
Photo 1. Inverters

THE INVERTER

by John Wiles

In our top-to-bottom perspective of a PV system, we have arrived at the inverter. The utility-interactive inverter is a key element in the PV system that helps to ensure safe and automatic operation of the system.

Peak Power Tracking

A PV array is a current source of energy and the output power depends on the load that the inverter places on the array. No loading (zero current) would operate the array at the open-circuit voltage point (V_{oc}) and the heaviest loading (a short-circuit, not achievable) would operate the array at the short-circuit current (I_{sc}) point. Neither of these operating points would produce any power output from the array. However, for every condition of sunlight intensity (irradiance) and array temperature, there is a load that will extract the maximum power from the array that the array can produce under those conditions. The utility-interactive inverter will find that maximum or peak power point and track that point as the sunlight and temperature vary throughout the day.

Automatic Operation

Today's utility-interactive (U-I) inverter is designed, manufactured, tested and certified/listed to operate automatically in the PV system. It seamlessly converts dc power from the PV array into ac power that is fed into the utility supplied premises wiring system. The output of the inverter is functionally connected in parallel with the premises wiring and the utility service.

One of the most important aspects of the inverter is the anti-islanding circuit. The anti-islanding circuit is designed to keep the utility electrical system (both premises wiring and utility feeder) safe in the event that the utility is being serviced or is disconnected at some point in the transmission system, distribution system or premises wiring system.

Unlike the engine-driven generator, which can feed power into a blacked out/disconnected local utility feeder system, the anti-islanding system prevents the inverter from energizing the "dead" power system.

This circuit prevents the inverter from delivering ac power if the utility voltage and frequency are not present, or if they are not within narrowly defined limits. This circuit monitors the voltage and frequency at the output terminals of the inverter. If the voltage varies more than plus ten percent or minus twelve percent from the nominal output voltage the inverter is designed for (120, 240, 208, 277, or 480 volts), the inverter cannot send power to the output terminals. Nor, is there any voltage on these terminals when the inverter shuts down. In a similar manner, if the frequency varies from 60 Hz more than 60.5 Hz or less than 59.3 Hz, the inverter also cannot send power to the ac output. If the utility power is suddenly not present at the output terminals for any reason (inverter ac output disconnect opened, service disconnect opened, meter removed from the socket, utility maintenance, or utility blackout), the inverter senses this and immediately ceases to send power to the output terminals.

The anti-islanding circuit in the inverter continues to monitor the ac output terminals and when the voltage and frequency from the utility return to specifications for a period of five minutes, the inverter is again able to send PV power to the ac output. When the inverter is not processing dc PV power into ac output power, it essentially disconnects from the PV array by moving the load on the PV system to a point where there is no power. Usually this is the V_{oc} point for the PV array.

Circuit Sizing

DC: The dc input circuit to the inverter is sized based on the dc short-circuit current in those conductors. Normally the PV array is rated in watts at standard test conditions (STC) of 1000 watts per square meter (W/m^2) of irradiance and a cell temperature of 25 degrees Celsius (°C). In most cases, the array will operate, on average, at a lower power output due to the normal and expected power lost due to module heating. For this reason, inverter manufacturers typically suggest sizing the PV array (STC dc watts) at ten to twenty percent greater than the inverter ac power output rating. It does no short-term harm to connect an even larger PV array to the inverter since the inverter must limit its output to the rated value no matter how much array power is applied. If this over-sized array is used, the inverter will spend more operating time each day at rated power output than it would with a normally sized array. The penalty for designing a system in this manner will be increased module cost for the larger array, some lost power

Photo 2. Cold weather increases Voc

Photo 3. Cold weather increases module voltages and sunlight helps too.

on sunny, cool days, and possibly some slight reduction in the inverter life due to longer high temperature operating temperatures.

AC: The ac output circuit of an inverter must be sized at 125 percent of the rated output current of the inverter (690.8). Some inverter manufacturers specify the rated current or a range of values (due to varying line voltages from nominal). If this specification is not given, then the rated power may be divided by the nominal line voltage to determine a rated current. For example, a 2500-watt inverter operating at a nominal voltage of 240 volts would have a rated current of

2500 watts/240 volts = 10.4 amps

These inverters are not capable of providing any sustained (more than a second) surge currents, so the rated output current is all that can be delivered. When faced with a short-circuit, the rated output current is all that can be delivered, but more than likely, the reduced line voltage due to the fault will cause the inverter to shut down.

Dedicated Circuit

NEC 690.64(B)(1) requires that the inverter output be connected to the utility power source at a dedicated disconnect and overcurrent protective device (OCPD). In most systems this is a backfed breaker in a load center/panelboard [690.64(B)]. Inverters may not have their outputs connected directly to another inverter or directly to an ac utility-supplied circuit without first being connected to the dedicated disconnect/OCPD. The utility-interactive micro inverters and the ac PV module are an exception to this rule since they are tested and listed to have multiple inverters connected in parallel on a single circuit with only one OCPD/disconnect device for the entire set of inverters.

The OCPD must be sized at a minimum of 125% of the rated inverter output current (or total of the output rated output current from multiple micro inverters or ac PV modules) and it must protect the circuit conductor from overcurrents from the utility side of the connection. It is usually *not* a good idea to install a larger OCPD than the minimum required value (allowing a round up to the next standard value is OK and needed) because the inverter may (as part of the listing/instructions) be using the OCPD to protect internal circuits.

Is It a Branch Circuit? Out #@$%^ Typo!

Consider the typical residential branch circuit.

1. It is protected by an OCPD at the source of power (the utility) *that can damage it* (emphasis added).

2. If the breaker protecting the branch circuit is opened, it becomes completely “dead” (deenergized).

3. If the branch circuit has a solid ground fault or a

line-to-line fault, the OCPD will open and protect the conductor.

4. The branch circuit may be wired with Type NM cable in residential applications.

Now consider the circuit between the utility-interactive inverter and the dedicated disconnect/OCPD (usually a breaker).

1. This circuit is protected by an OCPD at the source of power (the utility) that can damage it. Since the circuit is sized at 125 percent of the rated output current of the inverter and the inverter current is limited to the rating, the inverter is not a source of power that can damage the conductor.

2. If the breaker protecting this circuit is opened, it becomes completely "dead" (deenergized).

3. If this circuit has a solid ground fault or a line-to-line fault, the OCPD will open and protect the conductors. And the inverter will shut down.

4. It would appear in every practical sense that this utility-interactive inverter ac output circuit is just like a branch circuit and it, too, may be wired with Type NM cable in residential applications.

So, these ac output circuits from the utility-interactive inverters can be wired like any other branch circuit in a residence. Of course, the inverters are surface-mounted devices and there may be the possibility of exposed Type NM cables being subject to physical damage. If they are, then conduit or other wiring method would be required.

There are no flush mounted inverters on the market yet, but I expect they will appear with internal fans and vents to get rid of the heat they generate.

The typo

Inspectors. There is a typo in 690.31(E) of the *2005 NEC* and *2008 NEC*. I am the guilty party that let it slip through—on two code cycles. The first sentence starts out:

"Where direct-current source or output circuits *of* a utility interactive inverter from a building-integrated or other photovoltaic system …."

The word "of" should be "to" and will be corrected in the *2011 NEC*. The requirement for metallic raceways applies only to the sunlight-energized dc PV source or PV output conductor.

GFCIs and AFCIs

The ac output of a utility-interactive inverter should not be connected to a GFCI or AFCI breaker as these devices are not designed to be backfed and will be damaged if backfed. These devices have terminals marked line and load and have not been identified/tested/listed for back feeding.

Summary

A detailed understanding of PV equipment and how power flows in a PV system should enable better, more thorough inspections of these systems. Better inspections will result in better, safer PV installations. We will continue with more information on the utility-interactive inverter ac output in the next "Perspectives on PV" in our top-to-bottom tour of the PV system.

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: 575-646-6105

A color copy of the latest version (1.9) 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

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. 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: http://www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/Codes-Stds.html

The author makes 6–8 hour presentations on "PV Systems and the *NEC*" to groups of 60 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 IEE/SWTDI web site.

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