Making the Utility Connection

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More than 90 percent of new PV systems being installed throughout the United States are connected to the local utility with utility-interactive inverters. These inverters range in size from about 250 watts (rated AC output) to about 250 KW. Multiple inverters may be used at a single location to provide even higher outputs.

The connection requirements to the utility are established in various sections of the *National Electrical Code (NEC).* Unfortunately, in many cases, these requirements are not fully understood or complied with. This article concentrates on the requirements of the 2005 *NEC*, Section 690.64, Point of Connection, as they apply to residential PV installations.

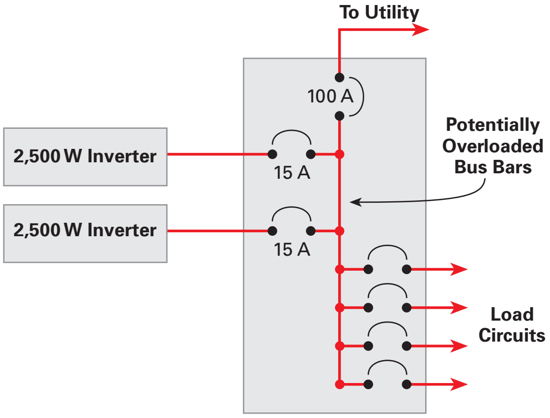
NEC *Details for Grid Connection*

Section 690.64 of the code allows the output of the inverter to be connected either on the supply (utility) side of the service disconnect or on the load (house) side of the service disconnect. Connections for dwellings are covered as an exception to the basic requirements of this code section, which deals with commercial, non-dwelling installations.

The requirements of 690.64(B)(2) are complex. Here is what the section (without the exception, which applies to residential installations) says:

The sum of the ampere ratings of overcurrent devices in circuits supplying power to a busbar or conductor shall not exceed the rating of the busbar or conductor.

Backfed breakers feeding a load center.



The key word is "supplying." In a load center or panel board, the main circuit breaker *supplies* power to the internal bus bars, as do any backfed circuit breakers *supplying* power from the PV inverters. The potential problem can be seen in the drawing below left.

The load center is rated at 100 amps, but the main circuit breaker can supply 100 amps to the bus bars, and at the same time, the inverters may add another 30 amps to the bus bars. If the loads were increased to 130 amps (for example, by increasing plug loads), no circuit breakers would trip, but the bus bars in the center of the panel, rated at 100 amps, would be overloaded, carrying 130 amps.

Exception for Dwelling Units

Now, examine the installation requirements for dwelling units. The exception for 690.64(B)(2) reads:

Exception: For a dwelling unit, the sum of the ampere ratings of the overcurrent devices shall not exceed 120 percent of the rating of the busbar or conductor.

With the exception, it's okay to add PV backfed circuit breakers to the dwelling (residential) load center with some leeway before having to change equipment. Normally, the main circuit breaker in a residential load center is rated the same as the residential load center. This exception allows the sum of the main circuit breaker plus the sum of any backfed PV circuit breakers to be 120 percent of the rating of the load center.

This additional 20 percent allowance is made because, generally, residential circuits are more lightly loaded (due to demand-factor calculations) than circuits in commercial buildings. If the loads remain below the rating of the busbar, the panel cannot be overloaded.

Where the main circuit breakers and panels have the same rating, the exception to 690.64(B)(2) allows 20 amps of backfed PV circuit breakers to be added to a 100-amp panel and 40 amps to be added to a 200-amp panel. Although these numbers translate to a 3,840-watt (AC inverter output) PV system on a 100-amp panel and a 7,680-watt PV system on a 200-amp panel, some people want to install bigger PV systems, which requires creative thinking. These limits include the normal 80 percent maximum continuous operating-current limitations on the circuit breakers.

Many common PV inverters are rated at 2,500 watts and 240 volts. The rated output current is 2,500 ÷ 240

= 10.4 amps. Using the *NEC*-required 1.25 multiplier (Section 690.8) yields a circuit breaker requirement of 13 amps, which rounds up to 15 amps as the rating of the backfed circuit breaker. On a 100-amp panel, with a 100-amp main circuit breaker, only one of these inverters can be accommodated. On a 200-amp panel, only two of these inverters may be connected, limiting the PV system to 5,000 watts and not the maximum potential of 7,680 watts.

However, the drawing at right shows a code-compliant way to add three of these 2,500-watt inverters to a 200-amp panel by using a subpanel. A subpanel is selected to accommodate the three, 15-amp backfed circuit breakers, one from each of the 2,500-watt inverters. The main circuit breaker on this dedicated (PV-only) subpanel has to have a minimum rating of 3 x 10.4 x 1.25 = 39 amps (rounded up to a 40-amp circuit breaker). This would also be the rating of the backfed circuit breaker in the main panel and, at 40 amps, would meet the code requirements for a 200-amp main panel.

Using a formula derived from the *NEC* requirements, the minimum size of the panel would be about 75 amps, which would round up to a 100-amp, standard-sized panel. The equation is:

$(3 \times 15) + 40 \leq 1.2Y$
Where Y is the panel size required

Solving for Y gives us: $Y \geq (45 + 40) \div 1.2 = 71$ amps. So, if you want to install larger PV systems on residential services, using a supply-side connection [690.64(A)] can meet the code requirements.

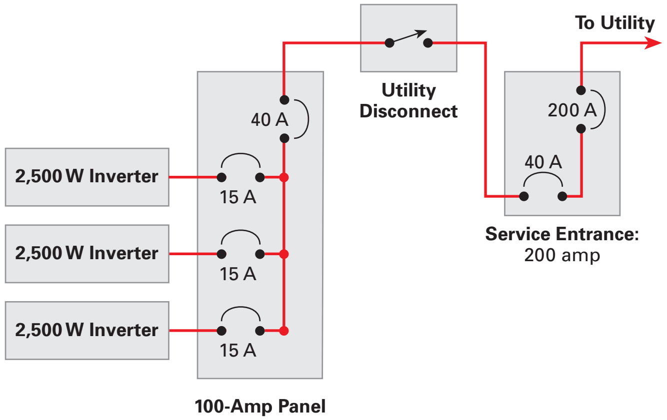
Line (Utility) Side of Ground-Fault Equipment—690.64(B)(3)

The code generally requires that all PV inverters be connected on the line (utility) side of any ground-fault protection equipment with an exception that allows backfed ground-fault protection (GFP) equipment when the protected circuits have ground-fault protection from all sources.

However, tests by SWTDI and Sandia National Laboratories on the typical 5- and 30-milliamp GFP circuit breakers have revealed that the internal sensing and trip circuits are destroyed when they are tripped while being backfed by a PV inverter. Conversations with manufacturers of the larger 100- to 800-amp ground-fault protection devices indicate that these devices may also be damaged when tripped while being backfed. Therefore, ground-fault protection equipment should only be backfed when it has been tested and listed for backfeeding.

Backfed Circuit Breakers—690.64(B)(5)

Although another section of the *NEC* [408.36(F)] requires that backfed circuit breakers be clamped, changes to 690.64(B)(5) in the 2005 *NEC* no longer require them to be clamped when connected to the output of utility-interactive inverters. Section 690.3 allows the 690 requirements to override the 408 requirement. A Fine Print Note explains that circuit breakers suitable for backfeeding are not marked with "Line" and "Load" designations.



Inverter subpanel feeding residential service entrance.

Battery Backup, Utility-Interactive Systems—More Complexity

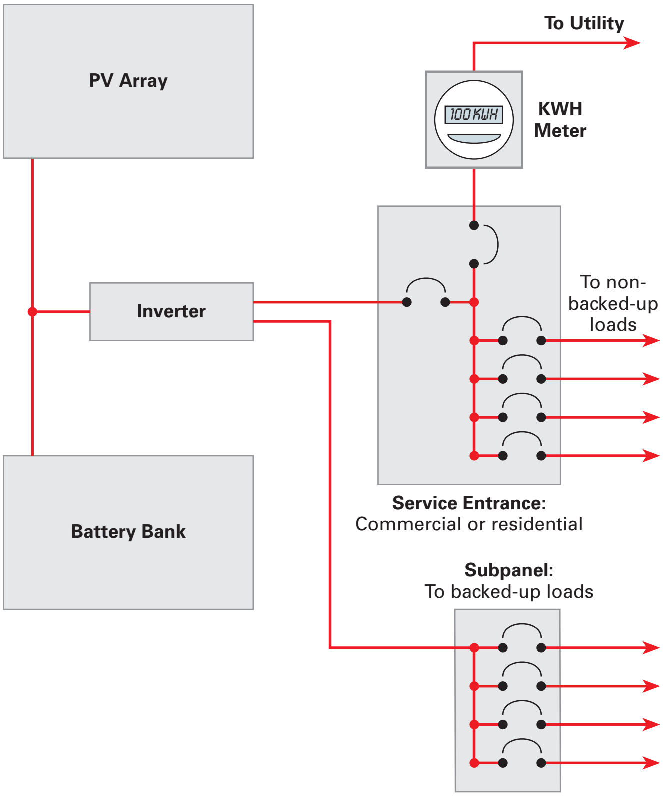
The specifications in Underwriters Laboratories (UL) Standard 1741 require that all utility-interactive inverters cease exporting power to the utility grid when the utility grid voltage and frequency deviate from very narrowly defined values. In blackout situations, the PV system and the standard batteryless utility-interactive inverter cease to operate and will not even supply power to local loads.

In areas where utility blackouts are a concern, some systems are being installed that have a battery-based energy storage system to provide local power during utility outages. The batteries are connected to a specially designed and listed utility-interactive inverter that, in the event of a utility outage, will disconnect from the utility system and provide a set of designated circuits with power from the PV system and the battery. All of these actions are done automatically with transfer devices built into the inverter. The drawing on the next page shows a simplified block diagram of a typical system. Several variations are possible.

Interfacing these systems with the utility grid and meeting 690.64(B)(2) requirements presents challenges for the system designer, the installer, and the inspector. Many of these inverters have internal transfer relays that are rated for 60 amps continuous duty, and that information is presented in the specifications.

This specification leads designers and installers to size the backup load subpanel for 60 amps and to use a 60-amp backfed circuit breaker to connect the inverter to the main load center where the utility connection is made. The use of 60-amp circuit breakers in both positions provides for best use of the internal 60-amp relay and appears to allow maximum loads to be connected to the backup subpanel. Unfortunately, the use of 60-amp circuit breakers poses two problems and code violations.

Inverters commonly used for grid-tied backup systems cannot source these high currents, but *NEC* Section 690.64 requires the load center to be sized based on the size of



Utility-interactive PV system with battery backup.

the breaker, not the rated output of the inverter in utility-intertie mode. Even though the inverter may be rated (and can be adjusted) to carry 60 amps, the external wiring and circuit breakers require the normal 80 percent continuous current derating. For a 60-amp continuous current, an 80-amp circuit breaker and conductors rated for at least 75 amps would be required.

Another option that will allow the 60-amp circuit breakers to be retained would be to adjust the inverter to not allow more than 48 amps of continuous current to be handled by these circuits. That adjustment is commonly available on most of these inverters, although there is some question about who has access to the adjustment (qualified or unqualified people).

Second, the 690.64(B)(2) requirements discussed above must be addressed. In a residential installation, a 60-amp backfed PV circuit breaker would dictate that at least a 300-amp main panel be used (60-amp PV circuit breaker + 300-amp main circuit breaker = 360 amps; 1.2 x 300 = 360). Residential load centers rated at 300 amps and above are available but not common. In a commercial installation, the existing load center would have to be replaced with one having at least a 60-amp greater rating than the original rating. In either case, a supply-side interconnection [690.64(A)] might be the more practical alternative. If the full 60-amp rating of the inverter is to be used, then, of course, 80-amp circuit breakers and 75-amp conductors should be used. The use of 80-amp overcurrent devices would require a 400-amp load center to meet *NEC* requirements.

In all cases, 120 percent of the load center rating must equal or exceed the sum of the main breaker and the 80-amp PV breaker. Some possible combinations would include a 200-amp panel and a 150-amp main breaker. A 300-amp panel could be used with a 240-amp main breaker.

To further complicate system design, many of these systems have an external inverter-bypass switch that is used if the inverter fails. This bypass switch, usually consisting of a pair of interlocked circuit breakers, is used to connect the backup subpanel directly to the main panel when the inverter fails. These circuit breakers are typically also rated at 60 amps and installed in a small 60-amp, three-position (three-phase) load center. Obviously, neither the circuit breakers nor the load center are rated to carry 60 amps continuously. The use of a larger load center and interlocked 80-amp circuit breakers would allow a full 60-amp rating for the inverter-bypass switch.

Some inverters have only 50-amp internal ratings. The ratings of the external overcurrent devices would have to be at least 70 amps and conductors would have to be rated for at least 63 amps. The load center would need to have a 400-amp rating unless a smaller main breaker could be used.

Summary

The requirements of *NEC* Section 690.64 can be met in nearly all installations. While the requirements, at first glance, are somewhat complex and sometimes overlooked, attention to these details in the design, installation, and inspection of these systems should help to ensure a safe, durable, and code-compliant installation.

Access

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Photovoltaic Power Systems & the 2005 NEC: Suggested Practices, a 145-page manual can be downloaded from the SWTDI web site • www.nmsu.edu/~tdi/photovoltaics/codes-stds/PVnecSugPract.htm

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The 2005 *NEC* and the *NEC Handbook* are available from the NFPA, 11 Tracy Drive, Avon, MA 02322 • 800-344-3555 or 508-895-8300 • Fax: 800-593-6372 or 508-895-8301 • custserv@nfpa.org • www.nfpa.org