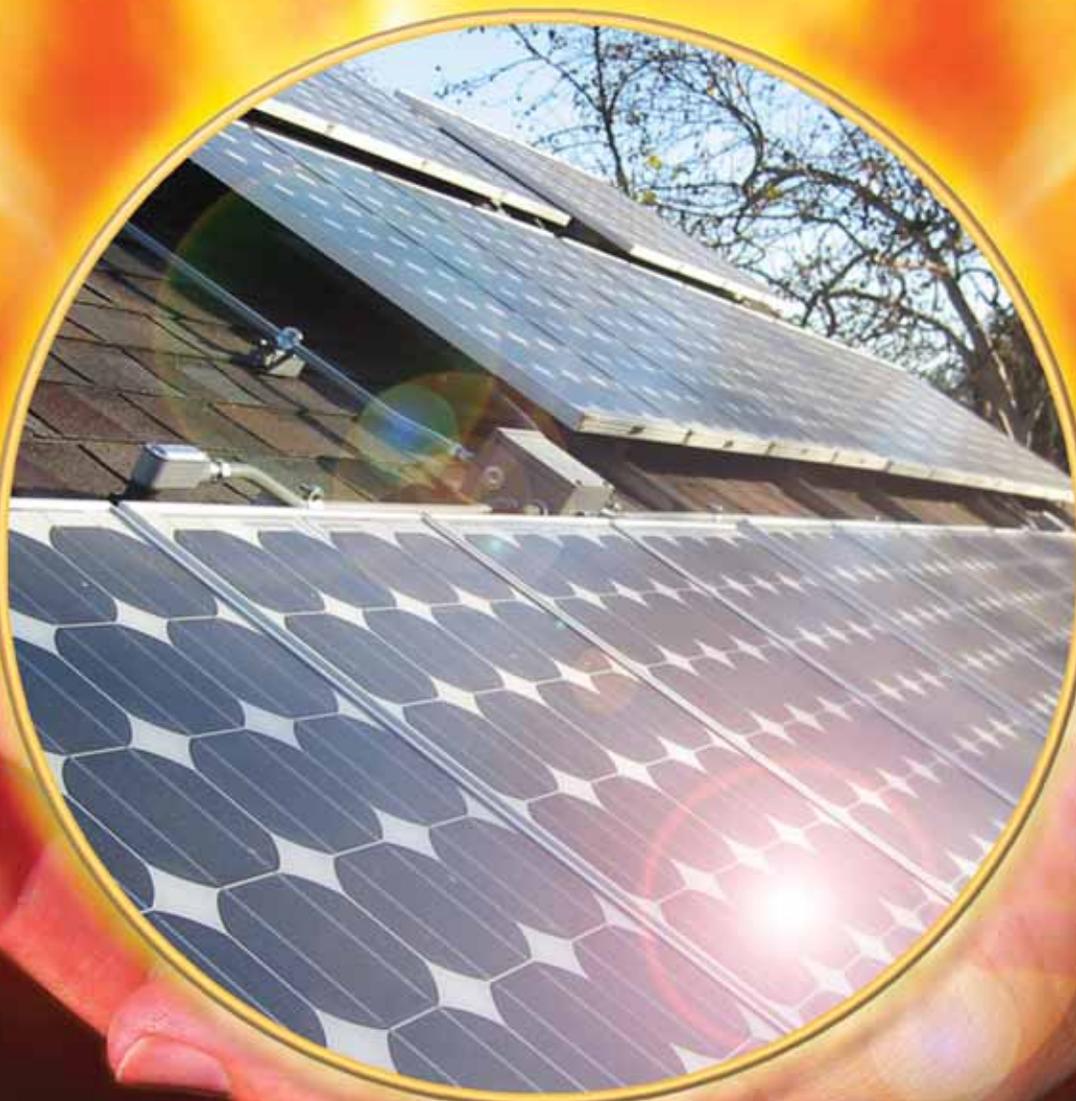


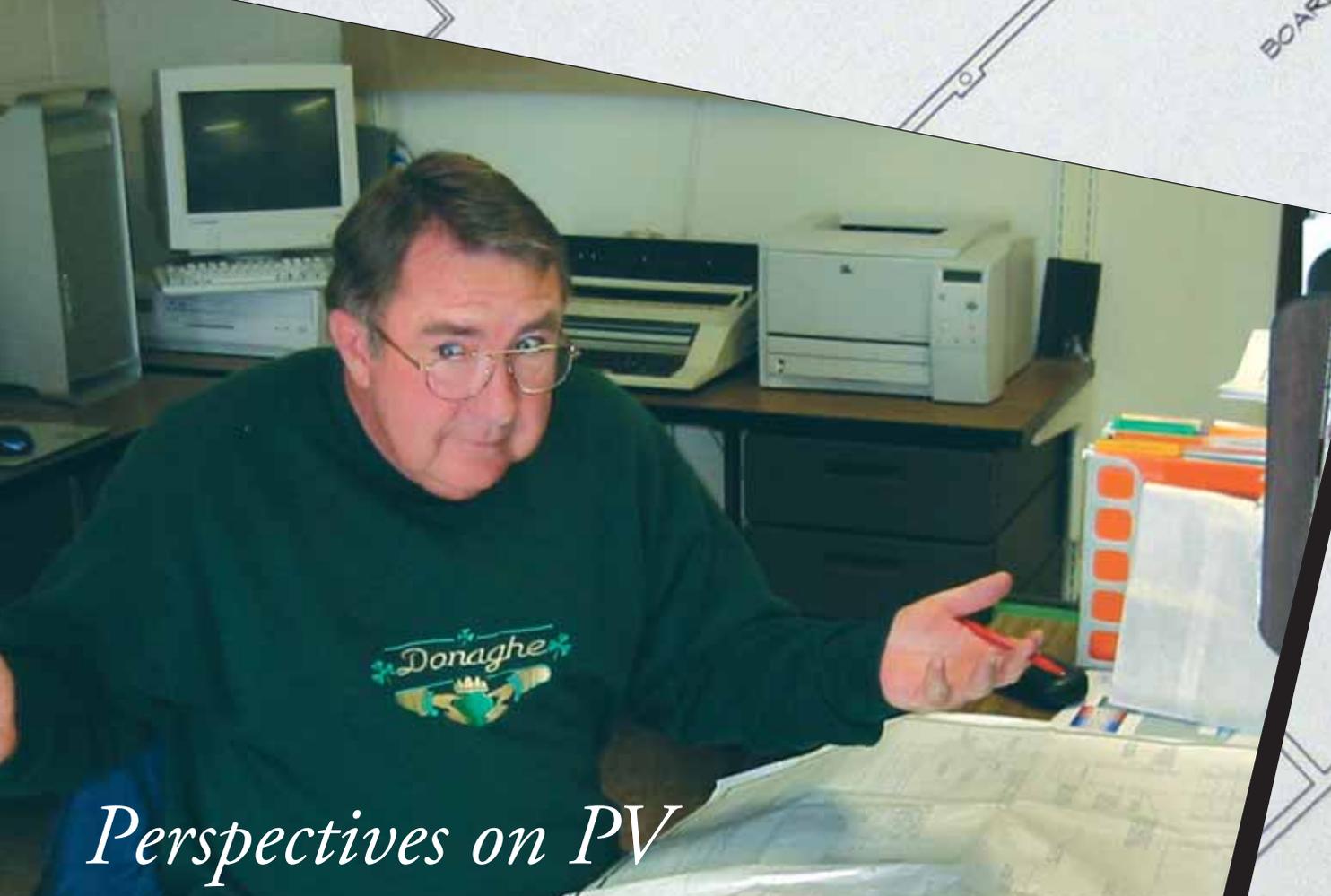
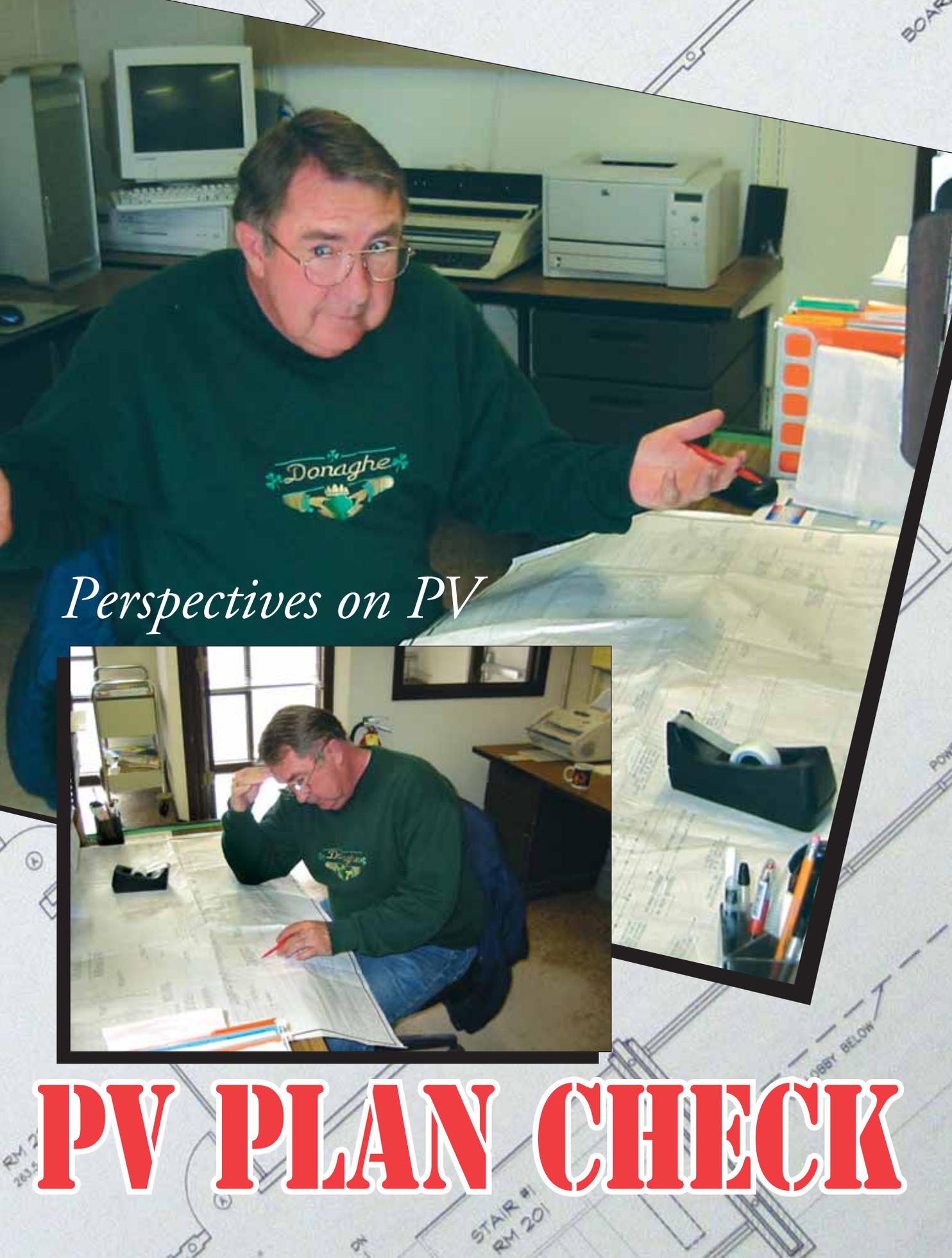
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**INTERNATIONAL ASSOCIATION
OF ELECTRICAL INSPECTORS**



Inspecting Photovoltaic Power Systems



Perspectives on PV



PV PLAN CHECK

Electrical inspectors and electrical permitting personnel are seeing increasing numbers of photovoltaic (PV) power systems, both at the permitting stage and at the initial inspection. Both processes go much more smoothly for all concerned when the electrical system is properly documented. Since the typical PV installer has not installed hundreds of the same PV system, and the inspector has not seen hundreds of these systems, the documentation for these systems must, by necessity, be somewhat more detailed than the documentation associated with a typical residential electrical system. This article will examine a typical *residential*, utility-interactive PV system in terms of a package that should be submitted by the installer when applying for a permit or discussing the system with the inspector prior to installation. Installers can use this material to develop the package.

The Single-Line Diagram

A one-line diagram such as shown in figure 1 should accompany the permit application. Actually, since the details of disconnects and grounding are not familiar to all involved, a three-line diagram would be even better as shown in figure 2. While a formal CAD-generated diagram on 24" x 36" paper is not generally required, something better than a back-of-the-envelope sketch

should be presented. The circled letters in the figures will be referenced below to indicate information that should appear on or be attached to the plan.

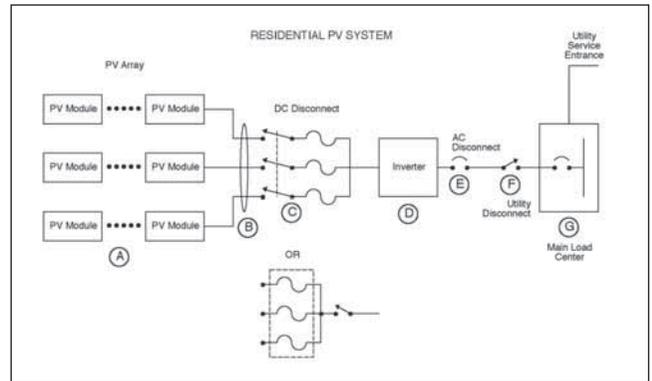


Figure 1. One-line PV system diagram

Equipment Lists and Specifications

A list of the equipment used and the specifications for that equipment should be included with the permit. This list would include the PV-specific equipment such as the PV modules, the inverter, the fuses, and circuit breakers. Listing/certification and rating information must be included. The specifications of this equipment are necessary to determine if the conductors have been properly sized and that the fuses and circuit breakers used in the dc portions of the system are properly rated. Factory cut sheets or pages from instruction manuals are the preferred way to present this information.

The System

On the one- and three-line diagrams, the following information should be indicated, or that information should be attached.

A. PV Array

A.1. The type and number of PV modules in each series string should be indicated. The open-circuit voltage (Voc) of each module, times the number of modules connected in series, times a cold temperature factor (690.7) equals the maximum systems voltage and must

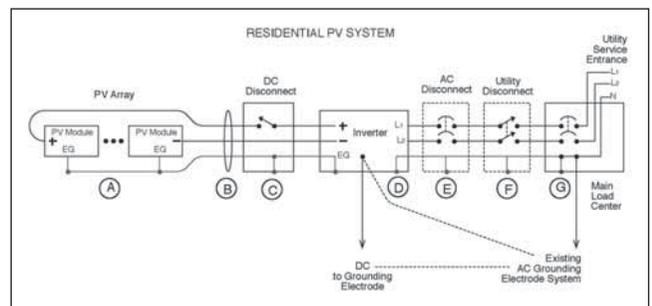


Figure 2. Three-line PV system diagram

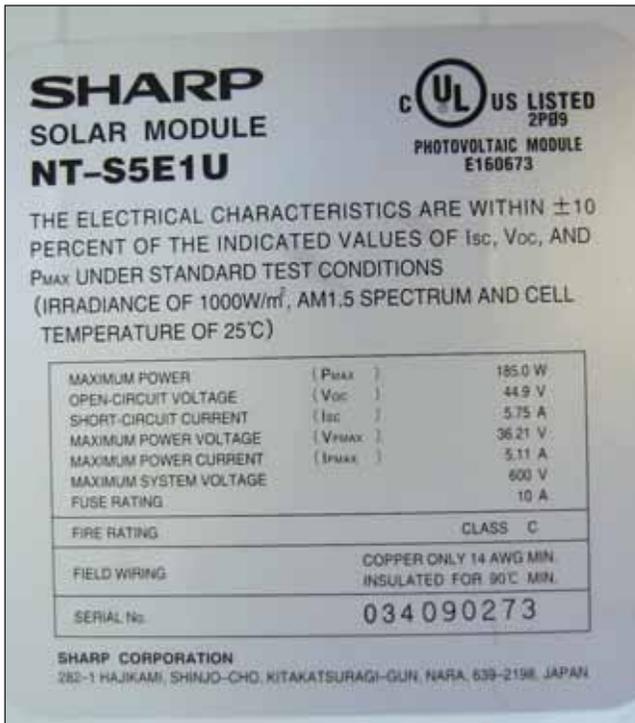


Photo 1. PV module label showing electrical ratings

be less than the maximum direct current (dc) input voltage of the inverter and less than the voltage rating of connected equipment (wires, overcurrent devices, disconnects). A label on the back of each module as shown in photo 1 will give the electrical parameters needed for the code-required calculations.

A.2. The ampacity of module interconnection cables, after corrections for conditions of use, must not be less than 1.56 times module short-circuit current (Isc) marked on the back of the module. Due to the exposed, outdoor location and high operating temperatures, all conductors should have insulation rated for 90°C and wet conditions (in conduit, THHN/THWN-2 or RHW-2). Exposed conductors (usually USE-2) must also be sunlight resistant.

B. Conduits

B.1. Conduits will typically be used throughout the system and specifically after the wiring leaves the PV array. They will be installed in various locations, some of which may be in sunlight. [See NEC-2005, 310.10 Exception No. 2]. Conduit fill and conductor ampacity calculations for conduit fill and temperature calculations should be included.

B.2. The PV source circuit or PV output conductors must remain outside the structure until they reach the readily accessible PV dc disconnect switch unless the conductors are installed in a metallic raceway [690.14, 690.31(E)].

C. Module and String Overcurrent Protection and PV DC Disconnect

C.1. Overcurrent protective devices (OCPD) in dc circuits may not be required when there are only one or two strings of modules. Three or more strings of modules typically require an OCPD in each string. The current rating of the OCPD, when required, should be 1.56 Isc for that circuit [690.8, 690.9]. The voltage rating of the OCPD should be not less than the maximum PV systems voltage found in A.1. The strings may be combined in parallel in a combiner box ahead of an unfused dc PV disconnect or combined at the output of the dc PV disconnect (figure 1 and photo 2). Appendix J in *PV Power Systems and the National Electrical Code: Suggested Practices* by the author has detailed calculations on the requirements for OCPD in the dc PV array circuits [see Additional Information below]. Any OCPD connected in series with a module or string of modules should not have a value greater than the maximum series fuse value marked on the back of the module (photo 1).

C.2. The PV array output should be connected to the top or line side of the main dc PV disconnect. The circuit to the inverter dc input should be connected to the bottom or load side of the disconnect. The grounded PV



Photo 2. DC PV disconnect with required markings

output conductor (usually the negative conductor) must not be switched by the disconnect, and this grounded conductor must be color-coded white. Some recent PV systems have a positive conductor that is the grounded conductor; it will be color-coded white, it will not be switched, and in this case, the ungrounded negative conductor will be connected to the switch pole. Future PV systems may not have any grounded PV array circuit conductors and then both PV output conductors would be switched and neither would be color-coded white [690.35].

C.3. PV output conductors, after any combining of series strings, should have an ampacity, after corrections for conditions of use, of not less than 1.56 times the module I_{sc} times the number of strings in parallel.

D. The Inverter

D.1. The inverter must be listed for utility-interactive (U-I) use [690.60].

D.2. The inverter maximum input voltage must not be exceeded in cold weather [110.3(B)]. See A.1.

D.3. For PV systems with the modules mounted on the roofs of dwellings, the inverter must have a 690.5 ground-fault protection device (GFPD). When a GFPD

is built in to the inverter (most U-I inverters below 10 kW), there should be no external (to the inverter) bond between the grounded circuit conductor and the grounding system.

D.4. In addition to ac and dc equipment grounding conductors, the inverter must also have a provision for a dc grounding electrode conductor, and that conductor must be properly connected to the grounding system (690.47). This requirement is not clearly spelled out in the *Code* and many U-I inverters meet the dc grounding requirements by using the ac equipment grounding conductor. The dotted lines in figure 2 show alternate routing and bonding for the dc grounding electrode conductors. See the July-August 2005 *IAEI News* "Perspectives on PV" article for details.

D.5. AC and/or dc disconnects internal to the inverter are acceptable if they are readily accessible and the AHJ judges that only qualified people will service the inverter (photo 3). Otherwise, external disconnects will be needed (photo 4). Internal disconnects, if circuit breakers, may not be suitably rated for the ampacity of PV output conductors (the rating may be too high) and external OCPD may be needed.

E. Inverter AC Output Overcurrent Device and Disconnect

E.1. Any OCPD located in the inverter ac output should be rated at 1.25 times the maximum continuous output current of the inverter. The maximum continuous current is specified in the inverter manual or is calculated by dividing the inverter rated output power by the nominal ac line voltage. This OCPD may be a backfed breaker located in the dwelling load center, the place where any possible fault currents for the inverter ac output conductor would originate. A backfed breaker in the dwelling load center could also be the inverter ac disconnect if the inverter were located near the load center.

E.2. The inverter ac disconnect should be "grouped" with the dc inverter disconnect and both should be "near" the inverter. The AHJ determines the meaning of "grouped" and "near." Most systems use the PV disconnect (see B.2.) as the dc inverter disconnect, but if the PV dc disconnect is on the outside of the building and the inverter is on the inside, a second dc inverter disconnect may be required inside the building at the inverter location. The same thing would apply if the backfed circuit breaker in the building load center was on the outside wall and the inverter was on the inside. A disconnect (usually a circuit breaker) would be required inside the building near the inverter.



Photo 3. Inverter with internal ac and dc disconnects



Photo 4. Inverter with external ac and dc disconnects

E.3. From the above, it becomes obvious that the system diagram should show the physical location of all components.

F. Utility-Required AC Disconnect

F.1. Many utilities require a visible-blade, lockable-open disconnect in the ac output circuit of the inverter. This disconnect is usually located within sight of the service entrance meter so that emergency response people can easily find it. The top terminals (line side) of this disconnect should be connected to the circuit that comes from the ac load center since it will usually be energized by utility voltage. The bottom terminals (load side) should be connected to the circuit from the inverter. This disconnect may be fused or unfused depending on the specific requirements of the utility. Photo 5 shows an ac disconnect to the right of the inverter that serves as both the ac inverter disconnect and the utility-required ac PV system disconnect. The utility point of connection is inside the house through a backfed circuit breaker in the load center.

F.2. The utility disconnect must have a minimum current rating of 1.25 times the maximum continuous output current of the inverter [690.8].

G. Point of Connection-Load Center

G.1. Most of the smaller residential PV systems will make the point of connection with the utility through a backfed breaker in the dwelling. *NEC* Section

690.64(B) establishes the requirements. If the load center is rated at 100 amps and has a 100-amp main breaker, the maximum current from all backfed PV breakers would be 20 amps (either or both phases of the 120/240 panel). A 200-amp load center with a 200-amp main breaker would be limited to 40 amps of backfed breakers. However, many installations have PV systems that are larger than the 100-amp or 200-amp load centers can accommodate. Other combinations are possible as is a supply-side tap of the service entrance conductors. See 690.64 and “Perspectives on PV” in the *IAEI News* in the September-October 2005 and January-February 2006 issues for more details.

Summary

All of the above information should be included in plans submitted for obtaining a permit for the installation of a PV system. The more information submitted, the easier it will be for the PV system designer/installer to communicate to the inspector/permitting official that the system design and component selection meet the requirements of the *NEC*. It is far more cost effective to change the design on paper before any hardware is purchased and installed than it would be after the system has been installed. Ready for the inspection? See the checklist and more details in “Perspectives on PV” in the May-June 2005 issue of the *IAEI News*.



Photo 5. Inverter ac disconnect combined with the utility disconnect to the right of the inverter

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

A PV Systems Inspector/Installer Checklist will be sent via e-mail to those requesting it. 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 web site (<http://www.nmsu.edu/~tdi>) maintains all copies of the previous “Perspectives on PV” articles. 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.

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 SWTDTI web site. ♪

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

This work was supported by the United States Department of Energy under Contract DE-FC04-00AL66794