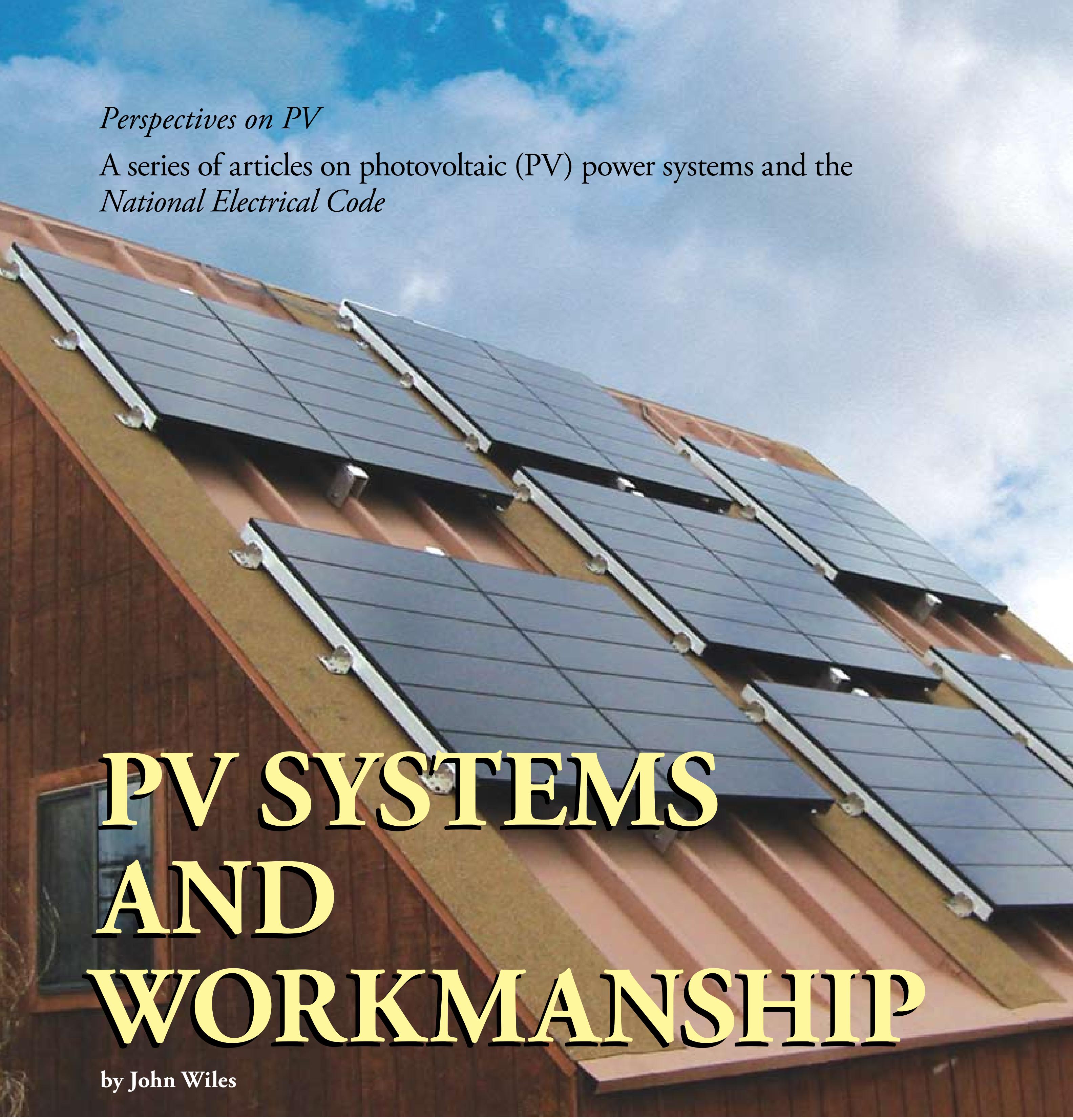

Perspectives on PV

A series of articles on photovoltaic (PV) power systems and the *National Electrical Code*

PV SYSTEMS AND WORKMANSHIP

by John Wiles

With electrical systems lifetimes exceeding forty years, PV systems must be installed using the best available workmanship to ensure public safety over the life of the system. Article 110, Requirements for Electrical Installations, and particularly Section 110.12, Mechanical Execution of Work, of the *National Electrical Code (NEC)* establish some general requirements for the installation of electrical equipment. A fine print note (FPN) to Section 110.12 references the National Electrical Contractors Association standard ANSI/NECA 1-2000 (latest edition is 2006) as describing accepted industry practices for electrical installations. This article will illustrate some areas that need attention when the workmanship of PV installations is being inspected. Of course, the local authority having jurisdiction (AHJ) determines what is acceptable.

Photo 1. PV module mounting hole and hardware

Photo 2. Module rack mounting bracket

Modules

PV modules must be securely mounted to a supporting structure. Mounting holes are provided in the frames of PV modules, and the modules have been tested under simulated high wind loadings using only these holes to ensure that the module can withstand normal and expected environmental conditions. These holes must be used to secure the module to a mounting rack, which is secured, in turn, to the roof of a building or to the ground. The hardware used must be of the appropriate size and be resistant to the exposed outdoor conditions. Stainless steel hardware is most commonly used (see photo 1).

The devices used to attach the PV array to the building must be robust and connect the mounting rack to the structural elements of the roof, such as the trusses or rafters. Attachment to only the roof sheathing generally does not provide adequate strength. All penetrations must be sealed against the environment. Photo 2 shows a PV array mounting bracket attached to a 2 x 6 under the shingles and sheathing with sealing to keep out the light rains found in New Mexico.

A few PV modules do not have frames but may have other mounting systems. Some have mounting attachment points bonded to the rear of the fameless modules (called laminates), and others are intended to be installed in a glazing system as part of a building integrated curtain wall or overhead transparent walkway covering. In all cases, the instructions furnished with the modules will show the mounting requirements. It should be noted that some PV modules without frames are not fully listed to UL Standard 1703. Modules in this category are marked with the UR (UL recognized component) mark and should be subject to a field inspection conducted by a nationally recognized testing laboratory (NRTL) that has field evaluation services (see photo 3).

Photo 3. Frameless PV modules in overhead canopy

Many PV modules now have exposed, single-conductor cables (one positive and one negative) attached to the backs of the modules. While these exposed conductors are allowed by Section 690.31, they are only to be used to make connections between the individual modules and should be terminated under or very near the PV array. At that point, 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 (see photo 4). The excess length must be controlled by gathering and fastening the excess cable and the connectors to the module racks. It should not be allowed to droop down and be exposed to abrasion damage due to wind and ice.

The fastening means should be robust; however, some plastic cable ties (especially the white nylon variety) do not resist the heat and ultra violet exposure well. Stainless steel pipe clamps in various sizes with EDPM rubber inserts appear to withstand various environments quite well, but other options are available.

Photo 4. Typical PV module with long interconnecting cables

Some installers will cut off the connectors and excess cable lengths and then solder the two cables together minimizing the excess length. The soldered splice is insulated with outdoor rated heat shrink tubing with an internal sealant that yields a splice that has the same electrical, mechanical, and insulation properties as the unspliced conductor. While this meets the *Code* requirements and results in a neat, durable, workman-like installation as shown in photo

Photo 5. Shortened, spliced, and secured module interconnections

5, a few module manufacturers maintain that splicing may violate the listing and/or the warranty on the module. If the heat shrink tubing does not have the same or greater thickness as the conductor insulation or the heat shrink is not rated for UV exposure, then the splice must be enclosed.

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. Photo 6 shows a crimp-on splicing connector that has been evaluated only for indoor applications (usually in a junction box) being used improperly outdoors.

Exposed Conduit Runs

Unless the provisions of 690.31(E) in *NEC*-2005 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 the readily accessible PV dc disconnect is reached. 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 sealed to prevent weather intrusions. In most cases, the *Code* establishes the support requirements for the various wiring methods.

Equipment Mounting

PV inverters, even in residential sized systems, can weigh over 100 pounds. These inverters as well as the various disconnects should be firmly attached to the walls with anchors that connect the equipment directly to the wall

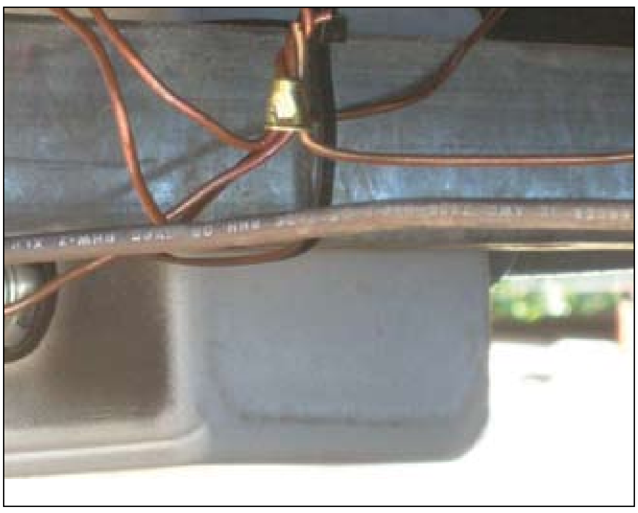

Photo 6. Dry location splicing device used improperly outdoors

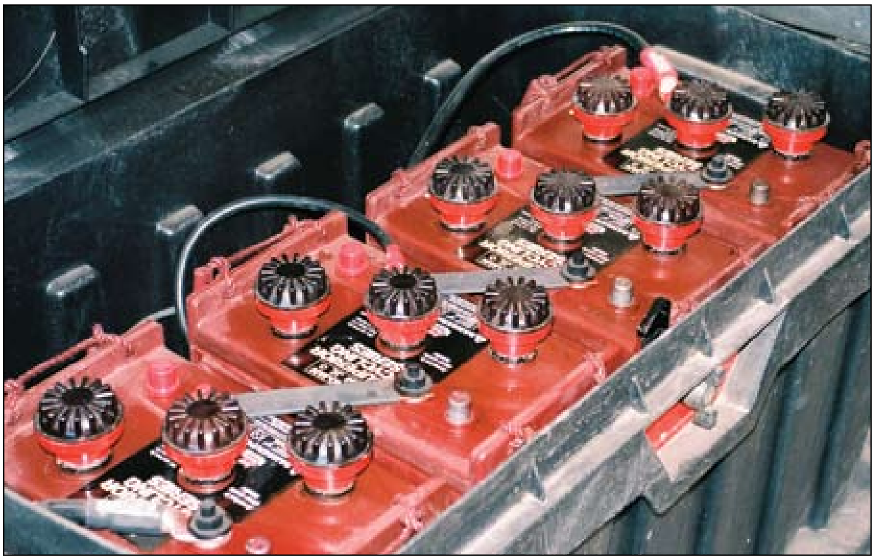

Photo 7. Flooded, lead-acid batteries in containers

studs or other internal load-bearing members. Connections to just the drywall are not sufficient. Lag screw and conduit penetrations should avoid, of course, any electrical circuits 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' 7" in the upper position, there appears to be no minimum height requirement. Common sense dictates that equipment, including PV inverters, not be mounted so low that water or splashing rain or mud can get into it. Some PV inverters have minimum space requirements at the bottom for ventilation. Access panels and fittings must be accessible.

The distance between disconnects associated with the term *grouping* is left to the AHJ. Since inverters must have ac and dc disconnects to allow for safe service and removal, it would seem appropriate that these disconnects be located 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 other side of a wall from the main PV dc disconnect or not near the back fed breaker in the main ac load center, then additional "servicing" disconnects will generally be required adjacent to the inverter.

When *all* of the PV-related equipment is mounted outside (or inside) the building, 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. See "Perspectives on PV" in the July/August *IAEI News* for examples.

Batteries

A comparatively small number of PV systems, both off grid and utility-interactive, will employ batteries for energy storage. There are two general categories of batteries used in renewable energy systems. The older types are like car batteries and are called flooded, lead-acid batteries (see photo 7). They outgas water vapor, some sulfuric acid fumes, hydrogen, and oxygen gas when being charged vigorously. The other category of battery is known as a valve-regulated, lead-acid (VRLA) battery and, under proper charging, does not release gas or fumes (see photo 8). Both battery types will have terminals between the cells and connecting cables that must be checked periodically. Therefore, both types should be installed in a manner that does not allow inadvertent contact with any exposed, energized terminals. The flooded, lead-acid batteries will require weekly to monthly addition of water to the cells, and contact with the cell caps should be restricted due to the normal presence of battery acid in these areas. In general, the flooded batteries should be mounted in containers (battery boxes) that will allow for frequent servicing while still preventing unqualified people from coming into contact with the battery tops or the energized contacts. Lockable, heavy-duty plastic toolboxes work well in this application. Spilled-electrolyte containment is also a consideration due to the infrequent overcharging that may occur. Hydrogen gas from the batteries is not normally found in explosive concentrations unless contained in small volumes, and small ventilation holes in the top of any battery box will allow it to escape into the room, which should be a well vented area like a garage or utility shed. Venting manifolds are generally not required or desired.

VRLA batteries are more easily installed and generally only need the terminals protected from accidental contact. Containers are normally not needed.

Conduit penetrations in containers with flooded batteries should be made in the sides of the container below the tops of the batteries. This will minimize the possibility of any hydrogen gas (which rises) from getting into the conduits.

Clearance Spaces

NEC 110.26 defines the clearances around electrical equipment that must be serviced when energized. Such equipment might include the PV dc disconnect, the inverter, and any batteries. The six-inch depth allowance in 110.26(A)(3) allows some leeway, but the AHJ will have to evaluate each installation. This is particularly true when the inverter has been placed above the batteries that have been mounted on the floor. The inverter requires clear space from floor to 6 1/2 ft and the batteries may stick out 6 in. in front of the inverter. Also, the batteries need the same clear space, but since the inverter usually has less depth than the batteries, it will not be an issue.

Some inverters have access requirements from the sides and this may pose additional space requirements. Also, the 90° 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, it becomes obvious that the materials, techniques, and workmanship requirements for a PV installation are going to resemble more closely a commercial electrical installation than a residential one. With PV modules generating dangerous amounts of electrical energy for 40 years or more, it behooves every one working with PV systems, from the designer to the inspector, to do everything possible to achieve the highest standards of workmanship.

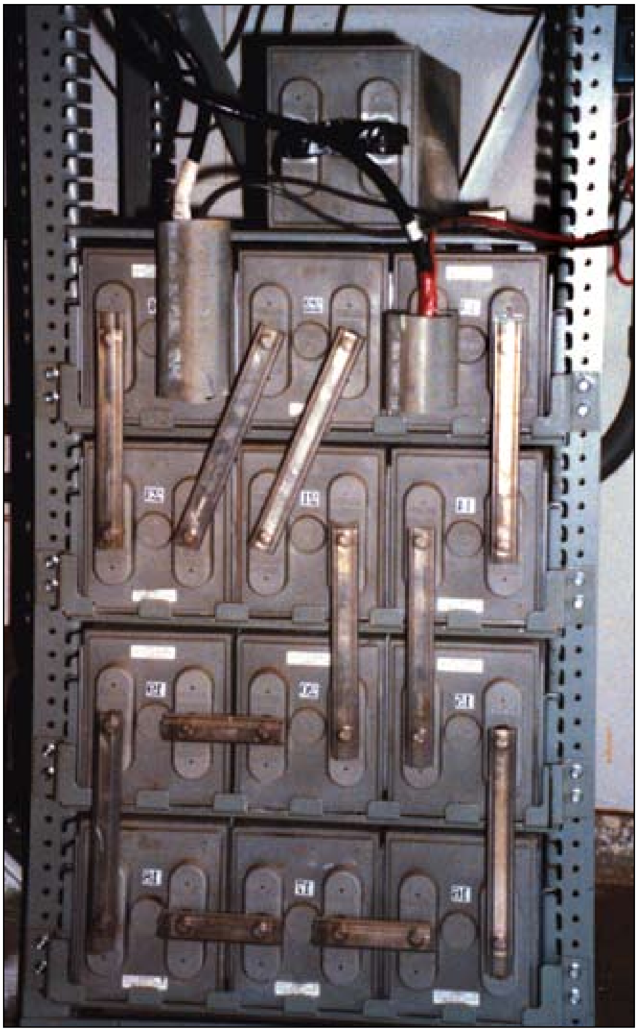

Photo 8. VRLA batteries with terminals covered

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: 505-646-6105

Here is a link to the National Electrical Contractors Association web site. They sell ANSI/NECA 1-2006, *Good Workmanship in Electrical Contracting*: http://www.necanet.org/store/index.cfm?fuseaction=search_results&index_number=NECA 1-06. A color copy of the 143-page, 2005 edition of the *Photovoltaic Power Systems and the 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/PVnecSugPact.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.

Proposals for the *2008 NEC* that were submitted by the PV Industry Forum may be downloaded from this web site: http://www.nmsu.edu/~tdi/pdf-resources/2008NECproposals2.pdf.

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 SWTDI web site.

John Wiles works at the Southwest Technology Development Institute (SWTDI) at New Mexico State University. SWTDI 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 40+ 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.

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