code corner

Ungrounded PV Systems

by John Wiles

More than 100 years ago, the debate on grounded versus ungrounded electrical systems began. The United States went with grounded, while many other countries went with ungrounded. The PV codes in the United States are now allowing some equipment that is used in other parts of the world.

When we discuss grounded versus ungrounded electrical systems, we are addressing whether one of the current-carrying circuit conductors, like the AC neutral conductor, is grounded or not. Except for ungrounded, three-phase delta-connected transmission and distribution systems, most of our electrical systems in the United States have a grounded circuit conductor. In Europe and elsewhere, ungrounded electrical systems are common. In Germany, ungrounded three-phase AC power at 230 V comes directly into dwellings.

To some extent, most electrical systems in developed counties use a system of equipment-grounding conductors—called protective earth (PE) in Europe—to provide an outer layer of defense against electrical shock from exposed conductive surfaces that could become energized. As in the United States, double-insulated appliances and electrical tools can be found that do not require equipment-grounding systems.

History, equipment, training, and experiences on both sides of the issue show that both systems provide equal levels of safety. As the world grows smaller, IEC standards in Europe are being harmonized with the standards developed by Underwriters Laboratories (UL) here in the United States—and the codes are slowly adopting similar requirements and allowances.

Impact on PV System Design

Since 1984, when PV requirements first appeared in the *National Electrical Code,* PV systems installed in the United States have been required to have a grounded circuit conductor. PV systems with maximum system voltages of 50 V or below were not required to have a grounded circuit conductor. In the *2005 NEC*, Section 690.35 was added to permit the use of ungrounded PV arrays. Ungrounded PV arrays do not have a conductor directly connected to the grounding electrode system like grounded arrays do. The ungrounded systems will still be required to use equipment grounding conductors, though, to provide protection from shock. Typically, these ungrounded PV arrays will operate at 125 V and up, but no specific voltage range or limit is imposed. Of course, Section 690.7 restricts residential PV arrays to 600 V, either grounded or ungrounded.

In utility-interactive PV systems, the inverter is a switching device and filter, with other added control components. The switch reverses the polarity of the DC output from the PV array 120 times per second, generating a 60 Hz wave form that is shaped into a sine wave by the filter. In Europe, 100 switches per second are used to generate 50 Hz.

Because European PV arrays and electrical systems are ungrounded, their utility-interactive inverters are relatively simple compared to U.S. inverters. In the United States, with a grounded circuit conductor from the PV array and a grounded circuit conductor in the AC inverter output circuit, using a direct switching device is not possible—the switch would be shorted as it tried to reverse the polarity of the DC circuit into an AC signal. A transformer is

SMA Sunny Boy 9 kW transformerless inverter.

Microinverter & AC PV Module Details

NEC requirements for microinverters, combinations of microinverters attached to PV modules, and AC PV modules continue to pose some confusion to installers and inspectors alike.

Both microinverters and microinverters attached to PV modules in the field or in the factory that have any exposed DC single conductor cables are required to meet all of the *NEC's* DC wiring requirements. These may include Section 690.5 ground-fault detector requirements, DC and AC disconnect requirements (potentially handled by connectors listed as disconnects), and inverter DC grounding-electrode requirements.

True AC PV modules, as defined on Sections 690.2 and 690.6, have a module and inverter factory-assembled as one environmentally protected unit—there is no accessible DC wiring, so none of the *Code's* DC wiring requirements apply. A single equipment-grounding connection will usually be the only requirement to properly ground an AC PV module.

required in inverters used in the United States to isolate the grounded DC circuits from the grounded AC circuits. The transformer is usually heavy, costly, and bulky—decreasing efficiency and increasing the inverter's size and shipping costs.

With the advent of Section 690.35 of the 2005 *NEC*, ungrounded PV arrays can be installed in the United States, using transformerless inverters now listed to UL Standard 1741. Several inverters are on the market now. So what are these systems going to look like to PV installers and inspectors?

Ungrounded Perspective

Ungrounded PV systems are not significantly different from common grounded PV systems found in the United States: They will continue to have equipment-grounding conductors that will connect the module frames, racks, enclosures of combiners, disconnects, and inverters together and to ground (in Europe, called "earth").

According to *NEC* Section 690.35 (B), DC overcurrent protection (for three or more strings of modules) will be required in both of the ungrounded circuit conductors. PV string combiners will have overcurrent protection in both the positive and negative DC inputs from each string of modules.

The PV DC disconnect will be required in both of the ungrounded conductors (690.35(A)). With disconnects required in each ungrounded circuit conductor, external and internal disconnects will have a switch pole in each of the circuit conductors coming from the PV array.

Ampacity calculations will be the same for grounded and ungrounded systems, and the calculations for maximum system voltage will be the same. The white color code for a grounded conductor *will no longer be used*. It is logical that the color code of red for a positive conductor and black for a negative conductor be used, but there is no *Code* requirement that these colors be used. As before, the module interconnecting cable and other short runs of exposed, single conductor cables will usually have black insulation (for superior UV resistance) with colored markings used for identification.

All exposed, single-conductor cables, including those attached directly to the module, must be the new PV Wire or PV Cable made and listed to UL Standard 4703 (690.35(D)(3)). The USE-2 conductors used in many applications for grounded PV arrays are not acceptable in these systems. Installers and inspectors should be aware that some of the European PV cables, PV wires, or other cables with similar names made for the European market (and even made to UL Standard 4703) may use fine-stranded, flexible conductors. Obtaining suitable lugs and terminals for use where these cables transition to a conduit wiring method may be difficult (see *NEC* 690. 31(F) and *Code Corner 104* for details).

The inverter must be listed and clearly marked for use with ungrounded PV arrays, and it must have an appropriate internal ground-fault detection and indication system (690.35(C)). That ground-fault circuit will not be required to interrupt the ground-fault current (as is required on grounded PV arrays) on an ungrounded system, since there will be no ground-fault currents. The inverter or charge controller will be required to shut down and indicate that a ground fault has occurred.

Access

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Southwest Technology Development Institute • www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/Codes-Stds.html • PV systems inspector/installer checklist, previous "Perspectives on PV" and *Code Corner* articles, and *Photovoltaic Power Systems & the 2005 National Electrical Code: Suggested Practices*, by John Wiles