November/December 2017

Role of SCADA | Using Margin and Markup

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Module-Level Power Electronics

Overview of MLPE Vendors and Platforms in North America

60-Cell PV Module Data

Product Specifications for 228 c-Si Models from 26 Manufacturers

Interview

Henk Rogers
Blue Planet Energy

Marine Corps Energy
MCAS Miramar
San Diego, CA

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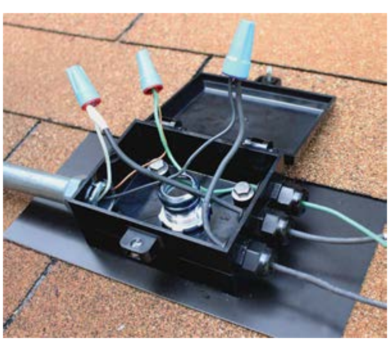

ON THE COVER The Marine Corps Air Station Miramar microgrid demonstration project incudes a 3.2 MW landfill gas energy plant, 1.3 MW of carport- and roof-mounted solar, and a 250 kW/1 MWh zinc-bromide flow battery from Primus Power.
Photo: Courtesy Primus Power

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Contributors

Experience + Expertise

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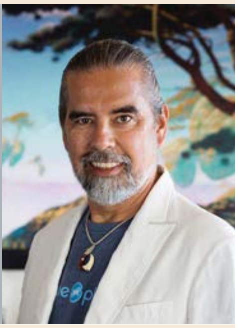
Diane McClelland is part of the business development team at Trimark Associates, an international utility-scale solar monitoring provider. She has more than 25 years' experience communicating high-tech solutions to a wide range of audiences.



Henk Rogers is a Dutch-born computer game designer known for producing the role-playing game The Black Onyx and securing the rights for Tetris. Now Blue Planet Foundation's principal, Rogers attended NYC's school for mathematics, science and technology, Stuyvesant High School, and studied computer science at the University of Hawaii.

Leslie Shiner has more than 25 years' experience as a financial and management consultant. She is the owner of The ShinerGroup, a firm providing financial and management consulting for the solar industry. She is the author of numerous publications, including *A Simple Guide to Turning a Profit as a Contractor.* Shiner holds an MBA from UC Berkeley.

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.

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SMA Announces 2,750 kW Sunny Central Inverter

[Rocklin, CA] SMA America's newest addition to its Sunny Central inverter family has a rated power of 2,750 kVA, making it 10% more powerful than previous models. Designed for high-voltage arrays, the Sunny Central 2750-EV-US has a MPP voltage range of 875 V–1,425 V at 25°C and a maximum dc input voltage of 1,500 V. The product can provide 0.8 lag-to-lead reactive power on demand and has a CEC-rated efficiency of 98.5%. Like previous models, it includes an integrated 8.4 kVA auxiliary power supply for internal consumption and external loads. SMA offers the product as a standalone device or as an integrated utility power solution, with a dc combiner, medium-voltage transformer and switchgear, power plant controller and tracker auxiliary rack. For improved harmonization with international standards, SMA is certifying its Sunny Central inverters to UL 62109, an equipment safety standard that applies specifically to PV inverters.

SMA America / 916.625.0870 / sma-america.com

SunWize Offers Component Enclosures

[Philomath, OR] Looking to source the perfect weatherproof enclosure for custom solar projects? SunWize manufactures seven product lines of enclosures designed for a wide range of industrial applications. Its enclosures are more than just aluminum NEMA 3R battery boxes: They feature a range of back plate, side plate and DIN rail options for mounting the various industrial equipment a project may require, including power conversion devices, OCPDs and terminal blocks. A complete 34-page catalog of SunWize's enclosure products is available for download from the company's website.

SunWize / 866.827.6527 / sunwize.com

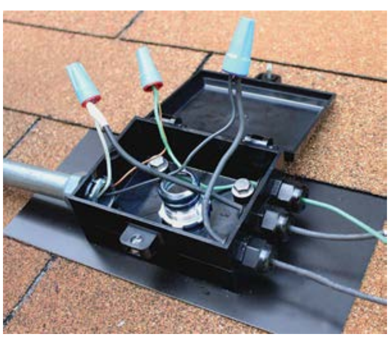
Huawei Introduces 95 kW, 1,500 V String Inverter

[Plano, TX] Huawei, the world leader in inverter shipments, is doubling down on 1,500 V string inverters for utility-scale applications. The company's latest FusionSolar Smart PV Solution is the SUN2000-95KTL-US, a 95 kVA string inverter. The product has 12 source-circuit inputs to six independent MPP trackers, which not only eliminates the need for series-string fuses but also provides design flexibility while maximizing yield. Like its 45 kVA predecessor, the 95KTL uses convection cooling technology, meaning there are no fans or filters to service or replace. To minimize ac losses, the platform uses an 800 Vac output stage. The company claims that its new 95KTL offers the industry's highest power-to-weight ratio and drastically reduces O&M costs in large-scale PV power systems.

Huawei Technologies USA / 214.919.6000 / solar.huawei.com

Quick Mount PV Introduces QBox Transition Enclosure

[Walnut Creek, CA] Quick Mount PV recently released its QBox array transition box for pitched roofs with composition shingles. The QBox is a flashed junction box with Quick Mount PV–patented QBlock Elevated Water Seal technology. It provides a waterproof pass-through for conduit from the roof-mounted box enclosure to the interior of a building. The QBox



product includes fasteners to install the enclosure on the roof deck, fittings for through-the-deck conduit attachment and wire nuts to transition or combine up to two pairs of source-circuit conductors. A 12-by-12-inch flashing with elevated water seal and a 5.5-by-5.75-inch weather-resistant polycarbonate enclosure comprise the QBox's main components. Quick Mount PV backs the QBox with a 5-year limited warranty.

Quick Mount PV / 925.478.8269 / quickmountpv.com

Energy Toolbase Quantifies Energy Storage Savings

[Los Angeles] Energy Toolbase has released a major software update to enhance the platform's energy storage modeling capabilities. The new release allows developers and service providers to quantify savings transparently in residential and commercial behind-the-meter energy storage applications, markets that analysts expect to grow rapidly in the next few years. Users can evaluate different combinations of distributed energy resources, storage system hardware, software control strategies, resource utilization restrictions, customer load profiles and utility rate assumptions. This objective third-party design approach empowers developers to identify the best customers, technologies and use cases for energy storage deployments. Since Energy Toolbase's initial release in 2014, more than 1,000 organizations in the US have adopted it and now use the software-as-a-service platform to perform utility rate and avoided cost analyses for solar and energy storage projects.

Energy Toolbase / 866.303.7786 / energytoolbase.com

Yaskawa Launches Two High-Power String Inverters

[Lawrence, MA] Yaskawa–Solectria Solar, the largest commercial inverter manufacturer in the US, has introduced two new made-in-America string inverter lines, the XGI 1000 and XGI 1500. Designed for commercial applications, the XGI 1000 product line includes 60 kW and 65 kW 3-phase string inverters for interconnection at 480 Vac. These 1,000 V–rated inverters have an operating MPPT voltage range of 300 Vdc–950 Vdc and a CEC-rated efficiency of 98%. The XGI 1500 utility product line includes 125 kW and 166 kW string inverters for 3-phase interconnection at 600 Vac. The XGI 1500-125 and XGI 1500-166 have an operating voltage range of 860 Vdc–1,450 Vdc and a CEC-rated efficiency of 98.5%. Both platforms have an advanced Wi-Fi–enabled user interface that provides access to all on-site inverters from one location, and they are SunSpec Modbus compliant for integration with third-party monitoring systems. Both product lines come standard with an RJ-485 Ethernet communication interface; the XGI 1500 is also available with an optional multimode fiber interface.

Yaskawa–Solectria Solar / 978.683.9700 / solectria.com

Clean Energy Credit Union Set to Launch

[Boulder, CO] The National Credit Union Administration recently announced that it has granted a federal charter to a new credit union based in Boulder, Colorado—the Clean Energy Credit Union (CECU). CECU is the first new credit union in Colorado to receive a federal charter in 31 years. It will focus exclusively on providing loans that help members afford to use clean energy products and services. Initially, CECU will offer savings accounts, clean energy CDs and loans for solar electric systems, clean energy vehicles, and energy-efficiency home improvements. It will bring expanded financial services offerings online following the first year of operations; these are likely to include checking accounts, debit cards, credit cards and a wider variety of clean energy–focused loan products. As a cooperative, the credit union is democratically owned, and its members control it on a one-vote-per-member basis. CECU has launched a crowdfunding campaign running through November 12, 2017 (http://www.worthwild.com/initiatives/71), to support its success.

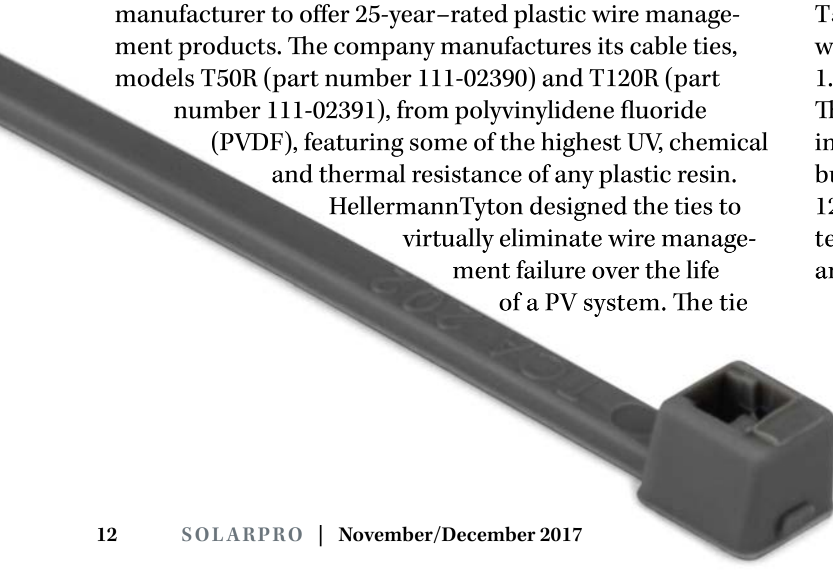
Clean Energy Credit Union / 720.479.7900 / cleanenergycu.org

Darfon Introduces Energy Storage Solutions

[Mountain View, CA] Darfon Electronics has expanded its product portfolio with the launch of its hybrid H5000 inverter-charger, which it integrates with three complete hybrid energy storage systems (ESSs). The H100 ESS integrates valve-regulated lead-acid (VRLA) batteries and the hybrid inverter into a rack enclosure. The H100 is designed to provide PV-supported backup. The H200 integrates lithium iron phosphate (LFP) batteries, the hybrid inverter and a battery management system into a rack enclosure. The H200 is designed to provide PV-supported backup and arbitrage. The H300 is a wall-mounted solution that includes a 5 kWh NMC-type lithium battery and the soon-to-be-released H5001 hybrid inverter with a preattached distribution box. The H300 is designed for homes with less than a 2 kW load to support.

Darfon America / 650.316.6300 / darfonsolar.com

HellermannTyton Offers PVDF Cable Ties



[Milwaukee] HellermannTyton is the solar industry's first manufacturer to offer 25-year–rated plastic wire management products. The company manufactures its cable ties, models T50R (part number 111-02390) and T120R (part number 111-02391), from polyvinylidene fluoride (PVDF), featuring some of the highest UV, chemical and thermal resistance of any plastic resin. HellermannTyton designed the ties to virtually eliminate wire management failure over the life of a PV system. The tie strap has smooth edges to prevent bundle damage. The T50R PVDF cable tie is 8 inches long and 0.18 inches wide, and can secure a maximum conductor bundle of 1.97 inches. Its minimum tensile strength is 50 pounds. The T120R PVDF cable tie is 15.2 inches long and 0.30 inches wide, and can secure a maximum conductor bundle of 4.1 inches. Its minimum tensile strength is 120 pounds. Both products are rated for operating temperatures between -40°F and +284°F (-40°C and +140°C).

HellermannTyton / 800.537.1512 / hellermanntyton.us

SCADA's Role in Utility-Scale PV Plants

Utility-scale power producers face a demanding and multi-faceted mission: Meet contract commitments, operate safely, support grid stability and maximize profits. Supervisory control and data acquisition (SCADA) systems play an essential role in meeting these objectives. SCADA systems monitor and control a variety of devices at utility-scale PV sites, including inverters, meters, trackers, meteorological stations, storage systems and other smart devices. Properly designed SCADA systems provide total site control to optimize power generation, control voltage, maximize revenue, ensure accurate settlements and satisfy utility compliance requirements.

Here I look at the role of SCADA systems in utility-scale PV power plants for compliance, operations management, asset management and revenue optimization. I conclude with an overview of design and deployment considerations.

Compliance, Grid Support and Security

On the regulatory compliance front, power producers use SCADA technology to honor contracts, meet regulatory compliance or both. For example, a power-producing site may have either a contractual or a compliance requirement to operate at a certain production level, a condition that effectively requires SCADA capabilities. Plant operators need to have not only visibility into how the site is performing currently, but also foresight into how it will perform in the future. SCADA systems can be invaluable in reviewing historical performance and correlating past values to projected weather patterns. These systems enable operators to provide accurate forecasts to address operational and compliance requirements.

SCADA systems also enable utility-mandated grid support functionality. With the right technology, the site can not only react to and counter the impact of variations in voltage, frequency or reactive power, but also can ride through transient events to avoid exacerbating a grid disturbance. The SCADA system evaluates grid conditions in real time and can make grid-support decisions automatically.

Site security is another important consideration with compliance implications. Technology plays a vital role in protecting large-scale power generation sites from those who intend to do harm, from unwanted access and control, or from unintended human error. Although physical security systems can limit perimeter access, operators must also implement cybersecurity systems to limit access to sensitive information and control activities. For large sites, the North American Electric Reliability Corporation (NERC) explicitly outlines cybersecurity requirements for low-, medium- and high-impact sites in its critical infrastructure plan (CIP) standards. Even if regulators do not require that a site meet these NERC CIP levels, operators must still address cybersecurity, as it is essential to successful plant operations.

Courtesy Trimark Associates

Monitoring versus control One of the primary differences between data acquisition systems and SCADA systems is that the latter layer command and control functionality on top of data monitoring, which allows PV power plants to respond to signals from the utility system operator.

Operations, Performance and Safety

To optimize operational management activities, plant operators need accurate and timely information. SCADA systems collect, analyze and present site information clearly and concisely so operators know how to prepare for and react to site events. Operators can leverage this technology to automatically react to values that exceed defined thresholds by adjusting how the site operates, by raising alarms or both. For example, an on-site SCADA system can compare actual production to expected production and raise an alarm if the site is not performing optimally. This ensures that restricted performance does not negatively impact overall revenue and profitability.

Operators can use a well-designed SCADA system to establish key performance indicators (KPIs) with the goal of streamlining operational activities. These KPIs allow operators to focus quickly on the actionable information they need to operate the site rather than having to review thousands of pieces of information. For example, rather than rely on an arbitrary washing schedule, operators can use SCADA systems to calculate the soiling impacts, and then present these data as a metric that indicates when to schedule panel washing. Ideally, the SCADA system identifies any gaps or anomalies in the data and makes the adjustments necessary to ensure data integrity. A customized SCADA solution can provide this extra level of data analysis.

To improve operational safety, SCADA systems can proactively identify events that may affect a plant's safe operation. If a power transformer shows signs of overheating, for instance, the SCADA system can raise an alarm so that the operator can dispatch a maintenance crew to investigate the problem. As an additional layer of protection, a well-implemented SCADA system can also vary plant behavior to compensate for this type of event before it becomes more serious and harmful. In the event of a transformer temperature alarm, for example, the SCADA system could automatically reduce or

Courtesy Trimark Associates

Key performance indicators This SCADA user interface screen displays key performance indicators in a dashboard where operators can access site controls and product reports, as well as respond to alerts.

curtail the power flowing through the transformer to lessen or eliminate the risk of equipment damage.

Asset Management and Capital Planning

The focus of asset management, which is necessary to meet the project's overall financial goals, is maximizing revenue from the site while minimizing operating costs. To support these business goals, operators can leverage SCADA systems to provide timely information about performance—not only in terms of kilowatt-hours but also in terms of dollars and cents. This revenue perspective is critical for determining maintenance priorities, as it allows operators to identify the items that have the largest returns.

Asset managers can use SCADA technologies to determine which preventative maintenance activities to schedule and when, so as to maximize revenue. With accurate forecasting, for example, the site operator can schedule inverter maintenance during lower power production periods, effectively minimizing the revenue impacts of taking equipment offline. It is also possible to use data analysis to make a business decision about when to repair nonproducing PV strings—either immediately or during the next scheduled maintenance visit.

Asset managers can also use SCADA solutions to optimize warranty activities. If an inverter fails while it is still under warranty, it is obviously to the asset manager's advantage to have the installer or manufacturer replace or repair the inverter according to the warranty terms. SCADA systems with full-featured asset management functionality can track how long equipment has been in operation relative to the warranty period, which has a positive impact on the bottom line. In other scenarios, asset managers might use SCADA technologies to perform an accurate lost-energy analysis as part of a warranty claim resolution.

SCADA systems can even help asset managers get the most out of critical or costly components by controlling this equipment with lifespan or duty cycles in mind. A site might have 50 inverters that operators must actively control to regulate power based on compliance and operating requirements. During curtailment or regulation activities, SCADA technologies can intentionally limit the contributions of older inverters or run different inverters at different power levels based on their efficiency curves.

When asset managers use SCADA capabilities to extend the life of devices, they are saving money by deferring equipment replacement cost. Optimizing inverter efficiency, meanwhile, can increase revenue. SCADA technology can also support capital planning and investment decisions. To the extent that asset managers can determine predictively when trackers or inverters are likely to need replacement, they can manage their capital plan for replacement purchases more effectively.

Power Generation and Revenue

An important best practice for utility-scale power producers is to use SCADA technology to measure, monitor and control power production at the point of interconnection (POI). Everything that happens before the POI is about the resource; everything that happens on the other side of that POI is about the grid. You should base every decision that you make about the resource—from the monitoring to the controls—on the effect it will have on that interconnection point with the grid. Using SCADA technology to make decisions based on what actually is going on at the POI, rather than assuming what is happening, maximizes the effects of your actions.

Power regulation is a good example. Perhaps a developer built a site to produce as much as 60 MW, but from a contractual standpoint, it needs to limit power production to 54 MW. If the installation has 60 inverters, each rated for 1 MW, they certainly would not all be producing the same amount of power all the time—therefore it would not be prudent to simply reduce all of the inverters by 10%. By taking measurements at the POI and adjusting each inverter to its individual capability, plant operators can generate the maximum amount of power allowable without exceeding the contracted power limit. Additionally, if an inverter has an issue or is undergoing maintenance, operators can leverage technology to recognize the lost production and adjust the remaining inverters to make up the difference automatically. This approach allows the system to maximize revenue while still meeting both contractual and operational requirements.

SCADA Feature Checklist

- ❑ Communication with all site devices, regardless of protocol
- ❑ Monitoring and control of any type of device
- ❑ Ability to capture, log and store data and events for analysis
- ❑ Flexible, dynamic and site-specific alarms
- ❑ Portfolio aggregation to manage multiple sites from one dashboard
- ❑ Compliance of critical infrastructure with NERC CIP
- ❑ Guaranteed power characteristics at the POI
- ❑ Integration with ISO's automated dispatch system
- ❑ Support for power-production forecasting
- ❑ Customizable production-value reporting and settlement reconcilements

Courtesy Trimark Associates

Key features SCADA systems provide multiple layers of functionality and must meet the needs of multiple users.

Implementation Considerations

Deploying the right technology can make all the difference in terms of project success or failure. Here are some important considerations when leveraging monitoring and control technologies to operate and manage a utility-scale power plant.

Use job-appropriate technology. Do not implement a commercial monitoring system when the plant needs a full SCADA system. (See "SCADA Feature Checklist.")

Keep the site secure. Layer security so that someone cannot damage the site intentionally or inadvertently. Make sure that information is accessible only to those who need it and not to unauthorized users.

Automate processes where possible. Automation ensures that people can focus on nonroutine, problem-solving knowledge work and not on mundane and tedious operational tasks. Automated controls can also eliminate unnecessary truck rolls to the site and reduce the labor expended on routine control activities.

Design for interoperability. Usually various business systems need to communicate and operate with the site. These can include energy management systems, operational data management systems and surveillance systems. Selecting the right technology ensures that all these systems use standard communications protocols to ease integration and interoperation.

Plan in advance. Implementing and leveraging technology is much easier if you make it part of the plan from the start. Industry regulations and best practices are changing constantly. Designing the site technology to adapt and interoperate with changing conditions will help ensure that the site does not become obsolete before its end of life.

—Diane McClelland / Trimark Associates / Folsom, CA / trimarkassoc.com

Do Not Confuse Margin with Markup

Many solar contractors use elaborate Microsoft Excel spreadsheets to create client proposals. They quote and track the cost per watt. But when they use the term *cost,* that amount typically represents the sales price, not the actual cost. Markup and margin percentage are two ways to keep track of both the cost and the price, but it is important not to confuse one with the other.

Margin versus Markup

While many solar contractors understand the difference between margin and markup, some small business owners continue to confuse the two numbers. I have spoken with many contractors who look at their profit and loss (P&L) statement and incorrectly interpret margin numbers, using these as their markup. The key is to remember that *margin* is always represented as a percentage of revenue; *markup* is always represented as a percentage of costs.

If you charge the customer $100 for something that costs you $65, then you make a $35 gross profit. That means you have $35 left over to pay your overhead, which hopefully leaves some profit. You determine the margin by dividing the gross profit ($35) by the sales ($100) to achieve 35%. Gross profit refers to dollars and gross margin refers to percentages. Therefore, in the above transaction, you earned a 35% gross margin.

You determine the markup by taking the gross profit ($35) and dividing it by the costs ($65) rather than the sales price. Therefore, you have a markup of 54%. You think: "Sure, I knew that!" The mistake comes when you use a margin number as a markup. In many cases, when you print out a P&L, it provides margin numbers only, representing all costs as a percentage of sales. If we sold 100 of the items above and created a P&L, it might look like Table 1.

Pitfalls of Using the Wrong Percentage

If you ask accountants what your overhead and profit are based on Table 1, they might just tell you that it is 25% and 10%, respectively. But these values are based on 35% of your sales rather than your costs. So what happens if you accidentally use the wrong value the next time you create a proposal?

If you have a job that includes the same $65 piece of equipment, you might be tempted to mark it up by 35%, with 25% going to overhead and 10% to profit. In this case, however, you are only charging $87.75 for the same product ($65 x 135%), and your financial statement would look like Table 2.

The pitfall of using a margin percentage from a P&L is that you could wind up losing money. The correct way to use margin numbers from your financial statements is to divide by the reciprocal of that margin. Going back to that $65 piece of equipment, as an example, you would divide the cost by 65% (100% minus 35%), as this produces the $100 sales price ($65 ÷ 65%).

Example P&L Statement

		Margin	Markup
Sales	100,000	100%	
COGS	-65,000		100%
Gross Profit	35,000	35%	54%
Overhead	-25,000	25%	38%
Net Profit	10,000	10%	15%

Table 1 Note that the gross margin percentage is based on total sales, whereas markup is based on the total cost of goods sold (COGS).

> If you use a margin number as a markup, you will not make enough money to cover your overhead, let alone earn a profit.

As I travel around the country speaking to contractors, I ask how many in the audience determine the sales price by multiplying expected costs by a number and how many divide by a number. The answer is typically about half and half. You can do it either way, but what you cannot do is determine the costs of the job and multiply by the margin goal. If you do, you will consistently underprice your jobs. You may stay busy, but sooner or later, you will not make enough money to cover your overhead, let alone earn a profit. You cannot use a margin number as a markup or you will lose money.

What Is the Right Number?

Now comes the $64,000 question: "What is a good markup?" or "What margin should I use?" I cannot answer that question, as you need to consider many factors. Your margin must provide enough money to cover your overhead, provide a profit and cover potential slippage.

Slippage occurs when you spend more money on the job than you

No Profit, Only Loss

		Margin	Markup
Sales	87,750	100%	
COGS	-65,000		100%
Gross Profit	22,750	26%	35%
Overhead	-25,000	28%	38%
Net Profit	-2,250	-3%	-3%

Table 2 If you mistakenly use margin percentage as a markup, you could wind up losing money.

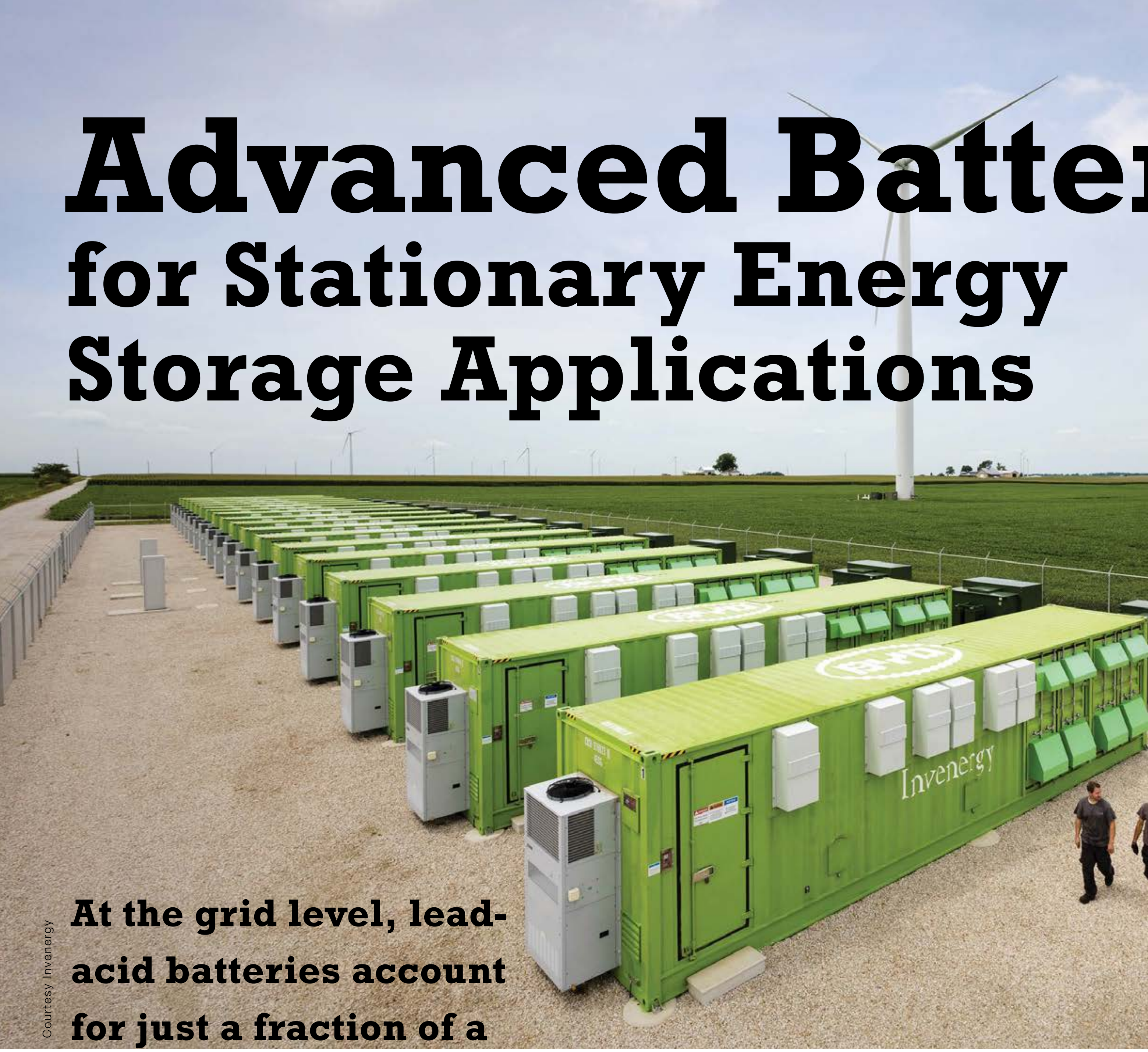
expected. If the gross margin is less than expected after you have completed the job, you have slippage. Therefore, if you consistently price jobs with a 40% margin, but you come in at 30%, you are not managing the jobs well, and your gross margin will suffer from slippage. If you always prepare your proposals with the sales price and do not convert to the estimated cost (or budget), then you will not be able to determine the source of your slippage. You will know only that the job did not produce the gross profit dollars you expected.

Many solar contractors are constantly busy these days and yet remain always concerned about volume and competition. If you reduce your prices to get more jobs, you may be underpricing jobs so drastically that you cannot cover your overhead. This is a dangerous position to be in. It is better to do less work with a consistent profit and higher margin than to do more work at a loss. Review your financial statements to determine what margin you are making on your jobs. Separate and analyze the margin on equipment compared to the margin on labor. If the margin you achieve on labor is significantly different than the margin you attain on equipment, you should reassess any proposal you produce that has a considerably different equipment-to-labor mix.

Look at the type of work you are doing. Commercial work, for example, typically yields a lower margin than residential work. If you are considering moving from one market to the other, make sure that you have a system in place to track actual costs against expected costs—and do not confuse your markup with your margin the next time you produce a proposal.

—Leslie Shiner / The ShinerGroup / Mill Valley, CA / shinergroup.com

Advanced Batteries for Stationary Energy Storage Applications



Courtesy Invenergy

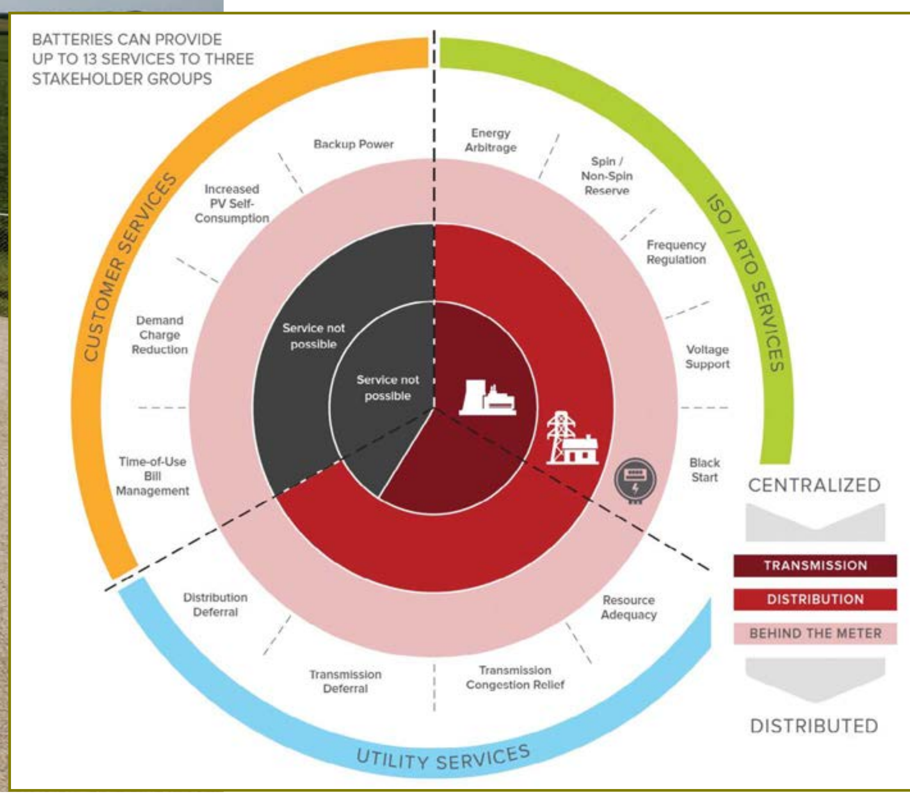
At the grid level, lead-acid batteries account for just a fraction of a percentage of new energy storage deployments. So, what battery chemistries are developers and utilities using today, and why?

A radical energy transformation is under way today, one that we will likely fully appreciate only in hindsight. Auto manufacturers are transitioning to electric vehicles, which will enable new transportation paradigms and vehicle-to-grid services. Utility regulators and operators are beginning to rebuild the bulk power system to make it more resilient and better able to accommodate high penetration levels of variable renewable generation. The prime mover in these transitions is the rapid advancement in electrochemical energy storage technologies.

In this article, I briefly review grid applications for energy storage solutions, both in front of and behind the customer meter. I then provide a compendium of advanced energy storage solutions for stationary energy storage applications, looking at representative technologies, vendors and ry Technologies

By David Brearley

Figure 1 The benefits of energy storage systems accrue to different stakeholder groups—utilities, system operators and end users—depending on location and application. In some cases, a system can provide multiple services to improve its value proposition, a practice known as *application stacking.*



Courtesy Rocky Mountain Institute

field deployments. Because there is much to cover here, this is less of a design guide for applications engineers than it is a snapshot of a very dynamic and exciting space, one that solar professionals would do well to keep tabs on.

Grid Applications for Energy Storage

It is with good reason that industry stakeholders, researchers and analysts often describe energy storage as the missing piece of the puzzle or the great enabler in the renewable energy revolution. Use cases for energy storage systems exist in front of the customer meter, at both the transmission and distribution level of the bulk power system, as well as behind the customer meter, in commercial and even residential applications. Depending on how and where developers deploy energy storage systems, benefits might accrue to a utility, reliability coordinator, balancing authority, third-party system operator, community, commercial or residential customer, society at large or some combination of these. As shown in Figure 1, a 2015 report published by the Rocky Mountain Institute (see Resources) identifies 13 different services that energy storage systems can provide to three general stakeholder groups.

Use cases for energy storage are generally built around opportunities to avoid incurring costs or opportunities to generate income. Examples of the former include energy storage deployments that allow utilities to defer transmission or distribution system upgrades, or that enable commercial and industrial customers to avoid demand charges. Examples of the latter include energy storage systems that participate in markets for ancillary services, such as frequency regulation, voltage support or demand response. Energy storage systems can also improve grid resiliency, provide generation capacity or facilitate the integration of more wind and solar. Some of these applications have broad societal benefits, such as disaster preparedness or greenhouse gas reductions, that are not easy to quantify in economic terms—at least not given today's market structures.

Though there are many opportunities to deploy grid-interactive energy storage systems, it is important to recognize that different applications are not created equally. Frequency regulation is a relatively short-duration service, measured in seconds or minutes, intended to reconcile momentary differences in the generation-to-load balance; as such, it favors a fast response time but does not necessarily require large amounts of energy, because the battery is alternately discharging and charging in rapid succession. Applications that shift electric energy in time, over a period of hours or even days, are comparatively more energy intensive but may have more modest power requirements. Other applications are potentially both energy and power intensive. In demand management applications, for example, batteries store off-peak energy for a period of hours, then discharge stored energy during on-peak pricing periods as needed to offset the demands associated with heavy loads.

These different application characteristics underscore the need for different batteries and battery technologies. Some chemistries or technologies are better suited for short-duration power applications, whereas others are better suited for long-duration energy applications. Since deploying an energy-optimized battery in a power application or vice versa can degrade system performance in the long term, some hybrid utility-scale applications actually utilize both power- and energy-type batteries. While it is tempting to describe grid-interactive energy storage systems in general as a Swiss Army knife, no one battery is the ideal tool for all applications.

Advanced Battery Technologies

Here I look specifically at those alternatives to conventional lead-acid energy storage technologies that are commercialized in stationary grid applications or deployed in pilot projects. Though lead-acid batteries have been commercialized for nearly 160 years, they have ceded market share in recent decades to next-generation secondary (rechargeable) battery technologies. This is perhaps most apparent in portable tools and consumer electronics, but is equally true in automotive traction and stationary grid applications. Lead-acid batteries have a long history in off-grid applications, but are seldom the technology of choice in emerging grid-interactive energy storage applications because of limitations associated with round-trip efficiency, energy density, depth of discharge and cycle life.

LITHIUM-ION BATTERIES

According to the most recent edition of the *US Energy Storage Monitor* (see Resources), lithium-ion (Li-ion) batteries are by far the dominant energy storage technology in today's grid-interactive applications. Continuing a trend that dates back to Q4 2014, Li-ion deployments accounted for 94.2% of the energy storage market in Q2 2017. The leading manufacturers in this space are generally subsidiaries or divisions of well-known multinationals or specialty battery vendors.

Lithium has several characteristics that make it ideal for use in batteries. For one, it is the third chemical element on the periodic table, after hydrogen and helium, making it the lightest of all elemental metals. Additionally, it has the highest electrochemical potential (-3.02 volts) of any metal and is highly reactive. Inherent advantages and disadvantages are associated with these chemical properties. On the one hand, Li-ion batteries provide excellent energy and power density; on the other, they present potential issues with chemical and thermal stability.

All Li-ion batteries have three basic parts: a positive electrode (cathode), a negative electrode (anode) and a chemical compound (electrolyte) that allows the movement of ions between the electrodes. The cathode material is often a metal oxide, and the anode is usually porous graphite. When a Li-ion battery is charging, lithium ions migrate from the cathode to the anode; on discharge, the anode loses electrons and the cathode gains electrodes.

Manufacturers package Li-ion cells individually, often in pouch or cylinder form, and integrate multiple cells into a battery module with a battery management system to keep each cell balanced. To scale systems up, companies integrate multiple battery modules into a battery rack. CONTINUED ON PAGE 24

Building blocks Each cell housing in this Kokam battery module contains a Li-ion pouch cell (inset). A battery rack integrates multiple modules.

Courtesy Kokam

Courtesy Blue Planet Energy

Safety first Blue Planet Energy selected Sony's battery modules for its Blue Ion 2.0 residential energy storage solution because LFP-type Li-ion cells offer a long lifespan and, even more important, excellent thermal and chemical stability. Murata acquired Sony's battery business division in late 2016.

Container-scale solutions incorporate multiple battery racks. Li-ion energy storage systems at this scale have multiple layers of battery management and control—at module level, rack level and system level—as well as multiple layers of safety and protection such as fuses, software, containment, climate control and so forth.

Li-ion batteries in general have relatively high intrinsic cell voltage and low self-discharge rates, and respond quickly when charging or discharging. Important differences exist between specific Li-ion chemistries, however, as each has different performance characteristics and a unique value proposition. In most cases, the name given to various Li-ion technologies refers to the chemistry of the cathode. Common Li-ion cathode chemistries in grid applications are lithium iron phosphate (LFP) and lithium nickel manganese cobalt oxide (NMC).

LFP-type Li-ion. In 1996, a research team led by John Goodenough at the University of Texas first described lithium ferro phosphate ($LiFePO_4$) as a cathode material for rechargeable Li-ion batteries. Superior chemical and thermal stability is one of the most compelling features of LFP-type Li-ion batteries. Phosphate-based cathode materials release little heat and oxygen gas when exposed to high-temperature or overvoltage conditions, which means they are not susceptible to thermal runaway. In addition to being chemically stable, LFP cells are not combustible, which further improves their safety relative to Li-ion batteries with metal oxide cathodes. LFP batteries also offer an extended cycle life and lifespan compared to competing technologies. The tradeoff is that while LFP batteries can support high load currents and retain their power capabilities at a low state of charge, they have a relatively lower energy density and a higher self-discharge rate.

Notable grid-interactive LFP battery vendors include BYD, a Chinese manufacturer of automobiles and rechargeable batteries, and Murata. LFP-type batteries are in use in a wide variety of stationary applications. At the grid scale, project developers or EPCs have deployed BYD's LFP-based energy storage systems at multiple locations across the US and Canada in both microgrid and frequency regulation applications. For example, EDF Store & Forecast commissioned a 19.8 MW/ 7.9 MWh battery storage project outside Chicago in January 2016 that provides the grid operator, PJM, with ancillary services, including autonomous frequency regulation and dynamic power reserves. At the other end of the application spectrum, Blue Planet Energy uses Murata's LFP-type batteries in its residential energy storage platform to support nanogrid, backup power and self-supply applications.

NMC-type Li-ion. In 2001, Zhonga Lu, a staff scientist for 3M, and Jeff Dahn, a physics and chemistry professor at Dalhousie University, filed international patents for lithium nickel manganese cobalt oxide ($LiNiMnCoO_2$) as a cathode material. As an industrial research chair for the Natural Sciences and Engineering Research Council of Canada, Dahn specializes in materials for advanced batteries. After completing a 20-year research agreement with 3M in 2016, Dahn's group began a 5-year research partnership with Tesla.

Cobalt is a common ingredient in many Li-ion battery cathodes because it provides a high energy density. The downside is that cobalt is expensive, and the cobalt-based chemistries used for portable electronics have issues with thermal stability and capacity fade. Adding nickel and magnesium to the mix not only reduces costs, because nickel is less expensive than cobalt, but also improves thermal stability and cycle life. Li-ion batteries with NMC-type cathodes are increasingly popular in the market because they offer good all-around performance—in terms of cost, safety and lifespan—and can be tailored for energy or power applications. In its 2017 report, "Status of the Rechargeable Li-ion Battery Industry," Yole Développement predicts that NMC materials will account for more than half of the global cathode market by 2022.

Notable grid-interactive NMC battery vendors include LG Chem; Kokam, a South Korean company that specializes in rechargeable Li-ion polymer batteries; Panasonic, which is Tesla's primary business partner in its much-anticipated Gigafactory; and Samsung. Kokam's Li-ion rack system,

Application stacking In 2016, S&C developed the first municipal utility–owned solar-plus-storage project in the US for the Village of Minster, Ohio. The project includes a 4.2 MW PV system and a 7 MW/3 MWh energy storage system with NMC-type Li-ion batteries from LG Chem. Stacked value streams associated with the energy storage system include frequency regulation, peak power shaving, voltage regulation and reactive power compensation hardware deferral.

Courtesy LG Chem

which is integral to its containerized energy storage systems, provides a good example of the flexibility of NMC batteries. With two battery racks in parallel, Kokam's high power–type NMC battery has a usable energy capacity of 211 kWh and a power rating of 888 kW when charging or discharging. By contrast, the same configuration of high energy–type NMC batteries provides 17% more usable energy (253 kWh), but only one-third as much power (266 kW). As a rule of thumb, high power–type NMC batteries are intended for short-duration (<1 hour) applications that require the rapid dispatch of large amounts of power; energy-type NMC batteries are intended for longer-duration (>1 hour) applications with more-continuous loads.

Project developers, utilities, EPCs and system integrators are deploying NMC-type batteries at every level of the electric power system, from grid-scale to customer-sited applications. For example, Tesla deployed a massive 20 MW/80 MWh energy storage system, consisting of CONTINUED ON PAGE 27

Energy Storage Glossary

If you have been in the solar business for more than 15 years, you are likely somewhat familiar with the lexicon of batteries. Before SMA America introduced its high-voltage string inverter to North America in the early 2000s, most PV systems in the US and Canada included an energy storage component, even in grid-interactive applications. Just 5 or 10 years ago, interactive PV systems with energy storage were the exception rather than the rule, but the pendulum is showing signs of swinging back in the other direction. This glossary defines some foundational terms, many of which I use in this article, that point out some important differences between solar and storage ratings and describe some battery failure modes.

Anode: The negatively charged terminal of a battery, under discharge conditions, where chemical energy is stored. Chemicals at this terminal have a surplus of electrons available for donation.

Anolyte: The negatively charged liquid electrolyte on the anode side of a flow battery or an electrochemical cell that is divided into two compartments.

Capacity: The nominal *energy* rating of an energy storage system as measured in kilowatt-hours. In the context of solar, capacity refers to the power (kilowatt) rating of a PV system under standard test conditions; in the context of batteries, it describes the amount of energy a system can deliver or absorb over the course of an hour, which will vary based on charge rate. Note that a battery's nameplate capacity rating does not equal its usable capacity, which is a function of other characteristics, such as allowable depth of discharge and system efficiencies, including inverter, cabling and transformer losses.

Cathode: The positively charged terminal of a battery under discharge conditions that establishes an electromotive force. Chemicals at this terminal have a deficit of electrons.

Catholyte: The positively charged liquid electrolyte on the cathode side of a flow battery or an electrochemical cell that is divided into two compartments.

Charge rate (or C-rate): 1. The rate at which a battery can charge; **2.** The rate at which a battery discharges relative to its maximum capacity; **3.** The maximum safe continuous discharge rate for a battery.

Cycle: One charge and discharge sequence. Note that all cycles are not created equally but vary in intensity based on C-rate and depth of discharge.

Cycle life: The rated number of charge-discharge cycles a battery supports based on a specific depth of discharge.

Dendrite formation: Needlelike metal accumulations on the anode of a battery that, if uncontrolled, can cause a hazardous short-circuit condition.

Depth of discharge: The energy discharged from a battery, expressed as a percentage, relative to the total amount of stored energy. While some batteries support 100% depth of discharge, many do not.

Discharge duration: The length of time that a battery can discharge at its nominal power rating.

Energy density: The amount of energy that a battery stores in relation to its volume. (See also *specific energy*)

Electrolyte: A chemical medium that allows the flow of electrons between the cathode and anode of a battery.

Oxidation: Chemical reactions that result in an electrode's release of electrons. This reaction occurs simultaneously with a reduction reaction at the opposite electrode.

Power density: The power level that a battery supports in relation to its volume. (See also *specific power.*)

Power rating: The kilowatt rating of an energy storage system, describing the amount of power that can flow instantaneously in or out of a battery.

Primary battery: A nonrechargeable battery constructed with cells whose electrochemical reaction is not reversible.

Reduction: Chemical reactions whereby an electrode accepts electrons. This reaction occurs at the same time as an oxidation reaction at the opposite electrode.

Response time: The length of time it takes for a battery to transition from no discharge to full discharge.

Secondary battery: A rechargeable battery constructed with cells whose electrical chemical reaction is reversible.

Specific energy: The amount of energy a battery delivers in relation to its mass.

Specific power: The amount of power a battery delivers in relation to its mass.

Thermal runaway. A potentially destructive positive feedback loop whereby an increase in temperature in a system generates heat, further increasing internal temperatures. Some types of batteries, including Li-ion cells, are susceptible to thermal runaway under abusive conditions during charging or discharging. Cascading thermal runaway occurs when the uncontrolled exothermic reaction in one cell spreads to adjacent cells. ●

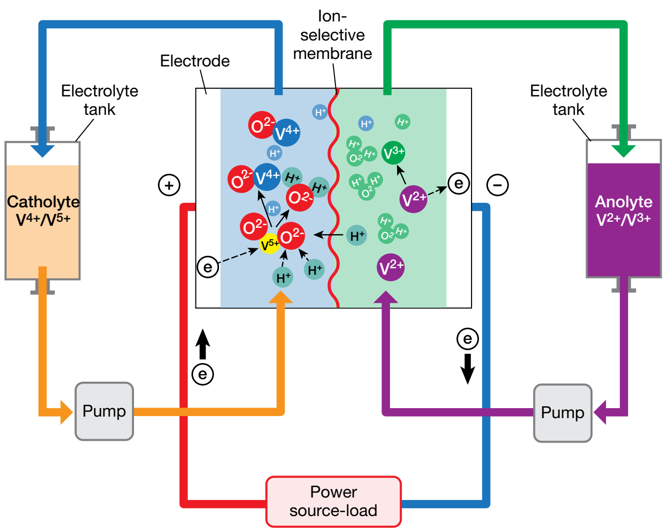


Figure 2 In a flow battery, large tanks that contain liquid electrolytes store electrochemical energy. To generate electricity, pumps circulate the anolyte and catholyte through a battery cell stack area with an ion-specific membrane, freeing electrons to do work.

roughly 400 Powerpack 2s, at the Southern California Edison (SCE) Mira Loma substation. SCE will use the project to store low-cost off-peak energy for dispatch as a means of reducing its reliance on natural gas peaker plants. At the other end of the size spectrum, Tesla and Green Mountain Power are providing Tesla's Powerwall 2 to residential customers in Vermont for a low monthly lease or up-front purchase price. Tesla is working with Green Mountain Power to aggregate these distributed residential energy storage resources and bundle them with Powerpack deployments located on utility-owned property for dispatch as a virtual power plant that can provide a variety of grid services.

FLOW BATTERIES

According to GTM Research, flow batteries accounted for just 5% of the US energy storage market in Q2 2017. As the technology matures, flow batteries could capture more market share in niche applications. While most analysts believe it will be difficult to displace Li-ion batteries, at least over the short term, in applications with a sub–4-hour discharge duration, many think that an opportunity exists for new technologies in applications where discharge duration is on the order of 4–6 hours or more. Examples of applications that favor a long-discharge battery include electric energy time shift or energy arbitrage, transmission and distribution upgrade deferral, and microgrids with variable renewable resources.

Flow batteries are constructed and scale up very differently from Li-ion batteries. Most flow batteries consist of two liquid electrolyte tanks and a cell stack area, like the vanadium-based flow battery in Figure 2. During operation, pumps circulate the electrolyte materials through porous electrodes in the cell stacks, which an ion-specific membrane separates to allow electron exchange between the positively charged catholyte and the negatively charged anolyte. The cell stack structure of this battery type is similar to that of a fuel cell, except that a secondary flow battery can re-energize and reuse the electrolyte.

Generally speaking, flow batteries are categorized as either true redox flow batteries or hybrid redox flow batteries. The term *redox* is a contraction of *reduction* and *oxidation* (see "Energy Storage Glossary"), which describes the ion exchange at the core of the flow battery. In a true redox flow battery, the electrolyte chemicals remain dissolved and in solution at all times; in a hybrid redox flow battery, some of the chemicals that store electrochemical energy are plated as a solid.

One of the unique aspects of the true redox battery configuration is that it effectively decouples the battery's energy rating from its power rating. The battery stores energy in the electrolyte itself, meaning that its energy rating increases or decreases in relation to tank volume. The power rating, meanwhile, is a function of cell stack area, meaning that it increases or decreases in relation to the number of cell stacks. By varying tank volume and the number of cell stacks, suppliers can tailor the energy and power ratings of a true redox flow battery to application-specific requirements.

While flow batteries do not provide the energy density of Li-ion devices, they have a much longer lifespan and present fewer safety concerns. Because the reactants are in the electrolyte, and the anode and cathode do not really participate in the chemical reaction, charge-discharge cycles do not age the electrodes, and battery capacity does not degrade. Because only a fraction of the electrolyte volume is in the battery cell stack at any one time, the short-circuit potential of a flow battery is negligible, typically posing no danger to equipment or personnel. Flow batteries also do not present a thermal runaway hazard, and the electrolyte is generally not flammable. Some flow batteries do not even require auxiliary cooling systems because the liquid electrolyte itself regulates temperatures inside the battery cell stack.

Though the hardware that makes up a flow battery is capital intensive, the product itself is relatively simple. Instead of having thousands of battery cells and cell-level management systems, the flow battery is more monolithic and has a lower parts count. Of course, moving parts such as pumps need replacing over the life of the system. In addition, even if the electrolyte is designed to last the service life of the battery, periodic electrolyte maintenance is required to reestablish the proper chemical balance and optimal fluid characteristics.

SDG&E goes with the flow In March 2017, Sumitomo commissioned this 2 MW/8 MWh vanadium redox flow battery system, the largest in the state of California, for San Diego Gas & Electric. Over a 4-year demonstration period, SDG&E will evaluate the technical and economic viability of using this battery technology to regulate frequency and voltage, provide emergency power and shift energy in time to tame the "duck curve."

Courtesy Sumitomo

As is the case with Li-ion batteries, different flow battery chemistries have different profiles in terms of performance, toxicity, cost and so forth. Examples of flow battery chemistries deployed in grid applications include all-iron hybrid redox, vanadium redox, zinc-bromine hybrid redox and zinc-iron hybrid redox.

All-iron hybrid redox. In October 2012, Portland, Oregon–based Energy Storage Systems (ESS) received a nearly $3M ARPA-E award to commercialize a 10 kW/80 kWh all-iron hybrid redox flow battery. Part of the value proposition of an iron-based flow battery is that it uses abundant, low-cost materials that are environmentally benign. When charging, ferrous ions plate out as solid iron on the negative electrode; on discharge, the solid iron dissolves and releases two electrons to the positive electrode. The benefit of using the same element on both sides of the battery is that this eliminates degradation issues associated with cross-contamination of the electrolyte materials. An inherent challenge of an all-iron design is finding ways to improve power density. ESS has fielded its all-iron flow batteries in a variety of grid applications, including a 60 kW/225 kWh microgrid demonstration project at Fort Leonard Wood in Missouri.

Vanadium redox. Among the various flow battery chemistries, vanadium redox is the current market leader. The vanadium redox flow battery is a true redox flow device that uses vanadium-based electrolytes on both the positive and negative sides of the battery. During the discharge cycle, vanadium^{2+} ions oxidize in the negative electrode to form vanadium^{3+}, allowing an electron to migrate to the positive electrode and reduce vanadium^{5+} ions to vanadium^{4+} ions, as shown in Figure 2 (p. 27). While vanadium is more expensive than iron, vanadium electrolytes provide a relatively higher cell voltage, which improves power and energy density. The downside of vanadium's energetic nature is that the sulfuric acid–based electrolytes are corrosive, which exposes battery subcomponents to chemical stresses.

In the late 1980s, the University of New South Wales fielded the first vanadium redox battery. Companies have deployed the technology at scale globally in demonstration projects and in commercial applications for roughly a decade. Active vanadium redox flow battery companies include Sumitomo Electric, a large Japanese conglomerate; Vionx Energy, a Massachusetts-based start-up founded in 2015; and UniEnergy Technologies (UET), a Seattle-based company founded in 2012. In partnership with the US Department of Energy and a number of national laboratories, EPB, a municipally owned utility serving the greater Chattanooga, Tennessee, area, recently deployed a 100 kW/400 kWh vanadium redox flow battery from UET as part of a smart grid demonstration project. EPB will use the battery for renewables integration, voltage regulation, backup power and advanced microgrid operations and energy management.

Zinc-bromine hybrid redox. Exxon developed the zinc-bromine hybrid redox flow battery in the early 1970s. During a charge, zinc is plated as a solid metal on the positive electrode in the battery cell stack; upon discharge, the zinc metal releases two electrons and oxidizes to form $zinc^{2+}$. This chemistry provides not only a high cell voltage, but also a very high energy density. Since 2012, Australia-based Redflow has deployed zinc-bromine hybrid redox flow batteries in a variety of interactive applications, from the grid scale down to the residential scale. In the US, California-based Primus Power recently released the EnergyPod 2, a second-generation zinc-bromine flow battery that is scalable in 25 kW/125 kWh increments up to 25 MW. The architecture that Primus Power uses is unique in that it features a single tank, a single pump and a single flow loop, eliminating components and costs relative to other flow batteries. The resulting battery has a 5-hour discharge duration and a small footprint.

Zinc-iron hybrid redox. Lockheed Martin pioneered the alkaline-based zinc-iron hybrid redox flow battery in the 1980s. In this battery, the catholyte is food-grade iron salt dissolved in an alkaline solution, and the anolyte is battery-grade zinc oxide suspended in an alkaline solution. During charging, zinc plates out of the anolyte onto the anode. While these electrolytes are caustic, they are nontoxic and do not require any exotic materials. Because the electrolyte is not acid based, the battery does not require complex, corrosion-resistant materials for the subcomponents. The resulting battery is less energy dense than an acid-based hybrid redox flow battery, but is also safer and costs less.

The highest-profile zinc-iron flow battery supplier is Austin, Texas–based ViZn Energy Systems. Founded in 2009, the company started deploying its batteries in pilot projects 6 years later. The company has since developed a suite of containerized solutions for commercial, industrial and utility applications that scale up from 100 kW to more than 100 MW and has delivered solutions to customers in the US, Canada, Central America, Europe and India. In March 2017, the company announced that it was supplying a 200 kW/800 kWh battery to a microgrid project at a luxury resort in Nicaragua that will include diesel backup and an 800 kW solar array.

Courtesy NGK Insulators

Sodium-sulfur batteries This 34 MW/224 MWh energy storage system in Japan uses NGK Insulator's NaS batteries for renewables integration. NaS batteries have lost market share in the US in recent years due to rapid price declines for Li-ion technologies.

OTHER TECHNOLOGIES

Though Li-ion and flow batteries account for the majority of the market in stationary applications, other technologies have some track record in the field or are beginning to come to market. Sodium-based chemistries, for example, had some market traction in the emerging grid-scale battery sector before the ascendance of Li-ion. In recent years, zinc-air batteries with aqueous electrolyte have made progress toward commercialization.

Sodium-sulfur batteries. The sodium-sulfur (NaS) battery uses molten sodium as the negative electrode and molten sulfur as the cathode. During discharge, the sodium donates an electron. Advantages of the NaS battery include high energy density, excellent cycle life, affordable materials, high efficiencies and low self-discharge. Disadvantages are that NaS batteries require high internal temperatures to keep electrolytes in a molten state and are not well suited for power applications. This technology is best for applications that require a long (>6 hour) discharge duration.

Tokyo-based NGK Insulators is a century-old Japanese ceramics company known for its insulators and NaS batteries. The company began developing molten-salt NaS batteries in 1984 and successfully commercialized large-scale products by 2002. NGK has deployed its NaS batteries at nearly 200 locations globally to provide a cumulative installation base of 530 MW/3,700 MWh for load leveling, renewables integration, transmission and distribution network management, and microgrid and ancillary services.

Zinc-air batteries. Nonrechargeable zinc-air batteries have a long commercial history, dating back to the 1930s. In the 1970s, companies started building small button-type

Courtesy Eos

Aqueous zinc-based battery Eos manufactures a proprietary zinc hybrid cathode battery with a saltwater electrolyte. The basic building block is a sealed-off static cell submodule rated at 1 kW/4 kWh, which the company aggregates into a 1 MW/4 MWh utility-scale product, the Eos Aurora 1000|4000.

zinc-air batteries to power hearing aids and other medical devices. Because atmospheric air serves as one of the reactants, these batteries offer excellent performance in terms of energy density and specific energy. Miro Zoric, a Slovenian inventor, produced the first rechargeable zinc-air battery in 1996 and began mass production in Singapore for traction applications the following year. Within the last 5 years, rechargeable zinc-air batteries have begun to make inroads in stationary grid applications. While zinc-air batteries cannot match Li-ion batteries for power delivery, they have the potential to be cost competitive and may be able to match the lifespan of flow batteries.

The companies pioneering grid applications for zinc-air batteries are generally small start-ups. For example, Eos, an Edison, New Jersey–based supplier founded in 2008, has developed a 1 MW/4 MWh zinc-air battery system for grid applications. The Eos Aurora 1000|4000 uses a zinc-hybrid cathode battery with an aqueous electrolyte. The company designed the product to provide 5,000 100% discharge cycles, which equates to a 15-year calendar life, and claims that it can undercut the per-kWh cost of Li-ion by as much as 50%. Scottsdale, Arizona–based Fluidic Energy, meanwhile, has been deploying commercial-scale zinc-air batteries in long-duration applications in the developing world as an alternative to lead-acid batteries. Bloomberg New Energy Finance selected Fluidic Energy as one of its ten 2017 New Energy Pioneers.

Market Maturation

The parallels between the nascent energy storage market and the early days of the solar market are striking. Promising and potentially disruptive technologies are moving from research and development to pilot projects and commercial applications. Venture capital–backed start-ups championing new technologies are going toe-to-toe with deep-pocketed multinational corporations heavily invested in somewhat more proven technologies. In spite of steep cost declines, viable business cases are few and far between. Though fielding projects is capital intensive, it is difficult to prove bankability and find financing. A few forward-looking states and utilities are developing and implementing goals, policies and incentives intended to jump-start the market. California and a handful of other states with high energy prices are leading the way in terms of field deployments.

For solar industry veterans, it is déjà vu all over again. The energy storage industry is changing so quickly that technologies and vendors in the ascendance last year could be out of the game next year. As was true in the Wild West days of solar, some pioneers of storage will take arrows and many will fail in order for a few to succeed. The stakes are high, however, as those settlers who succeed in staking a claim will transform the energy industry for decades to come.

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Module-Level Power Electronics Platforms

By Joe Schwartz

Courtesy Namaste Solar and SolarEdge Technologies

The development and deployment of module-level power electronics (MLPE) dates back to the introduction of products such as Ascension Technology's 300 W SunSine microinverter and Netherlands-based NKF Electronics' OK4 inverter line in the late 1990s. Enphase modernized the microinverter platform with the release of its M-175 model in 2008, and also created one of the first system-level MLPE solutions with array aggregation cabling products and its Enphase Enlighten web-based data acquisition and monitoring system. It was the first time that a mainstream PV solution allowed users to easily view and analyze system performance at the module level, and it was an eye-opening experience for solar installers and their customers.

In the decade that has elapsed since Enphase introduced its first-generation microinverter system, the MLPE landscape has slowly been moving toward a higher level of not only product integration but also MLPE-related business partnerships and acquisitions. Examples include SunPower's 2014 acquisition of microinverter manufacturer SolarBridge Technologies, SMA's 2016 acquisition of a 27% stake in dc optimizer vendor Tigo Energy, and the 2017 partnership between Enphase and LG to develop an ac module product. In comparison, SolarEdge Technologies built its product portfolio, which includes dc power optimizers that couple with its string inverters, from the ground up with a core focus on leveraging the benefits of MLPE.

While both technical advancements and business acquisitions and partnerships have been reshaping the evolving MLPE landscape, many industry stakeholders contend that regulatory directives, such as *NEC 2017* Section 690.12,

"Rapid Shutdown of PV Systems on Buildings," have provided MLPE vendors with a huge competitive boost in the US solar market. This article provides company and product information for eight companies that are active in the MLPE ecosystem in the US and beyond.

APsystems

In 2009, Dr. Zhi-Min Ling and Dr. Yuhao Luo founded microinverter systems vendor APsystems in California. It is currently headquartered in Seattle. Ling did postdoctoral work at the University of California, Berkeley, and Luo holds a PhD in electrical engineering from the University of California, Los Angeles. Ling and Luo were colleagues at Solaria prior to founding Altenergy Power, which rebranded as APsystems in 2015. APsystems currently has a global footprint with offices in Australia, China, Europe, Mexico and the US.

APsystem's flagship product, the YC500A microinverter, integrates with two modules and can interconnect with 240 Vac and 208 Vac services. At 240 Vac, it supports a maximum of seven microinverters (14 modules) per 2-pole 20 A branch circuit. With a peak ac power rating of 500 W, the YC500A can accommodate PV modules up to 365 W, but, per the manufacturer, is ideally suited for modules from 280 W to 310 W. The YC500A uses a daisy-chain ac output aggregation approach and power line communication (PLC) between the inverters and the system's energy communication unit gateway. APsystems also offers a slightly higher-power dual-MPPT YC500i microinverter model with an ac output rating of 548 W. The YC500i features an integrated

Courtesy APsystems

Dual module APsystems' recently released YC600 microinverter processes power for two 60- or 72-cell modules via dual independent MPP trackers. The YC600 is California Rule 21 compliant and meets *NEC 2014* and *2017* 690.12 rapid-shutdown requirements.

ground and a trunk cable ac aggregation architecture. It supports ac branch circuits of six microinverters (12 modules) per 2-pole 20 A branch circuit. Both the YC500 series inverters have a maximum input voltage of 55 Vdc and an MPP tracking range of 22 V–45 V.

In 2014, APsystems announced the availability of its 3-phase YC1000-3 microinverter. The YC1000-3 accommodates three modules up to 365 W each or four modules up to 310 W each. Two YC1000-3 models are available that are configured for 3-phase 277/480 V and 120/208 V services. Both models have a 900 Wac continuous power rating and provide phase-balanced and phase-monitored 3-phase ac output. On the dc side, the YC1000 models have a maximum input-voltage rating of 60 Vdc and a MPP tracking range of 16 V–55 V. The YC1000-3 microinverter system uses Zigbee wireless communication and includes an integrated ground.

At Solar Power International in Las Vegas this September, APsystems launched its next-generation YC600 dual-module utility-interactive microinverter. The recently launched microinverter meets the latest grid compliance standards, including UL 1741 SA requirements for California Rule 21. Developed for integration with 60-cell and 72-cell PV modules, the YC600 has a maximum continuous power rating of 548 W and a peak power output of 600 W. It has a maximum input voltage of 55 Vdc and an MPP tracking range of 22 V–45 V. With an ac trunk cable architecture, the system supports ac branch circuits of seven microinverters (14 modules) at 240 Vac and six microinverters (12 modules) at 208 Vac. APsystem's YC600 microinverter meets *NEC 2014* and *2017* Section 690.12 rapid-shutdown requirements. It features Zigbee wireless communication over a mesh network and free system monitoring using APsystem's ArrayApp software. To simplify installation, the platform Energy Communication Unit offers wireless connectivity to the site's internet network. APsystems offers 10- and 25-year warranty options on its microinverters.

APsystems / Seattle, WA / 844.666.7035 / usa.apsystems.com

Chilicon Power

Alexandre Kral and Dr. Christopher Jones founded privately held Chilicon Power in 2010. Both Kral and Jones have degrees in electrical engineering from the University of California, Los Angeles. One unique aspect of Chilicon Power's business is that the company's microinverter and gateway products are not only designed but also manufactured in California.

Chilicon Power's current microinverter is its CP-250E model, which is Rule 21 compliant and can provide reactive power on demand. To provide compatibility with both 60- and 72-cell PV modules, the CP-250E has a wide input-voltage range of 22 V–33.5 V and a maximum input-voltage rating of 60 Vdc. The CP-250E ships from the factory with a maximum continuous output-power level of 250 W, which supports 13-module branch circuits at 208 Vac or 15-module circuits at 240 Vac. Alternately, installers can use the CP-100 gateway to extend the maximum continuous output-power rating to 285 W; in this extended-power mode, the product supports 11-module branch circuits at 208 Vac or 13-module circuits at 240 Vac.

The CP-100 gateway features a 7-inch 800-by-480-pixel LCD touch screen. It uses PLC to interface with the system's microinverters and also offers Wi-Fi, Ethernet and Z-Wave connectivity. The Z-Wave wireless home automation mesh network protocol enables the gateway to interface with smart home security and

State-of-the-art gateway Chilicon Power's CP-100 gateway features a 7-inch 800-by-480-pixel LCD touch screen. In addition to aggregating microinverter production data for cloud-based viewing, the CP-100 offers Z-Wave connectivity, which allows the device to interface with smart home security and energy monitoring devices. Chilicon's gateway also supports zero net export and self-supply modes with the installation of CTs in the site's ac panel.

Courtesy Chilicon Power

energy monitoring devices from vendors such as Aeon Labs. The CP-100 can also provide consumption monitoring and supports zero net export and self-supply modes with the installation of current transformers in the site's ac panel. The gateway can be cloud interconnected or can operate as a standalone unit where connectivity is not available.

Chilicon Power's microinverter system is compatible with storage inverters from vendors including OutBack Power, Magnum Energy and Schneider Electric in ac-coupled configurations. The CP-250E microinverter carries a standard 25-year warranty.

Chilicon Power / Los Angeles, CA / 310.579.2449 / chiliconpower.com

Courtesy Darfon Electronics

Multivoltage options
Darfon Electronic's third-generation microinverter, the G320, is compatible with 60- and 72-cell modules with STC power ratings of up to 350 W. The microinverter platform is available in four voltage options set at the factory (208 V, 220 V, 240 V and 277 V), making the G320 suitable for deployment in residential, commercial and industrial applications.

Darfon Electronics

Founded in May 1997, Darfon Electronics has a design and manufacturing focus that includes a wide range of product groups such as human interface devices, power and energy devices, and integrated components. For example, Darfon is currently the world's number one notebook keyboard manufacturer. The company has a worldwide footprint that includes its global headquarters in Taiwan, as well as facilities in China, the Czech Republic and South Korea. Darfon's US subsidiary, Darfon America, is located in Mountain View, California. Darfon Electronics is one of 16 independently operated companies in the BenQ Group and is traded on the Taiwan Stock Exchange.

Darfon's current microinverter lineup includes two models, the MIG300 and the G320. The MIG300 has a continuous ac output-power rating of 250 W and a peak ac output rating of 260 W. It has a maximum input voltage of 60 Vdc and an MPP tracking range of 24 V–40 V. A trunk cable aggregates up to 16 microinverters per 20 A single-phase ac branch circuit and 24 microinverters per 30 A ac branch circuit. In 2015, Darfon partnered with PV mounting solutions provider IronRidge to develop the ACRak 300. The ACRak combines Darfon's MIG300 microinverter with IronRidge's XR100 XR Rails. To reduce installation time and improve overall installation quality assurance, the ACRak features factory-assembled sections of rail, microinverters and cabling.

Launched at Solar Power International 2016, Darfon's third-generation microinverter, the G320, is compatible with 60- and 72-cell modules with STC power ratings of up to 350 W. The microinverter platform has multiple phase configurations and is available in four voltage options that are set at the factory (208 V, 220 V, 240 V and 277 V), making it suitable for deployment in residential, commercial and industrial applications. The G320 has a maximum input voltage of 60 Vdc, an operating voltage range of 22 Vdc–60 Vdc and an MPPT range of 24 Vdc–45 Vdc. Its continuous power rating is 300 W. Crews can install a maximum of 19 G320s on a 30 A branch circuit in 240 Vac systems and up to 66 (balanced) units on a 30 A 277 Vac circuit. The platform features flexible cabling configurations with or without trunk cabling.

Darfon's microinverters carry a 25-year warranty. Its microinverter platform includes a cloud-based monitoring system. Darfon also offers a lineup of combiner boxes for branch circuit aggregation.

Darfon America / Mountain View, CA / 650.316.6300 / darfonsolar.com

Enphase Energy

Raghu Belur and former Cisco colleague Martin Fornage launched Enphase Energy in 2006 with the vision of creating not only a modern microinverter system that pushed power conversion and optimization into the array at the module level, but also a platform that enabled what was at the time an unprecedented level of system monitoring granularity. Both Belur and Fornage are still actively involved at Enphase, serving in the roles of vice president of products and strategic initiatives and chief technology officer, respectively. Enphase completed its IPO in 2012 and trades on the NASDAQ exchange with stock symbol ENPH. While Enphase has faced challenges in terms of its share price and profitability, it has clearly had the biggest impact of any microinverter system company on the development and advancement of the product class.

In early 2017, Enphase Energy began shipping its next-generation integrated solar, storage and energy management offering, the Enphase Home Energy Solution with IQ.

Courtesy Enphase Energy

AC modules Enphase Energy announced new ac module partners and products in 2017. LG's 60-cell 330 W NeON 2 ACe ac module integrates Enphase's IQ 6+ ACM microinverter. To allow sufficient airflow for cooling, 15 mm separates the microinverter from the module backsheet when deployed.

The system features the company's sixth-generation Enphase IQ Microinverter. The Enphase IQ 6+ Micro supports 60- and 72-cell modules up to 400 Wdc, and the Enphase IQ 6 Micro is compatible with modules up to 330 Wdc. The IQ 6+ model has a maximum input voltage of 62 Vdc and an MPP tracking range of 27 V–45 V. The IQ 6 model has a maximum input voltage of 48 Vdc and an MPP tracking range of 27 V–37 V. At 240 Vac the IQ 6 supports 20 A ac branch circuits of 16 modules, and the IQ 6+ supports 20 A ac branch circuits of 13 modules. The new microinverter design includes a double-insulated noncorroding polymeric enclosure. Enphase IQ 6 microinverters comply with fixed power factor, voltage and frequency ride-through requirements, and meet requirements for distributed solar on utility networks, including Rule 21 in California and Hawaiian Electric Company Rule 14H. Enphase IQ microinverters carry a warranty of 25 years. The C250 model, developed for 480 V 3-phase systems with 72-cell modules, rounds out Enphase's microinverter lineup.

From the start, Enphase has had a system-level engineering approach. In February 2017, it added an energy storage component to its system with the availability of its AC Battery in the US. The AC Battery, a scalable modular energy storage system, is a component of Enphase's Home Energy System, which includes the company's IQ microinverters, Envoy networking hub and gateway, and module-level Enlighten monitoring software. The Enphase AC Battery uses lithium iron phosphate chemistry from Eliiy Power. The cells provide 1.2 kWh of capacity at a nominal voltage of 25.6 Vdc. The AC Battery can discharge to 100% 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 wiring. Its enclosure is NEMA 2 rated for indoor installation in an unoccupied space. The AC Battery carries a 10-year or 7,300-cycle warranty for greater than 80% of its initial rated capacity.

In addition to offering integrated energy storage solutions, Enphase will add new ac module products in 2017, including some produced in partnerships with LG and Jinko Solar. Premiered in July at Intersolar North America in San Francisco, LG's 60-cell 330 Wdc NeON 2 ACe model integrates Enphase's IQ 6+ microinverter for ac module applications. This version, built on the IQ microinverter, includes an inverter-to-module mounting bracket that ships in a collapsed position, permitting optimal shipping density. Once on the rooftop, installers lift up the microinverter to connect the trunk cable, which elevates the microinverter off the back of the module by 15 mm to allow sufficient airflow for cooling. LG's NeON 2 ACe ac module has a continuous ac power rating of 280 W.

Enphase Energy / Petaluma, CA / 877.797.4743 / enphase.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 producing PV charge controllers, component integration panels and system monitoring equipment. In 2014, Sensata Technologies acquired Magnum Energy. Headquartered in Attleboro, Massachusetts, and founded in 1916, today Sensata Technologies is a global provider of sensing, electrical protection, control and power management solutions with operations and business centers in 13 countries.

In 2016, Magnum announced the launch of 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 with Magnum Energy battery-based inverters in ac-coupled mode to taper the charge based on temperature-compensated battery state-of-charge parameters.

Each dual-MPPT MicroGT 500 microinverter supports two PV modules. For the dc side, Magnum recommends a module

Courtesy Magnum Energy

AC coupled Designed for integration with Magnum Energy's battery-based inverter-charger systems, the MicroGT 500 microinverter communicates with Magnum's battery-based inverters in ac-coupled mode to taper the charge based on temperature-compensated battery state-of-charge parameters.

STC power range of 180 W–310 W, but the inverter can accommodate modules of up to 365 W. The microinverter has a maximum input voltage of 55 Vdc and an MPP tracking range of 22 V–45 V. Its rated ac power output is 500 W. Each 20 A breaker supports ac branch circuits of up to seven microinverters (14 modules). The MicroGT 500 is *NEC* 690.12 compliant.

Magnum was the first manufacturer in the US to offer inverter-charger models with split-phase 120/240 Vac output. Its 24 Vdc and 48 Vdc nominal MS-PAE series inverter-chargers connect to the grid for ac battery charging, but do not export power to the utility grid without the integration of an ac-coupled string or microinverter system, such as its MicroGT 500 microinverter. Magnum Energy's MagWeb GT communication unit provides an integrated dashboard of the MicroGT output and MS-PAE Inverter/Charger output, including the battery state of charge.

Magnum Energy / Everett, WA / 425.353.8833 / magnum-dimensions.com

SolarEdge Technologies

Founded in 2006, SolarEdge Technologies offers an end-to-end power electronics solution for distributed power projects. Its system includes module-level power optimizers, module-level monitoring, single- and 3-phase string inverters, and a dual-port inverter for energy storage systems. Guy Sella, currently serving as CEO, and Lior Handelsman, vice president of marketing and product strategy, founded the company. SolarEdge began commercial shipments of its first-generation 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 completed its IPO in 2015 and trades on the NASDAQ exchange with stock symbol SEDG.

SolarEdge offers both module-integrated and module–add-on power optimizers. Its P-Series optimizer is designed to integrate with a single module. The product lineup has five models. The P300 and P320 optimizers are compatible with 60-cell modules and have a maximum input voltage of 48 Vdc and an MPP tracking range of 8 V–48 V. With a maximum input voltage of 60 Vdc, the P370 optimizer is compatible with higher-power 60- and 72-cell modules. Developed for 72- and 96-cell modules, the P400 optimizer has a maximum input voltage of 80 Vdc and an MPP tracking range of 8 V–80 V. Rounding out the series, the P405 optimizer is compatible with the high-voltage and low-current characteristics of thin-film modules. It has a maximum input voltage of 125 Vdc and an MPP tracking range of 12.5 V–105 V. SolarEdge also offers a five-model P-Series Commercial optimizer lineup. The company designed the higher-power P-Series Commercial products for use with two PV modules connected in either series or parallel. All P-Series optimizers are rated for 1,000 V applications, carry a 25-year warranty and are designed specifically for integration with SolarEdge inverters.

SolarEdge's inverter portfolio includes both single- and 3-phase models, as well as a dual-port inverter for projects that require energy storage. In 2017, SolarEdge began shipping a new line of single-phase inverters with its HD-Wave

Commercial and industrial MLPE In addition to offering a full portfolio of dc-optimized power conversion electronics for residential applications, SolarEdge Technologies is targeting commercial, industrial and small utility systems with its new 100 kW dc-optimized inverter systems.

Courtesy SolarEdge Technologies

architecture. The inverter topology allows for high-power conversion efficiencies with a small form factor that is also extremely lightweight. The highest-capacity HD-Wave model, the 7.6 kWac SE7600H-US with disconnect switch, measures 17.7 by 14.6 by 6.8 inches (height by width by depth) and weighs only 26.2 pounds.

In September, SolarEdge and LG announced a partnership targeting the high-end residential and commercial PV rooftop markets in North America. The package combines LG's high-efficiency NeON modules with SolarEdge's string inverters and P370 and P800 power optimizers for residential and commercial installations, respectively. It also includes free module-level monitoring. The residential ac module is compatible with SolarEdge's HD-Wave and StorEdge inverters, as well as its recently launched inverter-integrated electric vehicle chargers.

SolarEdge Technologies / Fremont, CA / 510.498.3200 / solaredge.com

SunPower

Headquartered in San Jose, California, SunPower has achieved an impressive level of not only component but also business integration with its SunPower Equinox system for residential applications. All of the system's components—module, microinverter, racking and monitoring—are SunPower products and come with 25-year product and production warranties.

As a business entity, SunPower dates back to 1985, when its co-founder, Dr. Richard Swanson, a professor of electrical engineering at Stanford University, earned grants from the Electric Power Research Institute and the US Department of Energy to support his research into cost-effective PV cell designs. Additional investments by two venture capital firms led to the incorporation of SunPower in the same year. SunPower held an IPO in 2005 and trades as SPWR on the NASDAQ exchange. In 2011, Total, a French multinational oil and gas company, purchased a 60% stake in the company. In 2014, SunPower acquired Austin, Texas–based microinverter designer and manufacturer SolarBridge Technologies, paving the way for its ac module platform.

The SunPower Equinox system includes SunPower ac modules and factory-installed microinverter, a low-profile InvisiMount rail-based racking and mounting system, and an EnergyLink monitoring platform. SunPower's 96-cell SPR-X22-360-C-AC ac module has a nominal STC rating of 360 W with a +5/-0 power tolerance. Its average module conversion efficiency value is 22.2%. On the ac side, the SPR-X22-360-C-AC module has a maximum continuous power rating of 320 W. It supports single-phase 20 A branch circuits of up to 12 ac modules.

SunPower / San Jose, CA / 800.786.7693 / sunpower.com

End-to-end solutions SunPower has achieved an impressive level of not only component integration but also business integration with its SunPower Equinox system for residential applications. SunPower makes all of the system's components—module, microinverter, racking and monitoring—and they come with 25-year product and production warranties.

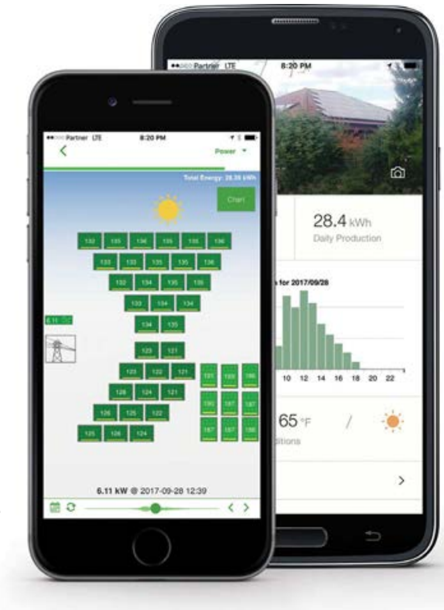
Courtesy SunPower

Tigo Energy

Headquartered in Los Gatos, California, privately held Tigo Energy was founded in 2007. Tigo was one of the first developers of dc optimizer platforms for PV systems and has ramped up its product innovation and release in recent years. The US Department of Energy awarded Tigo $3.5 million in 2012 as part of the SunShot Initiative incubator program. In 2016, SMA Solar Technology acquired a 27% stake in Tigo, opening the door for the development of dc-optimized SMA inverter designs.

Tigo developed its TS4 universal platform for both factory-integrated module applications, where the TS4 platform replaces the standard module junction box, and for retrofit applications, where installers deploy add-on units in the field. The TS4 system base provides a single plug-and-play interface for electronic covers that offer a range of functions: diodes that provide bypass functionality similar to that of conventional modules, except that the diodes are field replaceable; diodes plus monitoring; diodes with monitoring and safety, including *NEC* 690.12 rapid-shutdown compliance, module-level deactivation, automatic or manual shutdown, and overvoltage and overtemperature protection; diodes with monitoring, safety and module-level optimization; and finally, diodes with monitoring, safety, optimization and longer, higher-voltage string configurations. The TS4 platform is CSA listed to UL 1741. This year Tigo Energy has extended its modular TS4 platform design to support 1,500 Vdc PV systems.

In addition to partnering with SMA, Tigo has built relationships with inverter manufacturers thanks to the push to develop systems that meet *NEC 2017* rapid-shutdown



Courtesy Tigo Energy

Universal platform Tigo Energy's TS4 platform uses a universal base that integrates with plug-and-play electronic covers, offering a range of module-level functions such as optimization, safety (including *NEC* 690.12 rapid-shutdown compliance, module-level deactivation, automatic or manual shutdown, and overvoltage and overtemperature protection) and monitoring. Its SMART App allows installers to design, configure, register commission of and monitor Tigo systems from mobile devices.

requirements. This cooperation has allowed companies including ABB, Fronius USA, Ginlong Solis, Kaco new energy, Sungrow USA and Yaskawa–Solectria Solar to certify that their inverter products meet rapid-shutdown requirements when used in conjunction with Tigo's TS4 safety product.

In the fall of 2017, Tigo announced two new products. Its TS4 Duo add-on or retrofit product supports two PV modules connected in series with a combined power of up to 700 W and a combined voltage of up to 90 Vdc. Tigo offers three covers for the Duo product, including TS4-R-O-Duo (optimization), TS4-R-S-Duo (safety), and TS4-R-M-Duo (monitoring). Both the TS4-R-O-Duo and TS4-R-S-Duo are *NEC* 690.12 rapid-shutdown compliant and were pending UL approval at the time of publication. Additionally, Tigo released its new SMART App, which enables installers to design, configure, register commission of and monitor customers' PV systems from the field via a mobile phone.

Tigo's TS4 solution is available as a factory-integrated J box solution from module manufacturers including ET Solar, Jinko Solar, Sunpreme and Trina Solar. Tigo backs its TS4 products with a 25-year warranty.

Tigo Energy / Los Gatos, CA / 408.402.0802 / tigoenergy.com

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60-Cell PV Module

Data Aggregation by Joe Schwartz

For some installations, especially those on space-constrained residential and commercial rooftops, 60-cell modules can offer advantages over larger-format 72- or 96-cell modules. The lower maximum power point and open-circuit voltages of 60-cell modules offer installers more design flexibility when it comes to string sizing for systems that use string inverters. In terms of size, 60- and 72-cell modules generally have approximately the same width, but 60-cell modules are typically about 12 inches shorter than 72-cell modules. A 60-cell module's smaller footprint may allow installers to fit additional modules on rooftops. In addition, 60-cell modules are about 8 pounds lighter than larger-format modules. Combined, the smaller size and lighter weight make 60-cell modules easier for a single installer to handle. Our 2017 60-cell c-Si module specifications table includes electrical and physical specifications for 228 modules that are currently listed as available for US installations, from a total of 26 vendors.

Courtesy Cobalt Power Systems

Specifications

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PV Manufacturer Contact

Auxin Solar / 408.868.4380 / auxinsolar.com

AXITEC / 856.393.9057 / axitecsolar.com/us

Boviet Solar / 877.253.7800 / boviet.com

Canadian Solar / 888.998.7739 / canadiansolar.com

Centrosolar America / 877.348.2555 / centrosolaramerica.com

ET Solar / 925.460.9898 / etsolar.com

Hanwha Q Cells / 949.748.5996 / q-cells.com

Itek Energy / 360.647.9531 / itekenergy.com

JinkoSolar / 415.402.0502 / jinkosolar.com

Kyocera Solar / 800.223.9580 / kyocerasolar.com

LG / 888.865.3026 / lgsolarusa.com

Lumos Solar / 303.449.2394 / lumossolar.com

Mission Solar Energy / 210.531.8600 / missionsolar.com

Mitsubishi Electric / 714.220.2500 / mitsubishielectricsolar.com

Phono Solar / 855.408.9528 / phonosolar.com

Prism Solar / 855.807.7476 / prismsolar.com

Silfab Solar / 905.255.2501 / silfab.ca

SolarTech Universal / 561.440.8000 / solartechuniversal.com

SolarWorld / 503.844.3400 / solarworld-usa.com

Sonali Solar / 888.587.6527 / sonalisolar.com

Sunpreme / 866.245.1110 / sunpreme.com

Trina Solar / 800.696.7114 / trinasolar.com/us

Upsolar / 415.263.9920 / upsolar.com/usa

Vikram Solar USA / 609.686.7771 / vikramsolar.com

WINAICO / 844.946.2426 / winaico.com

Yingli Solar / yinglisolar.com

2017 60-Cell PV Module Specifications

Manufacturer	Model	Cell type	Rated power at STC (Wp)	Rated power tolerance (W or %)	Rated power per sq. ft. (W)	Module efficiency (%)	Max. system voltage UL (Vdc)	Max. power voltage (Vmp)	Max. power current (Imp)	Open-circuit voltage (Voc)	Short-circuit current (Isc)
Auxin Solar	AXN6P610T275	poly	275	0/+3%	15.70	16.9	1,000	32.4	8.49	38.91	9.10
Auxin Solar	AXN6P610T280	poly	280	0/+3%	15.99	17.2	1,000	32.64	8.58	39.24	9.24
Auxin Solar	AXN6P610T285	poly	285	0/+3%	16.27	17.5	1,000	32.89	8.67	39.57	9.38
Auxin Solar	AXN6P610T290	poly	290	0/+3%	16.56	17.8	1,000	33.14	8.75	39.91	9.52
Auxin Solar	AXN6M610T290	mono	290	0/+3%	16.56	17.8	1,000	32	9.06	39.77	9.62
Auxin Solar	AXN6M610T295	mono	295	0/+3%	16.84	18.1	1,000	32.24	9.15	40.11	9.77
Auxin Solar	AXN6M610T300	mono	300	0/+3%	17.13	18.4	1,000	32.48	9.24	40.45	9.91
Auxin Solar	AXN6M610T305	mono	305	0/+3%	17.41	18.7	1,000	32.73	9.32	40.79	10.06
AXITEC	AC-260M/156-60S	mono	260	0/+5 W	14.84	15.98	1,000	30.42	8.6	38.3	9.06
AXITEC	AC-265M/156-60S	mono	265	0/+5 W	15.13	16.29	1,000	30.85	8.65	38.42	9.2
AXITEC	AC-270M/156-60S	mono	270	0/+5 W	15.42	16.6	1,000	30.94	8.8	39.26	9.41
AXITEC	AC-275M/156-60S	mono	275	0/+5 W	15.70	16.9	1,000	31.2	8.86	39.32	9.5
AXITEC	AC-280M/156-60S	mono	280	0/+5 W	15.99	17.21	1,000	31.5	8.95	39.45	9.55
AXITEC	AC-285M/156-60S	mono	285	0/+5 W	16.27	17.52	1,000	31.59	9.09	39.56	9.68
AXITEC	AC-290M/156-60S	mono	290	0/+5 W	16.56	17.83	1,000	31.71	9.16	39.7	9.7
AXITEC	AC-270M/156-60S	mono	270	0/+5 W	15.42	16.6	1,000	30.94	8.8	39.26	9.41
AXITEC	AC-275M/156-60S	mono	275	0/+5 W	15.70	16.9	1,000	31.2	8.86	39.32	9.5
AXITEC	AC-280M/156-60S	mono	280	0/+5 W	15.99	17.21	1,000	31.5	8.95	39.45	9.55
AXITEC	AC-285M/156-60S	mono	285	0/+5 W	16.27	17.52	1,000	31.59	9.09	39.56	9.68
AXITEC	AC-290M/156-60S	mono	290	0/+5 W	16.56	17.83	1,000	31.71	9.16	39.7	9.7
Boviet Solar	BVM6610P-260	poly	260	0/+5 W	14.84	16	1,000	30.6	8.5	37.9	8.98
Boviet Solar	BVM6610P-265	poly	265	0/+5 W	15.13	16.3	1,000	30.8	8.61	38.1	9.07
Boviet Solar	BVM6610P-270	poly	270	0/+5 W	15.42	16.6	1,000	31	8.71	38.3	9.16
Boviet Solar	BVM6610P-275	poly	275	0/+5 W	15.70	16.9	1,000	31.2	8.82	38.5	9.25
Boviet Solar	BVM6610P-280	poly	280	0/+5 W	15.99	17.2	1,000	31.4	8.92	38.7	9.34
Boviet Solar	BVM6610M-280	mono	280	0/+5 W	15.99	17.2	1,000	31.7	8.84	38.8	9.4
Boviet Solar	BVM6610M-285	mono	285	0/+5 W	16.27	17.5	1,000	32	8.91	39.2	9.47
Boviet Solar	BVM6610M-290	mono	290	0/+5 W	16.56	17.8	1,000	32.3	8.98	39.6	9.54
Boviet Solar	BVM6610M-295	mono	295	0/+5 W	16.84	18.1	1,000	32.6	9.05	40	9.62
Canadian Solar	CS6K-260P-FG[1]	poly	260	0/+5 W	14.66	15.81	1,000	30.4	8.56	37.5	9.12
Canadian Solar	CS6K-265P-FG[1]	poly	265	0/+5 W	14.95	16.11	1,000	30.6	8.66	37.7	9.23
Canadian Solar	CS6K-270P-FG[1]	poly	270	0/+5 W	15.23	16.42	1,000	30.8	8.75	37.9	9.32
Canadian Solar	CS6K-275P-FG[1]	poly	275	0/+5 W	15.51	16.72	1,000	31	8.88	38	9.45
Canadian Solar	CS6K-265P	poly	265	0/+5 W	15.01	16.19	1,000	30.6	8.66	37.7	9.23
Canadian Solar	CS6K-270P	poly	270	0/+5 W	15.30	16.5	1,000	30.8	8.75	37.9	9.32
Canadian Solar	CS6K-275P	poly	275	0/+5 W	15.58	16.8	1,000	31	8.88	38	9.45
Canadian Solar	CS6K-275M	mono	275	0/+5 W	15.58	16.8	1,500	31.3	8.8	38.3	9.31
Canadian Solar	CS6K-280M	mono	280	0/+5 W	15.86	17.11	1,500	31.5	8.89	38.5	9.43

Footnote Key

Representative models shown for vendors with large numbers of SKUs.

[1] Double-glass module

[2] Double-glass module, bifacial

DNR = Does not report

Nominal operating cell temp. (°C)	Pmp temp. coeff. (%/°C)	Voc temp. coeff. (%/°C)	Isc temp. coeff. (%/°C)	Series fuse rating (A)	Fire type	Frame color	Backsheet color	Length (in.)	Width (in.)	Depth (in.)	Weight (lbs.)	Materials warranty (yrs.)	Power warranty (type, % at year)
47	-0.42	-0.32	0.05	15	2	slv/blk	wht/blk	64.57	39.06	1.57	39.8	10	linear, 25
47	-0.42	-0.32	0.05	15	2	slv/blk	wht/blk	64.57	39.06	1.57	39.8	10	linear, 25
47	-0.42	-0.32	0.05	15	2	slv/blk	wht/blk	64.57	39.06	1.57	39.8	10	linear, 25
47	-0.42	-0.32	0.05	15	2	slv/blk	wht/blk	64.57	39.06	1.57	39.8	10	linear, 25
46.7	-0.38	-0.28	0.04	15	2	slv/blk	wht/blk	64.57	39.06	1.57	41.9	10	linear, 25
46.7	-0.38	-0.28	0.04	15	2	slv/blk	wht/blk	64.57	39.06	1.57	41.9	10	linear, 25
46.7	-0.38	-0.28	0.04	15	2	slv/blk	wht/blk	64.57	39.06	1.57	41.9	10	linear, 25
46.7	-0.38	-0.28	0.04	15	2	slv/blk	wht/blk	64.57	39.06	1.57	41.9	10	linear, 25
45±2	-0.40	-0.30	0.04	15	1	black	black	64.57	39.06	1.38	39.68	12	linear, 85 @ 25
45±2	-0.40	-0.30	0.04	15	1	black	black	64.57	39.06	1.38	39.68	12	linear, 85 @ 25
45±2	-0.40	-0.30	0.04	15	1	black	black	64.57	39.06	1.38	39.68	12	linear, 85 @ 25
45±2	-0.40	-0.30	0.04	15	1	black	black	64.57	39.06	1.38	39.68	12	linear, 85 @ 25
45±2	-0.40	-0.30	0.04	15	1	black	black	64.57	39.06	1.38	39.68	12	linear, 85 @ 25
45±2	-0.40	-0.30	0.04	15	1	black	black	64.57	39.06	1.38	39.68	12	linear, 85 @ 25
45±2	-0.40	-0.30	0.04	15	1	black	black	64.57	39.06	1.38	39.68	12	linear, 85 @ 25
45±2	-0.40	-0.30	0.04	15	1	silver	white	64.57	39.06	1.38	39.68	12	linear, 85 @ 25
45±2	-0.40	-0.30	0.04	15	1	silver	white	64.57	39.06	1.38	39.68	12	linear, 85 @ 25
45±2	-0.40	-0.30	0.04	15	1	silver	white	64.57	39.06	1.38	39.68	12	linear, 85 @ 25
45±2	-0.40	-0.30	0.04	15	1	silver	white	64.57	39.06	1.38	39.68	12	linear, 85 @ 25
45±2	-0.40	-0.30	0.04	15	1	silver	white	64.57	39.06	1.38	39.68	12	linear, 85 @ 25
45±2	-0.41	-0.31	0.05	15	1	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.7 @ 25
45±2	-0.41	-0.31	0.05	15	1	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.7 @ 25
45±2	-0.41	-0.31	0.05	15	1	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.7 @ 25
45±2	-0.41	-0.31	0.05	15	1	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.7 @ 25
45±2	-0.41	-0.31	0.05	15	1	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.7 @ 25
45±2	-0.40	-0.32	0.06	15	1	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.7 @ 25
45±2	-0.40	-0.32	0.06	15	1	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.7 @ 25
45±2	-0.40	-0.32	0.06	15	1	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.7 @ 25
45±2	-0.40	-0.32	0.06	15	1	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.7 @ 25
45±2	-0.41	-0.31	0.05	15	3/13	frameless	clear	65.3	39.1	0.23	50.7	10	linear, 83 @ 30
45±2	-0.41	-0.31	0.05	15	3/13	frameless	clear	65.3	39.1	0.23	50.7	10	linear, 83 @ 30
45±2	-0.41	-0.31	0.05	15	3/13	frameless	clear	65.3	39.1	0.23	50.7	10	linear, 83 @ 30
45±2	-0.41	-0.31	0.05	15	3/13	frameless	clear	65.3	39.1	0.23	50.7	10	linear, 83 @ 30
45±2	-0.41	-0.31	0.05	15	1	black	white	65	39.1	1.57	40.1	10	linear, 80.7 @ 25
45±2	-0.41	-0.31	0.05	15	1	black	white	65	39.1	1.57	40.1	10	linear, 80.7 @ 25
45±2	-0.41	-0.31	0.05	15	1	black	white	65	39.1	1.57	40.1	10	linear, 80.7 @ 25
45±2	-0.41	-0.31	0.05	15	1	black	white	65	39.1	1.57	40.1	10	linear, 80.2 @ 25
45±2	-0.41	-0.31	0.05	15	1	black	white	65	39.1	1.57	40.1	10	linear, 80.2 @ 25

2017 60-Cell PV Module Specifications

Manufacturer	Model	Cell type	Rated power at STC (Wp)	Rated power tolerance (W or %)	Rated power per sq. ft. (W)	Module efficiency (%)	Max. system voltage UL (Vdc)	Max. power voltage (Vmp)	Max. power current (Imp)	Open-circuit voltage (Voc)	Short-circuit current (Isc)
Canadian Solar	CS6K-285M	mono	285	0/+5 W	16.15	17.41	1,500	31.7	8.98	38.6	9.51
Canadian Solar	CS6K-270M Black	mono	270	0/+5 W	15.30	16.5	1,000	31.1	8.67	38.2	9.19
Canadian Solar	CS6K-275M Black	mono	275	0/+5 W	15.58	16.8	1,000	31.3	8.8	38.3	9.31
Canadian Solar	CS6K-280M Black	mono	280	0/+5 W	15.86	17.11	1,000	31.5	8.89	38.5	9.43
Canadian Solar	CS6K-290MS	mono	290	0/+5 W	16.43	17.72	1,000	32.1	9.05	39.3	9.67
Canadian Solar	CS6K-295MS	mono	295	0/+5 W	16.71	18.02	1,000	32.3	9.14	39.5	9.75
Canadian Solar	CS6K-300MS	mono	300	0/+5 W	17.00	18.33	1,000	32.5	9.24	39.7	9.83
Centrosolar America	CP60 260BW	poly	260	0/+5 W	14.85	16	1,000	30.93	8.43	37.67	8.83
Centrosolar America	CP60 270BW	poly	270	0/+5 W	15.42	16.6	1,000	31.04	8.73	38.39	9.15
Centrosolar America	CM60 265BB	mono	265	0/+5 W	15.13	16.3	1,000	30.98	8.56	38.29	9.08
Centrosolar America	CM60 270BB	mono	270	0/+5 W	15.42	16.6	1,000	31.15	8.67	38.37	9.23
Centrosolar America	CM60 275BB	mono	275	0/+5 W	15.70	16.9	1,000	31.43	8.75	38.74	9.3
Centrosolar America	CM60 280BB	mono	280	0/+5 W	15.99	17.2	1,000	31.69	8.84	39.05	9.39
Centrosolar America	CM60 285BB	mono	285	0/+5 W	16.27	17.5	1,000	31.81	8.96	39.16	9.49
Centrosolar America	CM60 290BB	mono	290	0/+5 W	16.56	17.8	1,000	32.02	9.06	39.31	9.59
Centrosolar America	BM60 260BB	mono	260	0/+5 W	15.02	15.51	1,000	30.7	8.56	38.9	9.18
Centrosolar America	BM60 265BB	mono	265	0/+5 W	15.31	15.81	1,000	30.8	8.69	39	9.31
Centrosolar America	BM60 270BB	mono	270	0/+5 W	15.60	16.1	1,000	30.9	8.81	39.2	9.44
Centrosolar America	BM60 275BB	mono	275	0/+5 W	15.89	16.4	1,000	31	8.94	39.4	9.58
Centrosolar America	BM60 280BB	mono	280	0/+5 W	16.17	17	1,000	31.3	9.2	39.7	9.84
Centrosolar America	BM60 285BB	mono	285	0/+5 W	16.46	17.3	1,000	31.4	9.33	39.9	9.97
ET Solar	ET-P660260BB	poly	260	0/+5 W	14.84	15.98	1,000	30.59	8.5	38.16	9.07
ET Solar	ET-P660265BB	poly	265	0/+5 W	15.13	16.29	1,000	30.74	8.62	38.29	9.24
ET Solar	ET-P660270BB	poly	270	0/+5 W	15.42	16.6	1,000	30.97	8.72	38.72	9.31
ET Solar	ET-P660275BB	poly	275	0/+5 W	15.70	16.9	1,000	31.32	8.78	38.92	9.35
ET Solar	ET-P660265WW/WB	poly	265	0/+5 W	15.13	16.29	1,000	30.74	8.62	38.29	9.24
ET Solar	ET-P660270WW/WB	poly	270	0/+5 W	15.42	16.6	1,000	30.97	8.72	38.72	9.31
ET Solar	ET-P660275WW/WB	poly	275	0/+5 W	15.70	16.9	1,000	31.32	8.78	38.92	9.35
ET Solar	ET-P660280WW/WB	poly	280	0/+5 W	15.99	17.21	1,000	31.68	8.84	39.16	9.47
ET Solar	ET-M660265BB	mono	265	0/+5 W	15.13	16.29	1,000	30.64	8.65	38.29	9.1
ET Solar	ET-M660270BB	mono	270	0/+5 W	15.42	16.6	1,000	30.83	8.76	38.68	9.12
ET Solar	ET-M660275BB	mono	275	0/+5 W	15.70	16.9	1,000	30.97	8.88	39.08	9.14
ET Solar	ET-M660280BB	mono	280	0/+5 W	15.99	17.21	1,000	31.43	8.91	39.12	9.29
ET Solar	ET-M660285BB	mono	285	0/+5 W	16.27	17.52	1,000	31.85	8.95	39.18	9.46
ET Solar	ET-M660275WW/WB	mono	275	0/+5 W	15.70	16.9	1,000	30.97	8.88	39.08	9.14
ET Solar	ET-M660280WW/WB	mono	280	0/+5 W	15.99	17.21	1,000	31.43	8.91	39.12	9.29
ET Solar	ET-M660285WW/WB	mono	285	0/+5 W	16.27	17.52	1,000	31.85	8.95	39.18	9.46
ET Solar	ET-M660290WW/WB	mono	290	0/+5 W	16.56	17.83	1,000	32.12	9.03	39.68	9.59

Footnote Key

Representative models shown for vendors with large numbers of SKUs.

[1] Double-glass module

[2] Double-glass module, bifacial

DNR = Does not report

Nominal operating cell temp. (°C)	Pmp temp. coeff. (%/°C)	Voc temp. coeff. (%/°C)	Isc temp. coeff. (%/°C)	Series fuse rating (A)	Fire Type	Frame color	Backsheet color	Length (in.)	Width (in.)	Depth (in.)	Weight (lbs.)	Materials warranty (yrs.)	Power warranty (type, % at year)
45±2	-0.41	-0.31	0.05	15	1	black	white	65	39.1	1.57	40.1	10	linear, 82.5 @ 25
45±2	-0.41	-0.31	0.05	15	1	black	black	65	39.1	1.57	40.1	10	linear, 80.2 @ 25
45±2	-0.41	-0.31	0.05	15	1	black	black	65	39.1	1.57	40.1	10	linear, 80.2 @ 25
45±2	-0.41	-0.31	0.05	15	1	black	black	65	39.1	1.57	40.1	10	linear, 80.2 @ 25
45±2	-0.39	-0.30	0.05	15	1	black	white	65	39.1	1.57	40.1	10	linear, 80.2 @ 25
45±2	-0.39	-0.30	0.05	15	1	black	white	65	39.1	1.57	40.1	10	linear, 80.2 @ 25
45±2	-0.39	-0.30	0.05	15	1	black	white	65	39.1	1.57	40.1	10	linear, 80.2 @ 25
44±2	-0.42	-0.31	0.05	15	1	black	white	64.55	39.07	1.57	40.8	10	linear, 82.5 @ 25
44±2	-0.42	-0.31	0.05	15	1	black	white	64.55	39.07	1.57	40.8	10	linear, 82.5 @ 25
46±2	-0.43	-0.32	0.04	15	1	black	black	64.55	39.07	1.57	40.8	10	linear, 82.5 @ 25
46±2	-0.43	-0.32	0.04	15	1	black	black	64.55	39.07	1.57	40.8	10	linear, 82.5 @ 25
46±2	-0.43	-0.32	0.04	15	1	black	black	64.55	39.07	1.57	40.8	10	linear, 82.5 @ 25
46±2	-0.43	-0.32	0.04	15	1	black	black	64.55	39.07	1.57	40.8	10	linear, 82.5 @ 25
46±2	-0.43	-0.32	0.04	15	1	black	black	64.55	39.07	1.57	40.8	10	linear, 82.5 @ 25
46±2	-0.43	-0.32	0.04	15	1	black	black	64.55	39.07	1.57	40.8	10	linear, 82.5 @ 25
48	-0.43	-0.31	0.04	16	1	black	black	65.95	37.8	1.3	39.7	20	linear, 82.5 @ 25
48	-0.43	-0.31	0.04	16	1	black	black	65.95	37.8	1.3	39.7	20	linear, 82.5 @ 25
48	-0.43	-0.31	0.04	16	1	black	black	65.95	37.8	1.3	39.7	20	linear, 82.5 @ 25
48	-0.44	-0.31	0.04	25	1	black	black	65.95	37.8	1.3	39.7	20	linear, 82.5 @ 25
48	-0.44	-0.31	0.04	25	1	black	black	65.95	37.8	1.3	39.7	20	linear, 82.5 @ 25
48	-0.44	-0.31	0.04	25	1	black	black	65.95	37.8	1.3	39.7	20	linear, 82.5 @ 25
45±2	-0.41	-0.34	0.04	15	1	black	black	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.41	-0.34	0.04	15	1	black	black	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.41	-0.34	0.04	15	1	black	black	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.41	-0.34	0.04	15	1	black	black	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.41	-0.34	0.04	15	1	slv/blk	white	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.41	-0.34	0.04	15	1	slv/blk	white	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.41	-0.34	0.04	15	1	slv/blk	white	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.41	-0.34	0.04	15	1	slv/blk	white	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.43	-0.30	0.06	15	1	black	black	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.43	-0.30	0.06	15	1	black	black	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.43	-0.30	0.06	15	1	black	black	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.43	-0.30	0.06	15	1	black	black	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.43	-0.30	0.06	15	1	black	black	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.42	-0.30	0.05	15	1	slv/blk	white	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.42	-0.30	0.05	15	1	slv/blk	white	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.42	-0.30	0.05	15	1	slv/blk	white	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±2	-0.42	-0.30	0.05	15	1	slv/blk	white	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25

2017 60-Cell PV Module Specifications

Manufacturer	Model	Cell type	Rated power at STC (Wp)	Rated power tolerance (W or %)	Rated power per sq. ft. (W)	Module efficiency (%)	Max. system voltage UL (Vdc)	Max. power voltage (Vmp)	Max. power current (Imp)	Open-circuit voltage (Voc)	Short-circuit current (Isc)
ET Solar	ET-M660295WW/WB	mono	295	0/+5 W	16.84	18.13	1,000	32.35	9.12	39.78	9.65
Hanwha Q Cells	Q.Plus BFR-G4.1-280	mono	280	0/+5 W	15.58	16.8	1,000	31.67	8.84	38.97	9.41
Hanwha Q Cells	Q.Plus BFR-G4.1-285	mono	285	0/+5 W	15.85	17.1	1,000	31.99	8.91	39.22	9.46
Hanwha Q Cells	Q.Plus BFR-G4.1-290	mono	290	0/+5 W	16.13	17.4	1,000	32.29	8.98	39.48	9.52
Hanwha Q Cells	Q.Peak BLK-G4.1-285	mono	285	0/+5 W	15.85	17.1	1,000	31.73	8.98	38.91	9.56
Hanwha Q Cells	Q.Peak BLK-G4.1-290	mono	290	0/+5 W	16.13	17.4	1,000	31.96	9.07	39.19	9.63
Hanwha Q Cells	Q.Peak BLK-G4.1-295	mono	295	0/+5 W	16.41	17.7	1,000	32.19	9.17	39.48	9.7
Hanwha Q Cells	Q.Peak-G4.1-300	mono	300	0/+5 W	16.69	18	1,000	32.41	9.26	39.76	9.77
Hanwha Q Cells	Q.Peak-G4.1-305	mono	305	0/+5 W	16.97	18.3	1,000	32.62	9.35	40.05	9.84
Itek Energy	295 SE	mono	295	-2/+2%	16.35	17.59	1,000	32.8	8.9	39.7	9.6
Itek Energy	300 SE	mono	300	-2/+2%	16.62	17.89	1,000	32.9	9	39.8	9.7
Itek Energy	305 SE	mono	305	-2/+2%	16.90	18.19	1,000	33.1	9.1	40	9.8
Itek Energy	310 SE	mono	310	-2/+2%	17.18	18.49	1,000	33.2	9.2	39.7	9.9
Itek Energy	315 SE	mono	315	-2/+2%	17.45	18.78	1,000	33.3	9.3	39.8	10
JinkoSolar	JKM250P-B	poly	250	0/+3%	14.19	15.27	1,000	30.5	8.2	37.7	8.85
JinkoSolar	JKM255P-B	poly	255	0/+3%	14.47	15.58	1,000	30.8	8.28	38	8.92
JinkoSolar	JKM260P-B	poly	260	0/+3%	14.75	15.89	1,000	31.1	8.37	38.1	8.98
JinkoSolar	JKM265P-B	poly	265	0/+3%	15.04	16.19	1,000	31.4	8.44	38.6	9.03
JinkoSolar	JKM255PP	poly	255	0/+3%	14.47	15.58	1,000	30.8	8.28	38	8.92
JinkoSolar	JKM260PP	poly	260	0/+3%	14.75	15.89	1,000	31.1	8.37	38.1	8.98
JinkoSolar	JKM265PP	poly	265	0/+3%	15.04	16.19	1,000	31.4	8.44	38.6	9.03
JinkoSolar	JKM270PP	poly	270	0/+3%	15.32	16.5	1,000	31.7	8.52	38.8	9.09
JinkoSolar	JKMS255P	poly	255	0/+3%	14.47	15.58	1,000	30.8	8.28	38	8.92
JinkoSolar	JKMS260P	poly	260	0/+3%	14.75	15.89	1,000	31.1	8.37	38.1	8.98
JinkoSolar	JKMS265P	poly	265	0/+3%	15.04	16.19	1,000	31.4	8.44	38.6	9.03
JinkoSolar	JKMS270P	poly	270	0/+3%	15.32	16.5	1,000	31.7	8.52	38.8	9.09
Kyocera Solar	KU260-6MCA	poly	260	0/+5%	14.68	DNR	1,000	31	8.39	38.3	9.09
Kyocera Solar	KU265-6MCA	poly	265	0/+5%	14.96	DNR	1,000	31	8.55	38.3	9.26
Kyocera Solar	KU270-6MCA	poly	270	0/+5%	15.24	DNR	1,000	31	8.71	38.3	9.43
LG	LG300N1K-G4	mono	300	0/+3%	16.99	18.3	1,000	32.5	9.26	39.7	9.7
LG	LG305N1K-G4	mono	305	0/+3%	17.28	18.6	1,000	32.9	9.28	40.1	9.74
LG	LG315N1K-G4	mono	315	0/+3%	17.84	18.4	1,000	32.9	9.58	40.7	10.15
LG	LG320N1K-G4	mono	320	0/+3%	18.13	18.7	1,000	33.3	9.62	40.8	10.19
LG	LG305N1C-G4	mono	305	0/+3%	17.28	18.6	1,000	32.5	9.39	40.1	9.93
LG	LG310N1C-G4	mono	310	0/+3%	17.56	18.9	1,000	32.8	9.45	40.4	9.96
LG	LG315N1C-G4	mono	315	0/+3%	17.84	19.2	1,000	33.2	9.5	40.6	10.02
LG	LG320N1C-G4	mono	320	0/+3%	18.13	19.5	1,000	33.6	9.53	40.9	10.05
LG	LG325N1C-A5	mono	325	0/+3%	17.63	19	1,000	33.3	9.77	40.8	10.41

Footnote Key

Representative models shown for vendors with large numbers of SKUs.

[1] Double-glass module

[2] Double-glass module, bifacial

DNR = Does not report

Nominal operating cell temp. (°C)	Pmp temp. coeff. (%/°C)	Voc temp. coeff. (%/°C)	Isc temp. coeff. (%/°C)	Series fuse rating (A)	Fire Type	Frame color	Backsheet color	Length (in.)	Width (in.)	Depth (in.)	Weight (lbs.)	Materials warranty (yrs.)	Power warranty (type, % at year)
45±2	-0.42	-0.30	0.05	15	1	slv/blk	white	64.57	39.06	1.38	40.79	10	linear, 81.9 @ 25
45±3	-0.40	-0.29	0.04	20	1	black	white	65.7	39.4	1.26	41.45	12	linear, 83 @ 25
45±3	-0.40	-0.29	0.04	20	1	black	white	65.7	39.4	1.26	41.45	12	linear, 83 @ 25
45±3	-0.40	-0.29	0.04	20	1	black	white	65.7	39.4	1.26	41.45	12	linear, 83 @ 25
45±3	-0.39	-0.28	0.04	20	1	black	black	65.7	39.4	1.26	41.45	12	linear, 83.6 @ 25
45±3	-0.39	-0.28	0.04	20	1	black	black	65.7	39.4	1.26	41.45	12	linear, 83.6 @ 25
45±3	-0.39	-0.28	0.04	20	1	black	black	65.7	39.4	1.26	41.45	12	linear, 83.6 @ 25
45±3	-0.39	-0.28	0.04	20	1	black	white	65.7	39.4	1.26	41.45	12	linear, 83.6 @ 25
45±3	-0.39	-0.28	0.04	20	1	black	white	65.7	39.4	1.26	41.45	12	linear, 83.6 @ 25
45.01	-0.39	-0.29	0.04	15	1	silver	white	65.94	39.41	1.57	41	12	linear, 80 @ 25
45.01	-0.39	-0.29	0.04	15	1	silver	white	65.94	39.41	1.57	41	12	linear, 80 @ 25
45.01	-0.39	-0.29	0.04	15	1	silver	white	65.94	39.41	1.57	41	12	linear, 80 @ 25
45.01	-0.39	-0.29	0.04	15	1	silver	white	65.94	39.41	1.57	41	12	linear, 80 @ 25
45.01	-0.39	-0.29	0.04	15	1	silver	white	65.94	39.41	1.57	41	12	linear, 80 @ 25
45±2	-0.41	-0.31	0.06	15	1	black	black	64.97	39.06	1.57	41.9	10	linear, 80 @ 25
45±2	-0.41	-0.31	0.06	15	1	black	black	64.97	39.06	1.57	41.9	10	linear, 80 @ 25
45±2	-0.41	-0.31	0.06	15	1	black	black	64.97	39.06	1.57	41.9	10	linear, 80 @ 25
45±2	-0.41	-0.31	0.06	15	1	black	black	64.97	39.06	1.57	41.9	10	linear, 80 @ 25
45±2	-0.40	-0.30	0.06	15	1	slv/blk	white	64.97	39.06	1.57	41.9	10	linear, 80 @ 25
45±2	-0.40	-0.30	0.06	15	1	slv/blk	white	64.97	39.06	1.57	41.9	10	linear, 80 @ 25
45±2	-0.40	-0.30	0.06	15	1	slv/blk	white	64.97	39.06	1.57	41.9	10	linear, 80 @ 25
45±2	-0.40	-0.30	0.06	15	1	slv/blk	white	64.97	39.06	1.57	41.9	10	linear, 80 @ 25
45±2	-0.40	-0.30	0.06	15	1	slv/blk	white	64.97	39.06	1.57	41.9	10	linear, 80 @ 25
45±2	-0.40	-0.30	0.06	15	1	slv/blk	white	64.97	39.06	1.57	41.9	10	linear, 80 @ 25
45±2	-0.40	-0.30	0.06	15	1	slv/blk	white	64.97	39.06	1.57	41.9	10	linear, 80 @ 25
45±2	-0.40	-0.30	0.06	15	1	slv/blk	white	64.97	39.06	1.57	41.9	10	linear, 80 @ 25
45	-0.45	-0.36	0.06	15	2	black	white	65.43	38.98	1.81	41.9	10	linear, 80 @ 25
45	-0.45	-0.36	0.06	15	2	black	white	65.43	38.98	1.81	41.9	10	linear, 80 @ 25
45	-0.46	-0.36	0.06	15	2	black	white	65.43	38.98	1.81	41.9	10	linear, 80 @ 25
45±3	-0.38	-0.28	0.03	20	2	black	black	64.57	39.37	1.57	37.48	12	linear, 83.6 @ 25
45±3	-0.38	-0.28	0.03	20	2	black	black	64.57	39.37	1.57	37.48	12	linear, 83.6 @ 25
45±3	-0.38	-0.28	0.03	20	2	black	black	64.57	39.37	1.57	37.48	12	linear, 83.6 @ 25
45±3	-0.38	-0.28	0.03	20	2	black	black	64.57	39.37	1.57	37.48	12	linear, 83.6 @ 25
46±3	-0.38	-0.28	0.03	20	2	black	white	64.57	39.37	1.57	37.48	12	linear, 83.6 @ 25
46±3	-0.38	-0.28	0.03	20	2	black	white	64.57	39.37	1.57	37.48	12	linear, 83.6 @ 25
46±3	-0.38	-0.28	0.03	20	2	black	white	64.57	39.37	1.57	37.48	12	linear, 83.6 @ 25
46±3	-0.38	-0.28	0.03	20	2	black	white	64.57	39.37	1.57	37.48	12	linear, 83.6 @ 25
45±3	-0.37	-0.27	0.03	20	1	black	white	66.38	40	1.57	39.7	12	linear, 84.8 @ 25

2017 60-Cell PV Module Specifications

Manufacturer	Model	Cell type	Rated power at STC (Wp)	Rated power tolerance (W or %)	Rated power per sq. ft. (W)	Module efficiency (%)	Max. system voltage UL (Vdc)	Max. power voltage (Vmp)	Max. power current (Imp)	Open-circuit voltage (Voc)	Short-circuit current (Isc)
LG	LG330N1C-A5	mono	330	0/+3%	17.90	19.3	1,000	33.7	9.8	40.9	10.45
LG	LG335N1C-A5	mono	335	0/+3%	18.17	19.6	1,000	34.1	9.83	41	10.49
LG	LG350Q1C-A5	mono	350	0/+3%	18.83	20.3	1,000	36.1	9.7	42.7	10.77
LG	LG355Q1C-A5	mono	355	0/+3%	19.09	20.6	1,000	36.3	9.79	42.7	10.78
LG	LG360Q1C-A5	mono	360	0/+3%	19.36	20.8	1,000	36.5	9.87	42.7	10.79
LG	LG365Q1C-A5	mono	365	0/+3%	19.63	21.1	1,000	36.7	9.95	42.8	10.8
Lumos Solar	LSX275 [1]	mono	275	0/+3%	14.75	15.9	1,000	31.71	8.68	39.03	9.02
Lumos Solar	LSX280	mono	280	0/+3%	15.01	16.2	1,000	31.97	8.76	39.37	9.25
Lumos Solar	LSX285 [1]	mono	285	0/+3%	15.28	16.5	1,000	32.24	8.84	39.71	9.5
Lumos Solar	GSXBiFi300 [2]	mono	300	0/+5 W	16.39	19.4	1,000	32.48	9.24	40.45	9.91
Mission Solar Energy	MSE270SO5K	mono	270	0/+3%	15.09	16.26	1,000	30.79	8.78	37.64	9.28
Mission Solar Energy	MSE275SO5K	mono	275	0/+3%	15.37	16.55	1,000	30.95	8.89	37.82	9.34
Mission Solar Energy	MSE280SO5K	mono	280	0/+3%	15.65	16.85	1,000	31.37	8.93	38.22	9.37
Mission Solar Energy	MSE270SO5T	mono	270	0/+3%	15.09	16.26	1,000	31.28	8.64	38.21	9.09
Mission Solar Energy	MSE275SO5T	mono	275	0/+3%	15.37	16.55	1,000	31.55	8.72	38.45	9.17
Mission Solar Energy	MSE280SO5T	mono	280	0/+3%	15.65	16.85	1,000	31.87	8.79	38.6	9.27
Mission Solar Energy	MSE295SQ5K	mono	295	0/+3%	16.49	17.82	1,000	32.19	9.2	39.38	9.73
Mission Solar Energy	MSE300SQ5K	mono	300	0/+3%	16.77	18.06	1,000	32.38	9.27	39.72	9.77
Mission Solar Energy	MSE305SQ5K	mono	305	0/+3%	17.05	18.36	1,000	32.61	9.36	39.95	9.81
Mission Solar Energy	MSE290SQ5T	mono	290	0/+3%	16.21	17.45	1,000	32.54	8.95	39.81	9.44
Mission Solar Energy	MSE295SQ5T	mono	295	0/+3%	16.49	17.75	1,000	32.72	9.03	40.11	9.52
Mission Solar Energy	MSE300SQ5T	mono	300	0/+3%	16.77	18.05	1,000	32.8	9.17	40.18	9.61
Mitsubishi Electric	PV-MJE265FB	mono	265	0/+5%	14.97	16.1	1,000	30.9	8.59	38	9.1
Mitsubishi Electric	PV-MJE275FB	mono	275	0/+5%	15.53	16.7	1,000	31.3	8.79	38.3	9.36
Mitsubishi Electric	PV-MJE275FB-B	mono	275	0/+5%	15.53	16.7	1,000	31.3	8.79	38.3	9.36
Mitsubishi Electric	PV-MJE285FB-B	mono	285	0/+5%	16.10	17	1,000	31.5	8.9	38.4	9.5
Phono Solar	PS255PGF-22/U[1]	poly	255	0/+5 W	14.27	15.36	1,000	30.4	8.39	37.9	8.8
Phono Solar	PS260PGF-22/U[1]	poly	260	0/+5 W	14.55	15.66	1,000	30.56	8.51	38	8.9
Phono Solar	PS265PGF-22/U[1]	poly	265	0/+5 W	14.83	15.96	1,000	30.78	8.61	38.1	9
Phono Solar	PS270PGF-22/U[1]	poly	270	0/+5 W	15.11	16.26	1,000	31	8.71	38.2	9.1
Phono Solar	PS280MGF-22/U[1]	mono	280	0/+5 W	15.67	16.86	1,000	30.74	9.11	39.5	9.65
Phono Solar	PS285MGF-22/U[1]	mono	285	0/+5 W	15.94	17.16	1,000	31.08	9.17	39.6	9.68
Phono Solar	PS290MGF-22/U[1]	mono	290	0/+5 W	16.22	17.46	1,000	31.36	9.25	39.7	9.71
Phono Solar	PS295MGF-22/U[1]	mono	295	0/+5 W	16.50	17.76	1,000	31.69	9.31	39.8	9.74
Prism Solar	Bi60-362BSTC[2]	mono	285	-1.5/+3%	15.88	17.1	1,000	32.4	8.79	40.2	9.31
Prism Solar	Bi60-368BSTC[2]	mono	290	-1.5/+3%	16.15	17.4	1,000	32.4	8.95	40.2	9.48
Prism Solar	Bi60-375BSTC[2]	mono	295	-1.5/+3%	16.43	17.7	1,000	32.4	9.1	40.2	9.64
Silfab Solar	SLA-M 285	mono	285	0/+5 W	16.21	17.4	1,000	32	8.91	39.1	9.47

Footnote Key

Representative models shown for vendors with large numbers of SKUs.

[1] Double-glass module

[2] Double-glass module, bifacial

DNR = Does not report

Nominal operating cell temp. (°C)	Pmp temp. coeff. (%/°C)	Voc temp. coeff. (%/°C)	Isc temp. coeff. (%/°C)	Series fuse rating (A)	Fire Type	Frame color	Backsheet color	Length (in.)	Width (in.)	Depth (in.)	Weight (lbs.)	Materials warranty (yrs.)	Power warranty (type, % at year)
45±3	-0.37	-0.27	0.03	20	1	black	white	66.38	40	1.57	39.7	12	linear, 84.8 @ 25
45±3	-0.37	-0.27	0.03	20	1	black	white	66.38	40	1.57	39.7	12	linear, 84.8 @ 25
44±3	-0.30	-0.24	0.04	20	1	black	white	66.93	40	1.57	40.79	25	linear, 87 @ 25
44±3	-0.30	-0.24	0.04	20	1	black	white	66.93	40	1.57	40.79	25	linear, 87 @ 25
44±3	-0.30	-0.24	0.04	20	1	black	white	66.93	40	1.57	40.79	25	linear, 87 @ 25
44±3	-0.30	-0.24	0.04	20	1	black	white	66.93	40	1.57	40.79	25	linear, 87 @ 25
43.6	-0.45	-0.34	0.05	15	1	frameless	clear	65.5	41	1.1	62.6	DNR	linear, 82 @ 25
43.6	-0.45	-0.34	0.05	15	1	frameless	clear	65.5	41	1.1	62.6	DNR	linear, 82 @ 25
43.6	-0.45	-0.34	0.05	15	1	frameless	clear	65.5	41	1.1	62.6	DNR	linear, 82 @ 25
46.7	-0.38	-0.28	0.04	15	1	frameless	clear	66.9	39.4	0.3	66.8	DNR	linear, 80 @ 25
44±2	-0.45	-0.31	0.04	15	1	black	white	65.51	39.33	1.57	40.1	DNR	linear, 80.2 @ 25
44±2	-0.45	-0.31	0.04	15	1	black	white	65.51	39.33	1.57	40.1	DNR	linear, 80.2 @ 25
44±2	-0.45	-0.31	0.04	15	1	black	white	65.51	39.33	1.57	40.1	DNR	linear, 80.2 @ 25
44±2	-0.42	-0.31	0.04	15	1	black	black	65.51	39.33	1.57	40.1	DNR	linear, 80.2 @ 25
44±2	-0.42	-0.31	0.04	15	1	black	black	65.51	39.33	1.57	40.1	DNR	linear, 80.2 @ 25
44±2	-0.42	-0.31	0.04	15	1	black	black	65.51	39.33	1.57	40.1	DNR	linear, 80.2 @ 25
44±2	-0.43	-0.32	0.04	15	1	black	white	65.51	39.33	1.57	40.1	DNR	linear, 80.2 @ 25
44±2	-0.43	-0.32	0.04	15	1	black	white	65.51	39.33	1.57	40.1	DNR	linear, 80.2 @ 25
44±2	-0.43	-0.32	0.04	15	1	black	white	65.51	39.33	1.57	40.1	DNR	linear, 80.2 @ 25
44±2	-0.43	-0.32	0.04	15	1	black	white	65.51	39.33	1.57	40.1	DNR	linear, 80.2 @ 25
44±2	-0.43	-0.32	0.04	15	1	black	white	65.51	39.33	1.57	40.1	DNR	linear, 80.2 @ 25
44±2	-0.43	-0.32	0.04	15	1	black	black	65.51	39.33	1.57	40.1	DNR	linear, 80.2 @ 25
46	-0.45	-0.34	0.06	15	2/5/8	silver	white	65.2	39.1	1.81	41.8	10	linear, 80 @ 25
46	-0.44	-0.34	0.06	15	2/5/8	silver	white	65.2	39.1	1.81	41.8	10	linear, 80 @ 25
46	-0.44	-0.34	0.06	15	2/5/8	black	white	65.2	39.1	1.81	41.8	10	linear, 80 @ 25
46	-0.44	-0.34	0.06	15	2/5/8	black	white	65.2	39.1	1.81	41.8	10	linear, 80 @ 25
45±2	-0.41	-0.31	0.09	15	1	silver	clear	65.51	39.29	1.18	47.4	10	80 @ 30
45±2	-0.41	-0.31	0.09	15	1	silver	clear	65.51	39.29	1.18	47.4	10	80 @ 30
45±2	-0.41	-0.31	0.09	15	1	silver	clear	65.51	39.29	1.18	47.4	10	80 @ 30
45±2	-0.41	-0.31	0.09	15	1	silver	clear	65.51	39.29	1.18	47.4	10	80 @ 30
45±2	-0.42	-0.33	0.07	15	1	silver	clear	65.51	39.29	1.18	47.4	10	80 @ 30
45±2	-0.42	-0.33	0.07	15	1	silver	clear	65.51	39.29	1.18	47.4	10	80 @ 30
45±2	-0.42	-0.33	0.07	15	1	silver	clear	65.51	39.29	1.18	47.4	10	80 @ 30
45±2	-0.42	-0.33	0.07	15	1	silver	clear	65.51	39.29	1.18	47.4	10	80 @ 30
47±2	-0.41	-0.29	0.04	20	13	frameless	clear	66.73	38.74	0.28	63.75	10	DNR @ 30
47±2	-0.41	-0.29	0.04	20	13	frameless	clear	66.73	38.74	0.28	63.75	10	DNR @ 30
47±2	-0.41	-0.29	0.04	20	13	frameless	clear	66.73	38.74	0.28	63.75	10	DNR @ 30
45±2	-0.38	-0.30	0.03	15	1/2	black	black	64.96	38.97	1.5	41.9	12	linear, 82 @ 25

2017 60-Cell PV Module Specifications

Manufacturer	Model	Cell type	Rated power at STC (Wp)	Rated power tolerance (W or %)	Rated power per sq. ft. (W)	Module efficiency (%)	Max. system voltage UL (Vdc)	Max. power voltage (Vmp)	Max. power current (Imp)	Open-circuit voltage (Voc)	Short-circuit current (Isc)
Silfab Solar	SLA-M 290	mono	290	0/+5 W	16.50	17.8	1,000	32.4	8.97	39.4	9.54
Silfab Solar	SLA-M 300	mono	300	0/+5 W	17.07	18.4	1,000	32.8	9.16	39.85	9.71
Silfab Solar	SLA-M 310	mono	310	0/+5 W	17.07	19	1,000	33.05	9.38	40.25	9.93
Silfab Solar	SLA-X 290[2]	mono	290	0/+5 W	16.50	17.8	1,000	32.8	8.83	39.4	9.5
Silfab Solar	SLA-X 295[2]	mono	295	0/+5 W	16.78	18.4	1,000	33.17	8.89	39.48	9.58
SolarTech Universal	STU 300-HJT	mono	300	0/+5 W	16.83	18.4	1,000	35.7	8.4	44.4	9.8
SolarTech Universal	STU-PERC-300	mono	300	0/+5 W	16.83	18.4	1,000	33.4	9.3	41.1	9.8
SolarTech Universal	STU-PERC-305	mono	305	0/+5 W	17.11	18.7	1,000	33.9	9.4	41.8	10
SolarWorld	SWA 285 black	mono	285	0/+5 W	15.79	17	1,000	32	9	39.2	9.52
SolarWorld	SWA 290 black	mono	290	0/+5 W	16.07	17.3	1,000	32.2	9.12	39.5	9.6
SolarWorld	SWA 290	mono	290	0/+5 W	16.07	17.3	1,000	31.9	9.2	39.6	9.75
SolarWorld	SWA 295	mono	295	0/+5 W	16.35	17.59	1,000	32.3	9.25	39.8	9.78
SolarWorld	SWA 300	mono	300	0/+5 W	16.63	17.89	1,000	32.6	9.31	40	9.83
Sonali Solar	SS 230	poly	230	0/+3%	13.28	DNR	600	29.16	7.89	37.5	8.43
Sonali Solar	SS 240	poly	240	0/+3%	13.86	DNR	600	30.01	8	37.6	8.52
Sonali Solar	SS 250	poly	250	0/+3%	14.44	DNR	600	30.72	8.14	37.65	8.64
Sonali Solar	SS 260	poly	260	0/+3%	15.01	DNR	600	31.06	8.21	37.76	8.71
Sonali Solar	SS 270	poly	270	0/+3%	15.59	DNR	600	31.14	8.35	37.83	8.76
Sonali Solar	SS 280	poly	280	0/+3%	16.17	DNR	600	31.37	8.45	38.15	8.95
Sunpreme	GXB 300[2]	mono	300	-3/+5%	16.93	18.2	1,000	35.3	8.6	43.6	9.26
Sunpreme	GXB 310[2]	mono	310	-3/+5%	17.49	18.8	1,000	36	8.7	43.8	9.3
Sunpreme	GXB 320[2]	mono	320	-3/+5%	18.06	19.4	1,000	36.5	8.8	44	9.34
Sunpreme	GXB 300T[2]	mono	300	-3/+5%	16.93	18	1,000	35.3	8.6	43.6	9.26
Sunpreme	GXB 310T[2]	mono	310	-3/+5%	17.49	18.6	1,000	36	8.7	43.8	9.3
Sunpreme	GXB 320T[2]	mono	320	-3/+5%	18.06	19.2	1,000	36.5	8.8	44	9.34
Trina Solar	TSM-PD05-265	poly	265	0/+5 W	15.01	16.2	1,000	30.8	8.61	37.7	9.15
Trina Solar	TSM-PD05-270	poly	270	0/+5 W	15.30	16.5	1,000	30.9	8.73	37.9	9.22
Trina Solar	TSM-PD05-275	poly	275	0/+5 W	15.58	16.8	1,000	31.1	8.84	38.1	9.32
Trina Solar	TSM-PD05-280	poly	280	0/+5 W	15.86	17.1	1,000	31.4	8.92	38.2	9.4
Trina Solar	TSM-PD05-285	poly	285	0/+5 W	16.15	17.4	1,000	31.6	9.02	38.3	9.49
Trina Solar	TSM-DD05A-275	mono	275	0/+5 W	15.58	16.8	1,000	31.4	8.76	38.4	9.24
Trina Solar	TSM-DD05A-280	mono	280	0/+5 W	15.86	17.1	1,000	31.7	8.84	38.4	9.42
Trina Solar	TSM-DD05A-285	mono	285	0/+5 W	16.15	17.4	1,000	31.8	8.97	38.5	9.51
Trina Solar	TSM-DD05A-290	mono	290	0/+5 W	16.43	17.7	1,000	32.2	9.01	38.9	9.66
Trina Solar	TSM-DD05A-295	mono	295	0/+5 W	16.71	18	1,000	32.5	9.08	39.6	9.68
Trina Solar	TSM-DD05A-300	mono	300	0/+5 W	17.00	18.3	1,000	32.6	9.19	39.8	9.77
Trina Solar	TSM-DD05A-305	mono	305	0/+5 W	17.28	18.6	1,000	32.9	9.28	40	9.85
Trina Solar	TSM-DD05A-310	mono	310	0/+5 W	17.56	18.9	1,000	33.1	9.37	40.2	9.94

Footnote Key

Representative models shown for vendors with large numbers of SKUs.

[1] Double-glass module

[2] Double-glass module, bifacial

DNR = Does not report

Nominal operating cell temp. (°C)	Pmp temp. coeff. (%/°C)	Voc temp. coeff. (%/°C)	Isc temp. coeff. (%/°C)	Series fuse rating (A)	Fire Type	Frame color	Backsheet color	Length (in.)	Width (in.)	Depth (in.)	Weight (lbs.)	Materials warranty (yrs.)	Power warranty (type, % at year)
45±2	-0.38	-0.30	0.03	15	1/2	black	black	64.96	38.97	1.5	41.9	12	linear, 82 @ 25
45±2	-0.38	-0.30	0.03	15	1/2	black	black	64.96	38.97	1.5	41.9	12	linear, 82 @ 25
45±2	-0.38	-0.30	0.03	15	1/2	black	black	64.96	38.97	1.5	41.9	12	linear, 82 @ 25
43±2	-0.42	-0.28	0.04	15	1/2	black	black	64.96	38.97	1.5	41.9	12	linear, 82 @ 25
43±2	-0.42	-0.28	0.04	15	2	black	clear	64.96	38.97	1.5	41.9	12	linear, 88.4 @ 30
DNR	-0.34	-0.26	0.05	20	DNR	slv/blk	white	65.4	39.25	1.65	40	12	linear, 80 @ 30
45.7	-0.41	-0.29	0.04	20	DNR	slv/blk	white	65.4	39.25	1.65	40	12	linear, 80 @ 30
45.7	-0.41	-0.29	0.04	20	DNR	slv/blk	white	65.4	39.25	1.65	40	12	linear, 80 @ 30
46	-0.39	-0.29	0.07	DNR	1	black	black	65.95	39.4	1.3	39.7	20	linear, 80.2 @ 25
46	-0.39	-0.29	0.07	DNR	1	black	black	65.95	39.4	1.3	39.7	20	linear, 80.2 @ 25
46	-0.39	-0.29	0.07	DNR	1	black	white	65.95	39.4	1.3	39.7	20	linear, 80.2 @ 25
46	-0.39	-0.29	0.07	DNR	1	black	white	65.95	39.4	1.3	39.7	20	linear, 80.2 @ 25
46	-0.39	-0.29	0.07	DNR	1	black	white	65.95	39.4	1.3	39.7	20	linear, 80.2 @ 25
45±2	-0.44	-0.33	0.07	DNR	DNR	silver	white	64.57	38.62	1.57	41.89	10	80 @ 25
45±2	-0.44	-0.33	0.07	DNR	DNR	silver	white	64.57	38.62	1.57	41.89	10	80 @ 25
45±2	-0.44	-0.33	0.07	DNR	DNR	silver	white	64.57	38.62	1.57	41.89	10	80 @ 25
45±2	-0.44	-0.33	0.07	DNR	DNR	silver	white	64.57	38.62	1.57	41.89	10	80 @ 25
45±2	-0.44	-0.33	0.07	DNR	DNR	silver	white	64.57	38.62	1.57	41.89	10	80 @ 25
45±2	-0.44	-0.33	0.07	DNR	DNR	silver	white	64.57	38.62	1.57	41.89	10	80 @ 25
46±2	-0.28	-0.21	0.02	20	3	frameless	clear	65.47	38.98	0.24	55.6	15	linear, 85 @ 30
46±2	-0.28	-0.21	0.02	20	3	frameless	clear	65.47	38.98	0.24	55.6	15	linear, 85 @ 30
46±2	-0.28	-0.21	0.02	20	3	frameless	clear	65.47	38.98	0.24	55.6	15	linear, 85 @ 30
46±2	-0.28	-0.21	0.02	20	3	black	clear	65.47	38.98	0.24	55.6	15	linear, 85 @ 30
46±2	-0.28	-0.21	0.02	20	3	black	clear	65.47	38.98	0.24	55.6	15	linear, 85 @ 30
46±2	-0.28	-0.21	0.02	20	3	black	clear	65.47	38.98	0.24	55.6	15	linear, 85 @ 30
44±2	-0.41	-0.32	0.05	15	1/2	black	black	65	39.1	1.38	41	10	linear, 80 @ 25
44±2	-0.41	-0.32	0.05	15	1/2	black	wht/blk	65	39.1	1.38	41	10	linear, 80 @ 25
44±2	-0.41	-0.32	0.05	15	1/2	black	wht/blk	65	39.1	1.38	41	10	linear, 80 @ 25
44±2	-0.41	-0.32	0.05	15	1/2	black	wht/blk	65	39.1	1.38	41	10	linear, 80 @ 25
44±2	-0.41	-0.32	0.05	15	1/2	black	white	65	39.1	1.38	41	10	linear, 80 @ 25
44±2	-0.39	-0.29	0.05	15	1/2	black	black	65	39.1	1.38	41	10	linear, 80 @ 25
44±2	-0.39	-0.29	0.05	15	1/2	black	wht/blk	65	39.1	1.38	41	10	linear, 80 @ 25
44±2	-0.39	-0.29	0.05	15	1/2	black	wht/blk	65	39.1	1.38	41	10	linear, 80 @ 25
44±2	-0.39	-0.29	0.05	20	1/2	black	wht/blk	65	39.1	1.38	41	10	linear, 80 @ 25
44±2	-0.39	-0.29	0.05	20	1/2	black	wht/blk	65	39.1	1.38	41	10	linear, 80 @ 25
44±2	-0.39	-0.29	0.05	20	1/2	black	wht/blk	65	39.1	1.38	41	10	linear, 80 @ 25
44±2	-0.39	-0.29	0.05	20	1/2	black	wht/blk	65	39.1	1.38	41	10	linear, 80 @ 25
44±2	-0.39	-0.29	0.05	20	1/2	black	wht/blk	65	39.1	1.38	41	10	linear, 80 @ 25

2017 60-Cell PV Module Specifications

Manufacturer	Model	Cell type	Rated power at STC (Wp)	Rated power tolerance (W or %)	Rated power per sq. ft. (W)	Module efficiency (%)	Max. system voltage UL (Vdc)	Max. power voltage (Vmp)	Max. power current (Imp)	Open-circuit voltage (Voc)	Short-circuit current (Isc)
Trina Solar	TSM-DD05A-315	mono	315	0/+5 W	17.85	19.2	1,000	33.3	9.46	40.5	10
Upsolar	UP-M285M-B	mono	285	0/+3%	16.27	17.5	1,000	31.6	9.02	40.1	9.4
Upsolar	UP-M290M-B	mono	290	0/+3%	16.56	17.8	1,000	31.8	9.12	40.4	9.5
Upsolar	UP-M295M-B	mono	295	0/+3%	16.84	18.1	1,000	32	9.22	40.7	9.58
Upsolar	UP-M300M-B	mono	300	0/+3%	17.13	18.4	1,000	32.2	9.32	41	9.67
Upsolar	UP-M305M-B	mono	305	0/+3%	17.41	18.7	1,000	32.4	9.41	41.3	9.76
Upsolar	UP-M290M	mono	290	0/+3%	16.56	17.8	1,000	31.6	9.18	40.1	9.44
Upsolar	UP-M295M	mono	295	0/+3%	16.84	18.1	1,000	31.8	9.28	40.4	9.52
Upsolar	UP-M300M	mono	300	0/+3%	17.13	18.4	1,000	32	9.38	40.7	9.6
Upsolar	UP-M305M	mono	305	0/+3%	17.41	18.7	1,000	32.2	9.47	41	9.7
Upsolar	UP-M310M	mono	310	0/+3%	17.70	19.1	1,000	32.4	9.57	41.3	9.8
Vikram Solar	VSP.60.270.04.04	poly	270	0/+2.5 W	15.42	16.6	1,000	31	8.7	38.3	9.15
Vikram Solar	VSP.60.272.5.04.04	poly	272.5	0/+2.5 W	15.56	16.8	1,000	31.1	8.76	38.4	9.21
Vikram Solar	VSP.60.275.04.04	poly	275	0/+2.5 W	15.70	16.9	1,000	31.2	8.82	38.5	9.27
Vikram Solar	VSP.60.277.5.04.04	poly	277.5	0/+2.5 W	15.84	17.1	1,000	31.3	8.88	38.6	9.34
Vikram Solar	VSP.60.280.04.04	poly	280	0/+2.5 W	15.99	17.2	1,000	31.3	8.94	38.7	9.4
Vikram Solar	VSP.60.282.5.04.04	poly	282.5	0/+2.5 W	16.13	17.4	1,000	31.4	9	38.9	9.47
Vikram Solar	VSP.60.285.04.04	poly	285	0/+2.5 W	16.27	17.5	1,000	31.5	9.05	39	9.53
WINAICO	WST-275P6	poly	275	0/+5 W	15.37	16.5	1,000	31.3	8.81	38.5	9.41
WINAICO	WST-285P6	poly	285	0/+5 W	15.93	17.1	1,000	31.3	9.11	38.9	9.57
WINAICO	WST-290P6	poly	290	0/+5 W	16.21	17.4	1,000	31.3	9.27	39.1	9.65
WINAICO	WSP-300M6 black	mono	300	0/+5 W	16.76	18	1,000	32.3	9.31	39.8	9.86
WINAICO	WSP-300M6	mono	300	0/+5 W	16.76	18	1,000	32.3	9.31	39.6	9.86
WINAICO	WSP-305M6	mono	305	0/+5 W	17.04	18.3	1,000	32.6	9.36	40.1	9.96
WINAICO	WSP-310M6	mono	310	0/+5 W	17.32	18.6	1,000	32.9	9.42	40.3	10.1
WINAICO	WSP-315M6	mono	315	0/+5 W	17.59	18.9	1,000	33.2	9.48	40.4	10.2
Yingli Solar	YL250P-29b 1500	poly	250	0/+5 W	14.19	15.3	1,500	29.8	8.39	37.6	8.92
Yingli Solar	YL255P-29b 1500	poly	255	0/+5 W	14.47	15.6	1,500	30	8.49	37.7	9.01
Yingli Solar	YL260P-29b 1500	poly	260	0/+5 W	14.76	15.9	1,500	30.3	8.59	37.7	9.09
Yingli Solar	YL265P-29b 1500	poly	265	0/+5 W	15.04	16.2	1,500	30.5	8.7	37.8	9.18
Yingli Solar	YL270P-29b 1500	poly	270	0/+5 W	15.32	16.5	1,500	30.7	8.8	37.9	9.27
Yingli Solar	YL275P-29b 1500	poly	275	0/+5 W	15.61	16.8	1,500	31	8.9	37.9	9.35
Yingli Solar	YL255P-29b	poly	255	0/+5 W	14.47	15.6	1,000	30	8.49	37.7	9.01
Yingli Solar	YL260P-29b	poly	260	0/+5 W	14.76	15.9	1,000	30.3	8.59	37.7	0.09
Yingli Solar	YL265P-29b	poly	265	0/+5 W	15.04	16.2	1,000	30.5	8.7	37.8	9.18
Yingli Solar	YL270P-29b	poly	270	0/+5 W	15.32	16.5	1,000	30.7	8.8	37.9	9.27
Yingli Solar	YL275P-29b	poly	275	0/+5 W	15.61	16.8	1,000	31	8.9	37.9	9.35
Yingli Solar	YL280P-29b	poly	280	0/+5 W	15.89	17.1	1,000	31.4	8.92	38.2	9.45

Footnote Key

Respresentative models shown for vendors with large numbers of SKUs.

[1] Double-glass module

[2] Double-glass module, bifacial

DNR = Does not report

Nominal operating cell temp. (°C)	Pmp temp. coeff. (%/°C)	Voc temp. coeff. (%/°C)	Isc temp. coeff. (%/°C)	Series fuse rating (A)	Fire Type	Frame color	Backsheet color	Length (in.)	Width (in.)	Depth (in.)	Weight (lbs.)	Materials warranty (yrs.)	Power warranty (type, % at year)
44±2	-0.39	-0.29	0.05	20	1/2	black	white	65	39.1	1.38	41	10	linear, 80 @ 25
45±2	-0.43	-0.30	0.05	20	DNR	black	black	64.57	39.06	1.38	40.8	12	linear, 80.7 @ 25
45±2	-0.43	-0.30	0.05	20	DNR	black	black	64.57	39.06	1.38	40.8	12	linear, 80.7 @ 25
45±2	-0.43	-0.30	0.05	20	DNR	black	black	64.57	39.06	1.38	40.8	12	linear, 80.7 @ 25
45±2	-0.43	-0.30	0.05	20	DNR	black	black	64.57	39.06	1.38	40.8	12	linear, 80.7 @ 25
45±2	-0.43	-0.30	0.05	20	DNR	black	black	64.57	39.06	1.38	40.8	12	linear, 80.7 @ 25
45±2	-0.43	-0.30	0.05	20	DNR	silver	white	64.57	39.06	1.38	40.8	12	linear, 80.7 @ 25
45±2	-0.43	-0.30	0.05	20	DNR	silver	white	64.57	39.06	1.38	40.8	12	linear, 80.7 @ 25
45±2	-0.43	-0.30	0.05	20	DNR	silver	white	64.57	39.06	1.38	40.8	12	linear, 80.7 @ 25
45±2	-0.43	-0.30	0.05	20	DNR	silver	white	64.57	39.06	1.38	40.8	12	linear, 80.7 @ 25
45±2	-0.43	-0.30	0.05	20	DNR	silver	white	64.57	39.06	1.38	40.8	12	linear, 80.7 @ 25
45±2	-0.40	-0.31	0.06	15	2	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.1 @ 27
45±2	-0.40	-0.31	0.06	15	2	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.1 @ 27
45±2	-0.40	-0.31	0.06	15	2	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.1 @ 27
45±2	-0.40	-0.31	0.06	15	2	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.1 @ 27
45±2	-0.40	-0.31	0.06	15	2	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.1 @ 27
45±2	-0.40	-0.31	0.06	15	2	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.1 @ 27
45±2	-0.40	-0.31	0.06	15	2	silver	white	64.57	39.06	1.57	40.8	12	linear, 80.1 @ 27
45±3	-0.43	-0.33	0.06	20	1	black	white	65.5	39.33	1.38	41.9	15	linear, 80.2 @ 25
45±3	-0.43	-0.33	0.06	20	1	black	white	65.5	39.33	1.38	41.9	15	linear, 80.2 @ 25
45±3	-0.43	-0.33	0.06	20	1	black	white	65.5	39.33	1.38	41.9	15	linear, 80.2 @ 25
45±3	-0.43	-0.29	0.06	20	1	black	black	65.55	39.33	1.57	43.2	15	linear, 80.2 @ 25
45±3	-0.43	-0.29	0.06	20	1	black	white	65.55	39.33	1.57	43.2	15	linear, 80.2 @ 25
45±3	-0.43	-0.29	0.06	20	1	black	white	65.55	39.33	1.57	43.2	15	linear, 80.2 @ 25
45±3	-0.43	-0.29	0.06	20	1	black	white	65.55	39.33	1.57	43.2	15	linear, 80.2 @ 25
45±3	-0.43	-0.29	0.06	20	1	black	white	65.55	39.33	1.57	43.2	15	linear, 80.2 @ 25
46±2	-0.42	-0.32	0.05	15	1	silver	white	64.96	39.06	1.38	40.8	10	linear, 80.7 @ 25
46±2	-0.42	-0.32	0.05	15	1	silver	white	64.96	39.06	1.38	40.8	10	linear, 80.7 @ 25
46±2	-0.42	-0.32	0.05	15	1	silver	white	64.96	39.06	1.38	40.8	10	linear, 80.7 @ 25
46±2	-0.42	-0.32	0.05	15	1	silver	white	64.96	39.06	1.38	40.8	10	linear, 80.7 @ 25
46±2	-0.42	-0.32	0.05	15	1	silver	white	64.96	39.06	1.38	40.8	10	linear, 80.7 @ 25
46±2	-0.42	-0.32	0.05	15	1	silver	white	64.96	39.06	1.38	40.8	10	linear, 80.7 @ 25
46±2	-0.42	-0.32	0.05	15	1	silver	white	64.96	39.06	1.38	40.8	10	linear, 80.7 @ 25
46±2	-0.42	-0.32	0.05	15	1	silver	white	64.96	39.06	1.38	40.8	10	linear, 80.7 @ 25
46±2	-0.42	-0.32	0.05	15	1	silver	white	64.96	39.06	1.38	40.8	10	linear, 80.7 @ 25
46±2	-0.42	-0.32	0.05	15	1	silver	white	64.96	39.06	1.38	40.8	10	linear, 80.7 @ 25
46±2	-0.42	-0.32	0.05	15	1	silver	white	64.96	39.06	1.38	40.8	10	linear, 80.7 @ 25
46±2	-0.42	-0.32	0.05	15	1	silver	white	64.96	39.06	1.38	40.8	10	linear, 80.7 @ 25

Interview

An Experienced Perspective

Henk Rogers, Blue Planet Energy

Chief Executive Officer

In the 1980s, Henk Rogers made a name for himself in the global gaming industry as the producer of Japan's first role-playing video game and the entrepreneur behind the popular Tetris franchise, which sold more than 35 million units via a partnership with Nintendo. Today, Rogers is dedicated to putting the building blocks together to enable a transition from a fossil fuel–based economy to one based on renewables integration at a global scale. Rogers is a resident of Hawaii, which mandates 100% renewables by 2045, so this is not an academic exercise for him. To prove the viability of a carbon-free future, he built a state-of-the-art energy lab at his Pu'u Wa'awa'a Ranch facility, which serves as a real-world solar-plus-storage test bed that stores excess generation as hydrogen. After successfully taking his Big Island ranch off the grid, Rogers founded Blue Planet Energy to commercialize safe, reliable and easy-to-install energy storage solutions.

Henk Rogers Since suffering a heart attack in 2006, Henk Rogers has been a man on a mission. Rogers established the Blue Planet Foundation to accelerate Hawaii's transition to 100% clean energy. As the CEO of Blue Planet Energy, he is commercializing residential energy storage solutions. The company's Blue Ion 2.0 is a 48-volt lithium iron phosphate battery rack with a nominal capacity of 8 kWh–16 kWh per enclosure.

Courtesy Blue Planet Energy

SP: You are a gaming industry executive working in the energy storage space. How did that transition come about?

HR: It's funny, because I'm not the only one. Both Elon Musk and Jeff Bezos got off track from what people originally thought they were doing. One reason is that I can—I have the wherewithal. Another reason is that desire for sustainability has always been dormant in me. It is something that needs to be done. I don't want to spend the rest of my life making games and making money. That's not part of my mission in life. I found my life's missions 10 years ago after a heart attack. My first mission is to end the use of carbon-based fuels. Our children and their children need a future they can live in. As a serial entrepreneur, I got into renewables and energy storage because the transition to a sustainable future was taking too long.

SP: In 2007, you established the nonprofit Blue Planet Foundation, which has successfully executed a number of grassroots energy efficiency campaigns and influenced policy outcomes in Hawaii. What are the foundation's top priorities?

HR: As a start, we got Hawaii to agree to a 100% renewables mandate by 2045. Now we need to figure out why Hawaii isn't moving faster in terms of getting off oil and gas. As a state, we import \$5 billion in oil every year. It's insane. Some people are working two jobs. Others are homeless. So many are struggling. If we could reduce the amount of oil we buy by 20%, we could put that money back into people's pockets, raise standards of living and build decent housing for the homeless. That's just based on a 20% reduction. Imagine if we could eliminate oil entirely. If we really thought our way of life depended on it, we could transition to 100% renewables in 5 years.

During World War II, we went from biplanes to jet planes and invented the atom bomb, sonar and radar in a period of just 5 years. We made a mountain of progress because there was a sense of urgency. Today, we are facing another existential threat. Look at all the storms hitting the Caribbean and the Gulf Coast. The intensity and frequency of these storms is unprecedented. Human beings are at risk, but our actions are just making things worse.

SP: Why did you chose to build a microgrid research facility at your Pu'u Wa'awa'a Ranch?

HR: When we talk to electric companies about eliminating carbon-based fuels, they say, "We can only handle 15% renewables on our grid because wind and solar are intermittent." Okay, if they're intermittent, why don't you store the energy so you get rid of the intermittency? Then they argue that there is no such thing as storage at this time, which just supports the status quo. The truth is that it's hard for them to switch over because they make 10% on top of the price of oil. However, they will go out of business if they don't switch over.

So we started to look at what it means to become energy independent. The first thing my research group, Blue Planet Research, did was take the ranch off-grid. In the process, we learned a lot of interesting things. We found out that in order for us to make it through a cloudy day, we needed to have a certain amount of energy stored, and that meant that on a sunny day, we had all kinds of extra energy. Rather than throw that energy away, which is what the electric company does, we started looking for ways to use it.

Cobalt is a bad actor. Once it catches fire, it produces its own oxygen, meaning once the fire starts, it's unstoppable.

That's when we started making hydrogen. We don't have that much use for hydrogen on the ranch yet, but we are experimenting. We are learning how to cook with hydrogen, which is a whole different way of cooking. When you cook with hydrogen, your foods taste moist because you are creating H_2O instead of carbon monoxide or carbon dioxide. The heat also goes straight up, meaning there's no wasted radiant heat.

The hydrogen economy is coming. We believe Hawaii can use hydrogen as a fuel for moving trucks and buses and even cars. If you're not throwing away renewable energy that you can't use immediately or store in batteries, you cut the cost of solar and wind energy in half. We would also like to see people in the Third World cook with hydrogen because it eliminates dangerous gases. People die all the time because they are burning charcoal or wood inside their houses.

The net result of all of this is that I took my ranch off the grid, and I took my home in Honolulu off-grid. Then I started to show other people how easy it is to use solar and storage to eliminate carbon-based fuels. We have over 100 kWh of storage at the ranch and over 60 kWh at my Honolulu home. One day, I got this wonderful call from the electric company. "Mr. Rogers, we think there's something wrong with our meter at your house." I told the caller, "There's nothing wrong with your meter. I'm just not using any of your electricity." He said, "Do you mind if we go and have a look?" And I said, "No, not at all, you can look away." If and when they look, they will see that the wires coming out of their meter are capped and taped off. I'm not connected to their meter in any way. And if they want to take their meter back, they can have it.

SP: What energy storage technology did you use to go off-grid?

HR: We are using Sony lithium iron phosphate (LFP) batteries. They can go from a 100% state of charge down to zero, and they can do that for 20 years. With lead-acid batteries, you can use only half of the battery capacity, and you might get 3–5 years. Lithium-ion batteries also take up way less space than lead-acid. The problem with some lithium-ion chemistries is that they catch on fire under certain conditions. That is true of the batteries in my laptop, my phone and even my car, my Tesla. Take NMC batteries, for example, which use nickel, manganese and cobalt. Cobalt is a bad actor. Once it catches fire, it produces its own oxygen, meaning once the fire starts, it's unstoppable. That's fine for my car, because I trust Elon to have safety mechanisms in place. And if my car burns down, I'm fairly sure he will give me a new one. But if it's in my house, where my children and grandchildren sleep, I'm just not into that. That fire is contagious, meaning a fire in one battery can set other batteries next to it on fire. That's a fundamental difference between the LFP batteries we chose to use and other types of lithium-ion chemistries. Iron and phosphate are both benign chemicals that cannot overheat. You cannot overcharge these batteries, and they do not catch on fire if they get punctured.

SP: You started Blue Planet Energy to commercialize LFP-type Li-ion

Courtesy Blue Planet Energy

Energy Lab Rogers took his 28-acre Pu'u Wa'awa'a Ranch off the grid using an 85 kW PV array and over 100 kWh of energy storage. Rather than waste excess energy, the system incorporates a commercial electrolyzer and fuel cells. In addition to offering a carbon-free cooking fuel source, hydrogen stored in propane tanks provides roughly a 4-day supply of backup power for the ranch.

batteries for residential energy storage applications. What is your company's flagship product?

HR: Blue Plant Energy's product is Blue Ion, which gives you 16 kWh of storage in a package the size of a small wine refrigerator. The Blue Ion does not require any cooling system or any kind of fire suppressant. It will never overheat or catch on fire or endanger your house. It will just sit there for 20 years, and you can charge it to 100% and discharge it to zero on a daily basis. There's nothing else out there that will last that long. We package the Blue Ion in an off-the-shelf server cabinet rather than a fancy box and pass those savings right through to the customer.

Sony started making lithium-ion batteries in 1991 and came out with LFP batteries about 10 years ago. Within the last year, Sony sold its battery division to Murata. Sony is moving in the direction of content rather than electronics. Murata makes its money from electronic components, including many that are inside your iPhone. They want to own the global battery business. We are going to help make that happen.

SP: The US is lagging behind the rest of the world in terms of its residential energy storage market. What's it going to take for this to change?

HR: Battery prices are going to come down, just like computer processing power improves over time. All these different technologies are competing, with new technologies coming out of universities. The battery business is going to be a multibillion-dollar business within a couple years. Everybody is starting to smell that. All we need to do is bring the most reasonable technology to market.

I'm positive that things will change a lot faster than people think. We created a piece of legislation in Hawaii to help the solar industry by giving tax credits. The best estimates said that we would have 30 MW of solar in a couple years. Instead, we had 300 MW with 200 companies installing solar. Once these things get going, they happen so much faster than people believe they are going to. So there is hope.

SP: Commercializing energy storage isn't your only moon-shot project, so to speak. You are also literally helping to develop an International MoonBase. How did you get involved with these efforts?

HR: The MoonBase project is another one of my life missions. Mission number one is to end the use of carbon-based fuels. Number two is to end war. It's not so much that wars kill people—we've gotten very efficient at war and many fewer people die—but that we spend huge amounts of money on them. We've spent more money in Afghanistan than we spent in the entire history of NASA, including

> The first step to preserving a backup of life as we know it on other planets is to go to the moon and have a permanent settlement.

Alan Shepard's first manned flight, the Apollo program, the space shuttle, the International Space Station and the Mars rover. Think about how much technology came out of that space effort, including solar panels. But what do we have to show for the war in Afghanistan? We basically borrowed money from our children and gave it to the military industrial complex. It's a ridiculous waste of money. If we just could have spent that money on fixing climate change, we'd have solved the problem.

So mission number three is to make a backup of life on Earth. We live life on Earth in a biosphere that is only a couple miles thick. That living biosphere is equivalent to the skin of an apple, where everything inside and outside the skin is dead. We're seriously messing around with that skin, changing it drastically. The Earth has already undergone several extinction events. The next event of that magnitude is going to happen to us. The first step to preserving a backup of life as we know it on other planets is to go to the moon and have a permanent settlement. Then we go to Mars and make a settlement and live there sustainably. In the meantime, maybe we figure out how to do interstellar travel, and we find planets that are more Earth-like than the moon or Mars and we go there. Who knows?

To get off the planet, we need to practice here on Earth. Hawaii is an ideal test site because it just so happens to be made out of the same stuff as the moon. Regolith is basically powdered basalt. Our volcanoes create basalts. The moon created basalt 5 billion years ago. So our basalt is new; its basalt is old. But if we take basalt here, grind it up and use it to 3-D–print structures, we can do the same thing on the moon. All we need is energy, which we already know how to generate. With PV, we will be able to 3-D–print structures on the moon. And by the way, if we can learn to survive on the moon, Mars and other places, we will know how to live sustainably here on Earth. ⏚

Advertiser *Index*

Freedom Solar Power

East Austin Alley Flat

Courtesy David Brearley (4)

Overview

DESIGNER: Josh Meade, lead designer, Freedom Solar Power, freedomsolarpower.com

LEAD INSTALLER: Mark Bedell, master electrician, Freedom Solar Power; Ryan Albert, project manager, Freedom Solar Power

DATE COMMISSIONED: April 2017

INSTALLATION TIME FRAME: 2 days

LOCATION: Austin, TX, 30.3° N

SOLAR RESOURCE: 5.4 kWh/m^2/day

ASHRAE DESIGN TEMP: 99°F 2% average high, 23°F extreme minimum

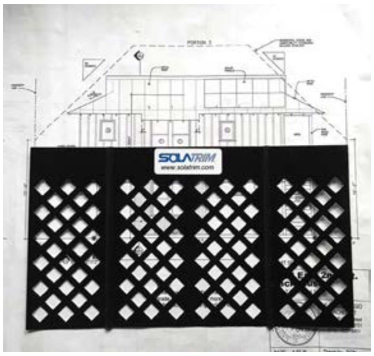
ARRAY CAPACITY: 4.1 kWdc

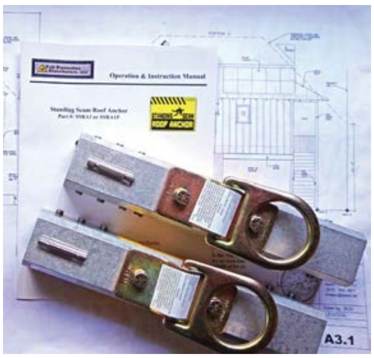
ANNUAL AC PRODUCTION: 5.5 MWh

In early 2016, David Brearley and his wife Molly O'Halloran contracted Austin, Texas–based Freedom Solar Power to permit and install a SunPower PV system for a new alley flat. The downstairs provides a small home office for Brearley, *SolarPro*'s senior technical editor. The upstairs is a licensed short-term rental unit that doubles as a guest suite. The roof hosts a 4.1 kW PV system that offsets all of the back house electrical loads and a majority of those for the entire property.

The couple developed the architectural plans for the alley flat with solar in mind, calling for a true standing-seam metal roof early in the design process. The plans also specified that all mechanical and plumbing vents had to exit the building via the north roof, ensuring that as much south-facing area as possible was available for solar. Together with their architect, the couple homed in on a hybrid hip-and-gable roof profile that both fits the neighborhood's historic character and justifies the array to the east to avoid afternoon shading from tall trees.

Because of shading issues and the small roof area, the application favored high-efficiency PV modules and module-level power electronics (MLPE). For optimal array capacity, the architect designed the length of the roof with SunPower modules in mind. In addition to mitigating shading, MLPE also meet Austin Energy's rapid-shutdown requirements. Brearley purchased SolaTrim protective barrier to proactively address potential issues





associated with nesting pigeons, squirrels and leaf litter, and acquired specialty standing-seam roof anchors from Fall Protection Distributors to provide permanent anchors for installers and future service technicians.

Freedom Solar Power was ideally suited to complete the installation. As SunPower's only master dealer in Texas, the company was able to offer 18-month same-as-cash financing. To stretch their budget, Brearley and O'Halloran acted as their own general contractor and did a lot of work themselves. By financing the PV system, which was the most expensive part of the new build, the couple was able to complete the construction project and start generating rental income before the solar bill came due. After reviewing two proposals, Brearley selected SolarEdge power electronics over ACPV modules. He also decided to oversize the inverter capacity to allow for future expansion, either to incorporate energy storage or to add a similarly sized array on the front house.

Installation logistics were somewhat complicated due to the dictates of new construction. Before the insulation contractor arrived on-site, Freedom Solar sent out a master electrician to hang the inverter, utility disconnect and meter base, and to complete all of the conduit runs, which are entirely hidden inside the exterior framing. The installation crew arrived a few days later to install the mounting system, optimizers, modules and protective barrier. To allow for a rebate inspection, Freedom Solar commissioned the system using temporary power in May 2016. Commercial operations did not commence until April 2017, after the city had closed all of the project permits.

> "Freedom Solar Power came highly recommended and did not disappoint. Its team exceeded my expectations at every step."
> —*David Brearley,* SolarPro

Equipment Specifications

MODULES: 12 SunPower SPR-X21-345, 345 W STC, rated power tolerance +5/-0%, 6.02 Imp, 57.3 Vmp, 6.39 Isc, 68.2 Voc

INVERTER: Single-phase, 120/240 Vac service; one SolarEdge SE7600A-US, 7.6 kWac 240 Vac output, 500 Vdc maximum input voltage, 350 Vdc nominal input voltage

POWER OPTIMIZERS: 12 SolarEdge P400 power optimizers (one per module), 400 W rated input, 8 Vdc–80 Vdc MPPT operating range, 80 Vdc maximum input voltage, 5,250 W maximum per dc source circuit for single-phase applications

ARRAY: One 12-module source circuit with a 350 Vdc nominal output voltage as controlled by the inverter and dc optimizers

ARRAY INSTALLATION: Standing-seam metal roof–mounted array, SunPower InvisiMount rail-based mounting system, S-5! mini-clamp attachments, SolaTrim protective barrier, array azimuth 205°, array tilt angle 27°

SYSTEM MONITORING: Inverter-direct SolarEdge module-level monitoring; CURB circuit-level monitoring in back and front house subpanels

Projects

Joule Energy

Old Alabama Road 2

Courtesy Joule Energy (3)

Overview

PROJECT TEAM: EPC—Joule Energy, joule-energy.com; owner—Boviet Solar USA, bovietsolarusa.com; developer—Hecate Energy, hecateenergy.com

DESIGN & INSTALLATION LEAD: Corey Shalanski, senior PV engineer, Joule Energy

DATE COMMISSIONED: April 2017

INSTALLATION TIME FRAME: 40 days

LOCATION: Woodland, GA 32.8°N

SOLAR RESOURCE: 4.59 kWh/m²/ day

ASHRAE DESIGN TEMPERATURES: 95°F 2% average high, 12.2°F extreme minimum

ARRAY CAPACITY: 1.613 MWdc

ANNUAL AC PRODUCTION: 2,826 MWh

Located in Woodland, Georgia, the Old Alabama Road 2 (OAR 2) solar project represents two trends present in many megawatt-scale ground-mounted PV installations—tracked arrays and the use of string inverters for power processing. The OAR 2 project team has three primary stakeholders: Boviet Solar, a subsidiary of Powerway Group, is the system owner and module vendor; Hecate Energy served as the project developer; and New Orleans–based Joule Energy was the project EPC firm.

Site grading began in late September 2016. Construction coincided with a significant drought that impacted much of western Georgia, and the drought conditions complicated early construction efforts. At one point in the site preparation process, the grading contractor was not able to secure burn permits. As a result, workers had to truck vegetation debris off-site, which added unanticipated cost and resulted in a minor project delay. Another early delay resulted from the severing of an unmapped 2-inch gas line during stump excavation. Further investigation revealed that the pipe had been abandoned and supposedly capped off many years ago. The project team worked with local officials to trace the source of the pipe and make the appropriate repairs quickly and safely.

With site preparation completed, Joule Energy opted to subcontract the tracker and module installation, focusing its efforts on realizing the cost savings

that optimizing the ac power collection system would offer. Considerations included the strategic location of power processing equipment and ac aggregation panels, as well as approaches to minimize the project's wiring material cost and speed conductor deployment. A total of 35 Ginlong Solis 40 kW 3-phase string inverters provides power conversion and optimization for OAR 2.

All array rows contain even numbers of tracker tables, which simplified the wiring plan. This configuration allowed Joule Energy to parallel two module source circuits and thereby minimize homerun wiring back to the string inverters. Joule developed a relatively simple homerun gauge scheme based on each string's position in its row. For shorter runs, it used 10 AWG and 8 AWG conductors; for longer runs, it stepped conductor size up to 6 AWG. Installers paralleled strings using Y-branch connectors for 10 AWG and 8 AWG conductors and Tyco GTAP connectors for 6 AWG conductors.

Joule Energy used the leapfrog wiring method shown in *SolarPro*'s April/May 2014 issue. This wiring configuration results in the collocation of each source circuit's homerun connections, which allowed OAR 2 installers to plug them directly into the parallel branch connector. The installation team ran all homerun conductor pairs to their respective inverter-input terminals with no intermediary breaks. This approach complicated the initial installation, particularly because the design called for direct burial of portions of each homerun. However, the design also significantly reduced the number of

Equipment Specifications

MODULES: 5,040 Boviet Solar BVM6612P-320, 320 W STC, +5/-0 W, 8.65 Imp, 37 Vmp, 9.17 Isc, 45.5 Voc

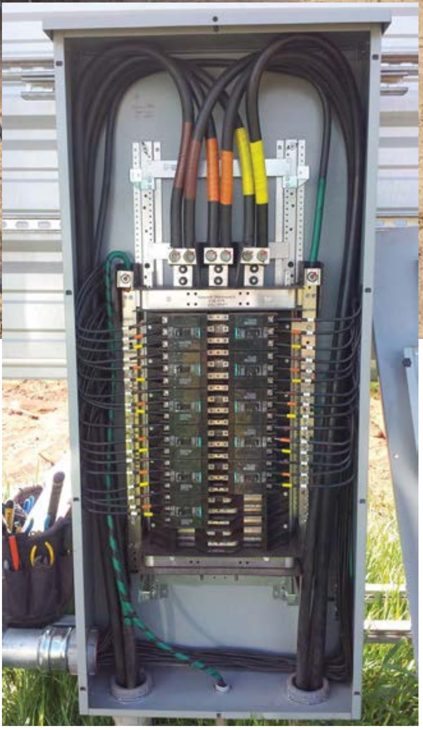
INVERTERS: 3-phase 277/480 Vac service, 35 Ginlong Technologies Solis-40K-US, 1,000 Vdc maximum input, 200 Vdc–800 Vdc MPPT range

ARRAY: 18 modules per source circuit (5,760 W STC, 8.65 Imp, 666 Vmp, 9.17 Isc, 819 Voc), eight source circuits per inverter (inverter 46.08 kW, 69.2 Imp, 666 Vmp, 73.36 Isc, 819 Voc), array total 1.613 MWdc

ARRAY INSTALLATION: GameChange Solar Genius Tracker, single axis, independent row, 90° standard rotational range (104° range option), Zigbee wireless network

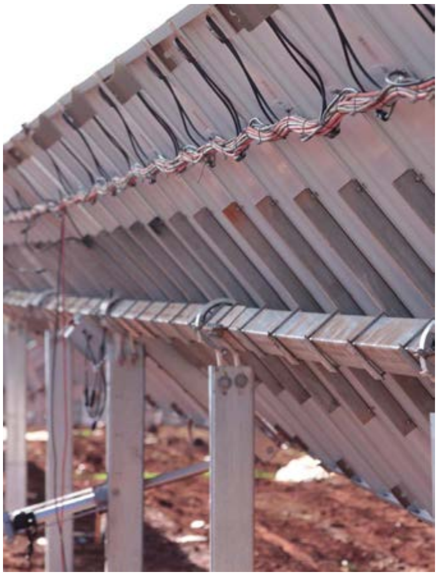
INVERTER AGGREGATION PANELS: Three 800 A panels with 800 A disconnects (two disconnects fused at 750 A and one fused at 700 A)

SYSTEM MONITORING: Locus Energy monitoring and analytics



Courtesy Joule Energy (3)

field-installed connections, which are among the Joule Energy O&M team's most frequently cited failure concerns. Because only two strings terminate at each inverter MPP tracker, the system did not require any in-field fuses, which further cut costs and simplified installation.



The installation team had to learn quickly how to deploy both large-gauge wire spools and large numbers of smaller-gauge spools. In early attempts, team members used an extendable-reach forklift and a custom-built lumber rack. The Joule Energy team has since learned that a more optimal approach is to use a full flatbed trailer with turntables underneath the spools, a setup it purchased for future projects.

Installers grouped the inverters at the site location nearest to the point of interconnection. They constructed two separate equipment walls, one comprising inverters serving the eastern rows of the array and one comprising inverters serving the central and western rows of the array. The equipment support structures include metal roofing panels along the top and back sides of the structure to shade the inverters. The 11 inverters on the eastern equipment wall combine at an 800 A breaker panel, as do each of the two sets of 12 inverters on the central and western equipment wall. Joule Energy minimized ac voltage drop by locating each inverter within 40 feet of its respective breaker panel, and the breaker panels within 120 feet of the system's fused disconnects.

"While this project is relatively small in size compared to many of today's solar farms, it represented a big accomplishment for our team. We applied a fresh perspective to the overall EPC process—focusing on design and installation efficiencies—and produced a showcase system that serves as the standard for our current and future work."
—Corey Shalanski, Joule Energy

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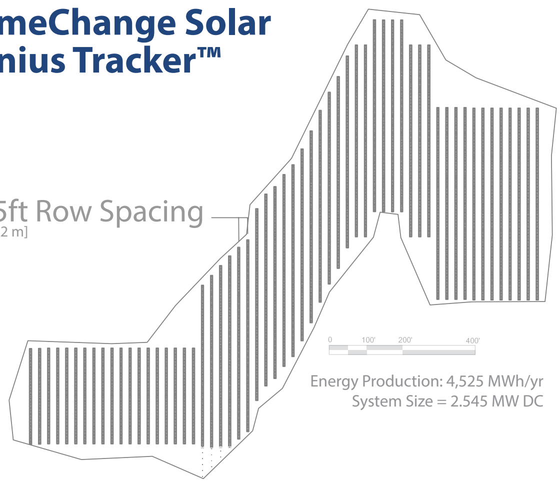
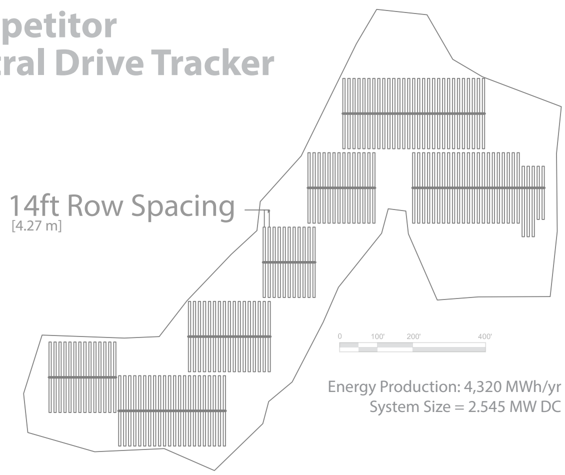
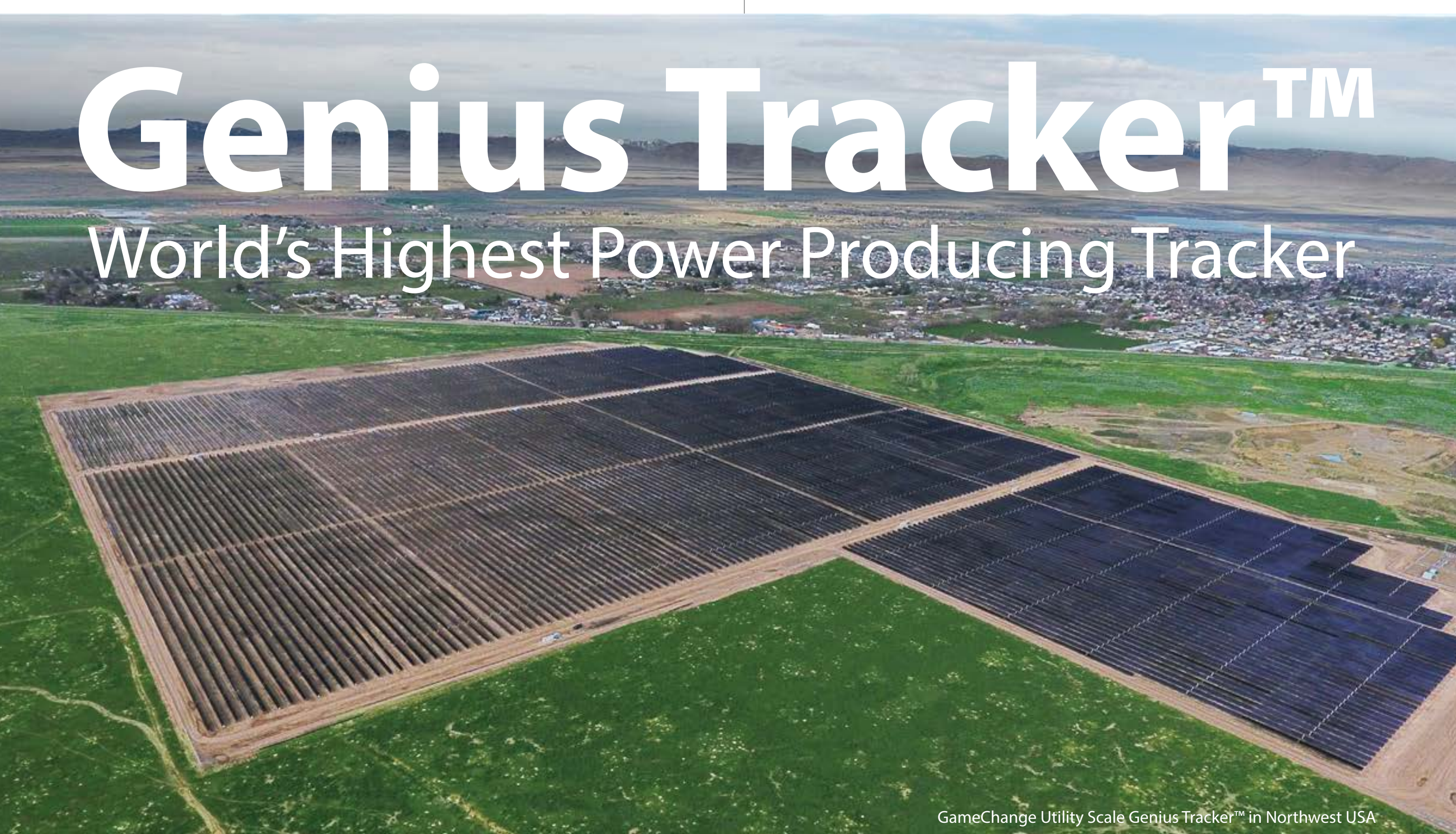


Competitor Central Drive Tracker





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