PV Grounding Continued

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Grounding PV modules was covered in *Code Corner* in *HP102*. In this column, the terminology used in grounded systems and some of the grounding methods will be covered.

The subject is quite complex. Grounding photovoltaic (PV) systems with both AC and DC sides is even more complex. Everyone involved in PV installations is encouraged to get a copy of the *National Electrical Code Handbook* for the additional details it provides on grounding.

Equipment-Grounding Conductors

In a grounded electrical system, several terms with the root term "ground" are used. If these terms are used improperly, it can be confusing and possibly unsafe. A "grounded" system is one that is connected to earth. (Europeans use the term "earthed.") All exposed metallic surfaces that could accidentally be energized (come into contact with an electrically "hot" or "live" conductor) must be connected to ground with "equipment-grounding conductors."

The requirement for equipment-grounding conductors applies to PV module frames, module mounting racks (if exposed, single-conductor cable is routed along them), switchgear enclosures, overcurrent enclosures, metallic conduit and raceways, inverters, charge controllers, and the like. A PV system at any voltage (even a 12-volt, off-grid system) should have a network of equipment-grounding conductors linking all of these exposed metal parts to each other and to the earth.

Equipment-grounding conductors do not carry electricity on a continuous basis. They are only intended to do so under ground-fault conditions (unintentional electrical circuits to ground). They represent one of several lines of defense against fires and shocks from electrical systems. First, the metal surface is connected to earth, and if it comes into contact with an energized conductor, any dangerous voltages will be reduced significantly in magnitude as energy is diverted into the grounding system. The equipment-grounding system is designed and connected so that most ground faults (where an energized conductor contacts an exposed metal surface) result in an overcurrent device (fuse or circuit breaker) opening and stopping the fault current.

The equipment-grounding conductor can be a bare conductor with no insulation, an insulated conductor with green insulation, or a conductor with green insulation and yellow stripes. Equipment-grounding conductors in DC, PV source and output circuits must have an ampacity at least 1.25 times the short-circuit current (I_{sc}) from the PV sources at that point in the circuit.

The ampacity of these conductors is calculated from Table 310.16 in the *NEC*. The insulation temperature rating used for the ampacity determination should be equal to the insulation temperature rating of the circuit conductors, even when the equipment-grounding conductor is bare.

Equipment-grounding conductors in other DC circuits and in AC circuits are sized according to Table 250.122 in the *NEC*. This table is based on the rating of the overcurrent device protecting the circuit. The table is used to determine the size of the equipment-grounding conductor in circuits *other* than DC, PV source and output circuits. If the circuit conductors have been oversized for voltage drop, then the equipment-grounding conductors from Table 250.122 must also be oversized proportionately.

Grounded Conductors

A "grounded conductor" is a circuit conductor that is normally electrified and is connected to earth. The connection to earth should be made at only one point in the DC part of the system and at only one point in the AC part of the system. In utility-interactive systems, the connection between the DC grounded conductor (usually the negative conductor from the PV array) and the rest of the DC

Equipment-Grounding Conductor Size

Overcurrent Device Rating (A)	Minimum Equipment-Grounding Conductor Size (AWG)
15	14
20	12
30	10
40	10
60	10
100	8
200	6
300	4

From Table 250.122 of the *NEC*.

grounding system is frequently made inside the inverter as part of the ground-fault protection device.

The insulation on a grounded circuit conductor is white for #6 (13 mm^2) conductors and smaller. If the conductor is larger than #6 (normally available only in black), the conductor must be marked with white tape or paint at each splice and termination. The code allows manufacturers to use three longitudinal white stripes on any colored conductor (except green) to indicate a grounded conductor. If exposed, USE-2 (normally available only in black), single-conductor cables are used for PV module interconnections, the grounded conductor must be marked with white tape or paint at each termination, even when the conductor is smaller than #6.

Main Bonding Jumper

In *NEC* language, the word "bonding" means to connect electrically. Equipment-bonding conductors and devices connect various parts of the equipment-grounding system together. For example, the green grounding screw on an AC switch or outlet is used to connect the equipment-grounding conductor. The main bonding jumpers connect the grounded circuit conductors (one for the DC sections of the system and one for the AC sections of the system) to the equipment-grounding conductor(s) at the main disconnects or main bonding points.

In the AC parts of PV systems (both utility-interactive and stand-alone), the main AC bonding jumper is usually installed in the main load center of the building where the AC service disconnect is commonly installed.

In a utility-interactive system, the main DC bonding jumper is frequently (but not always) internal to the inverter and is part of the internal ground-fault protection system required by the *NEC,* Section 690.5. Since utility-interactive inverters are frequently used on dwellings where the PV arrays are on the roof, many inverter manufacturers include the ground-fault protection device in all inverters.

In stand-alone systems where the modules are not mounted on the roof of a dwelling, the main DC bonding jumper can be installed anywhere on the DC circuits. It is frequently a large grounding block mounted in the DC disconnect enclosure between the inverter and the batteries. If the PV array is mounted on the roof of a dwelling, the main DC bonding jumper will be part of the *NEC* section 690.5 ground-fault protection device that will usually be mounted external to the inverter.

Grounding-Electrode Conductor

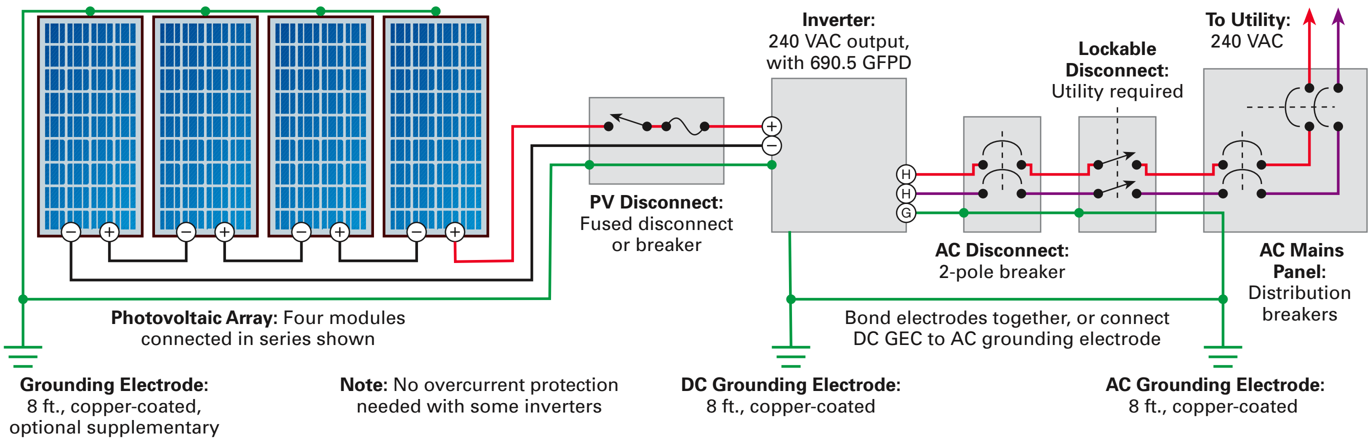
Because most inverters have transformers that isolate the DC grounded conductors from the AC grounded conductors, two grounding systems are usually required. Conductors are routed from a single main bonding point in the DC system and a single main bonding point in the AC system to grounding electrodes (the part of the grounding system that is in physical contact with the earth, such as a ground rod). The conductors from these main bonding points to the grounding electrode(s) are called the "grounding-electrode conductors" (GECs).

There will usually be a DC grounding-electrode conductor and an AC grounding-electrode conductor in systems with an inverter. In a PV installation where there is an existing AC electrical system, the AC grounding electrode is already installed. The DC grounding-electrode conductor may be connected to the AC grounding electrode or it may be connected to a new DC grounding electrode. This new DC grounding electrode must be bonded to the AC grounding electrode.

Grounding-electrode conductors may be either bare or insulated. No color is specified for this conductor (if insulated), but conventional practice suggests that it be black and not white, green, or green with yellow stripes. The smallest allowable size is #8 (8 mm^2); however, a grounding-electrode conductor this small must be installed in conduit for physical protection.

Many inspectors allow a #6 (13 mm^2) grounding-electrode conductor to be installed without conduit if it is attached to a building surface. The #8 and #6 conductors are normally allowed when the GEC is connected to a ground rod. When other grounding electrodes are used, the size of the required GEC may be larger. If a concrete-encased electrode in the

Grounding for a 240 VAC, Grid-Tied PV System



building slab is used as the grounding electrode, a #4 (21 mm^2) GEC is required.

The GEC must be unspliced (or spliced with irreversible splices—for example, exothermic welds or crimp-on splicing devices) from the bonding point to the grounding electrode or grounding-electrode system.

Grounding Electrode

The "grounding electrode" can be a number of different devices. In many places, the commonly used electrode is an 8-foot (2.4 m) long, 5/8-inch (16 mm) diameter copper-coated steel rod driven into the earth. The entire length of the rod must be in contact with the earth, so the top is usually flush with, or buried slightly below the surface. Clamps rated for direct burial are used to connect the grounding-electrode conductor to the grounding electrode.

The code requires that the resistance from the rod to the earth be 25 ohms or less. This measurement is difficult without specialized equipment. To do it accurately, you have to use instruments that cost hundreds of dollars.

If the measurement is greater than 25 ohms, a second rod must be driven at least 6 feet (1.8 m) away and bonded to the first rod. The bonding conductor must be the size of the grounding-electrode conductor. The rods may be driven up to 45 degrees from the vertical in rocky soils or buried in a trench horizontally at least 30 inches (76 cm) deep.

Sometimes, a 20-foot (6 m) length of #4 (21 mm^2) bare copper conductor is buried in the concrete footer or slab for the house, and serves as the grounding electrode. Connecting the grounding-electrode conductor to grounded water pipes, well casings, or grounded building steel is also allowed in some cases. These requirements are code minimums. If the installation is in a high lightning area, much more extensive grounding systems will be beneficial.

Ground-mounted PV arrays should have an additional grounding electrode at the array location. It is connected to the equipment-grounding system for the module frames and the array structure. Not only is this a code requirement (due to the location of the PV array away from the inverter), it will enhance the ability of the system to deal with lightning surges. This supplementary DC grounding electrode does not have to be bonded directly to the main DC grounding electrode. It is connected indirectly to the main DC grounding electrode through the equipment-grounding conductors.

Grounding is a complex subject, and the information here covers only the high points. For more information, see the suggested references in Access.

Access

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IAEI Soares Book on Grounding, 8th Edition, paper, 384 pages, 1-890659-27-4, US$44.25 from International Association of Electrical Inspectors, 901 Waterfall Way Ste. 602, Richardson, TX 75080 • 972-235-1455 • Fax: 972-235-6858 • customerservice@iaei.org • www.iaei.org

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