion on grounding. A revised *National Electrical Code*® comes out every three years; therefore professional designers and installers need to stay abreast of the changes and their implementation.

One important differentiation that needs to be established is equipment grounding versus system grounding. While both need to be addressed and correctly implemented, the requirements for each are different. In most electrical systems, there are many pieces of grounded equipment, while there is usually one system ground. This article will identify the requirements of the 2008 *NEC*® for the Equipment Grounding Conductor (EGC) in a PV system.

The 2008 *NEC* defines the EGC in Article 100 as "The conductive path installed to connect normally non-current-carrying metal parts of equipment together and to the system grounded conductor or to the grounding electrode conductor, or both." This connection ensures that all the exposed metallic portions of an electrical system are kept at the same electrical potential, thereby reducing the risk of electrical shock if any of those components become energized through a faulted conductor. In a PV system, the components that may make up this conductive path can include module frames; racking structure; bare ground wire; lugs or grounding clips on the modules or racks; and ground bus or terminals in combiner boxes, switchgear, and inverters.

EQUIPMENT GROUNDING REQUIREMENTS

There are numerous changes in Article 690 of the 2008 *NEC* that deal directly with equipment grounding. The first paragraph in 690.43 dictates that regardless of the system voltage, there must be an EGC installed for all exposed non-current-carrying metal equipment. The method of grounding should follow Articles 250.134 or 250.136(A).

Article 250.134 describes the methods by which fixed equipment shall be connected to the EGC. The most common application for PV installations is described in 250.134(A), which says the conductor types listed in 250.118 are permitted for use as an EGC. The other acceptable method is listed in 250.134(B), which allows the equipment to be connected to an EGC "contained within the same raceway, cable, or otherwise run with the circuit conductors."

Article 250.118 contains the list of what is allowed as an EGC: The first method on the list is "(1) 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." This is the most common method used for the EGCs on the PV modules themselves. Generally this is accomplished by placing a copper conductor in an approved ground lug on the module frame. The attachment forms the conductive path with the EGC. The EGC then enters a junction box or combiner box.

An EGC may also connect to the racking structure to bond all the exposed non-current-carrying metal parts together, rendering the rack grounded as well, as outlined in 250.136(A). From the enclosure, the EGC continues on to the remaining equipment according to one of the methods listed in 250.118.

Paragraph 250.136(A), referenced in Article 690.43, allows equipment to be considered grounded for "electrical equipment secured to and in electrical contact with a metal rack or structure provided for its support and connected to an equipment grounding conductor by one of the means indicated in 250.134." New language in 690.43 outlines the option of using equipment listed for bonding frames and racks together: "Devices listed and identified for grounding the metallic frames of PV modules shall be permitted to bond the exposed metallic frames of PV modules to grounded mounting structures." This additional language in 690.43 is helpful for the use of grounding clips that bond the modules to the racking system, which is then bonded to the ground bus in the junction box or combiner box. This specifies another method not previously spelled out in the *NEC* and clarifies the requirements listed in 250.136(A) on the appropriateness of using the racking structure in this application.

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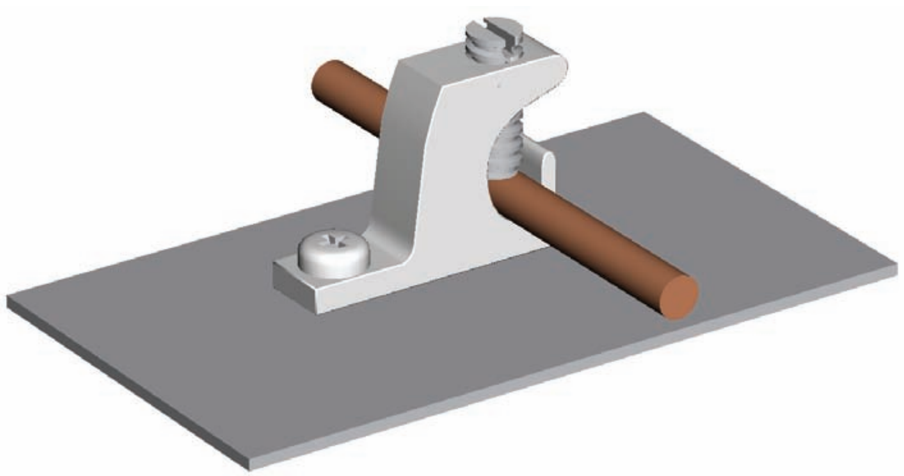


Rick Eberly

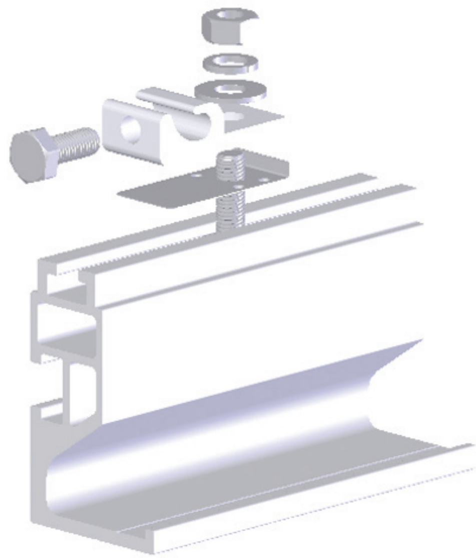
Grounding lug example Tin-plated copper lay-in lugs with stainless steel hardware, like the Ilsco GLB-4DBT, are a common choice to bond module frames to the EGC.

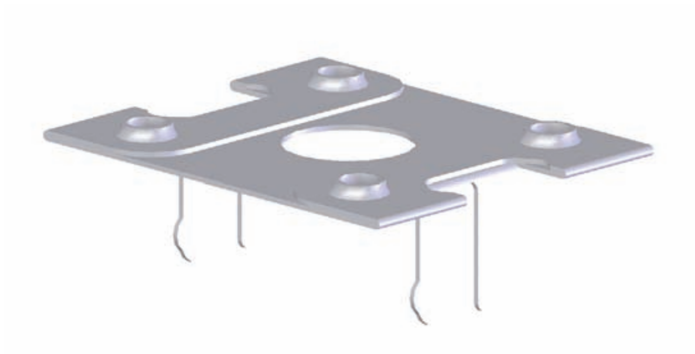
In addition, the first paragraph of 690.43 now requires that the EGC must be installed in accordance with Article 250.110. This provision clarifies the situations and equipment when an EGC is required between a PV array and the other equipment. Article 250.110 is a list of conditions that require exposed non-current-carrying metal parts likely to become energized be connected to an EGC. These conditions include being located in the vicinity of grounded metal objects and subject to contact by persons, installation in non-isolated wet or damp locations, and where any terminal operates in excess of 150 V.

The final paragraph of 690.43 stipulates that the EGCs shall be contained within the same raceway or run with the PV circuit conductors when the conductors leave the vicinity of the array. It is common for manufacturers to locate the grounding point in the middle of the module. Therefore, all the conductors will need to be brought to a common location before they leave the array to meet this requirement. This section of 690.43 takes precedence over parts of Articles 250.134(B) that allow the EGC to be run separately from the circuit conductors.

SIZING THE EQUIPMENT GROUNDING CONDUCTOR

690.45 dictates the size of the EGC for PV arrays. While this is not a new section in the 2008 *NEC*, the entire section has been updated. The size of the EGC is dictated by the overcurrent protection device in the PV source and output





Grounding clip example
The Wiley Electronic's ground lug assembly (exploded view)—with tin-plated copper lug— and the stainless steel WEEB grounding clip (detailed view) are designed to bond module frames to grounded mounting structures.

circuit(s), as well as the presence of ground-fault protection (GFP).

690.45(A) requires that the EGC in PV source and output circuits be sized in accordance with Table 250.122, reprinted here. This table dictates the minimum size EGC to be used based on the overcurrent protection in the circuit ahead of the equipment.

Therefore, if an array is installed with three series strings with each source circuit string protected by a 15 A fuse, the minimum size EGC to satisfy 690.45(A) would be a 14 AWG copper conductor. If these three strings are paralleled into a single PV output circuit protected by a 40 A fuse, the EGC would need to be minimally sized as a 10 AWG copper conductor. Note that the size of the EGC is the same—10 AWG—for overcurrent devices rated at 30, 40 or 60 A.

If there is no overcurrent protection in the source circuit, an assumed overcurrent protection device value of the short-circuit current shall be used in Table 250.122.

It is often possible to connect two series strings in parallel without overcurrent protection. As 690.9 outlines, when the PV array is connected to a device that is listed to not back feed current to the PV array in fault conditions, the only source of current is the array itself and overcurrent protection is not required. If each string has a short-circuit current of 6.5 A and the two strings are placed in parallel before connecting to the inverter, the EGC would use an assumed overcurrent protection size of 6.5 A x 2 = 13 A. Therefore, the minimum size per 690.45(A) would be 14 AWG copper.

Article 690.45(A) has two final provisions. If the circuit conductors are increased to account for voltage drop, the EGC does not need to be increased. Previously, the EGC would be increased proportionally to the circular mil area of the ungrounded conductors. This allows the installer to use the requirements in Table 250.122 CONTINUED ON PAGE 58

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
30	10	8
40	10	8
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	800
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

without having to resize the EGC to compensate for upsizing current-carrying conductors. Finally, 690.45(A) dictates that the EGC shall not be sized smaller than 14 AWG, which is consistent with the requirement in Table 250.122.

Most systems now require ground-fault protection. If the situation does not require ground-fault protection according to 690.5, then the EGC sizing takes on a different form. Article 690.45(B) requires that for non-dwelling units where GFP is not required, each EGC needs to have an ampacity rating of at least two times the conditional use value calculated for the circuit conductor ampacity. The system designer must determine corrected circuit conductor ampacity according to temperature and conduit fill corrections for both the PV source circuits and the PV output circuit(s). The EGC should have an ampacity of twice that value. For circuits exposed on rooftops the new Table 310.15(B)(2)(c) applies, in addition to the conduit fill table, 310.15(B)(2)(a). The fine print note following 690.45(B) offers explanation on this requirement. Since the EGC potentially will continuously carry the full fault current in systems without GFP, that conductor size needs to be calculated based off the ampacity and conditional use of the current-carrying conductors.

A TWIST ON EGC SIZING

Another addition to the EGC section of the 2008 *NEC* is 690.46, which requires that if the EGC is smaller than 6 AWG, it must comply with 250.120(C). This is a requirement that any EGC smaller than 6 AWG "shall be protected from physical damage by raceway or cable armor..., where not subject to physical damage, or where protected from physical damage."

This statement, "subject to physical damage," elicits different interpretations. Some jurisdictions consider the backs of arrays mounted parallel to the roof surface to be adequately protected from physical damage. In this situation, the 14 AWG EGC calculated for the two series strings placed in parallel would be acceptable. Other jurisdictions have a blanket policy of no EGC smaller than 6 AWG, due to the possibility of physical damage. The addition of 690.46 brings this requirement to the forefront and may require that some installers amend their current practices.

The "simple" concept of attaching an equipment grounding conductor to all of the metal parts of our PV systems can take interesting and complex turns. With the changes in the most recent *NEC* and the newest grounding products, this will continue to be one of the more debated topics for PV installations. ⏚

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