To Ground or Not to Ground: That is *Not* the Question (in the USA)

John Wiles

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"Even most 12 volt PV systems shall be grounded in some way," sayeth ye *National Electrical Code (NEC).* This Code Corner will begin with the code requirements for a PV system from the ground up.

Subsequent articles will discuss the code requirements for PV hardware on the roof and for the components in between. The terminology, the whys, and the hows of grounding PV systems will be addressed. Proper grounding will enhance safety (both user and equipment), improve performance, and may even reduce costs. Article 250 (Grounding) was completely revised in the 1999 edition of the *NEC* and references to Article 250 will refer to the new edition.

Why?

Research and experience have indicated that both grounded and ungrounded electrical systems can be safe. Europeans have a 100 year tradition of operating ungrounded electrical power systems, and European codes reflect this. The European Community also makes use of double-insulated components and electronic ground-fault detectors in many applications.

Reports in the U.S. have indicated that on ungrounded DC electrical systems (non-PV) used by electrical utilities, when a ground fault occurs that is undiscovered or unrepaired, a second ground fault will frequently occur for the same reason within two weeks. Double ground faults create problems because overcurrent devices may not sense them and may not offer protection. The utilities always rely on extensive electronic ground-fault detectors in their ungrounded DC electrical systems.

In the United States, the arguments for and against grounding were carried out over several decades as the *NEC* was being developed, just before the turn of the century. Unlike the Europeans, the U.S. decided to require the use of grounded systems. For those who want to achieve a good understanding of the subject of grounding, the *NEC Handbook* and the International Association of Electrical Inspectors (IAEI) *Soares Book on Grounding* are recommended (see Access). The IAEI book even gives some of the history of grounding requirements in the U.S.

Electrical systems in the U.S. (including PV systems) are generally solidly grounded to limit the voltage with reference to ground during normal operation, and to prevent excessive voltages due to surges from lightning or unintentional cross connections with higher voltage lines.

In PV systems, the modules are usually mounted in high, exposed locations where they are prone to picking up induced surges from nearby lightning strikes. Utility-interactive inverters are also subjected to surges on utility power lines. In addition, systems using PV power to run computers with hardwired modems are subject to surges from the telephone line. Proper grounding effectively reduces these potential problems and more.

Terminology

The term "grounded" indicates that one or more parts of the electrical system are connected to the earth, which is considered to have zero voltage or potential. The earth is used as a reference because there is so much of it, and many conductive surfaces are connected or in contact with it. Most metallic objects such as metal building frames, as well as other electrical/electronic systems (TV, telephones, etc.) are in contact with or connected to earth. In some areas, the term "earthing" is used instead of "grounding."

Plumbing (including bathtubs and sinks) used to be solidly grounded. But now it may be not connected to ground because of the use of plastic pipes and drains. When faults occur in electrical systems, those faults are frequently faults to earth (ground faults). To better understand the grounding requirements of the *NEC,* it is necessary to examine several terms used in conjunction with grounding.

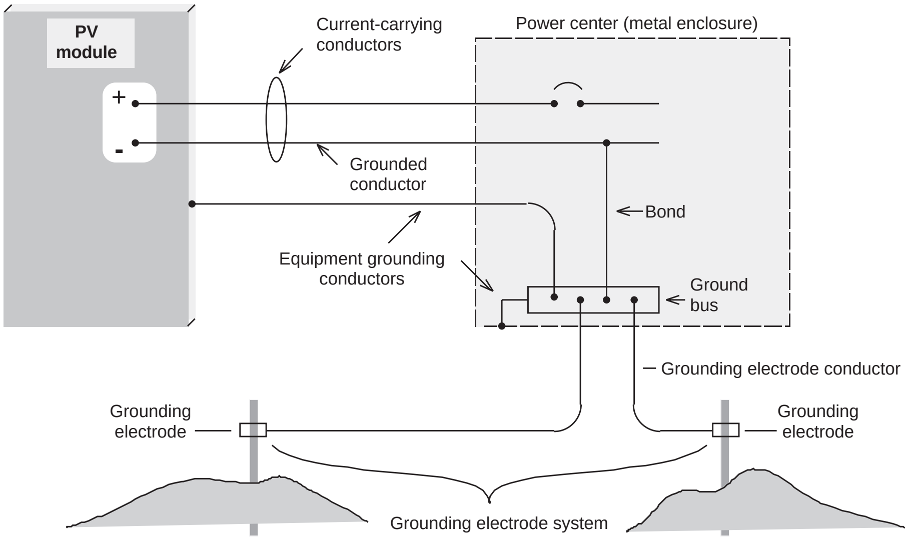
A *grounded conductor* is a conductor that normally carries current and is connected to the earth. Examples are the neutral conductor in AC wiring and the negative conductor in many DC systems. Note that some DC systems such as telephone systems connect the positive conductor to ground rather than the negative conductor. A system is a "grounded system" when one of the current-carrying conductors is grounded.

An *equipment-grounding conductor* is a conductor that does not normally carry current (except under fault conditions) and is also connected to earth. It is used to connect the exposed metal surfaces of electrical equipment together and then to ground. Examples are the bare conductor in non-metallic sheathed cable (Romex®) and the green, insulated conductor in power cords for portable equipment. These equipment-grounding conductors help to prevent electrical shocks and allow overcurrent devices to operate properly when ground faults occur.

A *grounding electrode conductor* is the conductor between a common single grounding point in the system and the grounding electrode. Splices are not normally made in this conductor. The *common single grounding point* is a point where the grounded conductor and the equipment-grounding conductors are connected to the grounding electrode conductor.

A *grounding electrode* is the metallic device that is used to make actual contact with the earth. There are "made" grounding electrodes, such as the common 5/8 inch diameter, 8 foot long (16 mm x 2.4 m) ground rod. Other types of grounding electrodes include metal water pipes, metal building frames, and concrete-encased cables (known as Ufers, after their inventor). Specific requirements for each of these grounding electrodes can be found in Article 250 of the *NEC.* Local codes and practices vary greatly and should be investigated to determine which types of electrodes are in common use.

Figure 1: Grounding Electrodes



Bond is a term that, as a verb, means to connect two or more points together. As a noun, it usually refers to the connection between the grounded conductor, the equipment-grounding conductors, and the grounding electrode conductor. Bonding is also used to describe connecting all of the exposed metal surfaces together to complete the equipment-grounding conductors.

A *grounding electrode system* is a system where two or more grounding electrodes are connected together. These systems are common in PV installations where there are two grounds (such as an existing one for the AC system and a new grounding electrode that has been installed for the DC system). See *NEC* Sections 250-81 through 250-86.

Figure 1 shows how the grounding components are related in a PV system.

There is Grounding and There is Grounding

NEC Requirements

The *NEC* establishes requirements for nearly all field-installed electrical systems that are not owned and operated by a utility on utility property. For example, it covers PV systems (Article 690), cranes and hoists (Article 610), EV charging stations (Article 625), electric welders (Article 630), computers (Article 645), communications systems (commercial and amateur, Chapter 8), and most other electrical installations.

The *NEC* covers low voltage systems (less than 50 volts) in Article 720 and high voltage systems (over 75 kilovolts) in Section 110. It covers systems with zero frequency (direct current) through radio frequency (RF) systems into the gigahertz range.

Equipment Grounding

With respect to grounding, the *NEC* requires that all PV systems have equipment-grounding conductors that connect all of the exposed metal surfaces of the system to a grounding electrode (690-43). This applies to any PV system that has field-installed wiring (items like solar wristwatches and path lights are excluded), even those operating at 12 volts. As noted above, the non-current-carrying conductors may be bare (uninsulated) or covered with green insulation. They are normally routed along with the current-carrying conductors.

System Grounding

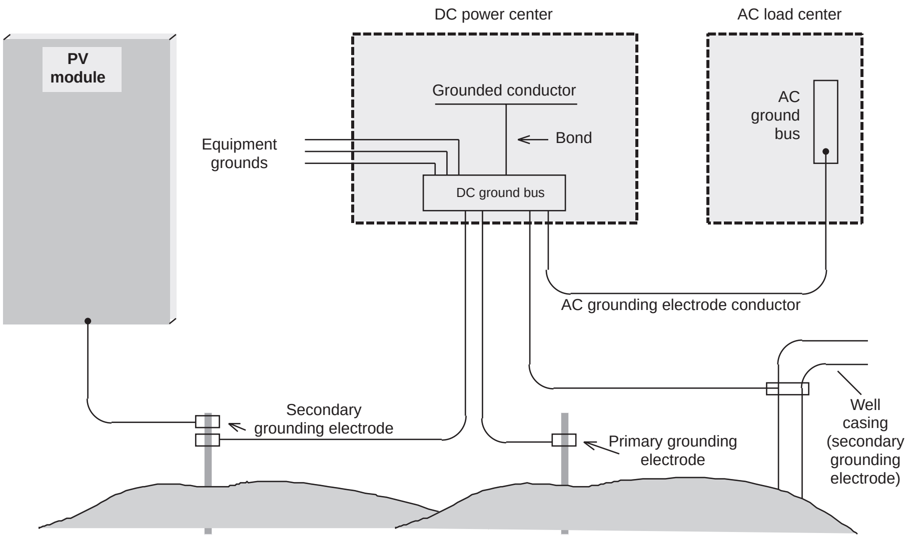
When it comes to the grounding of one of the current-carrying conductors, different rules apply. Those systems with a system voltage over 50 volts are required to be grounded by having one of the current-carrying conductors connected to the grounding electrode. The system voltage is the maximum open-circuit voltage of the system as defined in Article 690.

PV modules (crystalline silicon-based) have open-circuit voltages that increase with decreasing temperatures. At temperatures below 25°C (77°F), the open-circuit voltage will be higher than the open-circuit voltage marked on the back of the PV module. Since this system voltage is dependent on temperature, a temperature correction factor is necessary (Table 690-7). The correction factor is selected based on the lowest expected ambient temperature where the PV system is to be installed, and is used as a multiplier on the rated, open-circuit voltage of the module. At low temperatures and with high winds, or in the early morning hours, the PV module may not heat up, so the lowest ambient temperatures for the area should be used.

The calculations required by Section 690-7 and Table 690-7 of the *NEC* indicate that a nominal 12 volt PV system has a system voltage of about 27 volts in worst case, low-temperature installations. This is determined by multiplying the 22 volts open-circuit voltage at 25°C (77°F) by a correction factor of 1.25 for temperatures below -21°C (-6°F). Therefore, 12 volt systems do not have to have one of the current-carrying conductors grounded.

A nominal 24 volt system has a rated open-circuit voltage of about 44 volts at 25°C (77°F). This means that one of the current-carrying conductors must be connected to the grounding electrode when the expected lowest temperatures are below about -10°C (14°F). Temperatures below this will cause the open-circuit voltage to exceed 50 volts.

Figure 2: Multiple Grounding Electrodes



Prior to the 1999 edition, the *NEC* did not have Table 690-7, and the voltage multiplication factors were included in the instructions provided with listed PV modules. Since Underwriters Laboratories (UL) Standard 1703 for PV modules has not yet been revised, there will be PV modules in the distribution network that have the older instructions, duplicating the instructions in the 1999 *NEC.* Either the 125 percent factor in the PV module instructions or the Table 690-7 corrections should be applied, but not both.

System Grounding of 12 Volt Systems —Other Considerations

On 12 volt PV systems and some 24 volt PV systems, the grounding of one of the current-carrying conductors is optional, as noted above. However, in Articles 230, 240, and 690, the *NEC* requires that ungrounded conductors in any electrical system have overcurrent protection and disconnects. Since a 12 volt PV system must already have equipment-grounding conductors, a grounding electrode conductor, and a grounding electrode, there is a significant cost advantage and sometimes a performance advantage to grounding the system.

With the addition of one wire (the bond shown in Figure 1), the number of disconnect poles and overcurrent devices can be cut in half since these devices are not required in the now grounded, current-carrying conductor. Since each of those disconnects and overcurrent devices has some small but measurable voltage drop, eliminating as many of them as possible will improve system performance and increase reliability.

It should be noted that most PV power centers on the market have one of the conductors grounded internally and have provisions for only single-pole overcurrent devices and disconnects. They cannot be used in an ungrounded 12 volt system.

Furthermore, low-voltage fluorescent lamps start more reliably when installed in a grounded system and inverters and other electronic devices can be installed so that they radiate less noise when one conductor is grounded.

Equipment Grounding

Table 250-122 in the *NEC* specifies the size of the equipment-grounding conductors for each circuit. The size is based on the rating of the overcurrent device protecting the circuit and ranges from number 14 AWG (2 mm^2) conductor in a 15 amp circuit to a number 3 AWG (26.7 mm^2) equipment-grounding conductor in a 400 amp circuit.

Recent research has determined, however, that the equipment-grounding conductor for PV source and PV output circuits must at least be able to handle 125 percent of the PV short circuit currents. In most cases, this indicates that the equipment-grounding conductors for PV source circuits and PV output circuits must be the same size as the current-carrying conductors. These are sized at 156 percent of the module short-circuit current. Proposals for the 2002 *NEC* will be submitted to reflect this requirement.

Of particular interest to PV installers is Section 250-122(b) of the *NEC.* It states that if the current-carrying conductors have been oversized to minimize voltage drop, then the equipment-grounding conductors must also be oversized in the same proportion. But the grounding conductors never have to be larger than the current-carrying conductors. Oversized conductors (above minimum ampacity requirements) are frequently used on long circuits between the PV array and the charge controller to reduce voltage drops in these lines. Table 8 in Chapter 9 of the *NEC* shows the cross sectional area of different sized conductors, and the calculation is straightforward.

Oversizing the equipment-grounding conductors is required by the *NEC* to ensure that overcurrent devices function properly during ground faults. Section 250-122(a) says that the equipment-grounding conductors do not have to be larger than the current-carrying conductors.

In summary, the equipment-grounding conductor should be as large as the current-carrying conductors in PV source and PV output circuits. In other circuits, follow Table 250-122.

Equipment that must be connected to the equipment-grounding system includes the exterior metal surfaces of PV modules, power centers, charge controllers, inverters, switchgear, outlet boxes, and overcurrent devices. Equipment listed to UL standards will have properly marked connections and instructions for connection of the equipment-grounding conductors.

The equipment-grounding requirement in renewable energy systems is usually met by using a separate conductor run with the current-carrying conductors. If the system uses metal conduit (and many commercial systems do), then the conduit can serve as the equipment-grounding conductor when used with listed fittings.

The connection of the equipment-grounding conductor can run from module frame to module frame and then to the switchgear and power center. The order of the connections is not critical and multiple connections or parallel connections do not cause problems. Each equipment-grounding conductor may also be run from the metal surface being grounded to a central point like the power center.

The connections and wiring for the equipment-grounding conductor must be continuous to allow fault currents to properly operate overcurrent devices. Removal of a piece of equipment for servicing must not interrupt the equipment-grounding system for other equipment.

Generally, module frames are made of anodized aluminum. The anodized coating or aluminum oxide that forms on aluminum surfaces is a relatively good insulator. This is why listed PV modules have a special point marked for connecting the equipment-grounding conductor. A stainless steel screw is usually supplied which helps to ensure a good electrical connection.

It should be noted that while the anodized surface insulation on PV modules makes it hard to get a good equipment-grounding connection, the aluminum frame is still exposed metal. If it is not grounded, it can produce an electric shock when ground faults occur. These can occur between the current-carrying parts of the module and the frames, or when the frames are inadvertently energized by other power sources.

Aluminum PV module frames do not stay well grounded when they are only bolted to the metal mounting stands. If the UL listing allows, and the module manufacturer provides special parts and instructions, some PV modules may be grounded through the mounting bolts to the frame. The *NEC* prohibits the earth from being used as the sole equipment-grounding conductor, so bolting the PV modules to a metal stand that is inserted in the ground does not meet the requirements for a safe installation unless a separate equipment-grounding conductor is used from the frame to the main grounding point or electrode.

The *NEC* requires that all conductors for a given circuit be routed together in the same cable or conduit. An exception is the equipment-grounding conductor for DC circuits. When secondary grounding electrodes are used and they are bonded to the primary grounding electrode (as described below for surge protection) the bonding conductor may become an equipment-grounding conductor and should be sized appropriately. In this case, the DC equipment-grounding conductor may not be grouped with the current-carrying conductors.

Grounding the Current-Carrying Conductor

The connection between one of the current-carrying conductors and the grounding electrode conductor is made only at one point in the system. This is known as the system ground. This single-point connection is usually made in a power center and is shown as the bonding conductor in Figure 1. If this connection is inadvertently made in more than one place (for example, at the PV modules and in the power center or at the load), then unwanted currents will flow in the equipment-grounding conductors. These unwanted currents may cause inverters and charge controllers to be unreliable and may interfere with the operation of ground-fault detectors and overcurrent devices.

The use of RV and automotive electrical appliances and audio gear sometimes causes problems, as does the use of DC-powered radio and telephone equipment. Much of this equipment operates at 12 volts DC, with chassis and antenna ground connections that are common with the negative DC power conductor. It is pretty easy to get the negative DC conductor connected inadvertently to ground in two or more places when using these types of electrical devices.

The *NEC* also requires that equipment-grounding conductors be used with these appliances to ground the exposed metal surfaces. It becomes difficult to do this with a third conductor in a way that does not result in multiple point connections between the negative, current-carrying conductor and the grounding system. Solutions to minimize the problems include non-metallic enclosures to isolate the grounded chassis and ground-isolated antenna connections.

Listed power centers and disconnect switches usually have a provision for the single-point connection. In most DC power centers and AC load centers, the connection is automatically made when all equipment-grounding conductors, the negative conductors, and the grounding electrode are tied to a single, grounding bus bar which is also bolted to the metal enclosure.

When using standard, fused safety switches for disconnects throughout the system (PV array and subarray, battery, etc.), an insulated bus bar usually must be added. This is used to make the connections for the unswitched, grounded conductor running through the switch enclosure or subpanel.

There is frequently a bus bar supplied for the unswitched conductor. But this bus bar is sometimes grounded to the enclosure, presenting the opportunity for an inadvertent second grounding of the conductor that is intentionally grounded elsewhere in the system. Insulated, or ungrounded, bus bars should be used in these devices to prevent that second ground connection.

Grounding Electrode Conductor

The grounding electrode conductor (also known as the ground wire), is usually a single-conductor bare wire (it can also be insulated—color is not specified). It connects a grounding bus bar in a power center or another disconnect device to the grounding electrode (also known as the ground rod).

In the 1993 and earlier editions of the *NEC* this ground wire had to be the same size as the largest conductor in the DC system. In the 1996 *NEC* a number of exceptions, when met, allowed smaller conductors to be used. There are jurisdictions throughout the country that still are applying the 1993 and earlier versions of the *NEC* so some inspectors may require the larger conductors.

If there is only one conductor connected to the grounding electrode, then Section 250-166 of the 1999 *NEC* allows DC grounding electrode conductors as small as number 6 AWG (13 mm^2) copper to be used. Appropriate mechanical protection is required where this conductor may be subject to physical abuse. However, if multiple conductors are connected to the grounding electrode, a grounding electrode conductor as large as the largest conductor in the DC system must be used.

Multiple connections to the grounding electrode conductor refer to connections from the power system and do not refer to telephone, TV, cable, or other types of communications grounds. Multiple connections to the grounding electrode may also occur when several ground rods are bonded together to form a grounding electrode system, and when metal water pipes or well casings are bonded to the ground rod. Multiple connections are also common where DC and AC grounding electrode conductors are connected to the same ground rod. Several equipment-grounding conductors tied to the ground rod also nullify the use of a small grounding electrode conductor.

The reasoning behind not allowing a small grounding electrode conductor is this: if more than one conductor is connected to the ground rod, some of those conductors may be required to carry high fault currents. If only one conductor is connected to the ground rod, then the other properly sized and connected conductors in the system will carry the fault currents, and the smaller conductor to the ground rod will only be required to stabilize the system voltage with respect to earth. Only in lightning strikes and inadvertent connections to high voltages will the grounding electrode conductor be required to carry high currents. There are similar requirements and allowances for the AC grounding electrode conductor.

Practical Considerations

How then, can the system be connected so that a small equipment-grounding conductor can be used? One method is to designate a single grounding bus bar in the system. This bus bar is usually found in listed DC power centers. All equipment-grounding conductors should be connected to this bus bar. If there are multiple grounding electrodes in the system, the secondary electrodes should all be connected to this bus bar to complete the grounding electrode system.

If there is a requirement to provide a single-point ground for the AC portions of the system, then the grounding electrode conductor from the AC part of the system should be tied to this bus bar. Finally, the smaller (as allowed by the *NEC*) grounding electrode conductor can be connected from the grounding bus bar to the primary grounding electrode conductor. Figure 2 demonstrates these connections where the DC grounding electrode conductor is larger than the AC grounding electrode.

While this method meets the requirements of the *NEC,* it may not provide the best protection against lightning damage. Running all grounding conductors to a common point inside the building may increase the potential for damage from nearby lightning strikes.

In high lightning areas, it may be preferable to “bite the bullet” and use the larger grounding electrode conductor from the power center to the ground rod. Then secondary grounding rods and pipes and metal well casings can be connected directly to the primary grounding electrode without coming into the building. Equipment-grounding conductors from the PV modules may also be run directly to secondary or primary grounding electrodes providing additional surge protection.

Each of the grounding electrodes described below, where used as a primary electrode, has a different requirement for the size of the grounding electrode conductor. See *NEC* Sections 250-66 (AC) and 250-166 (DC). If the requirements for the AC and DC grounding electrode conductors are different, the larger of the two should be used for any common conductor. The common grounding point should be associated with the largest required grounding electrode conductor.

Grounding Electrodes

In Section 250-50, the *NEC* considers metal building frames that are in contact with the earth and metal water pipes connected to the earth to be the preferred grounding electrodes. Unfortunately, wood frame buildings, plastic pipes, and plastic sleeves on copper pipes make these options frequently unavailable to the renewable energy user.

The *NEC* describes commonly available grounding electrodes, such as “made” electrodes (the common 8 foot (2.4 m) ground rod), concrete encased cables or electrodes, and ring electrodes which consist of buried conductors encircling the building. Made grounding electrodes are listed by UL and are connected to the grounding electrode conductors with clamps that are listed for this purpose. If the clamps are to be buried, they should be listed and marked for such use.

As a primary grounding electrode, the ground rod must be driven into the earth to a depth of at least 8 feet (2.4 m). Angles of no more than 45 degrees away from vertical are allowed where the ground is rocky. If these conditions cannot be met, then a second rod or one of the other grounding electrodes must be used to supplement the primary electrode. Best performance will be achieved if the second electrode is more than six feet (1.8 m) away.

In some areas of the country where homes are built on concrete slabs, a grounding electrode is buried in the concrete slab. This usually works better as a grounding electrode than an eight foot (2.4 m) ground rod.

Summary

Equipment and system grounding are important details in a renewable energy system. They reduce the potential for electrical shock and allow the system to respond properly to ground faults. Proper application of the *NEC* requirements for grounding will result in safer systems, higher levels of performance, and reduced costs. The requirements for PV systems are generally the same as the requirements for other electrical power systems.

Questions or Comments?

If you have questions about the *NEC* or the implementation of PV systems within the requirements of the *NEC,* feel free to call, fax, email, or write me at the location below. Sandia National Laboratories sponsors my activities in this area as a support function to the PV industry. This work was supported by the United States Department of Energy under Contract DE-AC04-94AL8500. Sandia is a multi-program laboratory

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Author: John C. Wiles, Southwest Technology Development Institute, New Mexico State University, Box 30,001/ MSC 3 SOLAR, Las Cruces, NM 88003 • 505-646-6105
Fax: 505-646-3841 • jwiles@nmsu.edu

Sponsor: Sandia National Laboratories, Ward Bower, Department 6218, PO Box 5800 MS 0753, Albuquerque, NM 87185-0753 • 505-844-5206 • Fax: 505-844-6541
wibower@sandia.gov

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