

Ground-Fault Protection for.



by John Wiles

Once upon a time (the 1987 *Code* cycle) in the land of Quincy, a group of alchemists from a national laboratory was elaborating on the excellence of their photovoltaic (PV) test facility in the distant Land of Enchantment. They showed some senior firefighters a picture of a burned PV module that had been subject to a ground fault and had subsequently melted down. The alchemists failed to mention at the time that this was a prototype, unlisted PV module, that the module was on a concrete pad, and that ground faults in PV systems were somewhat rare. These firefighting pros said to themselves, “PV ground faults lead



PV Systems

to fires. Fires on the roofs and in the attics of dwellings are very hard to fight.” They then told the PV industry to propose Section 690.5 for the *1987 NEC* to require a ground-fault protection device (GFPD). The proposal was accepted and the requirement was established, but no hardware existed.

In 1989, I joined the PV industry as a full-time employee at the Southwest Technology Development Institute. One of my first projects was to develop prototype hardware that could be used to meet the new Section 690.5 requirement. This effort was funded under contract to Salt River Project, a Phoenix, Arizona, electric

utility. In the *1987 Code*, the requirements for this fire-reduction device were to:

1. Detect ground faults in PV arrays mounted on the roofs of dwellings
2. Interrupt the fault current
3. Indicate that a ground fault had occurred
4. Disconnect the faulted part of the PV array
5. Crowbar or short circuit the PV array

The original GFPD prototype was developed in two versions that were similar except for voltage rating. The basic concept was to insert a 0.5 or 1.0 amp circuit breaker in the dc system-bonding conductor connecting the grounded circuit conductor (usually the negative) to the grounding system (the point where equipment grounding conductors and grounding-electrode conductor are connected together). Any ground-fault currents must flow through this bond on their way from the ground-fault point back to the driving source, the PV module or PV array. See figure 1. When the current in this bond exceeds 0.5 or 1.0 amp, the circuit breaker trips to the open position. This action interrupts the fault current,

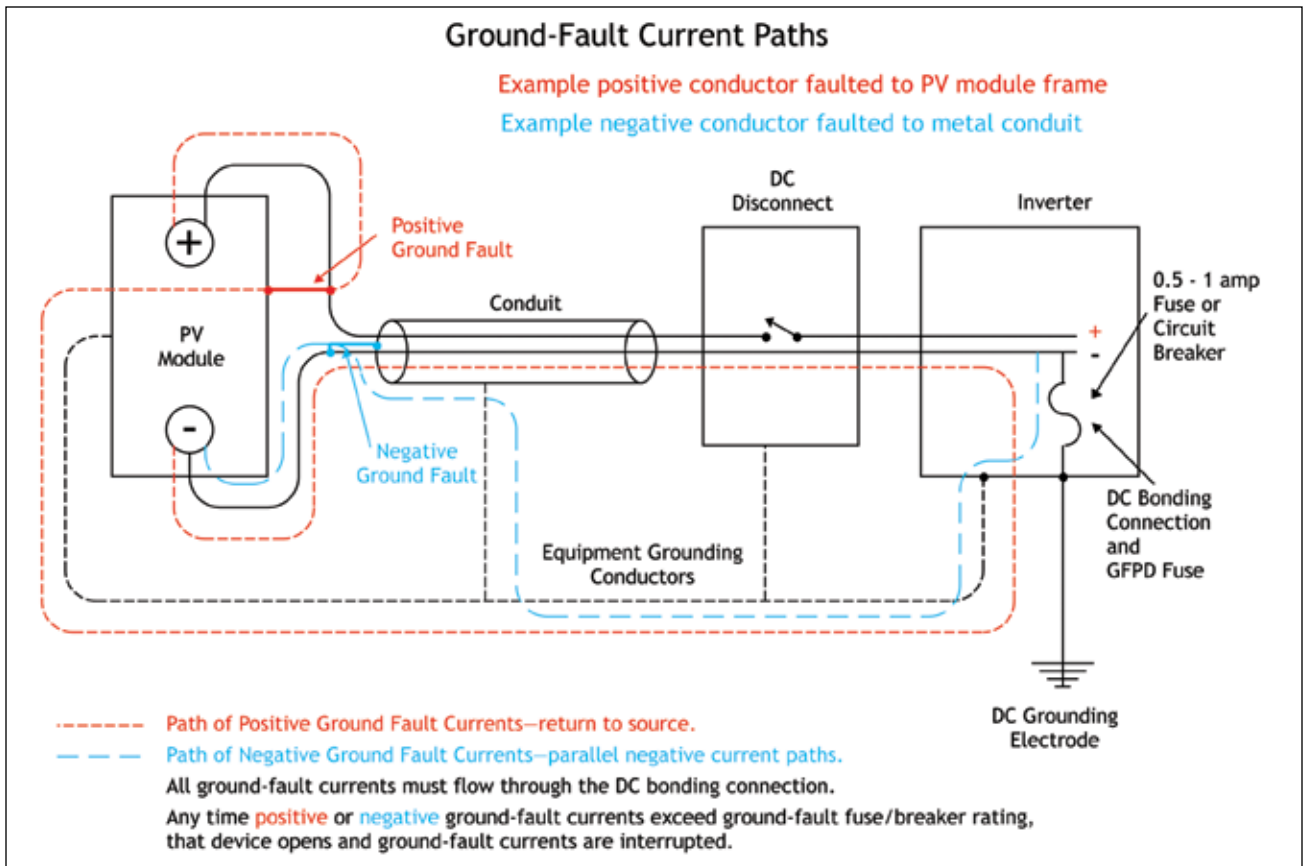


Figure 1. Ground-fault currents go through the bonding conductor.

even when the fault is many feet away on the roof of the building and provides the indication that a ground fault has occurred. Requirements 1, 2, and 3 are satisfied by these actions.

This small circuit breaker is mechanically linked to one to four large, 100-amp circuit breakers and they open when the 0.5 amp circuit breaker opens. These added breakers are connected in series with each of the incoming ungrounded conductors from the PV array and when they open, the PV array is disconnected from the rest of the system, thereby meeting requirement 4.

Requirement 5 was added to reduce the PV array voltage to zero by shorting the positive and negative conductors together to minimize a potential shock hazard. In the original GFPD design, this was accomplished either by using a motor-driven circuit breaker on 48-volt systems or by using a solenoid-driven (closed) shunt-trip breaker on the higher voltage systems. This fifth shorting requirement was later removed from the *NEC* when it was determined that it might be possible to damage a “new technology” PV module by short-circuiting it. The module was never produced, but the crowbar requirement was not reintroduced even though the PV wiring



Photo 1. One-pole, ground-fault protective device for 48-volt PV system



Photo 2. Two-pole, ground-fault protective device for 48-volt PV system



Photo 3. Four-pole, ground-fault protective device for 48-volt PV system

can handle the worst case short-circuit currents and is oversized by a factor of 125 percent. It is an impressive demonstration when circuit breakers rated at 750 volts close and short circuit a 100-amp PV array that has an open-circuit voltage of 600 volts.

Modern Ground Fault Protection Devices

The early designs of the prototype GFPDs were released

to the PV industry in 1991. Finally, in 1997, a GFPD was manufactured for the 48-volt and below PV systems, and that device used the exact design and components as the prototype. See photo 1. Other ground-fault devices for the low-voltage systems soon followed as these off-grid, stand-alone systems became more common and were inspected more frequently. See photos 2 and 3.

As the higher-voltage, utility-interactive PV inverters became available in the late 1990s, it was more cost-effective to use a 0.5 or 1.0 amp fuse as the sensing element and use the control electronics in the inverter to monitor the fuse, indicate that a ground fault had occurred (light or display), and shut down the inverter (effectively disconnecting the equipment). See photo 4.

Coming in 2008

NEC-2008 will require GFPDs on nearly all PV systems including those mounted on commercial buildings (non-dwellings) and on the ground. This requirement was added to the *NEC* because on the larger PV arrays, a ground fault, if not interrupted, can continue as long as the sun is shining, and may not be detected until significant damage has been done. The possible arc from the ground fault and the overloaded equipment grounding conductors may each pose hazards.



Photo 4. Ground-fault fuse on high-voltage inverter

Sizing equipment grounding conductors using *NEC* 250.122 for PV systems with fuses does not always result in a conductor size that can withstand continuous ground-fault currents. The conductor and overcurrent sizing requirements for PV source and output circuits and the current-limited nature of PV module outputs cannot ensure that overcurrent devices will open properly in a very short time as they do on ac circuits. Therefore, a requirement was added to interrupt the ground-fault currents on all PV systems when they exceed the low 0.5 or 1.0 amp value.

Before May 2007, inverters larger than about 10 kW had only partial GFPD functionality. They detected the ground faults, indicated that the fault had occurred, and shut down. However, they did not interrupt the fault currents. Now, with a change in *UL* Standard 1741 for PV inverters and the *2008 NEC*, all utility-interactive inverters will have full functionality with respect to ground faults and will act in a manner similar to the smaller residential units. Off grid, PV systems with batteries operating at 48 volts nominal, or less, will have the GFPD built into the charge controller, or an external device will have to be added. Small, dc off-grid systems that have no dc or ac wiring inside or on a building will be exempt from the GFPD requirement if the equipment grounding conductors are oversized by a factor of about two.

The AC Ground-Fault Issue

The common alternating-current ground-fault circuit interrupters (GFCI) are not designed to be backfed. The output of a utility-interactive inverter connected to the load terminals and backfeeding a receptacle or breaker GFCI, a 30-milliamp equipment protection ground-fault breaker, or even a 600–1200 amp main breaker with ground-fault elements may damage that device with no external indication of a problem. Anytime a utility-interactive PV system is installed, the entire ac premises wiring system should be examined all the way from the PV inverter output to the service entrance to ensure that there are no ground-fault devices in that circuit that may be subject to backfeeding. Some of the newest ground-fault breakers in the 1000 amp and larger sizes are listed as suitable for backfeeding, but that information must be obtained on any ac ground-fault device that could be subject to backfeeding.

Arc-Fault Circuit Interrupters

Arc-fault circuit interrupters (AFCI) are, in some ways, similar to GFCIs and should not be backfed by PV inverters unless listed and identified for backfeeding. They are being required in many locations thereby increasing the safety of electrical systems here in the U. S. DC arc-fault circuit interrupters are not currently available.

However, we know that there is some danger associated with a line-to-line fault in the dc wiring of a PV array. The PV industry and Underwriters Laboratories are studying the issue to determine the signature of a typical dc arc originating from a PV system and how, if possible, to detect, control, and extinguish that arc. This is not an easy task because the electrical sources (the PV modules) in any system are widely dispersed and numerous.

Summary

The number of PV installations is increasing at more than 20% a year. Nearly all PV systems will soon be required to have a ground-fault protective device that will minimize the possibility of fires starting from ground faults in PV arrays. Efforts are continuing to enhance the safety of PV systems for the general public through revisions and additions to the *National Electrical Code* and UL Standards. The goal is to have safe, reliable, and cost-effective PV systems. The green future must be a safe future.

For Additional Information

If this article has raised questions, do not hesitate to contact the author by phone or e-mail. E-mail: jwiles@nmsu.edu Phone: 575-646-6105

A color copy of the latest version (1.7a) of the 150-page, *Photovoltaic Power Systems and the 2005 National Electrical Code: Suggested Practices*, published by Sandia National Laboratories and written by the author, may be downloaded from this web site: <http://www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/PVnecSugPract.html>

The Southwest Technology Development Institute web site maintains a PV Systems Inspector/Installer Checklist and all copies of the previous “Perspectives on PV” articles for easy downloading. Copies of “Code Corner” written by the author and published in *Home Power Magazine* over the last 10 years are also available on this web site: <http://www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/Codes-Stds.html>

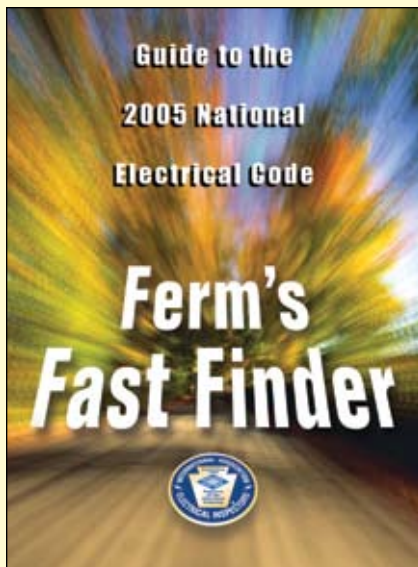
The author makes 6–8 hour presentations on “PV Systems and the NEC” to groups of 40 or more inspectors, electricians, electrical contractors, and PV professionals for a very nominal cost on an as-requested basis. A schedule of future presentations can be found on the IEE/SWTDI web site.✍



John Wiles works at the Institute for Energy and the Environment (IEE) (formerly the Southwest Technology Development Institute) at New Mexico State University. IEE has a contract with the US Department of Energy to provide engineering support to the PV industry and to provide that industry, electrical contractors, electricians, and electrical inspectors with a focal point for Code issues related to PV systems. He serves as the secretary of the PV Industry Forum that submitted 42 proposals for Article 690 in the 2008 NEC. He provides draft comments to NFPA for Article 690 in the NEC Handbook. As an old solar pioneer, he lived for 16 years in a stand-alone PV-power home in suburbia with his wife, two dogs, and a cat—permitted and inspected, of course. He has just installed a new PV system on his home that is utility-interactive with a full-house battery back up using a New Mexico Homeowner’s Electrical Permit.

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