Pulling

Strategies for Making Common Connections in PV Power Circuits

It All Together

By Tommy Jacoby and David Brearley

As defined in the *National Electrical Code* Article 690.2 a *photovoltaic power source* is "an array or aggregate of arrays that generates dc power at system voltage and current." Additional definitions clarify that at least three dc circuit types may be present in the PV power source for a grid-tied PV system, defined as *photovoltaic source circuit*, *photovoltaic output circuit* and *inverter input circuit*. While these terms are self-explanatory to many industry veterans, terminology common in the field may vary.

The photovoltaic source circuit, for example, is defined as "circuits between modules and from modules to the common connection point(s) of the dc system." In practice, PV source circuits are commonly referred to as *strings* or simply as *source circuits*. PV output circuits are often referred to as *array circuits*. The "common connection point(s) of the dc system" are multiple and varied, as reflected by the nomenclature—combiner boxes, recombiner or subcombiner boxes and so on. In some cases, connection points occur at dc disconnects that are inverter integrated or even external to the inverter. In this article we discuss the location and form of these common connection points and the intelligent use of the equipment options available to PV system designers and installers.

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Common connection point PV source circuits are connected in common at a SolarBOS combiner box at Riverdale High School, in Riverdale, CA. SPG Solar designed and installed the PV system for Honeywell, a provider of energy service solutions.

IDENTIFIED AND LISTED FOR THE APPLICATION

Although equipment for making common connections is often anonymously aggregated under the heading "balance of system components" (BOS), the 2008 *NEC* requires that source circuit combiners be "identified and listed for the application." So from a *Code* point of view, a combiner box is treated no differently than a PV module or a grid-direct inverter.

Prior to the 2008 *NEC*, it was not uncommon for PV installers to build their own PV source circuit combiner boxes. Many of these custom built combiners utilized high quality components that were properly rated for their application. However, while the individual components may have been listed, identified and even used properly (given the environmental conditions, system voltage and current, and so forth), the final product itself was not identified and listed as an assembly. Further, not all site built combiners included properly rated components.

John Berdner, groSolar VP of technology, notes that the use of plastic enclosures for combiner boxes is a common mistake. "Solar systems should be designed for a minimum life of 30 years," Berdner observes, "so enclosures should be metallic or fiberglass. Plastic degrades when exposed to sunlight. It gets brittle and will fail." This is precisely the sort of scenario that *NEC* 690.4(D) seeks to avoid.

For companies accustomed to building their own combiner boxes, the *NEC* requirements may seem unnecessary and inconvenient. But having combiner boxes independently tested and listed is in the best long-term interests of the PV industry. For example, AMtec Solar, a leading manufacturer of combiner and recombiner boxes, produces industrial grade equipment that is rated to UL 1741. In fact, the company goes one step further by building to a

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Do not touch! Finger safe busbars, as shown in this AMtec Solar recombiner, are not required by UL 1741 at present. Experts we talked with expect changes to the standard to require this feature in all combiners in the near future.

standard it anticipates UL 1741 will require of all combiner boxes in the future: silkscreened labeling, touch safe fuse holders, oversized output lugs, labeled torque values, busbars supported with large insulators and finger safe covers over all live busses. This approach gives AMtec Solar confidence that its products will last as long as a PV installation itself and be just as safe. As Tom Willis, sales manager at AMtec Solar, points out, "The combiner box is just as important as the inverter; if the combiner box fails, so does the system."

DEFINITIONS: IDENTIFIED AND LISTED

The authors of the *NEC* have a very specific intent in requiring combiner boxes that are "identified and listed for the application." This is clarified in Article 100, which provides specific definitions. When the term *identified* is applied to equipment, for example, the equipment is recognized as "suitable for the specific purpose, function, use and environment." Per the fine print note that follows, "investigation by a qualified testing laboratory" is one of the main ways that products are evaluated. This process is expanded upon in the definition of *listed*. Equipment is considered listed when it is "included in a list published by an organization … that maintains periodic inspection of production of listed equipment … and whose listing states that … the equipment … has been tested and found suitable for a specified purpose."

Embedded in this rather long definition of *listed* is a clause stating that the organization publishing the list shall be "acceptable to the authority having jurisdiction" (AHJ). In general, Underwriters Laboratories (UL) is the entity responsible for defining equipment listing and evaluation criteria in the US. But other independent testing agencies—like Intertek, the company that offers the ETL Listed Mark—can test to UL standards. Markings such as CSA or CE indicate that testing is performed to international or European standards. While these may meet or exceed UL standards, any electrician will tell you that it is unlikely that these listings alone will satisfy an AHJ in the US.

The combiner products that we discuss in this article and detail in the tables on pages 46 and 48 are listed by either UL or ETL or have pending listings. Many but not all of the products are correspondingly marked for use in Canada. Integrators there should verify the listing details for each product carefully or verify product acceptability in advance. Also, not all of the products we cover are currently listed to the same UL standard. This is a result of changes taking place in the industry to meet *NEC* 690.4(D), which requires that all combiners be listed to UL 1741, the safety standard for distributed generation equipment. Previously, some combiner boxes were listed to UL 508A, the safety standard for industrial control equipment. This does not necessarily mean that an AHJ will not accept inventoried combiner boxes that are listed to UL 508A. It does mean, however, that the practice of listing combiners to UL 508A is being eliminated.

COMING TO TERMS WITH COMBINERS

One of the main benefits that a combiner provides PV system integrators has nothing to do with connection points, our main focus in this article. Because PV source circuit wiring consists of expensive single conductor cable, installers often transition to less expensive wire that is protected in conduit or some other raceway. While this basic function does not require a combiner per se, often the switch happens in a combiner box. In many 1 kW to 3 kW grid-direct PV systems, there is no need for connecting PV source circuit conductors in common prior to the inverter or dc disconnect. This is the case in an array design that calls for a single series string of modules, for example. Often a junction box is installed in these systems, but it is not used to combine circuits. CONTINUED ON PAGE 32

Transition box Even on commercial projects, like this SPG Solar installation for the Gundlach Bundschu Winery, there is a need to transition from USE-2 in free air to THWN-2 in conduit without combining circuits.

We will refer to the simplest tool available to installers for this purpose as a *transition box*. As the term is used here, a transition box is an appropriately rated enclosure containing appropriately rated lugs or terminals that serve the sole purpose of transitioning between PV Cable or USE-2 single conductor in free air to THWN-2 or equivalent in conduit. This definition points out by contrast the other important functions that most combiner products provide.

In addition to allowing for wire types to transition, a combiner is generally also a place in a PV system where wire size is increased. Series electrical connections increase voltage; parallel electrical connections increase current. Increasing current requires using conductors with higher allowable ampacities. Transition boxes could also be used to increase wire size in a PV system, for example to account for voltage drop in a long wire run. However, while wire size may occasionally increase at a transition box, this is often unavoidable at a combiner. In combiners, increasing the available current requires increasing the circular mils of copper downstream from the point of common connection. Very often increasing the available current requires overcurrent protection.

Courtesy solarbos.com

Recombiner box Output from multiple combiner boxes can be connected at recombiner or subcombiner boxes like the SolarBOS Array Combiner.

Veteran designers and installers are well aware that one- or two-string array configurations—when used with an inverter that is certified not to backfeed fault current from the grid to the dc side of the system—do not require series string overcurrent protection. No source of fault currents exceeds the series fuse rating of the modules. In some cases, even a three-string array configuration will not require an overcurrent protection device (OCPD) in each series string. Designers have to do the math to make that determination. (To better understand PV source circuit overcurrent protection requirements, refer to John Wiles' Q&A, "Series String OCPD Requirements for Grid-Direct Inverter Applications," December/January 2009, *SolarPro* magazine.) Systems combining more than three series strings require overcurrent protection.

Besides serving as a location to transition between wire types and sizes, most combiners will therefore include overcurrent protection for ungrounded source circuit conductors and, on more complex systems, for the PV output conductors as well. In most cases, the OCPDs in a combiner protect the PV positive conductors, but not always. In a positively grounded SunPower system, for example, OCPDs will be located inline with the PV negative conductors. In a system using a transformerless inverter, the ungrounded array will have OCPDs protecting both the positive and negative conductors.

Having described the attributes that most combiners share, we can now draw distinctions. There are two main types of combiners: combiner boxes and recombiner boxes. These products are distinguished by where they fall in the PV system. A combiner for PV source circuit conductors is defined as a PV *source circuit combiner box*. In general, however, these are simply called *combiner boxes*, so when we refer to a combiner box, we are specifically referring to the source circuit combiner box. When we refer to combiners or combiner products, we mean the general category of equipment in all its forms.

The second main type of combiners is a *recombiner*, also referred to as an *array combiner* or *subcombiner*. In large PV systems, multiple combiner boxes are often necessary, and the outputs of these combiner boxes may need to be combined again—recombined—before reaching a central inverter. We use the term *recombiner* whenever PV output circuits are combined in the field, external to the inverter. Where inverter input circuits are combined internal to the inverter, we refer to this common connection point as a *subcombiner*. In practice, these terms are often used interchangeably.

Both recombiners and subcombiners share the features we discussed earlier. They accommodate an increase in wire size, or, in the case of a subcombiner, a transition to the inverter dc input busbar, and they incorporate OCPDs for conductors. Combining PV output or inverter input circuits requires overcurrent protection whenever the combined fault current available at the busbar exceeds the ampacity of the upstream conductors. Placing these fuses internal to or external to the inverter are just two of the many options available to PV system integrators.

OVERVIEW: COMMON COMBINER APPLICATIONS

Combiner products exist for three main PV applications: residential grid-direct PV systems; PV systems with battery banks, be they off-grid or utility interactive; and commercial, industrial or other large grid-direct PV systems. A wide variety of products can accommodate a range of applications; see the tables on pages 46 and 48 for details.

It is useful to examine some design and installation options for combiner products in these three contexts. It is also, however, a somewhat artificial exercise, and readers should keep this in mind. As long as the component's listing is maintained in the specific application, there is no reason why one product could not serve all three applications. At the same time there are certain products that will commonly be found in only relatively low voltage battery-based applications, for example, or in only relatively high current, high voltage grid-direct applications.

Also keep in mind that the examples in this article are intended to suggest the wide range of ways that combiners may be properly deployed. There are many creative and convenient ways to use combiner products. These examples are not comprehensive, nor are they exclusive of other solutions. In fact, the best solutions are specific to your application. In some cases this involves getting the best use out of an off-the-shelf product; in other cases this may mean placing a custom order.

Whatever your application, all of the products used in these examples are included in the companion table, as are many more products for designers and installers to choose from. (See Resources for all manufacturers' contact information.)

RESIDENTIAL GRID-DIRECT PV SYSTEMS

Perhaps the first question that designers and installers of residential grid-tied PV systems should ask is, "Do I even need a combiner box?" Many systems in the 1 kW to 3 kW size range may not. These are relatively high dc voltage applications, after all, with an approximate operating voltage between 300 Vdc and 500 Vdc, and a maximum open circuit voltage of 600 Vdc. The operating current in a system this size is often in the 5 A to 15 A range, and the available fault current is often in the 0 A to 10 A range, before any multipliers are applied.

Clearly, a one-string array design does not require a combiner box. A small NEMA 4 enclosure located on the roof and containing Polaris connectors will suffice to transition between PV Wire in free air and THWN-2 in conduit. In many cases, a rooftop transition box will also accommodate two-string array designs. This can be accomplished in a code compliant fashion with the proper components.

System without combiners. Consider a 3,150 W PV array made up of 18 SolarWorld 175 W mono Sunmodules that will be interconnected to the grid using a Fronius IG Plus 3.0. The Fronius Configuration Tool recommends an optimal array configuration of nine modules per series string and two strings in parallel. While the Fronius IG Plus inverters feature integrated PV source circuit combiners, the installer

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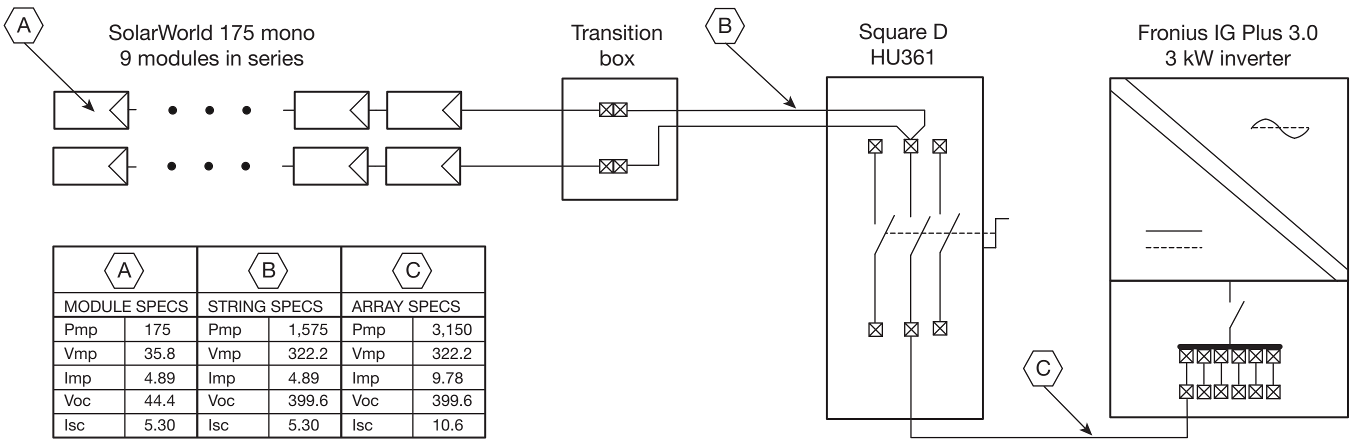
Proper grounding *NEC* 250.97 requires grounding metal raceways for circuits over 250 V to ground. In this case, a bonding bushing is used to properly ground the metal conduit leaving this fiberglass combiner box enclosure from Blue Oak PV Products.

must provide series fuses to meet the specific application. The inverter ships with a conductive slug installed in each fuse holder, and each dc input terminal is rated for up to 20 A. Even in this simple system a wide range of wiring options are available. These include bringing two pairs of USE-2 off the roof—in conduit, of course—down to the inverter. This would not be most installers' first choice. Alternately, the USE-2 can be transitioned to two pairs of THWN-2 in a transition box; the THWN-2 is then used for the homeruns off the roof.

In both these cases, two pairs of conductors are run all the way to the inverter. But it is also possible to design a two-string array in which only one pair of conductors is landed in the inverter. Not long ago most grid-tied PV installations required a dc service disconnect that was external to the inverter, simply because this feature was not included in the inverters themselves. This has changed significantly in recent years, but veteran designers are familiar with using a 30 A, 600 Vdc heavy duty safety switch from Square D, the HU361, to combine two series strings coming off the roof prior to the inverter. This is made possible by a listing specified in the Square D data bulletin "Direct Current and Photovoltaic Systems."

Per this data bulletin, Square D's 30 A, 60 A and 100 A heavy duty safety switches are listed for use in PV systems such that *each pole* of the switch has a maximum PV array current rating at 600 Vdc. Also, each of the three poles may be connected to a separate inverter. This is true of the fused versions (H361, H362 and H363) as well as the unfused versions (HU361, HU362 and HU363) of the switch. This assumes that



A		B		C	
MODULE SPECS		STRING SPECS		ARRAY SPECS	
Pmp	175	Pmp	1,575	Pmp	3,150
Vmp	35.8	Vmp	322.2	Vmp	322.2
Imp	4.89	Imp	4.89	Imp	9.78
Voc	44.4	Voc	399.6	Voc	399.6
Isc	5.30	Isc	5.30	Isc	10.6

Diagram 1 The Square D HU361 is listed for double lugging and 11.5 A Isc per pole; the dc inputs of the Fronius inverter are rated at 20 A each.

the inverter is incapable of backfeeding currents from the utility in the event of a fault or short circuit in the dc wiring. The HU361, an unfused 30 A device, carries a per pole maximum current rating of 18 A, which corresponds to an 11.5 A Isc rating per pole (18 A ÷ 1.56 = 11.5 A). Additionally, the H361 and HU361 are rated for double lugging in Table 2 of Square D's data bulletin. Per this listing two copper conductors, ranging from #14 to #10 solid or stranded, may be terminated on the line side terminals of this switch.

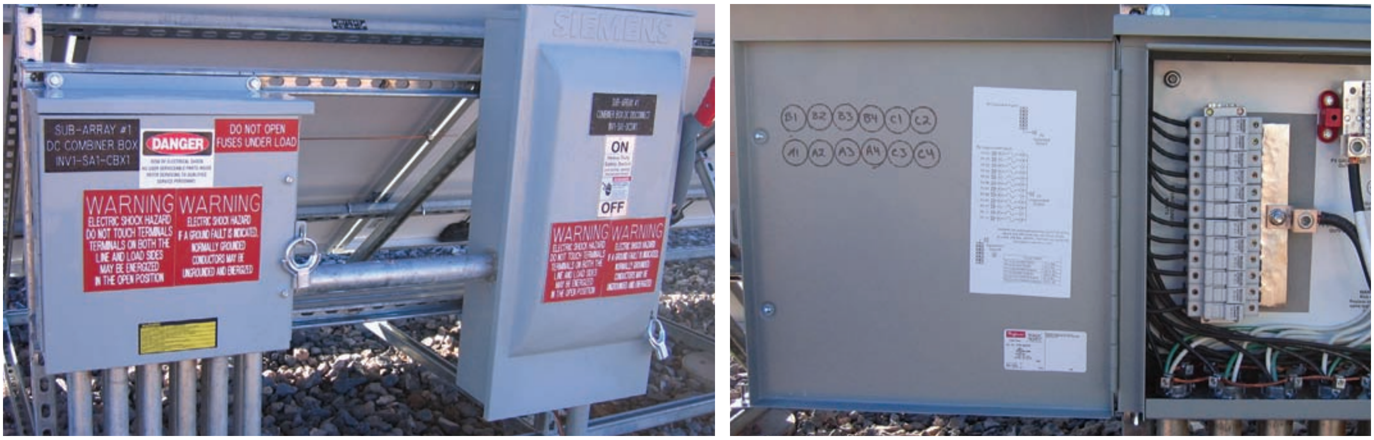
While Fronius IG Plus inverters, among others, include an integrated dc disconnect, some jurisdictions and some applications may call for an additional dc service disconnect prior to the inverter. If that is the case, using the Square D "H" series disconnects is often a convenient choice. Going back to the example with two strings of SolarWorld 175 mono Sunmodules feeding a Fronius IG Plus 3.0, if an external dc service disconnect were required or useful, the two ungrounded PV source circuit conductors could be terminated at a single pole of a Square D HU361RB, for example, and a single inverter input conductor could be used between the load side of this safety switch and the inverter. The neutral kit is also listed for double lugging and may be used for combining the grounded PV source circuit conductors. Diagram 1 details this scenario.

This diagram illustrates that a combiner box is not the only place used to combine circuits. In this case, the point of common connection is a lug in a dc disconnect. Because the Square D disconnect is listed for use with one inverter per pole of the disconnect, a designer could use this disconnect for up to two more inverters with arrays identical to the first. This is, at the very least, a good trick to have up your sleeve. This simple two-string array configuration also indicates the limited nature of the design possibilities available without the use of a combiner box. For most companies, and many clients, a primary goal is to install the largest system practicable. This requires more complex and flexible components and design strategies than those necessary in one- or two-string arrays.

System with combiners. When a combiner box is required, it is often mounted at the array. Especially on a residential pitched roof application, the best rooftop combiner solution is probably the least visible option, certainly as far as the customer is concerned. A rooftop combiner box is a convenient place to transition to THWN-2 in conduit, assuming you can find an out-of-the-way place to mount the box. In some cases a wall may be present. In general, however, rooftop combiner boxes are installed in the same plane as the roof, perhaps supported by an extension of the racking system. For most roofs, this requires a combiner box that is NEMA 4 or NEMA 4X rated.

While installing combiner boxes on the roof alongside the array is common practice, this solution is not necessarily ideal. "Fuses and breakers are thermal devices," points out groSolar's Berdner, "and placing combiners where they are exposed to direct sunlight can lead to nuisance tripping at high temperature." Assuming this happens, and assuming it gets noticed, a blown series fuse points to another drawback of rooftop combiners: access. A blown fuse or tripped breaker is easy to replace as long as it is not located on a 30° pitched metal roof that requires a 42-foot ladder to get to.

Luckily for customers, installers and service technicians alike, string inverters available today increasingly offer integrated combiner boxes and integrated dc service disconnects. The SMA Sunny Boy US series and the Fronius IG Plus series of string inverters are good examples. In both product lines, a combination fused PV source circuit combiner and dc service disconnect is integrated within an inverter enclosure. To customers this is one product hanging on their wall—rather than two or three—but to many inspectors, this is both an inverter and a *Code* compliant dc service disconnect. CONTINUED ON PAGE 36



Courtesy gardnerengineering.net (2)

Labeling combiners In addition to the *Code* required warning labels at this SMA combiner box and the adjacent dc disconnect, engraved black placards identify these system components. Labeling inside the 10-circuit combiner box provides additional information relevant to installation and maintenance personnel at this site in St. George, UT.

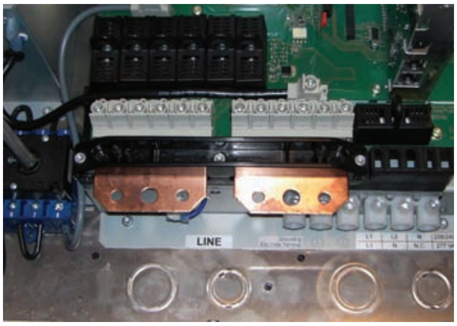
Whether these inverter integrated disconnects are acceptable on your project is ultimately determined by the local AHJ. John Wiles of the Institute for Energy and the Environment, an authority on *NEC* 690, explains his process for determining acceptance: "If the inverter can be separated from the disconnect, then I think no external disconnects should be required as long as the following two criteria are met: first, if the assembly is mounted outside, then it must be possible for the disconnect to remain waterproofed with the inverter removed; and, second, if the inverter is removed, the disconnect must remain finger safe, meaning no exposed wiring or live electrical parts."

Let us assume for the moment that an inverter integrated dc disconnect is acceptable. One of the subsequent decisions that designers need to make is whether to use the fused combiner box provided at the inverter or whether to combine source circuits elsewhere in the system. There are pros and cons to both approaches, but either technique can be done properly. The benefits of locating the fuses at the inverter are fairly obvious. This is a convenient location, and the fuses and inverter will, ideally, both be installed in a location that does not receive direct sunlight.

But what if this is a 7 kW PV array using Sanyo bifacial modules? Electrically the Sanyo bifacial modules look like thin film products, with a relatively high nominal operating voltage. They therefore require short series strings with more strings in parallel. Whether using a Fronius IG Plus 7.5 or an SMA SB7000US, the installer of a 7 kW array made up of 35 Sanyo bifacial HIT Double 200 modules will have at least five pairs of PV source circuit conductors to contend with. This is potentially an unwieldy wire pull. When installing several current-carrying conductors in the same conduit, these source circuit conductors would need to be derated by 50% per *NEC* 310.15(B)(2) to compensate for 10 current-carrying conductors in the same conduit. So this is a case where combining PV source circuits at the array might be desirable.

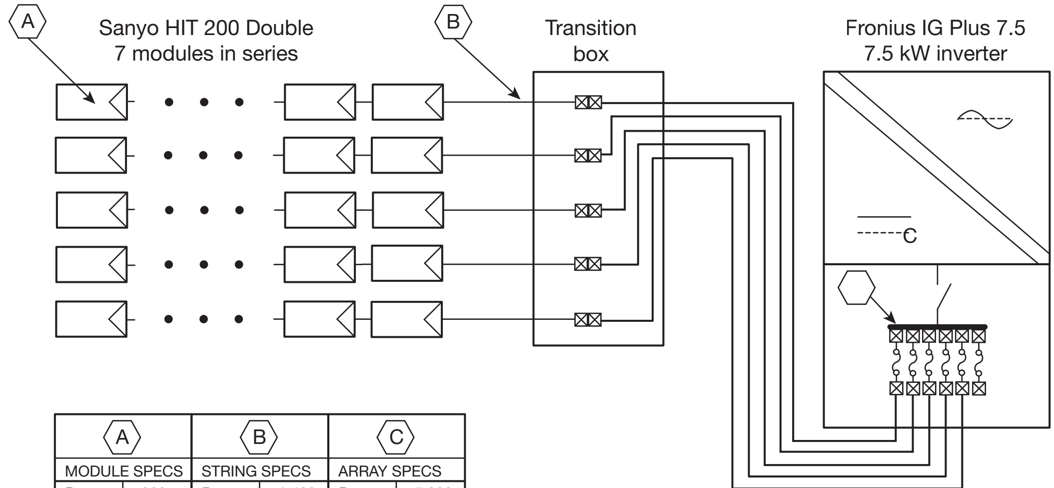
Both the Fronius IG Plus and the SMA Sunny Boy US products can accommodate this design decision. Undoubtedly other string inverters on the market do as well, or will soon. The Fronius IG Plus products specifically have six fusible dc inputs rated at 20 A each, but the fuses are optional. Not only does the inverter ship with a conductive slug in each fuse holder, but it is also possible to combine these six dc inputs into a common bus by ordering the six-toothed busbar that Fronius sells for this purpose.

A new dc disconnect is now available for use with the SMA Sunny Boy US series inverters. As with the earlier disconnects, the integral fuse combiner has four fused inputs. These four fuses will not accommodate the five source circuits in this example. Fortunately, the new SMA dc disconnect offers combined ungrounded and grounded terminal lugs. These are oversized lugs that bypass the fused inputs. Installers are free to combine PV source circuits in the field and still use the integrated dc disconnect at the inverter. These inverters can also

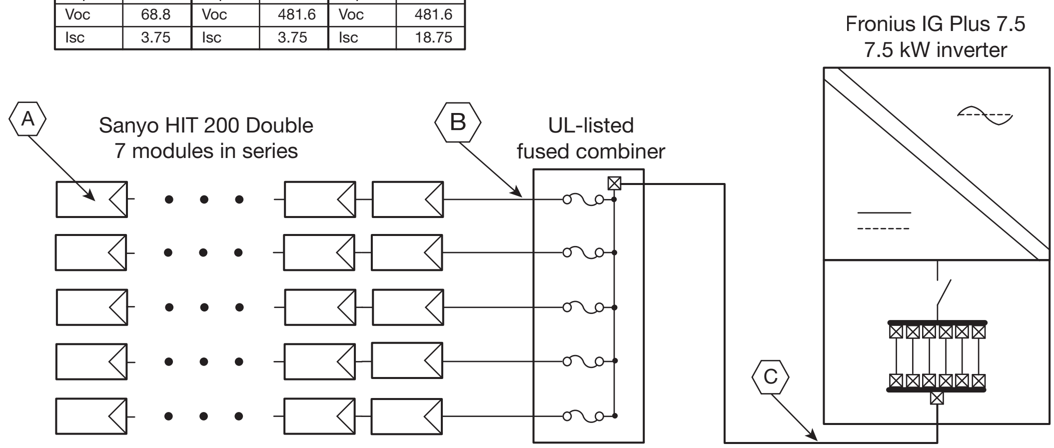


Courtesy fronius-usa.com

Optional input combiner Six grounded and ungrounded dc input terminals on this Fronius IG Plus inverter are separately bussed in common using a pair of six-fingered copper busbars. Inverter input circuit conductors are terminated with cable lugs and bolted to the copper input combiners.



A		B		C	
MODULE SPECS		STRING SPECS		ARRAY SPECS	
Pmp	200	Pmp	1,400	Pmp	7,000
Vmp	56.2	Vmp	393.4	Vmp	393.4
Imp	3.56	Imp	3.56	Imp	17.8
Voc	68.8	Voc	481.6	Voc	481.6
Isc	3.75	Isc	3.75	Isc	18.75



Diagrams 2a & 2b In Diagram 2a (top), the fused combiner at the inverter is used. In Diagram 2b, strings are combined at the array; the busbar combining dc input terminals at the inverter must be ordered separately.

be installed without the SMA dc disconnect, a handy feature for tight places.

Diagrams 2a and 2b show single-line diagrams for grid-direct 7 kW bifacial PV systems. The array specifications are the same in both systems. In the first diagram all five pairs of PV source circuits are combined at the inverter; in the second diagram the source circuits are connected in common at the array. The decision is up to the designer or installer. Following is a list of considerations to review when deciding whether to include a combiner box in systems using an inverter with an integrated fusible combiner box:

- What is the cost difference between a transition box—plus the necessary internal components—and a combiner box?
- What is the cost difference between installing multiple PV source circuits or one PV output circuit?
- Will using a separate combiner box require a separate dc disconnect switch? If yes, what is the additional cost to install?
- Will using a separate combiner box mean that the PV output circuit current rating exceeds the input rating of the inverter input combiner terminals or fuses?
- Does bypassing the integrated fusible combiner violate the product listing?
- Can the combined output circuit be installed per the manufacturer's specifications, as required in *NEC* 110.3(B)?
- Will combining the conductors change the required conduit size? If yes, how will this affect material and labor costs?
- Are there any other benefits to combining? Will the wire pull be easier or harder? Will fewer or more dc disconnects be required by the AHJ or the *Code*?

PV SYSTEMS WITH BATTERY BANKS

The use of combiner boxes in systems where the PV source circuits feed a charge controller, rather than a string inverter, is discussed at length in James Goodnight's article "Grid Down Power Up: Utility-Interactive Battery Backup System Design" (February/March 2009, *SolarPro* magazine). The main difference in these array designs is that allowable string voltages are lower, meaning fewer modules are connected in series. The PV output circuit currents are understandably higher as a result, meaning that larger dc wire gauges are common in these systems and voltage drop becomes more of an issue for designers.

The lower dc voltage range also allows for the use of circuit breakers as OCPDs. Circuit breakers are more convenient to use and less costly than touch safe fuse holders and fuses. They also offer an additional degree of safety because circuit breakers can be safely disconnected under load; touch safe fuse holders, however, should never be disconnected under load. Ryan Zahner, an engineering lead at Blue Oak Energy, reports that a common mistake that PV installers make is "using the fuse holder as a load-break switch during troubleshooting or commissioning." If a qualified person (per Article 100 of the *NEC*) can make this mistake, the risk of shock or fire is even higher with unqualified persons.

To minimize the risk, Robin Gudgel, owner of Midnite Solar, recommends using circuit breakers as OCPDs in combiner boxes where the PV output circuit connects to a charge controller. This is especially true with owner-installed systems, which are common in the off-grid market. "We simply do not want Joe Consumers using fuse holders in off-grid systems," Gudgel explains. "They just are not knowledgeable enough to avoid opening up a touch safe fuse holder under load."

Because the 150 Vdc rated circuit breakers recommended for this use have a narrow profile, it is not uncommon to see one combiner box serving two charge controllers. Diagram 3 illustrates this type of design. As drawn, two subarrays of 15 REC 230 W modules each feed a single combiner box with two PV output circuits. The design for this 6.9 kW array is typical of what one might see in 4 kW to 8 kW off-grid or utility-interactive battery backup applications.

COMMERCIAL AND INDUSTRIAL GRID-DIRECT PV SYSTEMS

In commercial, industrial and other large PV applications, the question is not *if* you are going to use combiners, but rather *how* you will use them. In most cases, this means designing around specific combiner box characteristics, as well as specific recombiner or subcombiner specifications. A primary consideration for designers and engineers is choosing combiners that efficiently aggregate dc circuits in a PV array. How the array is laid out and installed will also influence product selection. In a good design, appropriate combiner boxes and recombiners make life easier for the CONTINUED ON PAGE 40

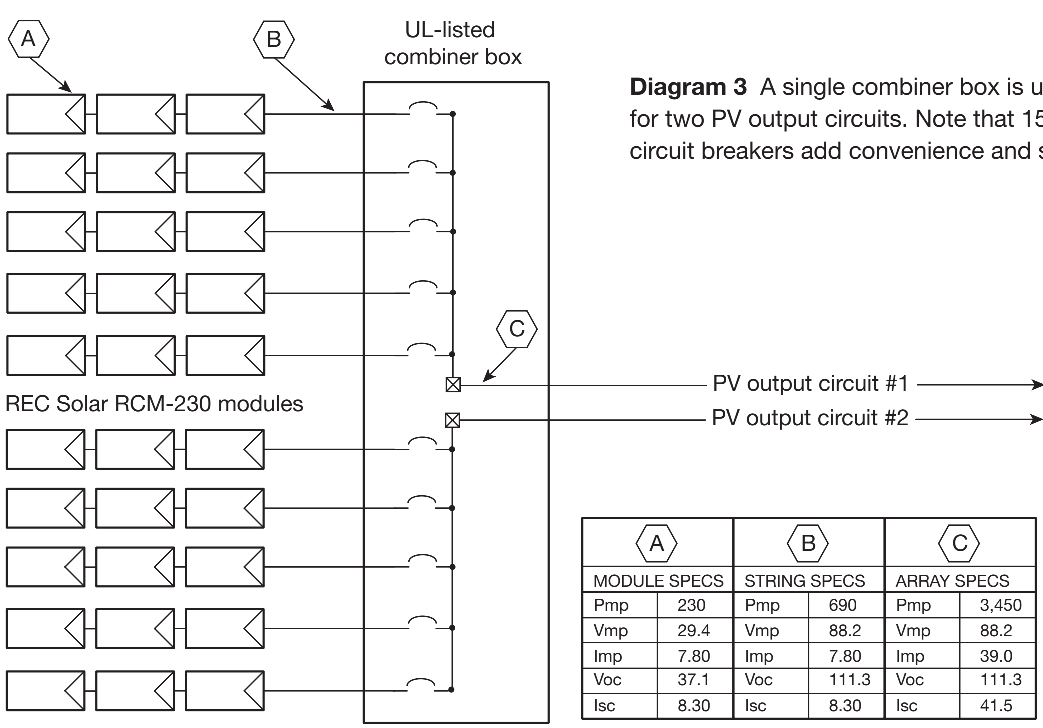
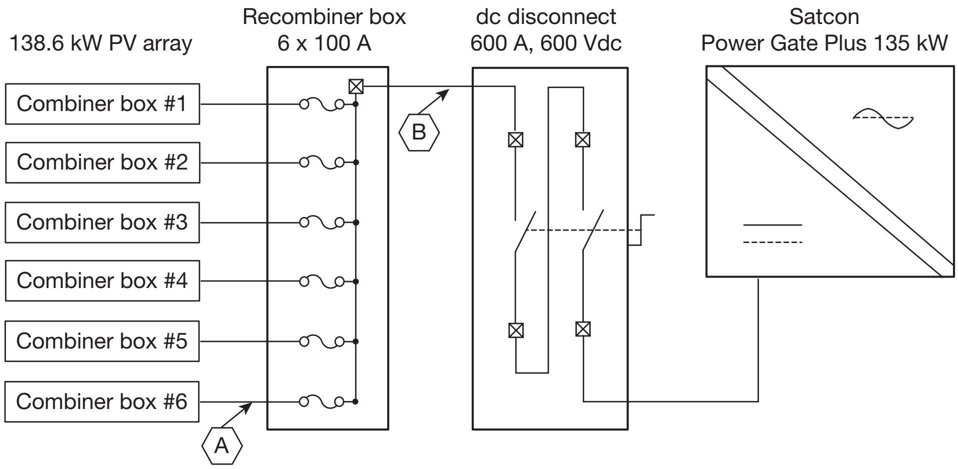


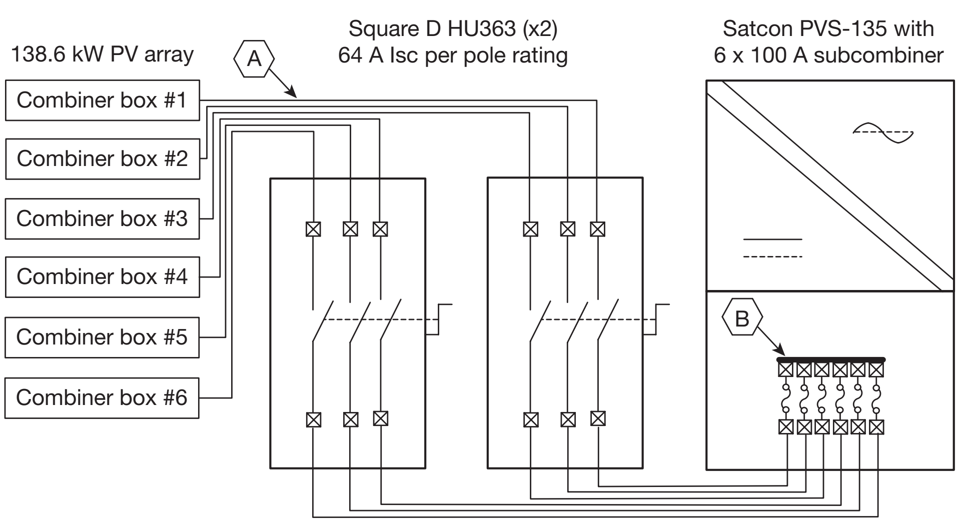
Diagram 3 A single combiner box is used for two PV output circuits. Note that 150 Vdc circuit breakers add convenience and safety.

A		B		C	
MODULE SPECS		STRING SPECS		ARRAY SPECS	
Pmp	230	Pmp	690	Pmp	3,450
Vmp	29.4	Vmp	88.2	Vmp	88.2
Imp	7.80	Imp	7.80	Imp	39.0
Voc	37.1	Voc	111.3	Voc	111.3
Isc	8.30	Isc	8.30	Isc	41.5

Diagrams 4a & 4b In Diagram 4a (top) a recombiner is used prior to the dc disconnect; in Diagram 4b a pair of Square D HU363 safety switches is used prior to an inverter integrated subcombiner.



MODULE SPECS		STRING SPECS		SUBARRAY SPECS (A)		ARRAY SPECS (B)	
Pmp	175	Pmp	1,925	Pmp	23,100	Pmp	138,600
Vmp	35.8	Vmp	393.8	Vmp	393.8	Vmp	393.8
Imp	4.89	Imp	4.89	Imp	58.68	Imp	352.1
Voc	44.4	Voc	488.4	Voc	488.4	Voc	488.4
Isc	5.30	Isc	5.30	Isc	63.6	Isc	381.6



installers, use resources wisely and meet applicable standards for safety.

Diagrams 4a and 4b illustrate two design options suitable for large capacity PV installations. In both examples the source circuit combiner box and inverter details are identical. What differs is how and in what order the PV output and inverter input circuits are recombined and disconnected. In both examples, a 138.6 kW array, made up of 792 SolarWorld 175 mono Sunmodules, is organized into 72 source circuits with 11 series connected modules per string. These 72 source circuits are evenly divided across six combiner boxes, such that 12 series strings are connected in parallel at each combiner box. Each combiner box contains the required string overcurrent protection; the maximum series string rating of the modules is 15 A. Ultimately, the 138.6 kW array in both examples is grid-interconnected by means of a Satcon 135 kW Power Gate Plus inverter.

Now let us look at how these examples differ. In Diagram 4a the output conductors from all six combiner boxes are connected in common at a 6 x 100 A recombiner box. The recombiner output can be disconnected by means of a heavy duty 600 Vdc safety switch located at the inverter. The equipment ratings along the way are determined by the following logic: Since the Isc rating of each module is 5.3 A, the combined Isc output of each combiner box is 63.6 A (5.3 A x 12 = 63.6 A). After these combiner box outputs are recombined, the total array Isc is equal to 381.6 A (63.6 A x 6 = 381.6 A). Per the *NEC*, these values are subject to a 1.56 multiplier for equipment and conductor selection. (A first 1.25 multiplier is applied to all circuits considered continuous; a second 1.25 multiplier is applied to PV power circuits to account for high irradiance conditions.) Thus the dc disconnect is sized to carry at least 595.3 A (381.6 A x 1.56 = 595.3 A); the next larger standard size of equipment is 600 A. Therefore, a 600 A, 600 Vdc heavy duty safety switch is used in this configuration. Note that to meet the general listing requirements for the device, two poles of the disconnect have to be connected in series.

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Special rating for PV applications Often the output from 8- to 12-circuit combiner boxes can be dedicated to the single pole of a Square D HU363 heavy duty safety switch. With three poles rated at 64 A Isc each, this NEMA 4, 100 A disconnect serves the three combiner boxes to its left.

Compare this to the configuration shown in Diagram 4b. In this case, 100 A, 600 Vdc Square D HU363 heavy duty safety switches are used *prior* to the PV output circuit conductors being recombined. This disconnect has a special listing for PV applications that allows for each pole of the switch to be used independently at the full 100 A, 600 Vdc rating. This means that each pole of the disconnect can accommodate an Isc of 64 A (100 A ÷ 1.56 = 64 A). In this configuration, the output conductor from each combiner box, which is calculated to have an Isc of 63.6 A, can be dedicated to its own pole in one of these heavy duty safety switches. Two dc disconnects, with a total of six poles, are required to accommodate all six combiner box outputs. The array conductors are protected by means of a 6 x 100 A fused subcombiner that is integrated with the Satcon inverter. This option can be specified when the product is ordered. An external recombiner could also be used between the dc disconnects and the inverter.

Energized circuits Insulating gloves for high voltage are required for protection when working on PV source circuits. As long as the array is exposed to the sun, circuits inside this Homerun combiner box by Blue Oak PV Products are energized and present an extreme shock hazard to workers.

Myriad design solutions are acceptable for this problem. The best solution is always site and project specific. Using a pair of 100 A dc disconnects rather than a single 600 A heavy duty safety switch is an undeniably efficient use of resources. In most cases this will save time and money and also minimize space requirements. A secondary benefit is that the array can be split in half for servicing or troubleshooting. As the system size increases, this feature becomes even more useful because an isolated problem will not require disconnecting an entire array.

SELECTING A COMBINER PRODUCT

The tables on pages 46 and 48 provide specifications for more than 50 combiner and recombiner boxes from seven manufacturers. Only standard products are listed in the tables, but some of the companies accommodate custom orders. All specifications listed are from cut sheets or were provided by the manufacturers. When selecting a product, keep in mind the following considerations as they relate to your application:

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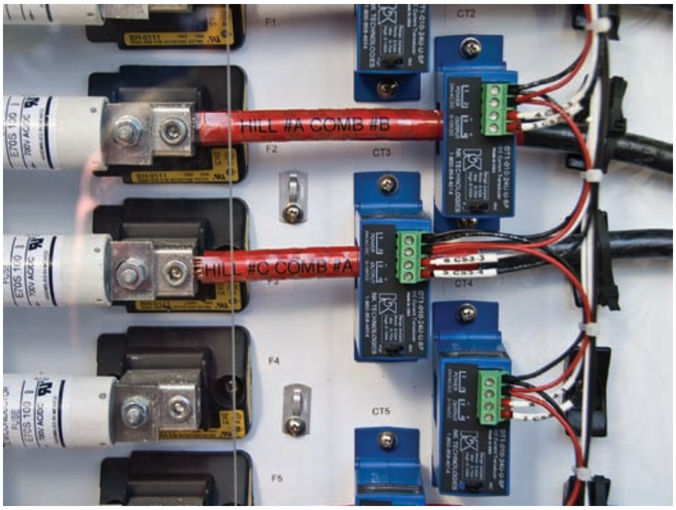
Why so negative? The PV system at the San Domenico School in Marin County, CA, is grid-interconnected using an AE Solaron inverter. The bipolar array design requires dedicated positive and negative combiners throughout the system. A dedicated monitoring recombiner for the positive half of the array (not shown) is installed to the left of this AMtec Eclipse 6 recombiner for the negative PV array circuits.



Zone-level monitoring The AMtec Solar Eclipse 6 recombiner box incorporates split core current transducers, allowing for zone level monitoring at the San Domenico School. Zones are monitored for proper performance by comparing the output of combiner boxes with identical array capacities.

- NEMA enclosure type rating
- Maximum dc voltage
- Maximum number of input circuits
- Maximum input fuse rating
- Acceptable wire ranges of lugs or terminals
- Number of dc output circuits
- Maximum continuous output circuit current
- Cable gland or cord grip bushing options
- Data acquisition goals

NEMA enclosure type rating. In general, source circuit combiner boxes are located in close proximity to the PV array. Common locations include rooftops or pole- or rack-mounted applications, often in the array field. The product's NEMA rating provides information on the approved mounting locations and orientations. For example, NEMA 4 and 4X ratings allow enclosures to be installed outdoors in any orientation, from vertical to horizontal. NEMA 3 and 3R rated products can be installed outdoors as well, but the allowable mounting orientations are limited.

Maximum dc voltage. The maximum PV system voltage determines the appropriate voltage ratings of cables, disconnects, overcurrent devices and other equipment. When selecting a combiner box, it is important to calculate the maximum PV system voltage and select models with adequately rated fuse holders, circuit breakers and other components. Exceeding the voltage rating of these components within a combiner box is dangerous and violates the listing. If a combiner box is listed to a maximum dc voltage, you can assume the internal components are rated at that voltage as well. This is especially relevant when working with combiner boxes that use circuit breakers as OCPDs. These circuit breakers CONTINUED ON PAGE 44

Watertight Maintaining the NEMA 4 rating of rooftop enclosures requires the correct use of properly listed hardware, such as watertight cable glands or cord grips with neoprene bushings for source circuits and weatherproof conduit hubs for output circuits. In this case, at REI in Sacramento, CA, Blue Oak Energy went one step further, applying sealant at each cable gland.

are commonly rated to 150 Vdc, whereas the rating for touch safe fuse holders may be as high as 1,000 Vdc.

Maximum number of input circuits. For combiner boxes, this refers to the maximum acceptable number of PV source circuits; for recombiners or subcombiners this refers to the maximum acceptable number of PV output circuits. Some combiner boxes can accommodate as many 52 PV source circuits, while others accept only three.

Maximum input fuse rating. This is the current rating of the largest allowable fuse or overcurrent device that can be used in the combiner. This specification is not used consistently between manufacturers. Some list the maximum OCPD rating assuming all input circuits are used. The minimum fuse size of the required PV source circuit overcurrent device is calculated per *NEC* 690.8(B)(1). In order to follow the product listing and ensure a safe installation, the combiner must have a maximum input fuse rating equal to or greater than the calculated rating for the dc circuit overcurrent device.

Acceptable wire ranges of lugs or terminals. The approved wire sizes for combiner input and output terminals or lugs must meet the application requirements. System designers often increase conductor size due to conduit fill requirements, temperature derating or voltage drop considerations. The combiner's terminals or lugs must be able to accept properly sized system conductors.

Number of dc output circuits. Depending on the model, combiner boxes may accommodate one or two output circuits. System designs may require more than one output circuit per combiner box for separate charge controllers, dc loads or

Combiner Manufacturers

AMtec Solar. AMtec manufactures durable and user friendly combiner boxes. All labels are silkscreened for maximum longevity; touch safe fuse holders are used; and finger safe covers protect live busbars. The Prominence series combiner boxes are available in 3 to 36 circuits; their NEMA 4X rating allows them to be installed in a variety of locations and orientations. AMtec offers a smart combiner box from the Prominence series capable of monitoring 8 or 16 circuits using Obvius current monitoring and modbus communication hardware. The smart combiners can interface with Fat Spaniel monitoring systems and will soon be compatible with Energy Recommerce

products. AMtec also offers a recombiner box for larger applications, the Eclipse series, consisting of 600 A and 1,200 A options. Smart recombiners are also available with built-in monitoring options. AMtec Solar sells direct to installers and integrators.

Blue Oak PV Products. Blue Oak offers a competitively priced product line designed to be easy to install. Its combiner boxes are listed to UL 1741.

The Type 4X enclosures can be installed in any orientation. They contain high grade plated components per ASTM standards, stainless steel hardware and touch safe fuse holders. Blue Oak offers 4-, 8- and 12-circuit combiner boxes. The 8- and 12-circuit models integrate well with array designs that incorporate Square D Heavy Duty HU363 100 A safety switches, allowing up to three combiner boxes to be switched with one 100 A switch. Blue Oak products can be purchased through DC Power. Direct purchases by large commercial or utility scale customers are welcome.

groSolar. At press time, groSolar's ReadyWatt line of ETL listed combiners are listed to UL 508A, but a switch to UL 1741 is anticipated later this year. The product line offers two combiner boxes that can each be configured for high or low voltage designs. The high voltage configurations accommodate 5 or 8 source circuits, depending on the model. The low voltage options use circuit breakers instead of touch safe fuse holders and accept 6 or 12 source circuits rated at 150 Vdc or less. Preinstalled cord grips are optional on each of the models. For larger projects, the ReadyWatt

Subcombiner (recombiner) product line can accommodate up to 4 circuits fused at 100 A each. Also available is the ReadyWatt Pass-Thru wiring box, an unfused NEMA 4 transition box. Custom builds are available upon request. Contact groSolar directly for purchasing.

Midnite Solar. The ETL listed combiner boxes available from Midnite Solar can be configured for low or high voltage applications. The company's MNPV series can be installed between a pitch of 3:12 (approximately 14°) and vertical. Most products in this series include a custom deadfront to hide wiring and inverters. Many combiner boxes, however, have a single termination for ungrounded and grounded conductors in each output circuit. The output terminals provided in recombiners are typically designed to accommodate parallel conductors for ungrounded and grounded output cabling, but only one output circuit is accommodated per recombiner.

Maximum continuous output circuit current. A combiner's continuous output current typically refers to the maximum continuous busbar rating established during UL 1741 testing. However, this may be defined differently by various manufacturers, and *NEC* derating may apply. Also, utilizing all source circuit inputs with the maximum allowable OCPD device may overload the busbar.

Cable gland or cord grip bushing options. A *cable gland,* also known as a *cord grip bushing*, may provide strain relief to PV source circuit conductors as they enter the combiner box enclosure, while still maintaining the product's NEMA rating. Some manufacturers offer combiner boxes with preinstalled cable glands or cord grips. These features can save installation time and eliminate the need to field modify an enclosure, which could compromise the enclosure's listing or NEMA rating.

Data acquisition goals. System monitoring is becoming a standard feature in many large PV systems. This is especially important on large PPA projects where every kWh matters, and the loss of a single module or string would be difficult to spot by monitoring the inverter. Increasingly, the means to collect and monitor that data is being integrated into combiner products. Combiners with integrated current monitoring are often referred to as CONTINUED ON PAGE 50

exposed live parts, though the 16- and 10-circuit models do not currently offer this feature. The low voltage configurations (150 Vdc) can accommodate 3, 6 or 12 circuits. The high voltage configurations (600 Vdc) use touch safe fuse holders and can accept 3, 4, 10 and 16 circuits. In preparation for the Midnite Solar Classic charge controller that is in development, Midnite Solar has designed a 300 Vdc rated combiner box product line that accepts 250 Vdc rated breakers. Midnite Solar products are available through major solar distributors, including AEE Solar, Conergy and SunWize Technologies.

OutBack Power Systems. The FWPV series of ETL listed combiner boxes from OutBack can be configured for low or high voltage applications. The enclosures can be installed between a pitch of 3:12 (approximately 14°) and vertical and include a custom deadfront to hide wiring and exposed live parts. The low voltage designs accommodate 8 or 12 source circuits, compared to 6 or 8 with the high voltage configuration that consists of 600 Vdc rated touch safe fuse holders. All of OutBack's enclosures are lockable. OutBack products are available through AEE Solar, Conergy, DC Power Systems, groSolar, Kyocera Solar and SunWize Technologies.

SMA America. After many years of experience combining large PV arrays used in conjunction with its central inverters, SMA recognized combiners to be a common point of system failure. This experience led the company to design and manufacture its SCCB line of combiner box models, which are ETL listed to UL 1741 standards. The products accommodate between 6 and 52 high voltage dc circuits. The steel NEMA 3R/4 enclosures include touch safe fuse holders. SMA's SCCB combiners can be purchased through various distributors.

SolarBOS. The SolarBOS line of products are UL listed and highly customizable. The line allows customers to specify the number of source circuits (between 4 and 24), the fuse rating, the NEMA rating (NEMA 3, 3R, 4 and 4X) and cable glands or conduit fittings. This range of NEMA ratings allows system designers to select the enclosure type per the desired mounting location and orientation. Several recombiner box models are available for larger installations. SolarBOS also offers smart combiner boxes, including Obvius current monitoring and modbus communication hardware, available with 4 to 24 inputs. SolarBOS sells direct to installers and integrators. ●

2009 PV Source Circuit Combiner Specifications

			PV Source Circuits				PV Output Circuit(s)						
Manufacturer	Model	Max Vdc	Max # of input circ.	Max OCPD rating (A)[1]	OCPD type	Wire range (AWG or kcmil)	Max # of output circ.	Max Cont. current (A)[2]	Wire range (AWG or kcmil)	Approved mounting orientation	Monitored option	Enclosure: NEMA type / material	Listing
AMtec Solar	Prominence 3R	600	3	15	fuse	18–8	1	45	14–4	vertical to horizontal	no	4 / black powder coated steel [3]	ETL to UL 1741
AMtec Solar	Prominence 6R	600	6	15	fuse	18–8	1	90	14–4	vertical to horizontal	no	4 / black powder coated steel [3]	ETL to UL 1741
AMtec Solar	Prominence 6	600	6	20	fuse	18–8	1	120	6–3/0	vertical to horizontal	no	4X / fiberglass [4]	ETL to UL 1741
AMtec Solar	Prominence 8M	600	8	20	fuse	18–8	1	160	6–350	vertical to horizontal	monitored only	4X / fiberglass [4]	ETL to UL 1741
AMtec Solar	Prominence 12	600	12	15	fuse	18–8	1	180	6–350	vertical to horizontal	no	4X / fiberglass [4]	ETL to UL 1741
AMtec Solar	Prominence 16M	600	16	20	fuse	18–8	1	320	6–350 (x2)	vertical to horizontal	monitored only	4X / fiberglass [4]	ETL to UL 1741
AMtec Solar	Prominence 24	600	24	15	fuse	18–8	1	360	6–350 (x2)	vertical to horizontal	no	4X / fiberglass [4]	ETL to UL 1741
AMtec Solar	Prominence 36	600	36	15	fuse	18–8	1	540	6–350 (x2)	vertical to horizontal	no	4X / fiberglass [4]	ETL to UL 1741
Blue Oak	HCB4	600	4	15	fuse	14–6	1	60	14–1/0	vertical to 14º	no	3R / powder coated AL	UL 1741
Blue Oak	HCB8	600	8	15	fuse	14–6	1	120	6–350	vertical to horizontal	yes [5]	4X / fiberglass	UL 1741
Blue Oak	HCB12	600	12	15	fuse	14–6	1	180	6–350	vertical to horizontal	yes	4X / fiberglass	UL 1741
groSolar	ReadyWatt 10x10 LV	150	6	20	CB	14–6	1	100	14–1/0	vertical to 14º	no	3R / painted steel [6]	ETL to UL 508A [7]
groSolar	ReadyWatt 10x10 HV	600	5	20	fuse	18–8	1	100	14–1/0	vertical to 14º	no	3R / painted steel [6]	ETL to UL 508A [7]
groSolar	ReadyWatt 12x12 LV	150	16	20	CB	14–6	2	100	14–1/0	vertical to 14º	no	3R / painted steel [6]	ETL to UL 508A [7]
groSolar	ReadyWatt 12x12 HV	600	8	20	fuse	18–8	2	100	14–1/0	vertical to 14º	no	3R / painted steel [6]	ETL to UL 508A [7]
Midnite	MNPV3	150	3	30	CB	14–6	1	60	14–1/0	vertical to 14º	no	3R / powder coated AL	ETL to UL 1741
		600	3	30	fuse								
Midnite	MNPV6	150	6	30	CB	14–6	2	120	14–1/0	vertical to 14º	no	3R / powder coated AL	ETL to UL 1741
		600	4	30	fuse		1						
Midnite	MNPV12	150	12	30	CB	14–6	2	200	14–2/0	vertical to 14º	no	3R / powder coated AL	ETL to UL 1741
		600	10	30	fuse								
Midnite	MNPV12-250	300	6	20	CB 300V	14–6	2	164	14-2/0	vertical to 14º	no	3R / powder coated AL	ETL to UL 1741
Midnite	MNPV16	600	16	30	fuse	14–6	1	240	6–250	vertical to 14º	no	3R / powder coated AL	ETL to UL 1741
Midnite	MNPV16-250	300	12	20	CB 300V	14–6	1	240	14-2/0	vertical to 14º	no	3R / powder coated AL	ETL to UL 1741
OutBack	FWPV-8	150	8	60	CB	14–6	1	120	14–2/0 (x2)	vertical to 14º	no	3R / powder coated AL	ETL to UL 1741
		600	6	30	fuse	14–10							
OutBack	FWPV-12	150	12	60	CB	14–6	2	180	14–2/0 (x2)	vertical to 14º	no	3R / powder coated AL	ETL to UL 1741
		600	8	30	fuse	14–10							
SMA	SBCB–6	600	6	15	fuse	10–6	1	90	6–350	vertical	no	3R /4 / painted steel	ETL to UL 1741
SMA	SCCB-10 thru 16	600	10–16	20	fuse	10–6	1	200–320	6–350 (x2)	vertical	no	3R / painted steel	ETL to UL 1741
SMA	SCCB-18 thru 28	600	18–28	15	fuse	10–6	1	270–420	6–350 (x2)	vertical	no	3R /4 / painted steel	ETL to UL 1741
SMA	SCCB-52	600	52	8	fuse	10–6	1	333	6–350 (x2)	vertical	no	3R /4 / painted steel	ETL to UL 1741

CONTINUED ON PAGE 48

2009 PV Source Circuit Combiner Specifications (continued)

			PV Source Circuits				PV Output Circuit(s)						
Manufacturer	Model	Max Vdc	Max # of input circ.	Max OCPD rating (A) [1]	OCPD type	Wire range (AWG or kcmil)	Max # of output circ.	Max Cont. current (A) [2]	Wire range (AWG or kcmil)	Approved mounting orientation	Monitored option	Enclosure: NEMA type / material	Listing
SolarBOS	CS-4 thru CS-12	600	4–12	30	fuse	16–4	1	310	6–350	varies by enclosure type	yes	3, 3R, 4, 4X / steel or fiberglass	ETL to UL 1741
SolarBOS	CS-12/12	600	4–12 (x2)	30	fuse	16–4	1	620	6–350 (x2)	varies by enclosure type	yes	3, 3R, 4, 4X / steel or fiberglass	ETL to UL 1741 [8]
SolarBOS	CSK-4 thru CSK-12	1000	4–12	30	fuse	16–4	1	310	6–350	varies by enclosure type	no	3, 3R, 4, 4X / steel or fiberglass	ETL to UL 1741 [8]
SolarBOS	CD-4 thru CD-12	600	4–12	30	fuse	16–4	1	310	6–350 (x2)	varies by enclosure type	yes	3, 3R, 4, 4X / steel or fiberglass	ETL to UL 1741
SolarBOS	CD-14 thru CD-24	600	14–24	30	fuse	16–4	1	400	6–350 (x2)	varies by enclosure type	yes	3, 3R, 4, 4X / steel or fiberglass	ETL to UL 1741
SolarBOS	CDK-14 thru CDK-24	1000	14–24	30	fuse	16–4	1	400	6–350 (x2)	varies by enclosure type	no	3, 3R, 4, 4X / steel or fiberglass	ETL to UL 1741 [8]
SolarBOS	CCS-2 thru CCS-8	600	2–8	30	fuse	16–4	1	100	14–2	vertical to horizontal	no	4X / fiberglass or polycarbonate	ETL to UL 1741 [8]
SolarBOS	C225-12 [9]	600	12	30	fuse	16–4	1	225	6–350	varies by enclosure type	yes	3, 3R, 4, 4X / steel or fiberglass	ETL to UL 1741 [8]

[1] Designer must calculate # input circuits vs. specified OCPD rating vs. output circuit max continuous current.
[2] Maximum current rating before any required derating per *NEC*
[3] NEMA 4x fiberglass or stainless options
[4] NEMA 4 powder coated steel & 4X stainless options
[5] HCB8-M monitored option has 6-250 output circuit wire range
[6] NEMA 4 painted steel & 4X fiberglass options
[7] ETL to UL 1741 listing pending
[8] Listing pending
[9] Built-in 600 Vdc contactor for remote disconnect
DNR–did not report

2009 PV Recombiner Specifications

			PV Source Circuits				PV Output Circuit(s)						
Manufacturer	Model	Max Vdc	Max # of input circ.	Max OCPD rating (A) [1]	OCPD type	Wire range (AWG or kcmil)	Max # of output circ.	Max Cont. current (A) [2]	Wire range (AWG or kcmil)	Approved mounting orientation	Monitored option	Enclosure: NEMA type / material	Listing
Amtec Solar	Eclipse 6	600	6	100 [3]	fuse	14–2/0	1	600	600 (x2)	vertical to horizontal	yes	4 / powder coated steel [4]	ETL to UL 1741 [5]
Amtec Solar	Eclipse 12	600	12	100 [3]	fuse	14–2/0	1	1200	600 (x4)	vertical	yes	4 / powder coated steel [4]	ETL to UL 1741 [5]
groSolar	ReadyWatt 4 Circuit	600	4	100	fuse	10–DNR	1	400	DNR–4/0	vertical to 14º	no	3R / painted steel	ETL to UL 508A [6]
SolarBOS	AC-02-100 thru AC-06-100	600	6	100	fuse	6–2/0	1	620	6–350 (x2)	vertical	yes	3, 3R, 4 / powder coated steel	ETL to UL 1741 [5]
							1	720	4–500 (x2)				
							1	1520	4–500 (x4)				
SolarBOS	AC-07-100 thru AC-12-100	600	12	100	fuse	6–2/0	1	1520	4–500 (x4)	vertical	yes	3, 3R, 4 / powder coated steel	ETL to UL 1741 [5]
SolarBOS	AC-02-200 thru AC-06-200	600	6	200	fuse	6–2/0	1	620	6–350 (x2)	vertical	yes	3, 3R, 4 / powder coated steel	ETL to UL 1741 [5]
							1	720	4–500 (x2)				
							1	1520	4–500 (x4)				
SolarBOS	AC-02-200 thru AC-12-200	600	12	200	fuse	6–2/0	1	1520	4–500 (x4)	vertical	yes	3, 3R, 4 / powder coated steel	ETL to UL 1741 [5]
SolarBOS	AC-02-400 thru AC-06-400	600	6	400	fuse	4–350	1	1520	4–500 (x4)	vertical	yes	3, 3R, 4 / powder coated steel	ETL to UL 1741 [5]

[1] Designer must calculate # input circuits vs. specified OCPD rating vs. output continuous circuit max current
[2] Maximum current rating before any required derating per *NEC*
[3] Can utilize larger fuses if not all inputs are used
[4] NEMA 4X fiberglass or stainless options
[5] Listing pending
[6] ETL to UL 1741 listing pending
DNR–did not report

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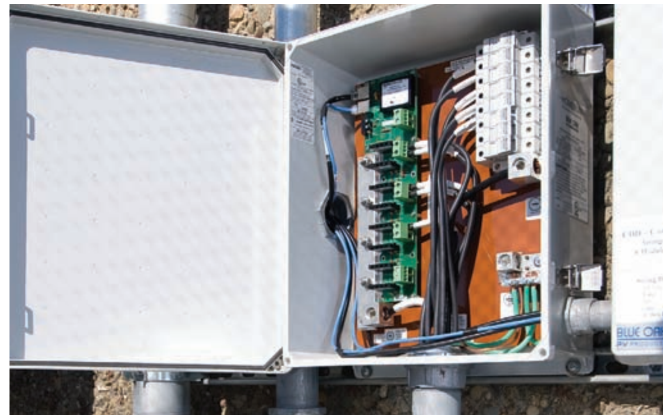
Wired for success The wiring inside this 6-circuit SolarBOS combiner box will put an inspector's mind at ease. Keeping conductors organized and properly identified, as executed here by SPG Solar at the Gundlach Bundschu Winery, is also essential to the safe and long-term operation of the PV system.

"smart" or "intelligent" combiners. A smart combiner box enables string level monitoring, for example, whereas a smart recombiner allows for zone level monitoring. groSolar's Berdner expects that "Intelligent combiners with integral current monitoring will become the standard for larger systems."

It is essential, therefore, that integrators know where to find these products. Integrating combiners and data monitoring capabilities can reduce the number of additional enclosures and conduits, as well as the installation labor required for PV data acquisition systems (DAS). Very often RFPs for large systems specify that the bidder must provide string level or zone level monitoring. It is also increasingly common for system owners or operators to monitor individual PV source circuits to ensure that long-term production goals are met. In the companion table, manufacturers of smart combiners or recombiners are noted as having products that are "DAS ready." In addition to the manufacturers listed in the table, companies such as DST Controls, Draker Laboratories, Energy Recommerce and PV Powered provide smart combiners exclusively. While the table does not provide specifications for all the available smart combiners, contact information for each of these companies is included in the Resources. ⏚



Smart combiner box String level monitoring products, like this Monitoring Homerun Combiner Box designed by Blue Oak PV Products and Draker Laboratories, provide PV system owners and operators with highly granular data to ensure optimal performance.

Thanks to all of the manufacturer representatives who helped with our research for this article. Special thanks are due to John Berdner at groSolar, Robin Gudgel at Midnite Solar, Jason Shripsema at SolarBOS, John Wiles at the Institute for Energy and the Environment, Tom Willis at AMtec Solar and Ryan Zahner at Blue Oak Energy for their generous and expert technical input.

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Resources

AMtec Solar / 510.887.2289 / amtecsolar.com
Blue Oak Energy / 530.747.2026 / blueoakpvproducts.com
Draker Laboratories / 802.865.3866 / drakerlabs.com
DST Controls / 800.251.0773 / dstcontrols.com
Energy Recommerce / 415.493.5402 / energyrecommerce.com
Fronius USA / 810.220.4414 / fronius-usa.com
Midnite Solar / 425.374.9060 / midnitesolar.com
National Electrical Manufacturers Association / 703.841.3200 / nema.org
groSolar / 800.374.4494 / grosolar.com
OutBack Power Systems / 360.435.6030 / outbackpower.com
PV Powered / 541.312.3832 / pvpowered.com
SMA America / 916.625.0870 / sma-america.com
SolarBOS / 925.456.7744 / solarbos.com
SolarWorld / 800.947.6527 / solarworld-usa.com
SPG Solar / 800.815.5562 / spgsolar.com
Square D / 888.778.2733 / squared.com