# Making the Grid Connection

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You are planning to install a utility-interactive PV system. You have sized the system, selected the modules and the inverter, and made all the DC wiring decisions. You now have to decide how to connect the AC output of the inverter to the grid.

A number of areas must be considered in connecting to the grid safely. The utility company should be notified and their technical and administrative requirements addressed. These requirements will vary widely from utility to utility. Permits and electrical inspections may be required. In harmony with the utility requirements, the *National Electrical Code (NEC)*, and any local code and inspection requirements, you will have to plan, select, and install the hardware that will be used to get from the inverter to the point where the AC power interfaces with the existing wiring in the building.

**The Utility Disconnect**

In most locations, the connection to the existing wiring will be through a backfed circuit breaker in an existing load center. However, some utilities, but not all, require a disconnect switch that is accessible to utility personnel between the output of the utility-interactive inverter and the connection to the existing wiring. If the inverter is to be mounted inside the building, the wiring from the inverter to that backfed circuit breaker must be routed outside the building, through this disconnect, and then back inside the building to the load center.

Utilities usually require that a switch-type disconnect with visible blades (so they can verify when it is open) be used, and that the disconnect can be locked in the "off" or "open circuit" position. The idea is to enable a utility lineman working on the distribution system to lock this switch in the "open" position. This ensures that the disconnected line or feeder cannot possibly be energized by any connected power generation source. The location of the switch also allows the rest of the house to receive grid electricity while the PV system is disconnected. This external AC disconnect, under utility control, is sometimes used to prevent the PV system from being connected to the grid until all of the contractual, technical, and billing details are resolved.

Some people have suggested that when the utility lines are being serviced, the meter be removed from the meter socket or base instead. But this is prohibited by utility regulations in some states, and may cause billing errors if a meter is inadvertently switched around. Usually only the utility metering departments are allowed to remove or change meters. Fire departments are also allowed to remove meters, but only in emergency situations when the main disconnects cannot be located.

**Inverter Size vs. the Load Center**

*NEC* Section 690.64(B)(2) is written to prevent unintentional overloading of circuits that may carry both grid power and power from a PV source. These circuits include feeders, branch circuits, load centers, and any other circuit that may be connected to multiple sources of power. Let's look at a load center in a commercial building first to see why this requirement (paraphrased below) exists. Then we'll examine the exception that applies to dwellings.

Suppose, for example, a load center in a commercial building is rated at 400 amps and has a 400 amp main breaker or a 400 amp breaker on the feeder supplying the load center. Since the load center is rated at 400 amps, this is also the rating of the bus bars in it. The *NEC* allows high loading of load centers in commercial buildings, and this particular load center is loaded to about 320 amps when the building is occupied—mostly during the normal daytime working hours. Like a residential load center, the ratings of the individual branch circuit breakers may total far more than the 400 amp rating of the load center, but the load design calculations used for the installation allow for up to 320 amps being drawn.

Now let's install an 80 amp, AC output, utility-interactive PV system on this commercial building, and backfeed a 100 amp breaker in the 400 amp load center. When the PV system is delivering the full 80 amps, some of the 320 amps of daytime load are being supplied by the PV system, while the grid supplies the remaining 240 amps. All circuits are properly loaded, no circuit is overloaded, and no circuit breakers trip. At night, the PV energy goes to zero. The grid, through the 400 amp main breaker, supplies any building load.

The PV system performs well and is "out of sight and out of mind." Sometime later, management decides to renovate the office space, and installs numerous computers that will be used by the office staff during the day. No one brings in an electrician or an engineer to reassess the new load. If the PV system had not been installed, the main 400 amp breaker would sense any overloading of the 400 amp load center. It would trip, protecting the load center. But now, let's see what happens when 100 amps of additional daytime load are added to the various branch circuits connected to the load center.

During sunny days, the PV system supplies 80 amps of the greater 420 amp load, and the grid supplies 340 amps. No circuit breakers trip, although the main breaker is being operated at more than 80 percent of rating. Everything appears normal until we look at the bus bars, rated at 400 amps, in the load center. They are now overloaded when carrying 420 amps, and that may cause them to generate excess heat and possibly, over the long term, cause nuisance tripping or shorten the life of the circuit breakers. At night, when the PV system is not producing, the load is also reduced and nothing is amiss. On cloudy days, the main breaker may trip, depending on the output of the PV system and the actual load.

This additional load, of course, has been applied improperly without a reassessment of the total load on the panel. However, these things do happen in many office complexes. The *NEC* recognizes this problem and hence the following requirement in *NEC* Section 690.64(B)(2) [paraphrased]: *The sum of the ampere ratings of all overcurrent devices supplying power to a circuit, feeder, bus bar, or the like shall not exceed the rating of that circuit, etc.*

Generally, in a commercial building, it is not possible to use a backfed circuit breaker in an existing load center to connect a utility-interactive PV system to the grid. There are a couple of proper ways that this connection can be made. The load center could be increased to say 600 amps (with 600 amp bus bars) and equipped with a 400 amp main breaker (or better yet, a 450 amp main breaker). Or a separate 100 amp fused disconnect or single breaker disconnect could be connected in parallel with the existing 400 amp load center (or the replacement load center installed to handle the increased load).

**Residential Installations and *NEC* 690.64(B)(2)**

Now that we have seen the problems and solutions with a commercial installation, what about a residential installation? Since residential load centers are more lightly loaded (by design and code), Section 690.64(B)(2) allows an exception to the general rule.

The exception allows the sum of all overcurrent devices connected to a circuit, load center, or feeder to exceed the rating of that circuit by 20 percent. For a 100 amp residential load center, 20 amps of backfed breakers (one on each side of the 120/240 volt line) may be connected. This represents about 4,800 watts with either two, 120 volt, 2,400 watt inverters or one, 4,800 watt, 240 volt inverter.

Since most of these breakers are limited to continuous currents at 80 percent of rating, the actual inverter power levels would be limited to 1,920 watts and 3,840 watts. For a 200 amp load center, two, 120 volt inverters of 3,840 watts each or a 7,680 watt, 240 volt inverter may be connected.

For larger PV systems using larger inverters with only 100 or 200 amp load centers, an external disconnect needs to be paralleled with the existing load center. This external disconnect must be rated as service entrance equipment because the connection amounts to a second service entrance on the house.

These limits are troublesome for those wanting to connect battery backup systems using the larger inverters that have 60 amps of grid feed-through, and lesser amounts of inverter output in the utility interactive mode. The desire is to install a 60 amp, backfed breaker to take full advantage of the grid feed-through. But as can be seen from the *NEC* limitations, the 60 amp breaker is not compatible with either of the common 100 amp or 200 amp load centers. To meet *NEC* requirements, the load center would have to be rated at 300 amps or larger (20 percent of 300 is 60 amps). These installations will normally require a parallel disconnect/overcurrent connection as described previously.

**Dedicated Circuit**

*NEC* Section 690.64(B)(1) requires that each utility-interactive inverter be connected to a dedicated circuit breaker or fused disconnect. The dedicated circuit requirement (up to the first disconnect device) is to minimize the possibility of creating an island within the building where a constant load on the same circuit matches the inverter output and allows the inverter to run after the disconnect is opened.

If a dedicated circuit is not used, there is also the possibility of connecting the inverter to a circuit that might have devices that could be damaged by the inverter. For example, the code requires that all utility-interactive inverters be connected on the line (grid) side of any ground-fault circuit equipment. When an inverter shuts down through loss of the grid signal, it does not shut down instantaneously.

The decaying voltage output of the inverter may be sufficient to destroy the trip coils in the antishock GFCI devices where the inverter is connected to the load side of the device. With burned out trip coils, the GFCI will no longer provide the antishock protection it was intended to provide. It will continue to carry power, but will not trip open when a 6 milliamp or greater ground-fault current is in the circuit.

In many commercial buildings with very large service entrance equipment, a 1,200 amp, equipment-protection, ground-fault device may be installed. It is important that any PV system be connected on the line (grid) side of this device to meet general safety and code requirements.

**Circuit Ratings**
The conductors between the inverter and the grid connection should have a temperature-derated ampacity of at least 125 percent of the continuous rated output current of the inverter. This current rating is determined from the manufacturer's specifications or by taking the rated inverter power output and dividing it by the line voltage.

Overcurrent devices in this circuit should also be rated at 125 percent of the continuous inverter output current, and be less than or equal to the conductor ampacity. These 125 percent factors are used to ensure that neither the overcurrent devices nor the conductors are used at more than 80 percent of their ratings.

For example, a 2,500 watt, 240 volt inverter has a continuous output current of 10.4 amps. This current must be multiplied by 125 percent to get 13 amps to determine the ampacity of the conductor and the rating of the overcurrent device. The next larger standard overcurrent device would be rated at 15 amps and a #14 (2 $mm^2$) or larger conductor could normally be used since it has an ampacity of at least 15 amps under typical residential use conditions.

Continuing the example, a 15 amp, double-pole, 240 volt circuit breaker could be used to connect one of these inverters to a 100 amp load center and meet the requirements of *NEC* Section 690.64(B)(2). With a 200 amp load center, it would be possible to connect three of these inverters if they were first connected to a subpanel. Three, 15 amp circuit breakers (one for each inverter) would feed a 100 amp subpanel, containing a 40 amp main breaker. The subpanel would meet 690.64(B)(2) requirements, since the total of all breakers feeding the 100 amp panel would be 85 amps (3 x 15 + 40).

This subpanel would then be connected to the main 200 amp load center through a backfed 40 amp breaker. The panel would meet 690.64(B)(2) requirements (20 percent of 200 is 40). Each of the 40 amp breakers would be appropriately rated (1.25 x 10.4 x 3 = 39), and each inverter would be on a dedicated circuit.

**Conductors & Wiring Methods**
Any wiring method found in Chapter 3 of the *NEC* is acceptable for connecting the inverter to the load center. Indoor wiring might include non-metallic sheathed cable (Type NM) or conductors (Types THWN or RHW) in conduit (either PVC or metallic). Outdoor inverter installations might also use conduit or possibly Type UF (Underground Feeder) cable marked "sunlight resistant." Wiring methods using conduit might be required on commercial buildings due to local codes.

**Disconnects**
If the inverter is within 5 feet (1.5 m) of the main load center, the backfed breaker could serve as the inverter AC disconnect for inverters not having an internal disconnect device that meets code requirements. If the inverter is more than 4 to 5 feet away from the main load center or the subpanel, and the inverter has no internal AC disconnect, an external disconnect device should be connected in the circuit near the inverter. Even though the inverter is usually power (and current) limited, some inspectors may require an overcurrent device at the inverter location. So using a circuit breaker makes sense for the disconnect.

**Grounding**
Each inverter will have a unique method of grounding the AC output, and the manufacturer's instructions should be followed. In most cases, for inverters less than about 15 KW, there is no internal bond between the AC neutral and the grounding system. This bond is made in the load center/mains panel to which the inverter is connected.

Inverters with external transformers may require special grounding considerations. In nearly all cases, the AC equipment-grounding conductor should be run with the circuit conductors (same conduit or cable) from the inverter to any connected equipment (switchgear, overcurrent devices), and then to the equipment-grounding system associated with the building.

**Marking Requirements & Plaques**
Part VI of Article 690 establishes the *NEC* requirements for marking the utility-interactive PV system. Section 690.53 requires a marking at the DC disconnect showing the operating and short-circuit current, operating voltage, and maximum system voltage. Section 690.54 requires that all points of interconnection with the grid be marked with the maximum AC output operating current and the operating voltage. This means marking each subpanel and the final load center or switchgear that have AC current from the inverter through them.

Additional marking requirements apply if the system has batteries or other sources of power. Section 690.55

specifies that if the system has energy storage devices, the maximum voltage (including any equalizing voltage for batteries) and the polarity of the system ground must be displayed.

Section 690.56 further requires that permanent directories or plaques showing all sources of power and disconnect locations be mounted on the outside of the building in a readily accessible location.

**Summary**

Connecting a utility-interactive PV system to the grid can be done in a way that is safe and meets utility and *NEC* requirements. By following the guidelines above and the details in the *NEC,* an approved connection will provide reliable and safe performance for many years.

Questions or Comments? If you have questions about the *NEC,* or the implementation of PV systems that follow the requirements of the *NEC,* feel free to call, fax, e-mail, or write me. Sandia National Laboratories sponsors my activities in this area as a support function to the PV industry. This work was supported by the United States Department of Energy under Contract DE-FC04-00AL66794. Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy.

**Access**

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