Using Y-Connectors in String Inverter Systems

At Solar Power International last year, a sales representative for one of our distribution partners inquired: "Why do so many of my customers order 30 A fuses in their source-circuit combiner boxes?" This is a good question. After all, most crystalline silicon (c-Si) PV modules have a short-circuit current (Isc) rating in the 8–9 A range and carry a 15 A–series fuse rating. This is so common that source-circuit combiners typically come standard with 15 A series fuses. Occasionally, an engineer might specify 20 A fuses to account for thermal derating. However, 30 A fusing assumes an Isc of roughly 18 A, which is an unprecedented series fuse rating for today's PV modules.

So why do integrators request combiners with 30 A fuses? The answer is not a function of module ratings per se, but rather of how system integrators deploy these modules. Specifically, more and more installation companies use special Y-connector assemblies to parallel PV source circuits in the array field as a way to optimize electrical balance of system (eBOS) costs.

About Y-Connectors

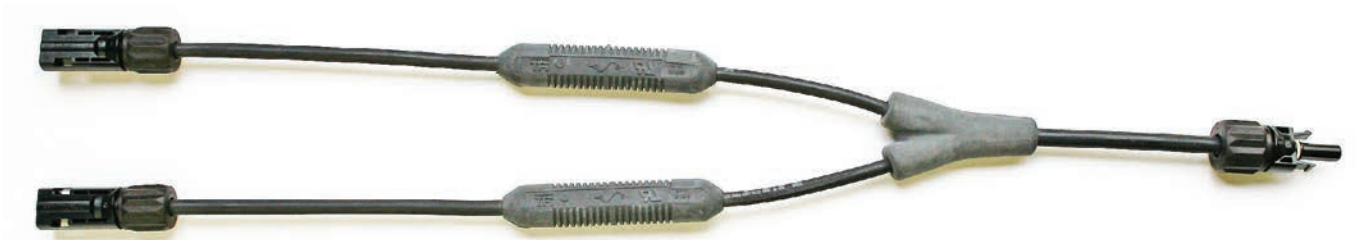
Most industry veterans have seen parallel branch connectors or Y-connector assemblies at conferences or pictured in trade publications or product catalogues. For example, both Amphenol and Multi-Contact offer male and female branch connectors rated for 30 A, as well as overmolded Y-connector assemblies with optional inline fuses. Many eBOS companies also offer customizable Y-connector assemblies. What these connectors and assemblies all have in common is that they have two inputs and one output, allowing installers to make plug-and-play parallel connections within the array.

Until recently, paralleling source circuits within an array was most common in thin-film applications. Compared to c-Si PV modules, thin-film technologies tend to have a higher Voc and a lower Isc. As a result, it behooves integrators to use wire harnesses with inline fuses to parallel thin-film PV source circuits prior to landing them in a combiner box. This practice is cost-effective because it improves conductor utilization within the array and limits the number of combiner box inputs.

Designers can apply these same principles to c-Si PV arrays. After all, touch-safe fuseholders in combiner or inverter wiring boxes are generally 30 A rated, whereas most PV modules have a 15 A series fuse–rating. Therefore, integrators may be able to improve project economics by using Y-connectors to parallel a pair of source circuits ahead of these fuseholders. Before evaluating the potential cost savings associated with this approach, let us review some practical considerations.

***Code* implications.** *NEC* Section 690.9 requires overcurrent protection for PV modules or source circuits, except when there are no external sources of fault current, or when the short-circuit currents from these sources do not exceed the ampacity of the conductors and the maximum series fuse rating. To make a parallel connection ahead of a combiner box, designers need to account for potential sources of fault currents as well as the module manufacturer's series fuse ratings. Generally speaking, parallel connections within the array require Y-connector assemblies with inline fuses. In effect, designers need to relocate 15 A series fuses from the combiner box out into the array wiring.

Since parallel connections increase current, designers also need to evaluate conductor ampacity between the Y-connector and the dc combiner or inverter-input wiring box. To achieve the desired cost savings, integrators need to be able to parallel source circuits within the array without unnecessarily incurring the expense of larger-diameter conductors. To avoid having to step from 10 AWG to 8 AWG copper conductors, for example, designers should avoid or minimize situations that require conductor ampacity adjustments according to Article 310. The



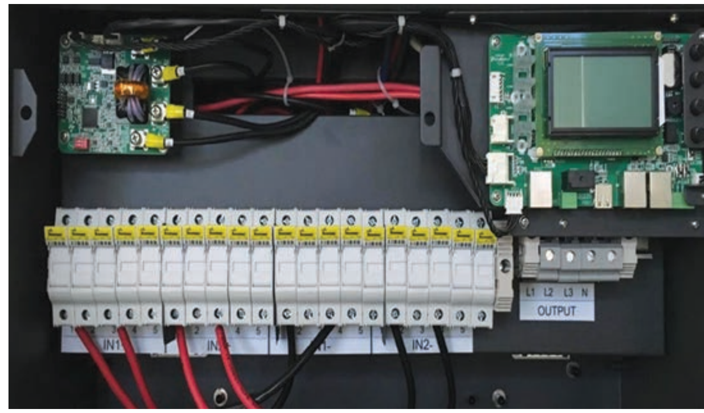
Courtesy SolarBOS

Y-connector An example of a Y-connector assembly with integral inline fuses is shown here.

two most common ampacity adjustment scenarios relate to the number of current-carrying conductors (see Table 310.15[B][3][a]) and distance above the roof (see Table 310.15[B][3][c]). When paralleling source circuits within the array, therefore, it generally makes sense to limit the number of conductors bundled or grouped together to no more than three and to maintain a distance above the roof of at least 12 inches.

Manufacturer limitations. While most of the finger-safe fuseholders for 10 mm by 38 mm fuses found in combiner boxes are manufacturer rated for 30 A, the busbars connected to the fuseholders are not always capable of carrying 30 A of current. Integrators should check with the combiner or inverter manufacturer to ensure that the product is compatible with the use of 30 A fuses.

In some cases, equipment manufacturers require an allowance for heat dissipation where fuseholders are fused at 30 A. The concern is that a lack of space between fuseholders can cause a fuseholder to overheat, potentially melting the plastic and causing a fault. This is not an issue when inputs are fused at 15 or 20 A, as is typical of most string inverter or combiner box applications. However, it may become an issue under continuous loading at full power with 30 A fuses. Landing input conductors on alternating fuseholders, as shown in Figure 1, and



Courtesy Yaskawa–Solectria Solar

Figure 1 To facilitate cooling and prevent overheating, manufacturers may recommend alternating input conductors, as shown here, so that every other fuseholder has a 30 A fuse and the rest of the inputs remain unused, with the fuses removed.

removing the unused fuses is one way to improve heat dissipation.

Commissioning and maintenance. From a commissioning and maintenance perspective, incorporating Y-connectors into the PV array wiring does compromise convenience somewhat. After all, landing individual source circuits in combiner boxes provides commissioning agents and service technicians with a convenient means of isolating individual circuits, both to validate proper installation and to establish baseline performance parameters. Using Y-connectors pushes some of the parallel connection points into the array, which can complicate some routine maintenance and troubleshooting procedures, such as taking Voc measurements on a single source circuit.

Arrays fielded with Y-connectors may also require specialized diagnostic tools. After array commissioning, source-circuit voltage measurements are less important than I-V curve traces, as the latter provide more insight into array health. To capture I-V curve traces on source circuits paralleled using a Y-connector, service technicians must have access to an I-V curve tracer rated to process the combined short-circuit current of both strings. At present, the Solmetric PVA-1000S is the only handheld I-V curve tracer offered with an optional 30 A measurement capability. With this 30 A–rated PV Analyzer, technicians can perform an I-V curve trace in a combiner box on two paralleled c-Si PV source circuits. If technicians have access to a 15 A–rated I-V curve tracer only, they will need to isolate the source circuits entering a Y-connector and trace each I-V curve individually.

Cost Reductions

The reason system integrators are willing to make a small sacrifice in convenience is that the proper use of Y-connectors reduces installed system costs. The savings are twofold: material savings associated with a reduction in the total length of PV Wire within the array field, and labor savings, since installers do not have to make as many terminations in source-circuit combiners.

To realize the maximum PV Wire savings, installers need to locate both poles of each PV source circuit at roughly the same spot within the array table. Using the leapfrog wiring method illustrated in Figure 2 is a good way to accomplish this. Where module wire whips are long enough to accommodate leapfrog wiring, this method eliminates about 30–60 feet of PV Wire per source circuit compared to daisy-chain wiring, with the reduction depending on string length (which is largely a function of nominal system voltage). Leapfrog wiring alone can reduce material costs by as much as $20,000 on a 5 MW PV system. (See "Cost-Saving PV Source Circuit Wiring Method," *SolarPro,* April/May 2014.) Integrators can reduce material costs even further by combining leapfrog wiring with Y-connectors.

Case study. To illustrate, let us consider a hypothetical example where the basic building block for a large-scale PV array is a 50 kW string inverter that is processing power from a 240-module array table. Each array table is mechanically configured two modules high by 120 modules wide and wired electrically with 12 parallel-connected 20-module source circuits. The wire whips are long enough to accommodate leapfrog wiring. A main service road runs north and south along the east edge of the array.

The reason system integrators are willing to make a small sacrifice in convenience is that the proper use of Y-connectors reduces installed system costs.

As shown in Figure 3 (p. 20), the total length of PV Wire per array table is a function of both inverter placement and array wiring. Locating the inverter at the east end of an array table, as assumed in Option 1, provides service technicians with optimal inverter access for O&M purposes but requires the most PV Wire per inverter. Mounting the inverter in the middle of an array table, as shown in Option 2, dramatically reduces PV Wire requirements, but complicates array serviceability. Service technicians will have a harder time reaching each inverter. It may also be impractical or undesirable to run ac conductors within the array field. Option 3, which combines leapfrog wiring with Y-connectors, provides the best of both worlds as it allows for optimal inverter placement and reduces the use of PV Wire significantly. CONTINUED ON PAGE 20

20-module PV source circuit connected in series using leapfrog wiring

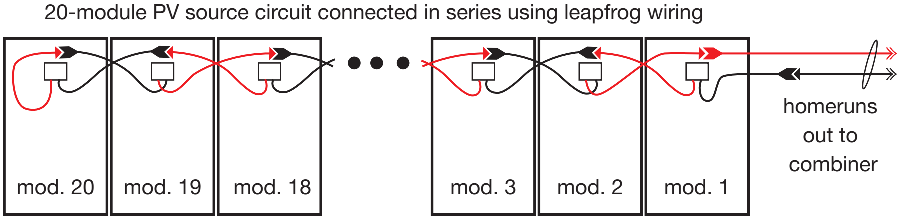
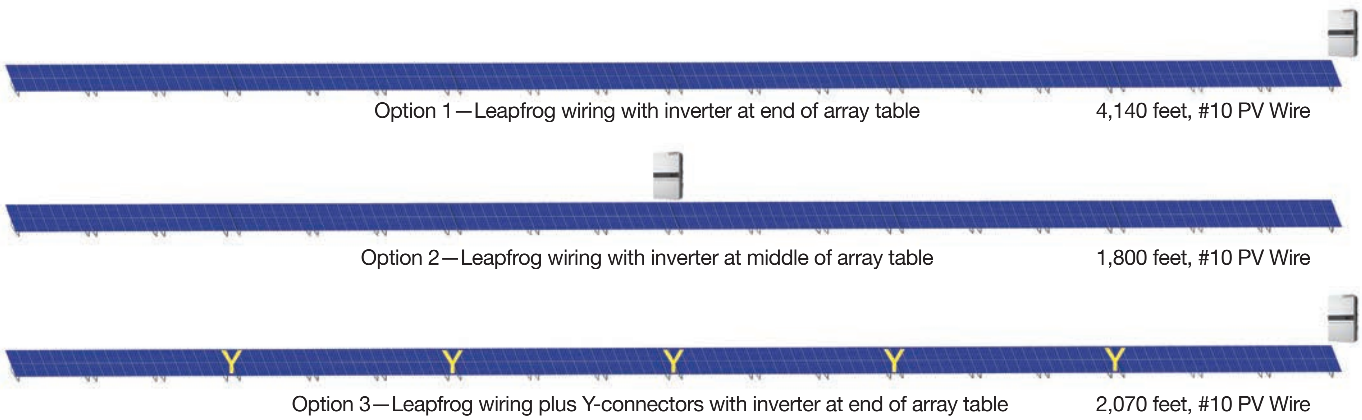


Figure 2 Where wire whips are long enough, installers can use the leapfrog wiring method shown here to colocate both poles of the PV source circuit, which facilitates the use of Y-connectors to parallel source circuits within the array.



Courtesy Yaskawa–Solectria Solar

Figure 3 This figure details the PV Wire requirements for three possible array table configurations. All three options assume leapfrog wiring. Inverter placement accounts for the difference between Options 1 and 2. Option 3 adds Y-connectors at 20-module intervals to parallel adjacent source circuits within the array.

As compared to Option 1, the combination of leapfrog wiring and Y-connectors in Option 3 effectively reduces the homerun conductor length within the array by half. This setup does not offer a free lunch, however, as the cost to purchase Y-connectors and inline fuses offsets some of the PV Wire savings. While it is possible to purchase inline fuseholders and unfused Y-connectors separately and plug them together in the field, it is generally more cost-effective to purchase an integrated assembly. Companies such as Amphenol, Eaton, Shoals Technologies Group and SolarBOS all offer Y-connector assemblies with integral inline fuses. When purchasing an all-in-one solution, integrators should order extra assemblies for O&M purposes; in the rare event that one fuse blows, they will need to replace the entire assembly.

Table 1 estimates the total material and labor savings associated with deploying array-table configuration Option 3 rather than Option 1. Assuming that 10-gauge PV Wire costs $0.20/foot, you can save more than $400 per array table by adding Y-connectors at the end of each adjacent pair of source circuits (2,070 ft. × $0.20/ft.). While it will cost $240 to add six pairs of fused Y-connector assemblies (12 Y-connectors x $20/each), the net material savings per array table are roughly $174 ($414 less $240). Labor savings are estimated at 1 hour per array table and reflect the fact that installers will spend less time managing homerun conductors within the array (saving roughly 45 minutes) and will have to make only half as many dc terminations at the inverter (saving roughly 15 minutes). Assuming a labor rate of $80 per hour, the total material and labor savings are $254 per array table, which extrapolates to $5,080 per MWac ($0.005/W).

Of course, every array is different, and material and labor costs vary from region to region, so results may vary. However, this case study is a good example of the type of analysis that can help reduce costs, improve profits and win more projects. According to GTM Research, the utility-scale solar market in the US will approach 12 GW in 2016. If each one of these large-scale projects could reduce eBOS costs by a half cent per watt, the industry as a whole would save $60 million.

—Eric Every / Yaskawa–Solectria Solar / Lawrence, MA / solectria.com

Estimated Savings per Array Table

	Amount	Unit cost	Extended cost
PV Wire (10 AWG)	2,070 ft.	$0.20/ft.	$414
Y-connectors	12 (six pairs)	$20	($240)
Labor	1 hr.	$80/hr.	$80
Material and labor savings per 50 kW inverter			$254
Estimated savings per MW			$5,080

Table 1 Using Y-connectors within the table depicted in Figure 3, Option 3, nets material and labor savings of $254 per array table and more than $5,000 per MWac.