

CONNECTING THE INVERTER

by John Wiles



Connecting the utility-interactive inverter properly is critical to the safe, long-term and reliable operation of the entire system. Proper grounding of the inverter will minimize the possibility of electrical shocks and damage from surge currents. Understanding and applying the requirements of *NEC 690.47* to the inverter grounding connections is somewhat complex but ensures that the user will be safe and that the inverter and other equipment will suffer minimum damage under surge conditions.

Equipment Grounding Conductors

In a typical residential or small commercial PV system (less than about 20 kW), the inverter serves as a central focal point for grounding connections. The dc equip-

ment 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 connected to the inverter. Under the *2005 NEC*, the dc equipment grounding conductors may be the only connection the module frames have to earth. UL Standard 1741, quoted in part below, requires equipment grounding terminals for both the ac and dc circuits.

18.1.8 Equipment grounding leads or equipment grounding terminals shall be provided for each input and each output circuit.

Grounding Electrode Terminal

Nearly all utility-interactive inverters installed today (2009) employ 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. Here is what UL Standard 1741 requires (in part) for the dc grounding electrode terminal.

18.2.1 Equipment intended to be installed as service entrance equipment or equipment containing the main dc or ac bonding connection shall be provided with a grounding electrode terminal.

These grounding connection requirements will require that each inverter have a minimum of three terminals available for making the proper connections. All three terminals may be on a common bus bar or mounted separately in the inverter. They will normally all be connected (bonded) together electrically in the inverter and they will be connected to the inverter chassis. See photos 1, 2 and 3.

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 letting inverters get on 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



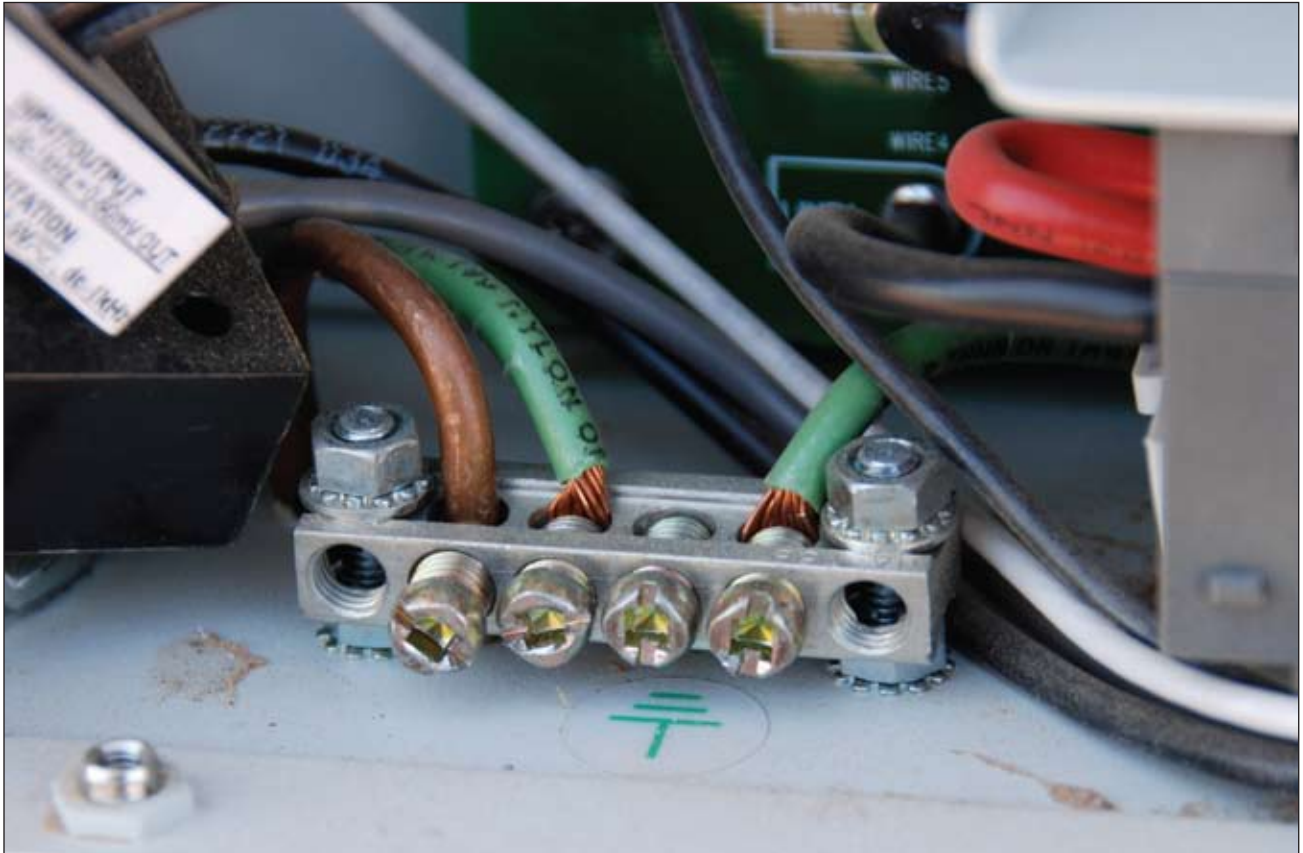


Photo 1. Three grounding terminals on bus bar

equipment grounding terminal, not the required two and do not even have a grounding electrode conductor terminal. See photo 4.

Some inverters have an external grounding electrode terminal and the equipment grounding conductors are permanent leads coming out of the inverter. See photos 5 and 6.

When the installer or inspector finds one of these inverters with missing grounding terminals, the manufacturer and the listing agency should be contacted. It is possible, in some cases, 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.



Photo 2. Grounding bus bar

Connecting the Inverter to Ground (Earth)

The *Code* had significant changes between the 2005 and 2008 editions in Section 690.47(C) that addresses the dc grounding electrode connection. As far as the author can determine, either the requirements of this section in *NEC-2005* or the permissive requirements in *NEC-2008* may be applied to connect the grounding electrode conductor when installing a system in jurisdictions using either *Code*. A proposal has been submitted for *NEC-2011* that includes all three methods and will have improved

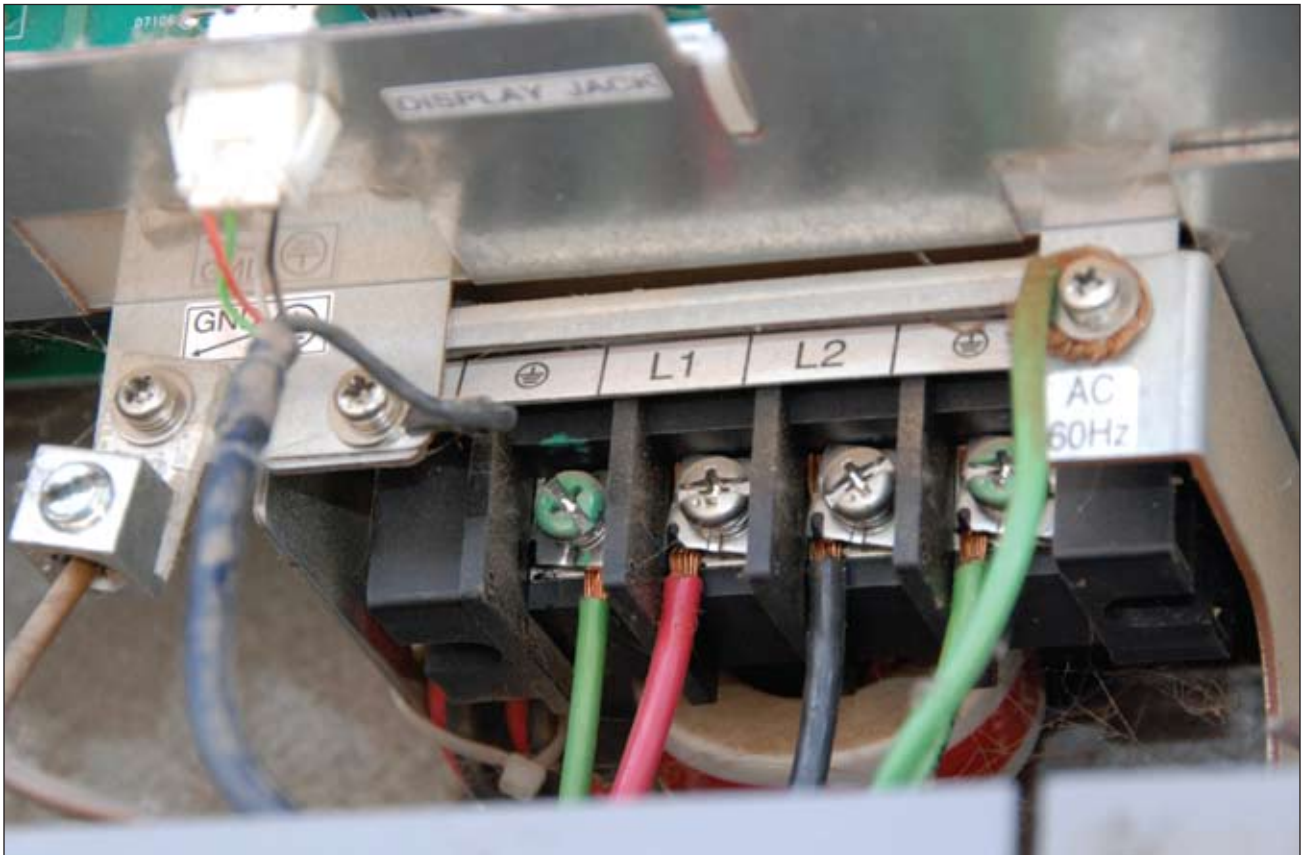


Photo 3. Three grounding terminals

clarity. That proposal is repeated and may help in understanding what the requirements are for 690.47(C) in *NEC-2008*. Note that paragraphs (1) and (2) align with 690.47(C)(1) and 690.47(C)(2) in *NEC-2005* and paragraph (3) aligns with 690.47(C) in *NEC-2008*. Reviewing this proposal may assist the reader in understanding the existing 690.47(C) in the 2005 and 2008 *Codes*.

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).

This section shall not apply to ac PV modules.

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.

FPN No. 1: ANSI/Underwriters Laboratory 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 busbar that has a marked dc GEC terminal.

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.

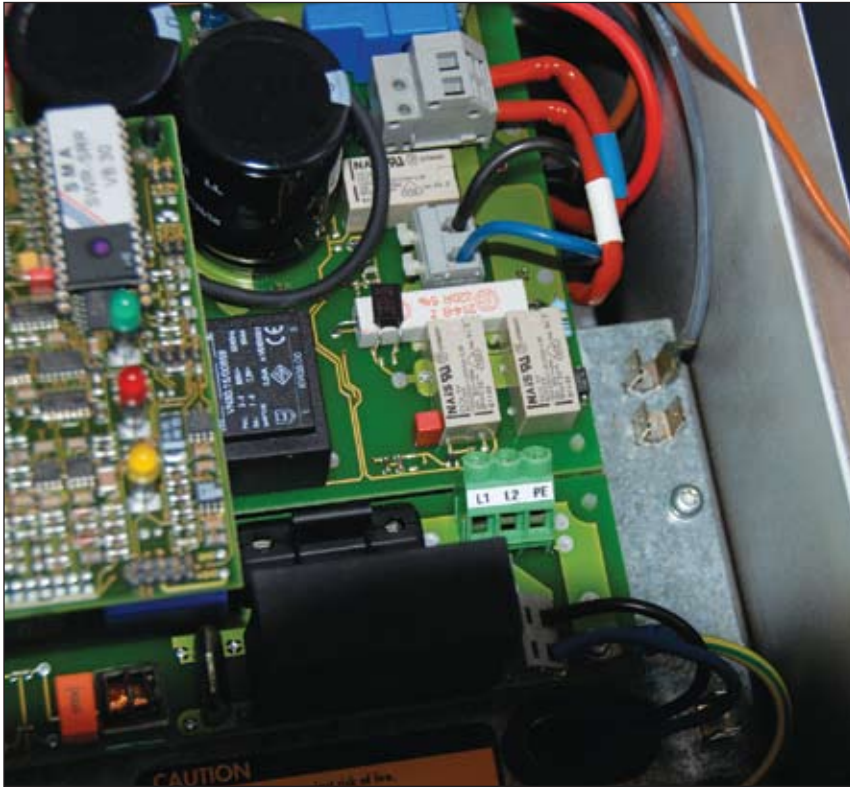


Photo 4. Only one equipment grounding terminal (PE) and no grounding electrode conductor terminal

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, in the above proposal, (similar to 690.47(C)(1) in *NEC-2005*) has the advantage of routing surges picked up by the array more directly to earth than methods 2 and 3. However, since the bonding conductor between the new dc grounding electrode must be bonded to the existing premises ac grounding electrode, there is the size, routing and cost of that conductor to consider.

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

Method 3 (similar 690.47(C) in *NEC-2008*) combines the inverter ac equipment grounding conductor with the dc grounding electrode terminal and thereby uses less copper. 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

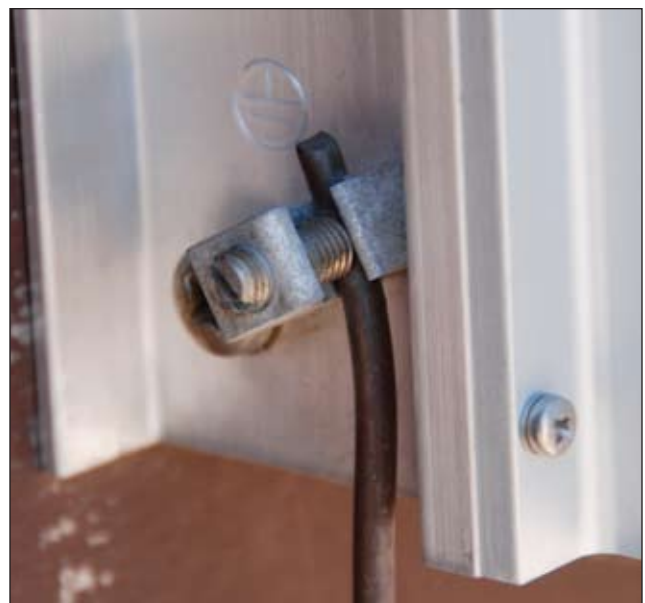


Photo 5. External grounding electrode terminal

IN ZINC and BRONZE

GROUNDING BRIDGE



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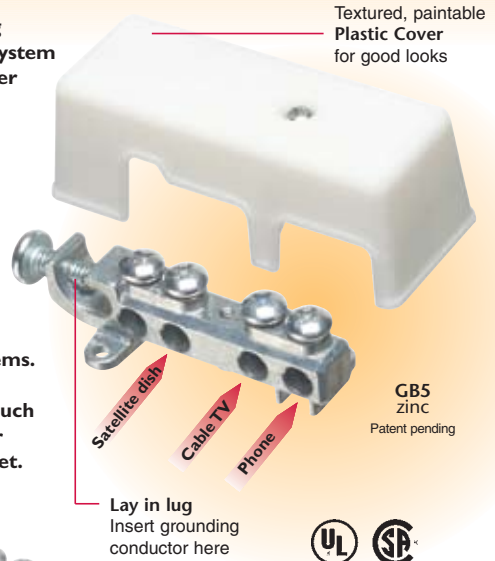
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Photo 6. Grounding electrode conductors permanently attached in conduit

be routed directly to the service equipment and may be more likely to enter the premises wiring system than when grounding electrode conductors are routed more directly to ground.

Summary

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.

In the next Perspectives on PV, we will cover the ac output circuits of the utility-interactive inverter.

For Additional Information

If this article has raised questions, do not hesitate to contact the author by phone or e-mail. E-mail: jwiles@nmsu.edu Phone: 575-646-6105

A color copy of the latest version (1.9) of the 150-page, *Photovoltaic Power Systems and the 2005 National Electrical Code: Suggested Practices*, written by the author, may be downloaded from this web site: <http://www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/Codes-Stds.html>

The Southwest Technology Development Institute web site maintains a PV Systems Inspector/Installer Checklist and all copies of the previous “Perspectives on PV” articles for easy downloading. Copies of “Code Corner” written by the author and published in *Home Power Magazine* over the last 10 years are also available on this web site: <http://www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/Codes-Stds.html>

The author makes 6–8 hour presentations on “PV Systems and the NEC” to groups of 60 or more inspectors, electricians, electrical contractors, and PV professionals for a very nominal cost on an as-requested basis. A schedule of future presentations can be found on the IEE/SWTDI web site.✍



John Wiles works at the Institute for Energy and the Environment (IEE) (formerly the Southwest Technology Development Institute) at New Mexico State University. IEE has a contract with the US Department of Energy to provide engineering support to the PV industry and to provide that industry, electrical contractors, electricians, and electrical inspectors with a focal point for Code issues related to PV systems. He serves as the secretary of the PV Industry Forum that submitted 54 proposals for the 2011 NEC. He provides draft comments to NFPA for Article 690 in the NEC Handbook. As an old solar pioneer, he lived for 16 years in a stand-alone PV-power home in suburbia with his wife, two dogs, and a cat—permitted and inspected, of course. The PV system on his home is a 5 kW (dc) utility-interactive system with a full-house battery back up.

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