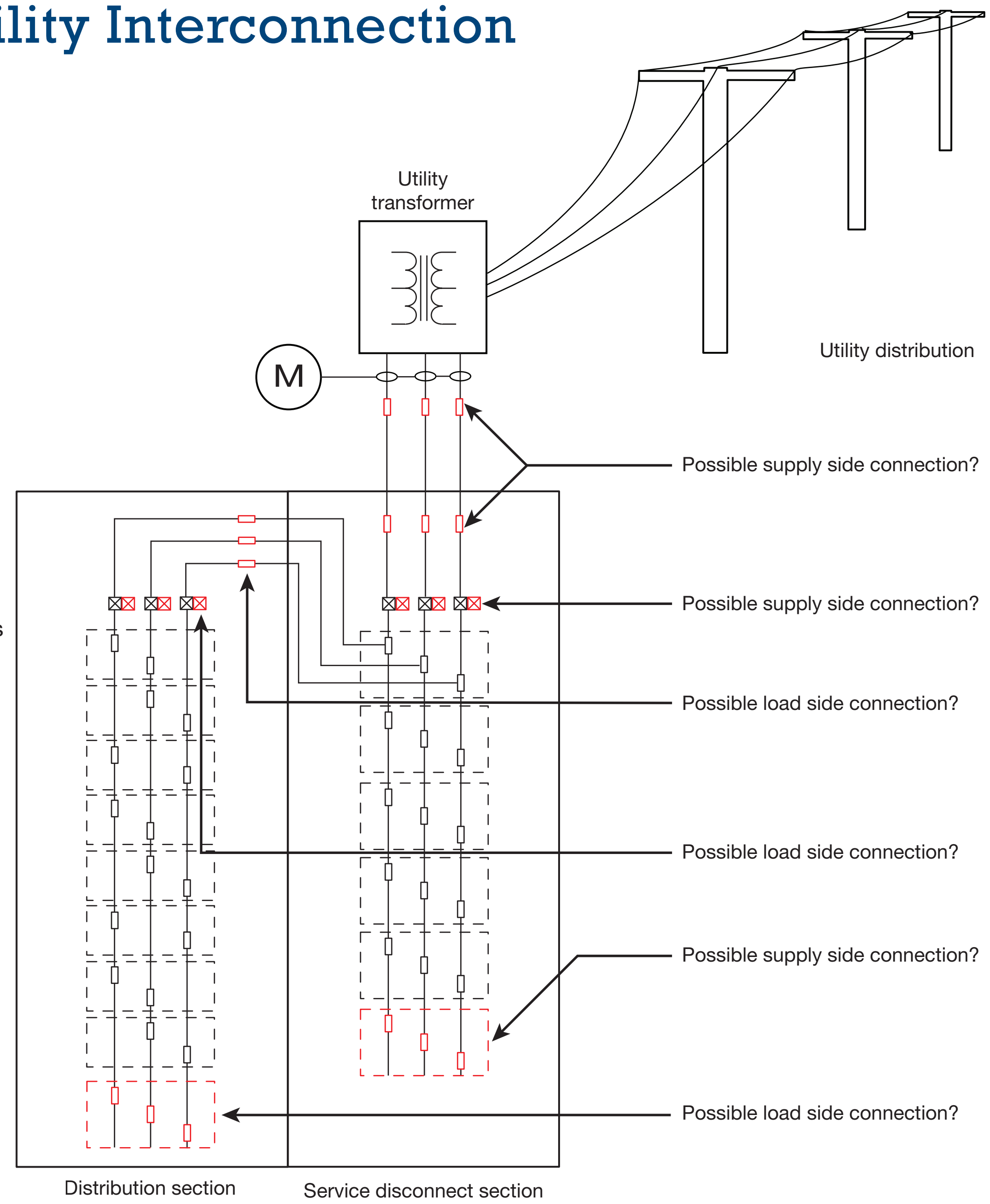
Can We

Means and Methods of PV System Utility Interconnection



Supply side or load side connection? *NEC* Article 690.64 allows for both supply side (or line side) and load side connections for utility-interactive PV systems.

Land?

By Ryan LeBlanc and Tarn Yates

When evaluating a site or plan set for the installation of a utility-interactive photovoltaic system, one of the most important steps is to determine how much solar power you can land on a breaker or tap into an existing or planned electrical system. The result of this site evaluation may ultimately limit the size of the PV system that can be cost effectively installed. The evaluation needs to be performed with care to avoid costly mitigation measures or a disappointed client. In this article we discuss methods for determining how much solar power can be safely and legally fed into an existing electrical infrastructure. We begin with identifying and evaluating the existing electrical system, for both residential and commercial PV systems, continue to *Code* compliance and methods of interconnection, and conclude with strategies for connecting to a utility grid.

SITE EVALUATION

Here we focus only on identifying and evaluating the existing electrical system during a site evaluation, with particular emphasis on existing facilities. If you have an electrical plan set in front of you for a new facility, you are looking for the same general information described. Once the electrical service is evaluated, you can determine the point of interconnection and the method of interconnecting your PV system to the utility grid. Take plenty of photographs during the site evaluation. Pictures of the electrical panel and labels may prove useful later. (Be sure to turn the flash off and the "macro" setting on when photographing metallic labels.)

Electrical service type. In the US we have centralized power generating facilities, mostly coal fired, natural gas and nuclear powered, charging independent grids at high voltages. Transmission voltages are usually 110 kV to 500 kV. Localized substations transform the high voltage feed down to less than 35 kV. Common medium voltages, as described by IEEE, are between 1 kV to 35 kV. The distribution voltage will vary, depending on the client, location and utility provider.

After the utility substation, pad- or pole-mounted transformers located close to businesses and homes knock the voltage down further. It is helpful to know the common voltages provided by the local utility when performing a site evaluation, especially when electrical equipment is not properly labeled. (For more information on electrical service types, see the sidebar in "From kW to MW: System Design Considerations," October/November 2008, *SolarPro* magazine.)

Utility-interactive inverters produce the most common voltages in both single-phase and 3-phase configurations: 120, 208, 240, 277 and 480 Vac. In general, 277/480 V 3-phase is used for larger commercial and industrial buildings; 120/208 V 3-phase is used for smaller commercial and large,

Thoroughness pays Remove panel covers and look inside any equipment you plan to work with, as this may eliminate costly surprises. Invariably the one thing you forget to record is essential later, so photograph everything and take detailed notes.

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Transformer markings Pole-mounted transformers are generally marked with their rating in a way that is visible from the ground. If not, the utility should be able to answer any questions you may have.

Main service enclosure Large commercial services typically house the main disconnect in the same enclosure as the meter, or in adjacent enclosures that are integrated together. Because there are multiple meters at this site, you must verify that the PV system is connected to the appropriate one.

multi-unit residential buildings; and 120/240 V single-phase is used for residential buildings; but other service configurations are possible. From these common voltages, ac transformers match less common voltages and accommodate electrical transmission over distances.

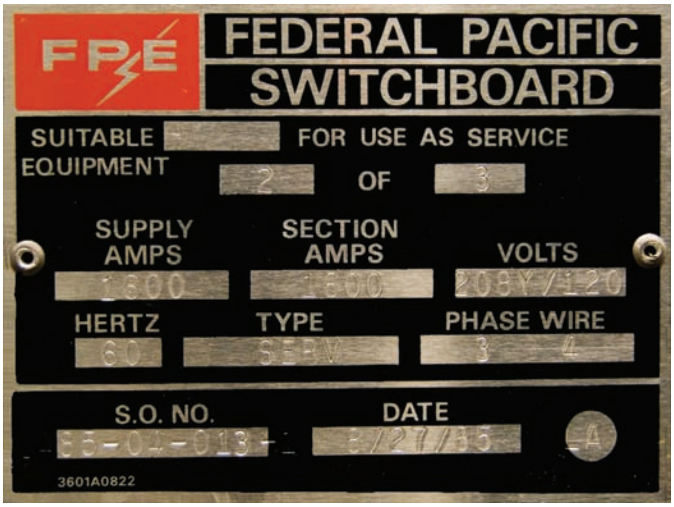
Utility transformer. The first piece of equipment between the customer and the medium voltage utility grid is the utility transformer. The transformer transfers electrical energy from one circuit to another using magnetic fields. Transformers have electrical and environmental ranges and limitations. They must be clearly and permanently labeled with their electrical characteristics. Utility transformers can be oil-filled or dry, and they come in many sizes, shapes and designs. Most often a utility transformer will be oil-filled and will either be pole mounted near the closest major road or pad mounted in various locations. The key utility transformer characteristics to record at a site inspection are primary and secondary voltages, phase type and power rating in kilovolt-amps (kVA). Also note the transformer number, as marked by the utility, and the approximate location of the transformer on a site map.

Several customers may share residential and small commercial utility transformers. Existing utility transformers may not be able to handle multiple systems installed on any of the shared client's meters, particularly when loads are very low and PV production is very high. The customer who installs a PV system that exceeds the capacity of the shared transformer will likely be charged for its replacement. This should be handled prior to installation, or it may go unnoticed until the transformer fails and causes a localized outage. Though larger commercial sites generally have dedicated utility transformers, they still have limits. In general, the sum of the PV inverter nameplate ratings should not exceed the kVA rating of the transformer.

Revenue meter. Just as the grid utilizes high voltages to transmit large amounts of power on small wires, it can be beneficial to interconnect a PV system at the highest voltage available on the client side of the meter. Because the highest voltages will generally be found at the meter, it is the next thing to look for after the utility transformer when identifying electrical systems. The faceplate will often provide important characteristics of the electrical system. Once you find the meter, record the meter number, manufacturer, model numbers, voltage range, number of wires and phase of the system.

You should also collect other pertinent information about the meter when possible. Document whether the meter is digital or analog, mono- or bidirectional and whether it is an inline electromechanical meter or based on a current transducer (CT). Most residential meters are inline types, in which the purchased electricity must flow through the meter for measurement. When you pull the meter out of its socket, the service is disconnected. Commercial 3-phase systems and residential systems above 400 A typically have CT-based meters, which monitor consumption by measuring the expanding and collapsing magnetic fields around the electrified busbars or conductors.

Larger commercial locations often have multiple meters, and it may make more sense to interconnect at an alternate meter that has a larger load or higher utility rate. Clients often will not care which loads are offset by the PV system, just that the system is as cost effective as possible. You may find that another meter is a better option because it CONTINUED ON PAGE 28



Courtesy spgsolar.com

Standard tag Many commercial enclosures have durable metal labels that provide the service voltage and configuration, as well as the amperage rating of the enclosure.

is closer to the PV system, allows a larger system or is more favorable to time-of-use metering, which is most advantageous when installing a PV system that offsets a large percentage of consumption.

Main service enclosure. Commonly referred to as the *main breaker panel* or *main distribution panel,* the main service enclosure is the next piece of equipment to find. The main service enclosure is usually near the meter and contains a breaker or switch labeled "main disconnect." Each site has its own unique conditions, and electrical systems can be configured any number of ways. On larger properties you may find the meter located a significant distance away, usually near the main access road, with the distribution panel remotely located at a building or dwelling.

Having found the panel, look for a label stamped with electrical characteristics. According to Article 408.58 of the 2008 *National Electrical Code,* "Panelboards shall be durably marked by the manufacturer with the voltage and the current rating and the number of phases for which they are designed." A label on the main service panel should provide the specifications for the electrical system. Capture everything indicated on the label, including manufacturer, model, voltage, amperage and phase.

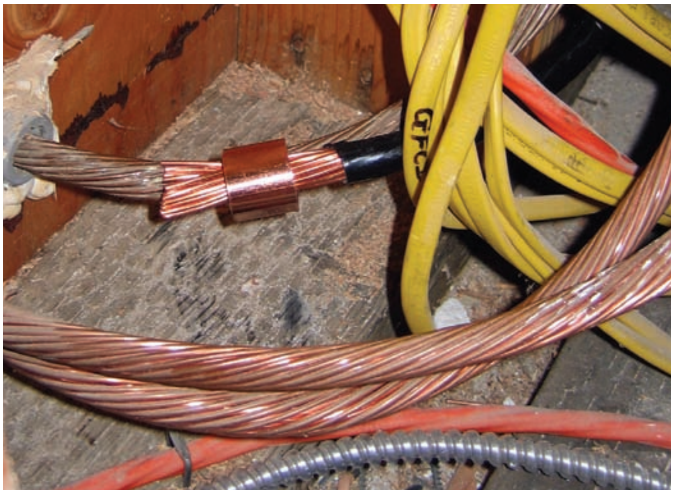
Labels can be incorrect or missing, so always verify the contents of any equipment you intend to work with. Over the years, electrical systems tend to take on a life of their own and may not be in *Code* compliant condition by the time you get to them. If you will be working on an electrical system that is not *Code* compliant, keep your eyes open for existing violations. You may be responsible for bringing the system up to *Code.* If you find any violations, document and discuss them with the client as soon as possible. If anything looks dangerous, you should assume it is and either stop this portion of the site evaluation or proceed with extreme caution.

Remove the dead front or section cover of the main panel to inspect its interior, enlisting the services of a qualified person if necessary. Verify the size, type and quantity of the service entrance conductors or busbars coming from the meter and the type of distribution within the enclosure, bus or conductors. This is very important when determining the method of interconnection. If you do not believe the labels on the equipment, you or the qualified professional can test the phase voltages with a multi-meter.

With the cover off, determine if there is enough space between the meter and the main disconnect to make a good electrical connection to the busbars or conductors. If the distribution inside the panel is bus type, take note of any predrilled holes, as these may be convenient interconnection locations. If the distribution is done with conductors, take measurements to verify adequate space to install often bulky insulated tapping devices.

Grounding electrode. Locate and photograph the service's grounding electrode system. Also follow and photograph any grounding electrode conductors (GEC) or other wires that are attached to it. In larger equipment, grounding electrodes, usually copper, are often contained inside the cabinet at floor level. Residential systems usually have an external ground rod driven into the earth or a concrete-encased electrode (Ufer) located in the slab. These systems may even use water pipes or other objects as the system grounding electrode. You can usually follow the bare copper wire from the grounded bus block of the main panel to locate the grounding electrode. If the grounding electrode is not accessible,

Plan ahead An irreversible splice connection is required between the inverter's grounding electrode conductor (GEC) and the existing grounding electrode or GEC.



Courtesy sunlightandpower.com

an additional one may be required, or you may be able to find a location to splice onto the GEC.

Service disconnecting means. Look closely at the main breaker or main disconnect switch, whichever is present. This should stand out as the largest breaker or switch in the system and should be clearly labeled "Main Disconnect" or "Service Disconnect." Record the device manufacturer, model and any electrical characteristics.

If you will be working on an electrical system that is not *Code* compliant, keep your eyes open for existing violations. You may be responsible for bringing the system up to *Code.*

Breakers and disconnects should be permanently stamped or marked with an amp rating as well as a kilo-amperes interrupting capacity (kAIC). Capture both of these numbers. The amp rating is the current that the device will allow to pass through it before tripping. The kAIC is the maximum current capacity that the device is capable of disconnecting. A fault situation exceeding the kAIC rating may render the disconnect device useless, so you need to know this rating when specifying equipment.

Once you have captured the main switch information, examine the rest of the breakers. Be sure to note the quantity and location of unused breaker spots. In some cases it is possible to use an existing spare breaker for the interconnection, so take note of the characteristics and quantity of any existing unused breakers. On 3-phase systems, keep an eye out for high leg or stinger service configurations, such as a 240 V delta. If you see a lot of blank breaker spaces every third breaker, that may indicate the stinger.

Courtesy spgsolar.com

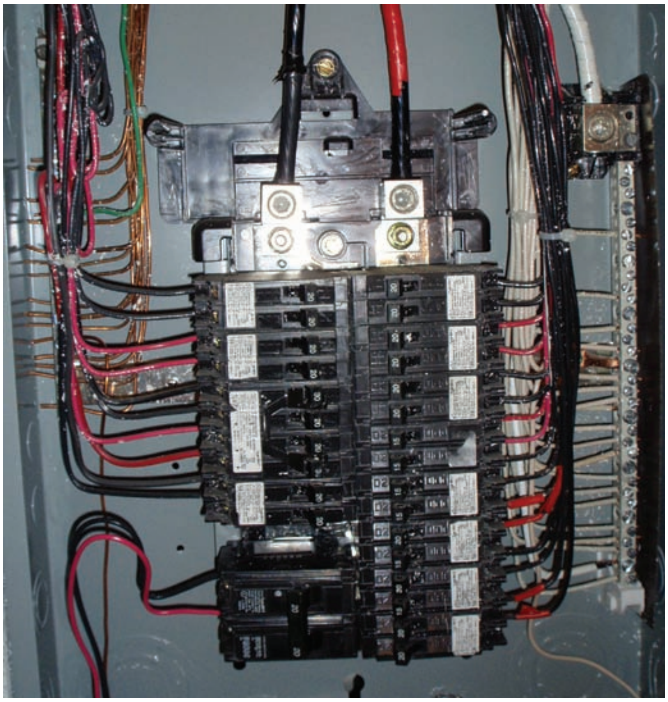
Main breaker The main disconnect, a main breaker in this case, is usually easy to spot as it is typically the largest device in the system, often isolated from other breakers or disconnects. In addition, *NEC* Article 230.70(C) requires permanent markings for all service disconnects.

Service entrance conductors. If you could not get a close look at the service entrance conductors leaving the meter, you should be able to view them entering the main switch. Record everything you can read on the insulation of the conductors and photograph them if possible. You need to note the quantity, size, insulation type and conductor material (usually copper or aluminum).

Inspect the conductor insulation; if it is in poor condition the conductors may need to be replaced. If you have trouble identifying the conductor size and type, it can be useful to carry samples of various sizes and types of wire for comparison. Larger commercial systems generally use busbar distribution, and in this case, only the busbar rating is necessary. For residential systems, *NEC* Table 310.15(B)(6) provides the minimum allowable conductor size for various service and feeder ratings.

Ground fault protection device. In larger commercial systems, it is common to find a ground fault protection device (GFP) installed in the main panel coupled with the main switch on the client side. The *NEC* 690.64(B)(3) prohibits backfeeding devices that are not listed as suitable for backfeeding, and most GFP devices today are not listed for this purpose. If a GFP is present in the system, capture its make, model and electrical characteristics and photograph it. You will likely be performing a line side interconnection or replacing the unlisted GFP with one that can be backfed.

Subpanels. You may want to interconnect within a subpanel, but you will need to do some wire sizing calculations and decision making to ensure *Code* compliance. Interconnecting PV systems at the main panel by a dedicated breaker or tap is generally preferred. However, if the array is located closer to a subpanel, you may consider using it. This can result in considerable savings in labor, BOS equipment, wiring and conduit costs. When it is possible to use a subpanel,



Courtesy sunlightandpower.com

Subpanel connection? The main lug only design of this residential panel is typical of a subpanel or a main panel fed from an enclosed main breaker integral with the revenue meter. In this case, the half-size twin and quad breakers are load breakers, and the full size 20 A, double-pole breaker at the bottom of the busbar is the PV interconnect breaker, per 2008 *NEC* Article 690.64(B)(7).

capture the same manufacturer and electrical information that was necessary for the main panel, as well as the size and type of the feeder breaker, conduit and conductors.

Locating subpanels should be relatively straightforward. Subpanels will either be fed by a breaker in the main or through a fused disconnect when connected by a tap. Start by looking in the main panel for labels and larger breakers, typically 60 A or more. If disconnects are present, look for their labels and, when possible, trace the circuit to the subpanel. Typically commercial buildings will have complete sets of single line drawings, as well as facility managers who can usually answer your questions. In residential situations, asking the homeowner should get you to most subpanels on-site.

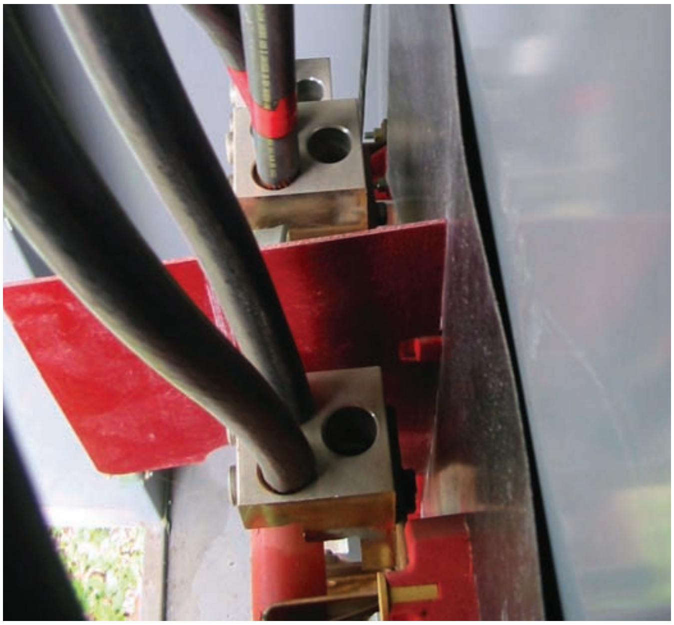
Some larger commercial buildings have bus ducts, basically a busbar distribution system within the building. Interconnecting at the bus duct is often acceptable and will allow you to tap into the load side of the main at the top floor, instead of connecting inside a smaller subpanel. This can be very helpful in rooftop PV installations on multiple story buildings, in some cases eliminating the need for thousands of feet of wire and conduit. Bus ducts, however, cannot be used for PV interconnection if a GFP is present that cannot be backfed.

Deciding on the best GEC sizing and routing method is one of the most challenging aspects of designing grid-tied PV systems. *NEC* Article 690.47 discusses GEC and bonding requirements for PV systems. Conduit size and type are also pertinent when interconnecting at a subpanel. Even if the existing feeder conductors are not large enough to handle adding the PV system, the existing conduit can still be useful. You may be able to pull larger wire through it that can support the system. Just being able to use the existing conduit has significant cost savings potential, so capture information about subpanels carefully.

POINT OF CONNECTION

Once you have completed a detailed site evaluation, you can determine if the existing electrical equipment will limit the size of the PV system. A thorough understanding of the interconnection options and limitations within the *NEC* will allow you to make safe, cost effective decisions. *NEC* Article 690.64 provides two methods for connecting the output of a utility-interactive inverter: supply side or load side.

There are benefits and limitations involved with each, and both have their share of interesting *Code* challenges. In this section, we highlight the *Code* CONTINUED ON PAGE 32



Courtesy meridiansolar.com

Empty lugs The empty lugs on the line side of this 600 A main service disconnect provide an opportunity to make a supply side connection, one that is subject to fewer size restrictions than a load side connection. When making a site survey take note of any empty lugs in electrical service equipment.

requirements for each method and discuss the important changes and clarifications made between the 2005 and the 2008 *NEC*.

SUPPLY SIDE CONNECTION

Article 690.64(A) of the *NEC* allows for a supply side connection in which a PV system is connected to busbars, conductors or lugs that are located between the utility meter and the service disconnect. A supply side connection is commonly called a *line side tap* though use of this term is controversial. The word *tap* can lead to confusion, causing many to mistakenly look to the "10-foot tap rule" or the other feeder tap rules found in *NEC* Article 240.21(B) for guidance. Since the service entrance conductors do not have overcurrent protection and are not feeders, these tap rules and all of Article 240, except 240.21(D), do not apply.

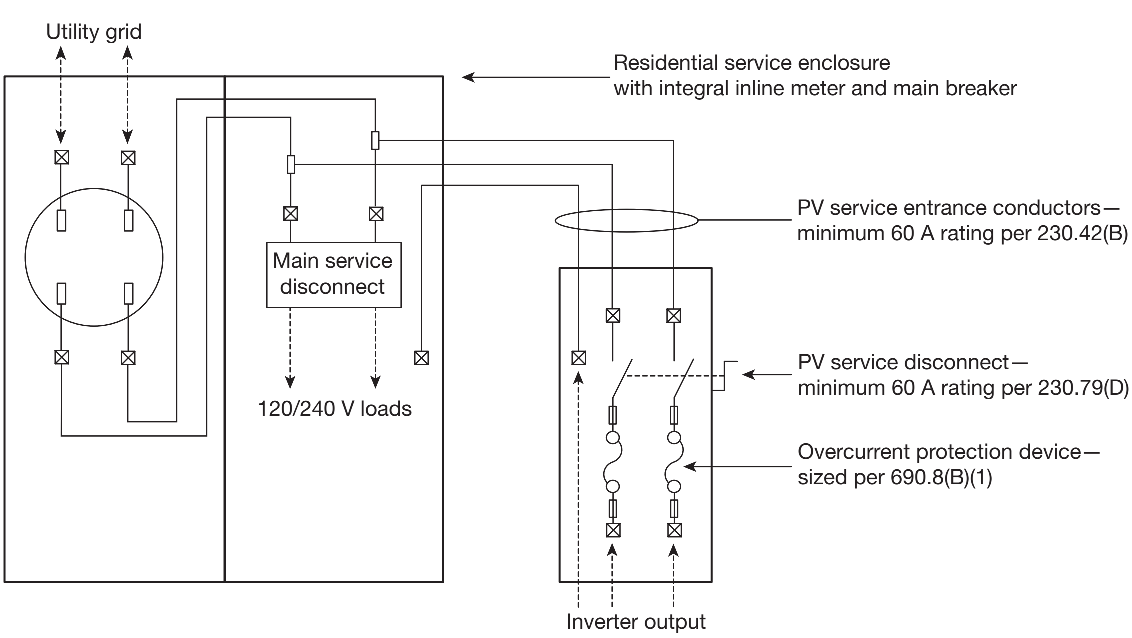
A supply side connection requires an additional service disconnect and new service entrance conductors. The applicable regulations for this are found mostly in *NEC* Article 230, which addresses the installation of services. A standard supply side connection, as seen in Diagram 1, includes new service entrance conductors, a fused PV service disconnect, fuses and bus or conductor tapping devices.

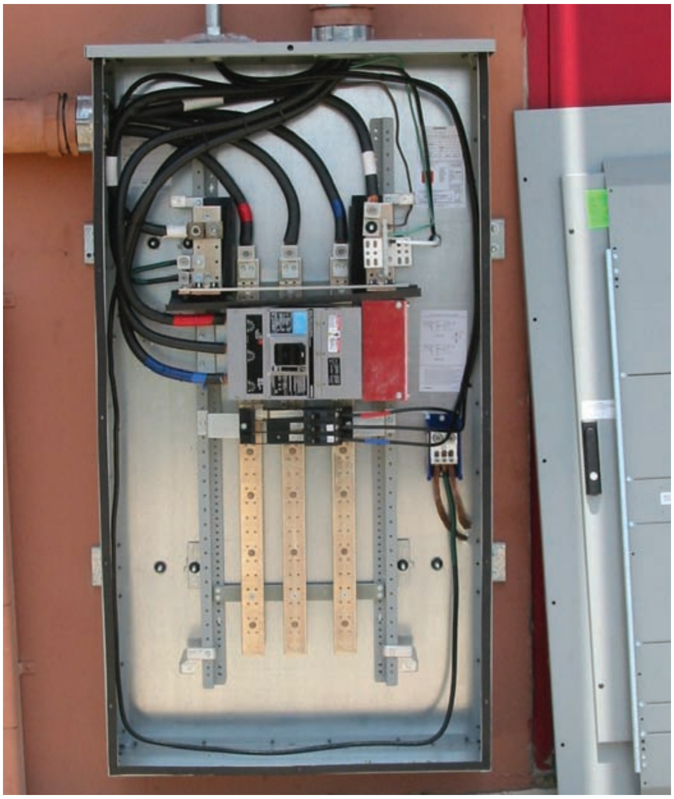
PV service disconnect. When a supply side connection is made, as permitted by Article 230.82(6), a minimum of two service disconnects are involved: the existing main disconnect and the new PV service disconnect.

Courtesy sunlightandpower.com

PV service disconnect A fused 3-phase safety switch serves as the PV service disconnect at a site employing a supply side connection. Note the use of paralleled conductors and lugs rated for two conductors each.

Diagram 1 Components of a typical residential supply side connection are shown here. Note that per *NEC* 230.79(D), the minimum rating of the new service entrance conductors and the PV service disconnect is 60 A.





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Supply side connection at breaker The original fused main disconnect at this site would not accommodate a supply side connection. Since a load side connection was not compliant per the 2005 *NEC,* the main disconnect was upgraded to a main distribution panel (MDP). Service breakers in the new MDP are subject to the six handle rule, providing room for future expansion.

Although multiple service disconnects may seem unusual, they are actually very common in the field. Article 230.71(A) addresses this issue, stating that no more than six switches or sets of breakers be required to disconnect a service. Commonly referred to as the "six switch rule" or "six handle rule," it makes supply side connections possible; but it can also be a limitation. A problem can arise when main panels are lug fed instead of having a main breaker. A PV breaker landed in this type of panel is a supply side connection and must be counted as one of the six allowed switches. If this type of panel already contains six breakers, and they often do, measures will need to be taken to enable a *Code* compliant installation.

Some jurisdictions do not allow a supply side connection. The AHJs in these areas argue that a supply side tap, made inside the enclosure, may void both the UL listing and the manufacturer's warranty for the existing service panel. Although it is possible to overcome these issues, these AHJs have gone with a better-safe-than-sorry approach, banning supply side connections altogether.

Selecting and locating the disconnect. *NEC* Article 230.66 requires that disconnects installed as part of a PV supply side connection be listed for use as service equipment. In addition, Article 230.70(A)(1) states that a "service disconnecting means shall be installed at a readily accessible location either outside of a building or structure or inside nearest the point of entrance of the service conductors." Article 230.72(A) clarifies the location of the service disconnect for the PV system, requiring that multiple service disconnects be grouped together. Taken in total, these rules require the use of a listed device that is accessible, near the service entrance conductors and grouped with the other service disconnects. The disconnect may also have to satisfy utility or fire marshal requirements.

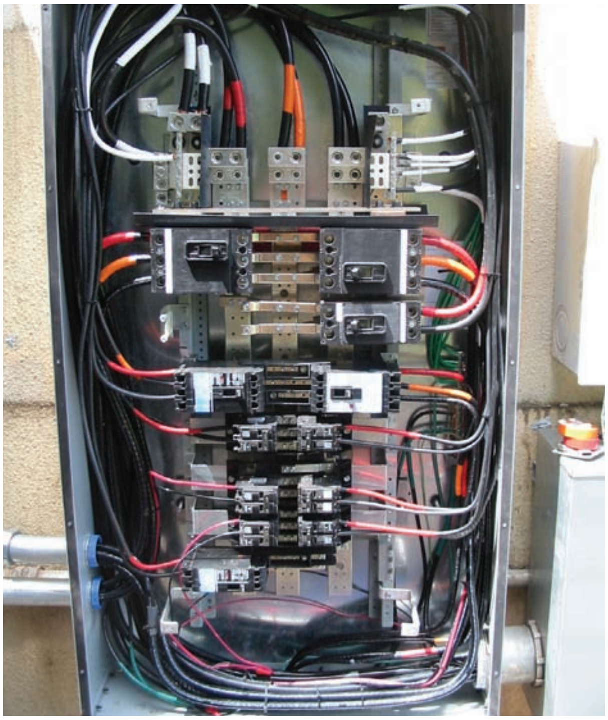
Ampacity ratings for equipment. There is some debate over the minimum rating of the PV service disconnect when making a supply side connection for a PV system requiring overcurrent protection of 30 A or less. Some industry experts believe that the PV service disconnect rating need only be large enough to handle the PV load. However, the prevailing opinion is that *NEC* Article 230.79(D) requires a minimum PV service disconnect rating of 60 A.

Article 230.42(B) requires that service entrance conductors have an ampacity not less than the rating of the service disconnecting means. For this reason the conductors that run between the PV service disconnect and supply side connection must have a minimum rating of 60 A. In most cases, *NEC* Article 240.21 requires that conductors have overcurrent protection at the point where the conductor is supplied with power. However, because the conductors running from the supply side connection to the PV service disconnect are considered service entrance conductors, Articles 240.21(D) and 230.91 allow them to be protected at the PV service disconnect. Some jurisdictions may require running the PV service entrance conductors in rigid metal conduit for additional protection.

The overcurrent protection in the PV service disconnect and the conductors that run between this disconnect and the inverter do not need to conform to the minimum 60 A rating. Instead, they should both be sized according to Article 690.8(B)(1), which requires them to carry at least 125% of the inverter's continuous output current.

Interrupt ratings for equipment. *NEC* Article 110.9 states that any new service equipment installed shall have an interrupt rating enabling it to withstand the total possible fault current in the system—the kAIC rating. In most cases, it is sufficient to use the rating of the existing service equipment as a minimum. However, the size of the available fault current is determined by the rating of the utility transformer supplying power to the location. The service equipment or utility transformer may have been changed since the original service was designed, so the safest bet is to contact the utility and request information about the available fault current for that specific site.

Sizing limitations. Electrically speaking, the size of a supply side connected PV system is limited only by the ampacity of the existing service entrance conductors. Article 230.90(A) indicates that the ratings of the PV service disconnect and overcurrent protection devices (OCPD) shall not exceed the rating of the existing service entrance conductors. For a supply side connection this means that the new PV service disconnect rating may be as large as that of the main service disconnect. At first glance, this might seem troublesome, since the service conductors are protected by overcurrent devices with a sum as much as double the ampacity of the conductors. When two to six circuit breakers or sets of fuses, however, are used to provide overload protection, you can look to Exception No. 3 under *NEC* Article 230.90(A), stating that the "sum of the ratings of the circuit breakers or fuses shall be permitted to exceed the ampacity of the service conductors, provided the calculated load does not exceed the ampacity of the service conductors." This rule applies because the power produced by a PV system will actually diminish the load being drawn from the utility, not add to it. Therefore, there is no danger of overloading the service conductors with the addition of a *Code* compliant PV system.



Courtesy meridiansolar.com

Load side connection at breaker This 800 A, 3-phase, 240 V delta panel is protected by a 600 A fused main disconnect switch (not shown), allowing for the connection of 200 A of PV per the 2005 *NEC* or 360 A of PV per the 2008 *NEC.* In this case, the 2005 *Code* applied, and the PV interconnect breaker is the third one down on the right side of the panel. Local codes require that the high leg—or stinger—is landed on the B phase.

LOAD SIDE CONNECTION

NEC Article 690.64(B) states that a load side connection is allowable at any distribution equipment on the premises, as long as the connection is made at a dedicated circuit breaker or fusible disconnection means. This type of connection most often consists of backfeeding a breaker, or multiple breakers, located in the main distribution panel. However, a load side connection can also be made through a backfed breaker located in a subpanel or by connecting to feeder conductors.

The 120% rule. This simple rule lets you determine how many amps you can backfeed through service equipment. *NEC* Article 690.64(B)(2), more than any other *Code* section, limits the size of a load side connected PV system. When a supply side connection is impossible or impractical, this rule is the limiting factor on the system size. The 2005 *NEC* states, "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." This rule is restrictive as most busbars and conductors are already fed at, or very near, their capacity. Most residential installations take advantage of the CONTINUED ON PAGE 36

Maximum Connected PV Inverter Watts

240 Volts, Single Phase			
Enclosure rating (amps)	Main breaker rating (amps)	Maximum sum of PV breaker size(s) (amps)	Maximum total inverter size (watts)
100	100	20	3,840
125	125	25	4,800
125	100	50	9,600
200	200	40	7,680
225	225	45	8,640
225	200	70	13,440
400	400	80	15,360
600	600	120	23,040

Table 1 This table shows the maximum PV inverter watts that can be connected to the load side of common single-phase residential electrical service equipment. Note how undersizing the main breaker relative to the panel's busbar rating allows for additional inverter capacity.

exception that follows, which allows the sum of the overcurrent protection devices supplying power to a busbar or conductor to be as much as 120% of the rating of the busbar or conductor.

The 2008 *NEC* expands the 120% rule to include commercial projects. These systems often connect to the supply side of the service, so they are generally unaffected by this rule. Because of its limitations, customers needing to use a load side connection must choose between a smaller system and a costly upgrade to their existing service. Many jurisdictions have not yet adopted the 2008 version of the *Code,* so it is important to check with the AHJ before proceeding with a project that requires utilizing this exception in a commercial setting.

The equation to determine the maximum sum of PV breakers that can be landed in a panel using the 120% rule follows:

$$B_{PV} = (1.2 \times A_{BB}) - A_{MB}$$

In this equation, B_{PV} is the maximum sum of the PV breakers, A_{BB} is the amperage rating of the panel busbars and A_{MB} is the amperage rating of the main breaker.

Commercial Interconnection SCENARIO with Single-Phase Inverters

- Desired system size: 22.5 kW
- Service voltage and configuration: 120/208 V, 3-phase
- Main enclosure rating: 400 A
- Main breaker rating: 400 A
- Empty breaker space: 15 empty single-pole breaker spaces
- No access for a supply side connection
- AHJ is enforcing the 2008 *NEC*

The PV system will be installed on three separate roof sections, each with a different orientation. To maximize production, the system will utilize three separate Fronius IG Plus 7.5-1 UNI inverters.

Challenge. To understand this scenario, we need to review how single-phase inverters are connected to a 3-phase panel. The distribution portion of a 3-phase panel consists of three busbars, one for each phase. When single-phase 208 V or 240 V inverters are connected to a 3-phase panel, each inverter connects to two of the three busbars, as shown in Diagrams 2a and 2b to the right. It is important to ensure that the phases do not become significantly out of balance due to the PV system. Most utilities require that no one phase in the system be supplied with 6,000 watts more or less than any other phase.

The 120% rule works the same in a 3-phase panel as it does in residential panels. No one busbar can be supplied by breakers that have an amperage greater than 120% of the busbar's rating. The output of a Fronius IG Plus 7.5-1 UNI inverter at 208 V is 36.1 A and must be protected by a 50 A breaker. As shown in Diagram 2a, when the proposed system is connected, 100 A of PV breakers feed each busbar. Since the busbars are 400 A rated and are supplied by a 400 A main breaker, only 80 A worth of connected PV breakers is allowed per busbar. The following calculations determine the maximum connected PV breaker rating:

$$B_{PV} = (1.2 \times A_{BB}) - A_{MB}$$
$$B_{PV} = (1.2 \times 400\text{ A}) - 400\text{ A}$$
$$B_{PV} = 480\text{ A} - 400\text{ A}$$
$$B_{PV} = 80\text{ A}$$

Solution. This problem can be solved by landing the PV system in a subpanel before connecting it in the main. The math needed to prove this point can be done in a variety of ways, some involving complex vector addition diagrams. A simple way to understand it is this: once a PV system consisting of balanced single-phase inverters has been connected in a subpanel, from that point on the math is done as if the system consisted of a single 3-phase inverter.

In our example, stacking three single-phase 7.5 kW Fronius IG Plus inverters across all three phases of the service results in the equivalent of a 22.5 kW 3-phase inverter. The math to calculate the phase current for this 3-phase system is relatively straightforward, as shown in the following formula, where I_{PH} is the phase current, W is the total watts of the inverter(s) and V is the system voltage:

$$I_{PH} = W \div (\sqrt{3} \times V)$$
$$I_{PH} = 22{,}500\text{ W} \div (1.732 \times 208\text{ V})$$
$$I_{PH} = 22{,}500\text{ W} \div 360\text{ V}$$
$$I_{PH} = 62.5\text{ A}$$

When this equation is applied to a 22.5 kW inverter, it yields a phase current of 62.5 A. This requires protection by an 80 A breaker (62.5 A x 1.25 = 78.1 A), the maximum size allowed to connect to a busbar that is rated at 400 A and supplied by a 400 A main breaker.

If the existing service were 3-phase 277/480 V, the math would have been much easier. In this case each single-phase inverter is connected between one phase and the neutral. The current per phase is simply the sum of the output current of all the

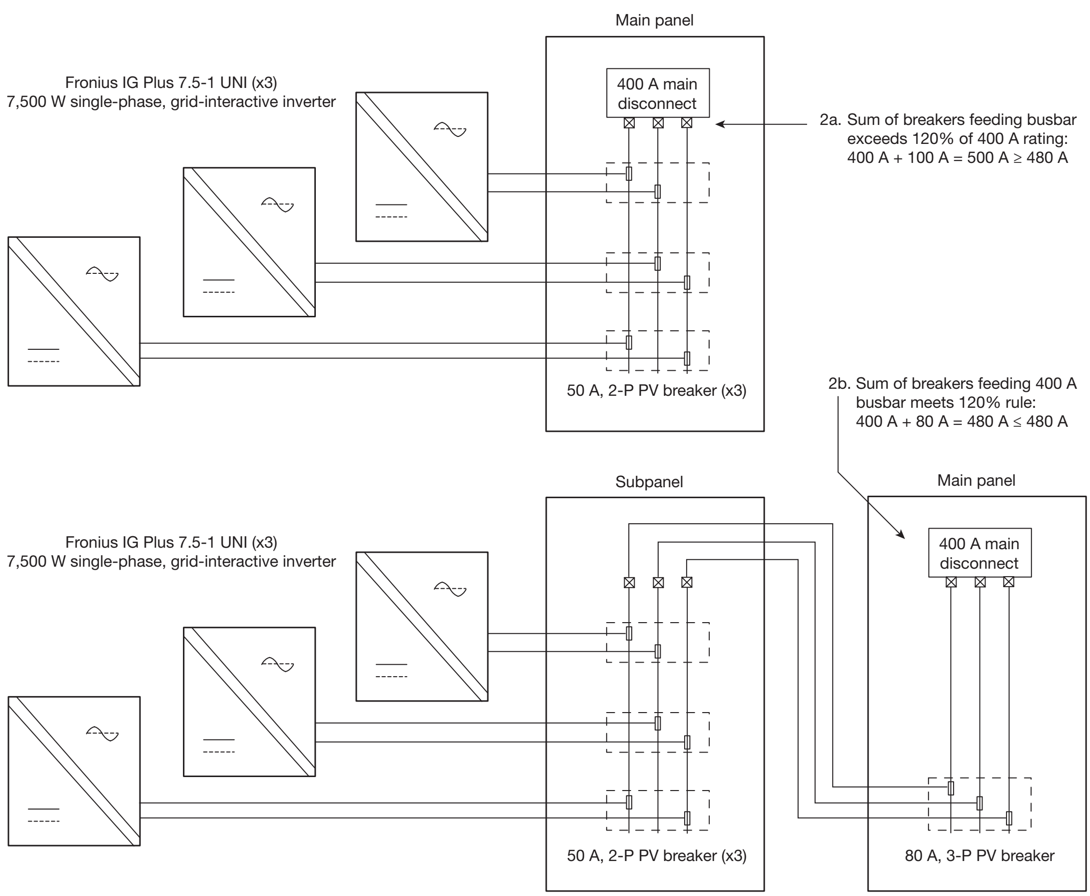
Ground fault protection. *NEC* Article 690.64(B) provides regulations governing load side connections. A PV power source should not be connected on the load side of ground fault protection (GFP). As noted by John Wiles in "Making the Utility Connection," June/July 2005, *Home Power* magazine, tests have shown that the sensing and trip circuits in GFP breakers can be destroyed if they are tripped while being backfed. This is the reason that a connection must be made on the line side of all ground fault devices, unless the particular device is listed as suitable for backfeeding. This issue often comes up on larger commercial systems, because many commercial locations include GFPs that are integral with the main service disconnect.

Listed breakers. Like a GFP device, a standard breaker can be damaged by backfeeding if it is not listed for the application. Article 690.64(B) in the 2008 *NEC* specifies that if a breaker is marked "Line" and "Load," it may be fed in only one direction. If a breaker has no such markings, it is suitable for backfeeding and may be used to connect a PV system. When connecting in a subpanel, it is important to determine

inverters connected to each phase. (For more examples of inverter output current calculations, see "From kW to MW: System Design Considerations," October/November 2008, *SolarPro* magazine.)

The calculations here work for systems with balanced inverters only. If a single Fronius IG Plus 5.0 were added to the system in this example, it would not be possible to calculate the phase current by considering the system to be a single 27.5 kW system. Instead, it would be necessary to add the 24 A output current of the additional inverter to the two phases it is connected to. ●

WEB EXCLUSIVE SEE THE ONLINE VERSION OF THIS ARTICLE AT SOLARPROFESSIONAL.COM FOR TWO ADDITIONAL INTERCONNECTION SCENARIOS.



Diagrams 2a & 2b In Diagram 2a (top), the sum of the breakers supplying each busbar exceeds the limits of the 120% rule. As shown in Diagram 2b, landing the inverters in a subpanel solves the problem.

whether every breaker that will be backfed by the PV system is acceptable for this use.

Inspectors familiar with *NEC* Article 408.36(F), which requires backfed breakers to be secured with an additional fastener, may need to be made aware of Article 690.64(B). This states that breakers supplying power to an electrical panel as part of a PV system do not need to be individually fastened to the panel. It is, however, important to make sure that the cover or dead front for the panel is in place.

PV breaker location. Changes in Article 690.64(B) of the 2008 *NEC* determine the PV breaker location when the sum of the breakers feeding a busbar is greater than the rating of the busbar. In such cases the PV breaker must be installed at the opposite end of the bus from the main breaker or feeder lugs, and a label must indicate that the breaker may not be relocated. This positioning ensures that the ampacity rating of the device is never exceeded at any point on the busbar.

New language in the 2008 *Code* clarifies the rules for connecting a PV system in a subpanel. Ambiguity in the 2005 version made it very difficult to employ the 120% rule. This is illustrated in Diagram 3. The new language, found in Article 690.64(B)(2) of the 2008 *NEC,* states that only breakers directly connected to the inverter are counted in the backfeed calculations.

Labeling requirements. *NEC* Article 690.64(B)(2) states that labeling is required for equipment containing an overcurrent device that supplies power to busbars or conductors that are fed from multiple sources. The label must indicate all sources of power to the busbar or conductor. CONTINUED ON PAGE 40

Courtesy meridiansolar.com

Line side residential at breaker This 200 A service panel from Midwest Electric Products is configurable as either a main breaker panel or a main lug panel, depending on the lugs where the utility service conductors are terminated. In this case, the panel is configured as main lug only, making both the 200 A main breaker and the 60 A PV breaker line side service equipment. This supply side connection does not have to comply with the 120% rule found in *NEC* 690.64(B).

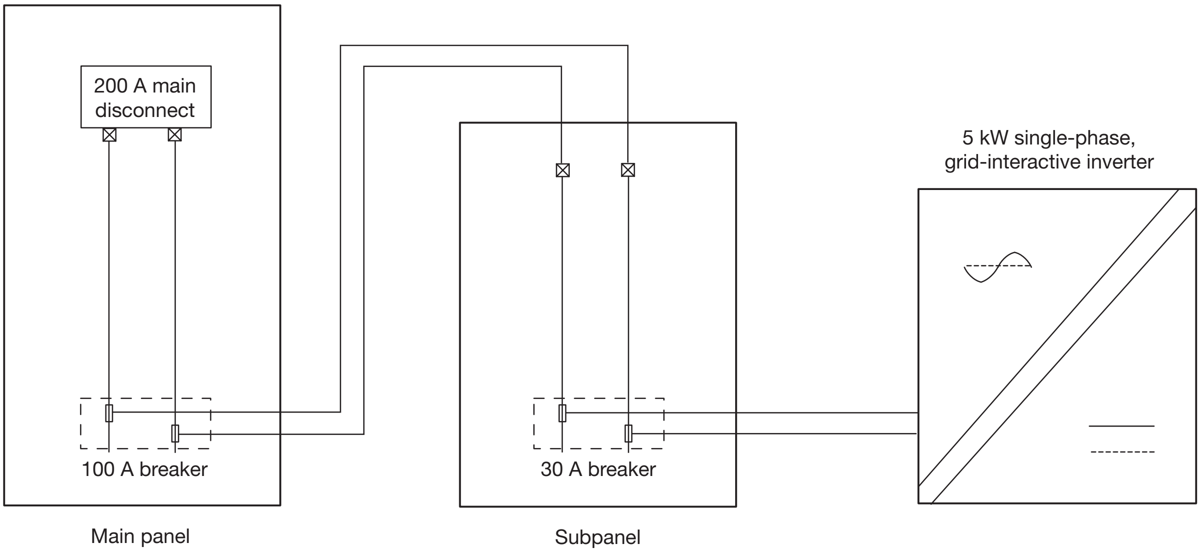


Diagram 3 Article 690.64(B)(2) of the 2005 *NEC* requires using the 100 A breaker in backfeed calculations for the main panel busbars. New language in the 2008 *NEC* clarifies that the rating of only the 30 A breaker is counted, although each panel must still be evaluated all the way back to the main.

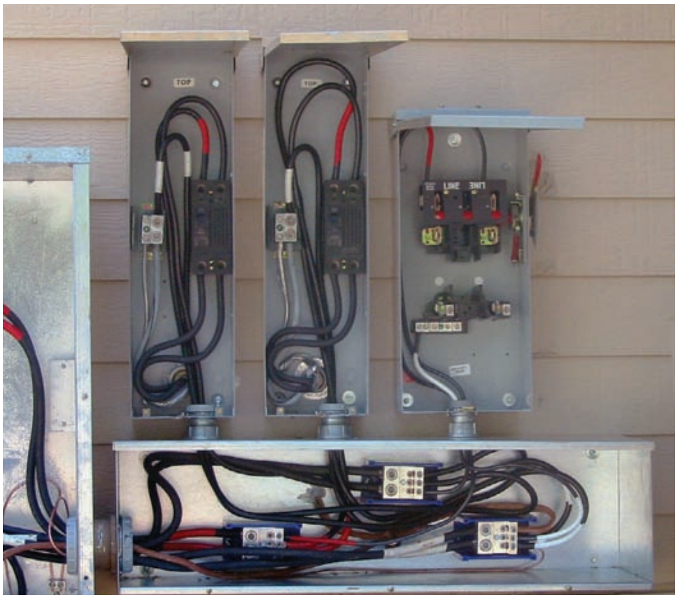
This is to prevent a mistaken assumption that electrical equipment is deenergized when only one of the power sources has been shut off. Article 705.10 further requires the installation of a permanent plaque or directory at every service equipment location, indicating all sources of electric power on the premises.

METHODS OF INTERCONNECTION

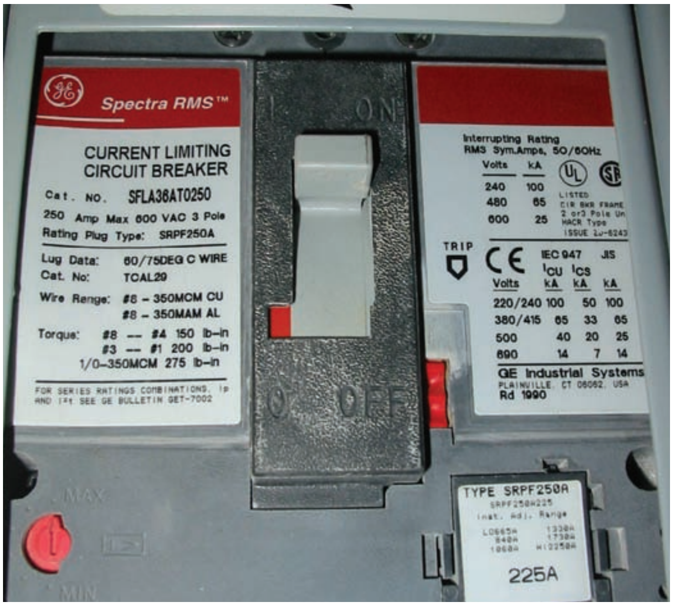
The *NEC* has many rules and provisions specific to the interconnection of photovoltaic systems. Making sense of all of these and putting them to practice is sometimes challenging. Here we discuss the most common compliant devices, practices and methods of interconnection. Although residential and commercial electrical systems vary in capacity, they are often made up of similar components and have similar methods of interconnection.

BACKFED BREAKERS

Backfeeding a breaker is a relatively fast and simple way to perform a load side connection. It requires few parts and often can be safely performed without disconnecting the service. This method requires only an installed breaker, conduit run from the inverter to the electrical panel and pulled and landed wires. The downside is that the 120% rule can severely limit the PV system size. Consider the following techniques for maximizing the amount of interconnected solar capacity.



Line side tap in gutter Insulated power distribution blocks in gutters are another convenient location for making a supply side connection. In this case, a new PV service disconnect (on the right) is installed alongside the existing service disconnects at the site. Make sure to use UL listed, not just UL recognized, power distribution blocks with dead front covers.



Courtesy meridiansolar.com (2)

Adjustable trip Replacing the rating plug in this 250 A breaker frame adjusts its trip rating. In this case, a 225 A rating plug is used. The breaker label includes a great deal of additional information useful to designers and installers, including interrupt ratings, wire ranges, torque specs and rating plug type.

Service-targeted inverters. Some inverters are specifically designed to maximize the amount of power connected to common residential services. A 3,800 W inverter, for example, has a required breaker size of 20 A at 240 Vac. This is targeted for a 100 A panel with a 100 A main breaker. Likewise, a 7,500 W inverter is targeted, at 240 Vac, to backfeed about as much solar capacity as possible onto a 40 A breaker, the largest size allowed by the 120% rule in a common 200 A panel with a 200 A main breaker.

Amp shaving with subpanels. In some cases it is possible to shave 5 A or more off the required breaker size by combining inverter outputs in a subpanel before connecting to the existing equipment. The Fronius IG 2000 and IG 3000 inverters are good examples. The maximum output current of the IG 2000 is 8.4 A and requires a 15 A breaker; the output current of the IG 3000 is 11.3 A and also requires a 15 A breaker. This results in a total of 30 A worth of breakers, if the inverters are landed separately in an existing panel. However, if the output of the inverters is combined in a subpanel first, the math works out differently. The combined output current of both inverters is 19.7 A, requiring protection by only a 25 A breaker (19.7 A x 1.25 = 24.63 A).

Downsizing the main breaker. To avoid nuisance tripping or worse, this technique must be done carefully. To appropriately downsize the main breaker, you must perform an accurate and detailed load calculation per *NEC* Article 220. When downsizing is possible, you gain the difference in amps between the old main service breaker and the new one. Coupling the 120% rule with the gained amps from downsizing may prove a cost effective way of installing the desired PV system size.

If you have a residential 200 A panel with a 200 A main breaker, for example, you can install up to 40 A of PV with the 120% rule. If the loads on that service never exceed 140 A, and a 175 A main breaker is available for the panel, you may consider downsizing the main breaker and installing up to a total of 65 A worth of solar. In some commercial applications, downsizing the main breaker will simply involve replacing the rating plug in the breaker.

Limited breaker space. Though the 120% rule can be limiting, there are many cases when it adequately supports the installation of an appropriately sized photovoltaic system. In some situations, however, even when the math allows a load side connection at a breaker, you may find that there is not enough space for the PV breaker. Two common strategies for resolving this issue are using thin breakers or installing subpanels.

Replacing existing full sized breakers with thin breakers often frees up room in a panel. A thin breaker operates just like a full sized breaker but takes up only half the space. A variety of thin breaker styles are available, including single-pole thin breakers, single-pole twin breakers, double-pole thin breakers and double-pole quad breakers. Examples are detailed in Table 2.

If a panel is already packed full of thin breakers or if the required thin breakers are unavailable, you can also make room in the existing panel by installing a new subpanel.

Thin Breaker Types

Manufacturer / Model	Single-Pole	Twin/Tandem	Double-Pole	Quad
GE / THQL	✓		✓	
Cutler-Hammer / BR		✓		✓
Cutler-Hammer / CH		✓		
Square D / Homeline		✓		✓
Square D / QO		✓		
Siemens / ITE		✓		✓

Table 2 Thin breaker types differ by manufacturer and model.

In some cases, money spent upgrading an existing service will not only allow the installation of a larger PV system, but it will also increase the safety of the home or business while allowing load expansion.

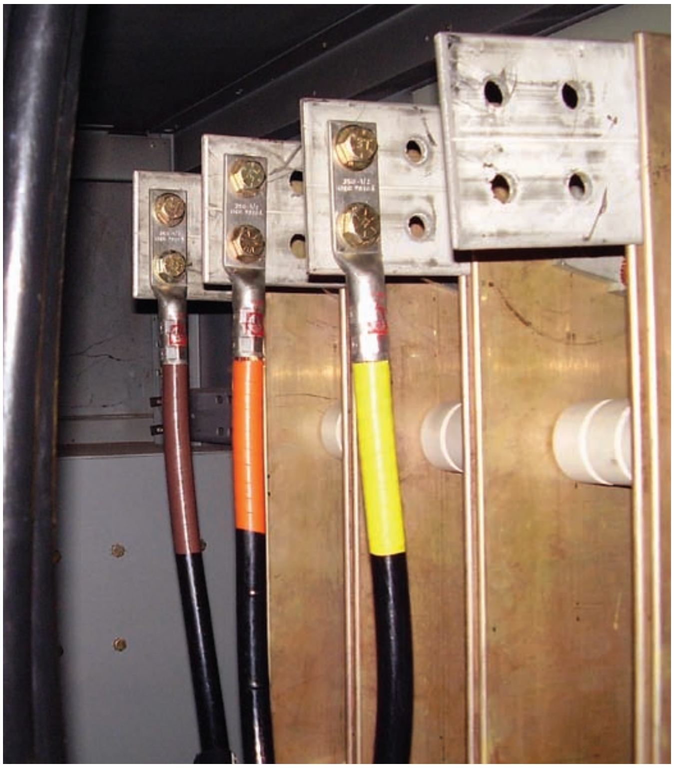
This can work in two ways. You may either move enough breakers out of the existing panel to land the backfed PV breaker there, or, if the new subpanel and feeder conductors are sized appropriately, the PV system can land in the subpanel. The downside to this is that it increases your involvement with the customer's electrical system. As a solar professional, you are in the business of installing PV, not dealing with time-consuming residential electrical issues. It may be best if the customer hires an electrician to install the new subpanel.

Breaker compatibility. The wide variety of panel and breaker manufacturers can lead to confusion about which breakers are appropriate for various panels. Though many breakers seem physically interchangeable, they may not be. A careful installer will ensure that a breaker is suitable for backfeeding and approved for use in the panel where it is to be installed.

It helps to understand the difference between a *specified breaker* and a *classified breaker.* A specified breaker is one that the panel manufacturer has listed as appropriate for use in its product. A classified breaker is one that has been tested by a third party—Underwriters Laboratories, for example—for use in a panel.

There should be no difference in the performance of specified or classified breakers, but some panel manufacturers may claim that the use of breakers other than their own will void the warranty. The Magnusson-Moss Warranty Act prohibits manufacturers from requiring their own replacement parts to maintain warranties. The use of a classified third party breaker should be acceptable, as long as the device is listed and identified for the application. As always, however, the use of these products is ultimately up to the AHJ.

Some manufacturers produce breakers that are classified for use in a wide range of panels. The Cutler-Hammer CL breaker, for example, is UL classified for use in Crouse Hinds, GE, ITE, Siemens, Square D Homeline and Murray panels. Stocking this model, or similar breakers, can save time and decrease the amount of inventory required.



Courtesy spgsolar.com

Supply side tap connection The inverter output conductors in this photo are tapped to the busbars that run between the meter and main disconnect in this main service enclosure. The connection in this case is made using crimp lugs that are bolted to existing holes in the busbars.

Service upgrade. Upgrading the existing service is usually the last option for increasing the allowable size of a PV system when connecting the system on a backfed breaker. Service upgrades are costly and may prove a barrier to a sale. In many cases, however, a service upgrade is a worthwhile improvement to a home or business, especially those with an older service.

Older homes often have electrical panels that are in poor condition, are not up to date with current *Code* requirements and may need to be replaced in the near future anyway. This is due in part to our ever-increasing electrical demands, as older services were never intended to support air conditioning and other large loads common today. In these cases, money spent upgrading an existing service will not only allow the installation of a larger PV system, but it will also increase the safety of the home or business while allowing load expansion.

When considering a service upgrade, check whether the service wires are overhead or underground. If the wires are underground, it is most likely the customer's responsibility to replace them. This can add further cost to an already pricey option. CONTINUED ON PAGE 44

shawnschreiner.com

AC side connections Borrego Solar line-side connected a 106 kW PV system at Veritable Vegetable's warehouse in San Francisco by landing at busbars between the revenue meter and main switch. Equipment right of the main service enclosure includes the fused PV system service disconnect, an inverter aggregation panel and 14 SMA inverters.

LOAD SIDE TAP

A load side tap is a connection made to busbars or conductors on the client's side of the main service disconnect or main breaker. The rules for carrying out this type of connection are not well defined, even in the 2008 *NEC*. There are, however, a few basic points that are important when considering a load side tap.

First, even though this is a tap connection, it must conform to the 120% rule as defined in Article 690.64(B). Perform calculations for all busbars upstream of the tap to ensure that the 120% factor is not violated. Second, busbars downstream from a load side tap must be protected by a main breaker, unless the sum of the overcurrent devices supplying power to that busbar—the PV breaker plus any other upstream feeder breaker—does not exceed the busbar's rating. Although this is not as explicitly stated in the 2008 *Code* as it was in the 2005 *NEC* 690.64(B)(2), it is necessary to prevent the downstream busbars from being fed at a level exceeding their ampacity. Third, all breakers between the tap and the utility should be checked to make sure that they are suitable for backfeeding. Finally, confirm that the tap is on the line side of all GFP equipment, unless the GFP is listed for backfeeding.

Furthermore, you may wish to consider the changes proposed for Article 705.12(D) in the 2011 *NEC* for a load side connection. Although these proposals may not make it to the next *Code* cycle, they do provide insight into the most recent thinking on load side connections. You can find the proposed *Code* changes that apply to PV systems on the Solar America Board for Codes and Standards Web site at solarabcs.org.

SUPPLY SIDE TAP

Briefly, a supply side tap is a connection made to the busbars or conductors on the line or utility side of the main service disconnect. Though you may regard a backfed breaker as easier to install, a supply side tap has its benefits as well. For example, a line side tap is the preferred method of interconnection when installing a PV system that exceeds the 120% rule.

Until your local AHJ adopts the 2008 *NEC,* a line side tap is probably your preferred connection for commercial photovoltaic installations. It is also the go-to method when a load side connection requires backfeeding an unlisted GFP device.

When performing a supply side tap, you are faced with the challenges of physically connecting to a conductor or busbar. An overview of the most common devices used for performing these connections follows. CONTINUED ON PAGE 46

Insulation-piercing tap splice connectors. Usually the easiest conductor tapping device to install is a tap splice connector that pierces the conductor's insulation to make electrical contact. These devices are available for a variety of wire sizes and types. Insulation-piercing tap splice connectors can be installed on live service conductors, making them the best choice when a shutdown is inconvenient or costly. These devices are often very bulky, however, and may not fit in even mildly crowded electrical panels. To avoid arcing and failure, secure insulation-piercing tap splice connectors at the specified torque values; some of these devices have snap-off plastic bolts that ensure the appropriate connection without the use of a torque wrench.

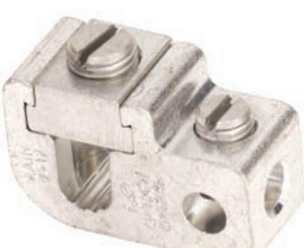
Courtesy idealindustries.com

Buchanan B-TAP

Courtesy greaves-usa.com

Insulated terminal block

Insulated terminal blocks. These simple tapping devices are available for a variety of wire gauges. Unlike insulation-piercing tap splice connectors, these devices require a service shutdown. Depending on appropriate sizing, the conductor being tapped may remain continuous passing through the device, or it may be cut and landed individually on a three-hole version. Though insulated terminal blocks are also bulky, they may be useful when insulation-piercing tap splice connectors will not work, as they can provide flexibility for positioning inside a panel.



Courtesy idealindustries.com

Parallel tap connector

Gutter or parallel tap connectors. These devices are similar to insulated terminal blocks in installation and application. Though more expensive, these connectors offer increased flexibility by allowing connections in limited spaces. With a lay-in-lug design, Greaves Gutter Tap connectors or the Parallel Tap Connector from Ideal Industries allow a continuous service conductor and perpendicular or parallel tap conductor positioning. Like terminal blocks, an electrical shutdown is necessary for installing and servicing this type of connector.

Courtesy burndy.com

Burndy H-Crimpit

Crimped devices. There are a variety of crimped devices available for making tap connections to conductors. These devices, such as the Burndy H-Crimpit, often require the use of a hydraulic crimping tool, fitted with a specific die. When appropriately installed, these connections are sturdy and irreversible, eliminating the need to maintain torque values over time. Crimped devices, purchased for specific conductor sizes, usually take up less space than other options, though the use of a crimping tool may be limiting in tight spaces.

Courtesy idealindustries.com

Split bolt

Split bolt. Products like this dual-rated, Type AS split bolt from Ideal Industries are a relatively simple, flexible and affordable method of making a connection to a continuous service entrance conductor run. These are bulky connections when properly taped, but the quality of the connection is high.

Courtesy greaves-usa.com

Compression lugs

Compression lugs. The most common method of tapping onto busbars are crimped lugs. These devices are crimped to the ends of the tap conductors and bolted to the busbars. When existing holes or bolts are not available, it may be possible to drill the busbars and recertify the equipment. Crimped lugs require relatively little space, though an electrical shutdown for installation and torque maintenance is required.

HAPPY LANDINGS

There are many important aspects involved in the connection of a utility-interactive PV system. These include performing a quality site evaluation, understanding the *NEC* and mastering the available methods of interconnection. All of these are relevant to a safe and cost effective installation. Many of these rules are still being developed and debated, and each new *Code* cycle brings changes to the industry and to interconnection methods.

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Manufacturers

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Greaves Electrical Connectors / 800.243.1130 / greaves-usa.com

Ideal Industries / 800.435.0705 / idealindustries.com

Midwest Electrical Products / 507.345.2505 / midwestelectric.com