Connecting Inverters to the Grid

Part 1: Load-Side Connections

by John Wiles

Properly connecting a grid-tied inverter to the utility grid is critical to the safe, long-term, reliable operation of the entire system. The AC output circuit requirements and the circuits that carry the inverter current in the premise's wiring are somewhat complex, but meeting *National Electrical Code* requirements is a must to ensure a safe and durable system.

Even though energy flows from the inverter to the utility, it's at the utility end of this circuit where the currents originate that can harm the conductors when faults occur. Any overcurrent protection should be located at the *utility* end of the inverter AC output circuit—not at the inverter end.

Although the inverter may require an external disconnect, if that disconnect function is by a circuit breaker, then the conductor ampacity calculations may be more complicated (see below). It is good practice to install the inverter near the back-fed load center so that the back-fed breaker commonly used to interconnect the inverter with the utility can also be used as the AC inverter disconnect required by *NEC* Section 690.15. This places the overcurrent device at the utility-supply end of the circuit and groups the AC disconnect for the inverter near the DC disconnect. Note that the local utility may also require a separate visible-blade, lockable disconnect.

Load-Side Connection

There are two types of connections allowed by the *Code* for interfacing any utility-interactive inverter's output to the utility power. These connections are made on either the supply side or the load side of the main service disconnect of a building or structure (690.64). The load side of the main service disconnect is the most common connection used for PV systems smaller than 10 kW. Section 690.64(B)—moving to 705.12(D) in the 2008 and 2011 editions—covers the requirements and it is heavy reading at best. (Note that changes exist in Section 690.64 between the *2005 NEC* and the *2008 NEC*. For more information, see *Code Corner* in *HP126*.)

Since the 1980s, code-making experts have maintained that 690.64(B)(2) should be rigorously applied to any circuits (panel-board bus bars or circuit conductors) supplied from multiple sources where protected by overcurrent protective devices (OCPDs) from each source. Such sources would include the output of PV inverter(s) and the utility supply.

This *NEC* section requires that the ratings of all OCPDs *supplying* power to a conductor or bus bar be added together for the necessary calculations. The sum of the ratings of those breakers may not exceed 120% of the rating of the bus bar or the ampacity of the conductor:

PV OCPD + Main OCPD ≤ 1.2 R, where R is the ampacity of the conductor or the bus bar rating.

120% Factor & Breaker Location

The demand factors on residential and small commercial systems are such that it is unlikely that the conductor or panel would ever be loaded to 100% of rating. Even if the sources could supply 120% of the rating of the bus bar or conductor, loads connected to that same bus bar or conductor—so long as they don't exceed the bus bar rating—would not pose an overload problem. As long as the actual load currents (limited by the ratings on the load breakers) do not exceed the bus bar rating, the currents through the bus bar to these loads cannot exceed its rating—even if greater supply currents were available (from either the utility through the main breaker or from the PV system through the back-fed PV breaker). The PV array will push power onto the bus bars, and the utility will simply supplement the additional power required by the loads. That is, the grid doesn't try to push extra power onto the bus bars simply because it has more headroom left on the circuit breaker.

To use this 120% factor, any back-fed breaker carrying PV current must be located at the opposite end of the bus bar from the main breaker or main lugs supplying current from the utility. This requirement keeps the supply currents distributed across the bus bar, rather than concentrated on one part of the bus bar. The same location requirement applies to the supply overcurrent devices on any conductor. If the PV inverter OCPD cannot be located as required, then the 120% in the above requirement drops to 100% and an installation using the load-side connection becomes more difficult.

The most rudimentary requirement is making sure there's an open space for the inverter breaker(s) on the opposite end of the bus bar from the main circuit breaker.
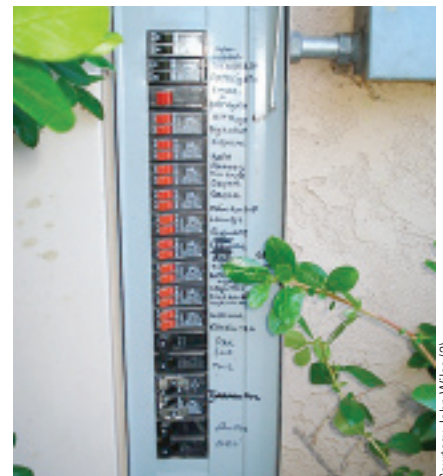
Courtesy John Wiles (2)

The Article 240 tap rules do not apply to these inverter connections since they were developed only for circuits with one source. The OCPD for the inverter output circuit should be located, as mentioned above, at the point nearest where the utility currents could feed the circuit in the event of a fault (i.e., in the main service panel or inverter AC combining panel, rather than at the inverter). It is a common mistake to apply the Article 240 tap rules incorrectly and locate the OCPD at some point away from the tap point. This may create conductor protection issues when multiple sources are involved.

Example Calculations

1. A dwelling has a 125-amp service panel (bus bar rating) with a 100 A main breaker at the top. How large can the back-fed PV breaker be that must be located at the bottom of the panel?

PV OCPD + Main OCPD ≤ 120% of service-panel rating
120% of panel rating = 1.2 x 125 A = 150 A
PV OCPD + 100 A ≤ 150 A
PV OCPD ≤ 150 A – 100 A or 50 A

The PV OCPD can be up to 50 A.

2. Suppose it was a 100 A service panel with a 100 A main breaker. What PV breaker could be added?

PV OCPD + 100 A ≤ 1.2 x 100 A
PV OCPD + 100 A ≤ 120 A
PV OCPD ≤ 120 A – 100 A or 20 A

The maximum PV back-fed circuit breaker would be rated at 20 A.

3. A 200 A main panel with a 200 A main breaker:

PV + 200 A ≤ 1.2 x 200
PV ≤ 240 A – 200 A or 40 A

Up to 40 A of PV breaker is allowed—in this case, it could be any combination of breakers that add up to 40 A on either line 1 or line 2 of the 120/240 V service panel (i.e., each bus bar can accommodate 40 A of back-fed circuit breakers).

4. Working the problem from the inverter end, we start with the continuous rated inverter output current. This is usually the rated power divided by the nominal line voltage, unless the inverter specifications list a higher continuous output current (sometimes given at a low line voltage).

A 3,500 W, 240 V inverter has a rated AC output current of 14.6 A (3,500 W ÷ 240 V). According to Section 690.8, the output circuit must be sized at 125% of the rated output, or 18.3 A (1.25 x 14.6 A).

The next larger overcurrent device would be a 20 A OCPD; consistent with the use of 12 AWG conductors if there were not any significant deratings applied for conditions of use. This system could be connected to a 100 or 200 A panel (where the main breaker in each panel has the same rating as the panel), provided that the back-fed 20 A breaker could be located at the bottom of the panel.

The equations would have to be revisited if the PV breaker could not be located at the opposite end of the panel from the main breaker (or utility input on a main lug panel). At this point, the 120% allowance drops to 100%. Normally, reducing the size of the main breaker would require a full *NEC* Chapter 2 load analysis on the building—and that analysis will frequently show that the breaker cannot be reduced.

There is sometimes a tendency to use whatever breaker and wire gauge that is easily at hand: 30 A breakers and 10 AWG conductors are common. While this would pose no problems for conductor ampacity or protection, bus bar calculations would need to be performed as shown above. Additionally, the inverter specifications may limit the maximum size of the output OCPD. If so, higher-rated breakers may not be used, according to Section 110.3(B).

No Bottom Breaker Position?

If the back-fed PV OCPD cannot be located at the bottom of the panel (assuming a main breaker at the top or main lugs at the top) or at the opposite end of the circuit conductor from the supply, it is not possible to install the back-fed breaker without changing something, and that 120% allowance drops to only 100%. In the above equations, no PV back-fed OCPD could be added to any service panel that has the same rating as the main breaker rating. The 100%-of-the-panel-rating factor (instead of 120%) would equal the rating of the main breaker and the equation would force the PV breaker rating to be zero.

In a few cases, conducting an *NEC* Chapter 2 load analysis might reveal that the service panel was oversized. For example, if a 200 A panel was installed with a 200 A main breaker to provide extra circuit positions, when a 150 A panel would have met the house's loads. In this case, it might be possible to substitute a 150 A main breaker for the 200 A breaker. Even without the bottom position being open, 50 A of PV breaker could be installed.
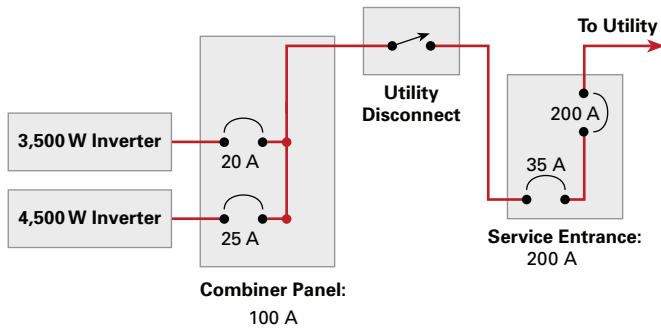
Systems with Multiple Inverters

Some systems use more than one inverter. If the local utility requires an accessible, visible-blade, lockable disconnect on

A multiple-inverter installation. Note DC and AC disconnects for each inverter, a PV subpanel combiner, and a whole-system AC disconnect.

One-Line Diagram of Two Inverters & an AC Combining Panel

To Utility

Utility Disconnect

3,500 W Inverter — 20 A

4,500 W Inverter — 25 A

200 A

35 A

Service Entrance: 200 A

Combiner Panel: 100 A

the output of the PV inverters, then more than one inverter could not be connected directly to the main panel. The two or more inverters would have to have their outputs combined in a PV AC subpanel before being routed through the utility disconnect and then to the main panel. The disconnect is not normally fused, but some are, depending on the system configuration. The PV AC subpanel rating, the rating of the disconnect, and the ampacity of the conductor to the main panel are also dictated by 690.64(B) requirements.

Here is another example: The dwelling has a 200 A main service panel with a 200 A main breaker. There is an empty breaker position at the bottom of the panel. The utility requires an external disconnect switch. The goal is to accommodate a PV system that has one 3,500 W and one 4,500 W inverter. A PV AC panel will be used to combine the outputs of the two inverters. The output of the PV AC panel will be routed through the utility disconnect and then to a single back-fed breaker in the main service panel.

The ratings of the output circuits of each inverter are:

Inverter 1:
3,500 W ÷ 240 V = 14.6 A
1.25 x 14.6 A = 18.3 A
Use a 20 A breaker and 12 AWG conductors.

Inverter 2:
4,500 W ÷ 240 V = 18.8 A
1.25 x 18.8 A = 23.5 A
Use a 25-amp breaker and 10 AWG conductors.

The 20 and 25 A breakers are mounted at the bottom of a PV AC panel and a main-lug-only panel will be installed. Normally, no loads will be connected to this subpanel. It will be dedicated to the PV system. Note that 690.64(B)(2) states, "In systems with panelboards connected in series, the rating of the first overcurrent device directly connected to the output of a utility-interactive inverter(s) shall be used in the calculations for all bus bars and conductors." Although this scenario would seem to be non-*NEC* compliant, since 20 A + 25 A = 45 A, which would be greater than the 40 A allowed to back-feed the main 200 A service panel with 200 A main breaker, this section of the *NEC* should have been a permissive requirement—rather than mandatory—and only applied where beneficial to the overall

design. There is currently an effort to fix this for the 2011 *NEC*.

The next step is to calculate the back-fed breaker that must be placed in the main service panel to handle the combined output of both inverters from the PV AC subpanel and to protect the conductor carrying those combined outputs under fault conditions from high utility currents.

The combined currents from both inverters are:

14.6 A + 18.8 A = 33.4 A

This sum must be multiplied by 1.25 to get the required output breaker (41.75 A). The overcurrent device should be 45 A. The ratings of OCPDs supplying the conductor from the PV AC subpanel to the 45 A breaker, the utility disconnect switch, and supplying that PV AC subpanel are now defined as 45, 20, and 25 A. The subpanel rating and the ampacity of the conductor are determined by 690.64(B)(2). It would be incorrect to guess that the answer might be 45 A, as it would be in a normal load subpanel.

45 A + 20 A + 25 A ≤ 120% R, where R is the panel rating or the ampacity of the conductors

90 A ≤ 1.2 R
90 A ÷ 1.2 = 75 A

The subpanel size would be rounded up to a 100 A (because there are very few 70 A or 75 A panels with multiple breaker positions), and a main-lug-only panel would be used. The conductor size for this ampacity would be 4 AWG since the breakers would typically have 75°C terminal temperature limits and a 6 AWG conductor operating over 65 A would get warmer than 75°C. But now we have a problem with the 200 A main panel: It cannot accept a 45 A backfed breaker and will have to be increased. However, closer examination shows that the panel rating is actually 225 A rather than 200 A, and the 45 A is acceptable. In fact, up to an 80 A backfed PV breaker woiuld be allowed:

(225 A x 1.25) - 200 A = 81 A

The load-side connection for the utility-interactive PV inverter is not the easiest subject to understand, but the correct application of these requirements will yield a safer, more durable system. When the requirements of load-side connections become complex and expensive, a supply-side connection is used, and we will examine those requirements in Part 2 in the next issue.

Access

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