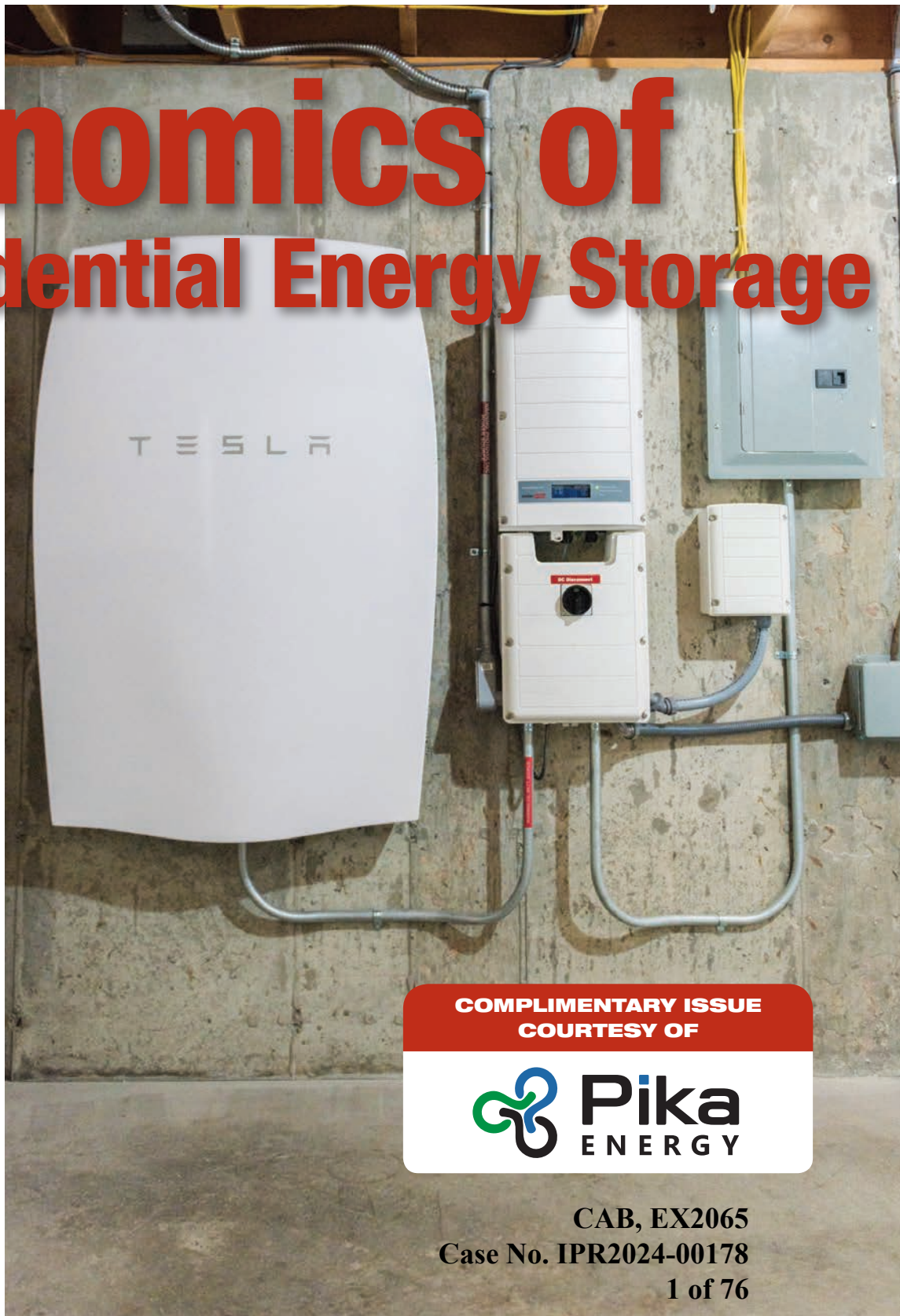
Y-Connectors in String Inverter Systems

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Economics of Residential Energy Storage



Energy Storage Power Electronics

Vendor and Platform Profiles for Residential System Components

Electrical BOS Optimization

Strategies, Opportunities and Best Practices for Cost-Effective Designs

Projects

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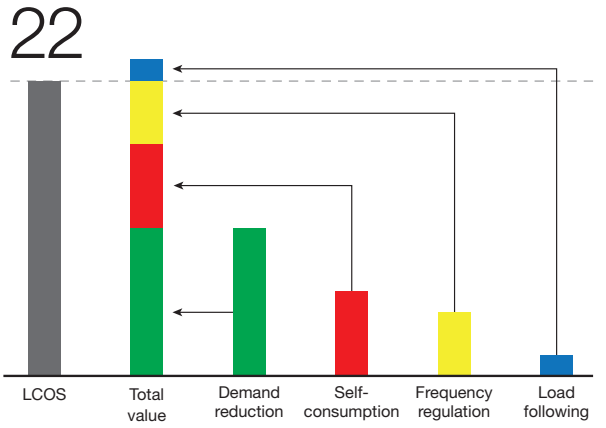
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In this article, we consider some of the use cases and emerging markets for residential grid-interactive energy storage systems. We then present a simplified levelized cost of stored energy (LCOS) metric, useful for analyzing the economics in residential energy storage applications. Throughout the article, we consider some of the ways in which the emerging energy storage market parallels the early days of the solar industry, and what this may tell us about its path forward.

BY MATTHIAS B. KRAUSE AND DAVID BREARLEY



38 Energy Storage Power Electronics: Vendor & Platform Profiles

Technological advancements, constrained electric grids with high penetrations of PV systems and the gradual erosion of net energy metering programs across the US may usher in a new era for distributed, grid-connected energy storage systems. Numerous manufacturers are banking on the expected proliferation of highly integrated, customer-sited energy storage. This article provides manufacturer and product line overviews for 14 power electronics and battery system vendors that are positioning themselves for the new energy storage market.

BY JOE SCHWARTZ

54 Opportunities, Strategies & Best Practices for Electrical Balance of System Optimization

SolarPro reached out to two stakeholder groups—solar project engineers and equipment vendors—to identify opportunities, strategies and best practices for eBOS cost reductions. The myriad responses illustrate that squeezing additional value out of commercial and large-scale PV systems is very much a multidisciplinary effort that requires holistic thinking. Design responses also vary depending on whether owners are most concerned about low up-front costs or the impact of O&M costs over time.

COMPILED BY DAVID BREARLEY

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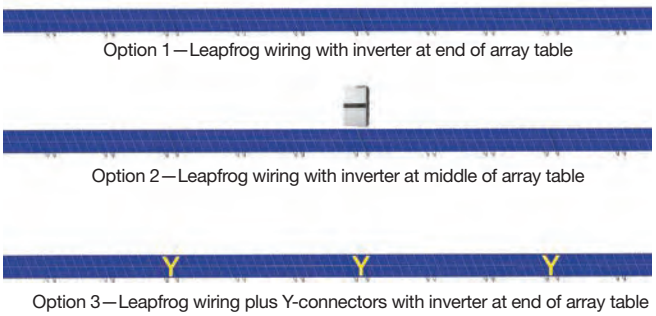
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Contributors

Experience + Expertise

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David Brearley is the senior technical editor for PV systems at *SolarPro*. His solar education began at the San Juan College Renewable Energy Program in Farmington, New Mexico. Brearley became NABCEP certified in 2004. After working for a national distributor, he transitioned to commercial and residential PV system integration in Austin, Texas.



Eric Every joined Solectria in 2011 and serves as its senior applications engineer. He holds a degree in electrical engineering from the University of Massachusetts Amherst. Every manages Solectria's Megawatt Solar Station projects and is instrumental in achieving project compliance with grid codes and utility requirements.



Matthias B. Krause is a Berkeley, California–based journalist covering energy, technology, business and the environment. Previously he served as the managing editor of PHOTON USA. Krause is a co-founder of "Solar Power Report," an independent guide to solar.



Joe Schwartz is the CEO of Home Power. He serves as the publisher and editor of *SolarPro* and the executive editor of *Home Power.* Schwartz worked as a PV, wind and hydro systems integrator prior to entering technical publishing. He holds a Limited Renewable Energy Technician license in the state of Oregon.

Publisher/Editor	Joe Schwartz
Managing Editor	Kathryn Houser
Senior Technical Editor/PV Systems	David Brearley
Technical Editor/PV Systems	Ryan Mayfield
Engineering Editor/PV Systems	Blake Gleason, PE
Creative Services	Midnight Oil Design
Copy Editors/Proofreaders	Kim Saccio-Kent, Gail Nelson-Bonebrake
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Solmetric Re-releases Shade Measurement Tool



[Sebastopol, CA] Solmetric recently announced that the SunEye 210 is again available for purchase. The handheld electronic tool measures available solar energy by day, month and year at the press of a button by determining the shading patterns of a particular site. The SunEye 210 incorporates a calibrated fish-eye camera, electronic compass, tilt sensor and GPS to give immediate measurements in the field. The re-released SunEye 210 now includes a lifetime license for Solmetric's PV Designer software, which enables users to import shade measurements, select modules and inverters, lay out arrays, simulate kWh production and generate PDF reports. At $2,195, the retail price of the SunEye 210 is the same as when it was discontinued in 2015.

Solmetric / 707.823.4600 / solmetric.com

Quick Mount PV Releases Tile Replacement Mount

[Walnut Creek, CA] The Tile Replacement Mount by Quick Mount PV eliminates the labor-intensive requirement for tile cutting and grinding when mounting PV arrays to tile roofs. The new mount replaces full tiles and is available in three profiles for compatibility with flat, S-shaped and W-shaped tile profiles. The double-flashed Tile Replacement Mount system uses a universal base mount that is compatible with all three flashing profiles. For stocking and staging flexibility, Quick Mount packages the Base Mount (12 units per box) separately from the Replacement Mount's Flashing Box, which includes the secondary flashing (12 units per box in W-tile, S-tile or flat-tile profile) and posts. Both the Base Mount box and the Flashing Box include all hardware required to seal and secure the included components. The system is IBC compliant and carries a 20-year warranty.

Quick Mount PV / 925.478.8269 / quickmountpv.com



Fronius Expands Rapid-Shutdown Solutions



[Portage, IN] Fronius USA's Rapid Shutdown Box-Multi is a streamlined solution that meets *NEC 2014* Section 690.12 requirements for rooftop PV systems when installed on the roof or racking within 10 feet of the array or in an accessible attic space within 5 feet of the array. It is NEMA 4X rated and compatible with all Fronius SnapINverter models in 600 Vdc applications. It supports one to four dc inputs and one or two independent outputs. The shutdown box communication cable connects directly to the inverter through the same conduit as the dc homeruns. It is powered by the PV array (maximum draw of 3 W) and does not require an additional power supply.

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Solaria Launches Two High-Efficiency Modules



[Fremont, CA] Solaria recently announced the launch of its PowerXT-R 330 W and PowerXT-U 400 W modules. Solaria's patented cell cutting and assembly methods form high-density substrings of rectangular mono-silicon cells that are larger than conventional solar cells. The cell shape and assembly approach minimizes inactive space between cells. Solaria developed its 320–330 W PowerXT-R modules for rooftop applications. The 330 W model has a module efficiency of 19.3%, a maximum power voltage of 36.6 Vdc and a maximum power current of 9.02 Imp. Solaria optimized its 390–400 W PowerXT-U models for tracked and fixed utility-scale PV plants. The 400 W model has a module efficiency of 19.03%, a maximum power voltage of 37.3 Vdc and a maximum power current of 11.4 Imp. Solaria backs its PowerXT modules with a 10-year product and 25-year linear power warranty.

Solaria / 510.270.2500 / solaria.com



Ginlong Solis Introduces Rapid-Shutdown Device

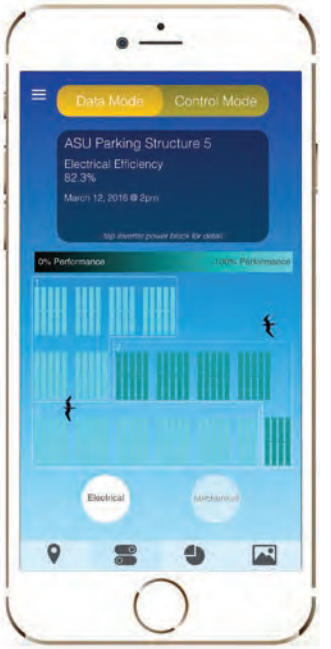
[Dublin, OH] Ginlong Solis has released two rapid-shutdown devices that provide compliance with *NEC 2014* Section 690.12 requirements. The company has designed the NEMA 4X low-profile Solis-RSD-1G for mounting to the PV rack under the modules. Its mounting plate is compatible with Burndy WEEB bonding clips. The two available models provide compatibility with Solis string inverters that have either one or two MPP trackers. The Solis-RSD-1G 1:1 has one input and one output. The Solis-RSD-1G 2:2 has two inputs and two independent outputs. The Solis-RSD-1G rapid-shutdown devices include prewired MC4 connectors for streamlined installation.

Ginlong Solis Technologies / 866.438.8408 / ginlong-usa.com

SunLink Announces VERTEX Control and Monitoring Platform

[Mill Valley, CA] VERTEX, SunLink's next-generation secure project platform for supervisory control and data acquisition (SCADA) and solar performance monitoring, is now available for download in the Apple Store. SunLink developed VERTEX with the goal of reducing PV plant O&M costs while improving long-term energy plant profitability and enhancing grid security. Using the app's customer portal, subscribers gain protected access for project stakeholders to both real-time data for control centers and mobile device–based controls to optimize performance project by project, as well as at a portfolio level. The platform alerts O&M providers to what needs their attention and how important the issue is to a site's energy production, allowing them to target and optimize troubleshooting activities.

SunLink / 415.925.9650 / sunlink.com



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SimpliPhi Offers Deep-Cycle Lithium Batteries

[Ojai, CA] SimpliPhi Power developed its deep-cycle lithium ferro phosphate (LFP) Smart-Tech battery models as drop-in replacements for lead-acid batteries in 24 Vdc and 48 Vdc nominal power systems. The UL- and CE-listed Smart-Tech product line does not require ventilation, cooling or thermal regulation. Each battery includes a built-in 80 A dc breaker on/off switch that increases safety during system installation, commissioning and O&M. SimpliPhi Smart-Tech batteries have no memory effect, offer a self-discharge rate of less than 1% per month and an operating efficiency of 98%, and can discharge to 100%. The PHI2.6 model weighs 57.5 pounds and has a rated capacity at C/2 of 2.62 kWh. The higher-capacity PHI3.4 weighs 75.5 pounds and has a rated capacity at C/2 of 3.44 kWh. Both models have an operating voltage range of 20–28.8 Vdc at 25.6 Vdc nominal and 40–57.6 Vdc at 51.2 Vdc nominal. SimpliPhi Smart-Tech batteries have a cycle life of 10,000 cycles and a warranty period of 10 years.

SimpliPhi Power / 805.640.6700 / simpliphipower.com



Ingeteam Launches 1,500 Vdc Central Inverter Line

[Milwaukee, WI] Ingeteam announced the launch of its 1,500 Vdc INGECON SUN PowerMax B series central inverters for utility-scale PV plants. The PowerMax B series comprises six 3-phase models with power classes ranging from 1,169 kVA to 1,637 kVA at 77°F. The inverters are ETL listed to UL 1741 and Rule 21 compliant. They feature a low-voltage ride-through capability and can deliver reactive power and control the active power delivered to the grid. Enclosures are available for both indoor and outdoor installations. In addition, symmetrical inverter configuration options locate the connection cabinet on the side opposite the inverter, making it possible to install two inverters facing each other with a common power supply point. The PowerMax B series has a peak efficiency of 98.9% and a CEC-weighted efficiency of 98.5%.



Ingeteam / 414.934.4100 / ingeteam.com

SMA Introduces Rapid-Shutdown System

[Rocklin, CA] SMA America recently announced its *NEC 2014* Section 690.12–compliant Rapid Shutdown System. The company engineered the system for compatibility with Sunny Boy TL-US and 5.0-US/6.0-US inverters that have multiple MPP tracking channels, and the system is also compatible with SMA's Secure Power Supply. Prewired MC4 connectors reduce materials and installation time. The SMA rapid-shutdown solution includes two main components.The Rapid Shut Down Box has a maximum input voltage of 600 Vdc and accommodates four PV source circuits (two in parallel per channel). The array powers the integrated power supply (maximum draw 5 W). SMA's Rapid Shutdown System performs an automatic self-test upon startup. The Rapid Shutdown Controller allows manual triggering of the system's rapid-shutdown function.



SMA America / 916.625.0870 / sma-america.com

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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

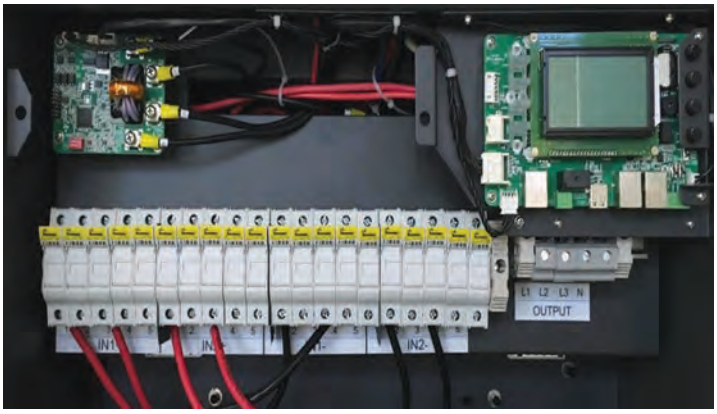
Y-connector An example of a Y-connector assembly with integral inline fuses is shown here.

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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.



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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.

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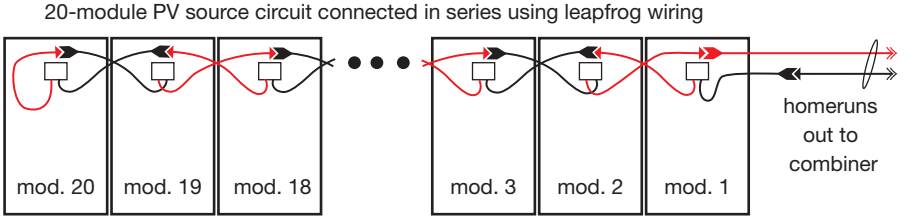


Figure 2 Where wire whips are long enough, installers can use the leapfrog wiring method shown here to colocate both poles of the PV source circuit, which facilitates the use of Y-connectors to parallel source circuits within the array.

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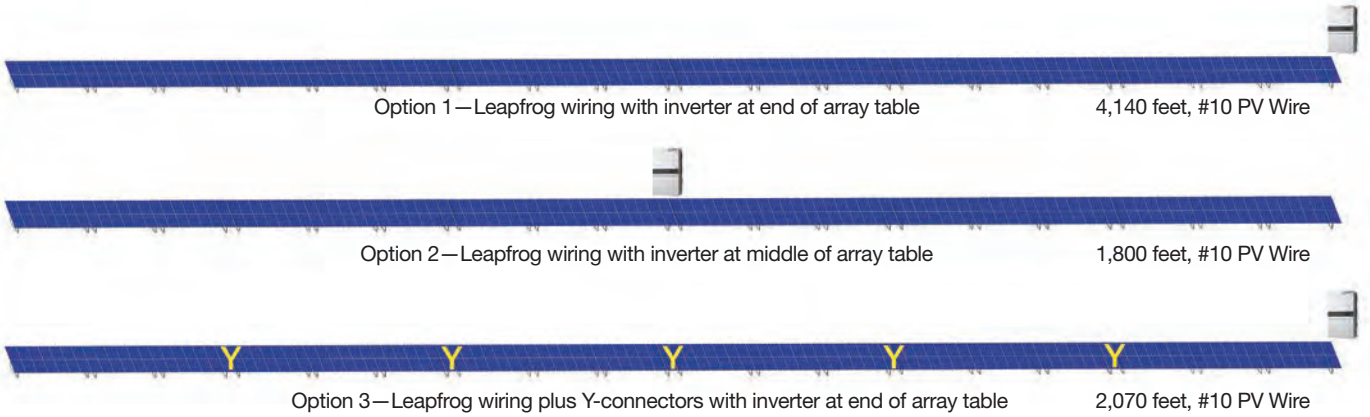
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Figure 3 This figure details the PV Wire requirements for three possible array table configurations. All three options assume leapfrog wiring. Inverter placement accounts for the difference between Options 1 and 2. Option 3 adds Y-connectors at 20-module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

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solar plus storage

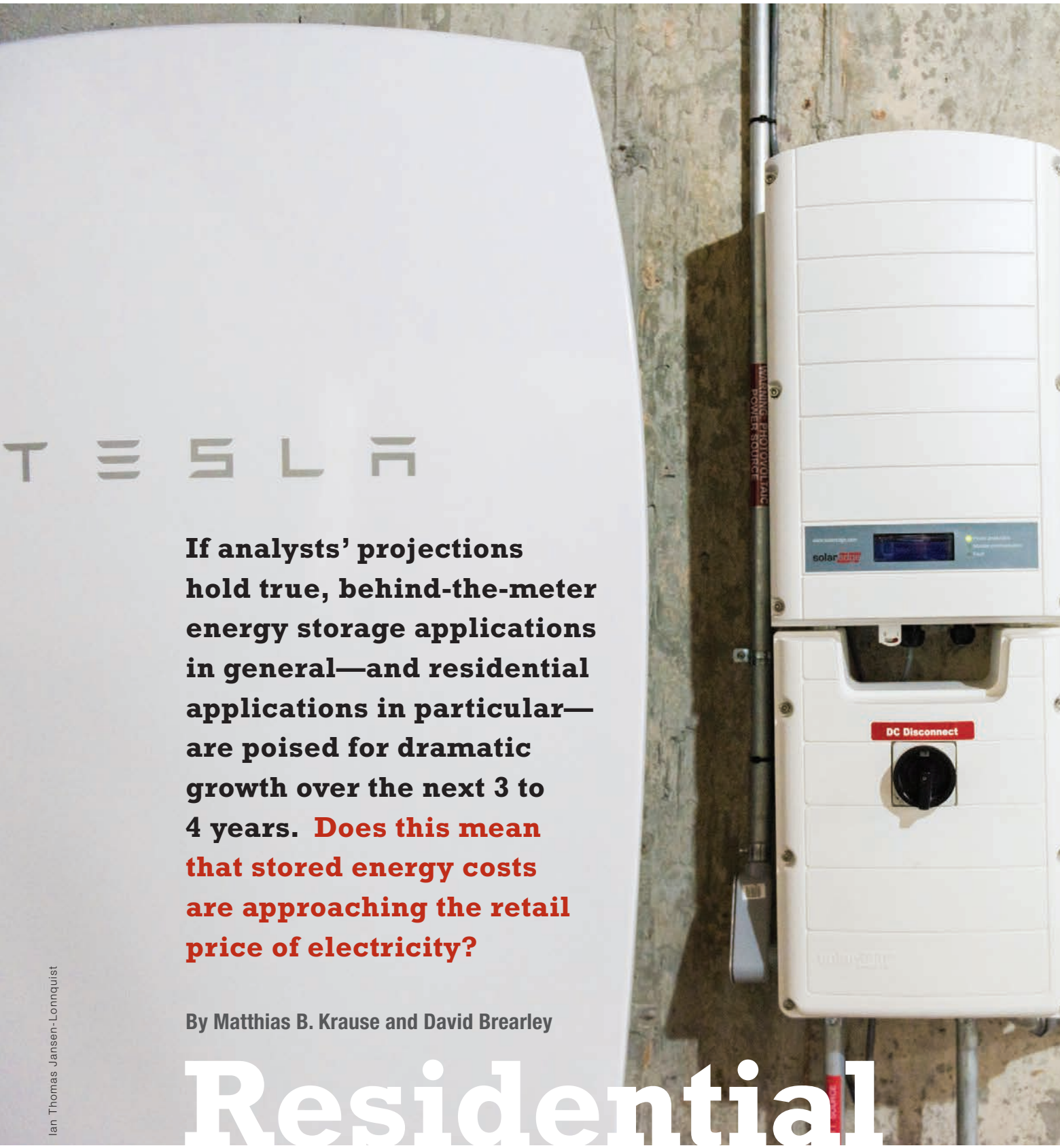
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Ian Thomas Jansen-Lonnquist

If analysts' projections hold true, behind-the-meter energy storage applications in general—and residential applications in particular—are poised for dramatic growth over the next 3 to 4 years. Does this mean that stored energy costs are approaching the retail price of electricity?

By Matthias B. Krause and David Brearley

Residential Energy Storag

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ge Economics

In "US Energy Storage Monitor: 2015 Year in Review" (see Resources), GTM Research forecasts that the US annual energy storage market will reach 1.7 GW by 2020, a 26-fold increase from 2014. The projected growth by market sector is of particular interest to solar installers. According to data that GTM Research and the Energy Storage Association gathered for the report, customer-sited behind-the-meter energy storage deployments accounted for roughly 11% of the total market in 2014 and 16% in 2015, with utility deployments comprising the vast majority of installed energy storage capacity. However, GTM Research expects that by 2019 the energy storage deployed behind the meter in nonresidential and residential applications will eclipse the utility segment.

In this article, we consider some of the use cases and emerging markets for residential grid-interactive energy storage systems. We then present a simplified levelized cost of stored energy (LCOS) metric, useful for analyzing the economics in residential energy storage applications. In addition to exploring the sensitivity of LCOS in relation to various parameters, we consider the practical limitations of this metric. Throughout the article, we consider some of the ways in which the emerging energy storage market parallels the early days of the solar industry, and what this may tell us about its path forward.

MARKET AND APPLICATIONS

The projected growth of the residential energy storage market presents a tremendous opportunity for solar installation companies. After all, interconnecting a battery-in-a-box type of appliance is not all that different from making the grid connection for an interactive PV system. Further, adding solar to an energy storage system can improve the overall value proposition, both by leveraging tax credits and by adding another battery charging source. Finally, solar companies can offer energy storage as a retrofit solution to existing customers or as an optional upgrade to new customers, which are compelling ways to drive down customer acquisition costs and increase sales revenue.

The challenge, of course, is that the energy storage market has made less progress along the classic technology adoption and hype cycle curves, shown in Figure 1 (p. 24),

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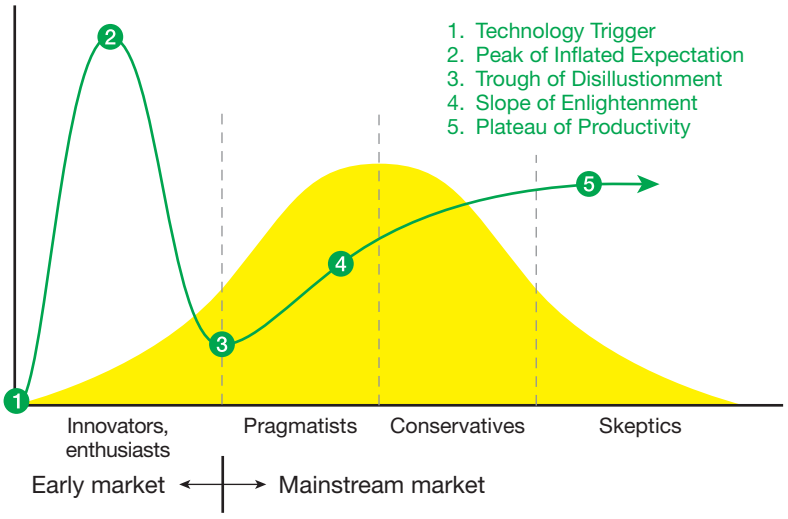


Figure 1 This diagram superimposes Gartner's hype cycle curve, which plots customer expectations over time, on Everett Roger's technology adoption curve, which plots market adoption over time. In markets such as California, solar appears to be progressing along the Slope of Enlightenment and appealing to pragmatic customers. By comparison, energy storage likely still has a way to go before it reaches the Peak of Inflated Expectations and moves beyond sales to early adopters.

than solar has. The California residential grid-tie solar market, for example, progressed from innovative pilot projects in the 1990s to a classic early adopter market at the beginning of the 2000s, when customer concerns about the environment or self-sufficiency drove sales more than economic self-interest. Now that residential solar has reached grid parity in California, the technology appeals more broadly to economic pragmatists, which is characteristic of an early majority market. While solar market maturity varies from state to state, GTM Research's latest in its series of US solar market reports (see Resources) estimates that solar has reached grid parity in 19 states plus the District of Columbia, meaning that the levelized cost of energy for PV is equal to or lower than the retail price of electricity in these markets—after accounting for incentives and tax credits.

By comparison, these are very early days for the residential energy storage market in the US. The authors of the Rocky Mountain Institute (RMI) report "The Economics of Grid Defection" (see Resources) estimate that residential solar-plus-storage has the potential to achieve grid parity in Hawaii today under certain scenarios that assume improvements in demand-side load management and battery cost reductions. Under a more realistic base case scenario, the authors project the following: "Residential [solar-plus-battery] systems will reach grid parity as early as the early 2020s in Hawaii, late 2030s in Los Angeles, and late 2040s in [Westchester, New York]."

While Tesla succeeded in creating a lot of buzz about energy storage with its Powerwall announcements, it is reasonable to wonder whether current technology and business cases can meet customer expectations. If not, energy storage likely still has a hill to climb before it overcomes its own hype, as represented by the slope leading to the Peak of Inflated Expectation in Figure 1. By comparison, the leading solar markets in the US are more developed, advancing perhaps along the Slope of Enlightenment.

Part of the challenge facing residential energy storage in the US is that its use cases or applications are limited compared to those of maturing energy storage markets elsewhere in the world or even of domestic commercial deployments. The authors of a more recent RMI report, "The Economics of Battery Energy Storage" (see Resources), identify four customer services for behind-the-meter energy storage: backup power, increased PV self-consumption, time-of-use bill management and demand reduction. To put these applications in context, let us briefly review the goals and ideal economic environment for each scenario.

Backup power. The role of energy storage in backup power applications, of course, is to support loads in the event of a grid failure. Generally speaking, the installer relocates a subset of the home's branch circuits to a new subpanel. In the event of a grid failure, loads connected to this backup-loads subpanel can operate for as long as the battery state of charge remains above its allowable depth of discharge. The duration of backup power varies based on the load profile and the battery capacity. A benefit of solar in this scenario is that it provides a battery charging source when the grid is down, which can extend backup power availability from a period of hours to days.

Backup power is a classic early adopter market, one driven more by customer desire than by economics.

Demand for backup power is an important driver in residential energy storage applications, especially in the short term. However, this is also a classic early adopter market, one driven more by customer desire than by economics. It is simply not possible to develop a business case that justifies residential energy storage for backup power on a dollar per kilowatt-hour basis. Instead, customers willing to pay a premium price to have the latest technology or to ensure that they can keep lights on during an outage are the ones driving these sales.

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THE POWER TO TAKE ACTION IN THE PALM OF YOUR HAND



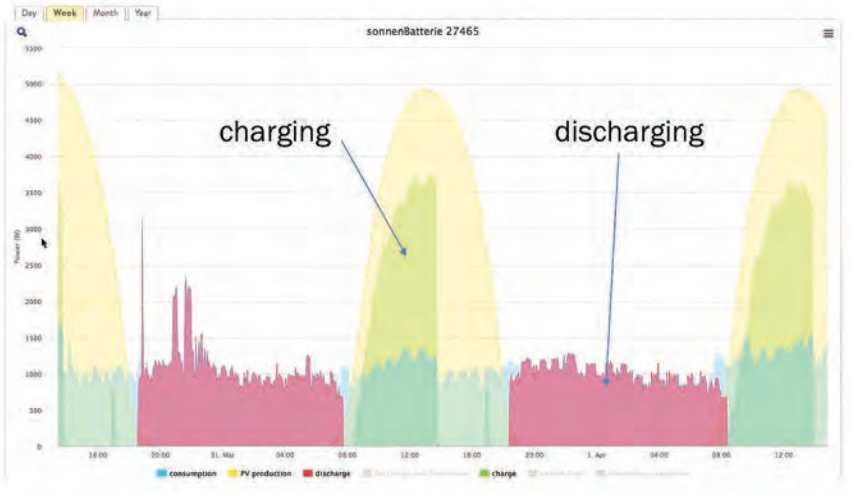
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Figure 2 This sonnenBatterie screen capture illustrates how an energy storage system is cycled in a self-consumption application. Software controls divert excess solar generation to the battery early in the day, and then use this stored energy to offset loads after the sun goes down.

PV self-consumption. The role of energy storage in a self-consumption or zero-export scenario is to store excess PV production and discharge this stored energy later. Self-consumption and zero-export applications always include solar. As compared to standard interactive or backup power systems, self-consumption applications require additional energy monitoring. In effect, the solar-plus-storage system needs to see the home energy consumption in real time to optimize energy inflows and outflows for maximum customer benefit. Moreover, zero-export systems need to curtail PV production whenever generation exceeds on-site loads and the battery bank's capacity to store energy.

Markets where utilities value PV outflows at a rate that is lower than the retail price of electricity, or where they simply will not allow PV outflows, drive the demand for PV self-consumption or zero-export systems. In markets with net energy metering (NEM), customers can effectively store excess solar generation on the utility grid. Since these customers receive the full retail price for outflows, the only benefit of adding energy storage is as a hedge against the loss of NEM. In markets without NEM, however, PV customers can use a battery to shift delivery of excess PV generation in time for use later, as illustrated in Figure 2. To be economically viable, self-consumption applications need to offset the inherent efficiency losses associated with energy storage, as well as the substantial up-front costs associated with the additional hardware.

Time of use. As with PV self-consumption systems, the role of energy storage for time-of-use bill management is to store energy for use later. The primary difference between these scenarios is the logic they employ to define high-value versus low-value energy. Since NEM rules do not apply in a self-consumption scenario, customers get a retail credit only for PV generation that directly offsets household loads; they get a fraction of this value for PV outflows, which the utility might credit at the wholesale or avoided cost of electricity. In a time-of-use regime, the standard NEM logic applies; however, the retail rate structure itself values energy differently over the course of a day or year, as illustrated in Table 1 (p. 28). Utilities intentionally design these price differences to correspond with the relative demand for energy, as these signals can help level out electricity demand and even defer infrastructure upgrades.

In a time-of-use scenario, energy has the highest value during periods of peak demand, such as weekday afternoons or evenings in summer, and relatively lower worth at other times. The prime economic driver in these scenarios is the magnitude of the difference between on-peak and off-peak energy rates. In theory, if the spread between high-value and low-value energy is large enough, energy storage customers can achieve a return on investment by storing energy during off-peak periods and discharging it when on-peak prices are in effect. In practice, battery costs are relatively high and retail energy prices are relatively low in most of the US, which works against this business case.

Though demand reduction is an excellent use case for energy storage, very few utilities factor demand into residential rate structures.

Demand reduction. Demand-reduction applications use stored energy to reduce instantaneous power demand. Demand reduction is one of the most attractive business cases for behind-the-meter energy storage in commercial applications. Whereas utilities typically bill residential customers strictly based on monthly energy (kWh) consumption, they bill commercial and industrial users based on both energy consumption and peak power (kW) demand, typically as measured over a 15-minute interval. For commercial and industrial customers, peak demand charges are not only the fastest-growing part of their electric bill, but also may account for up to 50% of the total. In these applications, service providers

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Weekday Tiers for PG&E's E6 Rate Plan

Rate structure		Tier 1 (¢/kWh)	Tier 2 (¢/kWh)	Tier 3 (¢/kWh)	Tier 4 (¢/kWh)	Time of day
May–Oct	Peak	34.2	38.4	44.4	52.2	1pm–7pm
	Partial peak	22.6	26.9	32.9	40.7	10am–1pm; 7pm–9pm
	Off-peak	15.0	19.2	25.2	33.0	9pm–10am
Nov–Apr	Partial peak	17.1	21.3	27.4	35.2	5pm–8pm
	Off-peak	15.4	19.7	25.7	33.5	8pm–5pm
Volumetric tiers (baseline amount varies by territory)		≤ baseline	101%–129% of baseline	130%–200% of baseline	>200% of baseline	

Table 1 PG&E's E6 rate plan, which the company closed to new subscribers at the end of May, is a multiple-tiered time-of-use rate with different tiers for weekdays (shown here), weekends and holidays. Volumetric tiers, relative to a baseline kWh allowance that varies by territory, also apply.

can use advanced monitoring and control capabilities to discharge stored energy from the batteries coincident with peak loads.

Though demand reduction is an excellent use case for energy storage, very few utilities factor demand into residential rate structures. A notable exception is Arizona's Salt River Project, which recently implemented a pilot program for a residential demand–based price plan. Unless residential demand charges apply, demand reduction is not a viable market for in-home energy storage.

STORED ENERGY COSTS

The US Energy Information Administration (EIA) tracks average electricity prices by state and market sector over time. In October 2015, EIA published its recently aggregated annual energy cost data, which indicate that the average retail price of electricity in the residential sector was 12.52 cents per kWh in 2014. Drilling down on the state-level data, Washington, which gets 65% of its electricity from hydro, had the lowest residential electricity prices (8.67 cents per kWh), whereas Hawaii,



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which gets the lion's share of its electricity from fuel oil, had the nation's highest prices (37.04 cents per kWh).

So how does the cost to store energy in residential applications compare to retail electricity prices? In reality, this depends largely on the energy storage system's use and cycling practices. However, it is possible to use the simplified formula in Equation 1 to derive a back-of-the-napkin value for the LCOS:

$$\text{LCOS} = \text{Cost} \div (\text{Usable Capacity} \times \text{Cycles} \times \text{Efficiency}) \qquad (1)$$

Cost. In the *SolarPro* article "Levelized Cost of Energy" (April/May 2012), Tarn Yates and Bradley Hibberd note that LCOE calculations "should include all costs that the project incurs—including construction and operation—and may incorporate any salvage or residual value at the end of the project's lifetime." They go on to explain how to account for project financing costs, discounted cash flow and depreciation in these calculations. As the formulas in the 2012 article evidence, detailed LCOE calculations can become quite complicated.

For the purposes of this article, we intentionally strip away many of these layers of complexity. We do not factor the time value of money into our LCOS calculations; we do not consider the residual value of the equipment at the end of its life cycle; we do not even consider O&M costs. Instead, we use the initial installed cost of the energy storage system and the associated power electronics as a proxy for the total life cycle costs.

To justify this simplified approach, we look specifically at the LCOS for a representative set of lithium-ion energy storage solutions and applications. Since vendors advertise these advanced battery appliances as maintenance-free

LCOS in Relation to System Cost

	Utility provider	Retail provider
Installed cost	$6,500	$9,000
Nominal capacity (kWh)	6.40	6.40
Number of cycles	3,650	3,650
Round-trip efficiency	90%	90%
Warranted capacity (kWh)	18,000	18,000
Best-case LCOS ($/kWh)	$0.31	$0.43
Warranted LCOS ($/kWh)	$0.40	$0.56

Table 2 In this scenario, we model LCOS for a turnkey Tesla Powerwall system—fully installed with SolarEdge components (StorEdge inverter, autoformer and energy meter) and backup loads relocated to a dedicated subpanel—based on Green Mountain Power's pilot program price and the estimated retail price through TreeHouse, Tesla's first Powerwall retailer.



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solutions, we assume that the user does not incur any additional costs to maintain and operate the energy storage asset. Note that if you wanted to use this formula to analyze the LCOS for an energy storage system with flooded lead-acid batteries, which have lower up-front costs than lithium-ion batteries, you would have to factor in O&M costs over the life of the system. These costs vary based on labor rates and travel times.

Table 2 (p. 29) illustrates the sensitivity of LCOS to costs. On one hand, Green Mountain Power, Vermont's largest electric utility, is selling turnkey Tesla Powerwall solutions—complete with a SolarEdge StorEdge inverter, autotransformer and energy meter—for an installed price of $6,500, made possible in part by a bulk purchase order for 500 units and the fact that the utility can use its own technicians to install the systems. On the other hand, TreeHouse, an Austin, Texas–based sustainable home improvement store, is the nation's first retailer to offer Tesla's Powerwall, which it provides through a network of licensed installation partners. According to one of these installation partners, the initial turnkey cost for a StorEdge plus Powerwall system in Austin will likely be "closer to $9,000." This $2,500 difference in up-front costs results in a $0.16/kWh difference in the LCOS between the utility provider and the retail provider.

Usable capacity. An energy storage system's usable capacity is primarily a function of nameplate kWh capacity, the allowable depth of discharge and battery capacity degradation over time. For example, Adara Power (formerly JuiceBox Energy) sells a residential energy storage system with a nominal 8.6 kWh lithium-ion battery. According to the company's CEO, Neil Maguire, the maximum allowable depth of discharge for these nickel manganese cobalt oxide batteries, which Samsung manufactures, is 75%. Based on this allowable depth of discharge, the usable capacity of Adara's energy storage system is 6.45 kWh (8.6 kWh x 0.75). However, this is the nominal battery capacity on day 1 only. This battery capacity will invariably decline over the life of the system, based in part on aging and in part on usage.

There are challenges associated with deriving a realistic value for an energy storage system's usable capacity. Notably, the energy storage industry lacks nameplate and datasheet reporting standards and independent third-party verification requirements. This scenario is not unlike the early days of the US solar industry, when some manufacturers batched modules according to very tight nameplate power tolerances, such as +5% to −0%, while others had a very wide window, such as +5 to −10%. It is also reminiscent of the days before the CEC established independent verification test requirements for PV modules (PTC ratings) and inverters (CEC-weighted efficiency).

Without access to standardized data verified by a third party, the battery warranty may provide the best approximation of usable capacity over the life of an energy storage system. For example, Tesla nominally rates its Powerwall at 6.4 kWh when used for daily cycling. If we assume that a Powerwall cycles to capacity 3,650 times over its 10-year warranty period, the best-case LCOS falls in the $0.31–$0.43/kWh range, depending on system cost. However, if we review the Powerwall warranty, which accounts for the stepped degradation over time shown in Figure 3, we see that Tesla guarantees "18 MWh of aggregate discharge" from the battery cells. If we calculate LCOS based on the warranted battery capacity, LCOS increases to $0.40–$0.56.

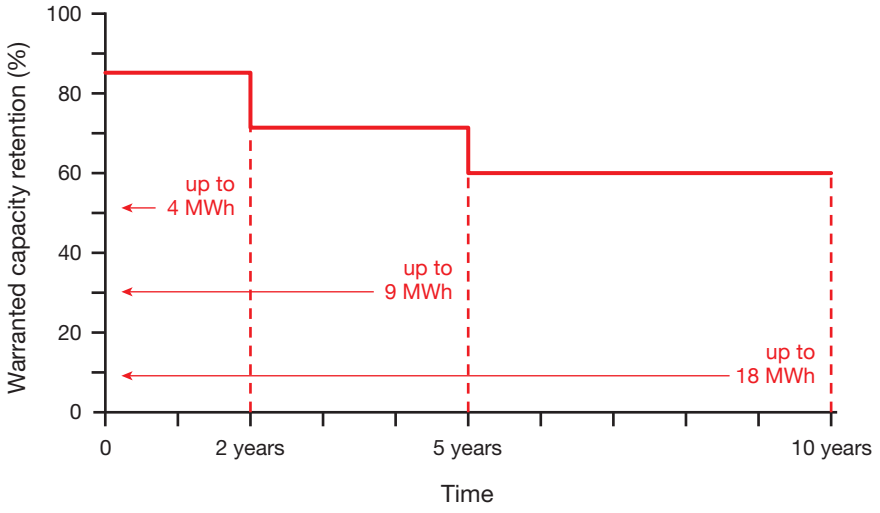


Figure 3 Tesla's Powerwall warranty takes battery aging and usage into account, guaranteeing >85% of initial rated capacity through 2 years or 4 MWh of aggregate discharge, >72% capacity through 5 years or 9 MWh, and >60% capacity through 10 years or 18 MWh. Unfortunately, most energy storage system vendors do not yet publish this level of warranty detail.

Cycles. Battery life depends strongly on usage patterns, as anyone with a cell phone or laptop computer can attest. So a manufacturer might rate a particular battery for 4,000 cycles at a 70% depth of discharge or 3,000 cycles at an 85% depth of discharge. Ideally, system integrators and customers should have access to these data, either in tabular form or in graphs that plot battery cycle life in relation to depth of discharge. In practice, these data are difficult if not impossible to find.

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LCOS in Relation to Cycling

	Daily cycling	Maximum cycling
Installed cost	$15,000	$15,000
Usable capacity (kWh)	6.0	6.0
Number of cycles	3,650	10,000
Round-trip efficiency	87%	87%
Capacity adjustment factor	92.6%	83.6%
Best-case LCOS ($/kWh)	$0.79	$0.29
Adjusted LCOS ($/kWh)	$0.85	$0.34

Table 3 This scenario illustrates that resource utilization strongly influences LCOS. To achieve the lowest possible LCOS, you need to use 100% of the storage capacity over the life of the system. The adjusted LCOS values in this table take into account battery degradation due to aging and usage.

One of the reasons battery cycle ratings are so important is that customers get the most value out of a battery that is the right size for their application. For example, sonnen guarantees all of its sonnenBatterie eco series of energy storage systems for "10,000 cycles or 10 years." Since daily cycling accounts for only 3,650 cycles over a 10-year period, you would need to cycle these batteries an average of 2.7 times per day to approach 10,000 cycles over the warranty period. To achieve this level of usage, you would likely need to deploy the energy storage system in an application where it provides more than one service, a practice known as *application stacking*. An example might be an application where you are using an energy storage system for both self-consumption and time-of-use bill management or demand reduction.

Table 3 illustrates the sensitivity of LCOS to the total number of cycles. According to Greg Smith, sonnen's senior technical trainer, the retail price for a sonnenBatterie eco 6 is roughly $12,000, and installation costs (including relocating circuits to a protected-loads subpanel) are likely to fall in the $1,500–$3,000 range. Using conservative cost assumptions—and ignoring, for the moment, battery capacity losses over 10 years—we can see that the best-case LCOS varies dramatically depending on whether the user is full-cycling the battery once per day ($0.79/kWh at 3,650 cycles) or for maximum usage ($0.29/kWh at 10,000 cycles). While this is an extreme example of how the number of cycles relates to LCOS, this basic relationship holds for all energy storage applications. Anything less than 100% resource utilization drives up the LCOS.



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It is worth noting that the best-case LCOS values in Table 3 do not take into account battery capacity losses over the life of the installation. In this case, sonnen does not publish a warranted maximum aggregate discharge value or provide any information about capacity retention over time. A simple way to account for the inevitable effects of battery degradation is to apply a capacity adjustment factor that accounts for battery aging and usage. In this case, sonnen's warranty guarantees 70% of the original rated capacity after 10 years. If we assume that we reach 70% of capacity in the maximum cycling scenario and that capacity degrades linearly over time, then the average battery capacity over the 10-year period is 83.6%. For the daily-cycling application, we assume 0.5% of battery degradation per year due to aging and 1% due to usage, which works out to a 92.6% adjustment factor. If these assumptions seem overly optimistic or conservative, simply increase or decrease the adjustment factor accordingly.

Efficiency. Charging and discharging a battery incurs an internal cost. If you charge a battery from the grid during off-peak hours and discharge it on peak, you lose some amount of energy along the way. Conversion losses in both the battery and the inverter, as well as voltage drop losses in the conductors and electrical connections, occur during periods of active charging and discharging; the battery even has self-discharge losses when it is doing no work at all. The efficiency value in Equation 1 accounts for the fact that we do not get all of the energy out of a battery that we put into it.

LCOS in Relation to Efficiency

	DC coupled	AC coupled
Installed cost	$11,500	$11,500
Usable capacity (kWh)	6.45	6.45
Number of cycles	4,000	4,000
Round-trip efficiency	87.5%	81.2%
LCOS ($/kWh)	$0.51	$0.55
Post-ITC LCOS	$0.36	$0.38

Table 4 This scenario illustrates how LCOS varies based on round-trip efficiency—which is a function of elements such as battery technology, system configuration, power conversion equipment and so forth—as well as the potential impact of the 30% tax credit for qualifying solar-plus-storage systems. Note that neither of these LCOS estimates accounts for battery degradation over time.

These round-trip efficiency losses are significant in solar-plus-storage systems, especially in comparison to losses in an interactive PV system. Today's non-isolated string inverters have weighted efficiencies in the 96%–98% range. By comparison, Tesla states that the "beginning of life" round-trip efficiency for its Powerwall is 92.5%. While round-trip efficiency data can be difficult to find—and third-party verified weighted data reflecting real-world scenarios do not exist—these losses depend somewhat on power processing and battery configuration.

Round-trip efficiency losses are significant in solar-plus-storage systems, especially in comparison to losses in an interactive PV system.

SolarEdge and Fronius, for example, offer multiport inverters that work with high-voltage lithium-ion batteries such as Tesla's Powerwall. In these systems, the PV array and battery both connect to the dc bus of a transformerless inverter, which is very efficient but provides modest surge capacity for motor loads. By contrast, Adara Power and sonnen have designed their energy storage systems around transformer-based inverter platforms (from Schneider Electric and Outback Power, respectively) that use a 48 V nominal battery bank. While these systems are somewhat less efficient, they offer excellent surge ratings for backup loads, which is critical to customers who need to run essential equipment—say, a well pump—during a power outage. To add solar to a sonnenBatterie, integrators must ac-couple an interactive inverter with the battery-based inverter via the ac bus in the backup-loads subpanel. The Adara Power system accommodates both ac- and dc-coupled configurations. The former is most cost-effective in retrofit applications where an existing interactive inverter can process PV power. The latter uses a 600 V Schneider charge controller to integrate the PV power source. SMA, meanwhile, is releasing a new Sunny Boy Storage inverter—designed especially with the retrofit market in mind—that will allow integrators to ac-couple solar with a high-voltage battery.

As the market matures, we will likely see increased demand for something parallel to an Energy Star rating method targeting home energy storage systems. This may be a long time coming in practice, however, based on the slow progress in the multiyear international efforts to develop comparative tests and ratings for PV modules. In the meanwhile, system integrators and developers may want to take vendors' round-trip efficiency claims with a grain of salt. Self-reported efficiency values are suspect, if only because they likely reflect best-case scenarios. In the real world, inverter loading and battery cycling is highly variable, which could reduce round-trip system efficiency in the field.

Table 4 illustrates the sensitivity of LCOS to round-trip efficiency. In this example, we assume

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REAL VALUE

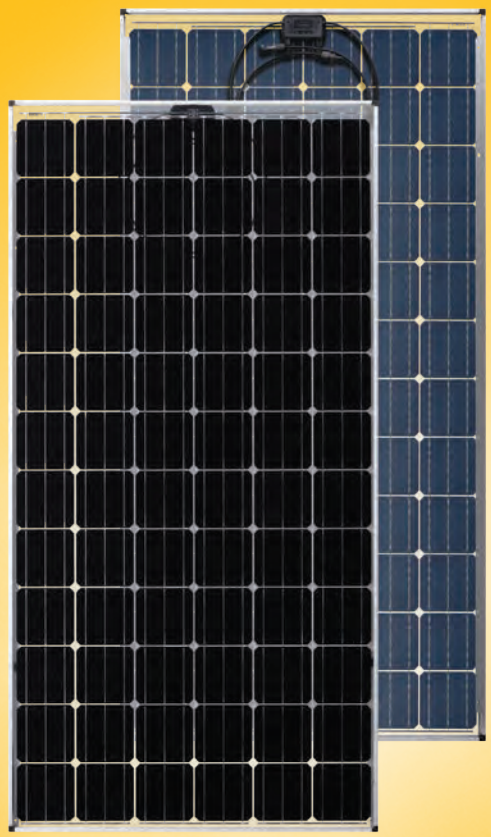
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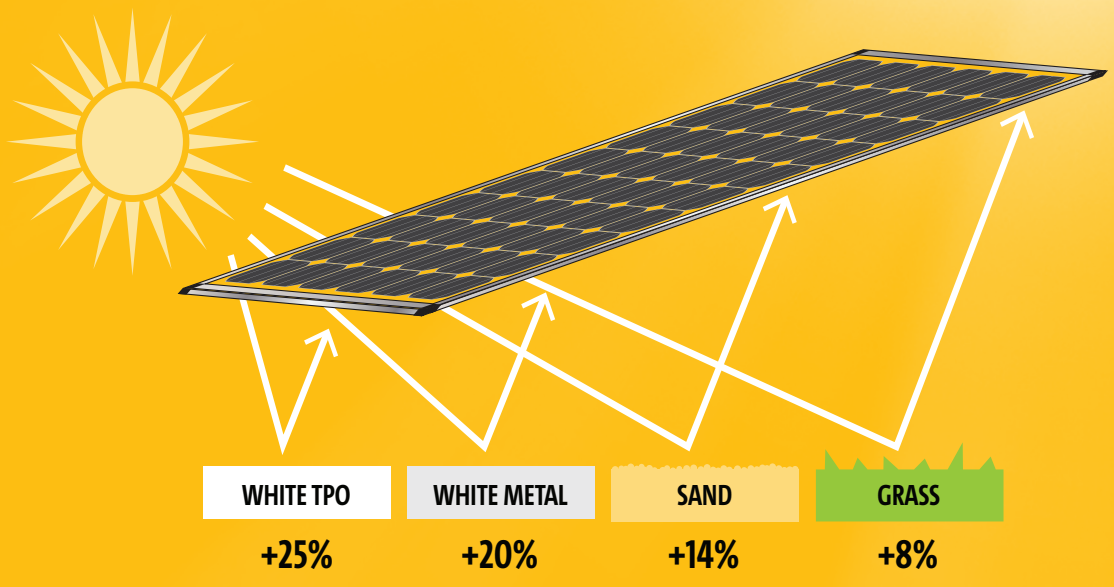
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that Adara Power's energy storage system, warranted for 10 years or 4,000 cycles, costs $11,500 fully installed, and that the PV system bears the cost of the charge controller or inverter processing power from the PV array. According to Adara, the round-trip efficiency of each battery charge and discharge cycle is 98%, which suggests that it has chosen to publish the efficiency value for the battery management system and battery chemistry. After all, the Schneider Electric XW+ 5548, which Adara uses in its systems, has a CEC efficiency rating of 93%. Moreover, the manufacturer-reported efficiency of Schneider Electric's 600 V charge controller is 96% in a 48 V application. Based on these efficiency ratings, the best-case round-trip efficiency for a dc-coupled Adara Power solar-plus-storage system is roughly 87.5% (0.98 x 0.93 x 0.96).

To estimate the round-trip efficiency for the ac-coupled configuration, we assumed that the interactive inverter is 96% efficient. We then looked at the battery-based inverter's charging efficiency, which Schneider Electric describes in detail in its user manual for the XW+ 5548. In comparison to the inverting efficiency curve, the charging efficiency curve has a slightly lower peak value and a more pronounced downward slope. Based on a comparison of these curves, we estimate that the weighted average charging efficiency for the XW+ 5548 is roughly 91%. So in the ac-coupled solar-plus-storage configuration, we estimate that the round-trip efficiency is closer to 81.2% (0.96 x 0.91 x 0.93), which means the unsubsidized LCOS is about $0.04/kWh more than that for the dc-coupled configuration. While the storage component of a solar-plus-storage system does not automatically qualify for the 30% solar Investment Tax Credit (ITC), the post-ITC LCOS value in Table 4 (p. 32) illustrates the impact of the federal tax credit on qualifying systems.

> It is important to recognize that the LCOS metric has some limitations as a basis of comparison and a project assessment tool.

LCOS USES AND LIMITATIONS

As these case studies illustrate, you can use LCOS calculations to quickly compare energy storage solutions for a



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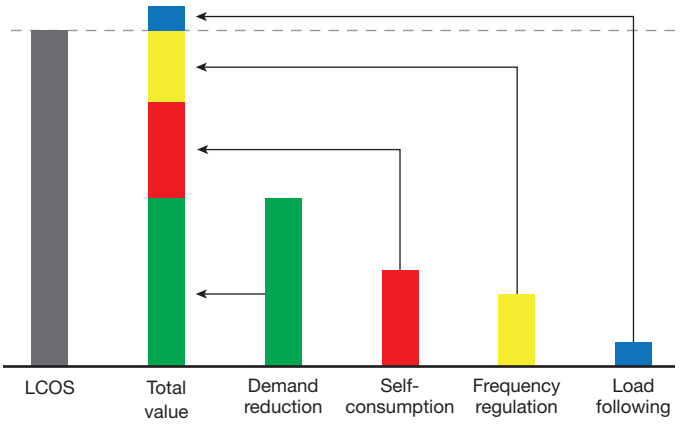


Figure 4 Removing regulatory barriers and developing new rate structures permits application stacking, whereby an energy storage system or network of systems can provide multiple services. This theoretical scenario shows how unlocking multiple revenue streams improves the value proposition for energy storage.

specific application or to evaluate the impact of changing certain design variables and assumptions. As useful as this may be, it is important to recognize that the LCOS metric has some limitations as a basis of comparison and a project assessment tool.

Cost vs. value. In late 2015, the financial advisory and asset management firm Lazard published a detailed cost comparison of various energy storage technologies in a wide variety of applications on both sides of the meter. "Lazard's Levelized Cost of Storage Analysis—Version 1.0" (see Resources) not only models LCOS based on current technology prices, but also looks at how LCOS might change in the next 5 years based on projected capital cost decreases. While the authors compare the LCOS for various storage technologies, including lithium-ion batteries, to that of a gas peaker plant as a baseline, they also note that LCOS does not "purport to provide an 'apples-to-apples' comparison to conventional or renewable electric generation."

This is true in part because cost tells only a piece of the story. An interactive PV system, for example, clearly has a lower levelized cost of energy than an energy storage system. However, the energy storage system can keep the customer's lights on in the event of a power outage, which is very important to some customers. A cost-oriented metric such as LCOS does not capture that value. Similarly,

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some energy storage systems can support specific loads or applications that others cannot. For example, adding inverter capacity to a sonnenBatterie increases system costs and negatively impacts LCOS, but could improve the value proposition for the customer if the expanded system is able to power a deep-well pump in the event of an outage. Value-based considerations are very important when comparing energy storage systems, which residential applications often deploy as a means of improving service reliability. In many energy storage scenarios, the cheapest solution may not provide the best value.

Stacking revenue and benefits. Even if we exclude factors that are difficult to quantify in dollars and cents—such as reliability or environmental attributes—it is impossible to understand the value proposition for energy storage without considering the revenue side of the equation, which can quickly get complicated. In an ideal use case, an energy storage system provides multiple revenue-generating services via application stacking, as illustrated in Figure 4 (p. 35). Some of these revenue streams, including time-of-use and demand reduction savings, depend entirely on variable load profiles and utility tariffs. To model these revenues, you need access to specialized software, detailed interval meter data and a database of utility rate structures.

Perhaps the most important challenge facing residential energy storage is the need to unlock additional revenue streams, which is as much a policy problem for utility regulators as it is a technology problem for manufacturers and vendors. The authors of RMI's report on battery economics note that when you use an energy storage system for a single application, such as self-consumption or backup power, that leaves something like 50%–99% of the battery capacity unused over the life of the system. The bad news, of course, is that resource underutilization leaves potential value on the table and increases the LCOS. The good news is that removing the regulatory barriers that prevent application and revenue stacking can tilt the economics in favor of behind-the-meter energy storage.

Green Mountain Power's pilot program offering Tesla Powerwall batteries to its customers is a good example of how an innovative utility can leverage additional value from residential energy storage systems. According to public filings, the utility estimates that its net present value for a leased Powerwall is roughly $50 per system per month over a 10-year term. (A $37.50 per month customer fee offsets the additional monthly costs associated with the Powerwall deployments.) To create this revenue stream, the utility will discharge the Powerwall batteries during "times of high market prices to help lower its energy costs," as well as during "times of peak load to reduce significant capacity and transmission expenses." Green Mountain Power expects that in addition to providing backup power for end users, the Powerwall deployments will "smooth grid impacts caused by a high penetration of solar energy, potentially avoiding more expensive, traditional upgrades." The company is also deploying 10 additional units as part of a pilot microgrid project, which will "contribute to improving the reliability of the Rutland 46 kW subtransmission network during system contingencies."

> Grid parity for energy storage is about leveraging and monetizing many value streams.

While current business models typically leverage one or two use cases for energy storage, RMI identifies "thirteen fundamental electricity services" that can benefit "three major stakeholder groups" (system operators, utilities and end users). The report also notes that "the further downstream battery-based energy storage systems are located, the more services they can offer to the system at large." Utilities can even aggregate a network of residential energy storage systems and operate this as a virtual power plant. At the end of the day, grid parity for energy storage is more about leveraging and monetizing these many value streams than it is about achieving a LCOS lower than the retail price of electricity.

CONTACT

Matthias B. Krause / Berkeley, CA / matthiasbkrause@gmail.com

David Brearley / *SolarPro* / Ashland, OR / david.brearley@solarprofessional.com / solarprofessional.com

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ENERGY Storage

By Joe Schwartz

For decades, off-grid battery-based energy storage systems powered by PV or other renewable energy sources such as wind and small-scale hydroelectric turbines have been cost-effective for many rural and remote residences across the US. The financial case for deploying energy storage in residential grid-connected applications has been a more difficult one to make. However, technological advancements, constrained electric grids with high penetrations of PV systems and the gradual erosion of net energy metering programs across the US may usher in a new era for distributed, grid-connected energy storage systems.

Numerous manufacturers are banking on the expected proliferation of highly integrated, customer-sited energy storage systems. This article provides manufacturer and product line overviews for 14 power electronics and battery system vendors that are positioning themselves for the new energy storage market. Some of the companies, or current incarnations of them, were foundational to the US solar industry a decade before grid-tied systems began to gain popularity. Others are recent entrants to energy storage and solar energy. And a third group of established solar power electronics manufacturers are reimagining their products for modern energy storage applications.

Adara Power

Founded in 2013, Adara Power (formerly JuiceBox Energy) develops lithium-ion energy storage systems layered with monitoring and control software for peak shift, load shave and backup power applications. As of early June 2016, it has units deployed in seven US states. Adara aims to ramp up the adoption of its energy storage technology in key markets, including Hawaii, Nevada and California, via its Adara Energy Storage System Certified Installer program.



Courtesy Adara Power

Adara Power, 8.6 kWh ESS

At the core of Adara's 8.6 kWh residential Energy Storage System (ESS) are Samsung lithium nickel manganese cobalt oxide (NMC) cells, configured to operate at 50 Vdc nominal. Adara specifies a rated energy capacity of 8.6 kWh, 5.5 kW continuous power output and a round-trip battery charge and discharge cycle efficiency of 98%. Rated power at a



Courtesy Adara Power

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POWER Electronics

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C/2 discharge rate per the California Self-Generation Incentive Program (CA SGIP) is 4 kW. The Adara energy storage system uses a web-enabled interface that allows homeowners to monitor real-time and historical system performance. Integrators have access to 140 battery, inverter and charge controller parameters for remote system diagnostics. Safety protection includes over-voltage and over-temperature shutdown, three-level redundancy on over-voltage control, eight independent temperature measurements and autonomous operation of the product's safety systems if web connectivity is lost. The system's battery is certified to UL 1642, and has a specified minimum life of 10 years.

The Adara ESS is compatible with the Schneider Electric XW+ 5548 inverter/charger. Designs can dc- or ac-couple solar arrays to the Adara system. While system designers should verify available support and warranties for ac-coupling products from different manufacturers, integrators have deployed ac-coupled Adara systems with various string inverters, including products from SMA America and SolarEdge.

Adara Power • Milpitas, California • 844.223.2969 • adarapower.com

concept by US

Based in Pompano Beach, Florida, and founded in 2012, concept by US has developed a scalable utility-interactive energy storage system, the Powerstation 247, for residential and small business backup power and self-consumption applications. The product line is ETL listed to UL 1741. Concept by US reports that it designs and manufactures all the product's main components in house, with the exception of the system's lithium iron phosphate (LiFeYPO4) batteries. This is a high degree of vertical integration for a relatively young company.



Courtesy concept by US

concept by US, Powerstation 247

The Powerstation 247 integrates up to three 5 kW Powermodule hybrid inverters, MPP trackers, charge control, batteries and all required field wiring terminals, disconnects and overcurrent protection in a NEMA 1 enclosure

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intended for indoor environments. Regardless of the number of Powermodules it includes, the Powerstation 247 employs 17.28 kWh of battery storage configured for a nominal dc bus voltage of 96 Vdc (93–105 Vdc operating voltage range). The battery is ETL certified to UL 1642.

Each Powermodule includes two MPP trackers along with PV wiring terminals and disconnects integrated with the unit's enclosure. Electrical specifications for each PV input are 500 Vdc maximum, 180–500 Vdc operational voltage range, 240–400 Vdc MPPT range and 3,000 W maximum power per PV input channel. The Powerstation 247 is available with one, two or three Powermodules for ac power outputs of 5 kW, 10 kW and 15 kW, respectively. AC output in both grid-tie and stand-alone modes is 120/240 Vac. The Powerstation 247 has a 5-year warranty.

concept by US • Pompano Beach, Florida • powerstation247.com

Eguana Technologies

Eguana Technologies designs and manufactures power electronics for distributed smart grid and microgrid applications. Founded in 1999, Eguana initially focused on developing low-voltage inverters for utility-interactive fuel cell systems. It launched its first-generation Sunergy inverter in 2010 and second-generation Paralex inverter for thin-film PV applications in 2012. In 2014, Eguana introduced its Bi-Direx inverter for grid-tied energy storage systems. The inverter's initial target was the European energy storage market, where it shipped more than 4,000 units in 2014–2015. In 2015, Equana launched the AC Battery, an integrated battery-ready power electronics platform for solar self-consumption and backup power applications, in the North American market.

The flexibility of Eguana's AC Battery system allows for integration with diverse storage technologies that include LG Chem's lithium-ion batteries, Aquion Energy's saltwater electrolyte Aqueous Hybrid Ion products and Primus Power's flow batteries, as well as VRLA lead-acid battery models from various manufacturers. Eguana manufactures five Bi-Direx inverter models. Developed for the US market and certified to UL 1741, the B5048US model is designed to integrate with 120/240 Vac 60 Hz electrical services. On the dc side, the B5048US has a nominal voltage of 48 Vdc and an operating range of 40–66 Vdc.

The standard AC Battery configuration couples Eguana's Bi-Direx inverter with LG Chem M4860P2S2 lithium-ion batteries configured at 48 Vdc nominal (42–58 Vdc operating range) for use with the AC Battery product. Five battery storage system capacities are available with ratings at C/1 of 6 kWh, 9 kWh, 12 kWh, 15 kWh and 18 kWh. The batteries are rated for 4,000 cycles at 90% depth of discharge (DOD), 25°C and C/1. Users can ac-couple solar arrays to the system via third-party string or microinverters, which perform system MPP tracking and array dc-to-ac conversion. The system's SunSpec-compliant Modbus communications interface integrates with third-party energy management systems and gateways that enable self-consumption functionality. Eguana Technologies' AC Battery carries a standard 10-year warranty.

Eguana Technologies • Calgary, Alberta, Canada • 403.508.7177 • eguanatech.com

Enphase Energy

Founded in 2006, Enphase Energy is largely responsible for creating the modern microinverter product class. With an eye toward current and projected changes in net energy metering programs and policies that limit exporting solar energy to the grid in the US and beyond, Enphase developed its AC Battery for global markets that benefit from or require self-consumption functionality or energy time-of-use optimization. After announcing the product in October 2015, Enphase began marketing the current design in February 2016 and expects US availability in late 2016.



Courtesy Enphase Energy

Enphase Energy, AC Battery

The AC Battery is a scalable, modular energy storage system. Designs can ac couple it with Enphase's microinverters and module-level online monitoring platform. Enphase also designed the AC Battery for compatibility with any grid-tied system, regardless of the brand and model of a given system's inverter or modules, with the addition of its Envoy-S Metered gateway and Enlighten monitoring products.

The Enphase AC Battery uses lithium iron phosphate cells configured to provide 1.2 kWh of capacity. It can discharge to greater than 95% of rated capacity and has a round-trip cell efficiency specification of 96%. Weighing only 55 pounds, the AC Battery is designed for single-person installation and interconnection with standard household

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wiring. Its enclosure is NEMA 2 rated for indoor installation in an unoccupied space. Certifications to UL 1741, UL 1973 and UL 9540 are pending. The AC Battery carries a 10-year or 7,300 cycle warranty for greater than 80% of its initial rated capacity.

Enphase Energy • Petaluma, California • 877.797.4743 • enphase.com

Fronius USA

Founded in 1945 in Pettenbach, Austria, as a welding equipment manufacturer, Fronius today focuses on products and systems for welding, battery charging and solar energy applications. Fronius USA is headquartered in Portage, Indiana, where it develops and manufactures string inverters and related equipment for the US solar market. In 2014, Fronius began rolling out its SnapINverter generation of single and 3-phase string inverters for solar projects in North America.



Courtesy Fronius USA

Fronius, Primo Hybrid

Fronius gained its early experience with power electronics for energy storage applications in the European self-consumption market, where the company combined its long history in battery charging–equipment design and manufacturing with its solar product development efforts. With established availability in Europe, the Fronius Energy Package includes a Fronius Symo Hybrid multiport inverter, a lithium iron phosphate Fronius Solar Battery and a Fronius Smart Meter to monitor system energy flow.

In 2015, Fronius shared the headlines with Tesla as one of two inverter manufacturers developing a high–dc-voltage multiport inverter for integration with Tesla's Powerwall Home Battery. Fronius' initial relationship with Tesla stems from the welding systems it supplies for manufacturing Tesla electric vehicles. Scheduled for a Q4 2016 release, Fronius' first dc-coupled storage system for the US

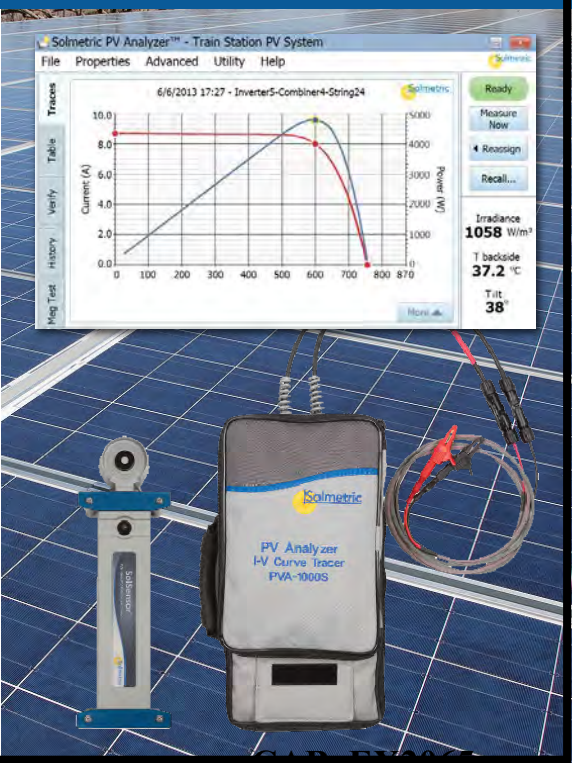
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market is its multiport Primo Hybrid. The Tesla-compatible inverter will be available in power classes ranging from 5 kWac to 11.4 kWac and will feature three dc inputs: two solar MPP trackers and one battery input. The MPP trackers' input voltage range is 80–600 Vdc. For seamless integration with Tesla's Powerwall battery, the inverter's dc bus operates at 350–450 Vdc. Both the Fronius Primo Hybrid inverter and the Tesla Powerwall battery are rated for outdoor installations.

Fronius has also partnered with JLM Energy to integrate Fronius inverters with JLM's lithium iron phosphate battery systems, as well as its products that monitor and control self-consumption and energy time-of-use optimization. JLM's battery products and the Fronius inverters communicate via the SunSpec-compliant Modbus RTU interface. JLM's residential solutions couple Fronius' standard Primo inverter with JLM's Energizr 200 storage system to create an integrated system for self-consumption, peak shaving and load shifting applications.

Fronius USA • Portage, Indiana • 219.734.5500 • fronius-usa.com



Courtesy JLM Energy

JLM Energy, Energizr 200

JLM Energy

Based in Rocklin, California, JLM Energy designs and manufactures products for energy storage, management and control. It specializes in proprietary software developed in-house for automation and component integration. Founded in 2011, JLM Energy has two core products for residential applications—the Energizr 100 and the Energizr 200. Both use specific configurations of the JLM Battery Pack. Each lithium iron phosphate (LiFePO4) battery pack has a nominal voltage of 52 Vdc, a nominal capacity of 50 Ah, and an operating voltage range of 40–57.6 Vdc. JLM specifies a cycle life of 3,000 cycles at 80% DOD and discharge under 25°C, and a cycle life of 5,000 cycles at 50% DOD and discharge under 25°C. The Energizr 100 uses four Battery Packs configured in parallel for a nominal operating voltage of 52 Vdc



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Additional Equipment for Energy Storage Systems and Integration

While this article focuses on integrated systems that include inverter/chargers, PV controllers, integration panels, and monitoring and control software, as well as some new lithium-ion–based storage systems, integrators have historically used BOS components from a wide array of vendors for energy storage applications. MidNite Solar offers an extensive line of high-voltage MPPT charge controllers, inverter integration panels, battery enclosures and rapid-shutdown equipment that can help you solve energy storage system integration challenges. Morningstar provides MPPT controllers specifically designed for retrofitting grid-direct systems with battery backup. Iron Edison has reintroduced nickel-iron batteries to the market, as well as adding new lithium-iron models. And while the industry appears to be on the cusp of a transition to lithium-ion batteries for some grid-tied applications, such as daily cycling, VRLA type batteries from manufacturers including Concorde Battery, Deka Solar, MK Battery, Trojan Battery and U.S. Battery are still mainstays for grid-tied energy storage systems. ●



Courtesy MidNite Solar

MidNite Solar, Classic

and a capacity of 10.4 kWh. The higher-capacity Energizr 200 accommodates up to eight Battery Packs in series for a nominal voltage of 416 Vdc and a storage capacity of 20.8 kWh.

JLM developed the Energizr 100 primarily as a grid-independent system for backup power applications. Its design allows installers to integrate the battery system with a residence's grid-direct PV system string inverter, electrical loads, the utility grid and even a backup ac generator. During a utility outage, the product creates a local microgrid that allows the grid-tied inverter to continue to generate energy for battery charging. If the grid is unavailable and the battery is at a full state of charge, the Energizr 100 regulates battery charging. In backup mode, the product has a continuous output power rating of 4,400 W and a 5-second surge of 8,500 W. The Energizr 100 is also compatible with AGM, gel and flooded lead-acid battery types. Measurz, JLM Energy's cloud-based monitoring platform, monitors the system in real time.

The more feature-rich Energizr 200 offers peak load shaving and integrated support for smart thermostats, real-time whole-house power measurement and load control. JLM's Measurz software analyzes user habits and provides efficiency recommendations for homeowners. The mobile app enables remote control of appliances, including HVAC systems and smart thermostats.

JLM Energy • Rocklin, California • 916.304.1603 • jlmei.com

Magnum Energy

Magnum Energy, founded in 2006, designs and manufactures inverter/chargers for mobile, marine, off-grid and backup power applications, as well as PV charge controllers, component integration panels and system monitoring equipment. The company's DNA goes back to the formation of Trace Engineering in Arlington, Washington, in 1984. In 2014, Sensata Technologies, a supplier CONTINUED ON PAGE 46

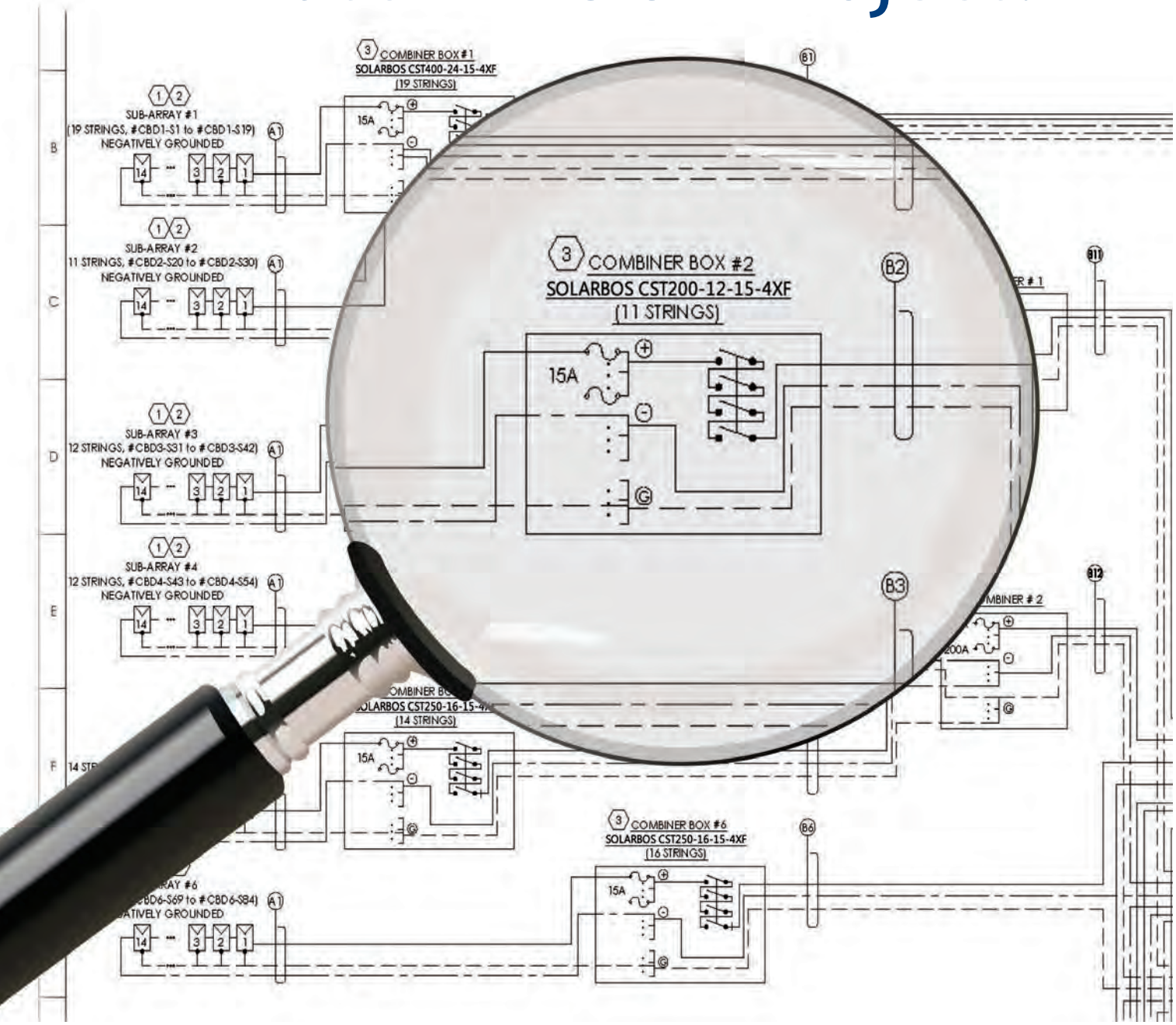


Courtesy Magnum Energy

Magnum Energy, dual MS-PAE with Magnum Panel

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What's in YOUR Project?



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SOLAR BOS

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of sensing, electrical protection, control and power management solutions, acquired Magnum.

Magnum was the first manufacturer to offer inverter/charger models with split-phase 120/240 Vac output in the US. Magnum designed its MS-PAE series of inverter/chargers to connect to the grid for ac battery charging, but never chose to develop utility-interactive models that export power to the utility grid without the integration of an ac-coupled third-party string or microinverter system. In hindsight, this was an interesting choice given the current shift to nonexporting PV systems in some US markets.

The MS-PAE 120/240 Vac series inverter/chargers are available in 24 Vdc and 48 Vdc nominal versions. The 48 Vdc MS4448PAE model has a continuous power rating of 4,400 W and surge capability to power larger inductive loads such as well pumps. The MS4448PAE has a 5-second surge rating of 8,500 W, a 30-second surge rating of 6,000 W, a 5-minute surge rating of 5,400 W and a 100-millisecond surge current rating of 40 Aac line-to-line. In 2015, Magnum launched its PT-100 solar charge controller, which is compatible with 12, 24 and 48 Vdc nominal battery systems and has a maximum output power rating of 6,600 W. Its maximum input voltage is the lower value of either 200 Vdc plus battery voltage or 240 Vdc. The PT-100 controller also provides GFDI and AFCI circuit protection. Magnum offers an extensive line of prewired Magnum Panels and accessories for component integration.

In 2016, Magnum announced its MicroGT 500 microinverter. Designed for integration with the company's battery-based inverter/charger systems, as well as for use in grid-direct power export applications, the MicroGT 500 communicates seamlessly with Magnum Energy battery-based inverters in ac-coupled mode to taper charging based on temperature-compensated battery state of charge (SOC) parameters. Each dual-MPPT microinverter supports two PV modules. Magnum's ECU communication interface allows system owners and integrators to monitor system PV production via a web-based dashboard.

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OutBack Power

OutBack Power is a manufacturer of power electronics for battery-based renewable energy applications including solar, wind, microhydro and utility-interactive systems. Engineers integral to the early success of Trace Engineering—and the

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Courtesy OutBack Power

OutBack Power, SystemEdge

company's SW series inverter/charger that became an early staple for battery-based renewable energy, backup and utility-interactive systems—launched OutBack in 2001. In 2010, the Alpha Group acquired OutBack Power.

OutBack's flagship power conversion products, the FX series inverter/charger and MX series solar charge controllers, have evolved over the years. The current FXR/VXFR series of grid/hybrid inverter/chargers offer stand-alone, backup and utility-interactive solar export functionality. The FXR/VXFR line features seven operational modes, including GridZero, which prioritizes the use of battery or renewable sources to power loads and uses renewable energy sources such as PV only to recharge a system's battery pack. An Advanced Battery Charging profile option supports lithium-ion battery technologies. The 60 A and 80 A FLEXmax models, the successors to OutBack's original MX60 MPPT solar charge controllers, operate at dc voltages up to 150 Vdc.

In 2011, OutBack released its Radian series of hybrid, utility-interactive split-phase 120/240 Vac inverter/chargers. Available in 4,000 W and 8,000 W power classes, the Radian features two ac inputs for grid and ac generator connectivity. The 8,000 W GS8048A and the 4,000 W GS4048A have a 100-millisecond maximum output current rating of 70.7 Aac and 35.4 Aac, respectively. These models also include OutBack's GridZero mode and Advanced Battery Charging option.

Since its launch, OutBack has focused development efforts on system integration packages that allow prewiring and testing at certified facilities to reduce installation time and complexity in the field. OutBack's current SystemEdge prebundled equipment packages build on this early component integration focus. With the introduction of four VRLA storage batteries optimized for specific applications such as float service or regular deep cycling, as well as integration with its power conversion equipment, OutBack now offers

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Courtesy Pika Energy

Pika Energy, x7601

an extensive product family for energy storage applications listed to the relevant UL standards from end to end.

OutBack Power • Arlington, Washington • 360.435.6030 • outbackpower.com

Pika Energy

Headquartered in Westbrook, Maine, and founded in 2010, Pika Energy manufactures bidirectional inverters, solar charge controllers, substring solar optimizers and small wind turbines. Pika's patented bidirectional REbus DC nanogrid, a 380 Vdc (360–440 Vdc operating range) dc bus, enables power transmission, control and data functions to share the same conductors via power-line carrier communication (PLC). Pika Energy developed its Pika Energy Island system to provide residences and small businesses with a single inverter solution for backup power, self-consumption and demand charge reduction functionality. The Energy Island uses two Pika products, its X7601 Islanding Inverter and Pika's PV Link dc optimizer, as building blocks for the system.

The Pika Energy X7601 is a 7.6 kW bidirectional inverter that connects PV, energy storage, electrical loads and the grid, and supports 120/240 Vac critical loads without requiring an autoformer. Pika designed its inverter to leverage the efficiency advantages provided by a high-voltage 380 Vdc bus used in conjunction with lithium-ion batteries. However, the inverter can also integrate with 48 Vdc nominal lead acid batteries as well as Aquion Energy's AHI energy storage products. The X7601 inverter has a power rating of 7,600 W in grid-export mode and an 8,000 W continuous power rating with a 12 kW 10-second surge in stand-alone mode. It is certified to UL 1741, meets Rule 21 requirements and carries a 10-year standard warranty extendable to 20 years.

Pika Energy's PV Link S2501 subarray PV optimizer supports the creation of 380 Vdc nominal arrays compatible with its 7.6 kW bidirectional inverter and 380 Vdc system bus. The PV Link can interconnect two to nine modules to create subarrays of up to 2,500 W. The product is rapid-shutdown compliant and provides MPP tracking (60–360 Vmp range), shade mitigation, ground-fault protection, arc-fault protection and substring monitoring via PLC. Pika Energy backs its PV Link subarray optimizers with a 25-year limited warranty.

Pika Energy • Westbrook, Maine • 207.887.9105 • pika-energy.com

Schneider Electric

Schneider Electric's roots date back to 1836 when two brothers, Adolphe and Eugene Schneider, acquired mines, forges and foundries and became part of the Industrial Revolution. At the time, the company's main markets were heavy industry, railroads and shipbuilding. Today, Schneider Electric is a global manufacturer of power distribution and automation systems. Headquartered in Rueil-Malmaison, France, Schneider entered the solar industry with its 2008 acquisition of Xantrex Technologies (Xantrex acquired Trace Engineering in 2000).

Schneider offers two inverter/charger lines suitable for residential energy storage applications. For nonexport systems, its Conext SW-NA hybrid inverter/charger line offers models with nominal dc input voltage of 24 Vdc or 48 Vdc and continuous output power classes of 2,400 W and 3,400 W at 24 Vdc and 3,800 W at 48 Vdc. The inverter/chargers have split-phase 120/240 Vac output and are compatible with flooded and VRLA lead-acid battery types. The Conext SW-NA supports ac- and dc-coupled configurations and enables grid backup, self-consumption with solar prioritization, peak shaving and ac engine generator assist.

The more feature-rich utility-interactive Schneider Conext XW+ NA inverter/charger line was one of the first to support integration of lithium-ion battery types. As such, complete energy storage hardware and software solutions from other vendors commonly integrate with this equipment. Like Schneider's Conext SW-NA inverter/chargers, the Conext XW+ NA supports ac- and dc-coupled configurations and enables grid backup, self-consumption with solar prioritization, peak shaving and ac engine generator assist. It can also export power to the utility grid.



Courtesy Schneider Electric

Schneider Electric, Conext XW+ NA

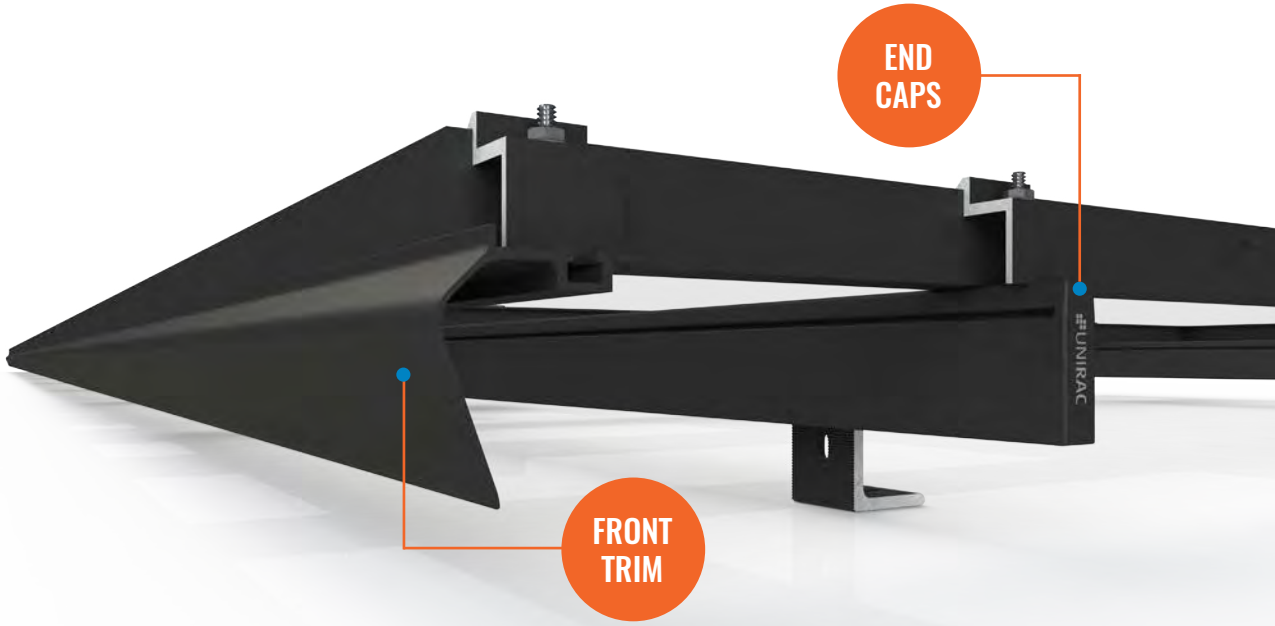
Schneider offers system integration panels for its inverter/chargers, as well as two MPPT solar charge controllers that customers can network with the overall power electronics system. The MPPT 60 150 controller has a maximum PV array open-circuit voltage rating of 150 Voc and a maximum output power rating of 3,500 W. The MPPT 80 600 model has a maximum PV array open-circuit voltage rating of 600 Voc and a maximum output power rating of 4,800 W at 48 Vdc nominal. Schneider Electric's MPPT charge controllers carry a standard 5-year warranty. Its

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Conext SW-NA and XW+ inverter/chargers carry a 2- to 5-year warranty, depending on the country of installation.

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SMA America

Founded in 1981, SMA Solar Technology has its global headquarters in Niestetal, Germany, and its US division is headquartered in Rocklin, California, with a US production facility in Denver. SMA was the first manufacturer to offer high-voltage string inverter models in the US market. It also pioneered the use of ac-coupling grid-direct string inverters with battery-based inverters and energy storage, a configuration common to many of the systems highlighted in this article. SMA has significant experience with self-consumption and energy storage systems in Europe and plans to offer additional equipment, such as its Energy Meter, in the US as markets develop.

SMA America offers single-phase Sunny Boy string inverter models, in power classes from 3,000 W to 11,000 W, that are suitable for ac-coupled residential PV applications. It also offers two models of its Sunny Island battery-based inverter/chargers—the 4548-US and 6048-US, with rated power outputs of 4,500 W and 5,750 W, respectively. SMA designed both models for operation with 48 Vdc nominal battery banks. They are compatible with lead-acid, nickel-cadmium and lithium-ion battery types as well as external battery management systems. Sunny Island inverter/chargers have single-phase 120 Vac output. Split-phase 120/240 Vac applications require two Sunny Island inverters or an autoformer.



Courtesy SMA America

SMA America, Sunny Island

In ac-coupled utility-interactive systems where one or more Sunny Boy inverters are connected to the ac side of a battery-based Sunny Island system, the Sunny Island limits string inverter output power via frequency shift if the batteries are at a full state of charge and the grid is unavailable. The Sunny Boy string inverter identifies and analyzes the frequency adjustment. When the power frequency increases and exceeds a



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defined value, the Sunny Boy limits its power accordingly. The result is well-regulated and optimized battery charging.

SMA plans to release a high-voltage Tesla-compatible battery-based inverter for the US market in early 2017. Coupled with SMA's energy-management platform, the power electronics and storage energy solution will enable streamlined integration with existing PV systems as well as cost-effective new solar-plus-storage projects.

SMA America • Rocklin, California • 916.625.0870 • sma-america.com



Courtesy SolarEdge Technologies

SolarEdge, StorEdge SE7600A-USS with Tesla Powerwall Home Battery

SolarEdge Technologies

Founded in 2006, SolarEdge Technologies began commercial shipments of its string inverter, module-level dc optimizer and monitoring systems in 2010. The company's global headquarters are in Herzliya, Israel, and its US division is headquartered in Fremont, California. SolarEdge was one of two inverter manufacturers participating in the PR wave that announced Tesla's lithium-ion Powerwall Home Battery and is the first inverter manufacturer to have fielded Powerwall systems in the US.

SolarEdge's single-inverter StorEdge system has four primary components. The system's single-phase StorEdge dual-port inverter and Connection Unit functions as an optimized PV inverter that also provides power conversion and management for battery charging. Tesla's 6.4 kWh lithium-ion Powerwall Home Battery provides energy storage. A 120/240 Vac split-phase autoformer performs phase load balancing in StorEdge systems configured for backup power during grid interruptions. Finally, the addition of SolarEdge's Electricity Meter enables smart energy management functionality that includes export power control, time-of-use shifting, maximized self-consumption, demand response and peak shaving capabilities.

The StorEdge inverter for the US market, model SE7600A-USS, has a rated ac power output of 7,600 W and a maximum



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ac power output of 8,350 W when feeding electrical loads or exporting to the grid. In backup mode, it has a rated power output of 5,000 W and a maximum 10-second ac surge rating of 7,600 W. The inverter's nominal dc bus voltage is 400 Vdc. SolarEdge's StorEdge inverter and module-level dc optimizers provide *NEC 2014* Section 690.12 rapid-shutdown functionality for the PV array and battery. StorEdge system's Electricity Meter carries a 5-year warranty. Its autoformer and inverter carry a 12-year warranty, with an option to extend that to 25 years on the StorEdge inverter.

SolarEdge Technologies • Fremont, California • 510.498.3200 • solaredge.com

sonnen

With corporate headquarters in Bavaria, Germany, and US headquarters in Los Angeles, sonnen has deployed more than 10,000 of its sonnenBatterie–integrated energy storage systems, primarily in European self-consumption markets. Founded in 2008, sonnen announced availability of its sonnenBatterie eco and sonnenBatterie pro models for the US market in December 2015. One element of sonnen's long-term vision for its business is a virtual power plant model, the sonnenCommunity, that aggregates customer-sited sonnen energy storage systems and monetizes the pooled stored energy capacity and associated grid resources.

The sonnenBatterie eco energy storage solution, designed for residential self-consumption and grid backup applications, integrates power electronics, Sony Fortelion lithium iron phosphate (LiFePO4) cells, and proprietary management and monitoring software. The eco comes in seven energy storage capacity options, ranging from 4 kWh (eco 4 model) to 16 kWh (eco 16 model) in 2 kWh increments, with a usable capacity based on a 100% cell DOD. sonnen has configured the lithium iron phosphate cells for a low-voltage dc bus with an operational range of 48–56 Vdc. The company warranties the eco system's batteries for 10 years or 10,000 cycles.

The eco system has a split-phase 120/240 Vac output and can be ac coupled with existing or new PV installations. In stand-alone mode, the eco 4 through eco 8 models have a 100-millisecond maximum power rating of 8,500 W and a 5-second maximum power rating of 6,000 W. The higher-capacity models, the eco 10 through eco 16, have a 100-millisecond maximum power rating of 17,000 W and a 5-second maximum power rating of 12,000 W. Non–revenue grade PV and load metering is standard. The sonnenBatterie eco system's power electronics are certified to UL 1741 and carry a 10-year standard warranty.

sonnen • Los Angeles • 310.853.2404 • sonnen-batterie.com



Courtesy sonnen

sonnen, sonnenBatterie eco

Sunverge

Headquartered in San Francisco, Sunverge was founded in 2009. In February 2016, it announced its second-generation Solar Integration System (SIS) energy storage platform, with a streamlined design, more battery options and greater system intelligence than the original SIS. While other vendors offer fully integrated system packages for residential and small business storage systems that couple power electronics with lithium-ion batteries and are certified to the relevant UL standards, Sunverge has a forward-looking vision for its SIS product, with the goal of aggregating reserve energy from every SIS system under management and pooling it in the cloud. The resulting virtual power plants of cloud-aggregated SIS units would provide utilities and third parties a pooled resource they could monetize and use to balance grid demands.

Sunverge's current SIS product integrates lithium-ion batteries, power electronics and cloud-based management software in a single enclosure with options for indoor or outdoor installation. It supports multiple lithium-ion battery chemistries and storage capacities from 6 kWh to 25 kWh. For residential installations, its power electronics package interconnects with split-phase 120/240 Vac services. It is designed to ac-couple existing or new PV systems of up to 8 kWdc, with options to support larger secondary systems. Operational modes include backup, self-consumption, self-consumption with grid leveling, time-of-use optimization and peak shifting. The Sunverge SIS is certified to UL 1741 and UL 1778 and carries a 10-year standard warranty.

Sunverge • San Francisco • 415.795.3660 • sunverge.com

CONTACT

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As module prices have fallen—dropping roughly from $4 per watt in 2006 to $0.60 per watt in 2016—the costs for BOS components in general and electrical BOS (eBOS) components in particular have become a larger percentage of installed PV system costs. Moreover, the industry has largely identified and leveraged the low-hanging fruit of eBOS cost reductions, such as increasing the nominal system voltage on nonresidential systems from 600 Vdc to 1,000 Vdc and making widespread use of aluminum rather than copper conductors on large-scale systems. So where will eBOS cost reductions come from next?

For this article, I reached out to two stakeholder groups—solar project engineers and equipment vendors—to identify opportunities, strategies and best practices for eBOS cost reductions. The myriad responses, organized here according to different perspectives, illustrate that squeezing additional value out of commercial and large-scale PV systems is very much a multidisciplinary effort that requires holistic thinking. Design responses also vary depending on whether owners are most concerned about low up-front costs or the impact of O&M costs over time.

Large-Scale Project Perspective

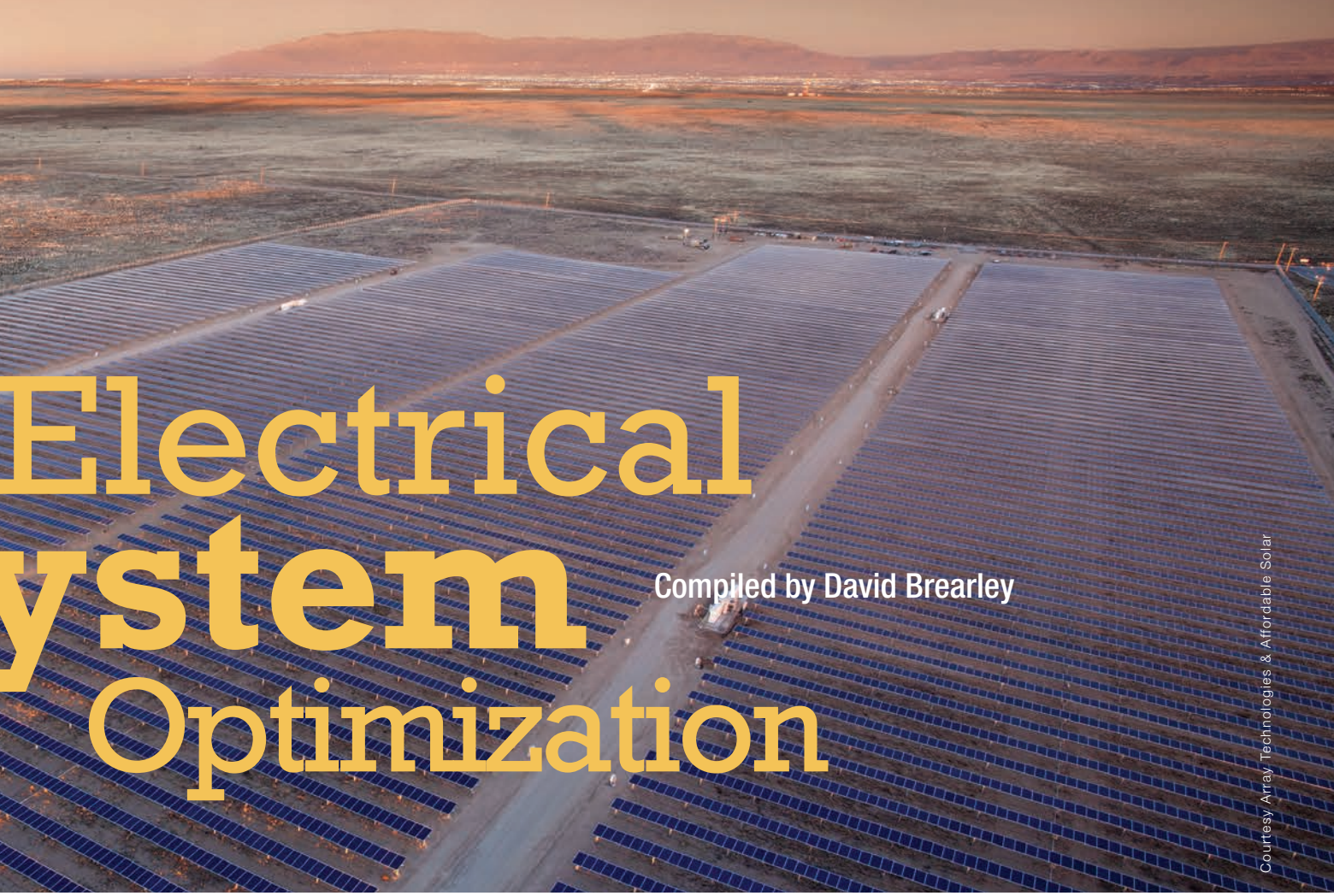
Blue Oak Engineering (BOE) is a multidisciplinary solar engineering firm based in Davis, California, with both civil and electrical engineers on staff as well as in-house project management and construction teams. The company has extensive experience engineering, constructing and operating large-scale PV assets. BOE's director of engineering, Bill Reaugh, connected *SolarPro* with a cross-section of the company's subject matter experts.

SP: **What eBOS optimization strategies have been most effective for BOE in recent years?**

BOE: BOE has identified cost savings in two major areas: array harmonization, whereby we keep the dc blocks of a project as homogeneous as possible, and the specifics of wire management within the block. In the first case, we reduce design customization in the project, which cuts down engineering and installation time and increases installation quality since it leaves fewer opportunities for mistakes. Savings in the second case come from paying attention to wire management details and identifying the most appropriate approach for each project.

Wire management strategies include placing combiner boxes so that homeruns to the inverter are straight or have the fewest number of right angles, sharing trenches with the largest number of conductor runs possible, using direct-buried conductors rather than conductors in conduit, and specifying racking with integrated grounding or integrated string wire management. While these approaches have all yielded procurement and installation cost reductions, not

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Electrical System Optimization

Compiled by David Brearley

Courtesy Array Technologies & Affordable Solar

every wire management technique is applicable on every project. For example, using direct-buried cables in areas with a high concentration of underground rodents may lead to maintenance headaches.

—Jayme Garcia, PE, senior engineering project manager

SP: **What are the most promising opportunities for additional eBOS cost reductions in the near term?**

BOE: There is some potential for savings when increasing from 1,000 Vdc to 1,500 Vdc. However, these savings are not as significant as the move from 600 Vdc to 1,000 Vdc, which represents a 66% increase in string length and a 40% reduction in the number of module strings. Moving from 1,000 Vdc to 1,500 Vdc represents only a 50% increase in string length and 33% decrease in string count. Moreover, an increase in eBOS component costs may offset the potential savings associated with this reduced string count in the near term because 1,500 Vdc is not a standard voltage rating for electrical equipment. At present, equipment rated to 2,000 Vdc commands a premium price compared to that rated to 1,000 Vdc.

A second area that could improve project economics is SCADA integration, which has so far been largely an afterthought in project design and planning. This lack of foresight can lead to cost and schedule overruns when you do not plan well to allow time for integration and testing. If you consider SCADA early in the process, you can better harmonize the design with the rest of the project, minimizing cost and schedule impacts.

—Jayme Garcia, PE



Courtesy AMtec Solar

Inverter skid components Some eBOS manufacturers offer integrated SCADA equipment or custom skid components—such as this auxiliary power cabinet from AMtec Solar for local loads or tracker motors—that EPC firms can use to reduce costs in the field.

SP: **What is BOE's experience with prefabricated wire harnesses or homerun assemblies? Do you ever precombine circuits in the array field to reduce or eliminate combiners?**

BOE: We have worked with various forms of wire harnesses for the last 7 years. We have found that wire harnesses provide installation and maintenance cost reductions with thin-film modules when a single series string does not take full advantage

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of the available conductor ampacity. String inverters, which we have recently begun to deploy on larger systems, in particular on carports and rooftops, reduce the need for harnesses.

Large, repeatable, fixed or tracking ground-mount systems represent an area where wire harnesses can have a great effect in reducing costs. However, you have to consider three major areas of concern in the use of wire harnesses: manufacturing quality, logistics and SKU management, and module series fuse ratings.

The quality of the weld, crimp or solder connections and the overwrap that protects them is of critical importance, as these are part of a system designed to operate for 20 years or more. BOE has observed connection failures in all types of harnesses from many different manufacturers. It is critical to thoroughly vet manufacturer quality control and factory acceptance test processes when procuring wire harnesses.

Cable harnesses Custom PV output cable harnesses—manufactured by Bentek to meet project-specific design criteria—hang from the ends of these tracker rows awaiting installation.



Courtesy Bentek

While wire harnesses are considered laborsaving devices, SKU management and design coordination become critical to avoid ballooning project logistics costs. You must have a strong project management and inventory tracking system in place to achieve cost savings.

Module electrical characteristics and series fuse ratings are key drivers in determining whether harnesses are feasible for a given project. Wire harnesses that do not require inline fusing are preferable to those that do. Wire harnesses with inline fuses introduce a potential failure point that is not obvious when troubleshooting.

—Ryan Zahner, PE, VP of operations, and Tim Brown, construction manager

SP: **In what applications does BOE use 3-phase string inverters in place of larger central inverters? Have you developed any strategies for optimizing ac circuit aggregation on these systems?**

BOE: For BOE, any project size up to about 10 MWac is a potential candidate for string inverters. We routinely use them on projects smaller than 2 MWac. The advantages of string inverters on these smaller projects—including shorter installation time, less complexity, increased energy harvest, reduced O&M expenses and less downtime—outweigh concerns we might have in using these types of inverters. We achieve savings with 3-phase string inverters in part by using off-the-shelf main lug only (MLO) panelboards with standard ampacity ratings as part of the ac aggregation design. These panelboards are routinely available at local electrical supply houses, which saves time and money.

Nearly all the commercially available 3-phase string inverters output at 277/480 Vac. With only a few exceptions, central inverters output at a custom ac voltage, so generally we use them only in large-scale projects with medium-voltage ac collection systems. It is impractical to use central inverters for systems that tie directly to a customer's main power system at typical utilization voltages. When we compare installation costs and factor in the expense of specialized labor, ac aggregation systems are substantially more cost-effective in most cases than dc aggregation systems up to a project capacity of 5 MW. Over 5 MW, variables such as the size of the inverter, the project layout and other design considerations tend to drive the choice of equipment.

—Bill Reaugh

SP: **To what extent does BOE's approach to eBOS optimization vary based on application specifics?**

BOE: In rooftop systems, the key drivers to eBOS design are the ability to modify the building envelope for ideal circuit routing, main service equipment design and thermal management. New construction provides many opportunities for reducing eBOS cost by coordinating the needs of the building with the needs of the PV system design. In ground-mount systems, placing equipment near access roads and power block pad locations, direct-burying conductors when conditions permit, and aligning tracker rows can all contribute to minimizing BOS costs.

—Joe Kopp, engineering project manager

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Aerial Cable Support Systems

For more than 40 years, the Cambria County Association for the Blind and Handicapped has manufactured and sold cable rings and saddles for aerial cable support under the CAB brand as a way of providing employment services to persons living with disabilities. Utility-scale solar is an emerging market for aerial cable support systems, which are deployed around the world in industrial, utility and electrical applications. I reached out to Tim Wedding, a solar specialist at CAB Solar, to learn more about the company's messenger-wire cable support solutions.



Courtesy CAB Solar

Messenger-wire cable support CAB Solar has developed more than 25 unique designs for cable rings and saddles that safely support large bundles of string wires, dc and ac feeders, data, grounding conductors or other cables.

SP: What is an aerial cable support system and how is it deployed in large-scale solar applications?

TW: The CAB cabling system consists of a high-strength messenger wire that is securely attached to mid and end piers within the solar array. PVC-coated steel hangers attach to the messenger wire, and installers load cables into the individual carrier sections and securely lock them in place on the messenger wire. Our multicarrier designs safely separate cables and large bundles to meet *NEC* standards. The hangers are totally insulated and durable in highly corrosive environments. Our 80-mil PVC coating is flame retardant, has a high-dielectric grade and is UV stabilized for a long service life.

SP: What are the benefits of messenger wire systems compared to trenching or cable tray?

TW: In the last year alone, more than 1.5 GW of fixed-tilt and single-axis tracker ground-mount installations have used the CAB cabling system. It is proving to have many important advantages over trenching or using cable tray. The cabling system offers large cost savings on both labor and material. It provides more-predictable costs, with no cost overruns from flooded trenches, deep mud, hard rock, a high water table or other unforeseen construction problems. It also benefits the environment with less digging and soil runoff, less disruption to native or endangered species, and less impact on archaeological or sensitive sites. The CAB cabling system ideally suits brownfields, landfills and sites that are rocky, wet or have less than desirable ground conditions. Another important advantage for solar developers is that CAB Solar's system standardizes cable management across an entire portfolio of projects, which greatly reduces engineering costs.

SP: What are the most cost-effective applications for CAB Solar's cable rings and saddles?

TW: The most cost-effective use of our system is for installing multiple bundles of cables, such as PV wires, dc and ac feeders, grounding conductors or data cables, into one run. The CAB cabling system safely separates cables to meet the *NEC*, and installers are widely using it for east–west and north-south homeruns.

—Tim Wedding, CAB Solar

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SP: **What are your preferred wire and cable management solutions? Have you identified any products that improve system safety and long-term performance while driving down up-front costs?**

BOE: While financial considerations are typically the biggest variable driving our choice of cable management solutions, we also consider whether the developer will own the asset long term or whether the developer plans to sell the asset. If the developer plans to keep the asset, that weights choices affecting long-term maintenance cost more heavily against first cost to purchase. In other cases, lowest first costs primarily drive choices, which may lead to higher maintenance costs in the long term.

We have a few favorite products that provide an optimal balance between first costs and long-term maintenance costs. For source-circuit conductor management, we like wire clips—such as the SunRunner clips from Heyco—that attach directly to the module frame. For dc homerun conductor management, we like Heyco's SunBundler stainless steel cable ties and messenger wire systems such as CAB's solar hangers. [See "Aerial Cable Support Systems."] In rooftop systems, we prefer cable tray over other cable management systems, as this protects conductors while reducing temperature derate effects. Overall, we believe that cable tray provides lower long-term costs for replacement and maintenance.

—Joe Kopp



Courtesy Borrego Solar

3-phase string inverters As a method of driving down eBOS costs, engineers are increasingly deploying 3-phase string inverters in commercial, industrial and utility applications—even on ground-mounted projects such as this 1.4 MW system Borrego Solar developed in Wareham, MA.

Distributed Generation Perspective

Standard Solar Inc. (SSI), based in Rockville, Maryland, is a full-service project developer that specializes in nonresidential distributed generation (DG). The company offers design, construction and installation services to commercial, utility and public sector customers. I interviewed the company's director of engineering, C. J. Colavito, to learn about eBOS trends and best practices in DG applications.

SP: **What types of eBOS optimization strategies has SSI employed in recent years?**

SSI: From a DG perspective, some of the things that work well for utility-scale designs do not provide the same value for one-off 2 MW projects. That said, one of the largest changes we have adopted is the use of 3-phase string inverters for just about all our projects, including rooftops, parking canopies and ground mounts. Moving to 3-phase string inverters has allowed for more system design standardization and simplified compliance with new *Code* requirements for rapid shutdown and arc-fault detection and interruption. The shift to 3-phase string inverters also eliminates the need for source-circuit combiner boxes and recombiners, as well as for any additional dc disconnecting means beyond the inverter-integrated dc disconnect. Access to larger-capacity 3-phase string inverters in the 50–60 kW range further simplifies things for ground-mounted systems over 2 MW and makes it easier to integrate this technology on larger sites.

SP: **Has SSI developed any techniques or strategies for optimizing ac circuit aggregation on these 3-phase inverter systems?**

SSI: Off-the-shelf ac panelboards are easier to source, have fewer application-specific requirements and are less specialized than dc combiners. However, a challenge we have faced moving to string inverters is that the nominal voltage for our long wire runs from the various portions of the PV array to the main equipment pad or transformer have gone from 700-plus Vdc to 480 Vac, which introduces some voltage drop complications. The fact that the ac output terminals of many 3-phase string inverters have limited compatibility with larger-diameter aluminum conductors exacerbates these considerations. One approach SSI has adopted to combat this challenge in ground-mount applications is to install small subgroups of four to six string inverters adjacent to a small panelboard that is compatible with aluminum compression lugs, allowing for a bolted connection to

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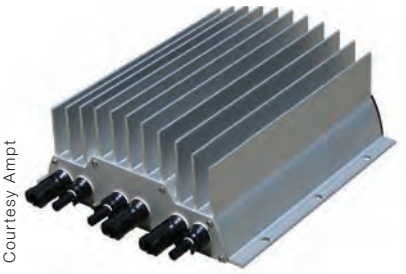
the busbar. This lets us upsize the aluminum conductors out of the panelboard as needed.

SP: **Are there situations where you like to use wire harnesses to precombine circuits in the array field to reduce or eliminate combiners?**

SSI: We have experimented with prefabricated wire harnesses for ground-mount applications. The use of wire harnesses can save time and money from a labor and material standpoint. However, it requires very careful, accurate planning and coordination from the wire harness supplier. It also requires collaboration and sharing of savings with installation labor, which a third-party subcontractor rather than in-house workers typically provides. We have had a mixed experience on 2 MWac ground-mount DG applications. Even when competitively bidding installation subcontractors, we encounter inconsistent and unreliable results with respect to extracting the savings from the subcontractor's fixed price to complete the work. Our experience is similar for other factory-assembled solutions, CONTINUED ON PAGE 62

Utility-Scale DC Optimizer System

Ampt is a founding member of the HDPV Alliance, a solar equipment manufacturer association with the goal of developing lower-cost and higher-performing PV systems. The company's Ampt String Optimizers are dc-to-dc converters developed specifically for large-scale PV applications. From an eBOS perspective, this design approach has a compelling value proposition, one that has gained traction in residential and commercial applications. I interviewed Mark Kanjorski, the company's director of marketing, to learn more about deploying dc optimizers at scale.



Courtesy Ampt

Ampt optimizer Ampt String Optimizers perform MPP tracking at higher granularity than central inverters, which improves energy harvest.

SP: **What are the basic components of an Ampt-optimized system? What are the benefits of this design approach?**

MK: Ampt String Optimizers are dc-to-dc converters that put voltage and current limits on each PV string. This allows system designers to double their string lengths and reduce the number of combiners, disconnects and homeruns by 50%, which provides savings on materials, shipping and installation costs. The current limits allow installers to use smaller-gauge wire, which further reduces costs. Ampt String Optimizers also deliver full array power at a voltage that is near the maximum system voltage, so inverters can narrow their operating range and deliver more power, which effectively reduces the inverter cost per watt.

SP: How does an Ampt-optimized PV system compare to a conventional 1,500 V system?

MK: As an industry, we can lower the cost of solar energy by reducing the system cost or by increasing energy production from a given system. Both 1,500 V systems and Ampt-optimized 1,000 V systems reduce total system costs, but only the Ampt-optimized approach increases lifetime energy production. While 1,500 V systems increase the string length by half to remove 33% of the eBOS components, Ampt doubles the string length to remove 50% of the eBOS components. So Ampt not only removes more eBOS but also allows developers to keep using lower-cost 1,000 V–rated components. Using string optimizers in PV systems increases the MPPT resolution to increase lifetime energy production. That extra production results in higher project revenues.

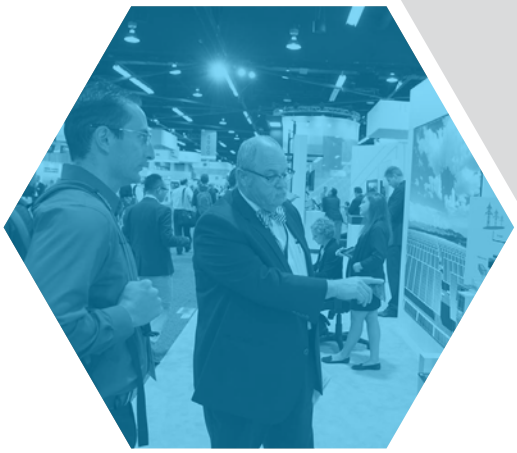
SP: **Can you describe Ampt's field deployments to date and its path to a broader market?**

MK: Most of our deployments are in North America, Europe and Asia. Our large-scale systems range in size from 1 to 2 MW to multiple tens of megawatts. In general, the qualification process for Ampt is similar to that of any supplier that serves the large-scale PV market. You need to have differentiated value to get in the door. Then you must demonstrate product quality and reliability, as well as strong pre- and post-sales support. Looking forward, we expect the market to increasingly deploy 1,500 V systems as the price premiums for 1,500 V modules and other barriers disappear. As that happens, Ampt will further optimize 1,500 V systems by eliminating another 50% of eBOS components and providing even more inverter savings. ●

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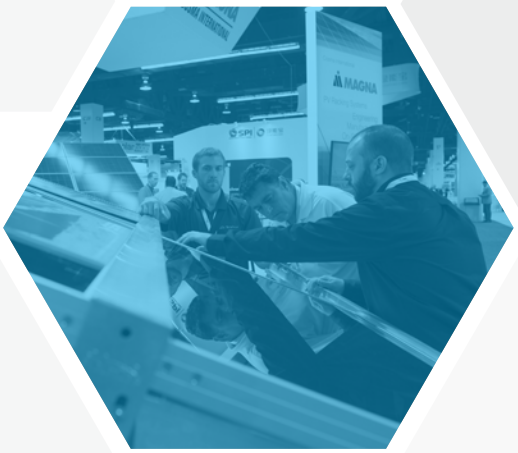


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Courtesy SolarBOS

Overmolded junctions The construction of inline junctions—such as these Y- and T-junctions manufactured by SolarBOS—prevents moisture from reaching and compromising the terminations.

such as prefabricated inverter pads or partially preassembled racking systems. To truly extract value from prefabricated and preassembled solutions, I think you need to either use in-house labor or have a very strong and open relationship with the installation subcontractor.

SP: **To what extent does your approach to eBOS optimization vary based on application specifics?**

SSI: It makes all the difference in the world. On ground-mounted projects where we mount portrait-oriented modules side by side in a long linear row, for example, we like to use a process we call *skip stringing* that takes advantage of generous module wire whip lengths. This wiring method connects every other module in the row in series so that the source circuit is wired as follows: 1 ► 3 ► 5 ► 7 ► 9 ► 11 ► 13 ► 15 ► 17 ► 19 ► 18 ► 16 ► 14 ► 12 ► 10 ► 8 ► 6 ► 4 ► 2. When we wire a source circuit in this manner, the positive and negative homerun wires end up at adjacent modules rather than on opposite ends of the row. [See Figure 2 on p. 18.] In this scenario, skip stringing eliminates a length of wire equivalent to the width of 18 modules or approximately 58 feet. When considered across a 2 MWac site, this results in wire savings of more than 25,000 feet of #10 PV Wire, a premium-priced conductor, plus the labor and materials to handle and secure that extra wire. Project size also has a significant impact on the eBOS optimization strategy. With a smaller rooftop system in the 300 kW range, for example, all we really need is a single

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ac accumulation panel. For a larger 2.5 MW ground mount, we need to have several ac accumulation panels feeding a master accumulation panel.

eBOS Vendor Perspectives

Equipment vendors have a unique perspective on eBOS optimization based on how customer orders and product requests change over time. I reached out to leading combiner box and wire harness suppliers to find out what products and solutions are in high demand and to get vendors' perspectives on eBOS optimization strategies.

What are the most effective strategies to achieve eBOS cost reductions for dc and ac circuit aggregation on commercial and utility-scale PV systems?

I firmly believe that a system-level approach is the best strategy. Engineers and integrators should work with their suppliers to fine-tune ways to make *all* of the components work well together and fit in with their construction practices. This might sound obvious, but you would be surprised how many people are still making assumptions about what you can and cannot do with eBOS. Involving the eBOS supplier or manufacturer early in the process can save lots of time and money down the road.

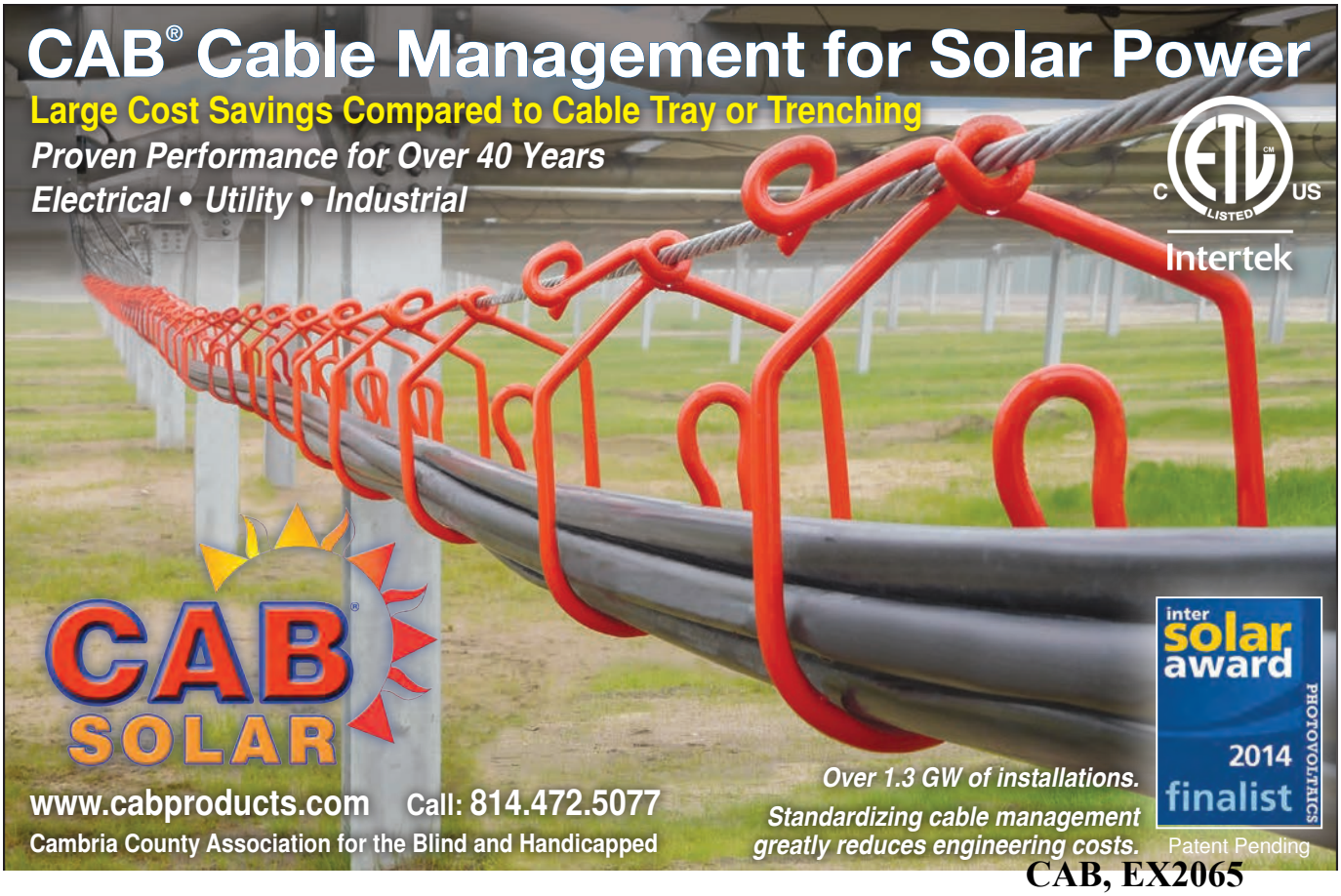
—Jason Schripsema, CEO, SolarBOS

Optimizing the distribution and aggregation of strings can help reduce eBOS costs. For example, on a crystalline-based system, combining two strings can yield significant cost reductions. However, combining a large number of strings does not yield the same results if the installation then requires oversized cable.

—Tony Gulrajani, solar marketing manager, Eaton

Beyond considering string aggregation on the dc side, customers are increasingly interested in coordinated combiner box and wire harness assemblies. We design these project-specific assemblies with the appropriate connections to support easier and faster installation, reduce labor costs and improve reliability.

—John Vernacchia, RE global segment manager, Eaton



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Aluminum homeruns
Eaton developed its Crouse-Hinds series Sunnector dc collection system with aluminum homeruns to reduce labor and material costs in utility-scale solar projects.

Courtesy Eaton

For large utility-scale projects, our customers are quickly moving from 1,000 Vdc to 1,500 Vdc. Bentek has already shipped more than 200 MW of complete UL 1741–listed 1,500 Vdc solutions.

—John Buckley, executive sales and marketing, Bentek

Most of today's jobs are systems that have higher-voltage ratings than in the past—1,000 V systems are becoming the industry standard. We are also seeing a lot of demand for 1,500 V combiner boxes and switch cabinets. We expect that trend to continue as it reduces the number of combiner boxes and strings required as well as the necessary wire diameter, which ultimately reduces the total cost of the project. About 90% of our customers are using aluminum for the feeders exiting the combiner boxes to the inverter. Combiners with prewired and preconfigured whips or pigtails that have watertight connectors are another standard solution for saving labor in the field. These whips come with string ID labels, inside and out, and are available in black, red or white.

—Tom Willis, director of sales, AMtec Solar

What types of wire harness assemblies or whip configurations are most popular with your customers?

In the utility space, we see a mix of 15 A and 30 A conductors from the modules to the combiner, but most of our customers are taking advantage of prewired or whipped combiners that have external connectors to speed up the installation process.

—Jason Schripsema, SolarBOS

Back in 2012, EPC firms and contractors considered a prefabricated system a secondary option. Now, few of our customers consider performing these aspects of a project themselves. This shift is mainly due to the fact that prefabricated assemblies provide significant time savings in the field and improve quality assurance. Our customers have asked for aluminum-based string wiring for several years, yet high-quality materials to support aluminum wiring systems have become available only recently. Eaton developed its Crouse-Hinds series dc collection system, Sunnector, to reduce costs and installation time in utility-scale solar projects. The Sunnector system uses aluminum for long-distance runs to reduce costs, but still incorporates industry-standard copper connections to PV modules. This way, contractors can use standard connectors and tools, while project owners can reduce costs by taking advantage of less costly aluminum wire. The specific cost savings correlate to string length. Our customers use both homerun and molded array harnesses in nearly all systems to support installation flexibility and reduce costs. For thin-film applications, Eaton has the ability to parallel multiple strings, which further enhances the layout by incorporating inline fusing and X/T junctions.

—Tony Gulrajani, Eaton

Our utility-scale ground-mount customers are moving to 1,500 Vdc cable harnesses that support both thin-film and crystalline modules. While the cable harness configurations vary depending on the layout of the PV project, we see more PV projects moving to a two-circuit parallel harness. This type of cable harness allows the PV designer to parallel two circuits together, which minimizes the customer's combiner costs by halving the number of input circuits while doubling the amperage of the fuses inside the string combiners. This cable harness and combiner configuration provides customers with a cost-effective solution that offers high reliability.

—John Buckley, Bentek

We receive more demand for whips than for harnesses, but this varies somewhat according to application. On roof-mount systems, for example, we see more demand for whips. On projects using thin-film panels, we are see more demand for harnesses with inline fusing and Y-connectors. Harnesses are a bit more involved—the main variables are string count, connector type and labeling. On all types of solutions, custom labeling and different color wires are very popular, as these features make installation go much more smoothly and reduce errors.

—Tom Willis, AMtec Solar

CONTACT

David Brearley / *SolarPro* / Ashland, OR /
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SOLARPRO

For some people, there's just no substitute for ink on paper



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Miller Bros.
Salisbury Project



Courtesy Solvida Design + Engineering (4)

Overview

DESIGN FIRM: Solvida Design + Engineering, solvidadesign.com

LEAD INSTALLER: Joe Marrone, project lead, Miller Bros., millerbros.us

DATE COMMISSIONED: December 2015

INSTALLATION TIME FRAME: 110 days

LOCATION: Salisbury, MD, 38.4°N

SOLAR RESOURCE: 4.12 kWh/m^2/day

ASHRAE DESIGN TEMPS: 91.4°F 2% average high, 6.8°F extreme minimum

ARRAY CAPACITY: 17.8 MWdc

ANNUAL AC PRODUCTION: 22.6 GWh

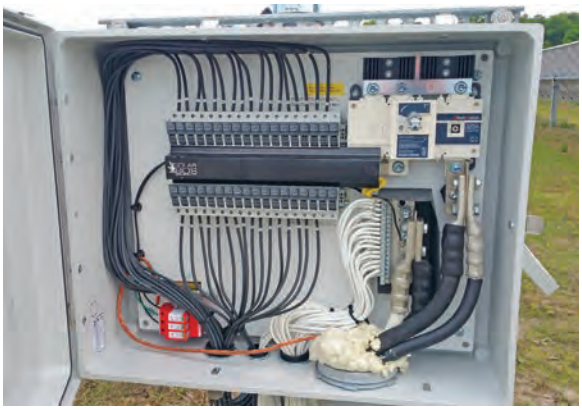
Miller Bros. (MB) is a leading utility-scale solar project construction, operations and maintenance business based in Pennsylvania, serving south-central states through the eastern seaboard. In April 2015, it employed Solvida Design + Engineering (SD+E) to provide electrical and structural design engineering services for a project expected to be the largest in the state—a challenging 17-plus MW solar power generation plant located on the Delmarva Peninsula near Salisbury, Maryland. SD+E, led by Stephen Smith, is a team of solar design experts with hundreds of megawatts of operational projects under their belts.

The project team's first challenge was to determine how to maximize system MWh production given the limited acreage and oddly shaped tree-lined site. To determine the most appropriate solution among a matrix of design possibilities, SD+E designers calculated each option's annual energy production forecast, construction cost, annual O&M costs and land utilizations. The team's final recommendation was a single-axis tracking system with a tight ground-cover ratio (GCR). This design fit the desired capacity within the space limitations and delivered



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the increased energy yield of a tracking system versus fixed-tilt mounting.

SD+E's next challenge was designing a cost-effective tracker foundation, given the site's poor soils and high-water table. The site was previously used for agriculture, and the subcontracted geotechnical report revealed relatively loose soils as far below grade as 4 feet in some locations. It also exposed seasonal and variable high-water table conditions. The geotechnical report recommended cast-in-concrete foundations for the trackers, which would likely have cost MB two times the labor and materials outlay, as well as longer installation time compared to a driven-steel pile. The SD+E team worked closely with the Array Technologies (ATI) services team to study other foundation options. The project team looked at worst-case scenario wind and structural loading, which was important given the site's close proximity to the Chesapeake Bay and Atlantic Ocean. With this data and the use of ATI's wind tunnel test data, SD+E's structural engineer was able to design and certify a standard 13-foot minimum embedment for a driven-steel pile.

Due to commissioning and interconnection deadlines, the team set the project build plan to an aggressive timeline, with construction beginning on June 15 and completion expected within 4 months. MB created carefully detailed construction schedules with additional crews and hours to accommodate the contracted build schedule. MB tasked SD+E to provide a site architecture and layout that allowed maximum labor crew access. SD+E's electrical design strategically placed dc combiners and located dc/ac feeders along east-west main access roads. This helped the MB installation teams erect tracker mechanical blocks and install dc systems rapidly. At maximum utilization, the site hosted 30 tracker and module assembly crews and six civil installation crews working harmoniously.

> "The most difficult part of these larger arrays is getting around the site and getting out of the way of other aspects of concurrent construction."
>
> *—Joe Marrone, Miller Bros.*
>
> "Miller Bros. are resourceful partners who pay attention to the details important to investors and project owners, including controlling costs, adhering to timelines and producing reliable, high-performance projects in spite of on-site challenges."
>
> *—Stephen Smith, COO, Solvida Design + Engineering*

Equipment Specifications

MODULES: 57,546 Renesola JC310M-24/Ab Virtus II, 310 W STC, +5/-0 W, 8.38 Imp, 37 Vmp, 8.8 Isc, 45 Voc

INVERTERS: 25 kV service; 20 Schneider Electric Conext Core XC 680-NA inverters, 680 kW rated output, 1,000 Vdc maximum input, 550–800 Vdc MPPT range, 380 Vac rated grid voltage; inverters integrated with five 2.72 MW Schneider Electric PV Skids, each with four Conext Core XC 680-NA inverters and two 1,360 kVA 25 kV/380 V ANSI C57 transformers in daisy-chain configuration to central point of interconnection

ARRAY: 19 modules per source circuit (5,890 W, 8.38 Imp, 703 Vmp, 8.8 Isc, 855 Voc), 30–36 source circuits per combiner, 131–156 source circuits per inverter, 3,440 kW–3,605 kW per power block, 17.8 MWdc array total

ARRAY INSTALLATION: Array Technologies DuraTrack HZ v2.5 single-axis tracking system, 41% ground cover ratio, 0° azimuth, ±45° tracking range

ARRAY SOURCE CIRCUIT COMBINERS: SolarBOS CSK350C-32A-15-N3 32-circuit Disconnect Combiners, 15 A fuses

ARRAY RECOMBINERS: Factory-integrated with Schneider Electric inverter package

SYSTEM MONITORING: AlsoEnergy performance monitoring and portfolio management

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Borrego Solar
Palmer Metropolitan Airfield



Courtesy Borrego Solar (3)

Overview

DESIGNERS: John Lagasse, development senior design engineer, and Aharon Wright, operations senior design engineer, Borrego Solar, borregosolar.com

LEAD INSTALLERS: Matt Martunas, project manager, and Robert Vessichio, site superintendent, Borrego Solar

DATE COMMISSIONED: December 2015

INSTALLATION TIME FRAME: 204 days

LOCATION: Palmer, MA, 42.2°N

SOLAR RESOURCE: 3.8 kWh/m²/per day

ASHRAE DESIGN TEMPS: 84.2°F 2% average high, -4°F extreme minimum

ARRAY CAPACITY: 6 MWdc

ANNUAL AC PRODUCTION: 8,484,310 kWh

The 6 MW Palmer Metropolitan Airfield installation is the largest Department of Energy Resources (DOER)–qualified brownfield project under the Massachusetts SREC II solar energy incentive program. The SREC II program promotes the positive reuse of sites cleaned up under Massachusetts Department of Environmental Protection supervision. Prior to qualifying the solar installation, the state remediated Palmer Airfield after 75 years of airfield operations dating back to the 1920s. Massachusetts caps projects such as the Palmer Airfield at 6 MWdc.

Multiple entities benefit directly from the project. The Town of Palmer will receive real and personal property tax revenue valued at approximately $2 million over the 20-year project term. Three public entities—the Town of Leicester, the Town of Spencer and Worcester State University—will together purchase all the net metering credits from the energy that the project generates, resulting in millions of dollars in energy savings for



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these entities over the 20-year terms of the agreements. Finally, the landowner, JenJill of Wilbraham, Massachusetts, which purchased the site and paid for its cleanup, will benefit from the long-term ground lease.

Borrego Solar designed and built the system, and negotiated and finalized off-taker agreements with the Town of Leicester and the Town of Spencer. Syncarpha Capital financed, owns and operates the Palmer Airfield facility. Renewable Energy Massachusetts, with assistance from Syncarpha Capital, gained site control and negotiated the lease with the landowner, performed all project development functions including permitting, initiated the National Grid interconnection process, cemented Worcester State University as a key energy off-taker and secured the DOER's SREC II Brownfield Qualification designation for the site.



The most difficult aspect of the Palmer Airfield project was the management of site logistics. The project has "Frankenstein" elements. The team had to account for, sort, install and commission eight module types. While 1,000 Vdc would have been the optimal system design voltage, Syncarpha Capital had a variety of safe-harbored 600 Vdc–rated modules that it preferred to utilize. Borrego determined that SMA Tripower inverters had a wide enough MPPT window to permit their use in both 600 Vdc and 1,000 Vdc source-circuit configurations on-site. Therefore, the installation team deployed the stored Canadian Solar and Suniva modules in 600 Vdc configurations and the newer 1,000 Vdc–rated Yingli modules in 1,000 Vdc configurations. Florence Electric played a central role in the project's success by managing and tracking the various module models and the specific rack purlins required to mount them.

Equipment Specifications

MODULES: 156 Canadian Solar CS6P-235M (235 W STC, +5/-0 W, 7.82 Imp, 30.1 Vmp, 8.34 Isc, 37.2 Voc), 533 Canadian Solar CS6P-240M (240 W STC, +5/-0 W, 7.95 Imp, 30.2 Vmp, 8.46 Isc, 37.3 Voc), 330 Canadian Solar CS6X-285M (285 W STC, +5/-0 W, 7.89 Imp, 36.1 Vmp, 8.40 Isc, 44.7 Voc), 20 Canadian Solar CS6X-290M (290 W STC, +5/-0 W, 8 Imp, 36.3 Vmp, 8.51 Isc, 44.7 Voc), 926 Canadian Solar CS6X-295M (295 W STC, +5/-0 W, 8.11 Imp, 36.4 Vmp, 8.63 Isc, 44.9 Voc), 1,820 Suniva OPT250-60-4-100 (250 W STC, +5/-0 W, 8.44 Imp, 29.6 Vmp, 8.98 Isc, 37.7 Voc), 3,341 Suniva OPT255-60-4-100 (255 W STC, +5/-0 W, 8.5 Imp, 30.2 Vmp, 9.05 Isc, 37.9 Voc), 13,851 Yingli Solar YL300P-35b (300 W STC, +5/-0 W, 8.37 Imp, 35.8 Vmp, 8.86 Isc, 45.2 Voc); 20,977 modules total

INVERTERS: 3-phase 13.2 kV medium-voltage interconnection; four SMA America SC800CP-US, 800 kW nominal output, 1,000 Vdc maximum input, 570–820 Vdc MPPT range, 360 Vac rated grid voltage; 70 SMA America Sunny Tripower STP-24000TL-US, 24 kW rated output, 1,000 Vdc maximum input, 450–800 Vdc rated MPPT range, 150–1,000 Vdc operating voltage range, 480/277 nominal ac voltage

ARRAY: 63 SMA STP-24000TL-US inverters are deployed with the following safe-harbored modules and source-circuit configurations: Canadian Solar CS6P-235M, Canadian Solar CS6P-240M, Suniva OPT250-60-4-100 and Suniva OPT255-60-4-100 configured in 13-module source circuits; Canadian Solar CS6X-285M, CS6X-290M and CS6X-295M configured in 11-module source circuits; two SMA SC800CP-US inverters with 174 19-module Yingli Solar YL300P-35b source circuits; two SMA SC800CP-US inverters with 173 19-module Yingli Solar YL300P-35b source circuits; seven SMA

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Equipment Specifications (continued)

STP-24000TL-US inverters with five 19-module Yingli Solar YL300P 35b source circuits; 5,999.93 kWdc array total

ARRAY INSTALLATION: TerraSmart TerraFarm non-ballasted racking, 180° azimuth, 30° tilt

SOURCE CIRCUIT COMBINERS: 17 SolarBOS CDK350C-24A-15-N3 AFCI Combiners, 350 A, 24 inputs, 15 A fuses; 17 SolarBOS CDK350C-32A-15-N3 AFCI Combiners, 350 A, 32 inputs, 15 A fuses; 63 SolarBOS FDK100-6-15-N14 Disconnect Combiners, 100 A, 6 inputs, 15 A fuses; seven SMA CU-1000-US-10 DC Connection Units

ARRAY RECOMBINERS: Four SolarBOS RCK-07-300BM-N3R, 300 A breakers

SYSTEM MONITORING: AlsoEnergy performance monitoring and portfolio management



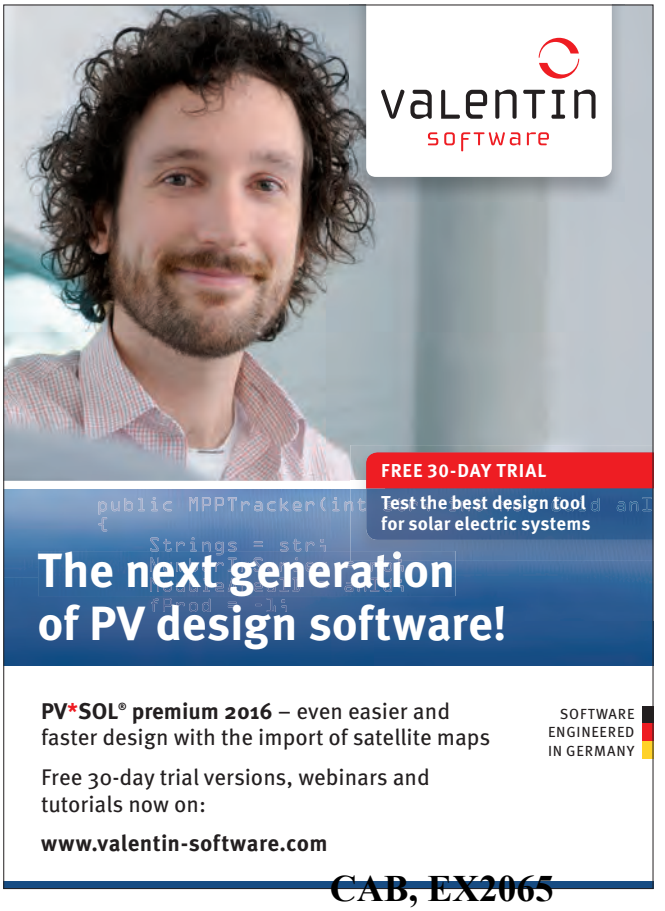
Courtesy Borrego Solar

Despite the challenges of incorporating different modules, workers completed the project's construction 7 weeks early. J. Bates and Son, the subcontractors, facilitated the presence of experienced workers on-site 7 days a week when necessary, enabling completion of the project well within its projected time line. This Palmer Airfield installation highlights the benefit of choosing reliable, high-quality construction partners and an EPC contractor that has those relationships in place.

"Throughout the duration of the project, all parties involved continuously maintained a keen focus on executing the project scope of work within the project schedule, while also maintaining a high level of quality control and assurance. Our civil contractor, J. Bates and Son, and our electrical contractor, Florence Electric, worked in partnership with Borrego Solar to control overruns and stay within the budget."

— Matt Martunas, Borrego Solar





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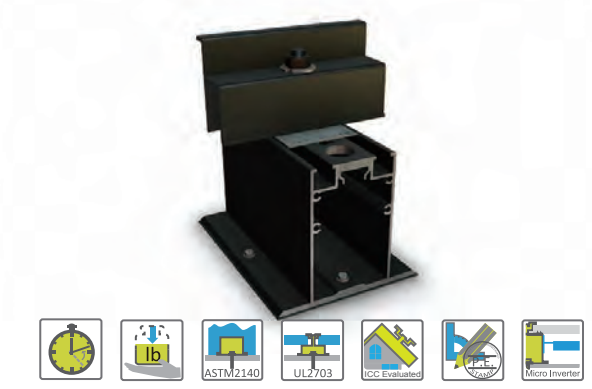
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Juapi Project Services

Parroquia San Antonio de Padua

Overview

DESIGNER: Orlando López de Victoria Vélez, PE, president, Juapi Project Services, juapiprojects.com

LEAD INSTALLER: Steven Benitez, lead electrician, Benitez Saez Electric Service

DATE COMMISSIONED: July 2015

INSTALLATION TIME FRAME: 14 days

LOCATION: Guayama, PR, 18°N

SOLAR RESOURCE: 5.5 kWh/m²/day

DESIGN TEMPERATURES: 90°F average high, 61°F extreme minimum

ARRAY CAPACITY: 30 kWdc

ANNUAL AC PRODUCTION: 46,535 kWh

Equipment Specifications

MODULES: 120 Q Cells Q.Pro BFR-G3 250, 250 W STC, +5/-0 W, 8.13 Imp, 30.76 Vmp, 8.62 Isc, 37.32 Voc

INVERTERS: 3-phase, 120/208 Vac service, three SMA Sunny Boy 9000TL-US-12; 9,000 W, 600 Vdc maximum input, 345–480 Vdc MPPT range

ARRAY: Array 1 and 2: 13 modules per source circuit (3,250 W, 8.13 Imp, 399.9 Vmp, 8.62 Isc, 485.2 Voc), three source circuits per inverter (9,750 W, 24.39 Imp, 399.9 Vmp, 25.86 Isc, 485.2 Voc); Array 3: 14 modules per source circuit (3,500 W, 8.13 Imp, 430.6 Vmp, 8.62 Isc, 522.5 Voc), three source circuits per inverter (10,500 W, 24.39 Imp, 430.6 Vmp, 25.86 Isc, 522.5 Voc), 30 kWdc array total

ARRAY INSTALLATION: Roof mount, IronRidge XR100 racking, custom aluminum stand-offs, 180° azimuth, 5° tilt

SYSTEM MONITORING: SMA Webbox, SMA Sunny Portal online platform



Courtesy Juapi Project Services (2)



The Catholic church declared San Antonio de Padua in Guayama, Puerto Rico, a Catholic parish in 1736, the same year the island's government recognized the town of Guayama. The Institute of Puerto Rican Culture designated the church a historic landmark, which means no one can make any aesthetic modifications or additions to it. This caveat did not deter Juapi Project Services (JPS), the project's solar integrator. The building next door also belongs to the church, and although the two structures have different electrical systems, JPS used the adjoining building's roof for the installation.

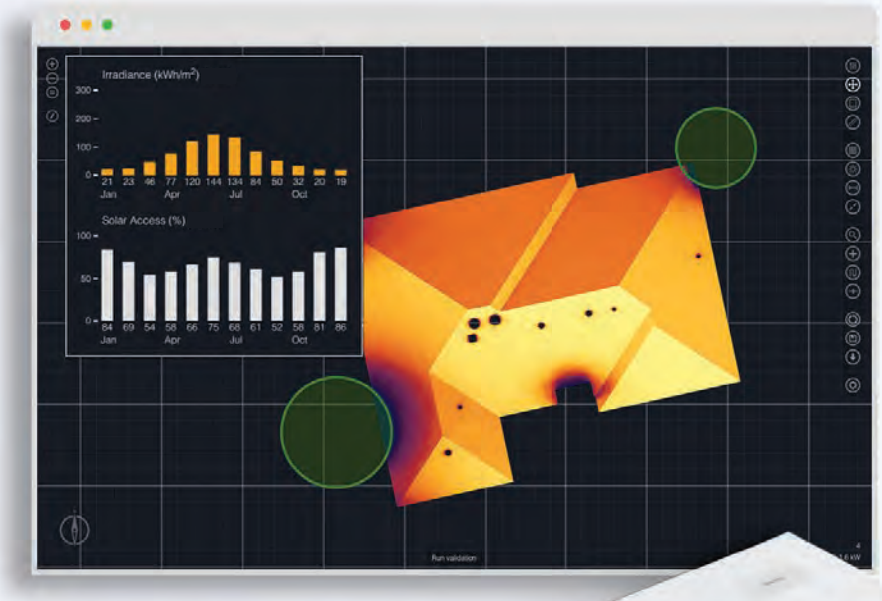
JPS designed the system to offset all of the church's electrical consumption. A variety of modules are available for distribution on the island. The project team selected Q Cells Q.Pro modules, which offer a 12-year product warranty instead of the more typical 10-year product warranty many modules carry. The rooftop has minimal shading, so a string inverter with a single MPP tracker was a good fit. JPS opted for SMA SunnyBoy 9000TL-US inverters due in part to their peak efficiency of 98.7%. Because of the high ambient temperatures in Guayama, installers located the inverters indoors to protect them and ensure a longer lifetime. The installation company located the main PV system disconnect at ground level next to the utility meter and point of interconnection with the Puerto Rico Electric Power Authority.

> "We are grateful for the opportunity to contribute and take part in a historical project such as this one that will hopefully, like the works of the parish, bring hope of a better world."
>
> *—Orlando López de Victoria Vélez, PE, Juapi Project Services*

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