The Front End

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PV modules—the “front end” of a PV system—are usually the most expensive part of the system. They are also very long lived. Getting them connected safely and correctly should be a top priority for anyone desiring a safe, durable, and high-performance renewable energy system.

Live Long & Prosper

Crystalline PV modules can have a very long life. Modules produced in the last few years can be expected to have electrical output for the next 40 years or more. No, they may not put out full power, or even meet the manufacturers’ expected output as the modules age, but they will probably be producing sufficient voltage and current to be useful. They will also still represent a source of electrical energy that may be hazardous if not properly installed.

PV system designers and installers should design the system and install and connect the PV modules so they function safely and reliably for many years with minimum maintenance. A number of issues must be addressed to accomplish this task. Some are related to the requirements of the *National Electrical Code (NEC),* some to good workmanship, and some to performance.

Inspectors & Instruction Manuals Are Your Friends

The local electrical inspector is a good person to keep informed about the design of your system. He or she will have ideas on how the installation should look, and may be able to offer valuable insights on how things are done locally. Foresight is a lot cheaper to implement than hindsight is to fix. Building codes may also affect the PV module or array installation.

It is beyond the scope of this column to go into detail about how and where the modules should be mounted. A general guideline is to mount all modules in the system pointed to true south, and tilted at an angle equal to the latitude. Moving the PV array away from this ideal orientation will result in lowered output. Shading the entire PV array or part of it will also decrease the output. (This decrease can be significant if the array is made up of a single series string.) Installing the PV array in two or more locations with different orientations may result in a significant mismatch of array voltages due to variations in array temperatures, shading, and insolation. This will decrease output, especially if a single inverter is used. The California Energy Commission has a design document on their Web site that discusses some of these mounting issues. See Access.

The instructions that come with the module should be studied carefully to determine the proper way to mechanically connect the module to the mounting rack. The instructions will also describe the proper methods that can be used to electrically connect the module to the system. These should be reviewed along with the general and specific requirements established by the *NEC.*

Generally, the labels and instructions provided with a listed product supplement the *NEC* requirements found in Article 690 on PV systems. These two sources of information supersede any general requirements found in other sections of the code. Unfortunately, some manuals include errors that conflict with *NEC* requirements. Where a conflict is found, the manufacturer and the local electrical inspector should be contacted.

The longevity of crystalline PV modules (and possibly other module technologies) dictate that only the very best methods, materials, and workmanship be used in the installations. Stainless steel hardware is suggested for mechanical connections. The PV system may outlast the roofing materials, and the PV array may have to be removed to repair the roof—ease of disassembly some years down the road is a must. Lock washers and other appropriate hardware should be used to ensure that wind-induced vibrations do not shake fasteners loose over the years. If the module manuals list torque specifications for mechanical or electrical connections, by all means get and use a torque wrench; cost can be less than US$25.

Conductors

As discussed in *Code Corner* in *HP90,* the module manufacturer should provide specific instructions and hardware for connecting the equipment-grounding conductor to the module frame. A bare or sunlight-resistant conductor (USE-2) should be used. The circuit conductors require more careful consideration.

These conductors should be of the highest quality, and installed so that they can provide many years of reliable service. Although several different types of conductors meet the requirements of the *NEC* (see previous *Code Corners*), a conductor type marked USE-2/RHW-2, with cross-linked polyethylene (XLP or XLPE) insulation is generally considered one of the highest quality conductors commonly available. This specific insulation type can be used outdoors in sunlight and also installed in conduit outdoors and indoors. Most electrical supply houses have or can get it, and many PV distributors carry it.

PV systems running at 48 volts nominal can have open-circuit voltages that exceed 100 volts. String inverters like the SMA Sunny Boy 2500 may have open-circuit PV voltages up to 600 volts. While code-compliant, single-conductor, USE-2 cables are available that are rated for 600 volts, some thought should be given to the effect that sunlight, weather, and time can have on these exposed, single-conductor cables. Unfortunately, cable manufacturers are unwilling to disclose how their cables perform when time periods of 20 to 30 years are brought up. So we don't really know how well these cables will hold up in PV applications.

I have had #10 (5 mm^2) USE/RHW XLPE cables exposed on my hot, sunny roof in Las Cruces, New Mexico for twelve years on fixed racks and trackers, with no visible signs of degradation. This is an anecdotal observation on a 24 volt system, and the cables have not been tested in any way to see if they are still good for 600 volts and have not physically or electrically degraded.

At least one manufacturer, SMA America, suggests that conduit be used on any PV system where the open-circuit voltages may exceed 100 volts. The recommendation is made for installations where the single-conductor cables are readily accessible to unqualified people. If the conductors are secured under roof-mounted modules and cannot easily be reached, SMA America suggests that the use of single-conductor, exposed cables is acceptable.

The use of conduit for the higher voltage systems provides an extra layer of protection from shock should the cable develop a crack in the insulation. It also shields and protects the conductor from adverse weather and long-term UV exposure. Another option that might increase the safety and durability of the installation is to use a two-conductor, jacketed tray cable.

Neither of these suggestions represents code requirements, but the *NEC* hasn't dealt very much with consumer-type electrical generators that may last for 40 years without maintenance. See past *Code Corners* for more discussion about conductor selection and sizing.

If modules with pigtails and connectors are being used rather than junction boxes and point-to-point wiring, other considerations come up. Underwriters Laboratories (UL) has found that these connectors, when unplugged under load, create a small arc that compromises the insulation of the tip of the connector. The insulation chars and becomes conductive, and the connector is no longer "finger safe." UL is considering requiring these connectors to be "locking," so that a tool is required to disconnect them.

Connector manufacturers are developing designs that will lock. Until then, the installer using these connectors may elect to encase each with a length of heat shrink tubing to keep unqualified people from opening them. This is not a code requirement, just a suggestion that may increase the safety and reliability of the system.

Conductors must make mechanically and electrically sound connections with the PV modules. They must also be able to resist external stresses such as wind, snow, and squirrel loading. Conduit provides mechanical protection. Where exposed single-conductor cables or tray cable is used, it must be supported and provided with a degree of physical protection so that no strain is applied to the electrical connections. Exposed cable should not be allowed to run unsupported for more than a few inches. Conduit should be secured and supported. Both should be firmly fastened to a supporting structure at intervals recommended in the NEC for the wiring method being used.

Overcurrent Protection

The front-end design should address two areas of overcurrent protection, although they might both be accomplished by using a single device. The back of all listed modules has a label that shows, among other things, a value of the "Maximum Protective Fuse." This fuse is intended to limit the reverse fault current through a module to a safe level (one that cannot cause external fires). The reverse current could be caused by wiring faults or by faults within the module.

Since this overcurrent device (fuse or circuit breaker) must also carry the forward current from the module, it must have a value of at least 1.56 times the short-circuit current (Isc). If the labeled value for this fuse does not comply with this relationship with Isc, the module manufacturer should be contacted. Each module must have this overcurrent device if there are any sources of current in the system that can exceed the reverse current rating of the module (fuse rating). In systems where modules are connected in series, only one fuse is used to protect all of the modules in a particular string.

The circuit conductors connected to the PV module must also be protected by an overcurrent device located at the source of any potential currents. This device should also be rated at 1.56 Isc. Only the ungrounded conductor(s) are required to have this overcurrent device. Since the source of potential overcurrents that might damage the module or the circuit conductors is the same for both problems, a single overcurrent device can usually satisfy both requirements.

Sources of overcurrents are modules or strings of modules connected in parallel, backfed current from batteries through the charge controller, and backfed current from the utility through the inverter. These source locations dictate that the fuse be located at the combiner box where multiple modules or strings of modules are connected in parallel.

In systems with a combiner box, an additional fuse is generally required near the battery, charge controller, or utility-interactive inverter to protect the conductors between that device and the combiner box. Systems with no combiner box generally have an overcurrent device for each module or string of modules mounted in a power center or in a utility-interactive inverter.

Fuses and circuit breakers are rated for operation at an ambient temperature of 40°C (104°F). If the temperatures around the overcurrent device exceed this value, the device manufacturer should be contacted and temperature deratings obtained. For this reason, combiner boxes containing overcurrent devices should be mounted in the shade where they are not affected by solar radiation and heating. If the installation is in the hot Southwest, with daily ambient temperatures in the summer of 40 to 50°C (104–122°F), the overcurrent devices will have to be temperature derated.

Overcurrent devices may not be required in a few areas in DC module circuits. They all deal with installations where there are no sources of short-circuit current in excess of the rating of the module protective fuse. One type of system could have only one or two strings of modules connected to a water pump with no battery. Another case might be in a utility-interactive system with no batteries that uses an inverter that cannot backfeed currents from the utility. The SMA Sunny Boy 2500 is such an inverter. Two, and sometimes three, strings of modules can be connected to this inverter through an appropriate disconnect switch without overcurrent protection in the DC PV source or output circuits.

Quality Components & Good Workmanship Equal Safety & Longevity

PV systems can be installed so that you get years of trouble-free operation. Meeting the requirements of the *NEC* while carefully selecting components with the best durability will help to ensure that the system remains safe over the decades, and continues to deliver satisfactory performance with minimal maintenance.

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. Sandia National Laboratories sponsors my activities in this area as a support function to the PV industry. This work was supported by the United States Department of Energy under Contract DE-FC04-00AL66794. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy.

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California Energy Commission Report: *A Guide to Photovoltaic (PV) Power Systems Design and Installation* • www.energy.ca.gov/reports/2001-09-04_500-01-020.PDF

The 2002 *NEC* and the *NEC Handbook* are available from the National Fire Protection Association (NFPA), 11 Tracy Dr., Avon, MA 02322 • 800-344-3555 or 508-895-8300 • Fax: 800-593-6372 or 508-895-8301
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