Ground-Fault Protection is Expanding

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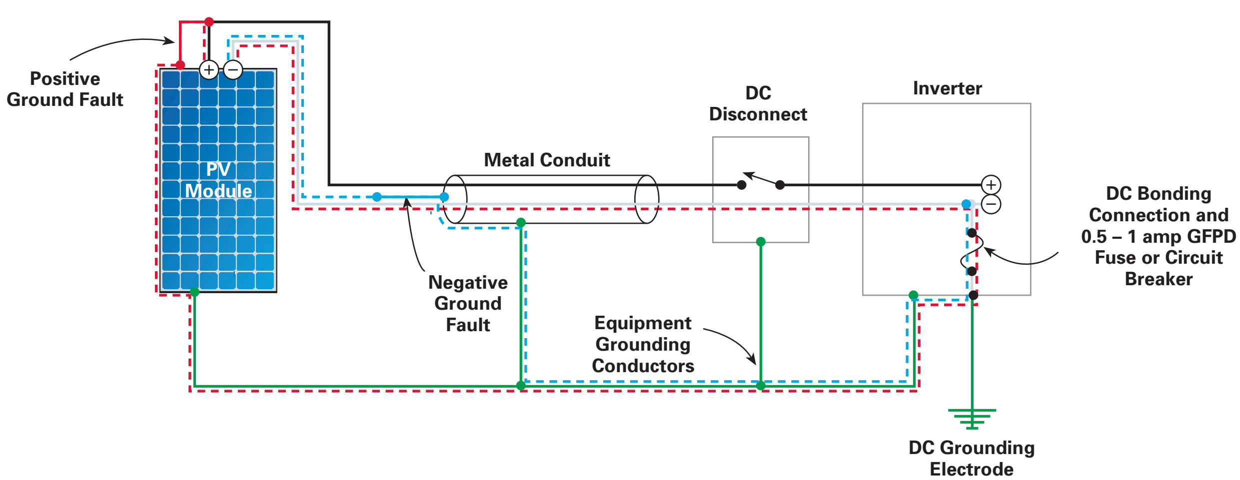
In 1984, engineers at the National Fire Protection Association (NFPA) directed the PV industry to propose Section 690.5 for the *1987 National Electrical Code (NEC),* which would require a ground-fault protection device (GFPD) on PV systems installed on dwellings. This requirement resulted from a presentation by engineers from a national laboratory that showed a PV module that had been subject to a ground fault and had subsequently caught fire and melted down. The engineers failed to mention that this was a prototype, unlisted PV module, the module was on a concrete pad, and that ground faults in PV systems were somewhat rare. So it's not surprising that these firefighters concluded that PV ground faults lead to fires, and directed the engineers to submit the proposal. However, when the requirement was established, no GFPDs existed for PV systems.

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. 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" (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-amp circuit breaker in the DC system-bonding conductor. This device connected the grounded circuit conductor (usually the negative) to the grounding system (the point where equipment-grounding conductors and the 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 array (see illustration). When the current in this bond exceeds the rated 0.5 or 1 amp, the circuit breaker trips to the open position. This action interrupts the fault current, even when the fault is

Ground-Fault Current Paths



Example positive conductor faulted to PV module frame. Path of positive ground-fault currents—return to source.
Example negative conductor faulted to metal conduit. Path of negative ground-fault currents—parallel negative current paths.

Note: All ground-fault currents must flow through the DC bonding connection.
Any time positive or negative ground-fault currents exceed ground-fault fuse/breaker rating, that device opens and ground-fault currents are interrupted.

Clockwise from upper left: One-pole, ground-fault protective device for a 48-volt PV system.

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

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

many feet away—on the roof of the building, for instance—and indicates that a ground fault has occurred. These actions satisfy requirements 1, 2, and 3.

This small circuit breaker is mechanically linked to between one and four large, 100-amp circuit breakers that open when the smaller, fault circuit breaker opens. These added breakers are connected in series with each of the incoming ungrounded conductors from the PV array and they disconnect the PV array 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 by using either a motor-driven circuit breaker on 48-volt systems or by using a solenoid-driven (closed) shunt-trip breaker on 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. Although that module never materialized, the crowbar requirement was not reintroduced—even though the PV wiring can handle the worst-case short-circuit currents, being oversized by a factor of 125%. It is an impressive demonstration (with a bright flash and a loud bang due to the DC arc) 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

Early GFPD prototypes were released to the PV industry in 1991. In 1997, a GFPD was manufactured for 48-volt (and below) PV systems. Other ground-fault devices for low-voltage systems soon followed, as off-grid, PV systems became more common and were inspected more frequently.

As higher-voltage, utility-interactive PV inverters became available in the late 1990s, using a 0.5- or 1.0-amp fuse as the sensing element and the inverter's control electronics to monitor the fuse was more cost effective. The inverter's fault lamp or display indicated that a ground fault had occurred and the inverter shut down, effectively disconnecting the equipment.

Coming in 2008

The *2008 NEC* will require GFPDs on nearly all PV systems, including those mounted on commercial buildings (nondwellings) and on ground or pole mounts. This requirement was added to the *NEC* because an uninterrupted ground fault on PV arrays 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 each pose serious hazards.

Sizing equipment-grounding conductors using *NEC* Section 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 circuit and the current-limited nature of PV module outputs do not 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 0.5- or 1-amp trip value.

The overcurrent trip value for larger systems (greater than 10 KW) will be higher than for smaller systems and is still under study. 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.

Ground-fault fuse location on a high-voltage inverter.

Now, with a change in UL Standard 1741 for PV inverters and the *2008 NEC*, all utility-interactive inverters will have full functionality for ground faults and will act in a manner similar to the smaller residential devices. Off-grid PV systems with batteries operating at 48 V nominal or less need to have a charge controller with GFPD built in, or an external device will have to be added.

Small (two series strings or less) off-grid systems that have no DC wiring inside or on a building will be exempt from the GFPD requirement. A water-pumping system with all circuits located away from a building is one example of such a system. A few nonresidential installations, where the equipment-grounding conductors are oversized by a factor of about two above the circuit conductors, may be exempt as well.

The AC Ground-Fault Issue

Common AC 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- to 1,200-amp main breaker with ground-fault elements may damage that device with no external indication of a problem. Any time a utility-interactive PV system is installed, the entire AC premises wiring system—from the PV inverter output to the service entrance—should be examined to ensure that there are no ground-fault devices in a circuit that may be subject to backfeeding. Some of the newest ground-fault breakers in the 1,000 amp and larger sizes are listed as suitable for backfeeding, but be sure to confirm that by reading the product literature. Usually in a residence, the PV currents do not flow *backwards* (load to line) through any ground-fault circuit interrupters and there would be no problems. However, many commercial buildings have main breakers that are ground-fault breakers, and a PV system on such a building could subject the breaker to backfeeding and possible damage.

Arc-Fault Circuit Interrupters

In some ways, arc-fault circuit interrupters (AFCI) are similar to GFCIs and should not be backfed by PV inverters unless listed and identified for backfeeding. The AFCI detects an arcing line-to-line fault in a house's AC wiring, in some cases even in an extension cord, and shuts off power to that circuit. The *2008 NEC* requires their installation throughout the house to increase the safety of electrical systems. DC arc-fault circuit interrupters are not currently available.

However, a line-to-line fault in the DC wiring of a PV array can pose danger. The PV industry and Underwriters Laboratories are studying the issue to determine the characteristics 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.

Finding Faults, Improving System Safety

In the United States, the number of PV installations continues to increase year by year. Nearly all PV systems will soon be required to have a GFPD. Efforts are continuing to enhance the safety of PV systems for the general public through revisions and additions to the *NEC* and UL Standards. The goal is to have safe, reliable, and cost-effective PV systems. The future of renewable energy must be a safe one.

Other Questions or Comments?

If you have questions about the *NEC* or the implementation of PV systems that follow the requirements of the *NEC*, feel free to contact me. See the SWTDI Web site (below) for more detailed articles. The U.S. Department of Energy sponsors my activities as a PV industry support function under Contract DE-FC 36-05-G015149.

Access

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The *2008 National Electrical Code* and the *NEC Handbook* are available from the National Fire Protection Association (NFPA) • 800-344-3555 or 508-895-8300 • www.nfpa.org