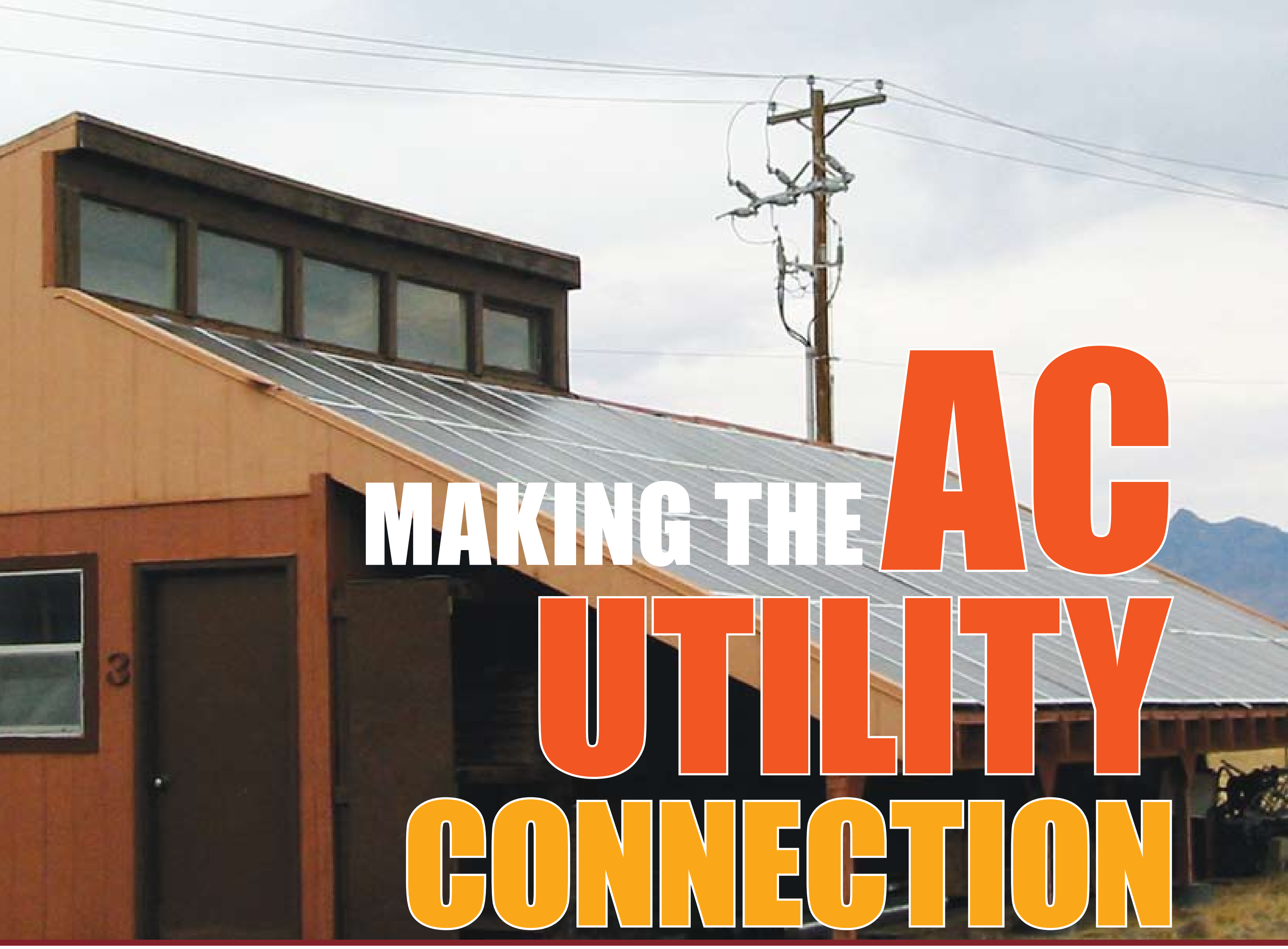

MAKING THE AC UTILITY CONNECTION

by John Wiles

Connecting the utility-interactive inverter to the utility grid properly is critical to the safe, long-term, and reliable operation of the entire system. The ac output circuit requirements and the circuits that carry the inverter current in the premises wiring are somewhat complex. However, meeting *Code* requirements can and should be accomplished to ensure a safe and durable system.

The circuit sizing and overcurrent device on the ac output of the utility-interactive inverter was covered in the September-October issue of *IAEI News*. Even though power and current flow from the inverter to the utility, it should be noted that the utility-end of this circuit is 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 and not at the inverter end of this circuit.

Although the inverter may require an external disconnect, if that disconnect function is achieved, as it commonly is, by a circuit breaker, then the conductor ampacity calculations may be more complicated as noted below. It is good practice to install the inverter near the backfed load center so that the backfed breaker commonly used to interconnect the inverter with the utility can also be used as the ac inverter disconnect required by 690.15. This places the overcurrent device at the utility-supply end of the circuit and groups the ac disconnect for the inverter with the dc disconnect.

Load-side connection

There are two types of connections allowed by the *Code* for interfacing the output of the utility-interactive inverter to the utility power. They 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 the residential system and smaller commercial system under about 10 kW. *NEC* 690.64(B) [moving to 705.12(D) in 2008 and 2011] covers the requirements and it is heavy reading at best.

There were changes in 690.64 between the *2005 NEC* and the *2008 NEC* and the *IAEI News* issue for July-August 2008 discussed them.

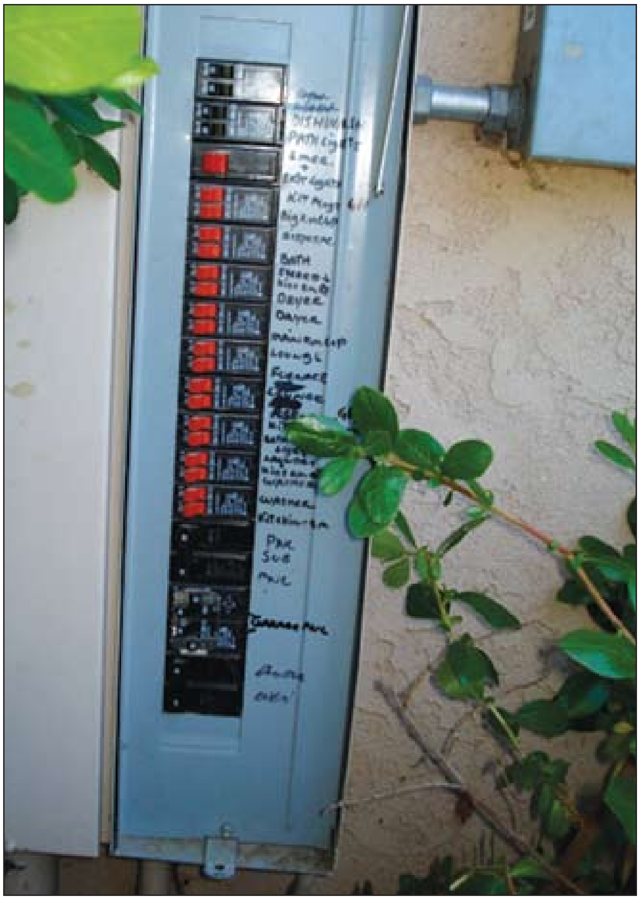

Photo 1. There must be an open space somewhere.

Inspectors need to know this material and how to apply it because many PV installers are not familiar with the details of the requirements.

Code-making panels since 1984 have maintained that 690.64(B)(2) will be rigorously applied to any circuits supplied from multiple sources where protected by overcurrent protective devices (OCPD) from each source. Such sources would include the output of PV inverter(s) and the utility supply.

This *Code* section requires that the ratings of all OCPD ***supplying*** power to a conductor or busbar be added together. The sum of the ratings of those breakers must be less than or equal (in other words: may not exceed) 120% of the rating of the busbar or the ampacity of the conductor. In equation form:

PV OCPD + Main OCPD <= 120% R, where R is the ampacity of conductor or rating of busbar.

120% factor depends on breaker location

The 120% factor came about in previous code cycles because it was determined that the demand factors on residential and small commercial systems would be such that it was 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 busbar or conductor, loads connected to that same busbar or conductor not exceeding the busbar rating would not pose an overload problem. In order to use this 120% factor, any backfed breaker carrying PV currents must be located at the opposite end of the busbar from the main breaker or main lugs supplying current from the utility (photo 1). The same location requirement would apply to any location of 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 back to 100% and the installation under the load side connection becomes more difficult.

The Article 240 tap rules do not apply to these inverter connections since the tap rules 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.

Examples

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

PV OCPD + Main OCPD <= 120% of Panel rating

120% of panel rating = 1.2 x 125 = 150 amps

PV + 100 <= 150, therefore the PV OCPD can be up to 50 amps

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

PV + 100 <= 1.2 x 100 = 120

The maximum PV backfed circuit breaker would be rated at 20 amps.

3. A 200-amp main panel with a 200-amp main breaker would allow up to 40 amps of PV breaker, which could be any combination of breakers that added up to 40 amps on either line 1 or line 2 of the 120/240V panel.

Photo 2. Multiple inverters require special connections

PV + 200 <= 1.2 x 200 = 240

PV <= 240-200= 40 amps

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 3500-watt, 240-volt inverter has a rated ac output current of 3500/240 = 14.58 amps.

The output circuit must be sized as 125% of 14.58 = 18.2 amps (690.8). The next larger overcurrent device would be a 20-amp OCPD and this would be consistent with the use of 12 AWG conductors if there were not any very large deratings applied for conditions of use. This system could be connected to a 200-amp panel or a 100-amp panel providing that the backfed 20-amp breaker could be located at the bottom of the panel.

There is sometimes a tendency to use that 30-amp breaker and those 10 AWG conductors that happen to be on the truck. While this would pose no problems for conductor ampacity or protection, the inverter specifications may limit the maximum size of the output OCPD and larger values may not be used (110.3(B)).

No bottom breaker position?

From the above equations, it can be seen that if the backfed PV OCPD cannot be located at the bottom of the panel or at the end of the circuit, it is not possible to install the backfed breaker without changing something. That 120% allowance drops to only 100%. Any panel that has a main breaker rated the same as the panel rating in the above equations would not allow any OCPD to be added. The 100%-of-the-panel-rating factor (instead of 120%)

Photo 3. Two inverters with PV ac combining panel

would equal the rating of the main breaker and the equation would force the PV breaker rating to be zero.

In a few cases, an *NEC* Chapter 2 load analysis might reveal that the service for the dwelling needed to be only 150 amps, but a 200-amp panel was installed with a 200-amp main breaker just to provide extra circuit positions. In this case, it might be possible to substitute a 150-amp main breaker for the 200-amp breaker, and even without the bottom position being open, 50 amps of PV breaker could be installed.

Systems with multiple inverters

Many residential and small commercial systems use more than one inverter (photo 2). If the local utility requires an accessible, visible-blade, lockable disconnect on the output of the PV inverters, then more than one inverter could not be connected directly to the main panel (photo 3). The two or more inverters would have to have their outputs combined in a PV ac inverter combining subpanel (PV ac subpanel) before being routed through the utility disconnect and then to the main panel (photo 4). 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 controlled by 690.64(B) requirements.

Here is another example

The dwelling has a 200-amp main service panel with a 200-amp main breaker and there is an empty breaker position (2-poles) at the bottom of the panel. The utility requires an external disconnect switch and it is desired to install a PV system that has a 3500-watt and a 4500-watt inverter. A PV ac panel will be used to combine the outputs of the two inverters and the output of that PV ac panel will be routed through the utility disconnect and then to a single backfed breaker in the main service panel.

The ratings of the output circuits of each inverter are:

3500/240 = 14.58 amps, 1.25 x 14.58 = 18.2 amps; use a 20-amp breaker and 12 AWG conductors.

4500/240 = 18.75 amps, 1.25 x 18.75 = 23.43 amps; use a 25-amp breaker and 10 AWG conductors.

The 20 and 25-amp breakers are mounted in 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.

The next step is to calculate the backfed 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 com-

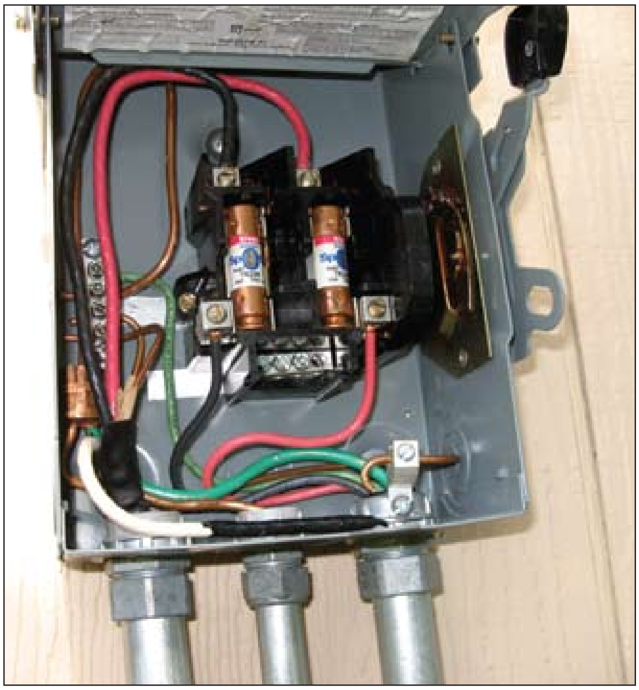

Photo 4. Utility-required disconnect, fused

bined outputs under fault conditions from high utility currents.

The combined currents from both inverters are:

14.58 + 18.75 x 1.25= 41.6
and the overcurrent device should be 45 amps.

The ratings of OCPD ***supplying*** the conductor from the PV ac subpanel to the 45-amp breaker, the utility disconnect switch, and supplying that PV ac panel are now defined as 45, 20, and 25 amps.

The panel rating and the ampacity of the conductor are controlled by 690.64(B)(2) and it would be incorrect to guess that the answer might be 45 amps as it would be a in a normal load subpanel.

45 + 20 + 25 <= 120% R,
where R is the panel rating or the ampacity of the conductors.

90 <= 1.2 R, R >= 90/1.2 = 75 amps.

With this number, we would round up to a 100-amp panel, and a 100-amp disconnect would be used. The conductor size for this ampacity would be 4 AWG since the breakers would typically have 75° C terminal temperature limits.

If the reader really wants to see why we must use 75 amps and not 45 amps for sizing the panel and the conductors, send the author e-mail for a white paper on the subject.

Summary

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 the next Perspectives on PV.

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.

John Wiles works at the Institute for Energy and the Environment (IEE) (formerly the Southwest Technology Development Institute) at New Mexico State University. IEE 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 54 proposals for the 2011 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. The PV system on his home is a 5 kW (dc) utility-interactive system with a full-house battery back up.

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