More Details on Making the Grid Connection—

Grounding, Backfed Breakers, & PV Disconnect

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In *Code Corner* for *HP89,* I discussed some general requirements for connecting a PV system to the grid. This time, I'll go a little deeper into the grounding and intertie requirements by applying some of the material covered in previous columns to a utility-interactive system.

Grounding for a utility-interactive PV system starts at the modules and ends at the ground rods, with all of the balance-of-systems equipment in between. The *NEC* requirements for grounding are some of the most complex and confusing requirements in the code.

Equipment Grounding

The instruction manual for a PV module will tell where and how the module frame must be grounded. Hardware is usually supplied to connect a bare copper conductor to the module frame at a designated location. Usually the hardware consists of a stainless steel, self-tapping screw and a stainless steel washer.

The screw is used in a marked hole in the module frame to cut threads into the aluminum frame. The tight threads are needed to penetrate the normal oxidation or intentional anodizing on the surface of the aluminum, which can be a partial insulator. The washer is used to isolate the copper wire from the aluminum surface to minimize galvanic corrosion. Just bolting the module frame to a grounded rack does not meet the code requirements for a good, long lasting, electrical connection for grounding. The tough aluminum anodizing or oxide film makes it difficult to achieve or maintain a durable, electrically conductive, bolted connection.

The equipment-grounding conductor for a PV module must be sized about the same size as the circuit conductors for the module (*NEC* 690.45). The actual ampacity of the equipment-grounding conductor must be 125 percent of the short-circuit current (Isc) of the module. If the system has a PV ground-fault protection device (*NEC* 690.5), either built into the inverter or as an external unit, the equipment-grounding conductor may be sized according to *NEC* Section 250.122—see the table.

If there is any possibility of physical damage, the equipment-grounding conductor should be increased to a #6 (13 mm^2) conductor, and possibly be provided with some sort of mechanical protection (250.120(C)). These requirements generally indicate that a #10 (5 mm^2) conductor would be suitable for most installations if protected from physical damage. The equipment-grounding conductor should be run with and in near proximity to the circuit conductors (if in free air) or in the same conduit with the circuit conductors.

If the system design uses a source circuit combiner box near the modules (rather than a combiner circuit in the inverter), the equipment-grounding conductor from that box to the inverter will have to be increased in size based on the short-circuit current of the combined PV output circuit. Again, the 125 percent Isc rule applies if no ground-fault device is used, and *NEC* 250.122 is used if an *NEC* 690.5 ground-fault device is in the system.

If long distances are involved between the PV array and the inverter and the conductors have been increased in size to minimize voltage drop, the equipment-grounding conductors must also be increased in size proportionately. However, they never have to be larger than the size of the circuit conductors.

If you have distances sufficient to require oversizing the current carrying conductors due to high resistances, the equipment-grounding conductors will also have high resistances. They must be oversized to lower the resistance in a fault circuit. In most cases, it is backfed currents from the battery, line-tie inverter, or from parallel strings that make up the high available fault currents that trip the overcurrent devices.

Equipment grounding of other circuits (AC and DC) should follow *NEC* 250.122, which requires the equipment-grounding conductor to be based on the rating of the overcurrent device protecting that circuit. The table shows some typical values for copper conductors. The larger sizes would be associated with utility-interactive systems that have battery backup supplies with cases that must be grounded.

Equipment-Grounding Conductor Size

Overcurrent Device Size (Amps)	*Conductor Size (AWG)*
15	14
20	12
30	10
40	10
60	10
100	8
200	6
300	4
400	3
500	2

System Grounding

Normally, AC and DC system grounding is handled inside the utility-interactive inverter. This is particularly true of inverters that include the *NEC* 690.5 ground-fault protection device. These inverters often provide grounding lugs or points for connecting external grounding conductors. In most cases, these grounding connection points are equipment-grounding points (tied to the chassis) that also serve as system grounding points for connection of the grounding electrode conductor to the grounding electrode (usually a ground rod).

In an installation where there is an existing AC load center and utility service entrance, this grounding point in the inverter can be connected to the grounding bus bar in the existing AC load center. The grounding bus bar in the AC load center is usually where the grounding electrode conductor is attached. For want of a better name, I would call this conductor a ground-bonding conductor. It should be sized as the larger of the conductors specified by *NEC* 250.106 (usually #6; 13 mm^2), or the largest equipment-grounding conductor in the system.

The actual name and size of this conductor is not specifically called out in the code. Since it may have to carry fault currents, as well as serve as a portion of the DC grounding electrode conductor, the size specified above should meet all code requirements. This bonding conductor should be routed in close proximity to the AC circuit conductors from the inverter to the AC load center.

It would also be possible to run a grounding electrode conductor from the grounding point in the inverter to a separate ground rod, and this ground rod should be bonded to any existing AC ground rod. If this approach is taken, an AC equipment-grounding conductor should still be run between the inverter and the AC load center, and sized per *NEC* 250.122.

Backfed Breakers

The National Fire Protection Association (NFPA) has issued an informal opinion (just as good as a formal one, but you get it quicker and not in writing) that the backfed circuit breakers used to connect a utility-interactive inverter to the load center must be clamped.

"Clamped" means that the individual circuit breaker must be attached to the load center back plane with a screw or other device specifically made for the purpose of preventing the breaker from being inadvertently pulled loose from the bus bars of the load center. The screw or other device is supplied by the manufacturer of the load center. Many load centers have no provisions for clamping, and therefore are not suitable for backfeeding.

NEC 690.64(B)(5) requires that such breakers be "identified" for backfeeding. According to Underwriters Laboratories (UL), an identified breaker is one that does not have terminals marked "line" and "load." The clamping requirement comes from *NEC* 408.16(F) in Chapter 4 of the code, one of the general chapters. A proposal to modify Article 690 will be submitted for changes to the 2005 *NEC*. But until then, the Chapter 4 requirement is the governing requirement, since nothing in Article 690 overrides it or even conflicts with it.

Most inspectors will accept the following reasons for not clamping a breaker being backfed from a utility-interactive inverter:

- The plug-in breaker will immediately become de-energized (dead) when the breaker is accidentally unplugged from the load center because of the anti-islanding circuits built into the listed inverter under UL Standard 1741.
- The front panel on most load centers actually clamps all circuit breakers to the bus bars, and this panel cannot be removed without a tool.
- Access to the inside of any load center connected to a utility feeder allows an unqualified person to easily come into contact with any exposed bus bar and the main feeder wires.

Here are several solutions if the inspector requires that the backfed breaker be clamped:

- Determine whether the existing load center has a kit that can be used to clamp breakers into position, and use that kit.
- Install a second service panel disconnect that bypasses the existing load center, as described in *HP89.* This service panel can be purchased from a number of vendors, and has only a single breaker that is bolted in place.

- Install a fused disconnect as the second service panel disconnect.
- Install a new load center that does have a breaker that can be clamped.

In the second and third options above, the second service panel or fused disconnect will have to be marked as being suitable for use as "service entrance equipment." After the utility power has been turned off (usually by the utility), the second service panel or fused disconnect will have to be connected in parallel with the existing lines between the meter and the original service panel.

PV Disconnect Location

A new requirement in Article 690 of the 2002 code, *NEC* Section 690.14(C)(1), is that the PV disconnect must be at the point where the conductors from the PV array first enter the building, or immediately inside the building at that point. Furthermore, the disconnect must be in a readily accessible location. Bathrooms are excluded as a possible location.

These requirements are really not new, and are very similar to the requirements for an AC utility service disconnect as described in *NEC* Article 230. Generally it means that it will no longer be possible to penetrate an attic and run cables through the house to a disconnect located inside the house near the inverter. Normally, the conductors from a roof-mounted PV array must be run down the outside of the building to a readily accessible (no ladders, locked doors, or limited access) location where the PV disconnect is to be mounted.

If the utility-interactive inverter is mounted outside on the wall and has the PV disconnect built in, that is acceptable. Mounting the inverter and built-in disconnect immediately inside the building at the point of penetration should also be acceptable. Installations requiring a remote location for the inverter could use a circuit breaker or fused disconnect on the outside of the building, and then have the inverter placed wherever required. There may be a requirement for a second PV disconnect near the inverter if a disconnect is not built into the unit.

For those inverters having multiple source circuit combiner functions, the source circuits may need to be combined in an external combiner box. Then the combined output is run through the readily accessible disconnect switch (one pole), and the PV output circuit is connected to the remotely located inverter. If this is not done, there is a requirement to have a multiple pole disconnect switch—one for each source circuit—mounted in a readily accessible location.

Proposals for the 2005 *NEC*

Proposals for the 2005 *National Electrical Code* are due by Friday November 1, 2002. The clock is running. The PV industry will be collaborating through the Industry Forum to write and substantiate a number of well-justified proposals in the next few months.

In the past, these proposals from the PV industry have had the highest adoption rate of any proposals submitted by a single group. Wrenches are encouraged to participate. E-mail your proposals to me with your substantiations as soon as possible. We will get them into the proper format, and circulate them throughout the industry via e-mail for comment. Normally we have our proposals reviewed by UL and others on the Code Making Panel to ensure that we get the votes needed to pass. Of course, you can always submit directly to NFPA—see the form in the back of the *NEC.*

Even if you don't want to submit a proposal, but do want to participate in the review process before submittal, send me your name, phone number, and e-mail address, and we will put you on the list.

Questions or Comments? If you have questions about the *NEC,* or the implementation of PV systems that follow the requirements of the *NEC*, feel free to call, fax, e-mail, or write. Sandia National Laboratories sponsors my activities in this area as a support function to the PV industry. This work is supported by the United States Department of Energy under Contract DE-FC04-00AL66794. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy.

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