Inverter Ins & Outs

by John Wiles

The utility-interactive inverter is a key element in a grid-tied PV system, and helps ensure safe and automatic operation of the system.

The output power of a PV array depends on the load that is on the array. No loading (0 amps) operates the array at its open-circuit voltage point (Voc), while the heaviest loading (a short-circuit) would operate the array at the short-circuit current (Isc) point. At either of these points, no power output from the array is available. However, for every condition of sunlight intensity (irradiance) and array temperature, there is a load that will extract the maximum power from the array. And a utility-interactive inverter will find that peak power point and readjust loading to maintain maximum power as sunlight and temperatures vary throughout the day. This is called maximum power point tracking and is a part of all grid-tied inverters.

Automatic Operation

Utility-interactive inverters are designed, manufactured, tested, and certified/listed to operate automatically. They seamlessly convert DC from the PV array into AC that is fed into the premise's AC wiring system. The output of the inverter is connected in parallel with this wiring and the utility service.

One of the most important aspects of the inverter is the anti-islanding circuit, which is designed to keep the premise's wiring and utility feeder de-energized in the event that utility power is not available—like if the grid is being serviced or has suffered an interruption.

Unlike an engine-driven generator which, if improperly installed, can feed power into a blacked out/disconnected local utility feeder system, the anti-islanding system prevents the inverter from energizing a "dead" electrical system. Anti-islanding prevents the inverter from delivering AC 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 inverter's output. If the voltage varies +10% to -12% from the nominal output voltage the inverter is designed for (120, 240, 208, 277, or 480 V), the circuit prevents the inverter from sending power to the output terminals. In a similar manner, if the frequency varies from 60 Hz—more than 60.5 Hz or less than 59.3 Hz—the circuit also prevents the inverter from sending power to the AC output.

When the voltage and frequency from the utility return to specifications for a period of 5 minutes, the inverter is again enabled 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 adjusting the load on the PV system to a point where there is no power, usually the array's Voc point.

Circuit & Array Sizing

Sizing the DC input circuit to the inverter is based on the DC short-circuit current (Isc) in those conductors. Although full ampacity calculations are too complex to cover in this article, the current rating for the DC input circuits is near 1.56 times the Isc (*NEC* Section 690.8). Normally, the PV array is rated in watts at standard test conditions of 1,000 watts per square meter of irradiance and a cell temperature of 25°C.

In most cases, the array will average a lower power output due to increased inefficiencies as PV cells heat up. For this reason, inverter manufacturers typically suggest sizing the PV array 10% to 20% greater than the inverter's AC output rating. If an oversized array is used, the inverter will spend more operating time each day closer to the rated power output than an inverter rated the same as the array's STC rating. The penalty for designing an oversized system is increased initial costs (more modules), some potential for lost power on sunny, cool days, and possibly some slight reduction in the inverter life due to longer operation at higher temperatures.

An inverter's AC output circuit must be sized at 125% of the inverter's rated output current (Section 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 2,500 W inverter operating at a nominal voltage of 240 V would have a rated current of 10.4 A (2,500 W ÷ 240 V), so the output circuit would need to be sized to handle 13 A (1.25 x 10.4). In this case, a 15 A breaker would be used.

Grid-tied inverters are not capable of providing sustained (more than 1 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 Section 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,

GFCIs & AFCIs

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

this is a backfed breaker in a load center [Section 690.64(B)]. Inverters may not have their outputs connected directly to another inverter or directly to a utility-supplied AC circuit without first being connected to a dedicated disconnect/OCPD. (Utility-interactive microinverters and AC PV modules 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 AC output of a utility-interactive inverter should not be connected to a GFCI or AFCI breaker, as these devices will be damaged if backfed. These devices have terminals marked "line" and "load" and have not been identified, tested, or listed for backfeeding.

The OCPD must be sized at a minimum of 125% of the rated inverter output current (or, in the case of multiple microinverters or AC PV modules, their total rated output current). This OCPD must protect the circuit conductor from overcurrent from the utility-side connection. It is usually not a good idea to install a larger OCPD than the minimum required value because the inverter may, as part of the listing/instructions, be using the OCPD to protect internal circuits. However, rounding up to the next standard breaker size is allowed per *NEC* 240.4(B), and is often needed.

Is it a Branch Circuit?

In every practical sense, the utility-interactive inverter AC output circuit is just like a branch circuit. Consider the typical residential branch circuit:

- It is protected by an OCPD at the source of power (the utility) that can damage it.
- If the breaker protecting the branch circuit is opened, it becomes deenergized.
- If the branch circuit suffers a solid ground fault or a line-to-line fault, the OCPD will open and protect the conductor.
- 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).

- It is also protected by an OCPD at the source of power (the utility) that can damage it. Since the circuit is sized at 125% 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.
- If the breaker protecting this circuit is opened, it becomes deenergized.
- If this circuit suffers a solid ground fault or a line-to-line fault, the OCPD will open, protecting the conductors—plus, the inverter will shut down.
- In residential applications, it also may be wired with Type NM cable.

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 another wiring method would be required.

NEC *Typo*

Section 690.31(E) in the 2005 and 2008 editions of the *NEC*, which addresses how PV circuit conductors enter a building, contains a typo. The first sentence starts: "Where direct-current source or output circuits *of* [emphasis added] a utility-interactive inverter from a building-integrated or other photovoltaic system…"

The word "of " should have been "to" and will be corrected in the *2011 NEC*.

Access

John Wiles (jwiles@nmsu.edu; 575-646-6105) works at the Institute for Energy and the Environment (IEE) at New Mexico State University. John provides engineering support to the PV industry and a focal point for PV system code issues.

Southwest Technology Development Institute • www.nmsu.edu/~tdi/Photovoltaics/Codes-Stds/Codes-Stds.html • PV systems inspector/installer checklist, previous "Perspectives on PV" and *Code Corner* articles, and *Photovoltaic Power Systems & the 2005 National Electrical Code: Suggested Practices* by John Wiles