Array to Inverter

& Things Between

by John Wiles

The direct-current world of PV systems can be somewhat unfamiliar to many electrical system designers and installers, and there are sometimes details that get overlooked in designing, installing, and inspecting these systems. This *Code Corner* covers a few of those commonly neglected details

Conductor Types

Single-conductor, exposed cables (type USE-2 or the new PV cable/PV wire) are used as module interconnecting cables. In each circuit, there is a need to be able to distinguish which conductor is the grounded conductor. For cables smaller than AWG #4, generally the requirement for grounded conductors is to use a conductor with white (or grey) insulation. However, both of these cable types will generally be available only in basic black. The *National Electrical Code* Section 200.6(A)(2) notes that this black cable, even when smaller than #4, may be marked "white" (with electrician's tape) as a grounded conductor at all termination points at the time of installation.

Normally, exposed single-conductor cables are transitioned to a conduit wiring method when the circuits leave the PV array. While it's possible to use USE-2/RHW-2 or PV wire, THHN/THWN-2 is typical, since it is less costly. The "2" rating is needed to withstand the high temperatures of conduit exposed to sunlight and in outdoor, wet-environment applications (Section 310.15(B)(2)).

Unfortunately, #14 through #10 conductors with THHN/THWN-2 insulation are not widely available. THHN/THWN is available, but it doesn't have the proper rating for these conditions. However, as inspectors start applying 310.15(B)(2) of the *2008 NEC* to rooftop HVAC installations, demand will increase for the small-conductor THHN/THWN-2 cables. For now, I tend to support the use of USE-2/RHW-2 (with a white marking for the grounded conductor) in the conduits, although the *NEC* does not clearly state that it can be used with markings in that location. XHHW-2 would also be a suitable alternative.

All circuits in a PV system, as in other electrical systems, must be wired using a *NEC* Chapter 3 or Article 690.31 method that is suitable for the application and the environment. However, there are frequent questions about the circuits between the PV DC disconnect and the inverter. As far as the *NEC* is concerned, if these circuits are in protected environments, they could be wired with type NM cable. Although they are still, technically, PV output circuits, after the PV DC disconnect, they no longer represent the same hazard and do not have to be in metallic raceways unless required by the authority having jurisdiction (AHJ).

Conductor Color-Coding

In the recent past, most PV arrays have grounded the DC negative conductor, which is colored white. Newly installed arrays may ground the DC *positive* conductor (also colored white). Although no designated color codes exist for the ungrounded conductor, common sense would suggest that on a negatively grounded array with the negative conductor colored white, the positive, ungrounded conductor would be most clearly marked and understandable if it were a different color—say, red. However, many installations use a *black* positive conductor, which is still acceptable under the *NEC*. In the positively grounded systems where the positive grounded conductor is colored white, the ungrounded negative conductor would be most clearly understood if it were black.

The increasing use of transformerless inverters will dictate the use of ungrounded PV arrays (Section 690.35). Then we can adopt a "red is positive" and "black is negative" color-coding, since there will be no grounded conductor. The newest bipolar PV arrays and bipolar inverters have red positive ungrounded conductors, black negative ungrounded conductors, and white grounded conductors.

As before, the grounded conductor in a PV DC disconnect should never be switched, although bolted, isolated, terminal-block connections are acceptable.

Inverters

Utility-interactive inverters range in size from 175 W to 1 megawatt and new models are being introduced regularly.

This inverter comes with internal disconnects, but the inverter electronics cannot be removed separately for servicing. The separate external disconnect can de-energize the DC wiring inside the inverter.

These inverters will be tested and listed to UL standards by an independent agency—usually Underwriters Laboratories (UL), or CSA, ETL, or TUV Rhineland, all of whom are designated as Nationally Recognized Testing Laboratories (NRTL) by OSHA for testing and listing PV modules, inverters, combiners, and charge controllers.

Some inverters have only a single set of DC input terminals. With these designs, an external PV DC disconnect must be installed. Very low-powered inverters, like the Enphase microinverter, are permitted to use the DC and AC connectors as the required disconnects because they can be safely opened at their low current and voltage levels. Even if the inverter has more than one set of input terminals for parallel separate strings (source circuits) of modules, external DC disconnects must be used on each input. Disconnects may be bolted terminals, connectors, breakers, or bladed switches. Square D has a self-certification rating of 600 volts per pole on their H361, 2, and 3 fused safety switches and unfused safety switches. Each input must still have a disconnect, or if a disconnect has multiple poles rated for 600 volts, it may be used to disconnect multiple inputs.

Other inverters have internal DC disconnects or disconnect housings that attach to the main inverter section containing the electronics package. The method used to mount the internal disconnects, the ease and accessibility of the disconnects, and the manner in which they are separated from the inverter electronics vary between products. The installer and the AHJ must reach a mutual conclusion on the suitability of these disconnects for meeting the various requirements in the *NEC*.

Since the inverters are listed with the disconnects, it can be presumed that the disconnects are properly rated for the DC load break operation. If the inverter were installed in a location that meets Section 690.14 requirements for the main PV DC disconnect, then it would appear that the internal disconnect would meet this requirement.

Meeting the requirement for maintenance disconnects (690.15) will require additional considerations. If the inverter were to require factory service, can the energized PV source or output circuits be disconnected from the inverter safely when there is no external disconnect? If a disconnect housing is attached to the inverter and that housing does not have to be removed to service the inverter, then some degree of safety is assured. However, if the energized conductors must be disconnected from internal switches and pulled through small conduit knockouts, the situation must be examined carefully. Will qualified people who know how to disable the array be performing the removal? Or is there a chance that energized conductors could be pulled through the knockouts?

DC Input Fusing

Some models of inverters have DC input fuses mounted inside the inverter or inside a combiner/disconnect device attached to the inverter. The smaller fuses (30 amps or less) are usually mounted in "finger-safe" fuse holders that allow the fuse to be safely replaced in an unenergized state. However, fuses—anywhere in the PV system—rated at greater than 30 A are mounted in exposed fuse holders or bolted directly to a DC bus bar. One side of each fuse is tied together with the DC input of the inverter. The other side of each fuse is hardwired to the output of a PV DC combiner. These combiners are placed throughout the PV array—and in large, commercial systems, sometimes scattered over acres of real estate. Although the inverter can be turned off and the DC input capacitors allowed to discharge (takes up to 5 minutes), each fuse is still energized from its own input and the combined inputs of all of the other fuses through the common bus bar. The only way to safely service these fuses is to find all of the combiners that feed the inverter's fuses, and open or pull every source circuit fuse (those less-than-30 A "finger safe" fuse holders). An optional disconnect at the output of every combiner speeds this process and makes servicing the recombiner or inverter fuses safer—but all disconnects must be located and opened.

For large systems with several series strings, a disconnect at the output of every combiner eases servicing the recombiner or inverter fuses.

When these fuses are present in the input of the larger inverters, providing for safe servicing means installing a DC disconnect near the inverter on each DC input to a fuse.

These co-located disconnects can be easily opened. With the inverter turned off, the fuses can be safely removed in a de-energized state.

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