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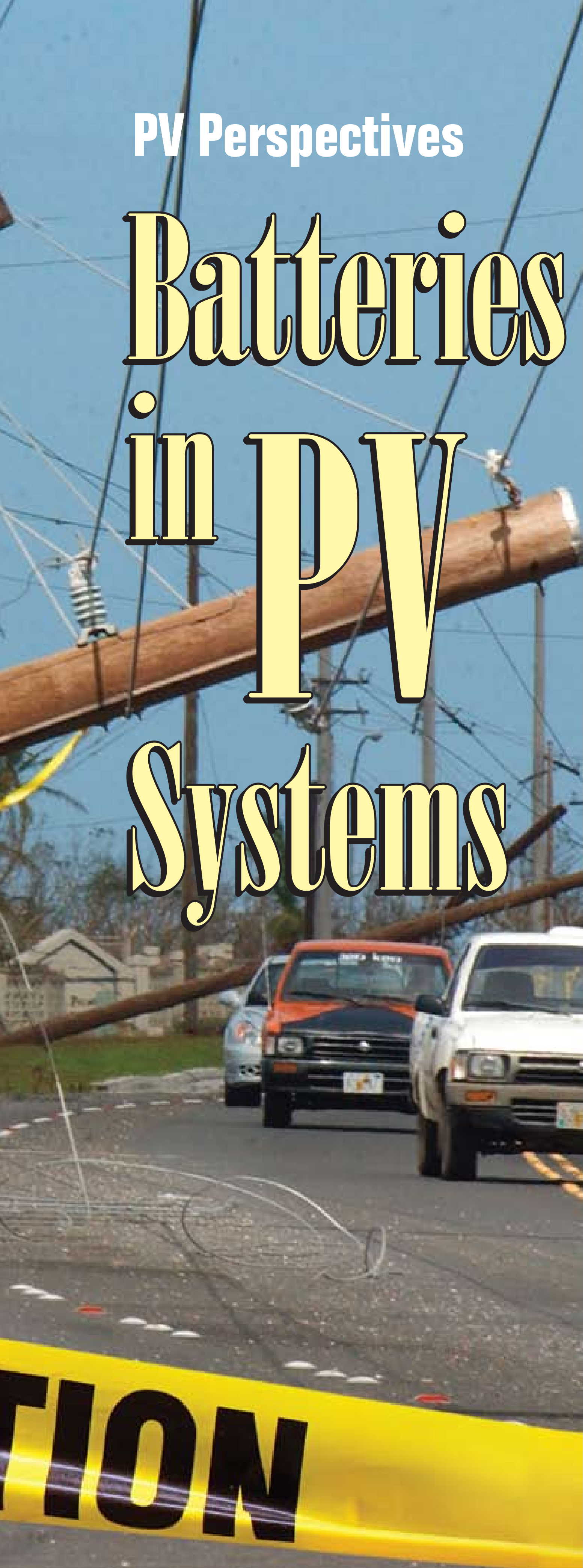

PV Perspectives

Batteries in PV Systems

by John Wiles

Electrical power outages are becoming more common in recent times with man-made and natural disasters, and the aging utility infrastructure. With natural disasters such as Hurricane Sandy, tornadoes, and other severe weather conditions, many people who are already using photovoltaic (PV) systems and many that do not have PV systems are going to be interested in utilizing PV systems in the event of electrical power outages. The electrical inspector can expect to see increasing numbers of battery-backed-up, utility-interactive photovoltaic power systems.

PV Plus Batteries Means Power When the Utility Goes Out

These backup systems allow the owners to operate some or all of the loads in the building using a specially designed and configured PV system with batteries in the absence of the utility service. These systems can be as small as a system that can power a radio or cell phone charger. They can also be as large as necessary to run all appliances and loads in a residence or commercial building. The size and number of electrical loads that can be operated and the period of time they can be operated depend on the size of the photovoltaic power system, the size of the battery bank, and the size of the specialized inverter.

There are characteristics of these PV systems with batteries that are different from those relating to the standard utility-interactive PV system. Obviously, the batteries pose some unique problems that the inspector must review and the connection of the inverters to not only the electrical system in the house but also to the utility requires looking at some different code sections than are normally used.

The multimode inverter that is used has characteristics of both the utility-interactive inverter and the standalone, off-grid inverter with features that are unique to the multimodal inverter. These inverters will be listed to UL Standard 1741. These inverters will have two sets of ac input/output terminals and a connection for the battery bank. Photo 1 shows the batteries and the multimode inverters in a system being installed.

Photo 1. Battery-backed-up, utility-interactive PV system during installation

Figure 1 shows the basic elements of a battery-backed-up, utility-interactive PV system. Green arrows represent dc power/energy flow and red arrows represent ac power/energy flow. Double-headed arrows represent bidirectional power/energy flow.

DC-Coupled Battery Charging

There are two main types of battery-backed-up, utility-interactive PV systems. The first and oldest is what is called a dc-coupled charging system. As shown in figure 2, the PV array has a nominal voltage of 24 volts or 48 volts and normally operates through a charge controller to charge a battery bank. The battery bank is connected to a multimode, utility-interactive inverter and that multimode inverter is connected to the house loads and to the utility using two separate and distinct ac input/output circuits. When the utility is present, the PV system charges the batteries through the charge controller; and power is taken from the batteries (or directly from the PV system when the batteries are fully charged) through the multimode inverter where it is converted to ac power.

The designated protected (backed up) loads may be supplied by either the utility (when present) or the PV inverter output (supplied from the batteries when the utility is absent). Where the PV system power output exceeds the building loads, the excess energy is fed into the utility and renewable energy credits (REC) or net-metering benefits may be accrued. At night or at other times when the PV production is low, power for the loads is purchased from the utility and fed to the main loads through the main panel or through the multimode inverter

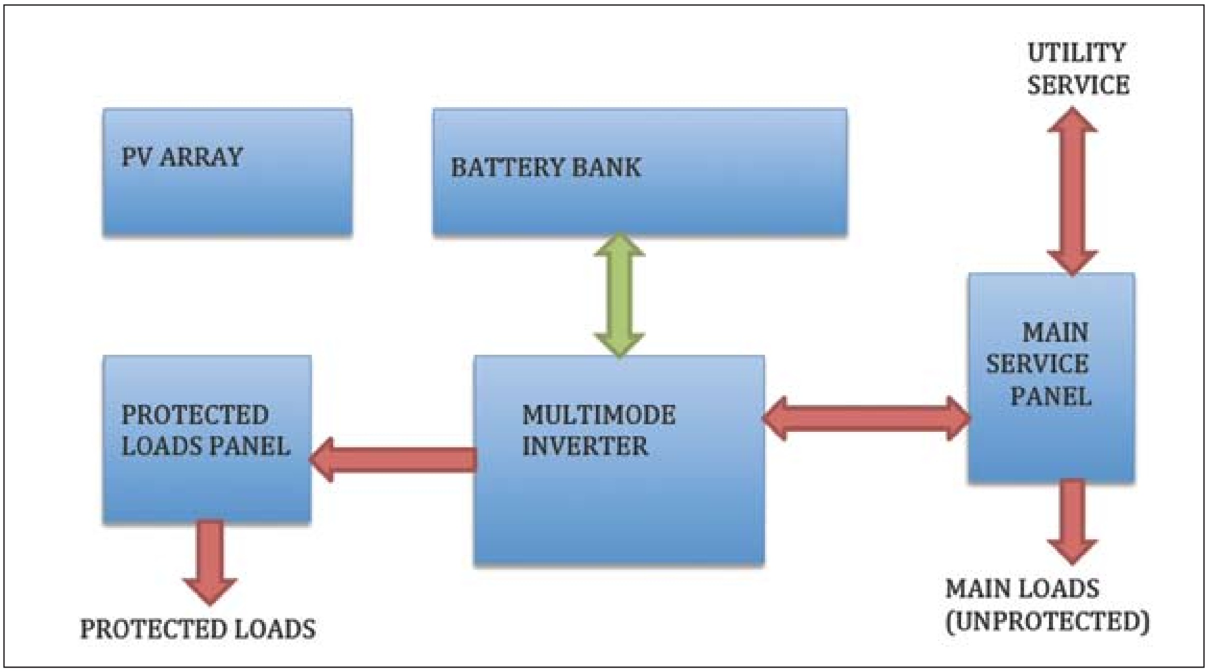

Figure 1. Components in a battery-backed-up, utility interactive PV system

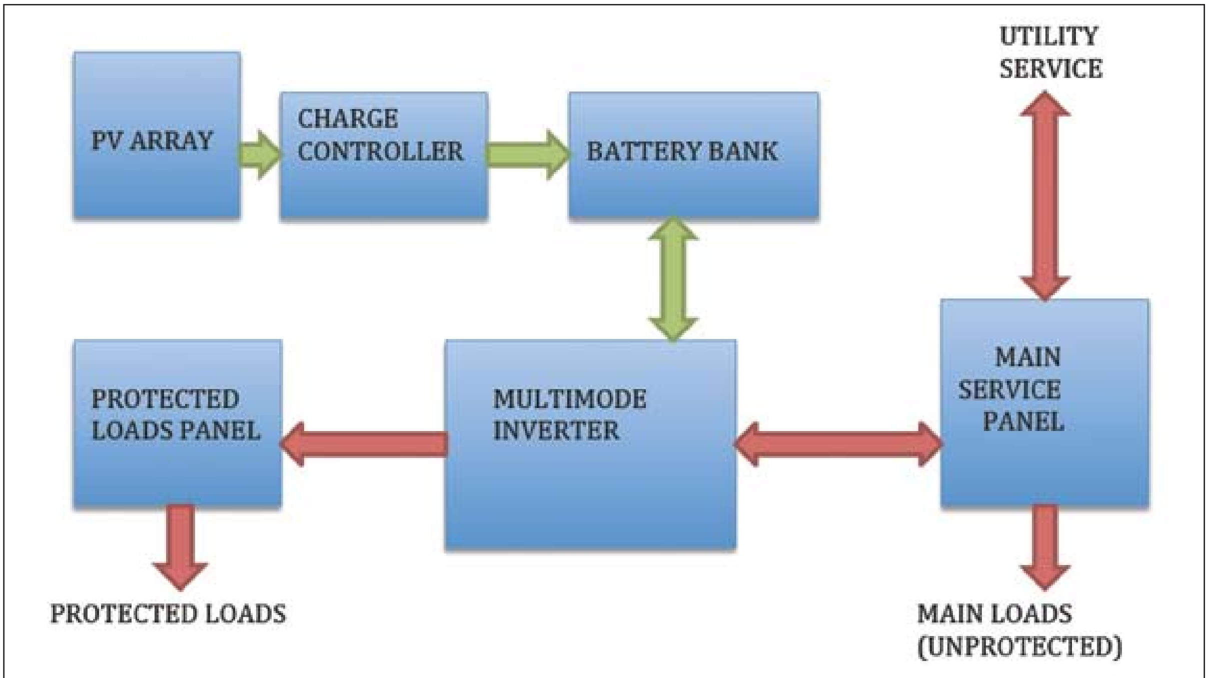

Figure 2. DC-coupled system interconnections and power flows

to the protected loads. In general, the battery stays fully charged at all times but there are some systems in which the stored energy in the battery can be sent ("sold") to the utility with proper programming of the equipment.

When the utility is not present, the PV array and battery combination and the multimode inverter continue to operate the loads connected to the protected loads subpanel to the extent that the size of the PV system and the capacity of the battery bank can supply the energy required by those protected loads. The multimode inverter will not send power to the main (unprotected) loads or to the utility connection but continues to monitor that utility connection

Photo 2. DC-coupled system

for voltage and frequency. And, the main panel gets no power from any source. When the utility comes back online with the proper voltage and frequency characteristics, the multimode inverter will reconnect and the system becomes utility interactive once again. Photo 2 shows a dc-coupled battery charging system. The three charge controllers are on the right and the four inverters are in the center between the ac and dc distribution panels.

AC-Coupled Battery Charging

Figure 3 shows a more recent type of system, known as ac-coupled charging system, where the PV modules are usually configured in a high voltage string configuration (200–600 volts) and provide dc voltage to a standard utility interactive inverter. The output of the utility-interactive inverter(s) is connected to the protected load subpanel with a backfed breaker [705.12(D)] and that subpanel is connected to the load ac input/output terminals of the multimode inverter. The battery again is connected to the multimode inverter dc input/output. The utility is connected to its unique ac input/output on the multimode inverter and when the utility is present, it feeds through the multimode inverter generally keeping the batteries charged at all times and providing energy to the protected load subpanel. The utility interactive inverter sees the proper voltage and frequency supplied by the utility and continues to convert dc PV energy into ac energy that can be used by the loads (both protected and main) and also be fed to the utility. When the utility goes down or has a brown out (voltage and/or frequency variation), the multimode inverter senses this and stops sending power to the now unenergized utility lines (and the main load panel) but continues to monitor them for proper voltage and frequency, which would indicate that the utility is back online. At this time, on the load ac input/output of the multimode inverter, the battery supplies energy to the inverter and it will become the correct frequency and voltage reference source to supply not only the protected loads, but also to keep the utility interactive inverter connected to the PV system, operating and producing energy (in the daytime).

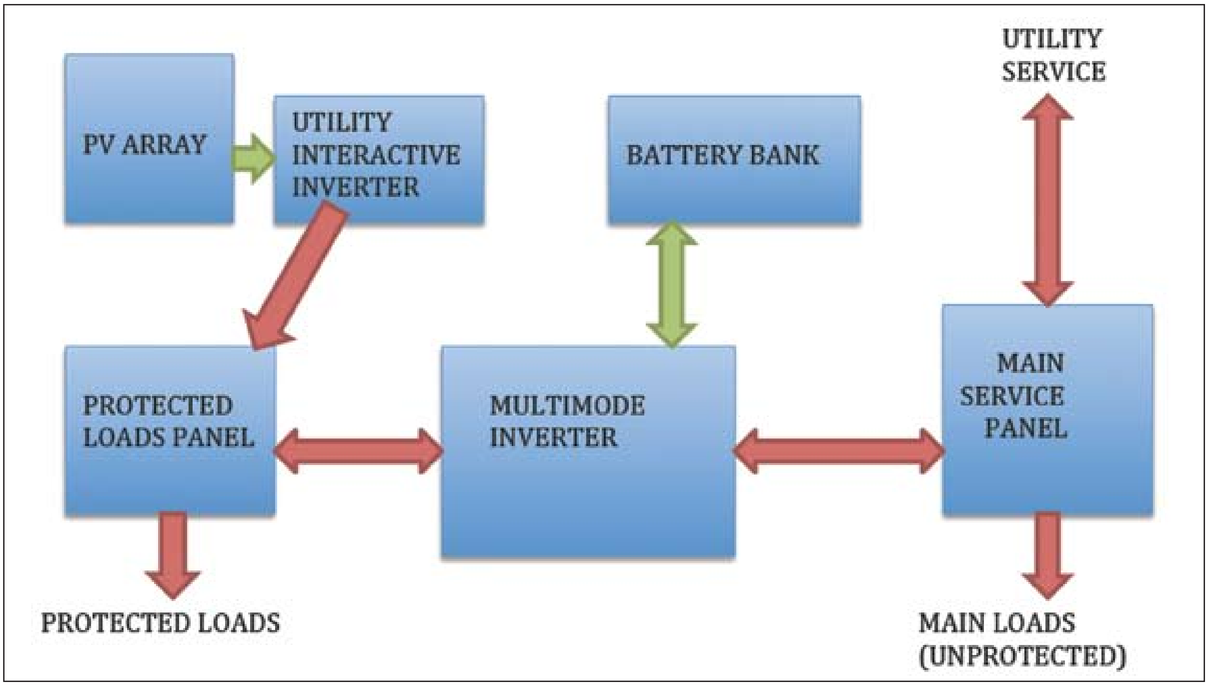

Figure 3. AC-coupled system interconnections and power flows

Photo 3. AC-coupled system

Again, the amount of loads that can be connected and operated for any short period or long period of time depends on the size of the PV array and the capacity of the battery bank. Typically the PV array may only supply energy for 4 to 6 hours per day. Loads obviously can operate 24 hours a day, so the total amount of PV array energy that can be stored in the battery and the capacity of the battery and size of the inverter determine how long the loads can be operated and how many loads can be connected at any one time.

Photo 3 shows an ac-coupled, battery-backed-up, utility-interactive system. The gray utility-interactive inverters are above the yellow multimode inverters and the batteries are in the rear of this very compact installation. There is normally a clear insulating service panel in front of the batteries; the panel was removed when the photo was taken.

In either case, with dc charging or ac-coupled charging of the batteries, the certified/listed multimode inverter ensures safety for the power line and utility personnel at anytime the utility is shutdown or operates abnormally.

Battery Considerations

Batteries, although not considered a source of energy, can store considerable amounts of energy. They *should not* be considered current-limited sources like PV modules are, but have the characteristics of a constant voltage output like an ac feeder with large amounts of available short-circuit current. Batteries must have overcurrent protection and disconnects on the output cables. The current between the battery and the multimode inverter is bidirectional. It flows to the batteries when the batteries are being charged by the multimode inverter or the charge controller, and it flows from the batteries when the multimode inverter is in the inverting mode supplying the protected loads with ac power.

In the dc coupled charging system, the cables between the charge controller and the battery are sized based on the rated output of the charge controller irrespective of the size of the PV system feeding it. These conductors should be sized at 125% of the rated output current of the charge controller. There should be an overcurrent device and a disconnect at the battery end of the circuit to protect these cables from high short-circuit currents originating at the battery. Depending on the location of the charge controller with respect to other components, there may be disconnects required on the input and output of the charge controller. A main PV dc disconnect located between the PV array and the charge controller will be required complying with 690.14.

Available short-circuit currents. The battery banks used in these types of systems typically will have an available short-circuit current at the output conductors from the battery bank less than 15,000 A. Cable lengths, connections, and cable resistances limit the available short-circuit current. Any overcurrent devices and/or disconnects must have ratings that can handle currents of this magnitude. Current-limiting fuses and dc rated circuit breakers are generally available with sufficient ratings and should be used.

Conductors. The conductors between the battery bank and the multimode inverter must carry bidirectional currents. The multimode inverter will use utility power or power from the utility interactive inverter in AC coupled systems to keep the battery charged and currents will flow from the inverter to the battery. When the multimode inverter is operating in the inverting mode and supplying protected loads with energy, the currents will flow from the battery to the multimode inverter. In general, the discharging currents flowing from the battery to the inverter will be larger than the charging currents flowing from the inverter to the battery. This is because the typical multimode inverter will be able to draw more current from the battery than it can provide to charge the battery. Therefore, the cables between the batteries and the inverter must be sized based on the maximum rated output of the multimode inverter in the inverting mode of operation. This continuous current should be specified in the inverter specification/installation manual and the cable sized at 125% of this continuous current. Of course, the battery cables should be in a raceway along with an equipment-grounding conductor, which would be used to ground any metallic battery rack and battery disconnect or overcurrent device enclosure. The size of the equipment-grounding conductor would be based on the rating of the overcurrent device protecting the circuit.

Many pre-manufactured battery cables are made with fine-stranded cables consisting of type AWM (appliance wire material) conductors. These cables are not suitable for use in battery PV systems since they are not mentioned directly in the *National Electrical Code* as one of the Chapter 3 wiring materials suitable for field installed wiring. The use of these manufactured cables is a gray area and could be considered an AHJ decision. And, in many cases au-

Photo 4. Battery disconnect and overcurrent protection located near the batteries

tomotive battery cables and welding cables have been used but these are typically fine stranded conductors which are very difficult to terminate properly at conventional disconnects and circuit breakers and they are not allowed in this application by the *Code*. See the find-stranded cable warning in Section 110.14 in the 2011 *NEC*. Also see the *IAEI News* article, "Do You Know Where Your Cables Are Tonight?" in the January–February 2005 issue.

Battery Circuit Overcurrent Protection and Disconnects. An overcurrent device should be located at the battery end of the circuit to protect this conductor from high available fault currents from the battery. This overcurrent device will be sized at 125% of the multimode inverter rated dc current in the inverting mode which is the same number used to size the cables. An overcurrent device at the inverter end of the circuit is normally not required because the inverter typically cannot source the same high fault currents that the battery can. A battery disconnect should be installed at the battery end of the circuit. Normally, if the inverter is within 4 to 5 feet of the battery bank, it is not practical or possible to put a disconnect any nearer to the battery than this distance. Therefore, the disconnect for this circuit can be near or at the inverter—usually in a power center. However, if the distance between the battery and the multimode inverter is more than 4 to 5 feet or the inverter is located in a different room than the battery bank, then there must be a disconnect at the battery end of the circuit in addition to the overcurrent protection required at that location. Photo 4 shows a battery disconnect/overcurrent protection enclosure using circuit breakers mounted just above a valve regulated (sealed) battery bank. These batteries release no hydrogen gas or acid fumes during normal operation.

Grounding. The nominal battery voltage in these systems is 48 V DC. The operating voltage may be as high as 62 to 65 V. Normally the multimode inverters do not ground one of the battery circuit conductors and the *NEC* requires that one of the battery circuit conductors be connected to earth with a grounding electrode conductor (690.41).

If the system uses DC coupled battery charging, the connection to Earth will be usually done through a distinct and separate ground fault detection/interruption system (GFDI) as required by *NEC* Section 690.5. In some cases the charge controller may have this GFDI built in.

On an AC coupled system the utility interactive inverters will have their normal GFDI internal circuitry, which will usually ground one of the PV array output conductors. But in the ac coupled systems, the dc battery circuit will still have to be grounded to keep costs down and to be compatible with available equipment that has been designed for use in grounded systems.

AC Circuit Considerations

Multi-wire branch circuits. Many houses today have several multi-wire branch circuits that have two branch circuits with a shared neutral conductor and are wired with a 14–3 AWG/with ground type NM cable. Multimode inverters come with either 120V AC outputs or 120/240V AC outputs. Neither of these multi-mode inverters should be connected to load circuits in the building that are part of a multi-wire branch circuit. See *NEC* 690.10(C). The inverters in the inverting mode, in some cases, may not be in synchronization with the utility power frequency waveform. This could cause overloading of the shared neutral that is associated with multi-wire branch circuits. If any of the circuits needing battery backup power protection are multi-wire branch circuits they should be segregated in their entirety (both circuits) in the special protected loads load center that is connected to the multimode inverter ac output.

Utility connections. One of the characteristics of most of the multimode inverters is that they can pass power *from* the utility through to the protected load circuits at a greater power level then they can supply power *to* the utility in the utility interactive mode. This indicates that the circuit and the overcurrent device, typically a breaker, between the utility connection and the multimode inverter must be rated at the full pass-through current capability of the inverter. A common value of this circuit breaker would be 60 or 70 amps. However, in the utility interactive mode, the inverter may be only able to source 33 amps from the PV system into the utility. In previous editions of the code, the 60 or 70 amp breaker would be used in the 705.12(D) calculations to determine panelboard/load center busbar ratings and conductor sizes. But, the danger to the circuit from overloading is related to the 33-amp output of the inverter when feeding the utility. Now, an exception to *NEC* Section 705.12(D)(2) allows the calculations for this requirement to be based on 125% of the rated utility interactive inverter output in the utility interactive mode. In this example, 41.25 amps (1.25 x 33) could be used in the calculations. And the circuit breaker connecting the inverter to the load center can still be rated at the higher 60 or 70 amps required to allow the protected loads to be operated in the pass-through mode of operation.

Summary

Aside from the battery circuits and the unique characteristics of the utility interconnection covered above, the multimode inverter in the battery backed up, utility-interactive PV system is connected to the utility in much the same manner as any normal utility interactive system. The dc PV circuits are connected in the same manner as those circuits in a standard utility interactive PV system for the ac coupled system. The dc-coupled systems require additional considerations for the low-voltage battery charging circuits.

For More Information

The author has retired from the Southwest Technology Development Institute at New Mexico State University, but is devoting about 25% of his time to PV activities in order to keep involved in writing these Perspectives on PV articles in the IAEI News and to stay active in the *NEC* and UL Standards development. He can be reached, sometimes, at: E-mail: jwiles@nmsu.edu Phone: 575-646-6105

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. A color copy of the latest version (1.93) of the 150-page, *Photovoltaic Power Systems and the 2005 National Electrical Code: Suggested Practices*, written by the author, may be downloaded from this web site: http://www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/Codes-Stds.html

It should be updated to the 2008 and 2011 *NEC* before the 2014 *NEC* arrives.

John Wiles works at the Southwest Technology Development Institute (SWTDI) at New Mexico State University. SWTDI provides engineering support to the PV industry and provides 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 55 proposals for the 2014 NEC. 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 two cats—permitted and inspected, of course. The PV system on his retirement home is a 9 kW (ac) utility-interactive system with a full-house battery backup.

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