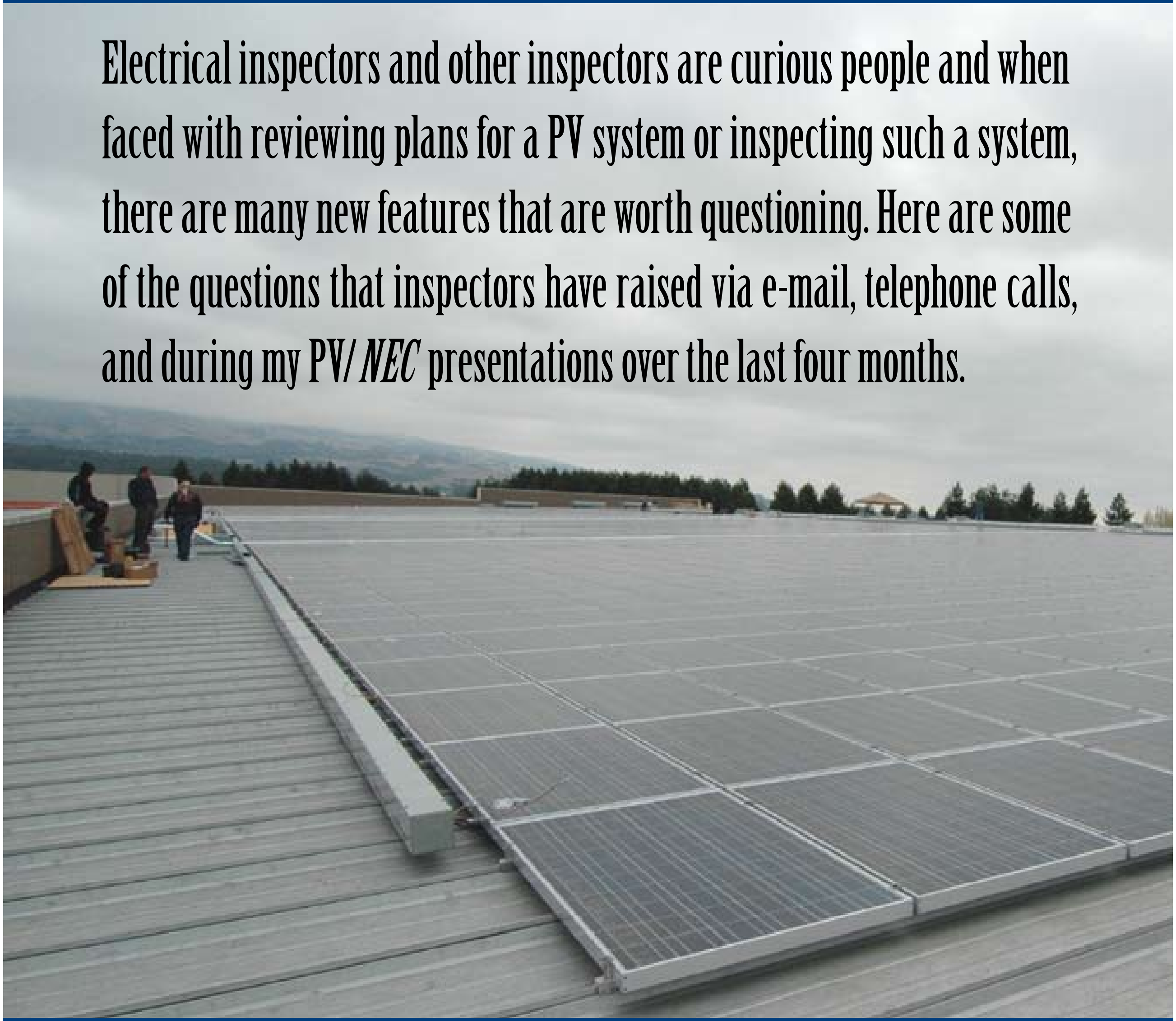
Perspectives on PV

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



Electrical inspectors and other inspectors are curious people and when faced with reviewing plans for a PV system or inspecting such a system, there are many new features that are worth questioning. Here are some of the questions that inspectors have raised via e-mail, telephone calls, and during my PV/*NEC* presentations over the last four months.

Inspectors Demand More Answers

by John Wiles

Question: When are fuses required in the dc wiring of a PV system?

Answer: Fuses are generally required in the dc sections of a utility-interactive PV system for two reasons. First, all ungrounded conductors must be protected from over currents. Second, each PV module must be protected from reverse currents that exceed the value of the module protective fuse that is marked on the back of the module (fuses and circuit breakers are considered equivalent) [see photo 1]. Overcurrents may result from a short circuit in the wiring, and reverse currents may result from either a short circuit or a shaded module or modules. In most cases, a single overcurrent device will satisfy both of these requirements and, in many small residential PV systems, no overcurrent device at all is required.

These overcurrent devices are required *only* when there are sources of over currents that could damage either the wiring or the module during shading or fault conditions. In the utility-interactive PV system, with a listed inverter, the only source of currents or over currents in the dc part of the system originate in the modules themselves. The inverter is not able to provide any current into the dc PV array, so it is not a source of currents other than a short transient current as the input noise filtering capacitors discharge.

In a single string of PV modules (a series connection of several modules from 2-20+), the only current in question is the current generated by the modules in the string. This current is, at a worst-case maximum, 125 percent of the rated module short-circuit current (Isc). This current is marked on the back of the module as shown in photo 1. Per *NEC* requirements (690.8 and 690.9), all circuit conductors will be sized at 156 percent of the same short-circuit current. Therefore, the conductors have no source of high overcurrents that would exceed their ampacity and they do not need overcurrent protection (690.9, Exception). Currents generated within a string of modules cannot produce reverse currents in that string and, since there are no external sources of currents, no overcurrent device is needed to protect the PV module. The result is that in a utility-interactive PV system with a single string of modules, no overcurrent device is needed in the dc circuit.


SHARP

SOLAR MODULE

ND-200U1

c UL US LISTED
2P09
PHOTOVOLTAIC MODULE
E160673

THE ELECTRICAL CHARACTERISTICS ARE WITHIN 10 PERCENT OF THE INDICATED VALUES OF I_{SC}, V_{OC}, AND +10/-5 PERCENT OF P_{MAX} UNDER STANDARD TEST CONDITIONS (IRRADIANCE OF 1000W/m^2, AM1.5 SPECTRUM AND CELL TEMPERATURE OF 25°C)

MAXIMUM POWER	(P_{MAX})	200.0 W
OPEN-CIRCUIT VOLTAGE	(V_{OC})	35.5 V
SHORT-CIRCUIT CURRENT	(I_{SC})	7.82 A
MAXIMUM POWER VOLTAGE	(V_{PMAX})	28.5 V
MAXIMUM POWER CURRENT	(I_{PMAX})	7.02 A
MAXIMUM SYSTEM VOLTAGE		600 V
FUSE RATING		15 A
FIRE RATING		CLASS C
FIELD WIRING		COPPER ONLY 14 AWG MIN. INSULATED FOR 90°C MIN.
SERIAL No.		05Y020944

Photo 1. Label on back of PV module

When there are two strings of modules, it is possible for one string to attempt to force currents back into the other string when that string is shaded. The unshaded string can produce up to 125 percent of the rated short-circuit current. All wiring in each string is sized at 156 percent of that same current so no overcurrent devices are required to protect the module wiring. Most PV modules have a marked, module-protective fuse that is well in excess of 156 percent of the rated short-circuit current, so again, there is no requirement for an overcurrent device to protect the modules. With two strings of modules connected in parallel, no overcurrent device is needed in the dc wiring.

When three or more strings of modules are connected in parallel, the situation may be different and a calculation must be made. If we assume that one string of modules is shaded, then the two unshaded strings of modules may attempt to force reverse current into the shaded string. Each of the unshaded strings can source up to 125 percent of the rated short-circuit current, so two strings can source up to 2 x 1.25 x Isc = 2.50 Isc. If this current (2.50 Isc) is greater than the value of the maximum module protective fuse marked on the module, then an overcurrent device must be installed in the ungrounded conductor of each string, and the value will be typically be 1.56 Isc or larger, up to the value of the maximum protective fuse. A minimum value of 1.56 Isc will protect the module from reverse currents and will also protect the conductors that have also been sized at 1.56 Isc. If a larger value of series overcurrent protective device is used (up to the allowed maximum protective fuse value), the ampacity of the conductors connecting the modules must be adjusted accordingly.

When there are more than three strings, the same calculation applies. Just take the number of strings in parallel and subtract one. Use this number times 1.25 x Isc to

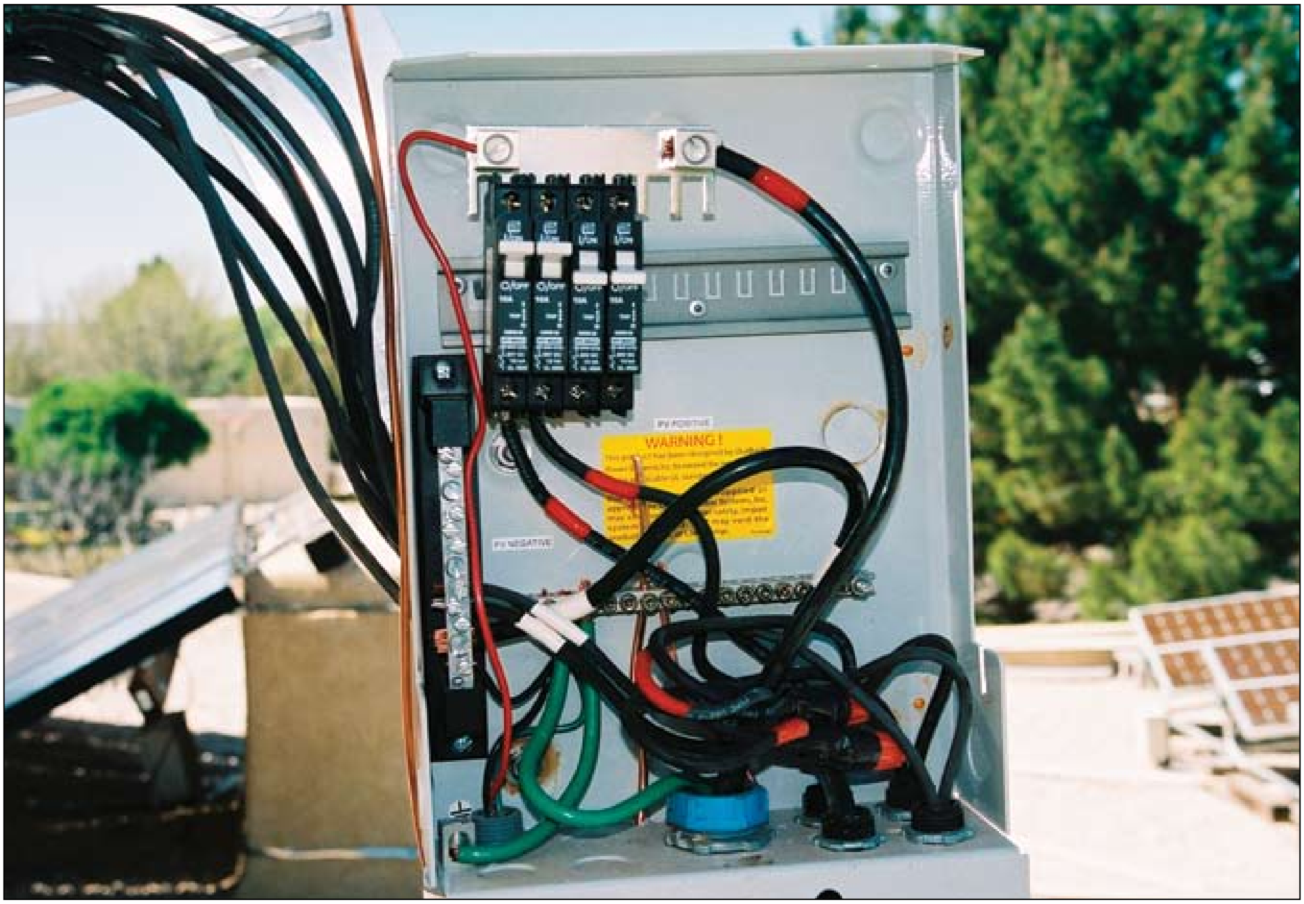


Photo 2. DC combiner box with circuit breakers operating up to 125 volts

get a number that will be compared to the value of the module protective fuse. If the calculated number is larger than the protective fuse value, then one overcurrent device will be required on each of the series-connected strings of modules. The overcurrent devices are usually mounted in a dc combiner box as shown in photos 2 and 3.

In summary, one and two strings of modules on a utility-interactive inverter will require no overcurrent devices in the dc circuits. When three or more strings are used, a calculation must be completed to determine if overcurrent devices are required or not.

There are a few modules currently on the market that have a series fuse rating that is less than 1.56 Isc. This creates a quandary for the installer and the inspector. *NEC* 110.3(B) requires that the module label be followed, but 690.8 and 690.9 require that an overcurrent device rated at 1.56 Isc be used. When these cases come up, it is time to call UL or enter a complaint through their AHJ/regulatory web site and get this continuing issue resolved.

Question: On PV systems with batteries, how is the ampacity of the conductor for the charge controller output circuit determined?

Answer: The ampacity of the charge controller output circuit must be based on the rated maximum output of the charge controller. This information should be in technical specifications or the instruction manual for the controller. The circuit ampacity and the rating of any overcurrent device must be at least 125 percent of the rated steady-state output currents. In some cases, the rated output current is not stated.

Photo 3. DC combiner boxes with fuses operating up to 600 volts.

Some controllers use a relay as the switching/controlling element. In this case, the rating of the relay becomes the rating for the controller.

In other cases, the charge controller does a voltage conversion and can take higher input voltages (such as 48-72 volts from the modules) and charge batteries at lower voltages such as a 24-volt or even a 12-volt battery. While the manuals for these charge controllers usually specify a rated output current, the installer (and the inspector) should verify that the PV system is not designed so that excessive currents are forced through the controller. If this happens, *NEC* 110.3(B) may be violated by using the listed controller in a manner that is not covered by the instructions. For example, a controller may be rated at 60 amps output when connected to a 24-volt battery. If this controller is connected to a 48-volt, 60-amp PV array, the controller will reduce the output voltage to 24 volts and, at the same time, try to increase the output current to almost 120 amps. While the controller will presumably protect the output circuit by limiting the output to 60 amps, the controller is not being used in accordance with the manufacturer's instructions [110.3(B)]. Most of these controllers list the maximum PV input power levels or maximum currents at various voltage levels for each battery output voltage.

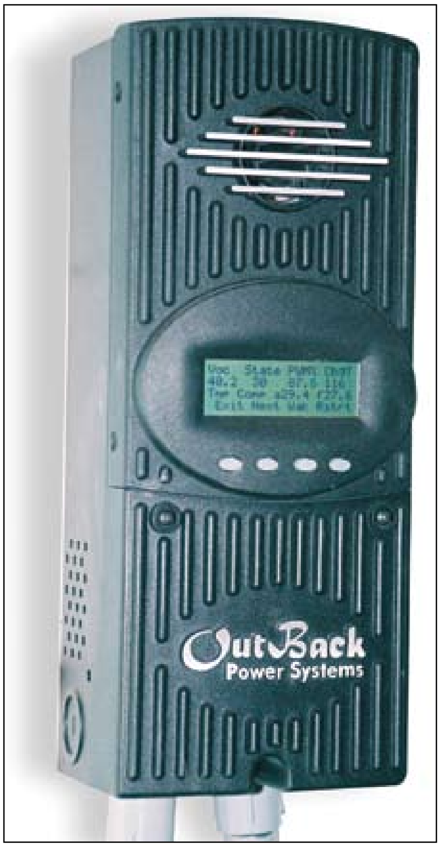


Photo 4. Battery charge controller

Question: What safety precautions should I observe when inspecting a PV system?

Answer: Keep in mind that the PV dc circuits between the PV modules and the dc disconnect will be energized any time the modules have light on them (even at dawn and dusk). Connections, switchgear, and other devices can be at voltages up to 600 volts. On any system showing signs of poor workmanship at a distance (inspectors know poor workmanship when they see it), the proper grounding of all metal surfaces should be inspected first. After that, it should be safe to open boxes and switchgear and inspect further. For additional details, see the "Perspective on PV" in the May/June 2006 edition of *IAEI News* (PDF available on the author's web site).

Question: What types of information should I be requesting on plans for PV systems being used to obtain a permit?

Answer: Since none of us have seen, installed, or inspected hundreds of PV systems and each one is different, we really need to get as many details as possible in the permitting package. It is far easier to verify Code compliance on paper in the comfort of the office and then check to see if it was installed per the permit. We need the following items in the permit package: 1) an overall description of the system and how it works, 2) specifi-

Photo 5. High voltage, high currents—*exercise caution!*

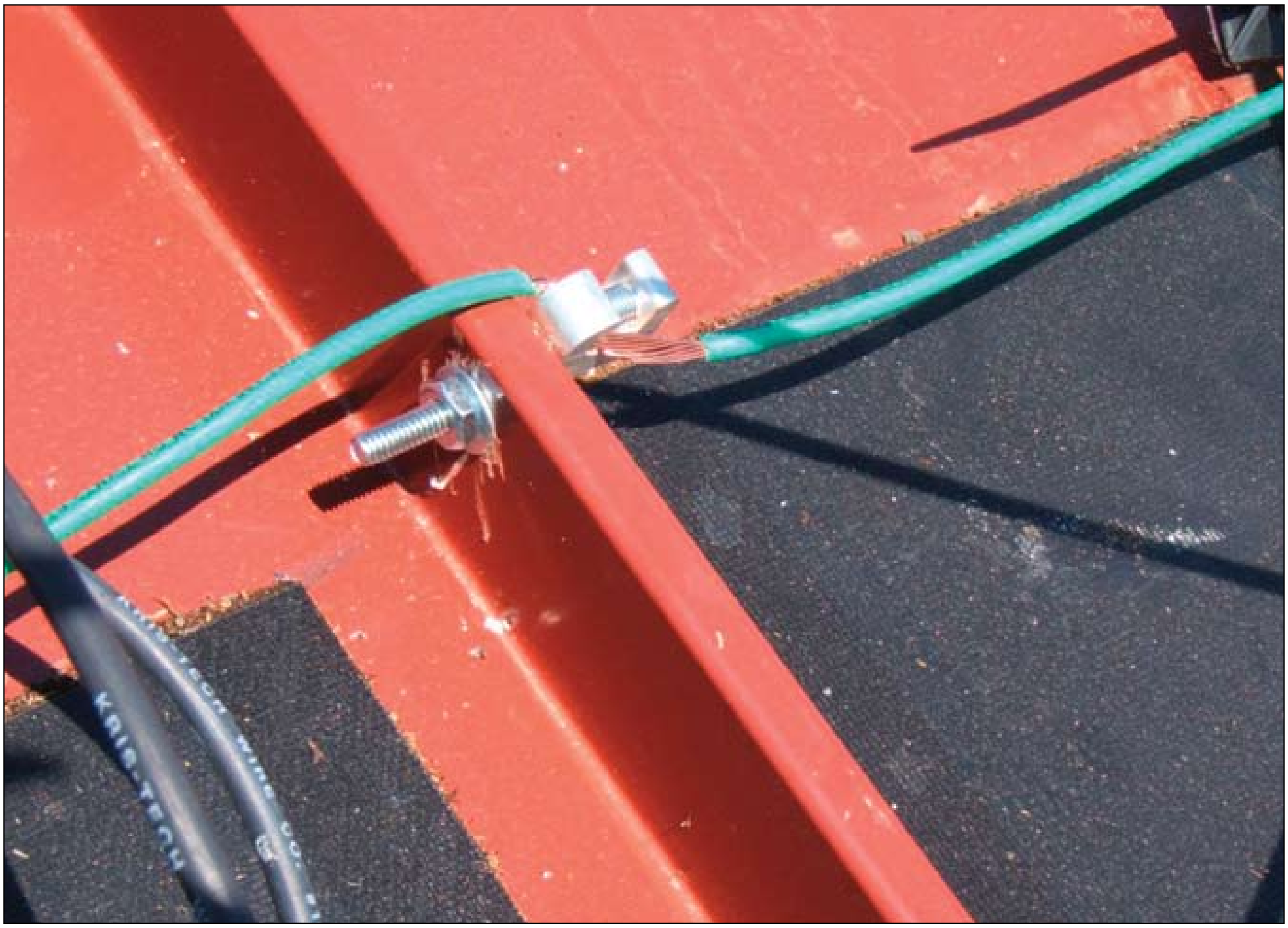


Photo 6. Grounding a metal roof, THHN questionable

cations for each of the major components and manuals for the modules, inverters, and any charge controllers, 3) a two- or three-line diagram showing the equipment-grounding provisions and system-grounding provisions, 4) calculations showing *Code* compliance for conductor ampacity and conditions of use deratings. See "Perspectives on PV" in the March-April 2006 edition of *IAEI News* (PDF available on the author's web site) for more details.

Question: What are the requirements for grounding a PV system that is installed on a metal roof.

Answer: The *National Electrical Code (NEC)* requires that any exposed non-current-carrying conductive surface that may be energized be grounded to minimize electrical shock hazards (Section 250.110).

Rooftop PV systems may operate at voltages approaching 600 volts. These voltages pose a significant shock hazard if they are allowed to energize conductive exposed surfaces that may be touched. Such exposed non-current-carrying conductive surfaces include the PV module frames, the metallic module mounting racks, and possibly the metal roof the racks are attached to. Effectively bonding these conductive surfaces together and grounding them will minimize shock hazards.

There are two primary wiring methods used for connecting PV modules together; single-conductor exposed cables and conduit. Each will dictate a different grounding method. In both situations, the PV module frames must always be grounded properly. See the "Perspectives on PV" article in the September-October 2004 issue of the *IAEI* News titled "PV System—Should They Be Grounded" for information on grounding PV modules. This article is also available on the author's web site

PV systems using exposed, single-conductor cables

PV modules connected together with exposed single-conductor cables (the most common installation method) would almost invariably have those cables touching the module mounting racks, and those racks should be grounded. Movement of the cables from wind, rain, and ice could cause the conductor insulation to deteriorate, and the bare conductors could energize the racks. Aluminum racks can be as difficult to ground as aluminum-framed PV modules.

In many cases, it would be difficult to keep these exposed cables from touching the metal roof. They could touch at initial installation, or they may come into contact with the roof at a later date as cable ties break or loosen. Wind, rain, and ice could cause the cable to rub against the metal roof, abrade the insulation, and allow the energized copper conductor to energize the roof.

Where these exposed single conductor cables are used for modules, the racks and the roof should be grounded. Instructions on how to properly ground a metal roof are not readily available, but photo 6 shows a possible method that might be used provided the non-UV rated THHN conductor were not used. A bare grounding conductor would be a better, code-compliant choice. Such connections should be made where water penetration would not be an issue.

PV systems using conduit between modules

When conduit is used between the individual modules (currently a rare situation) and there are no exposed, single-conductor cables, then it is unlikely that either the module racks or the roof would require grounding. The module frames should be grounded, and conduit should surround the conductors, protecting them from damage. The conduit may be insulating types like rigid nonmetallic conduit (RNC) and liquidtight flexible nonmetallic conduit (LFNC) or a metal type like electrical metallic tubing (EMT). The EMT would be grounded, the LFNC, RNC would not be grounded, and both would provide the desired physical protection. Even if the conductor insulation should fail, the conduit would prevent the rack or the roof from becoming energized. Neither the metal racks nor the metal roof would require grounding except in the event that significant and likely PV module damage could be expected. Such damage could cause the internal conductors of a shattered PV module to contact the rack or the roof. If such damage were expected, then grounding both the rack and the roof would be advised.

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 or phone: 505-646-6105

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/roswell-8opt.pdf.) The Southwest Technology Development Institute web site (http://www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/Codes-Stds.html) 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.

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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