Grounding

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In my last Code Corner Article, I mistakenly stated that Drake Chamberlin, in his Code Counterpoint letter in HP 62, thought there wasn't much reason to use 90°C wiring on PV modules. I am sorry that I misunderstood what Drake was trying to say. As a practicing electrician in Colorado, he is installing PV systems and knows the requirements of the NEC® and local codes. We both know that most listed PV modules are marked with a requirement to use 90°C conductors.

Grounding

I get more calls each month on grounding PV systems than any other subject. The NEC covers this subject in Article 250, Article 690, and in several other locations including definitions in Article 100. For those who want to achieve a good understanding of the subject of grounding, I recommend the National Electrical Code Handbook and the International Association of Electrical Inspectors (IAEI) Soares Book on Grounding. See Access. The Soares book even gives some of the 100-year history on the grounding requirements in the United States.

Definitions

Electrical systems (including PV systems) are 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 surges from nearby lighting strikes. Utility-interactive inverters are subjected to surges on the power line. Systems using PV power to run computers with hardwired modems are subject to surges from the telephone line. Proper grounding effectively deals with these potential problems and more.

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. Unfortunately, the earth isn't always at zero potential, and that complicates the grounding requirements. To better understand the grounding requirements, it is necessary to examine several terms used in conjunction with grounding.

The grounded conductor is a conductor that normally carries current and is connected to the earth. Examples are the neutral conductor in an 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.

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. An example of an equipment grounding conductor is the bare conductor in non-metallic sheathed cable (Romex®). The green-insulated conductor in power cords for ac-operated portable equipment is another example of an equipment grounding conductor. These equipment grounding conductors help to prevent electrical shocks and allow overcurrent devices to operate properly when ground faults occur.

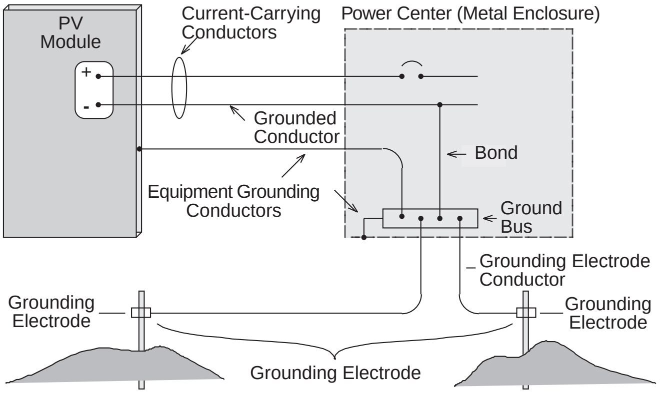
A grounding electrode conductor is a conductor between a common single grounding point in the system and the grounding electrode. Splices in this conductor must be made with special devices or welded.

A grounding electrode can refer to the common 5/8 inch diameter, 8-foot long ground rod or other metallic device that is used to make actual contact with the earth. There are "made" grounding electrodes (ground rods) and other types of grounding electrodes such as 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 being used.

Bond is a term that, as a verb, means to connect two or more points together. In common usage as a noun, it usually refers to the connection (bond) 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 these conductors are related in a PV system.



NEC Requirements

The NEC covers 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 (up to 230 kilovolts in Article 710). It covers systems with zero frequency (direct currents) through radio frequency (RF) systems.

With respect to grounding, the NEC requires that all PV systems (those that have field-installed wiring) have an equipment grounding system connected to a grounding electrode (690-43). Those systems with a rated voltage over 50 volts are required to be grounded by having one of the current-carrying conductors connected to the grounding electrode. The rated voltage is the maximum open-circuit voltage of the system after any UL requirements have been met. UL-listed PV modules come with instructions that require that the module rated open-circuit voltage (measured at 25°C and marked on the back of the module) be multiplied by 125% (UL Standard 1703) before any NEC requirements are addressed. This multiplier is used to ensure that modules used in cold temperatures (below 25°C -77°F) have connected components rated for adequate voltage. The output voltage of crystalline PV modules increases as temperature decreases.

This calculation indicates that a nominal 12-volt PV system has a rated voltage of about 27 volts (22 volts open circuit voltage at 25°C times 125%). A nominal 24-volt system has a rated voltage of about 55 volts which means that, in addition to the equipment grounding conductors, one of the current-carrying conductors must be connected to the grounding electrode.

The 1999 NEC will have a change that allows the maximum system voltage to be calculated based on the lowest temperature in the installation area. The 125% factor, presently a requirement UL Standard 1703 for listed modules, will be moved to the NEC and will apply only when low temperatures get to -40°C. In areas where low temperatures are more moderate, factors less than 125% (listed in a table) may be used when the 1999 NEC is adopted in those areas.

On 12-volt PV systems, the grounding of one of the current-carrying conductors is optional (NEC Section 690-41). However, the NEC, in Articles 240, 230, and 690, requires that each ungrounded conductor in any electrical system have overcurrent protection and disconnects. Since a 12-volt PV system must already have equipment grounding conductors, 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. 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.

Hows and Whys

Equipment Grounding Table 250-95 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 conductor in a 15-amp circuit to a number 3 AWG equipment grounding conductor in a 400-amp circuit.

Of particular interest to PV installers is Section 250-95 of the NEC that 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. Oversized conductors (above minimum ampacity requirements) are frequently used 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 straight forward. Oversizing the equipment grounding conductors is required by the NEC to ensure that overcurrent devices function properly during ground faults.

Equipment that must be connected to the equipment grounding system includes the exterior metal surfaces of PV modules, power centers, charge controllers, inverters, and switchgear 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. 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 switch gear and then the 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 operated overcurrent devices. Removal of a piece of equipment for service must not interrupt the equipment grounding system for other equipment.

Generally, module frames are made of aluminum which is anodized. 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, and if not grounded, can produce an electric shock when ground faults 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.

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 and 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 (e.g. at the PV modules and in the power center), 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-volt 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. Since the NEC also requires that equipment grounding conductors be used with these appliances to ground the exposed metal surfaces, it becomes problematic on how to do this with a third conductor that does not result in multiple point system grounds. 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 some DC power centers, ac load centers, and disconnect switches 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. A central location such as the inverter disconnect, battery disconnect or main power center is where the connection to the grounding electrode conductor is made.

When using standard, fused safety switches for disconnects throughout the system (PV subarray, string, array, battery, etc.), an insulated bus bar usually must be added for making the connections for the unswitched, grounded conductor running through the switch enclosure. While there is frequently a bus bar supplied for the unswitched conductor, 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.

The Grounding Electrode Conductor
The grounding electrode conductor (a.k.a. the ground wire), is usually a single conductor bare wire (it can also be insulated-color is not specified) connected from a grounding bus bar in a power center or other disconnect to the grounding electrode (a.k.a. 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, allow smaller conductors to be used. There are jurisdictions throughout the country that are still applying the 1993 and earlier versions of the NEC so some inspectors may require the larger conductors.

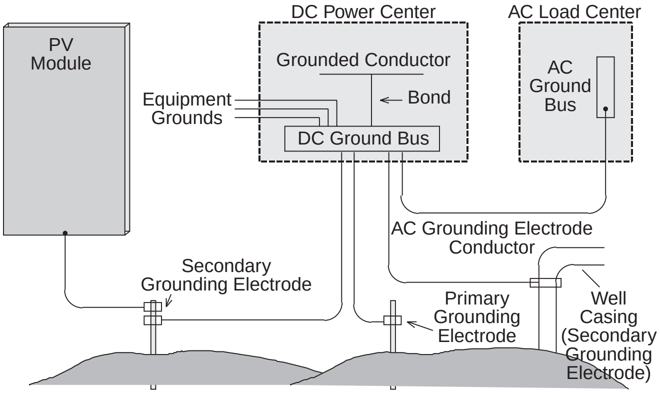
If there is only one conductor connected to the grounding electrode, then Section 250-93 of the 1996 NEC allows grounding electrode conductors as small as number 8 AWG copper to be used (see NEC Section 250-93 for the exact requirements). Appropriate mechanical protection is required where this conductor may be subject to physical abuse. However, if multiple conductors are connected to the grounding electrode, then the exceptions do not apply and 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 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 exceptions that allow a small grounding electrode conductor.

The reasoning behind the exceptions is that 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 Number 8 AWG 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 exceptions for the ac grounding electrode conductor.

How then, can the system be connected so that a small equipment grounding conductor 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.



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 have the potential for increasing 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 250-93 and 250-94. If the requirements for the ac and DC grounding electrode conductors are different, then the larger of the two should be used for any common conductor.

Grounding Electrodes

The NEC, in Sections 250-81 and 250-83, considers that metal building frames that are in contact with the earth and metal water pipes (also connected to the earth) are 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 details the more commonly available grounding electrodes such as “made” electrodes (the common 8-foot 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 bonded (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. Angles of no more than 45° away from the vertical are allowed where the ground is rocky. If these conditions cannot be met, then a second rod (best performance will be achieved if more than six feet away) or one of the other grounding electrodes must be used to supplement the primary electrode.

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

Summary

System grounding is an important detail of the renewable energy power system. It reduces the potential for electrical shock and allows the system to respond safely to ground faults. The requirements for PV systems are generally the same as the requirements for other electrical power systems that have evolved over the 100-year history of electrical power systems in the United States.

In the next Code Corner, several different types of grounding systems will be shown including examples of PV systems located in power buildings separate from the main house.

Questions or Comments?

If you have questions about the NEC or the implementation of PV systems following 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 operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy.

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