Combiners to DC Disconnects

by John Wiles

In *HP128, Code Corner* addressed some code requirements for PV arrays; *Code Corner* in *HP129* covered the math associated with voltage calculations. Now, it's time to safely route that power from the array.

The PV Combiner

PV-source circuits route from the array through combiners (on medium and large systems) and then on to the DC PV disconnect. Normally, two strings of modules can be connected in parallel without requiring a combiner containing overcurrent devices—see *NEC* Section 690.9(A) EX. Batteryless grid-tied PV systems rated above 6 kW may be configured with more than two strings. Since rated voltages range widely and module power ratings can vary from 40 to 300 W, there are no hard-and-fast rules relating the need for a DC combiner to a specific number of modules in an array. If more than two strings are needed, then overcurrent protection on each string may be required and these overcurrent devices are placed in a PV source-circuit combiner (see *Code Corner* in *HP125*).

A combiner may use fuses (typically on high-voltage, utility-interactive systems) or circuit breakers (commonly used on systems operating at 60 volts or below). The *2008 NEC* requires that combiners be listed to UL Standard 1741—the PV inverter standard: 690.4(D). Although listing is required, UL 1741 has not yet been modified to specifically require that combiners be "dead front" (have nonexposed circuit terminals and busbars once opened).

In cold weather, voltages on the exposed terminals and busbars may approach 600 V on many systems. These combiners meet the intent of the *NEC* requirement that a tool be used to access energized surfaces such as terminals and busbars—the combiner shown above has a cover that requires a screwdriver to open.

This combiner has accessible terminals that may be energized when open.

This "dead front" combiner has terminals safely covered.

Array to Disconnect

Conductors between modules and those between one end of a string and the other may be single conductor cables in free air. However, as soon as the PV circuits leave the array location, they must transition to a standard *NEC* Chapter 3 wiring method. For roof-mounted systems, that wiring method must be suitable for hot, wet environments and include UV resistance. Electrical metallic tubing (EMT) is frequently used. Conductors are selected based on the short-circuit current being carried in that circuit and must be corrected for the conditions of use, such as on rooftops. In many cases, terminal temperature limitations on combiners or fused disconnects may dictate further ampacity corrections (see *Code Corner* in *HP122* for details).

An equipment-grounding conductor should be run with the circuit conductors in the conduit. In many systems, the equipment-grounding conductors may be as small as #14 between the PV modules. However, in areas where wind, snow, ice, and other environmental factors may introduce mechanical damage, a larger equipment-grounding conductor between modules should be considered (Section 690.46). Where the PV source circuits are unfused, the *2005 NEC* calls for sizing the equipment-grounding conductor based on 125% of the circuit's rated short-circuit current (Isc). In the *2008 NEC*, Isc is used directly in Table 250.122 to select an equipment-grounding conductor. The reduction in size of the DC equipment grounding conductor is due to the *2008 NEC* requirement that nearly all PV systems have ground-fault protection. On systems with PV source or output circuit fuses,

the normal procedure is to use the fuse value in Table 250.122 to look up the required equipment-grounding conductor size (690.45).

The DC PV Disconnect

According to Section 690.14 of the *NEC*, the DC PV disconnect should be installed in a readily accessible location, either inside or outside the building at the point of first penetration of the conductors.

Since Section 690.31(E) allows the PV source or output conductors to penetrate the building surface on the roof (if they are routed in a metal raceway inside the building), it appears that the PV disconnect can be mounted inside the building in any readily accessible location. However, this *NEC* allowance may not be the safest option or even very clearly defined in the *Code*.

This parallel wording of 690.14(C)(1) with the requirements for the AC service disconnecting means that 230.70(A)(1) may need further examination. In the world of AC utility power, removal of the AC revenue meter can effectively disable the AC power in a structure, regardless of the AC service disconnect location. With a DC PV disconnect inside a locked structure, the "readily accessible" definition may not be appropriate. On residences, many jurisdictions require that the PV disconnect be located within sight of the AC service disconnect or meter, which typically means on the building's exterior. On commercial buildings, the PV system may be located far from the AC service disconnect and a directory may be used to show the location of all disconnects, both AC and DC (Section 705.10). When in doubt, consult with the authority having jurisdiction.

The PV disconnect should break all ungrounded conductors but *should not* open a grounded conductor. Grounded conductors in PV systems might be either the negative or positive source-circuit conductors and should have white insulation, or where larger than #6, be marked with a white marking. The type of module determines which circuit conductor should be grounded and the inverter must be compatible with the polarity of the grounded conductor.

If the grounded source-circuit conductor *is* opened by the switch in the disconnect, the marked grounded conductor becomes *ungrounded* and may be energized with respect to ground, up to the open-circuit voltage of the system. This

A properly labeled PV disconnect.

PV disconnects properly installed in a readily accessible location.

represents an unsafe condition for servicing the PV array. For that reason, the *NEC* prohibits the use of disconnects, breakers, or fuses in grounded PV DC conductors unless they are part of an automatic ground-fault detection/interruption system (Section 690.13).

Section 690.17 and 690.53 of the *NEC* require labeling on the front of a PV DC disconnect. The 690.17 warning is required because the load terminals of this disconnect are connected to the inverter DC input, which may still be energized for up to five minutes after the disconnect has been opened, as capacitors in the inverter are gradually discharged. The 690.53 label, with the DC voltage and current ratings, allow the AHJ to determine that the correct cables have been installed.

Although insulation partially covers upper line-side terminals on disconnects, the switch blades, fuse holder terminals (if any), and the lower, load-side terminals are exposed and easily touched. In the PV DC disconnect, the PV source or output circuits should always be connected to the line-side terminals. Electricity flows from the PV array through the DC PV disconnect, the inverter, the AC disconnect, and, finally, to the grid, so a general safety rule is that the most dangerous circuits should be connected to the protected line-side terminals. The DC input to the inverter is connected to the load-side terminals, and the 690.17 warning label is required as shown.

Attention to the *NEC* requirements in 690 and other articles, plus an understanding of PV equipment and how electricity flows in a PV system, should enable these systems to be installed and operated in a safe manner.

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