Beauty is in the Eye of the Inspector

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With electrical lifetimes exceeding 40 years, photovoltaic (PV) systems must be installed using the best available workmanship to ensure public safety over the life of the system. While the 700-plus pages of the *National Electrical Code* establish numerous requirements for electrical and mechanical procedures, the *Code* does not describe how many of these operations should be performed and how the final installation should look. This article will illustrate some areas that need attention before the workmanship of a PV installation is inspected. Of course, the local authority having jurisdiction (AHJ) has final approval of the workmanship.

Modules

PV modules must be securely mounted to a supporting structure. Mounting holes are provided in the frames of PV modules, and have been tested under simulated high wind loads to ensure that the module can withstand normal and expected environmental conditions. The hardware used to attach modules to a racking system must be appropriately sized and also be weather-resistant. Stainless steel hardware is most commonly used. Hardware used to secure PV modules to a building's roof must be robust and connect the mounting rack directly to the structural elements of the roof, such as the trusses or rafters. Attachment to only the roof sheathing generally will not provide adequate strength. All penetrations must be sealed with an appropriate sealant for the roofing material.

Many PV modules now have exposed, single-conductor cables attached to the backs of the modules. While Section 690.31 allows these exposed conductors, they should be used only to make connections between the individual modules, and should be terminated under or very near the PV array. There, the array output wiring should transition to one of the more common *NEC* Chapter 3 wiring methods, such as conductors in electrical metallic tubing (EMT). In general, these exposed, single-conductor cables, with attached connectors, will be longer than necessary when the modules are mounted side by side. The cables should not be allowed to droop, which could expose them to abrasion damage from wind and ice. Control this extra length by gathering the excess cable and connectors and fastening them to the module racks. Fastening hardware should be robust—stainless-steel pipe clamps in various sizes with EDPM rubber inserts are effective, but other options are available, including clips specifically designed to be used in conjunction with PV modules. Be wary of plastic cable ties—especially the white nylon variety—they do not resist heat and ultraviolet light exposure well.

Bare, equipment-grounding conductors should also be afforded the same mechanical protection as the exposed, single-conductor, insulated circuit conductors. When these bare conductors are spliced, the proper device must be used—usually a copper split bolt.

UV- and moisture-resistant cables on the back of a PV module. Inset: Stainless steel mounting hardware resists corrosion.

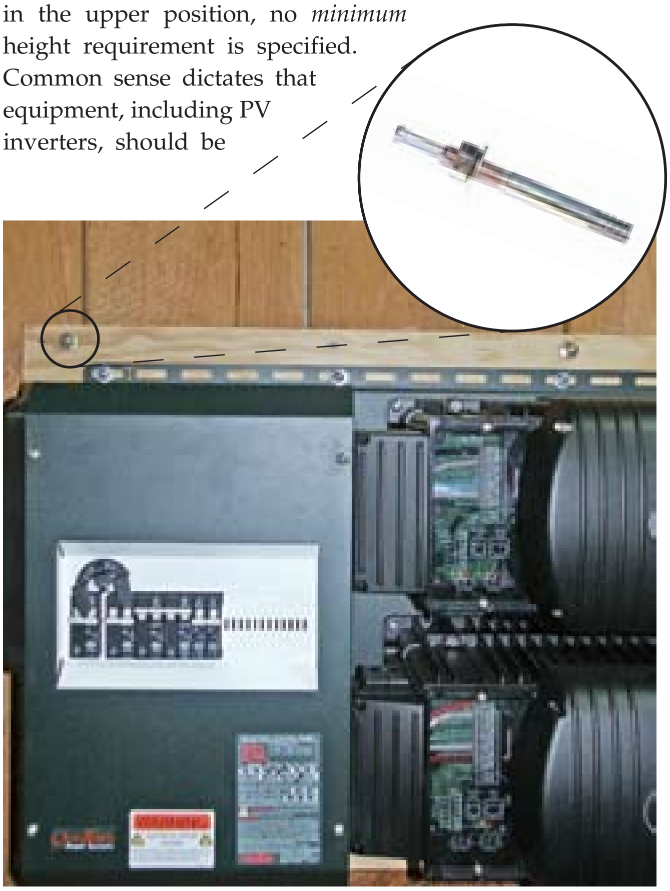
Exposed Conduit Runs

Unless the provisions of Section 690.31(E) in the 2005 *NEC* have been followed and the PV circuits are run in metallic raceways through the attic, the PV output circuits from the PV modules must remain *outside* the house until they reach the readily accessible PV DC disconnect (690.14). Conduits running across roofs and down the sides of houses and buildings must be appropriately supported and attached to the structure. Appropriate hardware must be used (again, stainless steel is popular) and any structural penetrations must be sealed to prevent weather intrusions. In most cases, the code establishes support requirements for the various wiring methods.

Equipment Mounting

PV inverters, even in residential-sized systems, can weigh more than 100 pounds. These inverters—as well as the various disconnects—should be firmly attached to the walls with anchors connecting the equipment to the wall studs or other internal load-bearing members. Lag screw and conduit penetrations should, of course, avoid any electrical wiring or plumbing in the wall cavity.

While the *NEC* (404.8) requires that the center of the grip on the disconnect handles be no higher than 6 feet, 7 inches in the upper position, no *minimum* height requirement is specified. Common sense dictates that equipment, including PV inverters, should be



Inverter power panels are heavy, and need to be securely mounted. Here, expansion bolts (inset) are used to fasten the panel to a wood-over-masonry wall.

mounted high enough to prevent splashing water or mud from entering. Some PV inverters have minimum space requirements below for ventilation. Access panels and fittings must be accessible so that electrical connections can be easily reached.

The distance between disconnects associated with the term "grouping" is left to the AHJ, and the allowed distance may be anywhere from a few feet to several yards. Since inverters must have AC and DC disconnects to allow for safe service and removal, it's appropriate to locate these disconnects adjacent to the inverter. While some inverters have internal disconnects, the AHJ must determine whether or not the inverter can be safely removed for service using these internal disconnects, or whether external disconnects must also be required. If the inverter is mounted on the opposite side of a wall from the main PV DC disconnect or far from the back-fed breaker in the main AC load center, additional "servicing" disconnects are generally required adjacent to the inverter.

When *all* of the PV-related equipment is grouped together—including the PV DC disconnect, the inverter, any utility-required disconnect, and the main load center for the dwelling—a minimum number of disconnects can be used, since all equipment is on one wall and is in close proximity.

Batteries

A comparatively small number of PV systems, both off grid and utility interactive, use batteries for energy storage. Two general categories of batteries are commonly used in renewable energy systems—flooded, lead-acid (LA) and sealed, valve-regulated, lead-acid (VRLA) batteries. Battery interconnect cables should be checked periodically for both tightness and corrosion. Batteries should always be installed in a manner that does not allow inadvertent contact with any exposed, energized terminals.

Flooded, lead-acid batteries require regular watering of the cells. In general, flooded batteries should be contained in battery boxes that allow for controlled access, preventing unqualified people from coming into contact with the battery tops or the energized contacts. Lockable, heavy-duty plastic toolboxes work well, and also help contain electrolyte that could leak out if the batteries are overcharged. Flooded, lead-acid batteries outgas water vapor, some sulfuric acid fumes and, when charged vigorously, hydrogen and oxygen gases. Small ventilation holes in the top of the battery box will allow hydrogen gas to escape, and boxes should be located in a well-vented area, such as a garage or utility shed. Venting manifolds are generally not required.

Conduit penetrations into battery boxes containing flooded LA batteries should be made into the sides of the container, below the tops of the batteries. This will minimize the possibility of any hydrogen gas (which rises) entering the conduit.

VRLA batteries are easier to maintain, and generally only need their terminals and busbars protected from accidental contact using insulators supplied by the manufacturer. Under proper charging regimes, VRLAs generally do not release gas fumes, and locating them in containers is normally unnecessary.

Battery enclosures protect individuals from accidentally coming into contact with energized terminals and cables.

Clearances

NEC Section 110.26 defines the clearances for electrical equipment that may need to be serviced when energized. Such equipment might include the PV DC disconnect, the inverter, and any batteries. The 6-inch depth allowance in 110.26(A)(3) allows some leeway, but the AHJ will evaluate each installation. This is particularly true when the inverter has been placed above batteries that are located on the floor. The inverter requires a 6.5-foot clearance from the floor, and the batteries may protrude no more than 6 inches in front of the inverter. The batteries require the same clearance, but since the inverter usually has less depth than the batteries, it's generally not an issue.

Some inverters have access requirements from the sides, and this may create additional space requirements. Also, the 90-degree opening requirements for doors and access panels may dictate additional space.

Summary

With the use of exterior or interior conduit runs, and the use of surface-mounted inverters and disconnects, the materials, techniques, and workmanship requirements for a PV installation resemble a commercial electrical installation more closely than a residential one. Excellent workmanship will give the inspector a good first impression. Make your PV system shine, put a smile on the inspector's face, and above all, be safe!

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 call, fax, e-mail, or write me at the location below. See the SWTDI Web site (below) for more detailed articles on these subjects. The U.S. Department of Energy sponsors my activities in this area as a support function to the PV industry under Contract DE-FC 36-05-G015149.

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The 2005 *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

Photovoltaic Power Systems & the 2005 National Electrical Code: Suggested Practices • www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/PVnecSugPract.html • Manual, 144 pages