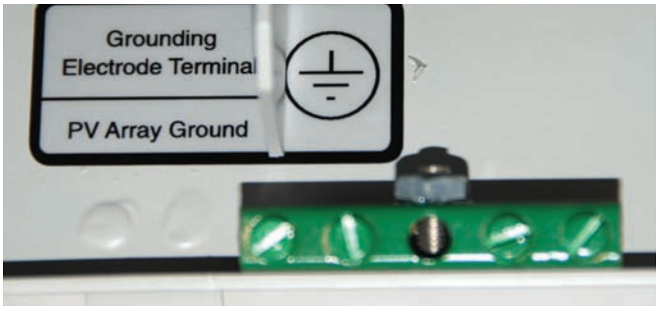
Inverter Grounding

by John Wiles

Properly connecting a utility-interactive inverter is critical to the safe, long-term, and reliable operation of the entire renewable energy system. Correct grounding of the inverter will minimize the possibility of electrical shock and damage from surge currents. While complex, it is important to understand and apply the requirements of Section 690.47 of the *National Electrical Code (NEC)* to the inverter grounding connections.

Equipment-Grounding Conductors

In a typical small PV system (less than 20 kW), the inverter serves as a central point for grounding connections. The DC equipment-grounding conductor from the PV array and the DC disconnect are connected to the inverter. The AC inverter output circuit equipment-grounding conductor leading to the point of connection with the utility is also connected to the inverter. Under the *2005 NEC,* the DC equipment-grounding conductors may be the only connection the module frames have to earth. If these grounding conductors are connected only to the inverter, then the inverter must be properly connected to ground (earth) for a safe installation. UL Standard 1741 requires equipment-grounding terminals for both the AC and DC circuits.

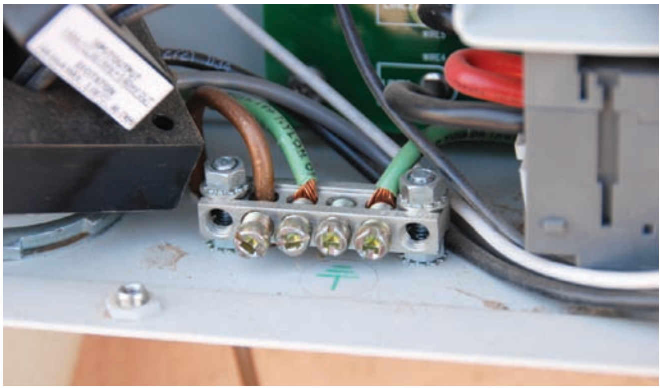


Close-up of an inverter with a grounding bus bar and the required grounding electrode conductor (GEC) terminal marking.

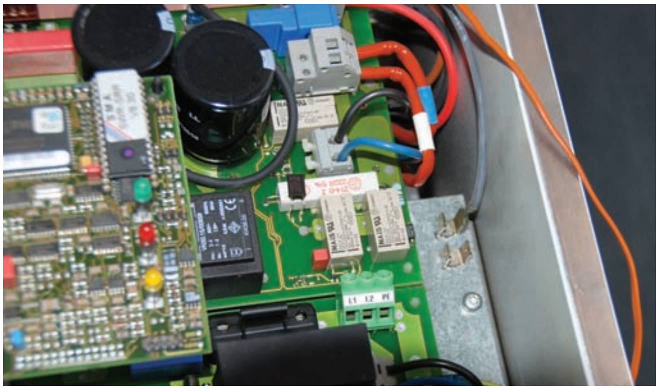
Grounding-Electrode Terminal

Nearly all utility-interactive inverters include transformers, are connected to grounded PV arrays, and have an internal ground-fault indication/detection (GFID) system. This GFID system includes the internal bonding jumper between the DC grounded conductor and the grounding system. The presence of this DC bonding jumper requires, according to UL Standard 1741, that the inverter have a DC grounding electrode terminal.

This inverter meets the minimum requirement of three grounding connection terminals.



With only one grounding terminal (PE), this inverter does not meet UL 1741 requirements.



Equipment grounding conductors are permanent leads coming out of the inverter.

Close-up of an external grounding electrode terminal.

These grounding connection requirements require that each inverter have a minimum of three terminals available. They will normally all be connected (bonded) together electrically in the inverter and they will be connected to the inverter chassis.

To ensure proper grounding of the entire PV system, it is necessary to connect all three of these terminals properly. Unfortunately, some manufacturers and their certification/listing agencies are allowing inverters to reach the market that do not have all three of these terminals. Because other countries do not ground PV systems like our Code requires, some inverters get certified/listed without a DC grounding-electrode terminal. The Europeans use the term "protective earth" (PE) terminal instead of "equipment grounding terminal." Others have only one equipment-grounding terminal, not the required two, and may not even have a grounding-electrode conductor terminal.

Some inverters have an external grounding electrode terminal (see photo, above right) and the equipment-grounding conductors are permanent leads coming out of the inverter (pictured in the photo above).

When using one of these inverters with missing grounding terminals, it is acceptable to splice the AC and DC equipment-grounding conductors together and connect them to a single equipment-grounding terminal. However, the grounding-electrode conductor must be connected directly to the proper terminal and should not be spliced.

Grounding the Inverter

Section 690.47(C) of the *NEC*, which addresses the DC grounding electrode connection, contains significant changes between the 2005 and 2008 editions. As far as I can determine, either the requirements of this section in the *2005 NEC* or the permissive requirements in the *2008 NEC* may be applied to connect the grounding-electrode conductor when using either Code. A proposal has been submitted for the *2011 NEC* that includes all three methods and will clarify what is acceptable. That proposal (below) may help interpret the requirements for 690.47(C) in the *2008 NEC.* The first two methods in the proposal align with 690.47(C)(1) and 690.47(C)(2) in the *2005 NEC*, while the third method coincides with 690.47(C) in the *2008 NEC.*

> 690.47(C) Systems with Alternating and Direct Current Grounding Requirements. PV systems having direct current (DC) circuits and alternating current (AC) circuits with no direct connection between the DC grounded conductor and AC grounded conductor shall have a DC grounding system. The DC grounding system shall be bonded to the AC grounding system by one of the methods listed in (1), (2), or (3).
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> This section shall not apply to AC PV modules.
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> When using the methods of (2) or (3), a visual inspection shall be made to ensure that the existing AC grounding-electrode system meets the applicable requirements of Article 250, Part III.
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> FPN No. 1: ANSI/Underwriters Laboratories Standard 1741 for PV inverters and charge controllers requires that any inverter or charge controller that has a bonding jumper between the grounded DC conductor and the grounding system connection point have that point marked as a grounding-electrode conductor (GEC) connection point. In PV inverters, the terminals for the DC equipment-grounding conductors and the terminals for AC equipment-grounding conductors

are generally connected to or electrically in common with a grounding bus bar that has a marked DC GEC terminal (depicted in the photo on page 106, upper right).

FPN No.2: For utility-interactive systems, the existing premises grounding system serves as the AC grounding system.

(1) Separate DC Grounding Electrode System Bonded to the AC Grounding Electrode System. A separate DC grounding electrode or system shall be installed, and it shall be bonded directly to the AC grounding-electrode system. The size of any bonding jumper(s) between AC and DC systems shall be based on the larger size of the existing AC grounding-electrode conductor or the size of the DC grounding-electrode conductor specified by 250.166. The DC grounding-electrode system conductor(s) or the bonding jumpers to the AC grounding-electrode system shall not be used as a substitute for any required AC equipment-grounding conductors.

Exception: Where the existing AC grounding electrode is not readily accessible, the bonding conductor shall be permitted to be connected to the AC grounding-electrode conductor as close as possible to the AC grounding electrode with an irreversible splice.

(2) Common DC and AC Grounding Electrode. A DC grounding-electrode conductor of the size specified by 250.166 shall be run from the marked direct-current grounding electrode connection point to the AC grounding-electrode. This DC grounding-electrode conductor shall not be used as a substitute for any required AC equipment-grounding conductors.

Exception: Where the existing AC grounding electrode is not readily accessible, the DC grounding electrode conductor shall be permitted to be connected to the AC grounding-electrode conductor as close as possible to the AC grounding electrode with an irreversible splice.

(3) Combined DC Grounding-Electrode Conductor and AC Equipment-Grounding Conductor. An unspliced, or irreversibly spliced, combined grounding conductor shall be run from the marked DC grounding-electrode conductor connection point along with the AC circuit conductors to the grounding bus bar in the associated AC equipment. This combined grounding conductor shall be the larger of the size specified by 250.122 or 250.166 and shall be installed in accordance with 250.64(E).

While any of the three methods of making connections to the inverter grounding electrode terminal may be used, there are advantages and disadvantages to each.

Method 1—similar to 690.47(C)(1) in the *2005 NEC*—has the advantage of routing surges picked up by the array more directly to earth than methods 2 or 3. However, since the bonding conductor between the new DC grounding electrode must be bonded to the existing building's AC grounding electrode, the size, routing, and cost of that conductor needs to be considered.

Method 2—similar to 690.47(C)(2) in the *2005 NEC*—uses fewer components than the other two methods and also routes surges to earth without getting near the AC service equipment.

Method 3 —similar to 690.47(C) in the *2008 NEC*—combines the inverter AC equipment-grounding conductor with the DC grounding-electrode terminal, saving wire. However, the requirement to bond the conductor at the entrance and exit of each metallic conduit and enclosure may become difficult with conductor sizes greater than about 6 AWG, especially since the conductor must remain unspliced or irreversibly spliced. Also, any surges picked up by the array will be routed directly to the service equipment and may be more likely to enter the building's wiring system than when grounding-electrode conductors are routed more directly to ground.

The complex and unclear section 690.47(D) in the *2008 NEC* requires a direct connection between the array and earth, in addition to any required equipment-grounding conductors between the array and the rest of the system. This requirement applies to ground- and pole-mounted PV arrays and to arrays where the inverter is mounted on a different structure than the array. There is an exception for systems where the PV array and the inverter are mounted on the same structure, but exactly what is excepted—the grounding electrode conductor, the grounding electrode, or both—is not clear. It has been proposed that this lightning damage reduction requirement be deleted from the *2011 NEC* as it is not directly related to safety.

Proper grounding connections at the inverter are critical to a safe and properly operating PV system. These connections may be the only connections that the entire system has to earth. All connections must be made, and that may prove difficult if manufacturers have not included the proper number of terminals.

Access

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Southwest Technology Development Institute • www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/Codes-Stds.html • PV systems inspector/installer checklist, previous "Perspectives on PV" and *Code Corner* articles, and *Photovoltaic Power Systems & the 2005 National Electrical Code: Suggested Practices*, by John Wiles