Roof-Mounted

PV System Design Challenges

by John Wiles

Designing and installing a PV system requires a lot of knowledge and skill. This column examines some of the less common issues faced in mounting rooftop PV arrays. This information may also be useful for potential PV system owners in evaluating the feasibility of a roof-mounted array.

Mechanical Considerations

The typical rooftop PV array consists of individual modules attached to a mechanical mounting system. This framework is usually attached to the roof's structural members. Although not an electrical-code issue, some attention must be given to the array's attachment to the building structure.

Most roofs are being designed based on span tables dictated by building codes or with trusses designed by professional engineers to accommodate live and dead roof loads. Adding a PV array to this structure brings its own considerations. A PV array may add up to 10 pounds per square foot of dead weight to the roof structural members, concentrated through the rack mounting feet. Because the PV array is typically elevated above the roof plane, the roof may be subjected to both uplift and down-force wind loads—again concentrated through the mounting feet of the rack. When further weighted with layers of old roofing materials, the structural limit of the roof may be breached.

Array mounts attached to the structural elements of a roof (trusses or rafters) require penetrating the roofing surface material and must be weatherproofed for the life of the roof. Stainless steel hardware is usually used to connect the modules to the racks for the corrosion resistance that is a must in most climates.

Electrical Connections

The PV array consists of PV modules wired in series using exposed single-conductor cables with "finger-safe" connectors. The conductors are typically USE-2 as allowed by *NEC* Section 690.31. In the *2008 NEC* Section 690.35, a new PV wire type is also allowed. This conductor is a "super" USE-2 with a thicker jacket (conduit-fill tables cannot be used with this cable). The PV wire, which is marked "Sunlight Resistant," passes a 720-hour accelerated UV test, and has the flame and smoke retardants of RHW-2. It can be used under and within the PV array for the module interconnections and in raceways in other locations. This new cable will soon be appearing on all modules because it facilitates the use of ungrounded PV arrays (as required by *NEC* 690.35) and transformerless inverters, offering less weight, higher efficiency, and lower-cost installations.

Most modules do not have J-boxes with knockouts for conduit, but come with single conductor cables with male and female connectors.

The electrical connectors attached to the ends of the module cables are "finger-safe"—until they are opened under load. The DC arc may damage the insulation, and then the connectors pose a shock hazard. Section 690.33 of the *2008 NEC* stipulates new requirements for locking connectors that require a tool for opening. These locking connectors will also soon appear on most, if not all, PV modules—although they are only required when the PV array wiring is operating above 30 volts and is readily accessible.

Another *2008 NEC* requirement applies to readily accessible PV source and output circuit conductors and AC conductors operating at more than 30 volts. Section 690.31(A) requires that these conductors must be installed in raceways. But most PV modules do not have junction boxes with knockouts that would accept a raceway—they come with permanently attached, exposed, single-conductor cables and connectors with no provision for attaching a conduit or other raceway. Fortunately, most residential rooftop PV arrays are not readily accessible.

For ground-mounted arrays that are readily accessible, a few manufacturers can provide conduit-ready modules on special order. The other solution is to make the wiring not readily accessible by placing some sort of barrier behind the modules that prevents the wiring from being touched.

A stainless steel loop strap and mounting bolt for securing module conductor leads.

Oops: An indoor lug and wrong conductor type were used for grounding this standing-seam metal roof.

However, fences with locked gates may not be a solution, because ground-mounted PV arrays usually need to have the grass mowed around them—a task usually done by people not qualified to work on PV or other electrical systems.

Another wiring consideration is conductor length and module orientation. Typically, conductor leads attached to modules are 40 inches or longer to allow series connection when modules are mounted in a landscape orientation. When the modules are mounted in portrait orientation, the excess lengths of conductors must be securely fastened against the module racks to resist abrasive damage due to wind, sleet, and ice. Many installers use plastic cable ties, but unless they are of very high quality, they may not last the required 40 years or more when exposed to the heat and UV radiation from sunlight. Some system integrators use a stainless-steel pipe clamp (a.k.a. loop strap) with an EDPM insert.

Single-conductor exposed wiring (USE-2 or PV wire) is allowed only in the near vicinity of the PV array to interconnect the modules and to return the end of the string conductor to the origination point of the string wiring (which is generally routed behind the modules). At this point, the exposed wiring must transition to one of the more common wiring systems found in Chapter 3 of the *NEC*. Typically, this transition will take place in a pull box, conduit body, or junction box. From there, the wiring will be run in some form of conduit, such as EMT. The transition device keeps water, dirt, rodents, and other material out of the conduit. Also, a rain head or a cord grip might be used, connected directly to the conduit in situations where a single type of conductor will be used for the entire DC system.

If the array output conductors penetrate the surface of the building before reaching the first readily accessible DC PV disconnect, then they must be housed in a metal raceway inside the structure. Metal raceways include rigid metal conduits and flexible metal conduit (FMC), but do not include metallic cable assemblies like Type MC and Type AC.

Grounding

Section 690.47(D) in the *2008 NEC* requires that metal surfaces of the PV array be connected directly to earth via a separate grounding electrode. This requirement provides a greater degree of lightning protection for PV systems than other *NEC* requirements and is in addition to the normal equipment-grounding conductors that run with the circuit conductors connected to earth (grounded) at locations remote from the PV array. If the array is on the same building that contains the inverter and the existing AC grounding electrode, the new grounding electrode conductor from the array may be connected directly to that electrode. A separate electrode will not be required. However, if the connection to an existing electrode requires a horizontal extension at ground level that's greater than 6 feet, a separate electrode is required. This new array-grounding electrode does not have to be bonded to any other electrode.

The module frames must be effectively grounded, and that is not always easy with aluminum frames and copper conductors. The racks must be grounded, and if the PV array is mounted on a metal roof, the roof should also be grounded, since rodent damage and abrasion to the conductors that come in contact with the roof could cause the roof to become energized.

Temperature Corrections

High temperatures can affect both modules and conductors. On a hot summer day, modules can operate under very high temperatures (158°F to 176°F). Exposed wiring can come into contact with hot surfaces, as can conductors that originate in the hot termination boxes attached to the backs of the modules. Because of this, field-installed wiring (and the leads connected directly to the module) must be evaluated for temperature, and ampacity corrections applied.

In most of the United States, a 75°C temperature correction factor is suggested for conductors near PV modules that are mounted roughly 4 inches or less from a surface like a roof.

A cord grip keeps water, critters, and detritus out of a raceway, while allowing the cable to pass through.

An abraded cable (in this case, rodent-damaged) can lead to shorts and malfunctioning systems.

The distance is not exact and is normally measured from the back of the module frame to the surface. However, 4 inches or less is insufficient clearance to allow optimum airflow behind the modules mounted in an array.

If the air space behind the modules is greater than 4 inches, then a 65°C temperature-correction factor is suggested. Again, these are not hard-and-fast numbers, and the individual installation location and microclimate (i.e., Death Valley, California vs. Nome, Alaska) may affect them.

Conductors in conduit exposed to sunlight are also vulnerable to solar heating. *2008 NEC* Section 310.15(B)(2) provides the temperature additions above the expected average high temperatures. These additions apply not only to PV systems but to any conduit run on roofs exposed to sunlight. In many cases, where the high average temperatures are in the 104°F to 113°F (40°C to 45°C) range and the conduit is installed close (1/2 inch or less) to the roof, a 73°C to 78°C correction factor would apply. Those conductors could be delivering energy for 40 years or more, so carefully applying these temperature-correction factors helps ensure that the insulation does not suffer premature degradation.

Access

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Photovoltaic Power Systems and the 2005 National Electrical Code: Suggested Practices by John Wiles • www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/PVnecSugPract.html

PV Systems Inspector/Installer Checklist and previous *Code Corner* articles • www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/Codes-Stds.html